RESPONSE OF WINTER WHEAT (*Triticum aestivum* L.) GENOTYPES TO IRRIGATION AT DIFFERENT GROWTH STAGES IN BOTSWANA

MASTER OF SCIENCE CROP SCIENCE (AGRONOMY)

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STATEMENT OF ORIGINALITY

The work contained in this thesis was compiled by the author at University of Botswana, Botswana College of Agriculture between August 2007 and July 2010. In exception of references made to, the work is original and it will not be submitted for award of any other degree or diploma of any other University.

Author's Signature

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ABSTRACT

A field experiment was conducted during 2009/2010 winter season to study the response of two winter wheat (*Triticum aestivum L.*) cultivars (Baviaans and 14SAWYT306) to irrigation at different growth stages (from emergence to stem extension, from stem extension up to physiological maturity and throughout the growth stages). Treatments were nil irrigation (I_0), irrigation up to stem extension (I_1), irrigation from stem extension up to physiological maturity (I_2) and irrigation throughout the growth stages (I_3).

Irrigation significantly increased biological yield and grain yield over nil irrigation treatments. Mean grain yield of non- irrigated crops was 1813.9 kg ha^{-1}, while crops irrigated throughout the planting season recorded mean grain yield of 3166.7 kg ha^{-1}. Like-wise mean biological yield for I_0 treatment was 3433.70 compared to 5128.30 of I_3 treatment. Cultivar difference in harvest index was statistically non-significant. However cultivar 14SAWYT306 produced higher harvest index by 13.52% than Baviaans.

Yield components were affected by cultivar differences. Spike length, number of spikelets per spike, number of grains per spike and number of tillers significantly differed at ($P < 5\%$) in the two cultivars. Baviaans (265.83m^2) produced higher number of tillers than cultivar 14SAWYT306 (219.83m^2). Irrigating crops at all stages of growth (I_3) increased number of tillers by 29.41% compared to I_0 treatment. Cultivar 14SAWYT306 produced higher number of grains per spike (17.88%) compared to Baviaans. I_3 treatment increased number of grains per spike by 21.60% compared to non- irrigated crop plants.

Cultivar 14SAWYT306 enhanced number of spikelets per spike with a mean of 14.97 over cultivar Baviaans, which recorded a mean of 12.24. Irrigation throughout the whole planting season increased number of spikelets per spikes by 23.68% for Baviaans compared to no irrigation treatment which recorded 10.83 spikelets per spike. Cultivar 14SAWYT306 recorded higher spike length mean value (9.44) than Baviaans (7.94).

Water stress increased grain protein content however, the highest grain protein content (13.59%) in wheat was recorded from crops irrigated at all stages of growth. Both Baviaans and 14SAWYT306 cultivars are recommended to Botswana farmers and there is need for winter wheat to be irrigated throughout the growing period to maximize yields under Botswana conditions.

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Symbol		Unit
*	Significant at or below 5 % ($p \leq 0.05$)	___
cm	centimeters	___
CV	coefficient of variation	%
DAS	days after sowing	___
g	grams	___
ha	hectare	___
kg	kilograms	___
LAI	leaf area index	___
m	meters	___
m^2	meter square	___
mm	millimeters	___
Ns	non- significant	___
WUE	water use efficiency	kg ha^{-1} mm^{-1}
I_0	Nil irrigation treatment	
I_1	Irrigation from up to stem extension	
I_2	Irrigation from stem extension up to physiological maturity	
I_3	Irrigation throughout the growth stages	

CHAPTER ONE

1.0 INTRODUCTION

In this scientific and technological advance period, food inadequacy is the greatest problem threatening the survival of humankind. The problem is more prevalent in less developed drought striken and poor countries of the world. Food shortage is exacerbated by the ever increasing world population. Increasing production of cereals such as wheat is therefore, strategically very important to ensure food self sufficiency (Sezen and Yazar, 1996).

Winter wheat (*Triticum aestivum L.*) is one of the most reliable traditional cereal crops of hot semi-arid and continental climates. Wheat belongs to the family Gramineae and is commonly called bread wheat. The plant is an annual grass which can grow up to 150 cm tall. Wheat crop can produce between 2 and 40 tillers, and spikelet size ranges between 10 and 15 mm long. It is adapted to a wide range of climatic and soil condition ranging from heavy clay to sandy. However, a fertile and well drained loam to clay loam soil is most suitable for higher production of wheat. The optimum pH ranges from 6 to 8. Its sensitivity to daylength differs among genotypes, but most are quantitative long-day plants, that is, they flower earlier at long daylength, but they do not require a particular daylength to induce flowering. Wheat normally can be grown in areas that receive 250 mm – 750 mm rain annually.

Wheat is primary grown across exceptionally diverse range of environments in the world (Slafer and Rawson, 1994). It is classified into spring or winter wheat referring to the season during which the crop is grown. Winter wheat is planted in winter season, while spring wheat, as the name implies, is usually planted in the spring. In the tropics, the highlands near the equator and in the lowlands away from the equator, wheat is grown under irrigation. In the subtropics with summer rainfall the crop is grown under irrigation in the winter months. In the subtropics, with winter rainfall, it is grown under supplementary irrigation. The length of the total growing period of winter wheat needs about 180 to 250 days to mature. Winter wheat requires a cold period or chilling (vernalization) during early growth for normal heading under long days. The complete crop cycle of bread wheat varies from 50–200 days in tropical Africa.

The world's wheat area and production are mainly concentrated in the northern hemisphere. Russia has the largest harvested area than any other country, but the Asian countries together have more. World wheat production was less than 600 000 million kg per year. Global wheat production is concentrated mainly in Australia, China, Canada, European Union, Russia, and Pakistan. Turkey, Ukraine and the United States of America accounted for over 80% of world wheat production. A good yield of wheat under irrigation is 4 000 to 6 000 kg ha^{-1} (12 - 15% moisture), but yields of bread wheat in tropical Africa vary from 400 kg ha^{-1} in Somalia and 700 kg ha^{-1} in Angola to 5000 kg ha^{-1} in Zambia and 6300 kg ha^{-1} in Zimbabwe (FAO, 2003). In Botswana yields of 6600 kg ha^{-1} has been reported (Imtiyaz *et al.* 1994). The mean yield of wheat in tropical Africa is estimated at about 1500 kg ha^{-1}. Maximum recorded grain yields of irrigated winter and spring wheat are 14, 000 and 9, 500 kg ha^{-1}, respectively; the absolute maximum yield, based on genetic potential, is estimated at 20, 000 kg ha^{-1}.

In Botswana wheat is not common, but however, provides a possible alternative crop for winter, when other cereals crops such as sorghum and maize may not survive. Few commercial farmers have tried to produce it in the late 1970s on a small scale. The Talana farms and Pandamatenga are some of the areas in which wheat was grown and yielded between 2700 and 5500 kg ha^{-1} under irrigation. However, cultivated area reduced drastically over the years from a total of 140 hectares in 1977 to 15 hectares in 2006. Production figures from Pandamatenga, in Botswana, show that 40 000 kg of wheat have been produced in a total area of 80 hectares for 2007/08 growing season (Central Statistics Office, 2009).This figures are much too low to meet demand of wheat and its products in this country. Botswana requires 83 000 000 kg of wheat annually, and this constitutes 26% cereals (maize, sorghum, millet, rice) annual gross domestic requirement. Annual per capita consumption of wheat in Botswana is 48 kg (Central Statistics Office, 2008). In 2008, Botswana imported a total of 67 973 097 kg of wheat, amounting to BWP 151 956 596 (Central Statistics Office, 2009). Producing wheat in Botswana will reduce the country's dependence on imported wheat, hence safe foreign currency.

Production of winter wheat in Botswana requires supplementary irrigation. Water is one of the most important factors that are necessary for proper growth, balanced development and higher yield of all crops, including wheat. Better performance of a crop depends upon availability of water, especially at various stages of growth. Wheat plant is more sensitive to stress during certain developmental stages (Baier and Robertson, 1967; Day and Intalap, 1970; Fischer, 1973; Passioura, 1977; Warrington *et al.*, 1977; Musick and Dusek, 1980; Entz and Fowler, 1988). The impact of soil moisture deficit on crop yield depends on the particular phenological stage of the crop, and the most sensitive stage can show region-by-region variations (Singh *et al.*, 1991). These differences relate to regional variability in environment and agronomic practices, information specific to a region is needed for developing and refining limited irrigation schemes.

Water used by crops is normally related to total dry matter production or economic yield (Taylor *et al.*, 1983). This led to the concept of water use efficiency (WUE) which was generally defined as crop yield per unit of water use. WUE is an important factor use to determine information on crop water requirement for specific crop. Accurate information concerning WUE and seasonal crop water requirements may facilitate improvement in crop management and increase crop production (Wajid, 2004). Applying water to crops at critical growth stages where the crop may utilize the water efficiently can also save water. Water plays a vital role in the growth of wheat as it affects grain yield and yield components. Grain yield in wheat and other cereals is the end result of a number of contributing and inter-related components. Amongst others are number of grains per ear, number of ear per unit area and mean grain mass. The magnitude of each component is determined by various processes such as tillering, ear development and grain filling, occurring at different stages of crop development. These investigation tend to address how a winter wheat crop react when grown under different irrigation regime, and discuss effects of such on yield and yield components of wheat under Sebele condition. in Botswana.

1.1 Justification

The great challenge for the coming decades will be the task of increasing food production to ensure food security in Botswana. Demand for food has increased but yield is low in most food crops produced in Botswana. This calls for alternative research and cultivation of crops such as winter wheat. Winter wheat is easy to thresh and its grains are processed into to bread flour, which is highly palatable in this country. However, the dependency on water for such food crop has become a critical constraint for increasing food production in Botswana. Winter wheat is sensitive in its responses to the timing of water availability. Hence, it is important to know when water situation is critical to particular wheat lines grown under Botswana conditions. The amount of irrigation water required by wheat should also be known in order to reduce wasting water resource, already a limiting factor in Botswana. Growing of winter wheat in dry season will also help utilize the land, which is normally left bare during winter season in Botswana. Thus, there is an urgent need to explore the possibility of planting winter wheat in Botswana, and irrigating it at timed critical crop stages which coincides with good water use efficiency and maximum grain yield.

In Botswana less research work has been conducted on winter wheat, and there are no reports on how irrigation impact on yield components and yield of wheat cultivars. Wheat genotypes used in this investigation are promising ones in terms of yield as they have been evaluated under Sebele condition in planting season 2006/07, 2007/08 and 2008/09, although without monitoring irrigation water. Therefore this research will try to answer the question on the effect of irrigation on yield and yield components of two winter wheat cultivars.

1.2 Objectives

The objectives of the study are:

1. To examine the effect of irrigation at different growth stages on yield and yield components of wheat genotypes.
2. To determine the water use efficiency of two winter wheat cultivars.
3. To determine grain protein content of two winter wheat cultivars irrigated at different growth stages.

CHAPTER TWO

2.0 LITERATURE REVIEW

Water deficit is often the primary limiting factor for crop production under arid and semi - arid condition (Hussain *et al.*, 2004). It affects nearly all the plant growth processes. Soil moisture deficit affects grain yield of wheat crop by affecting various yield components. Imtiyaz *et al.*, (1990) reported that grain yield reduction due to limited water depends on the degree and duration of soil moisture stress, cultivars and stage of crop development. Wajid *et al.*, (2004) shared similar sentiment that the stress response depends upon the intensity, rate and duration of exposure and the stage of crop growth.

Reddi and Reddi (1995) reported that moisture stress at flowering stage reduced the number of grains per ear, and stress at grain filling stage resulted in low grain weight. Lack of enough moisture during tillering, jointing, milk stage and pre-flowering stages reduced number of grains per ear, mean grain weight and ear number. The effect of water stress on growth and yield performance of four wheat cultivars was studied by Qadir *et al.*, (1999). The researchers concluded that stress during vegetative growth cause reduction of leaf area index and also reduced the number of fertile tillers per meter square. Final crop yield was also reduced significantly. Karim *et al.*, (2000) investigated the effect of water stress at reproductive stage on grain growth pattern and yield responses of wheat. Variety kanchan was grown under well-watered conditions in two large plots of 4 meters by 5 meters. One plot was subjected to water stress (1/3 moisture at field capacity) at heading stage, while the other plot received regular irrigation. Water stress affected most of the plant characters. 94% of tillers of irrigated plants produced ears, compared to 79% of the stressed plants. Grain yield was reduced to 65% in the stressed plants compared to that of irrigated plants. Tuong *et al.*, (2005) also found out that plant height, panicle length, panicle number, weight of 100 grain, number of tillers, total dry matter and yield were decreased under water stress compared to irrigated condition while working on rice in North Iran.

The effect of moisture stress during certain growth stages on crop yield was studied by Newman (1978, 1979). Peanuts crops were grown under six different irrigation treatments at various stages of crop growth. The investigators found out that failure to irrigate peanuts during flowering stage resulted in yield reduction, while irrigating at least once during each of the flowering, pegging and maturation growth stages resulted in yields nearly equal to fully irrigated treatment.

Zhang and Oweis (1999) tested bread wheat and durum wheat for ten years period under Mediterranean climate to evaluate water yield relation. Irrigation scheduling was proposed at the sensitive growth stages of wheat to water stress, from stem elongation to booting, anthesis and at grain filling stage. Crop yield of bread wheat increased by 160 kg per 10 mm increase of evapotranspiration above threshold of 200 mm, while that of durum wheat increased by 116 kg, with increase in evapotranspiration. Early studies at International Center for Agricultural Research in the Dry Areas (ICARDA) showed that applying two or three irrigations (80–200 mm) to wheat increased crop grain yield by 36 to 45%, and produced similar or even higher grain yields than in fully irrigated conditions

(Perrier and Salkini. 1991; Oweis, 1994). Singh and Uttam (1993) stated that when wheat cultivars K-2872, K-8027 and HUM- 206 irrigated at crown root initiation, booting stages and crown root initiation, or late tillering and flowering stage and crown root initiation gave mean grain yield of 2.26 t ha $^{-1}$, 2.91 t ha $^{-1}$ and 3.39 t ha $^{-1}$, respectively. Increase in irrigation frequency resulted in net return increase.

Singh and Singh (1995) planted sorghum, maize and pearl millet under four irrigation schedules in India during hot dry season. Dry matter yield did not differ significantly among the three species under wet condition irrigation treatment, but sorghum was superior to maize under all levels of irrigation. Higher values of total dry matter in irrigated plants compared to rain-fed wheat plants were also reported by Simane *et al.*, (1993), Sarker *et al.*, (1996), Sarker and Paul (1997), Nahar and Paul (1998), and Rahman *et al.*, (2001).

Wheat also has potential to efficiently utilize large irrigation amounts at critical growth stages (Dusek and Musick, 1992; Schneider and Howell, 1997). Aggarwal *et al.* (1986) reported that water use efficiency (WUE) for wheat decreased with increasing evapotranspiration (ET), whereas in another study (Musick *et al.*, 1994) it was found that WUE did not change with seasonal ET because of different varieties and environments. Gonzalez and Faci, (1992) conducted an experiment and concluded that water must be supplied during the critical growth stages of wheat crop in order to maximize water use efficiency. Carsky *et al.*, (1995) tested sorghum under dry farming by applying supplemental irrigation, and concluded that supplementary irrigation during growing season significantly increased yield.

Behera *et al.* (2002) studied the performance of wheat under varying irrigation levels and reported that the grain yield of *durum* and *aestivum* cultivars increased significantly with increasing levels of irrigation. The maximum grain yield of 5.4 t ha $^{-1}$ and 5.96 t ha $^{-1}$ was obtained during 1998-1999 and 1999-2000 seasons respectively. Lidder *et al.*, (1999) reported that wheat grain yields of 2.79 t ha $^{-1}$, 3.18 t ha $^{-1}$, 3.28 t ha $^{-1}$, and 3.53 t ha $^{-1}$ were obtained with 1, 2, 3, and 6 irrigations. Total water use increased and water use efficiency decreased with increase of irrigation.

Thakur *et al.* (1998) studied the effect of different levels of irrigation on wheat. They reported that the crop with 4 irrigations at crown root initiation, maximum tillering, boot and milk stages produced 4.07 kg grain ha^{-1} and consequently gave 33.8% and 32.4% higher energy through grain and total biomass respectively, along with higher grain energy use efficiency than 3 irrigations at maximum tillering, boot and milk stages.

Dahmen *et al.* (1980) found no significant differences in leaf area index between two groundnut varieties Spanish and Florunner, while evaluating the groundnut under seven different irrigation treatments. Kalwar and Tunio (1994) studied the effect of irrigation scheduling at different stages of three wheat cultivars. Plant height and number of tillers were significantly increased. Dry matter production in different wheat cultivars was studied by Singh and Patel (1995), under water stress at various growth stages. They reported that water stress at tillering and at flowering reduced the number of grains per spike, and at grain filling stage reduced mean grain weight. Stress at tillering, flowering, and grain-filling stages reduced both grain yield and biomass. The harvest index of both WH 283 and cultivar WH 331 was also lowered by water stress. Berenguer and Faci (2001) working on grain sorghum under various sowing densities and water availabilities concluded that yield, harvest index, and total dry matter production decreased as available water was decreased.

Hussain *et al.* (1997) reported that grain yield of an irrigated crop was (6.31 and 5.13 t ha^{-1}), about 80% higher than the yield of rain-fed crop. The increase in yield due to irrigation was mainly associated with increase in total dry matter production as the harvest index varied little with each treatment. Wheat can be efficiently deficit-irrigated over a large range of irrigation amounts, seasonal water use, and grain yields. Studies on the effects of limited irrigation on crop yield and water use efficiency (WUE) show that crop yield can largely be maintained and in some cases quality can be improved while substantially reducing irrigation volume (Zhang and Oweis, 1999; Kang *et al.*, 2002). Wheat has the potential for efficient use of small irrigation amounts applied throughout the growing season (English and Nakaruma, 1989). Adequate water use at or after anthesis allows the plant to increase photosynthesis rate but more importantly gives the plant extra time to translocate the carbohydrates to grains (Zhang *et al.*, 1998). This will improve grain size and ultimately result in grain yield.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

Two genotypes of wheat, namely Baviaans, and 14SAWYT306 were planted in a field at Department of Agricultural Research Station, Sebele, located at 24° 35' S, 25° 56' E, 993 meters above sea level, during winter season of 2009/2010. The soil in the field was sandy loam.

3.2. Experimental Design and treatments

The experimental design was a Randomized Complete Block Design with a split plot consisting of two wheat genotypes (Baviaans and 14SAWYT306) as main plot. The subplots had four treatments as follows: I_0 = no irrigation, I_1 = irrigation up to stem extension, I_2 = irrigation from stem extension up to physiological maturity, and I_3 = irrigation through out the growth stages. However, all the treatments were watered for the first two weeks to maintain seedling establishment. The plot size used was 1.0 meter × 2.0 meters and the treatments were replicated three times (Figures 1-4). Intra-row spacing was 0.15 meters and inter-row spacing of 0.20 meters. Before planting the field was flooded with water for 48 hours, and covered with a plastic shade to ensure maximum moisture field capacity.

At the beginning of the experiment and at the end of the experiment, soil samples from each plot were taken using soil auger at depths 10 cm, 20 cm and 30 cm. Each sample's wet mass was determined using an electronic balance scale, and the samples dried in an oven at 105^{o}C for 24 hours. Difference in the wet and dry mass of the soil samples denoted soil water content, and was expressed in grams. Soil bulk density was also determined for each treatment. The soil moisture content together with soil bulk density was used as some of the factors to estimate water use efficiency.

The genotypes were planted manually to a plant population of 333, 333 plants per hectare, with nitrogen and phosphorus applied at the rate of 120 kg ha $^{-1}$ and 100 kg ha $^{-1}$, respectively at sowing (Khan *et al*, 1994; Patel *et al*, 1995; and Tomar *et al.*, 1994). Half of the nitrogen was applied basally and the other half applied three weeks after sowing. Weeds, although not many, were removed manually by hand pulling and use of a hoe. Meteorological data was collected during the growing season from Department of Agricultural Research Station (Appendix 3).

Figure 1: Overview of experimental site (May 2009)

3.3 Irrigation Strategy

Pan evaporation method (Class A - pan) was used to calculate the amount of water required by the crops. Evaporation pan provide a measurement of the combined effect of temperature, humidity, wind speed and sunshine on the reference crop evapotranspiration (ET_0). The pan at the field was filled with a known quantity of water (the surface area of the pan is known and the water depth is measured). Each morning at 8 o'clock measurements of wind speed, relative humidity, and evaporation was recorded. The rainfall, if any, was measured simultaneously. The amount of evaporation per time unit (the difference between the two measured water depths) was calculated: This was the pan evaporation: E pan (in mm/24 hours). The E pan was multiplied by a pan coefficient, K pan, to obtain the ET_0.

Formula (1): $ET_0 = E\ pan \times K\ pan$

Where:

ET_0 is reference crop evapotranspiration;

K pan is pan coefficient

E pan is pan evaporation

A table (Appendix 1) developed by Food and Agricultural Organisation (FAO, 1998) was used to estimate K pan values on daily basis (Jensen 1983). Both the K pan and E pan values varied depending on the daily wind speed and relative humidity. Therefore E pan values were recorded as the amount of water evaporation from the pan on daily basis. If the water depth in the pan drops too much (due to lack of rain), water was added and the water depth measured before and after the water is added. When the water level rises too much (due to rain) water was taken out of the pan and the water depths before and after. was measured.

Crop water need or Crop evapotranspiration (ET_c) is influenced by crop type and growth stage. Hence, a crop factor, Kc, was introduced to the equation (1) to determine ET_c for wheat crop.

Formula (2): ET_c (mm/day) = $ET_o \times Kc$

Therefore Kc is a crop coefficient, and varies with crop growth stage. For wheat Kc crop coefficients are 0.35 at initial stage of growth (day 0 to 15 days after planting), 0.75 at crop development stage (day 16 to 45), 1.15 at mid-season stage (day 46 to 110) and 0.45 at late season stage (day 111 to 150) (FAO 1986). Area of the plot (2 m^2) was used as a factor to convert amount of water to be irrigated per plot from mm/day to liters per day. The ET_c was cumulated daily for a week and the amount of water was applied to crops weekly in liters using watering cans.

3.4 Measured parameters

3.4.1 Growth Parameters

Five randomly selected plants from each plot were tagged and the following parameters measured every 14 days: plant height, number of tillers, and number of leaves. The plant height was measured from soil surface to the tip of the spike using a meter ruler. At about 43 days after sowing two plants were sampled from each plot at fourteen days interval and measure the following parameters: number of leaves, number of tillers, plant height, leaf dry mass, leaf dry mass and leaf area. Two leaves from each plant where placed on a Delta T Scan (Splash cover) leaf area meter to measure leaf area of green foliage sub-samples and converted into square meters. From the leaf area measurements leaf area index was calculated as the ratio of total leaf area to land. The samples were oven dried at 70 ^{0}C for 24 hours to achieve a constant mass. Dry mass of all the fractions was added to estimate total dry matter produced per unit area.

3.4.2 Days to emergence

Date on which seedlings emerged was recorded for each experimental unit. Days to emergence was calculated as difference between date of emergence and date of sowing.

3.4.3 Days to anthesis

Date on which 75 percent of the spikes reached anthesis stage was recorded for each experimental unit. Days to anthesis was calculated as difference between date of anthesis and date of sowing.

3.4.4 Days to maturity

Date of physiological maturity was recorded for each experimental unit. Complete loss of green colour from glumes and penduncle was used as criteria for physiological maturity. Days to maturity was calculated as difference between the date of physiological maturity and date of sowing.

3.5 Parameters measured at harvesting

At maturity twenty randomly selected plants from each net plot were harvested. The following data were recorded:

3.5.1 Number of tillers

The total number of tillers was counted from each of the twenty plants, along with non-productive tillers. The productive tillers were computed by subtracting the non-productive tillers from the total number of tillers.

3.5.2 Plant height at maturity (m)

The plant height was measured from soil surface to the tip of the spike using a meter ruler.

3.5.3 Spike length (cm)

Length of the spikes in each of the twenty plants was measured using a meter ruler.

3.5.4 Number of spikelets spike $^{-1}$

Twenty spikes from the harvested plants were randomly chosen and the number of spikelets spike $^{-1}$ counted.

3.5.5 Grain yield (kg ha $^{-1}$)

The grains from the twenty plants was threshed manually, cleaned and grain yield per unit area at moisture content equal to or less than 12 % , was determined and converted to kg ha $^{-1}$

3.5.6 Number of grains spike $^{-1}$

Number of grains from the same twenty spikes was collected and then average number of grains spike $^{-1}$ calculated.

3.5.7 One thousand (1000) grain mass (g)

From each net plot a sub-sample of thousand grains was taken, and weighed using an electric balance at moisture content equal to or less than 12 %.

3.5.8 Biological yield (kg ha $^{-1}$)

The air-dried twenty plants material from each net plot was weighed to record biological yield, then biological yield kg ha $^{-1}$ calculated.

3.5.9 Straw yield (kg ha $^{-1}$)

Calculated grain yield was subtracted from biological yield to record straw yield.

3.5.10 Harvest index (HI) (%)

Harvest index of each plot was calculated as the ratio of grain yield to biological yield, and expressed in percentage.

$$HI = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.5.11 Water use efficiency (WUE) (kg mm^{-1} ha^{-1})

Water use efficiency was calculated by dividing the grain yield by evapotranspiration (Reddi and Reddy 2002).

$$WUE = \frac{\text{Grain yield}}{(\text{ET} + \text{rainfall})}$$

Where, ET is evapotranspiration.

Amount of water (grams) at the beginning and at the end of experiment was calculated and when the difference was a positive water of the same value was subtracted from the (ET + rainfall) value in the WUE above equation. When the difference was negative, water of the same value was added to the (ET + rainfall). Soil bulk density (g/cm^3) value was used as a factor to convert the water values to mm at depths 10, 20 and 30 cm.

3.5.12 Grain protein content (%)

Total content of nitrogen on grain samples was determined by Micro Kjeldahl Method (Tecator 1991). Dried grain samples were finely grinded and 0.5g of the sample taken in a kjeldahl flask with 3 grams of digestion mixture (K_2SO_4. $CuSO_4$.Se at 10.0: 1.0: 0.1). 20 ml of sulphuric acid was added to the mixture. The sample was boiled in digestion apparatus from 1.5 to 2.0 hours until the contents became clear. The digestion material was cooled and diluted with distilled water to fill a 250 ml volumetric flask. An aliquot 10 ml was transferred to micro kjeldahl distillation apparatus, and was mixed with 10 ml of 40 % NAOH and distilled in the presence of 50 mg of zinc dust.

Ammonia evolved was collected in a receiver containing 10 ml of 2 % boric acid solution with methyl red as indicator. The contents of distillate were titrated against the standard sulphuric acid (N / 10 H_2SO_4) to a light pink colour end point. From the volume of acid used, percentage of nitrogen was calculated on the basis of liberated ammonia. Protein percentage was determined by multiplying grain nitrogen content with 5.7, which is the appropriate factor worked out for wheat (Winkleman *et al.*, 1990).

$$\text{Nitrogen (\%)} = \frac{\text{Volume of acid used} \times 0.0014 \times 250 \times 100}{\text{Sample weight} \times 10 \text{ ml}}$$

Crude protein (%) = % Nitrogen × 5.7

3.6 Data analysis

Statistical Analysis System program package was used to analyze data by using the analysis of variance technique (Steel and Torrie, 1984) and Dunnett Test was used to find the difference of treatment means at ($P \leq 0.05$). Effect of irrigation levels was analyzed using degree of freedom contrast method within the analysis of variance structure. This method provided precise measurement of the effects of individual factors and their interactions.

Figure 2: Seedling of Baviaans at early stage of growth (29 DAS)

Figure 3: Cultivar 14SAWYT306 at 101 DAS (I_3,)

Figure 4: Cultivar Baviaans at116 DAS (I_3)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 PHENOLOGICAL PARAMETERS

Table 1 shows data relating to days to emergence, days to anthesis and days to maturity of two wheat cultivars Baviaans and 14SAWYT306 as affected by cultivar and irrigation at different stages of growth. The statistical analysis of days to emergence indicated that cultivars were significantly different at $P < 0.05$ in the number of days to emergence. Cultivar 14SAWYT306 emerged 0.59 days later than cultivar Baviaans. Irrigation levels had no effect on days to emergence. Mean days to emergence was 6.08 days after sowing (DAS) and 6.67 DAS for genotype Baviaans and 14SAWYT306 respectively.

In Baviaans and 14SAWYT306, least days to anthesis were observed at no irrigation (I_0) treatment, with means of 91.33 and 95.67 respectively. Crops irrigated throughout the stages of growth (I_3) recorded a longer time to anthesis in both cultivars. Statistical analysis showed differences in means between cultivars with 14SAWYT306 higher than Baviaans by 4.00 DAS.

The irrigation at all the growth stages showed the longest time to maturity for both cultivars at 141 days while no irrigation showed shortest time to maturity in both cultivars.

Table 1: The effect of irrigation and cultivar differences on days to emergence, anthesis and maturity

	Cultivar	I_0	I_1	I_2	I_3	Mean	CV (%)	LSD (0.05)
Days to emergence (DAS)	**Baviaans**	6.00	6.00	6.00	6.33	6.08^{b}		
	14SAWYT306	6.67	6.67	6.67	6.67	6.67^{a}	7.65	0.42
	Mean	6.33^{a}	6.33^{a}	6.33^{a}	6.50^{a}			
Days to anthesis (DAS)	**Baviaans**	91.33	92.67	90.67	94.67	92.33^{b}	3.54	2.93
	14SAWYT306	95.67	96.33	96.67	96.67	96.33^{a}		
	Mean	93.50^{a}	94.50^{a}	93.67^{a}	95.67^{a}			
Days to maturity (DAS)	**Baviaans**	132.0	135.0	138.0	141.0	136.5^{a}	0.00	0
	14SAWYT306	132.0	135.0	138.0	141.0	136.5^{a}		
	Mean	132.0^{d}	135.0^{c}	138.0^{b}	141.0^{a}			

NB: For each row and column within each response variable, means with same letter are not significantly different ($P \leq 0.05$)

4.2 GROWTH PARAMETERS

4.2.1 Leaf area index

Figure 1 shows mean leaf area index (LAI) of wheat cultivars during 2009/2010 growing season. Maximum LAI was reached in mid-August at 107 days after sowing (DAS) with Baviaans genotype recording 3.75 and genotype 14SAWYT306 recording LAI value of 3.50. Thereafter LAI values declined rapidly towards physiological maturity (114 DAS). In general, Baviaans genotype recorded higher LAI value than 14SAWYT306 throughout the season.

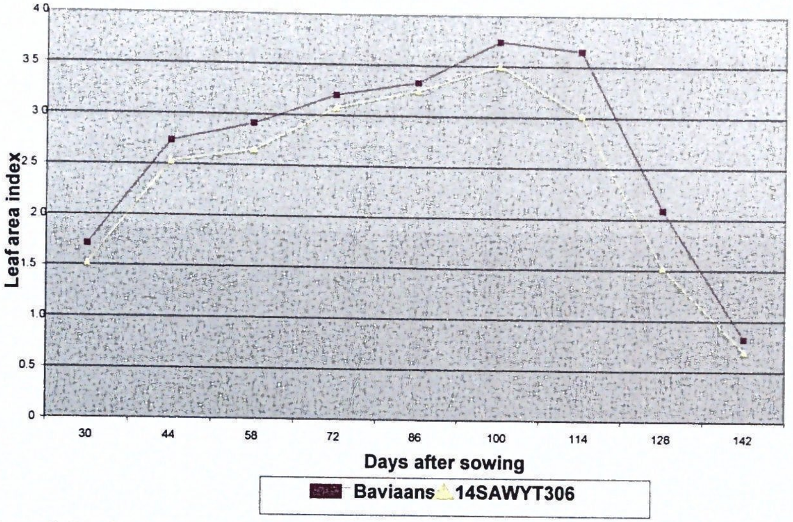

Figure 5: Leaf area index in wheat cultivar at 30 to 142 DAS

Figure 6 presents the effect of irrigation applied at different growth stages. Irrigation influenced leaf area index (LAI) significantly throughout the season over no irrigation treatment (I_0). Cortazar *et al*., (1995), Sharif (1999) and Wajid *et al.*, (2004) also reported positive effect of irrigation on leaf area index as compared to crop plants under stress. Similar results of higher LAI in irrigated plants than rain-fed plants were also reported in wheat by Nahar and Paul (1988), Siddique et al. (1999) and in barley by Kirby (1969). Maximum LAI was reached at 107 DAS, and it varied from 5.43 in irrigation at all stages treatment (I_3), 5.32 in irrigation from stem elongation up to physiological maturity (I_2), 5.20 in irrigation up to stem extension (I_1) and 3.38 in no irrigation (I_0) during the growing season. Thereafter, there was a decline in LAI values in all irrigation treatments.

Minimum values of LAI were reached on day 142 at harvest. From these results it was deduced that LAI positively correlated with period of crop growth. Similar results were noted by Cortazar et al., (1995) and Sharif (1999). Both researchers noted positive correlation of leaf area index and crop growth while working on wheat.

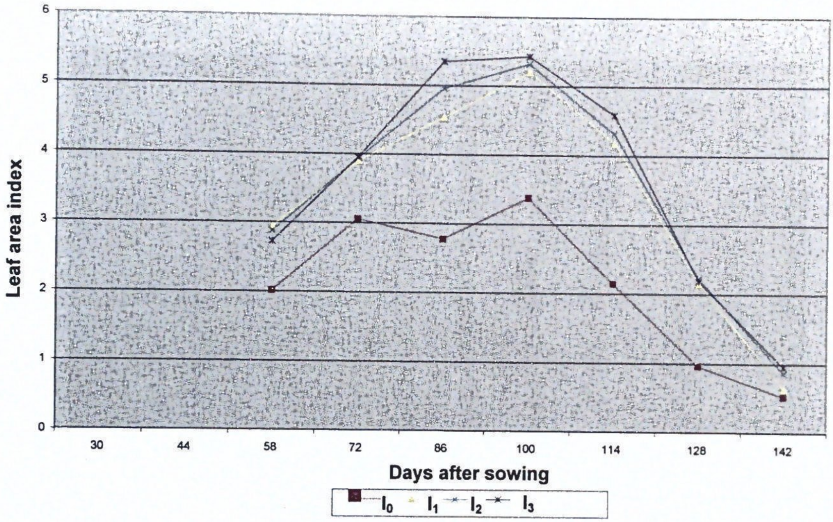

Figure 6: Effect of irrigation on leaf area index at 30 to 142 DAS

4.2.2 Leaf dry mass (g m^{-2})

Figure 7 shows the mean leaf dry mass of wheat cultivars. Cultivar Baviaans produced a higher leaf dry mass accumulation than cultivar 14SAWYT306 throughout the growing season. Leaf dry mass increased in both cultivars until 86 days after sowing (DAS) with values of 273.41 and 264.38g m^{-2} for Baviaans and 14SAWYT306 respectively. However, cultivar differences in dry matter accumulation were not significant throughout the growing season at $P < 0.05$ significance, except at 72 DAS. After 86 days leaf dry mass decreased continuously until at harvest, with cultivar Baviaans reaching 51.32g m^{-2} and cultivar 14SAWYT306 recorded 48.90g m^{-2} of leaf dry mass. Similar results of significant reductions in leaf dry mass of wheat at final harvest were reported by Khan (2000) and Naem (2001).

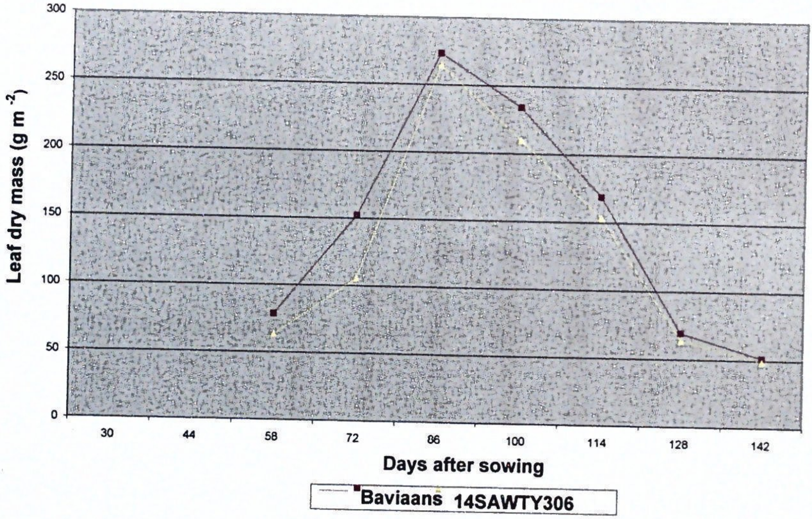

Figure 7: Leaf dry mass (g) in wheat cultivars at 58 to 142 DAS

Irrigation at various growth stages of crop growth showed significant effect on leaf dry mass over non-irrigated crops (Figure 8). Maximum leaf dry mass occurred at 86 DAS in I_1, I_2, and I_3 irrigation treatments, with values of 368.75, 392.4 and 410.14 g m^{-2} respectively. However, in I_0 irrigation treatment maximum leaf dry mass was reached at 100 DAS with a mean mass of 173.19 g m^{-2}.

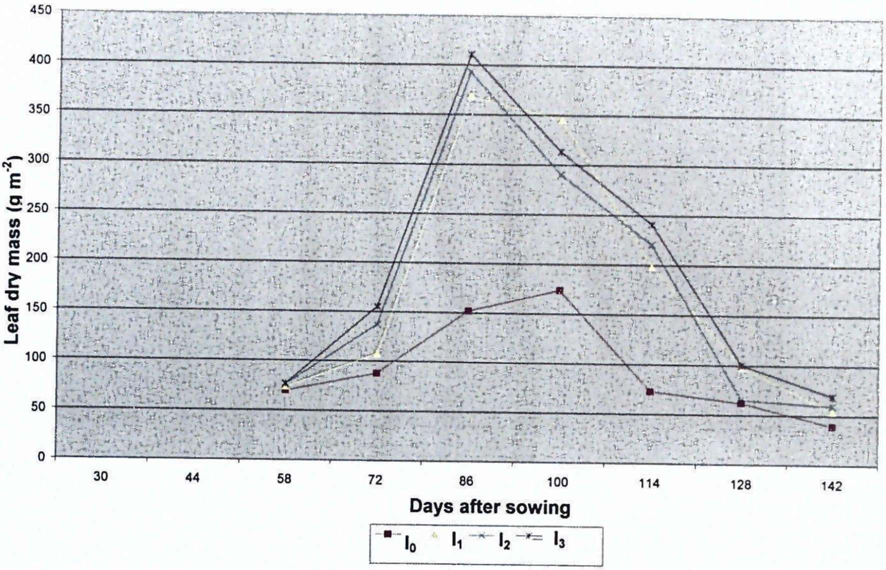

Figure 8: Effect of irrigation on leaf dry mass (g m^{-2}) at 58 to 142 DAS

4.2.3 Stem dry mass (g m^{-2})

Figure 9 shows the effect of stem dry mass on wheat cultivars. Leaf dry mass accumulation increased from 72 days after sowing (DAS) and means were not significantly different between the two cultivars until 128 DAS, when maximum stem dry mass was reached. Cultivar Baviaans produced higher stem dry mass than 14SAWYT306.

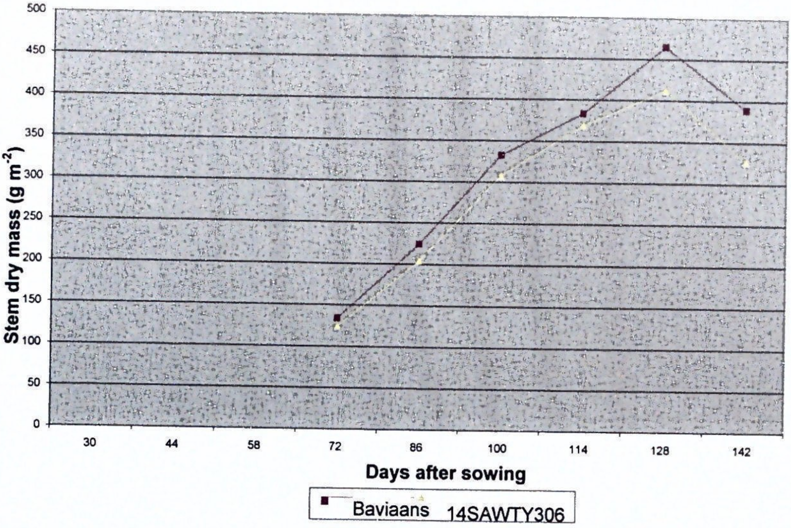

Figure 9: Stem dry mass (g m^{-2}) in wheat cultivars at 72 to 142 DAS

The differences in stem dry mass accumulation among various irrigation treatments were significant at $P < 0.05$ throughout the growing season (Figure 10). Irrigation at all growth stages (I_3) enhanced more stem dry mass than I_1 and I_2, with maximum values of 538.38, 475.91 and 448.77 g m^{-2} for treatments I_3, I_2 and I_1 respectively. These maximum values were obtained at 128 DAS, thereafter values decreased until harvest period. Irrigated crops at various stages of crop growth enhanced stem dry mass accumulation over no irrigation (I_0) treatment throughout the season.

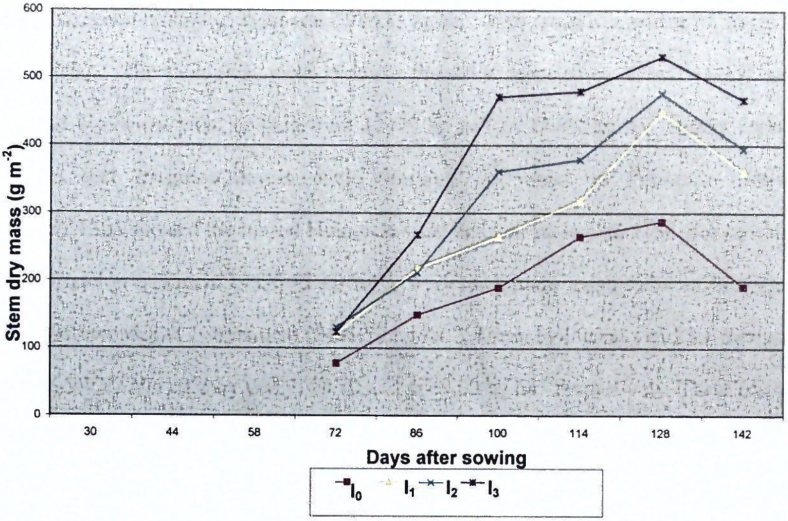

Figure 10: Effect of irrigation on stem dry mass (g m^{-2}) at 72 to 142 DAS

4.3 FINAL YIELDS

4.3.1 Biological yield (kg ha^{-1})

Table 2 shows the effect of irrigation on biological yield, straw yield, grain yield and harvest index on two wheat cultivars. There was no significant difference at $P < 0.05$ between cultivars with regard to biological yield. Irrigation treatments (I_1, I_2, I_3) enhanced biological yield over no irrigation (I_0). Cortazar *et al.*, (1995), Singh and Patel (1995), Sharif (1999), Sajjad (2001) and Wajid *at al.,* (2004) also noted similar increased effects of irrigation levels on total dry matter accumulation in wheat. Higher values of total dry matter in irrigated plants compared to rain-fed wheat plants was also reported by Simane *et al.*, (1993), Sarker *et al.*, (1996), Sarker and Paul (1997), Nahar and Paul (1998), and Rahman *et al.*, (2001).

In Baviaans cultivar mean biological yield was lowest at I_0 treatment (4030.57 kg ha^{-1}), while maximum biological yield was 5986.13 kg ha^{-1} from crops irrigated at all stages of growth (I_3). The biological yield is lower than that reported by Sharif (1999) who observed biological yield ranging from 12400 kg ha^{-1} to 14200 kg ha^{-1} among various cultivars and irrigation levels while working on wheat in Pakistan. Cultivar 14SAWYT306 showed the lowest biological yield and low biological yield was obtained at no irrigation treatment (2836.73 kg ha^{-1}), while maximum mean value of biological yield was recorded at I_1 treatment (5493.53 kg ha^{-1}). Mean biological yield for Baviaans and 14SAWYT306 cultivar was 5018.80 and 4049.00 kg ha^{-1} respectively. These overall means do not concur with that of 10600 kg ha^{-1} reported by Khan (2000) while working on wheat in Pakistan. Such difference in biological yield maybe attributed to cultivar variation and climatic conditions.

4.3.2 Straw yield (kg ha^{-1})

Cultivar differences in straw yield were not significant at $P < 0.05$, and Baviaans mean was 2559.10 while cultivar 14SAWYT306 recorded mean value of 1663.70 kg ha^{-1} (Table 2). Irrigating crop plants at different stages of growth showed no significant effect on straw yield. However, irrigated crop plants generally showed higher straw yield values over I_0, with maximum yield of 3161.07 kg ha^{-1} obtained under irrigation up to stem extension (I_1) treatment in regard to Baviaans cultivar. In 14SAWYT306 cultivar, highest value of straw yield was obtained from I_1 treatment with 2694.63 kg ha^{-1}, while I_3 recorded lowest value of 1088.14.

Table 2: Effect of irrigation on biological yield (kg ha^{-1}), straw yield (kg ha^{-1}), grain yield (kg ha^{-1}) and harvest index on two wheat cultivars

	Cultivar	I_0	I_1	I_2	I_3	Mean	CV (%)	LSD (0.05)
Biological yield (kg/ha)	**Baviaans**	4030.57	5675.53	4383.00	5986.13	5018.80^{a}	31.24	2376.9
	14SAWYT306	2836.73	5493.53	3596.57	4270.37	4049.00^{a}		
	Mean	3433.70^{b}	5584.50^{a}	3989.80^{ab}	5128.30^{ab}			
Straw yield (kg/ha)	**Baviaans**	2138.37	3161.07	2101.87	2835.03	2559.10^{a}	53.83	1907.20
	14SAWYT306	1101.17	2694.63	1771.00	1088.14	1663.70^{a}		
	Mean	1619.80^{a}	2927.90^{a}	1936.40^{a}	1961.60^{a}			
Grain yield (kg/ha)	**Baviaans**	1892.20	2514.47	2281.13	3151.10	2459.70^{a}	23.75	965.56
	14SAWYT306	1735.57	2798.90	1825.57	3182.23	2385.60^{a}		
	Mean	1813.90^{c}	2656.70^{ab}	2053.40^{bc}	3166.70^{a}			
Harvest index (%)	**Baviaans**	47.37	49.03	53.03	53.77	50.80^{a}	25.08	23.06
	14SAWYT306	59.07	51.30	50.57	74.03	58.74^{a}		
	Mean	53.22^{a}	50.17^{a}	51.80^{a}	63.90^{a}			

NB: For each row and column within each response variable, means with same letter are not significantly different ($P \leq 0.05$).

4.3.3 Grain yield (kg ha^{-1})

Grain yield of a genotype is the most integrative trait because it is influenced by all known and unknown factors (Wajid, 2004). Cultivar Baviaans gave higher grain yield than 14SAWYT306 by 3.01%. Different irrigation treatments significantly increased grain yield over no irrigation (I_0) treatment. Irrigation enhance grain yield by improving the growth of the crop and thus enabling it to intercept more photosynthetic radiation over non-irrigated crops (Sharif, 1999). Crop plants irrigated up to stem extension (I_1) had significantly increased grain yield by 22.71% than did plants irrigated from stem extension to physiological maturity (I_2) (2053.40 kg ha^{-1}). Crop plants irrigated at all stages of growth (3166.70 kg ha^{-1}) increased grain yield by 35.16% over plants irrigated from stem extension to physiological maturity. The increase in yield can be associated with an increase in total dry matter production as the harvest index varied little with each treatment (Hussain *et al.*, 1997).

In Baviaans cultivar, highest value of grain yield was reported in I_3 (3151.10 kg ha^{-1}), while I_0 gave lowest value of 1892.20 kg ha^{-1}. In cultivar 14SAWYT306, I_3 gave highest value (3182.23 kg ha^{-1}) compared to I_0, which gave lowest grain value (1735.57 kg ha^{-1}). Ranghuwanshi *et al.*, (2001) recorded grain yield value of 4500 kg ha^{-1} for cultivar WH416 while comparing six wheat cultivars, which is higher than produced in this study. Results from the current study confirm that grain yield was increased with irrigation over non- irrigation or less irrigated treatment. These results substantiate findings of Sharif (1999), Wajid, (2004), Nassar and Dawood (1993) who also noted similar effects of irrigation on grain yield while working on wheat. Yield of irrigated spring barley crops was increased by 88% while that of oats increased by 86% compared to non–irrigated crops (Karczmarczyk *et al.* (1999). Maqsood and Azam Ali (2007), Kumari (1988) and Mahalakshmi and Bidinger (1985) also reported that water stress in millet reduced seed yield.

4.3.4 Harvest index (HI) (%)

The ability of a cultivar to convert total dry matter into grain or economic yield is indicated by its harvest index value. The harvest index shows the ratio between grain yields to total plant weight. Cultivar 14SAWYT306 produced higher harvest index by 13.52% than Baviaans, which had HI value of 50.80%. Irrigation at all growth stages of crop plant (I_3) increased harvest index over no irrigation treatment. These results are similar to those of Wajid (2004) who found that wheat cultivars Pak 8, Punjab-85, and Kohinoor gave reduced values of harvest index under water stress conditions. In 14SAWYT306 cultivar, least value in harvest index was obtained in irrigation from stem extension to irrigation up to physiological maturity (I_2) treatment (50.57%), while maximum values was in irrigation at all growth stages (I_3) treatment (74.03%). These results showed that water stress up to stem extension reduced harvest index. Boogaard *et al.*, (1996), Sajjad (2001), and Sharif (1999) reported similar results on wheat. In Baviaans cultivar maximum harvest index was obtained in I_3 treatment (53.77%), while least harvest index was recorded in I_0 treatment (47.37%). Many other researchers have reported variable values of harvest index ranging from 33.9% to 38.6% under normal growing conditions for various genotypes (Naem, 2001).

4.4 YIELD COMPONENTS

4.4.1 Number of tillers m^{-2}

Irrigation treatment significantly affected number of tillers between cultivars (Table 3). Baviaans (265.83 m^{-2}) produced higher number of tillers than cultivar 14SAWYT306 (219.17 m^{-2}). In Baviaans cultivar, higher number of tillers was obtained in I_1 (282.22 m^{-2}) whereas least number of tillers was recorded in I_0 treatment (237.78 m^{-2}). Irrigating crops at stem extension stage (I_1) increased number of tillers by 15.75% compared to no irrigation. In 14SAWYT306 cultivar maximum number of tillers was recorded in I_3 treatment (264.44 m^{-2}), while least number of tillers was obtained from I_0 treatment (186.67 m^{-2}). Irrigating crops at all stages of growth (I_3) increased number of tillers by 29.41% compared to I_0 in 14SAWYT306 cultivar. Senghatoleslami *et al.*, (2008) reported a decline in number of tillers per plant under water deficit condition while working on millet in Iran. Tuong *et al.*, (2005) also found out that number of tillers was reduced under water stress compared to irrigated condition while investigating rice in North Iran. The average number of tillers per meter square obtained from this study was 212.22–267.22 m^{-2} and this is closely similar to that reported by Hussain et al., (1997) and Khan (2000), while working on wheat among different management practices, who found 279–333 tillers per meter square. Sharif (1999) reported higher number of tillers at 447 tillers per meter square.

Quadir *et al.*, (1999) studied the effect of water stress on growth and yield performance of four wheat cultivars and concluded that stress during vegetative growth resulted in reduced number of tillers per meter square. The reduction in number of tillers is an adaptive mechanism that has been induced in response to water stress. This reduction reduces the transpiration area and hence helps the plant to withstand against water stress. Significant effect of cultivar and irrigation at different growth stages, on number of tillers concurs with the previous work on wheat by Sajjad (2001) and Swati *et al.*, (1985).

Table 3: Effect of irrigation on number of tillers (m^{-2}), number of grains per spike, number of spikelets per spike, 1000-grain mass (g) and spike length (cm) on wheat cultivars

	Cultivar	I_0	I_1	I_2	I_3	Mean	CV (%)	LSD (0.05)
Number of tillers (m^{-2})	**Baviaans**	237.78	282.22	273.33	270.00	265.83^{a}		
	14SAWYT306	186.67	244.45	181.11	264.44	219.17^{b}	16.06	65.37
	Mean	212.22^{b}	263.34^{a}	227.22^{ab}	267.22^{a}			
Number of grains/spike	**Baviaans**	28.46	29.62	30.81	36.30	31.23^{b}		
	14SAWYT306	29.79	42.82	36.63	42.40	38.03^{a}	35.85	4.12
	Mean	29.09^{c}	36.22^{ab}	33.58^{b}	39.35^{a}			
Number of spikelets/spike	**Baviaans**	10.83	12.10	11.93	14.19	12.24^{b}	13.14	2.98
	14SAWYT306	13.02	16.28	14.61	15.86	14.97^{a}		
	Mean	11.87^{c}	14.19^{a}	13.20^{b}	15.03^{a}			
1000-grain mass (g)	**Baviaans**	37.20	35.47	38.03	38.47	37.29^{a}	8.11	5.01
	14SAWYT306	33.37	37.83	35.50	38.60	36.33^{a}		
	Mean	35.28^{a}	36.65^{a}	36.77^{a}	38.53^{a}			
Spike length (cm)	**Baviaans**	7.55	8.04	7.41	8.79	7.94^{b}	16.16	0.46
	14SAWYT306	8.92	10.27	9.07	9.45	9.44^{a}		
	Mean	8.21^{b}	9.15^{a}	8.20^{b}	9.12^{a}			

NB: For each row and column within each response variable, means with same letter are not significantly different ($P \leq 0.05$)

4.4.2 Number of grains per spike

The results showed a significant difference at $P < 0.05$ between cultivars, with 14SAWYT306 producing higher number of grains per spike by 17.88% compared to Baviaans (31.23 grains per spike) (Table 3). In Baviaans cultivar maximum number of grains per spike was recorded in crop plants irrigated at all stages of growth (I_3)

treatment, with a value of 36.30 grains per spike. The results show that I_3 treatment increased number of grains per spike by 21.60% compared to non- irrigated crop plants, which had 28.46 grains per spike. Bajwa *et al.*, (1993), Reddi and Reddi (1995), Sharif (1999), and Sajjad (2001) reported mean number of grains per spike of 38.78–43.62 in wheat. Wajid (2004) reported 34–46 grains per spike among different irrigation treatments while working on wheat in Pakistan. These results suggest that irrigating crops up to stem extension stage increased number of grains by 30.43% compared to no irrigation. Hussain *et al.*, (1997) and Khan (2000) reported similar results while working on wheat. Dencic *et al.*, (2000) found out that number of grains per spike were sensitive to drought stress, while working with 30 wheat cultivars from different countries under near optimum and drought stress conditions. Maqsood and Azam Ali (2007), Kumari (1988) and Mahalakshmi and Bidinger (1985) also reported that water stress in millet reduced number of seeds per ear.

4.4.3 Number of spikelets per spike

Significant differences at $P < 0.05$ were observed between cultivars in the number of spikelets per spike (Table 3). Cultivar 14SAWYT306 significantly enhanced number of spikelets per spike with a mean of 14.97 over cultivar Baviaans, which recorded a mean of 12.24. Khan (2000) reported 13.37–14.89 spikelets per spike while working on wheat under Faisalabad conditions in Pakistan. In Baviaans cultivar maximum number of spikelets per spike was obtained in crops irrigated at all stages of growth (I_3) treatment (14.19). These results suggest that irrigation throughout the whole planting season increased number of spikelets per spikes by 23.68% compared to no irrigation treatment which recorded 10.83 spikelets per spike. Wajid (2004) so revealed that irrigation treatments enhanced number of spikelets per spike over control treatment by 25.13% while working on two wheat cultivars Inqalab-91 and MH-97 in Pakistan. In cultivar 14SAWYT306 maximum number of spikelets per spike was obtained in I_1 treatment, while the least value was recorded in I_0 treatment.

4.4.4 One thousand grain mass (g)

1000-grain mass is an important yield-determining component of wheat. No significant difference in 1000-grain mass was observed between cultivars Baviaans (37.29g) and 14SAWYT306 (37.29g) (Table 3). Khan (2000) reported an average value of 39.35 grams per 1000 grain mass for wheat under Faisalabad conditions in Pakistan. Irrigation treatments (I_1, I_2 and I_3) showed higher 1000-grain mass values than non-irrigated crop plants. However differences in 1000-grain mass between all treatments were not significant. Tuong *et al.*, (2005) also reported reduced mass of grain under water stress compared to irrigated conditions while investigating rice in North Iran.

In Baviaans cultivar minimum value of 1000-grain mass was obtained in I_1 treatment 35.47g), while I_3 recorded highest value (38.47g). The results concurred with the findings of Bajwa *et al.*, (1993), Swati *et al.*, (1985), and Sajjad, (2001), Hussain et al., (1997) and Wajid (2004) who noted increased mass of grains with increased irrigation among various wheat cultivars. Prasad *et al.* (1988) in their experiment showed that irrigation increased 1000 grain mass of Proso millet.

4.4.5 Spike length (cm)

There was significant difference at $P < 0.05$ in spike length in cultivars 14SAWYT306 (9.44cm) and Baviaans (7.94cm). In Baviaans cultivar irrigation increased spike length by 14.11% compared to non irrigated crops. Maximum mean value of spike length was recorded in crops irrigated at all stages of growth (I_3) treatment (8.79cm), while lowest value of spike length was obtained from I_2 treatment (7.41cm). In cultivar 14SAWYT306 the highest value of spike length was recorded in crops irrigated up to stem extension (I_1) treatment (10.27cm), while least value of spike length was recorded in nil-irrigation treatment (8.92cm).

4.4.6 Relationship between grain yield and yield components

The number of tillers (0.80), number of grains per spike (0.66), number of spikelets per spike (0.60), grain mass (0.54) and harvest index (0.50) correlated positively with grain yield and significant differences were observed between yield and yield components (Table 4). Positive correlations were also observed between 1000 grain mass and number of tillers; spike length with number of spikelets per spike, number of grain per spike and harvest index; number of spikelets per spike with number of grains per spike and harvest index, number of grain per spike with harvest index.

The results are in line with work of Wajid (2004) who also noted significant correlation between wheat grain yield and yield components. Deniz *et al.*, (2009) found significant and positive association between grain yield and number of spikes and kernel number per meter square while working on barley in Turkey. Biscoe *et al.*, (1975) and Gallagher *et al.*, (1975) also found a positive relationship between yield and yield components while working on cereals. Grain yield and number of grains per ear unit area were found to positively correlate in wheat by Brooking *et al.*, (1981), Fischer *et al.*, (1986) and Perry *et al.*, (1989). This shows that yield increased with increase in yield components. A positive association between yield and yield components may serve as a basis for selection.

Table 4: Correlation among yield and yield components

Characters	Grain yield	Number of tillers	Spike length	1000 grain mass	Number of spikelets per spike	Number of grain per spike	Harvest index
Grain yield	1.00000						
Number of tillers	0.79747*	1.00000					
Spike length	0.38757	-0.01211	1.00000				
1000 grain mass	0.53545*	0.51144*	0.05187	1.00000			
Number of spikelets per spike	0.59425*	0.14454	0.91445*	0.20079	1.00000		
Number of grain per spike	0.66354*	0.27993	0.82040*	0.32486	0.93708*	1.00000	
Harvest index	0.49738*	0.35870Ns	0.42205*	0.33255Ns	0.49132*	0.57220*	1.00000

*: significant at $P \leq 0.05$

4.5 OTHER PARAMETERS

4.5.1 Plant height at maturity (cm)

Cultivar 14SAWYT306 (64.12 cm) recorded higher plant height than Baviaans cultivar (57.56cm), Table 5. There was a significant increase in plant height under irrigated plants treatment compared to non-irrigated plants. Conover and Soonick (1989) and Madakadze (1999) reported that drought stress reduces plant height in millet. Tuong *et al.*, (2005) also found out that plant height was reduced under water stress compared to irrigated condition while working on rice in North Iran. In Baviaans cultivar maximum plant height was recorded in I_3 treatment (62.46cm), while I_0 treatment gave least value

(54.66cm). These results show that irrigating the plants up to physiological maturity stage increased plant height by 12.49% compared to non irrigated plants. Plants under irrigation up to stem extension (I_1) were not significantly different to those of I_2 or I_3 treatments. In cultivar 14SAWYT306 crop plants in I_1 treatment (67.12cm) gave maximum plant height value whereas I_0 treatment gave the least value (59.76cm).

Table 5: Effects of irrigation on plant height (cm), water use efficiency (kg ha^{-1} mm^{-1}) and grain protein content (%) on wheat cultivars.

	Cultivar	I_0	I_1	I_2	I_3	Mean	CV (%)	LSD (0.05)
Plant height (cm)	**Baviaans**	54.66	58.24	55.11	62.46	57.56^b		
	14SAWYT306	59.76	67.12	63.69	65.67	64.12^a	12.08	2.44
	Mean	57.09^b	62.68^a	59.19^b	64.07^a			
Water use efficiency (kg ha^{-1} mm^{-1})	**Baviaans**	8.96	8.95	8.22	6.83	8.24^a	26.06	3.53
	14SAWYT306	8.22	9.97	6.58	6.89	7.91^a		
	Mean	8.59^a	9.46^a	7.40^a	6.86^a			
Grain protein content (%)	**Baviaans**	13.22	11.87	11.95	12.94	12.50^a	9.73	2.07
	14SAWYT306	13.05	12.18	12.05	14.23	12.88^a		
	Mean	13.14^a	12.03^a	11.99^a	13.59^a			

NB: For each row and column within each response variable means with same letter are not significantly different ($P \leq 0.05$)

4.5.2 Water use efficiency (WUE) (kg ha^{-1} mm^{-1})

Water used by crops is normally related to total dry matter production or grain yield (Taylor *et al.*, 1983). This led to the concept of water use efficiency (WUE) which is defined as crop yield per unit of water use. Table 5 present data on the response of grain yield to water applied (irrigation plus rainfall). Cultivar Baviaans recorded a higher response of grain yield per unit of water use than 14SAWYT306, with values of 8.24 and 7.91 kg ha^{-1} mm^{-1} respectively. Angus and Herwaarden (2001) reported similar WUE value range from 9.1 kg ha^{-1} mm^{-1} to 14.1 kg ha^{-1} mm^{-1} while working with 13 different wheat cultivars under different agronomic practices.

Non- irrigated crop plants (I_0) gave higher response of grain yield per unit of water use than I_2 and I_3 irrigated in Baviaans although the difference was not significant. Results implied that stressed plants gave higher grain yield per water applied to plants compared to plants under I_2 and I_3 irrigation treatment. Lidder *et al.*, (1999) also reported that water use efficiency decrease with increase of irrigation while working on wheat cultivars Maugla and WH147. Plants under I_1 treatment (9.46) recorded significantly higher grain yield per water used compared to I_2 (7.40 kg ha^{-1} mm^{-1}) and I_3 (6.86 kg ha^{-1} mm^{-1}) treatments. The results substantiate the findings of Wajid (2004) who also noted similar response of grain yield to water received in wheat. However, Ibrahim *et al.* (1995) reported that water stress reduced WUE of millet.

4.5.3 Grain protein content (%)

Cultivar 14SAWYT306 showed higher grain protein content value of 12.88 % compared to 12.50 % of cultivar Baviaans (Table 5) although the difference was non- significant at $P < 0.05$. I_1 and I_2 irrigation treatments reduced grain protein content over no irrigation treatment, whereas in I_3 treatment grain protein content was increased by 3.31% over I_0 treatment. Grain protein was significantly increased in crops irrigated throughout the season (13.59%) compared to crops irrigated from stem extension up to physiological maturity (11.99%).

CHAPTER FIVE

5.0 CONCLUSIONS

The results from the study indicated that irrigating winter wheat throughout the growing stages enhanced number of tillers, grains per spike, spikelets per spike, 1000-grain mass, spike length, grain protein, biological yield, grain yield and harvest index. No irrigation in winter wheat gave higher water use efficiency, whereas irrigating throughout the growing period gave lower water use efficiency, but significant differences were observed between the irrigation levels in water use efficiency. Water stress generally was found to increase grain protein content although, the highest grain protein content in wheat was recorded from crops irrigated at all stages of growth. Therefore, it can be concluded that it is important to irrigate winter wheat throughout the growing stages in order to achieve higher yield.

CHAPTER SIX

6.0 RECOMMENDATIONS

Wheat has become a staple for most Batswana and semi-arid areas of the developing world. However, research on the crop has not been given due attention especially in Botswana. Therefore, future studies on wheat should allow use of irrigation systems to increase production. Other parameters like leaf area duration, crop growth rate and net assimilation rate could also be included in future studies to help monitor precise analysis of crop growth. Further research work should include other agricultural regions of Botswana to investigate response in different locations.

CHAPTER SEVEN

7.0 REFERENCES

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Appendix 1: Pan coefficient (K pan) for class A-pan for different ground cover and levels of mean relative humidity and 24 hours wind

Class A pan	Case A: Pan placed in short green cropped area				Case B': Pan placed in fallow area			
RH mean %		low < 40	medium 40-70	high > 70		low < 40	medium 40-70	high > 70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light	1	0.55	0.65	0.75	1	0.7	0.8	0.85
< 175	10	0.65	0.75	0.85	10	0.6	0.7	0.8
	100	0.7	0.8	0.85	100	0.55	0.65	0.75
	1000	0.75	0.85	0.85	1000	0.5	0.6	0.7
Moderate	1	0.5	0.6	0.65	1	0.65	0.75	0.8
175-425	10	0.6	0.7	0.75	10	0.55	0.65	0.7
	100	0.65	0.75	0.8	100	0.5	0.6	0.65
	1000	0.7	0.8	0.8	1000	0.45	0.55	0.6
Strong	1	0.45	0.5	0.6	1	0.6	0.65	0.7
425-700	10	0.55	0.6	0.65	10	0.5	0.55	0.65
	100	0.6	0.65	0.7	100	0.45	0.5	0.6
	1000	0.65	0.7	0.75	1000	0.4	0.45	0.55
Very strong	1	0.4	0.45	0.5	1	0.5	0.6	0.65
> 700	10	0.45	0.55	0.6	10	0.45	0.5	0.55
	100	0.5	0.6	0.65	100	0.4	0.45	0.5
	1000	0.55	0.6	0.65	1000	0.35	0.4	0.45

Source: FAO 1998

Appendix 2: Amount of irrigation and rainfall during crop season

	I_0	I_1	I_2	I_3
Irrigation (mm)	14.99	106.34	133.02	316.97
Rainfall (mm)	164.5	164.5	164.5	164.5
Total water (mm)	179.49	270.84	297.52	481.47

Appendix 3: Monthly Meteorological data summary (Sebele) during planting winter season

DATE	Evaporation (mm)	Wind SPEED (km)	Sunshine (hours)	Min temperature (^{0}C)	Max temperature (^{0}C)	Relative humidity (%) 0800 a.m.
07/05/09	3.1	66.6	6.3	13.8	26.6	97
08/05/09	4.1	63.3	8.1	8.1	27.2	60
09/05/09	3.1	125.1	6.6	7.2	25.0	91
10/05/09	3.1	82.0	6.7	9.5	27.5	87
11/05/09	4.1	96.3	7.8	7.4	23.7	88
12/05/09	4.1	91.0	7.6	6.3	25.0	94
13/05/09	4.1	113.1	8.2	5.9	24.7	83
14/05/09	4.1	114.4	8.5	5.8	22.8	88
15/05/09	3.1	91.1	5.2	6.0	24.5	86
16/05/09	3.1	90.4	5.1	9.4	25.7	74
17/05/09	5.1	114.0	9.0	9.3	23.2	72
18/05/09	3.1	68.1	8.2	4.8	21.6	66
19/05/09	3.1	51.2	8.1	3.6	25.0	81
20/05/09	4.1	137.9	7.9	4.2	24.5	76
21/05/09	3.1	137.6	7.2	5.6	23.0	80
22/05/09	3.1	73.3	7.8	3.5	23.2	88
23/05/09	3.1	55.4	7.9	4.0	25.0	93
24/05/09	2.0	43.0	5.2	4.3	24.4	97
25/05/09	4.1	49.0	8.1	4.3	27.5	89
26/05/09	4.1	53.5	8.0	5.0	27.5	87
27/05/09	3.1	51.2	8.0	3.9	26.5	89
28/05/09	4.1	57.5	7.7	3.7	27.4	81
29/05/09	4.1	90.3	7.7	3.9	28.0	79
30/05/09	4.1	93.3	8.9	5.5	25.5	83
31/05/09	5.1	93.6	8.4	0.3	24.4	70
01/06/09	3.1	63.1	8.8	-0.7	24.6	76
02/06/09	4.1	55.7	8.9	0.9	26.5	94
03/06/09	3.1	75.5	8.7	2.9	28.6	78
04/06/09	3.1	69.2	6.8	2.1	28.5	78
05/06/09	3.1	88.4	8.5	2.1	28.8	80
06/06/09	4.1	33.5	7.5	3.1	29.9	83
07/06/09	2.0	99.8	5.7	2.9	28.4	73
08/06/09	0.0	269.5	0.0	8.4	18.9	66
09/06/09	0.0	198.5	0.0	11.5	13.1	88
10/06/09	0.0	222.5	0.0	11	13.6	96
11/06/09	3.6	26.2	2.0	11.3	18.4	94
12/06/09	1.0	46.4	2.0	8.8	18.2	95
13/06/09	3.1	102.2	7.4	5.7	23.5	97

14/06/09	3.1	56.1	7.4	8.5	26.4	83
15/06/09	3.1	102.4	7.3	7.9	27.1	97
16/06/09	1.0	100.0	1.6	9.5	22.6	97
17/06/09	1.0	47.2	0.9	12.6	21.6	88
18/06/09	3.1	94.4	7.0	8.0	21.6	84
19/06/09	2.0	185.7	7.2	6.2	22.7	96
20/06/09	3.1	87.4	0.5	4.9	22.2	97
21/06/09	3.1	65.8	7.5	5.4	22.8	91
22/06/09	3.1	136.7	6.9	5.5	26.2	96
23/06/09	4.1	120.7	8.3	10.3	19.2	60
24/06/09	1.0	97.5	7.3	1.4	19.5	93
25/06/09	3.1	67.3	7.5	1.6	26.6	93
26/06/09	2.0	74.5	8.7	3.1	18.0	81
27/06/09	2.0	65.0	7.3	-2.0	18.5	85
28/06/09	3.1	65.7	7.3	-0.5	21.6	91
29/06/09	2.0	119.6	6.9	-1.1	19.0	96
30/06/09	3.1	134.8	7.7	1.0	17.7	92
01/07/09	3.1	115.5	7.2	-0.1	18.5	76
02/07/09	3.1	125.5	7.1	-0.2	19.5	90
03/07/09	3.1	72.8	7.5	1.2	19.6	95
04/07/09	2.0	67.4	0.0	-0.5	2.1	78
05/07/09	1.0	72.3	1.6	0.2	17.5	90
06/07/09	2.0	44.2	2.3	4.9	19.2	96
07/07/09	3.1	67.7	7.5	3.1	21.8	97
08/07/09	2.0	96.4	8.3	1.9	21.0	86
09/07/09	3.1	76.6	7.7	0.7	20.5	95
10/07/09	3.1	52.1	8.1	-0.5	23.3	91
11/07/09	3.1	96.5	8.9	0.8	24.2	91
12/07/09	3.1	74.1	8.1	3.7	24.9	78
13/07/09	3.1	118.7	9.1	2.6	26.7	92
14/07/09	3.1	103.5	8.7	5.9	18.4	66
15/07/09	4.1	86.0	9.1	-1.6	19.2	89
16/07/09	4.1	12.5	8.5	-1.9	20.3	60
17/07/09	3.1	28.9	8.9	0.5	19.9	74
18/07/09	4.1	141.3	9.1	-0.3	20.3	86
19/07/09	3.1	166.9	7.2	1.0	20.9	91
20/07/09	3.1	152.4	9.4	-0.5	19.6	87
21/07/09	1.0	56.0	7.1	-1.0	19.4	91
22/07/09	3.1	73.0	8.4	1.2	22.6	88
23/07/09	3.1	125.6	9.2	1.0	22.6	97
24/07/09	4.1	112.1	9.0	-1.6	16.7	90
25/07/09	3.1	91.7	8.3	-2.0	16.5	96
26/07/09	3.1	89.0	7.4	-2.2	18.6	56
27/07/09	3.1	125.4	8.9	-1.9	19.9	88
28/07/09	4.1	121.0	8.4	-1.5	20.4	86

29/07/09	3.1	72.4	8.6	0.5	22.5	93
30/07/09	3.1	83.0	7.9	0.7	19.2	81
31/07/09	7.1	97.0	8.1	3.1	25.1	50
01/08/09	3.1	117.1	4.0	8.0	27.2	88
02/08/09	3.1	89.5	7.3	4.0	19.2	96
03/08/09	2.0	59.0	8.1	3.6	22.2	91
04/08/09	3.1	94.8	7.8	4.5	24.6	92
05/08/09	2.0	65.7	8.0	4.6	27.2	94
06/08/09	3.1	80.8	8.5	5.1	28.6	93
07/08/09	2.0	161.1	8.8	6.5	26.0	69
08/08/09	4.1	117.7	8.1	10.2	24.0	67
09/08/09	4.1	72.8	8.5	6.0	24.5	89
10/08/09	4.1	74.8	8.5	4.5	26.6	63
11/08/09	3.1	63.2	9.2	5.0	28.3	79
12/08/09	7.1	133.2	9.8	5.9	29.6	77
13/08/09	3.1	101.9	9.0	7.2	23.2	52
14/08/09	3.1	180.7	8.9	0.8	23.2	70
15/08/09	4.1	128.6	8.5	4.9	22.1	92
16/08/09	5.1	135.9	7.5	3.2	24.0	82
17/08/09	6.1	237.0	9.8	3.9	22.6	74
18/08/09	5.1	181.9	9.2	4.5	24.1	71
19/08/09	6.1	153.9	10.1	6.5	22.1	66
20/08/09	4.1	92.3	9.8	2.6	20.6	48
21/08/09	4.1	70.0	9.9	-1.2	23.5	69
22/08/09	4.1	146.2	10.0	-0.9	24.5	70
23/08/09	5.1	92.2	9.7	3.7	25.2	78
24/08/09	6.1	186.5	9.4	3.0	26.6	76
25/08/09	0.0	165.5	9.2	7.2	23.6	55
26/08/09	4.1	76.4	9.7	3.1	25.9	81
27/08/09	6.1	71.0	7.3	4.4	28.1	66
28/08/09	4.1	119.3	10.0	5.9	27.8	76
29/08/09	5.1	125.6	9.3	4.9	28.3	84
30/08/09	6.1	156.5	8.3	5.2	29.1	81
31/08/09	6.1	30.7	9.9	4.0	30.8	68
01/09/09	7.1	142.1	9.8	4.6	32.9	40
02/09/09	7.1	115.4	9.8	8.6	33.0	36
03/09/09	5.1	54.3	10.0	7.5	32.6	37
04/09/09	6.1	89.4	7.6	6.5	32.3	37
05/09/09	7.1	118.1	9.9	8.3	31.5	55
06/09/09	10.2	47.3	10.1	7.6	30.0	44
07/09/09	8.2	137.6	9.1	10.2	31.5	43
08/09/09	7.1	76.8	10.0	5.9	33.6	36
09/09/09	8.2	202.2	8.9	7.1	33.1	50
10/09/09	7.1	242.3	7.3	16.4	27.2	73
11/09/09	5.1	41.9	9.8	13.0	26.5	89

12/09/09	6.1	216.5	2.7	8.9	28.3	43
13/09/09	4.1	89.4	9.5	9.6	30.0	72
14/09/09	5.1	112.7	9.6	10.2	32.6	69
15/09/09	5.1	92.0	8.8	11.5	33.4	43
16/09/09	7.1	66.9	9.8	11.4	34.6	45
17/09/09	9.2	170.0	9.3	13.0	37.4	42
18/09/09	8.2	166.7	10.5	17.7	28.6	18
19/09/09	10.2	192.7	9.0	16.4	28.0	22
20/09/09	5.1	175.3	3.8	13.5	23.5	66
21/09/09	7.1	99.3	9.3	7.3	29.5	71
22/09/09	9.7	268.5	9.3	8.7	34.3	79
23/09/09	7.1	143.6	7.8	16.2	32.5	59
24/09/09	9.2	218.8	7.7	14.9	32.0	83
25/09/09	4.6	158.7	0.0	17.6	21.0	88
26/09/09	6.1	71.9	8.1	12.0	27.8	90
27/09/09	11.2	72.0	9.8	11.7	32.5	76
28/09/09	9.2	277.6	8.3	14.9	32.7	73
29/09/09	5.1	341.4	9.7	15.8	26.2	85
30/09/09	5.1	190.9	5.3	14.6	25.0	71
01/10/09	5.1	99.1	7.5	12.4	27.8	88
02/10/09	10.2	300.6	7.4	13.3	29.8	65
03/10/09	5.1	286.0	1.6	15.7	24.0	80
04/10/09	4.6	103.6	2.3	13.8	21.4	87
05/10/09	4.1	48.0	8.8	12.5	27.1	95
06/10/09	7.1	80.2	10.9	12.4	32.2	85
07/10/09	8.2	117.0	10.9	14.1	36.1	61
08/10/09	8.2	80.9	10.6	13.6	36.0	33
09/10/09	4.1	59.3	6.7	15.9	34.5	48
10/10/09	2.0	269.7	0.4	16.1	31.8	52
11/10/09	3.1	301.2	0.0	15.6	33.0	64
12/10/09	7.1	195.5	9.3	16.4	33.1	79
13/10/09	7.1	70.3	10.6	14.0	32.6	59
14/10/09	10.1	293.2	9.5	14.5	33.0	61
15/10/09	4.1	118.6	7.1	17.2	31.0	71
16/10/09	6.1	99.6	7.8	15.7	32.6	61
17/10/09	4.1	84.2	0.7	20.7	29.5	40
18/10/09	8.2	139.6	10.6	15.9	30.2	84
19/10/09	7.1	244.0	11.7	14.1	31.0	70
20/10/09	9.2	155.9	12.0	14.5	29.9	67
21/10/09	8.2	84.8	12.0	12.0	34.4	53
22/10/09	12.2	270.1	10.1	18.2	30.7	54
23/10/09	10.2	183.6	10.6	19.6	31.9	67
24/10/09	9.2	109.2	11.1	15.9	34.6	39
25/10/09	11.4	238.5	10.8	16.3	36.1	46
26/10/09	11.2	506.2	10.4	17.5	34.1	48

27/10/09	10.2	293.2	10.1	18.2	30.9	62
28/10/09	4.1	135.5	4.8	18.4	31.0	61
29/10/09	6.6	145.8	7.1	17.0	33.4	60
30/10/09	10.1	385.5	8.1	14.9	30.0	82
31/10/09	3.1	236.7	1.7	15.5	22.7	95

Appendix 4: Summary of ANOVA table for measured parameters of winter wheat.

i) ANOVA table for Biological yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	3478625.33	1739312.67	0.87	0.4416
treat	3	17782171.43	5927390.48	2.95	0.0689
var	1	5639678.45	5639678.45	2.81	0.1158
treat*var	3	1891363.55	630454.52	0.31	0.8148
Error	14	28088121.18	2006294.37		
Total	23	56879959.94			

ii) ANOVA table for Straw yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	745431.896	372715.948	0.29	0.7537
treat	3	5768113.828	1922704.609	1.49	0.2607
var	1	4809909.735	4809909.735	3.72	0.0742
treat*var	3	1871804.648	623934.883	0.48	0.6994
Error	14	18083659.03	1291689.93		
Total	23	31278919.14			

iii) ANOVA table for Grain yield

Source	DF	Type I SS	Mean Square	F Value	Pr > F
treat	3	221.4440425	73.8146808	12.39	0.0001
rep	2	220.3049400	110.1524700	18.49	0.0001
var	1	0.8438314	0.8438314	0.14	0.7068
treat*var	3	23.9632410	7.9877470	1.34	0.2604
Error	470	2799.572038	5.956536		
Total	479	3266.128093			

iv) ANOVA table for Harvest index

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	1216.850833	608.425417	3.22	0.0706
treat	3	694.687917	231.562639	1.23	0.3370
var	1	378.420417	378.420417	2.00	0.1787
treat*var	3	459.854583	153.284861	0.81	0.5083
Error	14	2643.475833	188.819702		
Total	23	5393.289583			

v) ANOVA table for number of tillers m^{-2}

Source	DF	Type I SS	Mean Square	F Value	Pr > F
treat	3	57.54166667	19.18055556	7.10	0.0001
rep	2	74.71250000	37.35625000	13.83	0.0001
var	1	49.95319670	49.95319670	18.50	0.0001
treat*var	3	12.36292694	4.12097565	1.53	0.2070
Error	470	1269.354710	2.700755		
Total	479	1463.925000			

vi) ANOVA table for number of grains per spike

Source	DF	Type I SS	Mean Square	F Value	Pr > F
treat	3	6787.383333	2262.461111	14.74	0.0001
rep	2	4950.429167	2475.214583	16.13	0.0001
var	1	5246.967042	5246.967042	34.18	0.0001
treat*var	3	2163.747703	721.249234	4.70	0.0030
Error	470	72139.83942			
Total	479	91288.36667			

vii) ANOVA table for number of spikelets per spike

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	28.67583333	14.33791667	1.61	0.2352
treat	3	31.96833333	10.65611111	1.19	0.3476
var	1	5.60666667	5.60666667	0.63	0.4411
treat*var	3	34.49000000	11.49666667	1.29	0.3168
Error	14	124.8575000	8.9183929		
Total	23	225.5983333			

viii) ANOVA table for one thousand grain mass

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	28.67583333	14.33791667	1.61	0.2352
treat	3	31.96833333	10.65611111	1.19	0.3476
var	1	5.60666667	5.60666667	0.63	0.4411
treat*var	3	34.49000000	11.49666667	1.29	0.3168
Error	14	124.8575000	8.9183929		
Total	23	225.5983333			

ix) ANOVA table for spike length

Source	DF	Type I SS	Mean Square	F Value	Pr > F
treat	3	105.3357500	35.1119167	17.87	0.0001
rep	2	37.2882917	18.6441458	9.49	0.0001
var	1	261.7193705	261.7193705	133.22	0.0001
treat*var	3	38.8479436	12.9493145	6.59	0.0002
Error	470	923.344561	1.964563		
Total	479	1366.535917			

x) ANOVA table for plant height

Source	DF	Type I SS	Mean Square	F Value	Pr > F
treat	3	3670.413833	1223.471278	22.70	0.0001
rep	2	1663.668667	831.834333	15.43	0.0001
var	1	4967.951596	4967.951596	92.16	0.0001
treat*var	3	680.647002	226.882334	4.21	0.0059
Error	470	25336.76257	53.90801		
Total	479	36319.44367			

xi) ANOVA table for water use efficiency

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	49.08865833	24.54432917	5.54	0.0169
treat	3	24.60850000	8.20283333	1.85	0.1844
var	1	0.63375000	0.63375000	0.14	0.7110
treat*var	3	5.79555000	1.93185000	0.44	0.7308
Error	14	62.0488750	4.4320625		
Total	23	142.175333			

xii) ANOVA table for grain protein content

Source	DF	Type I SS	Mean Square	F Value	Pr > F
rep	2	1.84840000	0.92420000	0.61	0.5590
treat	3	11.50925000	3.83641667	2.52	0.1004
var	1	0.88166667	0.88166667	0.58	0.4595
treat*var	3	1.81266667	0.60422222	0.40	0.7576
Error	14	213350667	1.52393333		
Total	23	37.38705000			