PERFORMANCE OF SPRING WHEAT UNDER SUMMER RAINFALL AND WINTER IRRIGATED CONDITIONS IN ZAMBIA

BY

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DECLARATION

I Batiseba Tembo declare that all the work presented in this dissertation is my work and has not been submitted for a degree at any other University.

Signature..................................

Date......................................

APPROVAL

This dissertation of Batiseba Tembo was approved as fulfilling part of the requirement for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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ABSTRACT

A study was conducted at Zambia Agricultural Research Institute at Mt.Makulu in Chilanga, Lusaka province of Zambia to study the comparative performance of five spring wheat varieties (UNZAWV1, UNZAWV2, Coucal, Sahai and Loerrie II) in two growing environments (seasons), that is the rainy season under rainfed conditions and under irrigation in the cool dry winter season at different seed rates, i.e 60, 80, 100, 120 and 140 kg/ha. The treatments were replicated four times in a split plot of a randomized complete block design. The varieties were assigned to the main plots with seed rates as subplots. Grain yield, ear length, grains per ear, number of tillers per square meter, leaf area index, root biomass, peduncle length, plant height, days to heading and days to maturity were recorded for each plot. Intra season and a combined analysis for season 1 and season 2 was carried out.

The varieties did not differ significantly in yield, biological yield, 1000- grain weight, ear length, number of tillers per meter square, leaf area index, grains per ear and days to maturity across seasons. Varieties differed significantly in plant height and peduncle length across seasons. Seasons significantly influenced grain yield and all the yield components, plant height, days to heading and days to maturity. The irrigated season had a greater yield compared to the rainy season.

The results also indicated that seed rate significantly affected grain yield, biological yield and days to heading across seasons. However all the yield components including plant height were not affected significantly by seasons. Seed rate of 140 kg/ha gave

the highest yield of 1392.30 kg/ha while 60 kg/ha gave the lowest yield of 1077.04 kg/ha across seasons.

A simple correlation across seasons showed number of tillers per square meter, grains per ear and above ground biomass as being the most important traits explaining the variation in grain yield across seasons. Plant height, days to heading, ear length, 1000-grain weight, days to maturity showing a marginal effect.

This study therefore indicates that targeting the characters that most affect grain yield such as number of fertile tillers per square meter, grains per ear and above ground biomass would lead to greater yield performance under both rain fed summer and irrigated cool dry conditions. This would even encourage wheat production in summer rainfall environment among both commercial and small scale farmers as the cost of production arising from irrigation would be cut down.

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1.0 INTRODUCTION

Wheat (*Trcticum aestivum.L)* is a small grain cereal food crop consumed by people worldwide. It is grown on more than 240 million hectares and continues to be the most important grain for humans. It's production leads all food crops including rice, maize and potatoes (Curtis, 2002). World trade in wheat exceeds all other crops combined. It is the best of the cereal foods and provides more nourishment for humans than other food source. Wheat is also a popular source of animal feed and can also be used in the production of alcohol (Curtis, 2002; Gooding and Davies, 1997)

Wheat is classified into spring or winter wheat type. Curtis (2002) stated that the classification into spring or winter wheat is common and traditionally refers to the season during which the crop is gown. For winter wheat, heading is delayed until the plant experiences a period of cold winter temperatures, for a process known as vernalisation. Winter wheat needs this chilling period for it to flower and set seed. If it is not exposed to chilling temperatures, it will not flower but will remain in the vegetative phase only. Winter wheat is mainly grown in the temperate climate. Spring wheat on the other hand, does not need vernalisation. It is planted in spring and matures in summer. Spring wheat is grown in tropical and sub tropical environments.

Spring wheat can be grown under rainfed or irrigated conditions. Three quarters of wheat grown in developing countries is spring while a quarter is winter wheat. The bulk of wheat produced world wide is bread wheat. About ninety two percent (92%) of total area planted is bread wheat with eight percent (8%) being planted with durum wheat (Heisey *et. al.*, 2002).

Although wheat is typically a crop of the temperate and winter – rainfall regions, it is adapted to many climates.

Although wheat is not a traditional staple food in Zambia, the convenience of bread and other wheat products such as fast foods, especially in the urban areas, has increased its popularity making it one of the most important cereals in the country, second only to maize (Mooleki, 1997).

Wheat production in Zambia is relatively low. The country produces seventy thousand metric tonnes against annual consumption of two hundred thousand metric tonnes. (C.S.O., 2006). The country imports the balance to meet the increasing demand. Recently, there has been an increasing demand for wheat and wheat products on the world market. This situation opens up opportunities for large scale wheat production in countries like Zambia which are not traditionally wheat producing nations but which have all the climatic requirements and the soils for producing the crop. This can help to increase food security as well as earn foreign exchange for the country.

In order to become self sufficient in wheat and to reduce hunger, some seed companies in Zambia claim to have come up with new wheat varieties that are more productive during both rain season (summer, November to March) and cool dry season (April to September). The technological requirements of these varieties such as planting density (seed rates) being one of them need to be examined continuously for the purpose of determining their requirements in specific conditions. Hussain *et al.* (2001) reported that seeding rates affected growth and yield parameters like total number of tillers per meter square, number of grains per spike and grain yield.

In Zambia, wheat is produced under irrigation during the cool dry season as a cash crop by large-scale farmers. The optimum planting period is mid April to early June at a seed rate of 90-100 kg/ha (Mooleki, 1997). The cost of wheat production under irrigation is high due to high electricity bills. For this reason large scale growers of wheat in Zambia have been enquiring whether it is possible to grow a good wheat crop under rain fed conditions so as to cut down on the cost of production arising from irrigation. In the early 1980's, the government of the Republic of Zambia promoted rain fed wheat production by small scale farmers. Small scale farmers and some commercial farmers started growing rain fed wheat in Mpika and Mbala districts of the Northern province of Zambia. Rain fed wheat was promoted to small scale farmers due to lower cost of production since it does not involve expensive irrigation equipment needed for irrigated wheat production. However, the rain fed wheat production promotion did not last long (Mooleki, 1997). The decline in production of wheat in the rain season has been due to low yields obtained in that season compared to the dry season. This is because the rain season is associated with increase in disease incidences and higher temperatures than the dry season (Mooleki, 1997). The relatively warmer temperatures during the rain season compared to the cool season results in poor tillering in wheat which further results in lower yields (Khatib *et.al.*, 1999).Whether the poor tillering in rain season can be compensated for with a high seed rate, it's a factor that will have to be established.

Development of wheat varieties that will give consistently high grain yields even if the crop is sown in rain season or dry season would be an advantage for wheat growers in Zambia. However the causes of lower yields for rainfed wheat have to be established. This information will be of great benefit to plant breeder in the development of rain fed wheat varieties for Zambia. The effects of seed rate on yield and yield components and other related agronomic traits will be required to be established in order to maximise yield potential of wheat.

Objectives

The objectives of this study were to study the comparative performance of spring wheat in two growing environments, that is rainy season under rainfed conditions and under irrigation in the cool dry season.

The specific objectives were:

a) To study the tillering capacity and the compensatory effect of seed rate on productivity in wheat under summer rainfall conditions and under irrigation in the cool dry season.

b) To study the comparative performance of the morpho-physiological components of grain yield of wheat under summer rainfall and irrigated cool season conditions as determined by the variety-seed rate conditions.

Hypothesis

The performance of wheat varieties grown under rain-fed conditions could be just as productive as under irrigated conditions.

2.0 LITERATURE REVIEW

2.1 Wheat production in the world

Wheat (*Triticum aestivum L.)* is the leading cereal crop in the world. Its cultivation reaches far back into history and it is the world's single most important food crop in terms of tones of grain produced each year (Gooding and Davies, 1997). Wheat is highly adapted. It grows successfully on a number of soil types, however the crop is susceptible to a number of abiotic and biotic stresses.

Wheat contributes more calories and protein to human diets and the world trade of wheat exceeds all other grains combined. As a food, wheat has many natural advantages over other cereal grains. It is nutritious, easily stored and transported and easily processed to give highly refined raw foods such as flour and pasta. These fit into countless recipes and suit many tastes (Choudhri, 1987).

In Zambia Wheat grows successfully on a number of soil types. However, the crop grows best on well-drained, fertile, medium textured soils with a moderate capacity to hold water. Water logging conditions may cause low yields. This is due to numerous factors acting upon the wheat plants, such as changes in soil chemistry like denitrification of soil nitrogen, increase in manganese concentration and decrease in soil oxygen (Samad *et. al.*, 2001). The climate in Zambia is ideal for wheat production and thus has the potential to be produced under both rain fed and irrigated conditions.

2.2 Climatic Requirements

Although wheat is typically a crop of the temperate and winter - rainfall regions, it is adapted to many climates. It grows well at latitudes ranging from 60°N and 40°S, and at altitudes ranging from the sea level to 3,300 meters above sea level, provided there is a relatively cool, moist growing season followed by a warm, dry season for ripening (Choudhri, 1987)

2.2.1 Effects of ambient temperature on wheat growth.

Temperature is the most important of all environmental factors for wheat, determining the growing season and the optimum sowing time wherever wheat is grown. The optimum growing temperature of wheat is about 25°C, with minimum and maximum growth temperatures of 3°C to 4°C and 30 to 32°C (Al-Khatib *et.al.*, 1999 and Curtis, 2002). Warmer temperatures during the early growth period result in poor tillering and early heading while hot temperatures towards the end of the growing period restricts the grain filling period, growth and hastens maturity. In addition ears become small and the kernels inadequately filled. Gibson and Paulsen (1999) found that increasing day and night temperatures ten days after anthesis to maturity reduced grain yield by 78 %, kernel weight by 29 % and kernel number by 35 % . Excessive respiration and possible detrimental effects on sink formation may further reduce yield potential (Mukwavi *et.al,* 1991.). Habitats of cereals differ dramatically, and temperatures above 35°C are not uncommon in both temperate and Tropical regions. Cereals that are native to temperate regions usually lack the thermo tolerance that characterizes most tropical species and frequently suffer greater injury during stress (Al-Khatib *et. al*, 1999). Wheat is particularly sensitive to heat injury. Injury may occur during vegetative or productive phases depending on the location and season.

2.2.2 Moisture requirements of wheat.

Wheat is adapted to a broad range of moisture conditions. Wheat can be grown in locations where precipitation ranges from 250 mm to 1750 mm (Curtis, 2002). However, too much precipitation can lead to yield loses from diseases and root problems. In the most important wheat producing areas of the world, annual rainfall is less than 700 mm. Wheat will succeed with as little as 200 mm of annual rainfall depending on its distribution (Choudhri, 1987). Water deficit during anthesis however, affects the grain filling process which cause a reduction in grain yield by reducing spike and spikelet number and the fertility of surviving spikelets (Garcia de Moral L.F, 2003). Tiller proliferation, which is one of the first developmental process, is also affected by water deficit as it depends mainly on the availability of water. Under water deficit, most tillers abort or linger to form green immature, nuisance heads at harvest (Okuyama, 2005).

2.3 Soils suitable for wheat production

Wheat is adapted to a range of soils. However, it is best adapted to fertile medium to heavy-textured soils that are well drained with pH above 5.6. The silt and clay loams in general give highest yields of wheat, but the crop can also be successfully grown on either clay soils or fine sandy loams. It however does not perform very well on sandy or poorly drained soils. In acidic soils it is adversely affected by aluminium toxicity as already stated above.

2.4 The physiological aspect of the wheat crop

Most wheat breeding programmes are currently incorporating physiological selection traits in their programmes. Selection for physiological traits with strong association to yield in target environments has a potential for yield improvement. As a result of this, physiological selection techniques are now being evaluated for their role as complementary tools in wheat breeding.

2.4.1 Crop establishment.

The adaptation of the wheat crop has been principally a matter of matching the maturity pattern of a cultivar to the length of the growing season. Researchers have reported that many factors associated with sowing a wheat crop have large impact on the plant establishment. The degree to which the plants are then able to compensate determines the subsequent effects on yield. It is reported that final grain quality can also be influenced by sowing factors, but the reported effects are often small (Kiyomoto, 1986: cited by Gooding and Davies, 1997). Some elements that can have an effect on plant establishment include seedbed preparation, sowing date, seeding rate and also sowing method.Sowing date is largely governed by the climate and the requirements of rotation. Matching cultivar maturity to the sowing date is a key element for maximizing wheat grain yield. It helps to increase productivity and reduces seasonal risks. Rajaram *et al.*, (1999) reported that experiments in Sonora, Mexico, showed that late planting could reduce yield by as much as 50 % while in South Asia late planting caused drastic reductions in yield than in Sonora. Researchers have reported that early sowing causes weakness of the straw, great lodging and also increase the severity of diseases.

2.4.2 Seed rate effects on yield and yield components and other agronomic traits on wheat.

Planting rate, or seed rate, in plant production is considered to be the beginning of the technological process of the crop growing affecting a number of other cultivar practices but also the product yield and quality (Bokan and Malesevic *et. al.*, 2004). Plant density is a factor of particular importance in wheat production systems because it can be controlled. It is one of the major factors determining the ability of the crop to capture resources. Optimum plant densities vary greatly between areas according to climatic conditions, soil, sowing time and varieties. Consequently, there is a value in defining the relationship between density and wheat yield to establish optimum seeding rates (Lloveras, 2004). When plant population is high, it increases interplant competition and may also lead to weaker and taller stems. More densely sown crops often have an increased susceptibility to a number of diseases such as powdery mildew and *septoria* (Gooding and Davies, 1997). Converserly, when the plant number is lower than an ideal one, there is an intensive water loss, excessive soil heating, irrational nutrient utilization and a more intensive weed infestation. Samuel and East (1990, cited by Gooding and Davies, 1997) reported that in organic farming low seed rates resulted in low protein values when weed pressures were high and where weed pressure was low protein concentration declined as seed rates and yield increased. Reduced seed rate can also cause prodigious tillering, which could cause variable and delayed maturation making the crop uneven and difficult to manage and harvest. Under optimal condition a plant can use sunlight, water and nutrients more efficiently. It has been reported that increasing planting density increases leaf area indices (Bavec *et. al.*, 2007).

Dencic (1990, cited by Bokan and Malesevic, 2004) observed that the spike number is always greater than planting density, being the result of productive wheat tillering. With the planting density increase the spike number also increases.

One thousand grain weight as a varietal trait is susceptible to cultural and agro-ecological conditions. With the planting density increase there is a rise in the spike number yielding kernels of smaller size and smaller weight (Stojanovic, 1993, cited byBokan and Malesevic, 2004.)

2.4.3 Relationship between yield and morpho-physiological yield components

Trethowan and Crossa (2007) defined yield potential as the maximum attainable yield within the limits imposed by the genetic constitution and the production environment. Better understanding of these constraints and the underlying causes of genotype x environment interaction will improve productivity regionally and globally. Yield potential has been used to assess progress in plant breeding programs and to analyze the relative contributions of plant breeding and agronomic advances to past increase in crop yields. Interpretations of the physiological basis of increases in yield potential have also been used to assess the scope for further increases in yield and to guide selection.

Yield of wheat can be expressed as the product of, kernel number (KNO) per meter square and kernel weight (KW) in grams (Acevedo *et al.* 2002). According to Acevedo *et al.*, (2002), wheat yield potential could be achieved through changes in kernel number (KNO) and \ or kernel weight (KW). KNO is the product of plants per m^2, spikes per plant, spikelets per spike, florets per spike and grains per floret. Yield progress in cereals has been strongly associated with increased KNO. It is reported that kernel number per spike is a basic yield component (Fisher., 1975; Abeledo 2003). Bokan and Malesevic (2004) observed that grain yield is more dependent on kernel number per spike much more than on the spike length. Similar observation were made by Kelly *et. al.*, (1994), showing that compared to the 1000-grain weight, spike number and kernel number/m², the kernel number per spike is more a reliable trait for assessing the size the wheat grain yield. Grain yield in wheat is a complex phenomenon entailing several contributing factors that are in turn highly susceptible to environmental influences (Khaliq *et. al.*, 2001; Khan *et. al.* (2003); Zhang *et. al.*, 2008). Understanding the factors that affect the number of grains per unit area and its variation is essential for identifying both management options to achieve greater number of grains and breeding options to increase wheat yield potential. According to Khan *et. al.* (2003) grain yield in wheat is a complex phenomenon as it is polygenically controlled. Khaliq *et. al.* (2001) reported that number of tillers and thousand –grain weight were positively and significantly correlated with grain yield. Chowdhry *et. al.*, (2000) reported that yield components like tillers per plant, grains per spike and thousand-grain weight were main contributors to grain yield in wheat. Zhang *et al.*, (2008) reported that for a given environment, the most important component influencing grain yield is the number of grains per unit area. Understanding the factors that affect the number of grains per unit area and its variation is essential for identifying both management options to achieve greater number of grains and breeding options to increase wheat yield potential Nabi *et al.* (1998, cited by Khaliq *et. al*, (2001) reported positive relationship between spike length, peduncle length and grain yield but a negative correlation between plant height and grain yield. Basaik *et al.* (1991, cited by Khan *et al.* 2003) reported positive correlation between grain yield and peduncle length.

Plant height is also another important plant trait in the selection of wheat varieties. Growers may select short plants to limit the amount of post harvest debris. Tall plants may be selected by growers to maximise on straw yield. Bruening (2005) reported no relationship between plant height and yield. Researchers (Slafer *et al.*, accessed on 3rd December 2008) reported that the relationship between plant height and yield is parabolic and tall plant have a low yield due to low harvest index where as short plants have a low yield due to smaller final biomass.

Leaf area index (LAI) is a parameter that reflects the development of plant stand. It is connected with photosynthesis as well as with transpiration and, to a certain degree with the above ground biomass of the stand (Reining, 2002). Bavec *et. al.,* (2007) reported that increasing leaf area index (which may be changed by the production system) decreases light interception and net assimilation rate depending on plant morphology. In wheat, LAI formation is obtained by tillering and by number of tillers per plant (Bavec *et. al,* (2007). Recently, leaf area index or indices of vegetation have been used in agricultural models for biomass estimation and yield prediction (Pectu *et al.,* 2003).

Researchers proposed that any increase in the yield potential of wheat would come from breeding. It is reported that progress in breeding is more likely to occur if specific characteristics are targeted as has occurred in grain quality improvement and disease resistance breeding. A number of researches showed that increase in grain yield came from an increase in harvest index (HI) rather than an increase in kernel weight (Calderini, 1994). Sharma *et al.,*(1986), in a study of selection for high and low harvest index in three winter populations, observed that harvest index may be a useful selection trait in yield improvement. Fisher and Kertiz (1976, cited by Benmahammed, 2008) stated that harvest index is the best predictor of grain yield in later generations because it is less influenced by environmental changes compared to grain yield. Smith *et.al.*, (1999) defined harvest index as the ratio of the dry weight of desirable crop material to the total above ground dry matter produced by the crop. HI is most useful as an index of productivity for small grain cereal crops and pulses. Peltonen- Sainio (1999) reported that HI is the most frequent used indicator to show the success of the plant to partition dry matter to grain rather than non yield structures. Salman and Brinkman (1992) (cited by Peltonen- Sainio 1999) found that the correlation between HI and grain yield was positive. Bhatt, (1976) reported that HI was a useful selection criterion for improving grain yield in two crosses of spring wheat and was considered more reliable at high population densities than low densities.

2.4.4 Influence of root biomass on yield. The hidden component of crop physiology

Plants have a remarkable capacity to co-ordinate the growth of their organs, so that there is generally a tight balance between the biomass invested in the shoot and that invested in the roots (Pooter *et al.*, 2000). The control of root and shoot growth is reciprocal (Peltonen-Sainio, 1999). Plants shift the allocation of resources towards the shoots if the carbon gain of the shoot is impaired by a low level of above-ground resources. Similary, plants shift allocation towards roots at a low level below-ground resources (Peltonen-Sainio, 1999, Pooter *et al.*, 2000). Varietal differences in structure and function of the root system may contribute more to the differences in yield.

Root biomass measurements in the field experiments have been reported to be very tedious and time consuming. For this reason few values of root biomass under natural conditions have been reported (Baret *et al.*, 1992)

2.5 Wheat Production Environments

Wheat is produced either as an irrigated crop in the dry cool weather or as a dryland rain fed crop. Wheat production under irrigation provides optimal growing conditions because water application can be controlled so that optimal moisture requirement of the crop is applied. Dryland wheat production on the other hand is to do with growing the wheat crop under rain fed conditions. The challenges of the dryland wheat production are the same as for any other crop grown under rain fed conditions. This is to do with unpredictable weather conditions, leading to erratic rainfall and this affects yield.

2.5.1 Irrigated conditions

Almost all the wheat grown in Zambia is irrigated spring wheat. Irrigated wheat is grown by commercial farmers as it is a capital-intensive operation and it is grown as a cash crop. Wheat is grown during dry season, with sowing done in mid April to early May. This allows the crop to grow during the cool months of June and July. The cool weather encourages tillering growth and the overall performance of the wheat crop. Yileds in excess of ten metric tones per hectare are not uncommon under irrigated farming.

2.5.2 Dryland Wheat Production.

Dryland wheat production can be divided into winter rainfall environment and summer rainfall environment.

2.5.2.1 Winter Rainfall Environment

Winter rainfall areas or Mediterranean-type environment where winter rainfall prevails, contributes a major part of the world's dryland wheat. In these areas wheat is often the dominant crop. The Mediterranean-type environment are located on the west coast of the continents in both hemispheres between latitude 20° and 40°. The longest area is in the North Africa, West Asia and Southern Europe around the Mediterranean basin. Small areas are found in the Pacific North West area of the United States, in Chile, Southern Australia and South Africa (Anderson and Impiglia, 2002).

The mean temperature of the coldest months varies from –5°C to 10°C. The mean maximums during the grain maturation period can be as high as 30°C. The growing season for wheat varies from 100 to 125 days in the countries of the Mediterranean basin. Variability of rainfall amount and distribution during the growing season is a characteristic of these environments.

The challenge for the plant breeder in the dryland winter rainfall environments is to match the cultivar to the dryland environment and to apply the knowledge of climatic, edaphic, biological and economic factors to devise systems that optimize grain yield, yield stability, grain quality and long term viability of the wheat cropping system (Fisher, 1985).

2.5.2.2 Summer rainfall environments.

The summer rainfall environment is the most challenging. This is so because wheat is poorly adapted to warm moist climate, unless there is a comparatively cool dry season which favours plant growth and retards parasitic diseases. Hence, matching wheat varieties to summer rainfall environment is a very difficulty challenge. However, in the tropical areas these environments offer a great opportunity for small scale farmers who can not afford irrigation equipment to participate in wheat production.

In Zambia very little production is done under rainfed conditions in summer and a likely reason for this is that the rain season is characterized by unpredictable and highly variable seasonal rainfall and, hence, highly but low variable yields. This is also due to disease and weed pressure and warm temperatures during the rainy season which reduces tillering and other traits. In Zambia rainfed wheat is mostly produced by small-scale farmers in Mbala District of the Northern Province as it requires low-input management levels of production and mostly without power machinery. Recently, in Zambia, some commercial farmers have shown interest to grow rain fed wheat, as it would reduce on cost of production, since the irrigation cost a major component in wheat production would be removed from the wheat production cost profile.

Musa (1983) reported that the optimum planting time for the rain fed season is mid to late January, which is some three months after the usual onset of the rains. It is reported that earlier plantings results in a high development of *Helminthosporium sativum* and therefore low yields. Mooleki (1997) reported that in any given region later planted crops have lower disease incidence than earlier plantings. However, planting should be well timed to ensure that grain filling period is not forced far beyond the rainfall period. It is important to mention that any kind of agricultural product grown in the field is prone to diseases.

3.0 MATERIALS AND METHODS.

3.1 Experimental Site

The study was carried out at the Zambia Agricultural Research Institute (ZARI) at Mt.Makulu in Chilanga, which is at latitude 15° 33' south and the longitude is 28° 15' east in Chilanga, Lusaka province. It was planted in two seasons that is in the summer of 2007/2008 under rainfed conditions and in the winter of 2008 under irrigation.

The soils of Mt.Makulu are the Makeni series sandy loam type. With regards to the soil taxonomy classification the soil is classified as Alfisol (Veldkamp, 1984). Prior to planting, soil samples were collected from the study site for soil analysis. The textural class of the soil where the study was conducted was found to be clay loam. The soil analysis showed that the soil had the following analysis (Table 1).

Table 1 **Soil Analysis for Zambia Agricultural Research Institute (ZARI), Chilanga.**

pH CaCl	N %	Ca Me%	K Me%	P ppm	Mg Me%	Na Me%	Zinc ppm	Fe ppm	Cu ppm	Mn ppm
7.2	0.04	27.9	0.61	9.0	3.9	0.29	2.0	148	1.0	364

3.2 Treatments and conduct of the experiment

The study involved five varieties, that is: UNZA WV1, UNZA WV2, Sahai, Coucal and Loerrie II. Table 2 gives the pedigree of the varieties involved in the study and the characteristics for where the varieties were selected. The UNZA varieties were selected for heat tolerance while Coucal and Sahai were selected for rainfed or summer rainfall dryland growing conditions. Loerrie II is a high yielding variety for winter irrigated conditions. Loerrie II is used as a local check. Sahai is from Seed-Co, a private seed company in Zambia. Sahai like Coucal from ZARI is also a rainfed variety. Apart from studying the comparative performance of the five varieties under the two environments, the effect of seeding rates on yield and traits like above ground biomass, tillers per meter square, plant height, peduncle length, grains per spike and spike length, and also days to heading and days to maturity was also investigated. Five seeding rates, that is 60 kg/ha, 80 kg/ha, 100 kg/ha, 120 kg/ha and 140 kg/ha were used in the study. These seed rates were selected to check whether they had any effect on tillering capacity and the yield on the varieties used in the study.

The experimental design was a split plot with treatments arranged in a randomized complete block design with four replications. The varieties were Factor A (main plot) and seeding rates were factor B (sub plot) that is for within the season. For the combined analysis a split –split plot design was used. Season was factor A (main plot) with varieties being factor B (sub plot) and seed rate factor being C (sub-subplot).

The plots were ploughed and disked to prepare the seed bed for planting. The plot size was 6m². There were five six meter rows spaced 20cm apart and one meter between plots. The first planting was done in summer on 15th January, 2008 and the second planting was done in winter season on 23rd June, 2008. Planting was done by hand. Compound D, a basal dressing fertilizer at 500 kg/ha (10:20:10, Nitrogen, Phosphorus and Potassium respectively by composition) was applied to all plots at planting. Four weeks after planting, Urea a top dressing fertilizer of 250 kg/ha (46% Nitrogen by composition) was applied to all plots.

Weeding was done using hand hoes whenever weeds appeared in order to eliminate any possible weed competition with the crop.

Table 2 **Spring wheat cultivars used in the study**

Variety	**Pedigree**	**Source**	**Seasonal adaptation**
Coucal	CM70377-3MB-0MM-1MB0MM-2MM-0MM	ZARI	Rainfed/Aluminium toxicity tolerance
Loerrie II	CM33027-F-15M-500Y-0M-87B-0Y	ZARI	Irrigated
UNZAWV1	CMBW90MY3058-74M-015Y-015M-1Y-OBATTILA/3*BCN	UNZA	Heat tolerant
UNZAWV2	CMBW90Y4399-OTOPM-1Y-010-01OY-8M	UNZA	Heat tolerant
Sahai			Rainfed

NOTE: ZARI is an acronym for Zambia Agricultural Research Institute while UNZA refers to the University of Zambia

3.3 Data collection and analysis

3.3.1 Yield and other measurements

Data on morpho-physiological traits was collected. The traits measured were plant height, peduncle length, ear length, root biomass, leaf area index and harvest index. The phenological traits, days to heading and days to maturity were also assessed. Days to heading were recorded as the date when the spike completely emerged from the flag-leaf sheath on 50% of the plants in the plot, while days to maturity was recorded as the date when 50% of the spikes (head) had lost the green colour (turned yellow). The head count was used as a proxy for the number of fertile tillers per meter square a yield component obtained by counting the total number of heads within a randomly selected quadrant per replicate. Other yield components assessed were grains per ear and 1000- grain weight (grams).

Plants were hand-harvested by cutting them at ground level from the harvest area of $3m^2$. The above ground biomass from each plot was bulked into a sheath and weighed. Plants were threshed by hand. Grain from the bulked sheath from each plot was obtained and weighed to give grain yield (economic yield).

3.4 Statistical analyses.

The data that was obtained was analysed by IRRISTAT version 4 software 2004 . Analysis of variance (ANOVA) for a split-plot design was performed on the data.

The linear statistical model for the split-plot design used in data analysis was:

$$y_{ijk} = \mu + T_i + \beta_j + (T\beta)_{ij} + \gamma_k + (\beta\gamma)_{jk} + \alpha_{ijk}$$

Where Y = Parameters

μ= Mean

T= Replication

β= Varieties (factor A)

T β = Main plot error

γ= Seed rates (Factor B)

Bγ= Varieties x seed rate interaction

α = Error

A combined analysis of variance for grain yield and its related characters and other morpho-physiological characters was performed over trials. A split-split- plot design was used for the combined analysis. The seasons were factor A (main plot), varieties were factor B (subplot) and seed rates were factor C (sub-subplot). Least Significant differences (LSD) were calculated at 5 % and 1 % levels of probability for mean comparison.

4.0 RESULTS AND DISCUSSION

The season specific findings will be first presented and discussed followed by the combined across season results.

4.1 Experiment 1: 2007/2008 rainy season (Season 1)

4.1 .1 Effect of variety on grain yield and other plant traits in seasons

The varieties in season 1(summer season or rainfed) did not differ significantly (Table 3) in grain yield per hectare, number of grains per ear, head count (number of tillers per square meter) and leaf area index. Though there were no differences in these parameters, it was observed that the rainfed varieties (Coucal and Sahai) and the heat tolerant (UNZAWV1 and UNZAWV2) had slight grain yield advantage over Loerrie II, the check variety. It was observed that UNZAWV2 had the most yield advantage of 52 % over Loerrie II and this could have been mainly due to both higher number of heads per meter square and grains per ear expression of the two varieties compared to Loerrie II which had a lower number of grains per ear and number of heads per square meter (Table 4). Sahai had a high grain yield though having lower number of grains per ear and number of heads per meter square. This could have been due to higher kernel weight expressed by this variety. Coucal although having higher number of heads per meter square and grains per ear had intermediate yield. This was due to lower kernel weight. Significant difference was observed among varieties for plant height, thousand-grain weight, peduncle length, ear length, days to heading and days to maturity (Table 3).

Table 3 **A split- plot analysis of variance of yield and other plant traits in Season 1(rain season)**

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		Grain yield		Above ground biomass		1000-grain weight		Leaf area index		Plant height	
Source of Variation	Df	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob
Replication	3	2849224		22370412		6.01		934.18		221.40	
Variety	4	8722.85	0.958	1410091	0.022*	80.64	0.013*	6.14	0.597	239.07	0.000*
Error	12	73804.6		589033.		16.01		8.54		10.49	
Seed rate	4	26373.1	0.003*	1874582	0.005*	20.99	0.058*	14.32	0.296	15.76	0.166
Variety * Seed rate	16	48955.3	0.613	441643.	0.502	15.29	0.060	18.98	0.079	10.52	0.358
Residual	60	56735.7		456416.		8.70		11.39		9.39	
CV%		29.8		30.2		8.3		31.8		4.8	

Note: * denotes significant at 5% level of probability

Table 3 continued

		Days to heading		Days to maturity		Grains per ear		Peduncle length		Ear length		Number of tillers	
Source of Variation	Df	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	F	Ms	Prob
Replication	3	43.64		29.27		166.39		18.07		73.4		2411.19	
Variety	4	110.59	0.000*	16.48	0.002*	19.41	0.637	74.47	0.001*	18.84	0.002*	147.76	0.320
Error	12	6.70		4.99		29.66		7.02		0.24		112.62	
Seed rate	4	16.06	0.096	12.36	0.010*	29.50	0.465	8.34	0.397	0.64	0.081	198.33	0.009*
Variety * Seed rate	16	3.75	0.946	3.45	0.441	26.08	0.673	7.15	0.585	0.34	0.331	48.48	0.563
Residual	60	7.78		3.35		32.35		8.05		0.29		53.34	
CV%		5.4		2.0		16.0		29.9		7.1		20.9	

Note: * denotes significant at 5% level of probability

Table 4 **Means of variety on grain yield and other plant traits of wheat grown in Season 1**

Variety	Grain Yield (Kg/ha)	Leaf area index	Grains /ear	Peduncle Length (cm)	Ear length (cm)	Plant height (cm)	Number of Head/m²	Biological yield (Kg/ha)	1000-grain weight (g)	Harvest Index	Days to heading	Days to maturity
UNZAWV1	799.07	10.58	34.85	8.58	7.90	60.90	34.67	2069.75	38.17	38.83	50	90
COUCAL	794.59	10.12	35.70	12.77	7.24	69.38	37.03	2555.30	33.88	31.62	52	90
SAHAI	801.86	10.73	35.08	7.87	8.00	63.77	32.65	2059.22	37.17	32.98	52	92
UNZAWV2	811.68	10.17	37.20	9.60	7.56	62.23	38.32	2456.24	33.80	40.02	56	92
LOERRIE II	757.25	11.49	34.90	8.677	7.52	61.32	32.03	1964.35	34.66	38.84	50	91
5%LSD 12DF	150.71	201.376	375.257	182.656	0.334823	223.132	731.180	427.454	2.75690	4.67721	176.439	115.852
Significance	NS	NS	NS	NS	*	*	NS	NS	*	*	*	*

NS = not significant at 0.05 probability level

* = significant at 5 % probability level

The variety Coucal was the tallest followed by Sahai, UNZAWV2, Loerrie II and then UNZAWV1 (Table 4). Plant height had a positive effect on the above ground biomass (biological yield) as well as an effect on the grain yield.

Coucal had the longest peduncle length followed by UNZAWV2, Loerrie II, UNZAWV1 and Sahai. Sahai had the longest ear length as well as the highest grain yield per hectare. It was observed that UNZAWV2 had more tillers compared to Coucal, UNZAWV1, Sahai and Loerrie II (Table 4)

4.1.2 Experiment 2. 2008 Irrigated condition (season 2)

In season 2, there were no significant differences among the five varieties in grain yield per hectare, the ear length, biological yield, leaf area index and days to maturity (Table 5). The varieties showed significant differences in the following morpho- physiological traits, plant height, tillers per square meter, peduncle length, grains per ear, thousand grain weight and days to heading. UNZAWV1 out yielded the other varieties in grain yield followed by Loerrie II, Coucal, UNZAWV2 and then Sahai (Table 6). Sahai had the lowest grain yield although having intermediate number of heads per meter square and grains per ear, this could have been due to lower kernel weight. Coucal was the tallest variety in season 2 followed by UNZAWV2, Sahai, Loerrie II then UNZAWV1. Coucal, which was the tallest variety, had also a higher above ground biomass (biological yield) (see Table 6) and a longer peduncle length UNZAWV1 had a higher leaf area compared to the other varieties and also a higher grain yield per hectare. Table 6 shows that Coucal had more number of tillers per square meter compared to other varieties.

The yield potential of the rainfed, irrigated and the heat torrelant varieties used in the study is over 3,000 kg per hectare and between 6,000 kg and 12,000 kg per hectare, respectively

(Mooleki, 1997, http://www.seedcogroup.com/country/zimwheat.htmt accessed on 19.01.2009)). In this trial the average yields of the varieties in season 1 ranged from 757.07 kg/ha to 811.68 kg/ha. These yields are very much lower than expected and the drop in yield could be attributed to water stress as a result of a dry spell with high temperatures that occurred during the vegetative growth. The high temperatures are known to have a negative effect on yield and yield components (Mukwavi *et.al.*,1991). Irrigation was also a problem for the irrigated crop due to load shading by the power utility company, Zambia Electricity Supply Company, (ZESCO). This resulted in poor crop stand and hence yields. The crop had also stalk borers during ripening and leaf rust which were controlled successfully. The above stated problems could have affected the yield as the crop could not perform to the maximum potential. Hares also heavily attacked the fourth replication during milk stage (soft dough stage) during rain season due to its proximity to the bush.

The yield for the wheat under irrigation (season 2) had average yields ranging from 1572.67 kg/ha to 1738.95 kg/ha. These yields are also lower than expected. The reduction in yield during season 2 could be associated with poor irrigation due to frequent breakages of the pump. This caused the crop to experience water stress during the period of maximum water use by the crop, i.e. period of ear emergence and grain formation. Mooleki (1997) observed that lack of moisture during this period adversely affects both grain number per spike, grain size, and may result in sterile ears at harvest.

Table 5 **A split- plot analysis of variance of yield and other plant traits in Season 2 (Irrigated season)**

		Grain yield		Biological yield		1000-grain weight		Leaf area index		Plant height	
Source of Variation	Df	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob
Replication	3	949970		1942854383		7.07		48.27		170.72	
Variety	4	15353	0.464	17800108	0.705	46.37	0.000*	7.52	0.50	1227.72	0.000*
Error	12	204756		1839074		3.33		7.73		36.49	
Seed rate	4	391682	0.066	76800987	0.063	4.38	0.229	6.98	0.60	14.08	0.830
Variety * Seed rate	16	122073	0.758	3625753	0.363	4.74	0.107	11.11	0.40	46.05	0.284
Residual	60	168309		3252351		3.02		10.39		37.92	
CV%		24.8		28.7		4.5		31.6		8.6	

Note: * denotes significant at 5% level of probability

Table 5. continued.

		Number of tillers		Days to heading		Days to maturity		Grains per ear		Peduncle length		Ear length	
Source of Variation	Df	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob
Replication	3	1522.27		0.41		4.59		34.92		12.34		2.75	
Variety	4	1331.72	0.000*	1.086	0.004*	7.51	0.090	372.62	0.00*	121.76	0.000*	0.47	0.453
Error	12	249.61		1.55		6.29		23.01		3.98		0.38	
Seed rate	4	57.20	0.855	9.79	0.008*	1.01	0.886	100.35	0.016*	5.50	0.855	0.57	0.350
Variety * Seed rate	16	65.24	0.982	2.40	0.530	3.06	0.615	35.79	0.305	4.34	0.332	0.34	0.800
Residual	60	171.24		2.55		3.56		30.17		3.77		0.50	
CV%		24.6		2.6		2.0		10.0		16.4		8.5	

Note: * denotes significant at 5% level of probability

Table 6 **Means of effect of variety on grain yield and morpho- physiological traits of wheat grown in season 2.**

Variety	Grain yield (Kg/ha)	Plant height (cm)	Number of tillers/m²	Peduncle length (cm)	Ear length (cm)	Grains\Ear	Biological yield (Kg/ha)	Harvest index	Thousand grain weight	Leaf area	Leaf area index	Days to heading	Days to maturity
UNZAWV1	1753.94	66.78	49.87	10.53	8.36	56.00	6247.04	42.29	38.63	380.459	11.10	63	95
Coucal	1602.16	85.25	67.12	16.24	8.51	47.57	6794.32	24.30	36.31	344.450	10.13	63	94
Sahai	1572.67	67.45	52.75	10.50	8.11	55.42	6255.54	26.59	38.60	340.322	10.01	61	97
UNZAWV2	1588.93	71.95	45.80	11.25	8.23	57.10	6104.22	27.08	40.60	345.945	10.17	62	95
Loerrie II	1738.95	67.28	50.63	10.76	8.25	58.70	6036.73	29.72	38.32	323.175	9.50	61	95
5%LSD	259.58	3.89	8.28	1.23	0.45	3.47	1140.66	19.29	1.10	69.34	2.04	1.01	1.19
Significance	NS	*	*	*	NS	*	NS	NS	*	NS	NS	*	NS

4.2 Effect Seed rate on grain yield and other Plant traits within seasons

The results of how the seed rate affected the grain yield and other plant traits are presented in Table 7. An average grain yield of 916.08 kg per hectare across varieties was achieved for the 140 kg/ha seed rate. Biological yield, days to heading and days to maturity were highly significantly affected by sowing density (see Table 3). The higher the density the greater the biological yield. This could be explained by the fact that there were more plants per unit area. The analysis of variance, (Table 3), revealed that seed rate in season 1 had no effect on the grains/ear, peduncle length, leaf area index, plant height, thousand-grain weight and ear length on the varieties used in the study. Though there was no significant effect of seed rate on LAI, results show that increasing density increases the LAI (Table 7). Seed rate or density had a positive effect on the number of tillers per unit area and grain yield on the varieties used. These findings were in line with those of Hussein *et al.*, (2001). The highest numbers of tillers per meter square was obtained with 140 kg/ ha planting density.

There were no variety x sowing density interactions on all the parameters of yield and yield components. The non significant variety x sowing density interaction observed for the morpho-physiological traits in season 1 showed that the varieties did not respond differently to the sowing densities.

For the irrigated wheat (season 2), there were no significant differences shown on grain yield, biological yield, the plant height, peduncle length, ear length, thousand grain weight, leaf area index and days to maturity. Although there were no significant differences shown on these parameters, the highest grain yield and biological yield per hectare was shown with 140 kg/ha planting density. The highest grain yield was

1868.52 kg/ha and the lowest was 1531.18 kg/ha obtained with seed rate of 60 kg/ha (Table 8). Seed rate had an effect on the grains per ear and days to heading (Table 8). The highest number of grains per ear was obtained with seed rate of 60 kg/ha and 80 kg/ha, followed by 100 kg/ha, 120 kg/ha and 140 kg/ha respectively. There was a general decrease in grains per ear after the 80 kg/ha seed rate. This could be due to less number of tillers with lower seed rate as a result there was a reduction in the competition among plants for essential nutrients including sunlight, hence more grains per ear.

Table 7 Means of effect of seed rate on grain yield and other morpho-physiological traits grown in season 1

Seed rate	Grain yield (Kg/ha)	Ear length (cm)	Thousand Grain weight	Harvest index	Biological yield (Kg/ha)	Days to heading	Days to Maturity	Leaf area index	Grains/ear	Peduncle length (cm)	Plant height (g)	Number of heads/m²
60	619.90	7.89	33.88	34.17	1769.05	53.	92	9.86	37	8.89	62.68	31
80	742.87	7.55	35.73	35.59	2180.96	52	92	10.57	36	9.25	63.22	33
100	851.78	7.61	35.69	39.04	2265.89	52	91	10.06	36	9.30	63.35	35
120	833.83	7.42	35.66	36.71	2259.15	51	90	10.59	34	10.59	63.32	36
140	916.08	7.74	36.71	36.77	2628.91	51	91	12.02	35	9.47	65.03	39
5%LSD	150.71	0.34	186.60	631.609	427.45	1.76	1.15	213.51	359.88	179.41	93.82	461.94
Significance	*	NS	NS	NS	*	*	*	NS	NS	NS	*	*

Table 8. **Means of effect of seed rate (density) on morpho physiological components of yield and grain yield of wheat grown in season 2.**

DENSITY	Grain yield (Kg/ha)	Biological yield (Kg/ha)	Harvest index	1000-grain weight	Leaf area Index	Days to heading	Days to maturity	Plant Height(cm)	Number of tillers /m²	Peduncle length(cm)	Ear length(cm)	Grains\Ear
60	1531.18	5430.62	43.1222	38.11	10.91	63	95	71.00	53	11.16	8.20	57
80	1704.53	6768.49	26.1387	37.97	10.03	62	95	72.63	51	11.57	8.52	57
100	1540.07	6037.40	27.0791	39.10	9.45	62	95	72.33	52	12.11	8.41	55
120	1612.34	6205.88	26.6670	38.77	10.67	62	94	70.72	54	11.89	8.22	53
140	1868.52	6995.47	26.9779	38.50	9.94	61	95	72.02	55	12.54	8.11	52
5%LSD 0	259.58	1140.66	19.29	1.10	2.04	1.01	1.19	3.89	8.28	1.23	0.45	3.47
Significance	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	*

There was no significant variety x density interaction in season 2 indicating that the varieties did not perform differently with different densities.

In both seasons the highest yields were obtained by planting 140 kg/ha of seed. The yields of 916.06 kg/ha and 1868.52 kg/ha was achieved in season 1and 2, respectively.

4.3 Combined Across Season Analysis of Results (Seasons 1and 2)

4.3.1 Response of wheat grain yield, yield components and other plant traits to seed rates and seasons (combined analysis).

The seasons had a significant influence on yield and all the yield components and some plant traits as shown in Table 9. Results showed that season had a significant influence on days to heading and days to maturity. There was also a variety x season interaction on plant height, number of tillers per meter square, days to heading, grains per ear, ear length and thousand grain weight, indicating that the varieties performed differently in different seasons on the mentioned traits. Season did not affect leaf area index.

a. Grain yield (Kg/ha).

Results in Table 9 indicated that grain yields were not significantly affected by the varieties. Similarly, the interaction between varieties and seasons, varieties and seed rate and season and seed rate was also non-significant. Season as well as different seed rates significantly affected grain yield per hectare. Grain yield was lower in season 1 (Figure 1) with an average of 793.49 kg/ha. The highest yield of an average of 1649.62 kg/ha was recorded in season 2 which had 856.13 kg more than the yield obtained in season 1 for the same size of land planted. These results showed a significant difference in yield between seasons. The results presented in this study are in accordance with the results by other authors who have observed a decrease in yield in season 1 (rainfed) compared to season 2 (irrigated) (Mooleki, 1997, http://www.seedcogroup.com/country/zimwheat.htmt accessed on 19.01.2009). This implies that for high yield potential, season 2 (irrigated season) is the most desirable one for the varieties used in the study. Although irrigation costs are very high for the irrigated season, the returns on investment are very high as yields were higher than season 1 due to lower disease incidences, cool temperatures that allowed plant to tiller and produce more grains per hectare. In case of the seed rates, for the combined average of the two seasons, the highest grain yield was recorded in 140 kg/ha (1392.30 kg/ha), followed by 80 kg/ha (1223.70 kg/ha), 120 kg/ha (1223.08 kg/ha), 100 kg/ha (1191.66 kg/ha) and then 60 kg/ha (1077.04 kg/ha) (Figure 2). Such results are in agreement with those of Sharma and Smith (1987, cited by Hussain *et. al.*, 2001, Gooding and Davies, 1997, Lloveras *et. al.*, 2004) who observed an increase in grain yield with increase in seed rate.

b.Biological yield.

There was a significant difference in biological yield due to the effect of seasons and difference in seed rates (Table 9). There were no-significant differences from the different varieties and also between the interaction of varieties and season. Season 2 yielded more than season 1 (Figure 1). Seed rate of 140 kg/ha had the highest biological yield of 4812 kg/ha (Figure 3). The lower biological yield obtained in the 60 kg/ha was due to the lower number of tillers per meter square (Table 12).

Table 9. **Combined analysis of variance for season 1 and season 2**

Source of variation	Df	Grain yield		Biological yield		1000-grain weight		Leaf area index		Plant height		Number of tillers	
		Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob
Replication	3	3320671.		38640000		6.029		372.31		365.39		3055.7	
Season	1	36846115.	0.003*	827140000	<.001*	436.318	0.004*	8.68	0.913	3378.58	0.002*	16731.3	0.022*
Main plot error	3	479268.		3164000		7.063		610.14		26.73		877.7	
Variety	4	58935.	0.790	2614000	0. 106	100.508	<.001*	4.17	0.727	1271.53	<.001*	1004.4	0.003*
Season x variety	4	103375.	0.573	585100	0.749	26.499	0.052	9.50	0.350	195.26	<.001*	475.1	0.060
Subplot error	24	139270.		121400		9.672		8.14		23.49		181.1	
Seed rate	4	511531.	0.002*	798900	0.003*	16.090	0.032	8.21	0.557	19.29	0.518	183.7	0.170
Season x Seed rate	4	144165.	0.281	156800	0.502	9.295	0.183	13.10	0.314	10.56	0.775	71.8	0.635
Variety x Seed rate	16	82089.	0.759	2024200	0.379	10.533	0.039	21.55	0.020*	38.17	0.075	63.3	0.905
Season x Variety x Seed rate	16	88965.	0.693	205100	0.365	9.506	0.073*	8.54	0.701	18.40	0.707	50.7	0.965
Sub subplot error	120	112522.		187000		5.861		10.90		23.66		112.3	
CV %		27.4		32.1		6.5		31.7		7.2		24.0	

Note: * denotes significant at 5% level of probability

Table 9 continued.

		Days to heading		Days to maturity		Grains per ear		Peduncle length		Ear length	
Source of variation	Df	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob	Ms	Prob
Replication	3	25.893		10.473		108.25		29.171		6.3381	
Season	1	4743.380	<.001*	669.780	0.013*	18841.29	<.001*	277.443	<.001*	21.0795	0.099
Main plot error	3	18.153		23.380		93.16		1.243		3.7537	
Variety	4	54.562	<.001*	17.320	0.036*	173.37	0.001*	184.712	<.001*	0.8176	0.057
Season x variety	4	66.892	<.001*	6.680	0.343	218.67	<.001*	11.521	0.113	1.5332	0.005*
Sub plot error	24	4.127		5.643		26.36		5.504		0.3076	
Seed rate	4	20.225	0.005*	8.407	0.051	109.17	0.010*	9.208	0.190	0.3609	0.462
Season x Seed rate	4	5.630	0.365	4.967	0.226	20.66	0.620	4.630	0.538	0.8517	0.080
Variety x Seed rate	16	3.553	0.801	4.151	0.278	29,66	0.516	3.617	0.869	0.2266	0.901
Season x variety x density	16	2.596	0.942	2.367	0.804	32.23	0.430	7.879	0.188	0.4559	0.322
Sub subplot error	120	5.165		3.458		31.25		5.910		0.3981	
CV %		4.0		2.0		12.4		22.8		7.9	

Note: * denotes significant at 5% level of probability

Table 10. **Means for Season effect on grain yield and other plant traits.**

SEASON	Grain yield. Kg/ha	Peduncle length	Ear length (cm)	Biological yield Kg/ha	Harvest index	Thousand grain weight(g)	Leaf area index	Plant height (cm)	Number of tillers/m²	Days to heading	Days to maturity	Grains per/ea
Season 1	793.49	9.50	7.64	2223.20	36.47	35.58	10.62	63.52	35	52	91	36
Season 2	1649.62	11.86	8.29	6287.57	30.10	38.48	10.20	71.74	53	62	95	55
5%LSD	307.62	0.50	0.87	798.288	12.96	1.14	11.07	2.32	13.28	1.91	2.17	4.20

Note: * denotes significant at 5% level of probability

Table 11 **Means of variety effect on grain yield and other plant traits for combined analysis of season 1 and season 2**

Variety	Grain yield. Kg/ha	Leaf area index	Plant height (cm)	Number of tillers/m²	Days to heading	Days to maturity	Grains per/ear	Peduncle length (cm)	Ear length (cm)	Biological yield Kg/ha	Harvest index	Thousand grain weight (g)
UNZAWV1	1276.51	10.88	63.84	42	56	92	45.42	9.56	8.13	4158.40	40.56	38.34
Coucal	1198.37	10.12	77.32	52	57	92	41.60	14.51	7.88	4674.81	27.96	35.09
Sahai	1183.00	10.09	64.84	45	56	93	46.31	10.05	7.83	4157.38	33.55	36.18
UNZAWV2	1201.80	10.45	67.86	39	59	93	46.21	9.56	8.11	4285.80	30.07	39.00
Loerrie II	1248.10	10.50	64.29	41	56	93	46.80	9.72	7.88	4000.54	34.28	36.49
5%LSD	204.124	1.91	8.66	13.51	5.07	1.60	9.10	2.10	0.77	483.568	11.93	3.14

Table 12. **Means of effect of seed rate on grain yield and other morpho-physiological traits for combined analysis of season 1 and season 2**

DENSITY	Grain yield. Kg/ha	Leaf area index	Plant height (cm)	Number of tillers/m²	Days to heading	Days to maturity	Grains per/ear	Peduncle length (cm)	Ear length (cm)	Biological yield Kg/ha	Harvest index	Thousand grain weight (g)
60	1077.04	10.39	66.84	42	58	93	47.05	10.03	8.05	3605.86	38.68	36.10
80	1223.70	10.30	67.92	42	57	93	46.80	10.41	8.03	4474.72	30.86	36.85
100	1191.66	9.75	67.84	44	57	93	45.41	10.71	8.01	4151.64	33.31	37.37
120	1223.08	10.63	67.02	45	56	92	43.53	11.24	7.82	4232.51	31.69	37.22
140	1392.30	10.98	68.52	47	56	93	43.59	11.00	7.93	4812.19	31.87	37.61
5%LSD 0	151.102	1.43	2.15	4.92	1.00	0.86	2.43	1.07	0.27	585.73	9.98	1.12

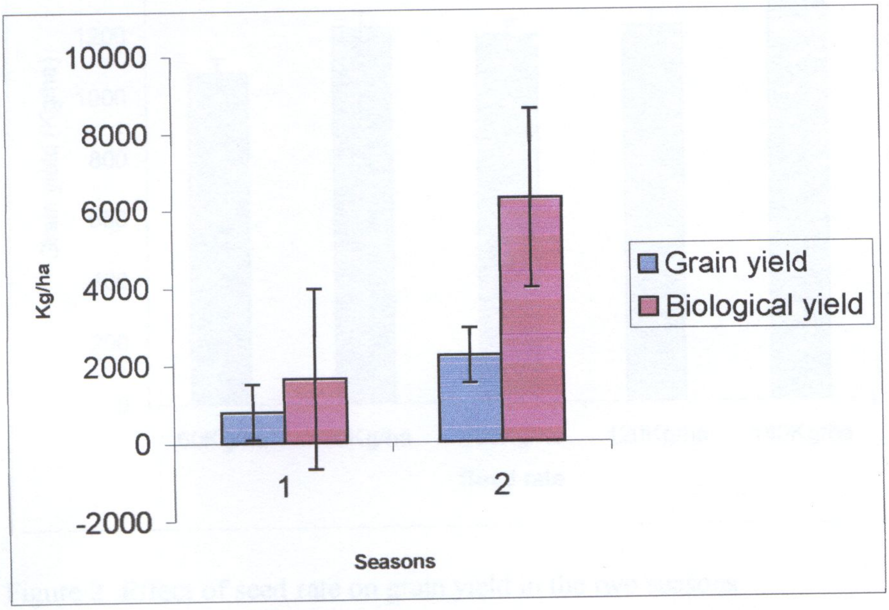

Figure 1. Comparison of grain yield and above ground biomass average two seasons.

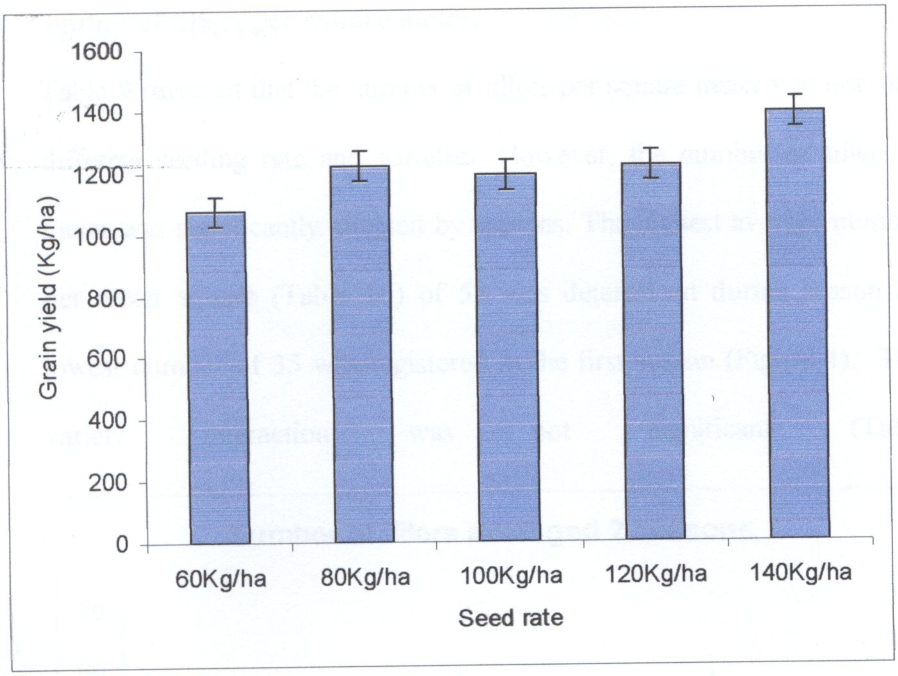

Figure 2. Effect of seed rate on grain yield in the two seasons

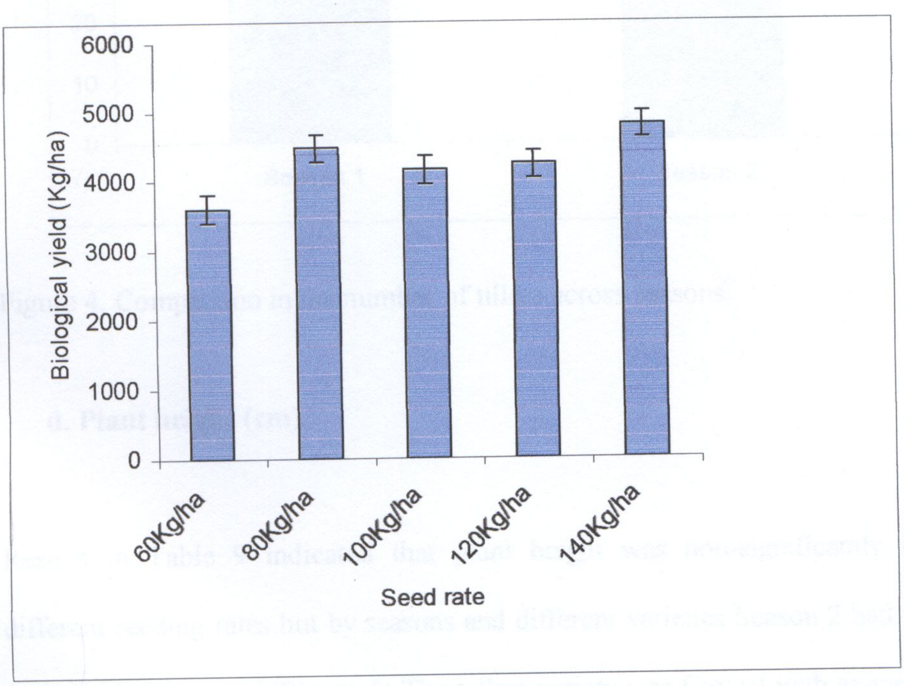

Figure 3. Effect of seed rate on biological yield averaged 2 seasons

c. Number of tillers per square meter.

Table 9 revealed that the number of tillers per square meter was not influenced by different seeding rate and varieties. However, the number of tillers per square meter was significantly affected by seasons. The highest average number of tillers per meter square (Table 10) of 53 was determined during season 2 while the lowest number of 35 was registered in the first season (Figure 4). The season x variety interaction was not significant (Table 9).

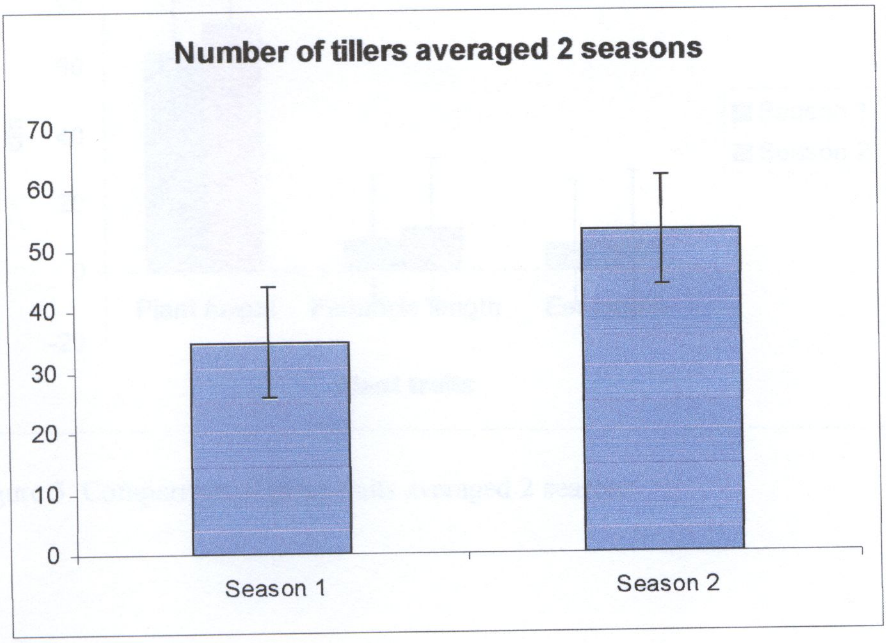

Figure 4. Comparison in the number of tillers across seasons

d. Plant height (cm).

Results in Table 9 indicated that plant height was non-significantly affected by different seeding rates but by seasons and different varieties Season 2 had taller plants compared to season 1(Figure 5) The tallest variety was Coucal with average height of 77.32 cm UNZAWV1 produced plants of the shortest height, 63.84 cm. The difference in plant height of the varieties was attributed to differences in their genetic make up. These results are in agreement with those of Hussain *et.al.*, (2001). The interaction between variety and season was significant, indicating that varieties performed differently in different seasons (Figure 6).

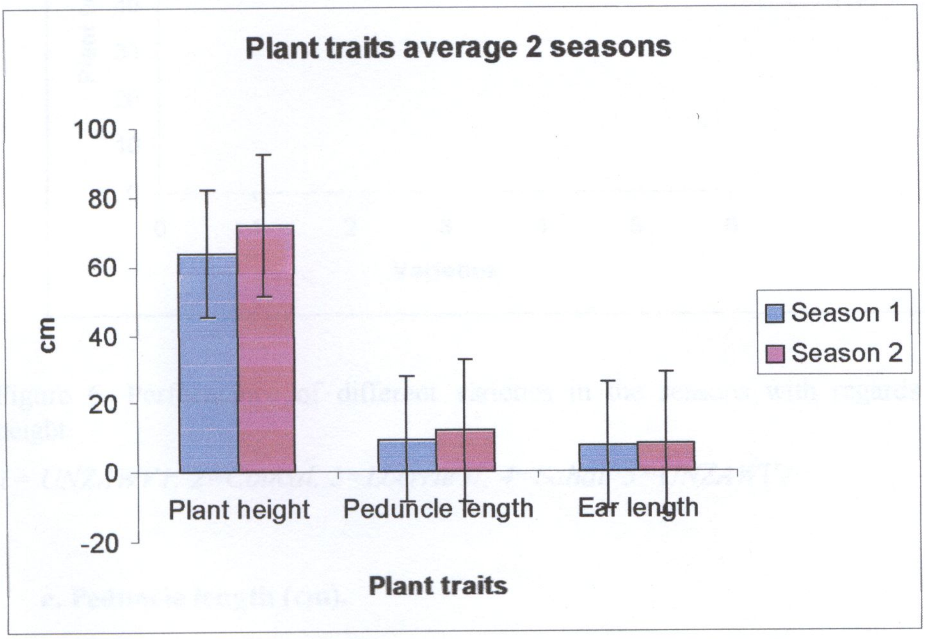

Figure 5. Comparison of plant traits averaged 2 seasons

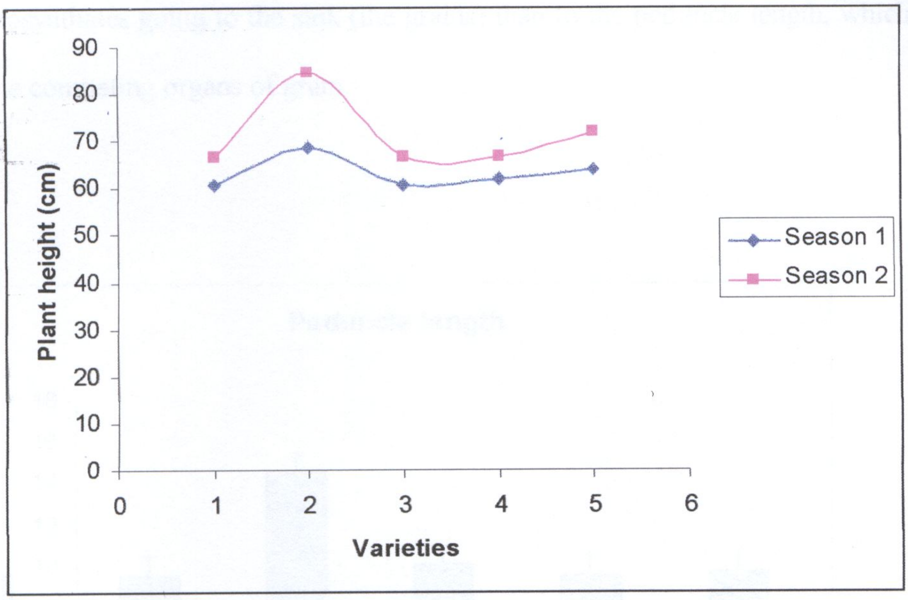

Figure 6. Performance of different varieties in the seasons with regards to plant height.

1= UNZAWV1, 2=Coucal, 3=Loerrie II, 4=Sahai, 5=UNZAWV2

e. Peduncle length (cm).

The results presented in Table 9 shows that peduncle length was significantly affected by season and different varieties, while different densities had no effect on the peduncle length. The longest peduncle length was obtained in season 2 (Figure 5). Averaging the two seasons, Coucal had the longest peduncle length of 14.51cm (Table11 and Figure 7) with an ear length of 7.88cm and 42 grains per ear, followed by Sahai with 10.05 cm peduncle length, 7.83cm ear length and 46 grains per ear. Loerrie II had an intermediate peduncle length of 9.72 cm, 7.88 cm ear length and 46 grains per ear. UNZAWV1 and UNZAWV2 had 9.56 cm peduncle length, 8.13 cm and 8.11 cm ear length and 45.42 and 46.21 grains per ear respectively. It was observed that varieties that had shorter peduncle length had longer ear length, more grains per ear consequently more grain yield per hectare. This could be due to more photosynthates going to the sink (the grains) than to the peduncle length, which is one of the competing organs of grain.

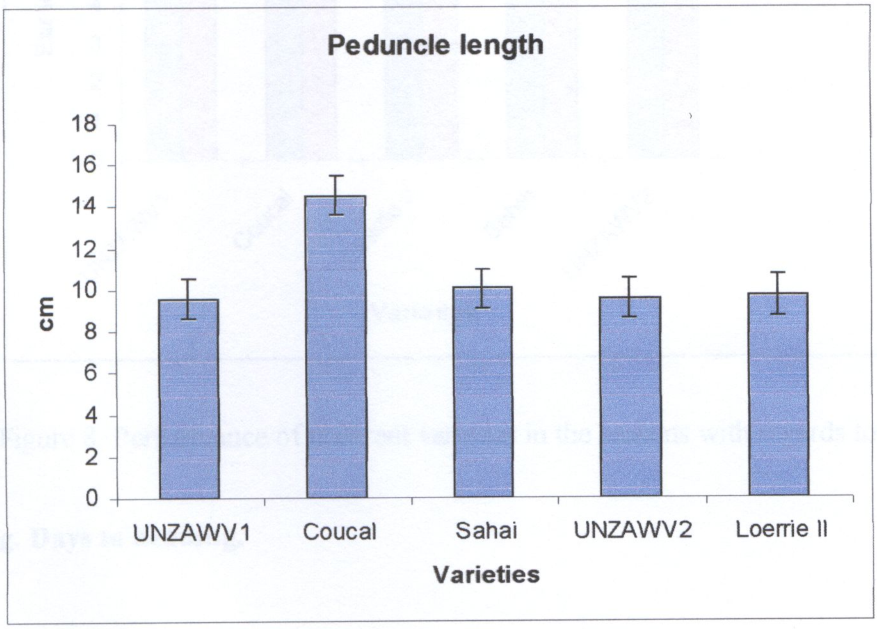

Figure 7.Comparison of peduncle length in different varieties averaged 2 seasons

f. Ear length (cm).

Results showed that ear length was non-significantly affected by the different varieties and different seed rates (Table 9). However, ear length was significantly affected by seasons (See Figure 5). The interaction between varieties and seasons was also significant (Figure 8).

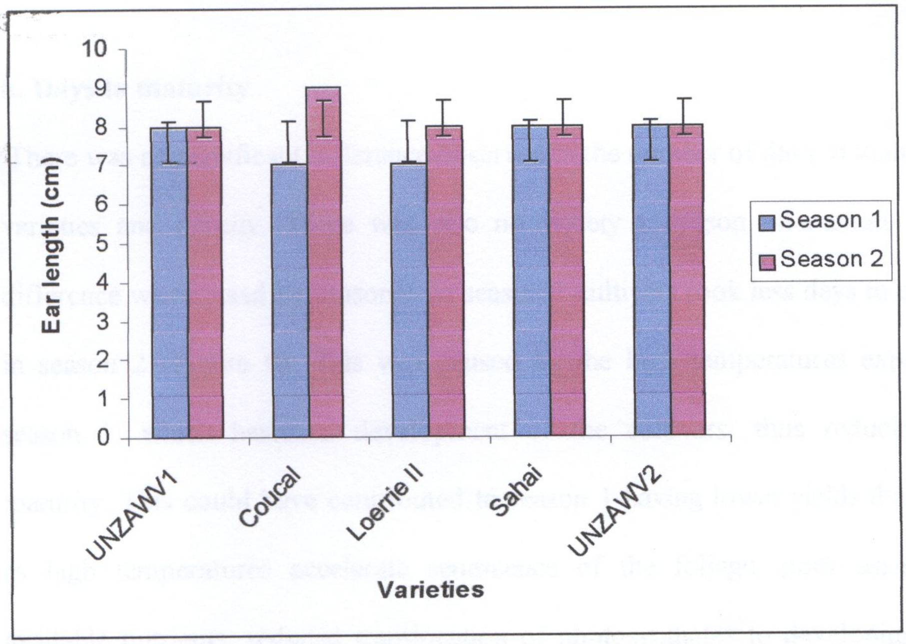

Figure 8. Performance of different varieties in the seasons with regards to ear length

g. Days to heading.

The different seeding rates and seasons had an effect on the number of days the different varieties took to head. There were no significant differences observed on days to heading between varieties. There was a significant varieties x season interaction (Table 9). Varieties in season 1 took an average of 52 days to head while those in season 2 took an average of 62 days (Figure 9). The shorter period to heading in season 1 could be as a result of the high temperatures as a result of the dry spell during the crop growth. This could have shortened the vegetative phase. This facilitated the heading of the plants so as to finish the life cycle. Results in Table 9 showed that seed rates affected the days to heading. The days to heading in both seasons decreased consistently with increase in seed rate. This was probably due to plants competing for nutrients, water and also sunlight.

h. Days to maturity.

There was no significant difference observed in the number of days to maturity due to varieties and density. There was also no variety x season interaction. Significant difference was caused by seasons. In season 1 cultivars took less days to mature than in season 2 (Figure 9). This was caused by the high temperatures experienced in season 1, which hastened development of the cultivars, thus reducing days to maturity. This could have contributed to season 1 having lower yields than season 2, as high temperatures accelerate senescence of the foliage, poor assimilation of available nutrients, reduced translocation of photosynthates to developing grain and respiratory loses (Paulsen and Al-Khatib, 1984).

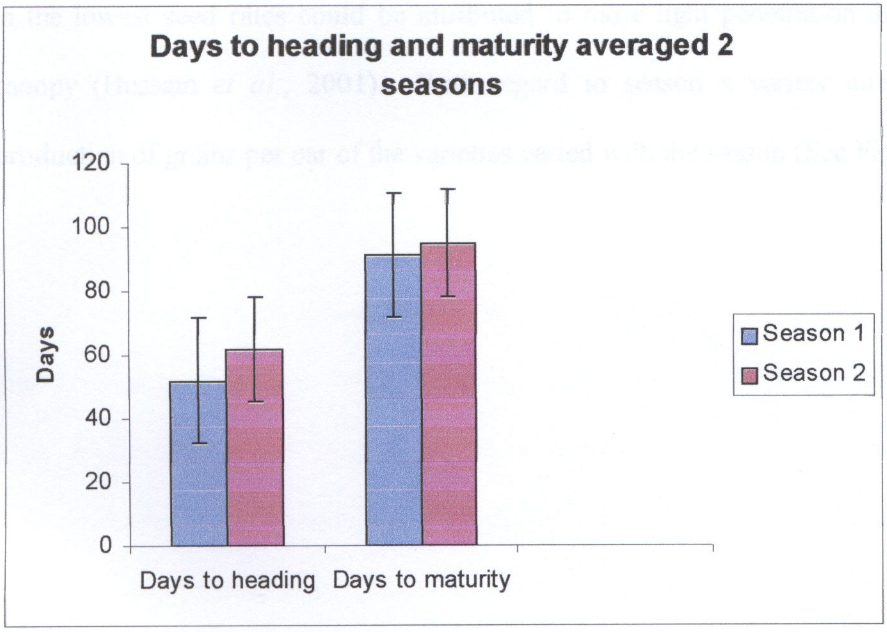

Figure 9.Comparison of days to heading and days to maturity averaged 2 seasons.

i. Grains per ear.

The results in (Table 9) revealed there were no significant differences in the number of grains per ear in the different varieties used in the study. Seasons and differences in the seeding rates significantly affected number of grains per ear. Similar findings were reported by Lloveras *et al.,(*2004). The interaction between season and variety was also significant. Season 2 produced more grains per ear (55) compared to season 1 (36) (see Table 11). This could be attributed to differences in the growing conditions. Season 2 had a cool dry period with fewer diseases while season 1 had a warm wet season with more disease prevalence. It was observed that there was a consistence decrease in the number of grains produced per ear with increasing seed rate. Seed rate 60 kg/ha produced the highest number of grains per ear followed by 80 kg/ha while 140 kg/ha produced the least grains per ear. The higher grain number per ear obtained in the lowest seed rates could be attributed to more light penetration through plant canopy (Hussain *et al.*, 2001). With regard to season x variety interaction, the production of grains per ear of the varieties varied with the season (See Figure 10).

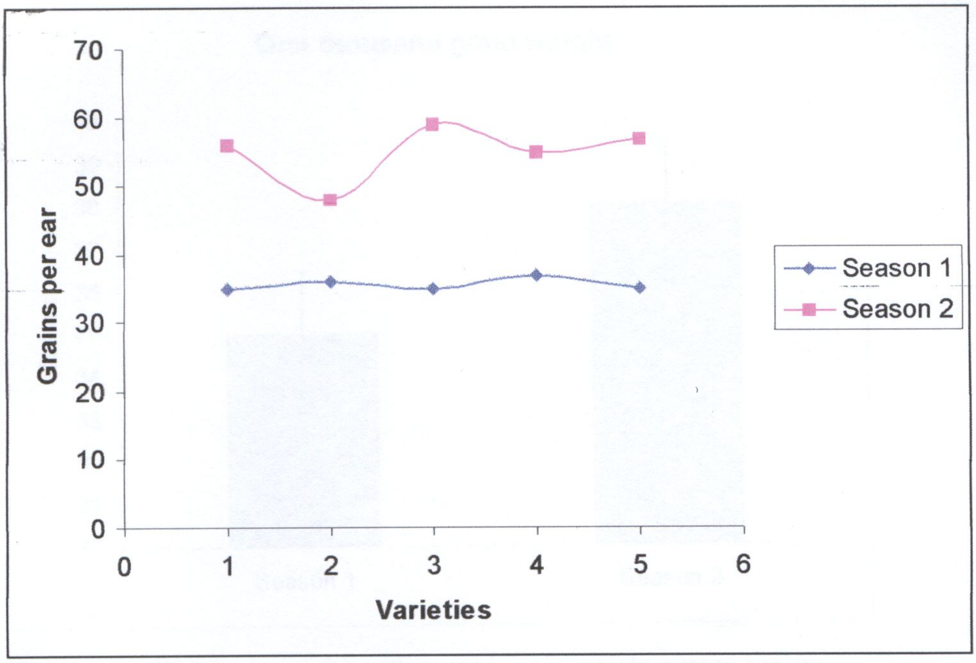

Figure 10. Performance of different varieties in the seasons with regards to grains per ear

1= UNZAWV1, 2=Coucal, 3=Loerrie II, 4=Sahai, 5=UNZAWV2

j. One thousand grain weight (grams).

According to the analysis of variance in Table 9, the difference in 1000-grain weight due to seasons was significant whilst those of varieties and seed rates were non-significant. As reported by other researchers, the 1000-grain weight is not significantly affected by seeding density (Lloveras et. al., 2004). The interaction between varieties and seasons was significant. The highest 1000-grain weight was in season 2, (38.48g), 3g more than those of season1 (Figure 11).

It is also important to mention that no interaction was observed on season by seed rate and variety by seed rate on all traits.

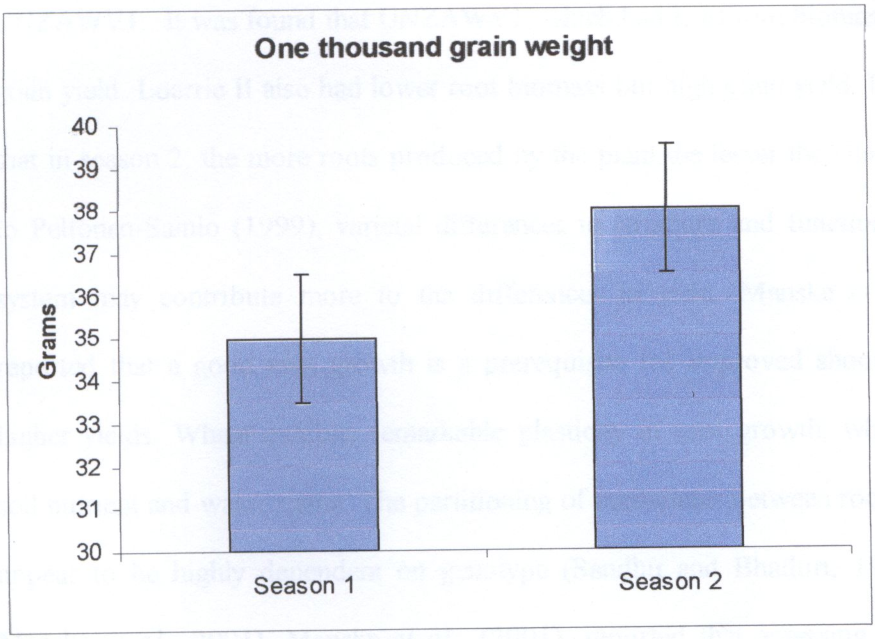

Figure 11. . Comparison of one thousand grain weight across season

4.4 Influence of root biomass on grain yield

The ANOVA (appendix 23) showed that the varieties in season 1 did not differ significantly in the amount of root biomass produced. However, Sahai variety had more root biomass followed by Loerrie II, UNZAWV2, UNZAWV1 and Coucal in season 1 (Table 13). It was observed that the variety UNZAWV2, which had intermediate root biomass, had higher grain yield followed by Sahai, UNZAWV1, Coucal and loerrie II in season 1. This was examined at the recommended seed rate of 100 kg/ha under Zambian conditions (Mooleki, 1997).

According to the ANOVA (appendix 24) there was also no significant differences observed in the root biomass on the varieties involved in the study in season 2. Although no differences were observed, (Table 13) shows that UNZAWV2 had more root biomass compared to the other varieties followed by coucal, Sahai, Loerrie II and

UNZAWV1. It was found that UNZAWV1, which had least root biomass, had higher grain yield. Loerrie II also had lower root biomass but high grain yield. It is observed that in season 2, the more roots produced by the plant the lesser the yield. According to Peltonen-Sainio (1999), varietal differences in structure and function of the root system may contribute more to the differences in yield. Manske *et al.*, (2001), reported that a good root growth is a prerequisite for improved shoot growth and higher yields. Wheat exhibits remarkable plasticity in root growth, which adjust to soil nutrient and water status. The partitioning of assimilates between roots and shoots appear to be highly dependent on genotype (Sandhu and Bhaduri, 1984: cited by Manske *et al.*, 2001). Manske *et al.*, (2001), reported that assessing root traits in wheat is essential in cases like to improve nutrient acquisition, drought tolerance, tolerance to mineral toxicity and lodging resistance.

Table 13 .**Means of effect of root biomass of wheat grown under rainfed (season 1) and irrigated (season 2) conditions.**

Variety	Root biomass(g) **Season 1**	Root biomass (g) **Season 2**
Sahai	10.13	3.09
Coucal	2.86	3.34
UNZAWV2	6.05	3.66
Loerrie II	6.93	2.58
UNZAWV1	5.59	2.15
5%LSD	5.12	1.08

4.5 Simple linear correlation, r, for combined analysis between morpho-physiological traits, phenological traits with grain yield of wheat varieties for the two seasons.

The results in Table 14 showed a positive and significant correlation between grains per ear and grain yield. These findings are similar to those of Acevedo *et al.* (2002), Bokan *et.al.,* (2004), Bhutta *et.al.,*(2005) and Zhang *et.al.,*(2008). There was also a positive and significant correlation between above ground biomass and grain yield. These results are in agreement with those of Pectu *et.al.*, (2003).

The number of tillers per square meter had a positive and significant correlation with grain yield. Khaliq *et.al.*(2001) has previously reported similar results. This shows tillers are important traits in the production of high grain yield per hectare.

A review of table 14 indicated that plant height showed a positive and strong but non-significant correlation with grain yield. Almost similar results have earlier been reported by Khaliq *et.al.*,(2001), and Bhutta *et.al.*(2005).

Ear length, peduncle length, leaf area index, days to heading, days to maturity and 1000-grain weight showed a positive and a non-significant relationship with grain yield.

Table 14. **Simple correlation between plant traits and grain yield across seasons.**

Trait	r
Plant height	0.517
Number of tillers/m²	0.672*
Ear length	0.453
Peduncle length	0.332
Leaf area index	0.226
Days to heading	0.521
Days to maturity	0.295
Grains/ear	0.630*
Above ground biomass	0.865*
1000-grain weight	0.376

*- Significant at 5% probability.

5.0 Disease and pest situation

Pests and diseases attacked most varieties grown in season 1 (rainfed). Stalk borer attacked all the varieties (Table 15) during the ripening stage and the pests were mainly seen on the stalks of the crop, no control measures was taken to control the stalk borers. Rabbits were other pests that destroyed the crop during milk stage.

The most severe disease that attacked the crop during the rain season was leaf rust (*Puccinia recondita)*. This disease affected all varieties but the most severely attacked varieties were Coucal and Loerrie II. UNZAWV1 and UNZAWV2 leaf rust occurred at low levels (Table 16). Sahai was the most resistant variety. The disease was observed during soft dough stage. The disease may have in some way affected grain yield as it might have affected the performance of the crop. The disease was effectively controlled.

Crops grown in season 2 (irrigated) were not attacked by both diseases and pests. This could be due to the season being cool and dry and not conducive for disease prevalence.

Table 15. **Stalk borer scores in varieties grown during rain season**

Variety	Approximate growth stage	Score
Coucal	soft dough stage	1
Loerrie II	soft dough stage	1
Sahai	soft dough stage	3
UNZAWV1	soft dough stage	2
UNZAWV2	soft dough stage	2

3-severe

2-moderate severe

1-moderate

0-No attack

Table 16. **Puccinia Recondita scores in varieties grown during rain season**

Variety	approximate Growth stage	Score
Coucal	soft dough stage	S
Loerrie II	soft dough stage	S
Sahai	soft dough stage	R
UNZAWV1	soft dough stage	MS
UNZAWV2	soft dough stage	MS

S- Severe

MS-Moderate severe

R- Resistant

6.0 CONCLUSION

The study has showed that non-significant differences were observed on grain yield, grains per ear, number of tillers per square meter and leaf area index in season 1. Although there was no significant difference observed in yield, the study has shown that UNZAWV2 gave the highest average yield (811.68 kg/ha), while Loerrie II gave the lowest yield (757.25 Kg/ha). Varieties in season 1 differed significantly in plant height, 1000-grain weight, peduncle length, ear length, days to heading and days to maturity. Coucal variety was the tallest (69.38 cm) and the shortest was UNZAWV1 (60.90 cm). UNZAWV1 and Coucal varieties took less number of days to mature compared to the other varieties. Similarly, varieties grown in season 2 differed significantly in plant height, peduncle length, 1000-grain weight, and days to heading. Siginficant difference was also observed in grains per ear and number of tillers per meter square. Varieties did not differ significantly in ear length, biological yield, leaf area index, days to maturity. Like in season 1, grain yield did not differ significantly in season 2. Grain yield in season 2 ranged from 1753.94 kg/ha to 1588.93 kg/ha.

With regards to seed rate, the results showed that the performance of varieties in both seasons was not affected by the seed rate. In season 1, the seed rate mainly affected the yield, number of tillers per square meter, above ground biomass, days to heading and days to maturity. On the other hand, the seed rate in season 2 had an effect on grains per ear and days to heading. The average yield in season 1 ranged from 916.08 kg/ha to 619.90 kg/ha whilst a yield of between 1868.52 kg/ha to 1531.18 kg/ha was attained in season 2 using the seed rate of 140 kg/ha and 60 kg/ha in season 1 and season 2, respectively. The study has shown that increasing seed rate also increases grain yield per hectare in both seasons.

Despite the general reduction in yield in all the varieties, season 2 tended to have an edge in yield compared to season 1.

A correlation analysis between traits and grain yield across seasons identified number of fertile tillers per meter square, grains per ear and above ground biomass as being the most important traits explaining variation in yield across seasons. These traits showed a strong positive and significant relationship with grain yield and could be used by wheat breeders as potential indirect selection criteria for yield and yield stability across seasons. Other components, which had positive but non-significant relationship with grain yield, were days to heading, plant height, and ear length. This study therefore indicates that targeting the characters that most affect grain yield such as number of fertile tillers per square meter, grains per ear and above ground biomass would lead to greater yield performance under both rain fed summer conditions and irrigated cool dry conditions. This would also encourage wheat production in summer rainfall environment among both commercial and small scale farmers as the cost of production arising from irrigation would be cut down.

This study was done at one location and only once each season, it is recommended for it to be done at other locations to find out if variety by seed rate combination affects the performance of the morpho-physiological components of grain yield under summer rainfall and irrigated conditions and also the tillering capacity and the compensatory effect of seed rate under the same conditions.

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8.0 APPENDICES

Appendix 1.Analysis of variance for leaf area index for season 1

SOURCE OF VARIATION	DF†	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	24.5690	6.14226	0.72	0.597
Replication	3	2802.53	934.177	109.36	
Main plot error	12	102.505	8.54210	0.75	
Seed rate	4	57.2954	14.3239	1.26	0.296
Variety x Seed rate	16	303.725	18.9828	1.67	0.079
Error	60	683.699	11.3950		
Total	99	3974.33			

† DF – Degrees of freedom

Appendix 2. Analysis of variance for grains per ear season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	77.6.249	19.4062	0.65	0.637
Replication	3	499.186	166.395	5.61	
Main plot error	12	355.950	29.6625	0.92	
Seed rate	4	118.013	29.5033	0.91	0.465
Variety x Seed rate	16	417.347	26.0842	0.81	0.673
Error	59	1908.75	32.3517		
Total	99	3376.87			

Appendix 3. Analysis of variance for peduncle length season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	297.884	74.4710	10.60	0.001*
Replication	3	54.2.217	18.0739	2.57	
Main plot error	12	84.3.330	7.02775	0.87	
Seed rate	4	33.3.569	8.33922	1.04	0.397
Variety x Seed rate	16	114.440	7.15249	0.89	0.585
Error	60	482.774	8.04623		
TOTAL	99	1067.01			

* denotes significant at 5 percent probability

Appendix 4. Analysis of variance for ear length season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	75.3825	18.8456	7.98	0.002*
Replication	3	220.165	73.3884	31.08	
Main plot error	12	28.3376	.236147	0.80	
Seed rate	4	25.8258	.645646	2.18	0.081
Variety x Seed rate	16	54.5268	.340792	1.15	0.331
Error	60	177.436	.295726		
TOTAL	99	581.673			

* denotes significant at 5 percent probability

Appendix 5. Analysis of variance for 1000-grain weight season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	322.559	80.6396	5.04	0.013*
Replication	3	18.0.469	6.01562	0.38	
Main plot error	12	192.121	16.0101	1.84	
Seed rate	4	83.9.775	20.9944	2.41	0.058
Variety x Seed rate	16	244.699	15.2937	1.76	0.060
Error	59	513.180	8.69797		
TOTAL	99	1374.58			

* Denotes significant at 5 percent probability

Appendix 6. Analysis of variance for plant height season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	956.282	239.071	22.80	0.000*
Replication	3	664.204	221.401	21.11	
Main plot error	12	125.851	10.4876	1.12	
Seed rate	4	63.0.489	15.7622	1.68	0.166
Variety x Seed rate	16	168.351	10.5219	1.12	0.358
Error	60	563.444	9.39.074		
TOTAL	99	2541.18			

* Denotes significant at 5 percent probability

Appendix 7. Analysis of variance for number of tillers per square meter season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Variety	4	591.029	147.757	1.31	0.320
Replication	3	7233.58	2411.19	21.41	
Main plot error	12	1351.39	112.616	2.11	
Seed rate	4	793.340	198.335	3.72	0.009*
Variety x Seed rate	16	775.660	48.4788	0.91	0.563
Error	60	3200.42	53.3404		
TOTAL	99	13945.4			

* denotes significant at 5 percent probability

Appendix 8. Analysis of variance for days to heading season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	130.910	43.6367	5.61	
Variety	4	442.360	110.590	14.21	0.000*
Main plot error	12	80.4400	6.70333	0.86	
Seed rate	4	64.2600	16.0650	2.06	0.096
Variety x Seed rate	16	60.0400	3.75250	0.48	0.946
Error	60	466.900	7.78167		
TOTAL	99	1244.91			

* denotes significant at 5 percent probability

Appendix 9. Analysis of variance for days to maturity season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	87.8000	29.2667	8.72	
Variety	4	65.9400	16.4850	4.91	0.002*
Main plot error	12	59.9000	4.99167	1.49	
Seed rate	4	49.4400	12.3600	3.68	0.010*
Variety x Seed rate	16	55.2600	3.45375	1.03	0.441
Error	60	201.300	3.35500		
TOTAL	99	519.640			

* denotes significant at 5 percent probability

Appendix 10. Analysis of variance for above ground biomass season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	6711122	22370412	49.01	
Variety	4	5640354	1410091	3.09	0.022*
Main plot error	12	7068390	589033.	1.29	
Seed rate	4	7498324	1874582	4.11	0.005*
Variety x Seed rate	16	7066281	441643.	0.97	0.502
Error	59	26928582	456416.		
TOTAL	99	121313421	1225384		

* Denotes significant at 5 percent probability

Appendix 11. Analysis of variance for grain yield season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	8547660	2849224	50.22	
Variety	4	34891.4	8722.85	0.15	0.958
Main plot error	12	885655.	73804.6	1.30	
Seed rate	4	1054924	263731.	4.65	0.003*
Variety x Seed rate	16	783284.	48955.3	0.86	0.613
Error	59	3347406	56735.7		
TOTAL	99	14653800			

* Denotes significant at 5 percent probability

Appendix 12. Analysis of variance for plant height for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	512.159	170.720	4.50	
Variety	4	4910.88	1227.72	32.38	0.000*
Main plot error	12	437.873	36.4894	0.96	
Seed rate	4	56.3376	14.0844	0.37	0.830
Variety x Seed rate	16	736.883	46.0552	1.21	0.284
Error	60	2275.29	37.9215		
TOTAL	99	8929.42			

* Denotes significant at 5 percent probability

Appendix 13. Analysis of variance for number of tillers per meter square for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	4566.81	1522.27	8.89	
Variety	4	5326.87	1331.72	7.78	0.000*
Main plot error	12	2995.32	249.610	1.46	
Seed rate	4	228.819	57.2047	0.33	0.855
Variety x Seed rate	16	1047.81	65.4880	0.38	0.982
Error	60	10274.5	171.242		
TOTAL	99	24440.1			

* Denotes significant at 5 percent probability

Appendix 14. Analysis of variance for peduncle length for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	37.0.209	12.3403	3.27	
Variety	4	487.047	121.762	32.27	0.000*
Main plot error	12	47.7.603	3.98003	1.05	
Seed rate	4	21.9.913	5.49783	1.46	0.226
Variety x Seed rate	16	694.999	4.34375	1.15	0.332
Error	60	226.415	3.77358		
TOTAL	99	889.734			

* Denotes significant at 5 percent probability

Appendix 15. Analysis of variance for ear length for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	8.25890	2.75297	5.50	
Variety	4	1.86518	.466296	0.93	0.453
Main plot error	12	4.54818	.379015	0.76	
Seed rate	4	2.26773	.566933	1.13	0.350
Variety x Seed rate	16	5.46766	.341729	0.68	0.800
Error	60	30.0258	.500430		
TOTAL	99	52.4334	.529631		

* Denotes significant at 5 percent probability

Appendix 16. Analysis of variance for grains per ear for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	104.763	34.9211	1.16	
Variety	4	1490.48	372.620	12.35	0.000*
Main plot error	12	276.181	23.0151	0.76	
Seed rate	4	401.419	100.355	3.33	0.016*
Variety x Seed rate	16	572.696	35.7935	1.19	0.305
Error	60	1810.38	30.1729		
TOTAL	99	4655.91			

* Denotes significant at 5 percent probability

Appendix 17. Analysis of variance grain yield for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	2849910	949970.	5.64	
Variety	4	614145.	153536.	0.91	0.464
Main plot error	12	2457080	204756.	1.22	
Seed rate	4	1566731	391682.	2.33	0.066
Variety x Seed rate	16	1953160	122073.	0.73	0.758
Error	59	9930210	168309.		
TOTAL	99	19381236			

* Denotes significant at 5 percent probability

Appendix 18. Analysis of variance for biological yield for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	582854383	194285461	5.97	
Variety	4	7120031	17800108	0.55	0.705
Main plot error	12	220689889	1839074	0.57	
Seed rate	4	307204391	7680098	2.36	0.063
Variety x Seed rate	16	58012053	3625753	1.11	0.363
Error	60	19514104	3252351		
TOTAL	99	371347795	375099		

* Denotes significant at 5 percent probability

Appendix 19. Analysis of variance for 1000-grain weight for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	21.2164	7.07215	2.34	
Variety	4	185491	46.3729	15.33	0.000*
Main plot error	12	39.9222	3.32685	1.10	
Seed rate	4	17.5072	4.37679	1.45	0.229
Variety x Seed rate	16	75.8047	4.73779	1.57	0.107
Error	59	178.452	3.02460		
TOTAL	99	518.393			

* Denotes significant at 5 percent probability

Appendix 20. Analysis of variance for leaf area index for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	144.827	48.2756	4.64	
Variety	4	30.0909	7.52273	0.72	0.5
Main plot error	12	92.8413	7.73678	0.74	
Seed rate	4	279.329	6.98323	0.67	0.6
Variety x Seed rate	16	177.800	11.1125	1.07	0.4
Error	60	623.749	10.3958		
TOTAL	99	1097.24			

* Denotes significant at 5 percent probability

Appendix 21. Analysis of variance for days to heading for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	12.3000	.410000	0.16	
Variety	4	43.4600	1.08650	4.26	0.004*
Main plot error	12	18.6200	1.55167	0.61	
Seed rate	4	39.1600	9.79000	3.84	0.008*
Variety x Seed rate	16	38.3400	2.39625	0.94	0.530
Error	60	152.900	2.54833		
TOTAL	99	293.710			

* Denotes significant at 5 percent probability

Appendix 22. Analysis of variance for days to maturity for season 2

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	13.7600	4.58667	1.29	
Variety	4	30.0600	7.51500	2.11	0.090
Main plot error	12	75.5400	6.29500	1.77	
Seed rate	4	4.06000	1.01500	0.28	0.886
Variety x Seed rate	16	49.0400	3.06500	0.86	0.615
Error	60	213.700	3.56167		
TOTAL	99	386.160			

* Denotes significant at 5 percent probability

Appendix 23. Analysis of variance for root biomass season 1

SOURCE OF VARIATION	DF	SUMS OF SQUARES	MEAN SQUARES	F RATIO	PROB
Replication	3	35.1459	11.7153	1.06	
Variety	4	109.852	27.4630	2.48	0.099
Error	12	132.748	11.0623		
TOTAL	19	277.746			