THE EFFECT OF MOISTURE STRESS AT DIFFERENT GROWTH STAGES UNDER VARIOUS SEED RATES ON WHEAT (*Triticum aestivum* L.)

BY

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CERTIFICATION

This thesis entitled 'THE EFFECT OF MOISTURE STRESS AT DIFFERENT GROWTH STAGES UNDER VARIOUS SEED RATES ON WHEAT (Triticum aestivum L)' by Usman A. HASSAN meets the regulations governing the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. All quotations are indicated and the sources of information are specifically acknowledged by means of references.

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ABSTRACT

In order to study the effects of moisture stress imposed at different growth stages of wheat under various seed rates, a field trial was conducted at Ahmadu Bello University farm, Samaru, during the 1981/82 dry season with three levels of seed rate (75, 100 and 150 kg ha^{-1}) and eight irrigation treatments consisting of normal irrigation at every ten days and missing one or two irrigation(s) at different growth stages.

Withholding irrigation at any growth stage before anthesis reduced most of the growth characters. Missing two consectutive irrigations during early stages from crown root initiation (CRI) to jointing reduced most of the yield-related characters. Missing two consecutive irrigations at any stage reduced grain yield more than missing one irrigation. The maximum yield reduction levels of 13.3 and 65.4 percent were obtained when one irrigation was missed at CRI and when two consecutive irrigations were missed at jointing, respectively.

A seed rate of 100 kg ha^{-1} was found to be the optimum for efficient water utilization in wheat.

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CHAPTER 1

INTRODUCTION

Wheat (Triticum aestivum L.) is one of the oldest crops domesticated by man and the most extensively grown. Among grain crops, it ranks first in hectarage and production in the world. Year after year its total hectarage and production are increasing. In 1980, the total hectarage and production of wheat in the world were 237.4 million hectares and 444.5 million tonnes, respectively (F.A.O., 1980).

Although wheat is essentially a temperate cereal, it is also grown in the tropical and sub-tropical regions of the world. In the tropics wheat is grown at high altitudes or in the plains, where suitable conditions, especially low temperatures, exist.

The earliest reports of wheat cultivation in Nigeria dates back to the 18th century around Borno (Anonymous, 1979). Its cultivation was confined to the cool dry season (November to March) in heavy lowland soils (fadama) with residual moisture. The locally produced wheat was mainly used for making luxury products such as 'alkaki', 'pate' and 'bura busko'.

The consumption of wheat in the form of bread was introduced to Nigeria on a modest scale during the colonial period. Soon bread eating habit spread rapidly and widely from cities into the rural areas all over the country. The

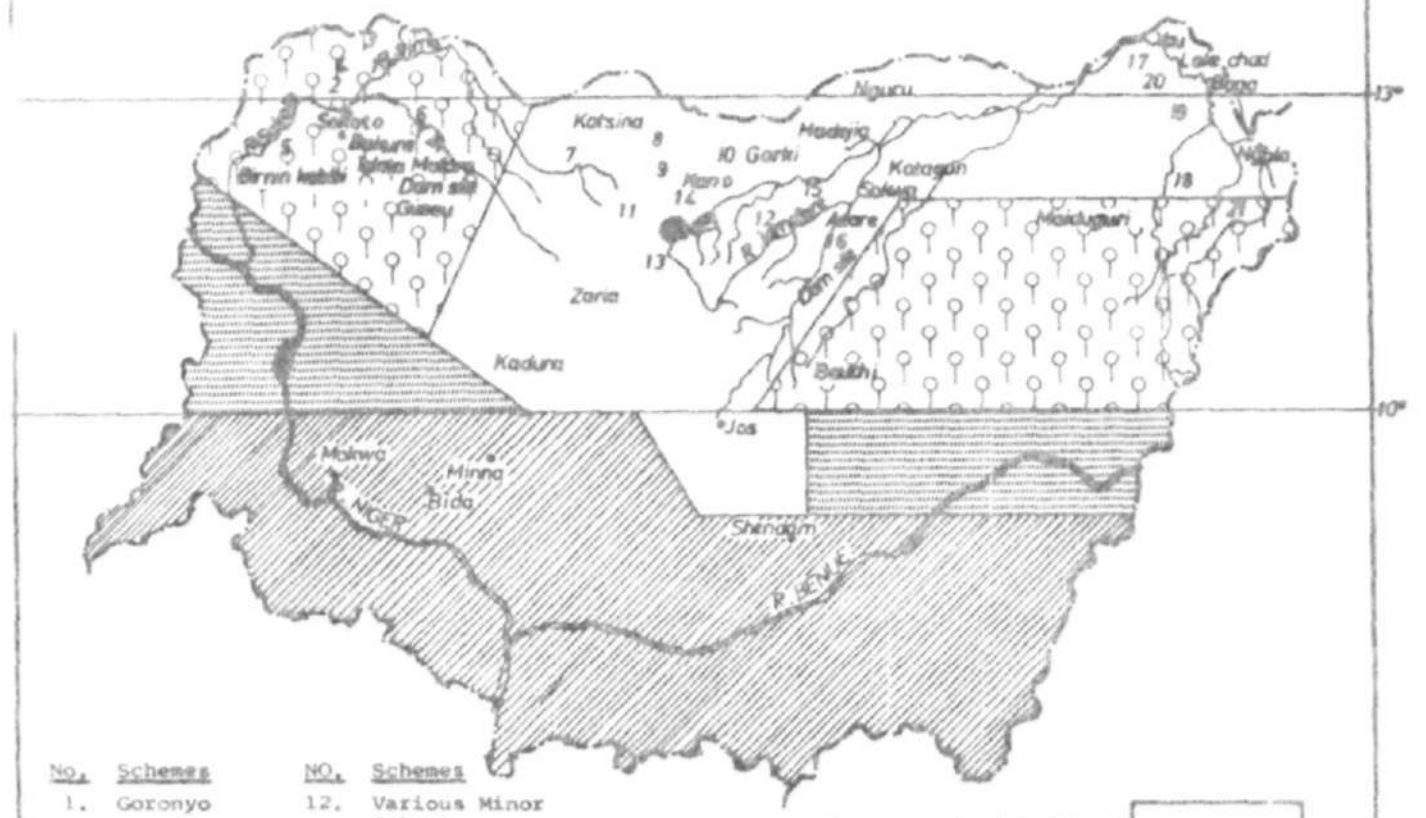
average consumption of bread in Nigeria was 26.3 gm/head/day in 1977 ranging from a maximum of 162.0 gm/head/day in Lagos to negligible levels in rural areas (Anonymous, 1979).

The increasing trend in the wheat import bill between 1969 and 1977 in Nigeria evidently illustrates the importance of wheat crop in the economy of the nation. From 1969 to 1977, imports of wheat increased from 188,200 tonnes valued at ₦12.5 million to 719,700 tonnes valued at ₦96.4 million (Anonymous, 1977). Such staggering import bills constitute a big drain on the country's foreign exchange.

Because of its wide adaptability, wheat is grown over a wide range of edaphic and climatic conditions in different parts of the world. In Nigeria wheat is grown almost entirely under irrigation in the Northern States between latitude 10-14^{o}N and altitudes 240-360m (Olugbemi, 1973). The areas suitable for wheat production in Nigeria are indicated in figure 1. The factor which limits the extention of the crop southwords is temperature. Essentially, south of latitude 10^{o}N, where the cool period from November to end of February has a maximum temperature consistently above 32.5^{o}C, conditions are too warm for satisfactory tillering and large spikes necessary for high wheat yields (Anonymous, 1979).

Out of the eleven River Basin Development Authorities

Fig. 1. Climatic Zones For Wheat in Nigeria and Projected Irrigation Schemes



No.	Schemes	No.	Schemes
1.	Goronyo	12.	Various Minor Schemes
2.	Wurno	13.	Kano River Phase I
3.	Kalmalo	14.	Kano River Phase 2
4.	Tungun Tudu	15.	Hadejia Basin
5.	Kardi	16.	Jama'are Basin
6.	Bakalori	17.	Yau MNR Borno
7.	Karaduwa	18.	Scipp
8.	Gari River	19.	Kironowa Polder
9.	Tomas River	20.	Baga Polder
10.	Jakara River	21.	Yedseram
11.	Watari River		

Zone very suited to Wheat

Zone suited to Wheat

Zone poor for Wheat

Zone unsuited to Wheat

13°

10°

5°

Source: Report on wheat production and marketing in Nigeria (197).

established in 1976, three of these, the Chad Basin Development Authority under the South Chad Irrigation Project (SCIP), the Sokoto-Rima Development Authority under the Bakolori Dam and Irrigation Project, and the Hadejia-Jama'are River Basin Development Authority under the Kano River Project (KRP), are to emphasize wheat production (Olugbemi, 1980). In 1970 about 3,035 hectares of irrigated wheat was grown and by 1985 this figure is projected to rise to about 141,643 hectares. When the three schemes are fully operational, a total area of about 200,000 hectares will be put to wheat production. Presently, the production and yield of wheat in Nigeria are about 15,000 tonnes and 2,000 kg/ha, respectively (Olugbemi, 1980).

Since wheat cultivation is almost entirely under irrigation, available soil moisture is a major yield determining factor. Although water is a renewable resource it is increasingly becoming a subject of competition between agricultural, urban and industrial requirements. As water needs for other purposes increase, less water will become available for irrigation purposes, giving less scope for increase in yield through intensive irrigation practice.

Both surplus of water and its deficits have deleterious effects on crop growth, development and production. Water availability affects almost every process that occurs in plants, and the relationships are complex, varying with plant characteristics, stage of development, as well as

edaphic and climatic conditions (Chang, 1968). Excessive irrigation not only directly damages crops by limiting nutrient uptake and respiratory metabolism of roots but also exposes the soil to the problem of salinity, sodicity, waterlogging and rise in the water table, which are common problems of arid and semi-arid irrigated lands. A better understanding of how growth and yield are affected by water aids irrigation efficiency and practices.

Seed rate is another important yield determinant as it determines the plant population. In many crops, the effects of plant population on yield are generally attributed to inter-plant and intra-plant competition for water, nutrients and light. In tiller-producing plants like wheat, both kinds of competition greatly influence growth and productivity (Darwinkle, 1978). The selection of optimum seed rate is based on the fact that competition for water, nutrients and light increases with increasing plant population, leading to the lowering of productivity in the individual plants, and the final yield depends upon the compensation in individual and group performances of the plants. The optimum seed rate is that which causes the maximum yield in quantity and quality.

Even though research on wheat has been going on in Nigeria for about a decade, only little work on water management and population density aspects has been done. Also farmers in the irrigation schemes have little skill

and experience with irrigation practices and the wheat crop. There is, therefore, the need to conduct research on these aspects to make some valuable recommendations. The present study was, therefore, undertaken with the following objectives.

1. To assess the growth, development and yield responses of wheat to timing of irrigation.

2. To determine the most critical stage(s) of growth and development to soil moisture stress.

3. To determine the optimum seed rate for efficient water utilisation by wheat.

CHAPTER II

LITERATURE REVIEW

Agronomic studies on wheat have been carried out in different parts of the world. The available literature on the effect of irrigation and seed rates on the growth, yield components and yields of wheat is reviewed.

EFFECTS OF IRRIGATION ON PLANT GROWTH

Growth of a wheat plant is measured in terms of height, number of tillers, leaf area and dry matter accumulation. Investigations have been carried out on different aspects of irrigation practices including irrigation frequencies, irrigation depth, soil moisture stress at different growth stages of wheat, soil moisture depletion, and so forth.

Investigations have been carried out on the number and timing of irrigation. In India, Singh and Singh (1971/72) reported that applying first irrigation on 21 days after sowing (DAS), coinciding with crown root initiation (CRI), had favourable effects on tillering, plant height, dry matter and leaf number per plant. On the other hand Srivastava and Bansal (1975), also in India, found that delaying the first irrigation from 21 to 28 or 35 days after sowing in black soils had no adverse effect on tiller production, but further delay to 45 days decreased tillering. In Egypt, El-Hattab and Ibrahim (1974) found

that irrigating wheat six times at 20 days interval increased plant height. El-Dababy et al. (1978) found that plant height increased as the number of irrigations was increased from three to seven. Hussain et al. (1978) also found an increase in plant height with increase in irrigation number from one to six. Abdel-Gawaad et al. (1979) and Ibrahim et al. (1979) reported that the height of wheat plants was influenced favourably by giving irrigation at three - and six-leaf stages and at heading.

Depletion of soil moisture below a certain level is another approach to irrigation practice of wheat. In Poland, Panek (1976) found that irrigating wheat crop when the depletion reached below 70 per cent of the available moisture was necessary for increased leaf area and plant height.

Under rain-fed cropping, supplementary irrigation was important to obtain normal plant growth, especially in years with low rainfall. Panek (1976) and Prusty (1976) found an increase in plant height, leaf area and dry matter accumulation after applying irrigation in dryland farming. Cooper (1980) and Musick and Dusek (1980) found that water deficits had adverse effects on all the growth characters of the wheat crop. In Nigeria, Anonymous (1980) found that plant height was not affected by different moisture stress treatments.

The effects of moisture stress effected by withholding irrigation at different stages of crop growth of wheat, have been investigated by some workers. EL-Nadi (1969) in the Sudan reported significant reductions in plant height and number of tillers per plant when the wheat crop was stressed during the vegetative phase, prior to heading. In Nigeria, Anonymous (1980) observed that plant height was not affected by different moisture stress treatments.

EFFECTS OF IRRIGATION ON YIELD COMPONENTS AND YIELD

The yield components of wheat include the number of spikes per unit area or plant, length of spike, number of spikelets per spike, number of grains per spike, spike grain weight and 1000-grain weight. These components differ in their reactions to irrigation or moisture stress because of the fact that they are being determined at different times in the life cycle of the crop.

i) Number of spikes per unit area of land

Tillering behaviour of dwarf wheat is very much influenced by crown roots and any unfavourable condition at the time of crown root initiation (CRI) will definitely affect tillering. Water availability is one of the most important factors that influence CRI and thus the formation of tillers. Moisture availability in the soil during the vegetative phase to ear emergence has significant effects on the vitality and survival of tillers. The vitality of

tillers is measured by the number of spikes per unit area or per plant (effective tillers). Storrier (1965) in Australia found that the application of water at jointing and all pre-anthesis stages increased spike number and any stress occurring during this stage significantly reduced this attribute. Talha (1966) had reported that soil moisture stress during tillering, elongation and spike emergence (all prior to anthesis) caused highly significant reduction in number of spikes per plant. He further stated that moisture stress that took place at any of the grain development stages had no effect on the production of spikes per plant. Many other workers, including EL-Nadi (1969), Wilson (1974), Panek (1976), Abdel-Motaleb (1978), Ibrahim et al. (1979) and Cooper (1980), agreed that the occurrence of moisture stress at any stage prior to anthesis caused significant reduction in the number of effective tillers per unit area of land.

ii) Length of spike

Abdel-Gawaad et al. (1979) found in their study that irrigation had no effect on spike length.

iii) Number of spikelets per spike

There is a general agreement among workers that this yield contributing character is significantly reduced by moisture stress occurring at stages prior to anthesis (Aspinall et al. 1964; Day and Intalap, 1970; Shrotriya et al.

1970; Hussein et al, 1978; Musick and Dusek 1980).

iv) Number of grains per spike

The number of grains per spike is determined during inflorescence development (Slatyer, 1969 and 1973; Fischer, 1973). Abdul-Galil (1964) found no effect of number of irrigation on this character. Wilson (1969) reported that moisture stress occurring before spike emergence had no effect on the number of grains per spike. On the other hand Day and Intalap (1970) found significant reduction in the number of grains per spike with moisture stress during jointing. Singh and Singh (1971/72) reported that giving first irrigation at 21 DAS was best in increasing the number of grains per spike. EL-Sharkawy et al. (1976) found that withholding irrigation at either milk-ripe or dough-ripe stage had little effect on the number of grains per spike. Langer (1978) found that water stress taking place three weeks after spike emergence caused severe reduction in grain number per spike. The essentiality of the moisture availability during flowering and fertilization stages was investigated by Abdel-Motaleb (1978) and Musick and Dusek (1980) who reported that there should be no water stress during these critical stages if maximum number of grains per spikelet or per spike is to be attained.

v) Spike-grain weight

The spike-grain weight is a function of both number of grains per spike and 1000-grain weight. Any

unfavourable condition that affects either or both of these two characters undoubtedly will affect the spike-grain weight. Moisture stress during any stage in the reproductive phase adversely affects the weight of spike-grain (Abdel-Motaleb, 1978; El-Dababy et al. 1978; Ibrahim et al. 1979).

vi) 1000-grain weight

Another important yield component is grain size, expressed as 1000-grain weight. The time of water stress occurrence exercises a great effect on grain size. Misra et al. (1969) reported that irrigating a wheat crop four times at CRI, late tillering, flowering and dough stages increased the weight of 1000-grains. Moisture stress prior to spike emergence increased 1000-grain weight whereas withholding irrigation at either milk-ripe or dough stages decreased grain weight (Wilson, 1969). Mosaad (1975), Misra et al. (1976) and El-Dababy et al. (1978) also reported reductions in 1000-grain weight due to moisture stress at grain filling stage. On the other hand, Cooper (1980) did not observe similar results. According to him, as the irrigation frequency was increased the individual grain weight declined. He explained this decline in grain size to be a result of frequent irrigation that encourages the formation of late tillers, which have less time for complete grain development and in turn results in smaller grain size.

vii) Grain Yield

The ultimate goal of an efficient water use by a crop is to produce maximum yield per unit volume of water. The detrimental effect of moisture stress on grain yield varies depending on its duration and the stage of plant development during which the water stress has occurred.

Abdul-Galil (1964) found no significant differences when three, four and five irrigations were used. On the other hand, Gill et al. (1971) obtained significantly higher yield of grain with eight to nine irrigations than with five to six irrigations. Madalageri et al. (1973) reported that five irrigations given at 25, 35, 50, 65 and 80 DAS gave the best results.

Withholding irrigation at different growth stages differ in their effects on grain yield. Bhardwaj et al. (1971) reported that early irrigation at CRI and late irrigation at milk or grain filling stage were most critical for the wheat crop. They calculated the reduction in grain yield as 18.2, 1.9, 10.7, 11.8 and 0.0 per cent by withholding irrigation at CRI, late tillering, flowering, milk and dough stages, respectively. Patel et al. (1971) reported that six irrigations applied at the CRI (21 DAS), late tillering (42 DAS), late jointing (60 DAS), flowering (80 DAS), milk-ripe (95 DAS), and dough ripe (115 DAS), stages gave the highest average

grain yields. Withholding irrigation at the late tillering and/or dough ripe stages caused more reduction in grain yield than withholding irrigation at late jointing stage. Cheema et al. (1973) also reported that grain yield decreased by 27, 23 and 20 per cent when irrigation was missed at CRI, late tillering and flowering, respectively, but missing two consecutive irrigations at CRI and late tillering reduced yield by 60 per cent. Rajput and Yadav (1974) also reported that irrigations at CRI, booting and flowering were minimal in their effects to bring about high yields. Similar views were expressed by Koregave and Deshmane (1975). Based on the magnitudes of reduction in grain yield resulting from moisture stress Patel and Patel (1975) arranged the different critical stages in descending order of importance as milk ripe, booting, late jointing, CRI and flowering stages. Singh et al. (1975) reported that CRI was the most sensitive stage followed by late tillering, flowering and milk ripe. Singh et al. (1976), Tomar et al.(1976), Bhan (1978), Malik (1978), and Musick and Dusek (1980) confirmed that CRI is the most important stage. Anonymous (1980) reported from Nigeria that flowering is the most sensitive growth stage to moisture stress with respect to its effects on grain yields.

viii) Straw Yield

Wilson (1974) reported that irrigation increased

straw yield to a greater extent than it did grain yield. Abdel-Motaleb (1978) found that irrigating wheat six times (at CRI, late tillering, jointing, flowering, milk and dough stages) or four times (at CRI, late tillering, jointing and flowering) gave the highest straw yield. Hussein et al. (1978) recorded the heaviest weight of straw under four to six irrigations as compared to one to three irrigations. Abdel-Gawaad et al. (1979) found that maximum straw yield was obtained by irrigating wheat at the three - and six-leaf stages and at heading while minimum yield of straw was obtained by irrigating wheat at the three-leaf stage.

EFFECTS OF SEED RATES ON PLANT GROWTH

Pendleton and Dungan (1960), Wilson and Swanson (1962), Sorour and EL-Sharkawy (1976) and Darwinkle (1978) reported that seed rate is one of the most important factors affecting the growth and yield of wheat. Abdul-Galil (1964) found that plant height and number of tillers per plant were decreased when seed rate was increased from 83 to 166 kg ha^{-1}. By using 500, 600 and 700 seeds m^{-2} Suput (1966) observed less tillering with increasing seed rate. Chlopecki (1972) in Poland using 40, 80 and 120 kg seed ha^{-1} also reported a reduction in tillering as seed rate was increased. Ibrahim (1972) reported that when seed rate was increased from 50 to 150 kg ha^{-1}, there was notable increase in plant height up

to 60 DAS. There occurred decreases in leaf area per plant, dry matter production, and an increase in leaf area index.

Foltyn and Skorpik (1974) from Czechoslovakia reported that increase in seed rate from 0.22 million to 4.5 million seeds ha^{-1} resulted in decreased flag leaf area. Ruzha and Adamovich (1976) reported that leaf area was increased with an increase in the seeds per hectare from 4.5 million to 7.0 million. They also observed that increase in rate of seeding decreased leaf area per plant.

Suryanarayana (1977) found that increasing seed rate from 80 to 160 kg ha^{-1} increased leaf area index during crown root initiation to flowering period and increased net assimilation rate during flowering to maturation. Hughes et al. (1978) in England found that increased sowing density resulted in fewer surviving tillers per plant, a larger number of tillers per unit area and consequently a narrower range of tiller development.

Bassiouny (1979) working in Egypt reported that increasing the seed rate to 166 kg ha^{-1} was accompanied by an increase in plant height and a decrease in the number of tillers per plant, leaf area per plant and flag leaf area. Habib and Makki (1979) in Saudi Arabia found that plant height and tiller number were not affected by increasing seed rate from 50 to 200 kg ha^{-1}. However, from Nigeria, Ubi (1981) reported that plant height and number of tillers per unit area were increased by increasing

the seed rate from 50 to 150 kg ha^{-1} while number of tillers per plant and flag leaf area were decreased.

EFFECTS OF SEED RATES ON YIELD COMPONENTS AND YIELD

Seed rate determines the number of plants per unit area, which plays a very important role in determining the level of yield of a crop. It is a fact that competition for space, light, nutrients and moisture increases with increasing plant population, leading to a lowering of the productivity of the individual plant. Increasing yield of individual plants by decreasing plant population below a certain specific level does not compensate for the loss due to diminished population, and increasing it above a certain limit makes individual plants too weak to produce normal yields. The choice of an optimum seed rate is based on this fact. Optimum seed rate is, therefore, that which ensures the maximum yield, both in quantity and physical quality.

i) Number of spikes per unit land area

The number of effective tillers or number of spikes produced per plant or per unit area of land is influenced by seed rate. Abdul-Galil (1964), Ibrahim (1972), Ahmed (1973), Rule and Fiddian (1974), Sorour and EL-Sharkawy (1976), Sorour et al. (1977) and Bassiouny (1979) found that number of spikes per plant declines when seed rate was increased. Investigators like Zeidan (1974), Abdel-Wahab (1976), Day et al. (1979), Smid and

Jenkinson (1979) and Ubi (1981) reported that the number of spikes produced per unit area increased as seed rate was increased.

ii) Length of spike

Most workers like Foltyn and Shorpik (1974), Abdel-Wahab (1976), Khalil et al. (1977) and Bassiouny (1979) reported reductions in spike length with an increase in seed rate.

iii) Number of spikelets per spike

Ahmed (1973), Dougherty et al. (1974), Abu-Hagaza (1977), Gomaa et al. (1977), Khalil et al. (1977) and Ubi (1981) found significant reductions in the number of spikelets per spike with increasing seed rate. On the other hand, Nazir et al. (1975) found that the number of spikelets per spike increased with increasing seed rate.

Bassiouny (1979) obtained a consistent significant decrease in the number of fertile spikelets and an increase in sterile spikelets per spike with increase in the rate of seeding from 83 to 166 kg ha^{-1}.

iv) Number of grains per spike

Many workers including Abdul-Galil (1964), Sinha and Singh (1970), Ahmed (1973), Zeidan (1974), Ballatore et al. (1975), Nazir et al. (1975), Abdel-Wahab et al. (1976), Sorour and EL-Sharkawy (1976), Abu-Hagaza (1977), Gomaa et al. (1977), Khalil et al. (1977), Dougherty et al. (1978), Darwinkle (1979), and Smid and Jenkinson

(1979) found that the number of grains per spike decreased significantly by increasing the seed rate. But Bassiouny (1979) did not find any effect of seed rate on this character. Sorour et al. (1977) counting the number of grains per spike and number of grains per unit area reported a reduction in the former and no change in the latter. This indicates that the individual plant was adversely affected by the increase in population, but the overall effect on the grains produced per unit area was nullified by increasing the population.

v) Spike-grain weight

Ahmed (1973), Mahendra Singh and Sharma (1973), Foltyn and Skorpik (1974), Ballatore et al. (1975), Abu-Hagaza (1977), Gomaa et al. (1977), Khalil et al. (1977) and Bassiouny (1979) reported that the increase in the rate of seeding influenced the spike-grain weight in favour of the lowest seed rates. On the other hand, Abdul-Galil (1964) and Ubi (1981) did not find any effect of seed rates on the spike-grain weight.

vi) 1000-grain weight

There are conflicting reports regarding the effect of seed rate on the weight of 1000-grains in wheat. Abdul-Galil (1964), Singh et al. (1971), Ahmed (1973), Day et al. (1976) and Eissa (1979) using seed rates that varied from 29 to 240 kg ha^{-1} found that 1000-grain weight was not

affected by seed rates. However, Ibrahim (1972) found that increasing seed rate from 50 to 100 kg ha^{-1} had no effect on the weight of 1000-grains but further increase in seed rate to 150 kg ha^{-1} had an adverse effect. Suput (1966), Sinha and Singh (1970), Agarwal et al. (1972), Zeidan (1974), Nazir et al.(1975), Abdel-Wahab (1976), Abu-Hagaza (1977), Gomaa et al. (1977), Khalil et al. (1977), Bassiouny (1979) and Saleh (1981) reported reductions in 1000-grain weight with increased seed rate.

vii) Grain Yield

Different workers have expressed contradictory views on the effect of seed rate on the yields of wheat grain. Abdul-Galil (1964), Sharma et al.(1971), Agarwal et al. (1972), Mehta and Mathur (1972) Mosaad (1975), Day et al. (1976), Khalil et al. (1977), Randhawa et al. (1977) and Bassiouny (1979) reported that grain yield was not affected by seed rate, while Suput (1966), Ahmed (1973), Stoskopf et al. (1974), Briggs (1975), Ridder (1976), Harmati and Szemes (1978), Briggs et al. (1979), Eissa (1979) and Riverland et al. (1979) found that increased seed rates resulted in increased grain yield in wheat. Conversely, however, Gomaa et al. (1977) found that grain yield was decreased by increasing seed rate up to 600 seeds m^{-2}.

Dubey and Lal (1970) obtained the highest yield at

90 kg seeds ha^{-1} while Sinha and Singh (1970) found that the rate of 100 kg seeds ha^{-1} was adequate to produce the maximum grain yield. Singh et al. (1971) reported that the optimum seed rate for dwarf wheat varieties lies between 100 - 125 kg ha^{-1} and that under late sowing, 150 kg ha^{-1} rate gave maximum yield. Ibrahim (1972) and Ubi (1981) reported similar results.

viii) Straw Yield

Regarding the effect of seed rate on straw yield, Abdul-Galil (1964), Sharma et al. (1971), Sorour and EL-Sharkawy (1976) and Bassiouny (1979) found that this character was not affected by varying the rate of seeding. On the other hand, Singh et al. (1971), Agarwal et al. (1972), Ibrahim (1972), Ahmed (1973) Ballatore et al. (1975), Abdel-Wahab (1976), Sorour et al. (1977) and Ubi (1981) reported significant increases in straw yield by increasing seed rate.

CHAPTER III

MATERIALS AND METHODS

Site:

The experiment was conducted during the dry season (November to March) of 1981/82 at the Ahmadu Bello University farm, Samaru ($11^{O}11^{'}$ N, 07^{O} $38^{'}$ E and 685m above sea level) in the Northern Guinea savanna zone. The temperature data for 1981/82 dry season recorded from meteorological laboratory, Samaru, are presented in Table 3:1. The physical and chemical properties of soils were analyzed by adopting the following methods. Particle size analysis was carried out as described by Day (1965). The soil P^{H} was determined in a 1:1 soil to water paste. The P^{H} of the paste was measured using a glass electrode P^{H}-meter kent model 7010. Calcium and magnesium were determined by using atomic absorption spectrometer (model Perkin-Elmer 290B) while potassium and sodium were read using EEL flame photometer. Organic carbon was determined by acid dichromate digestion methods as described by Walkley-Black (1965). The cation exchange capacity was determined by titrating distilate from the soil used in the determination of exchangeable bases with 0.2NHcl and the base saturation percentage was calculated with the aid of the formula:

$$B\% = \frac{\text{sum of the bases}}{\text{C.E.C. meq/100g soil}} \times 100$$

The physical and chemical properties of the soil are presented in Table 3:2.

Experimental Design and Plot size

The experiment was laid out using the split - plot design with 24 treatments. Eight irrigation and three seed rates treatments were allocated at random in the main-plot and sub-plot, respectively. The treatments were replicated four times, giving a total of 96 plots (Figure 2). The size of each sub-plot was 3m x 2m. To prevent seepage from the adjoining plots a border 1.5m wide was left between the main-plots. Yield data were collected from net plots measuring 2m x 0.8m, while other observations were carried out on the remaining stands within each plot.

Treatments:

Irrigation treatments: Eight in number as shown below:

I_1 - Control; irrigating at every 10 days.

I_2 - Missing one irrigation at CRI*(20 DAS).

I_3 - Missing one irrigation at early jointing (40 DAS**).

I_4 - Missing one irrigation at heading (60 DAS).

I_5 - Missing one irrigation at milk-ripe (80 DAS).

I_6 - Missing two irrigations at CRI and tillering (20 and 30 DAS).

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* CRI - Crown root initiation.

** DAS - Days after sowing.

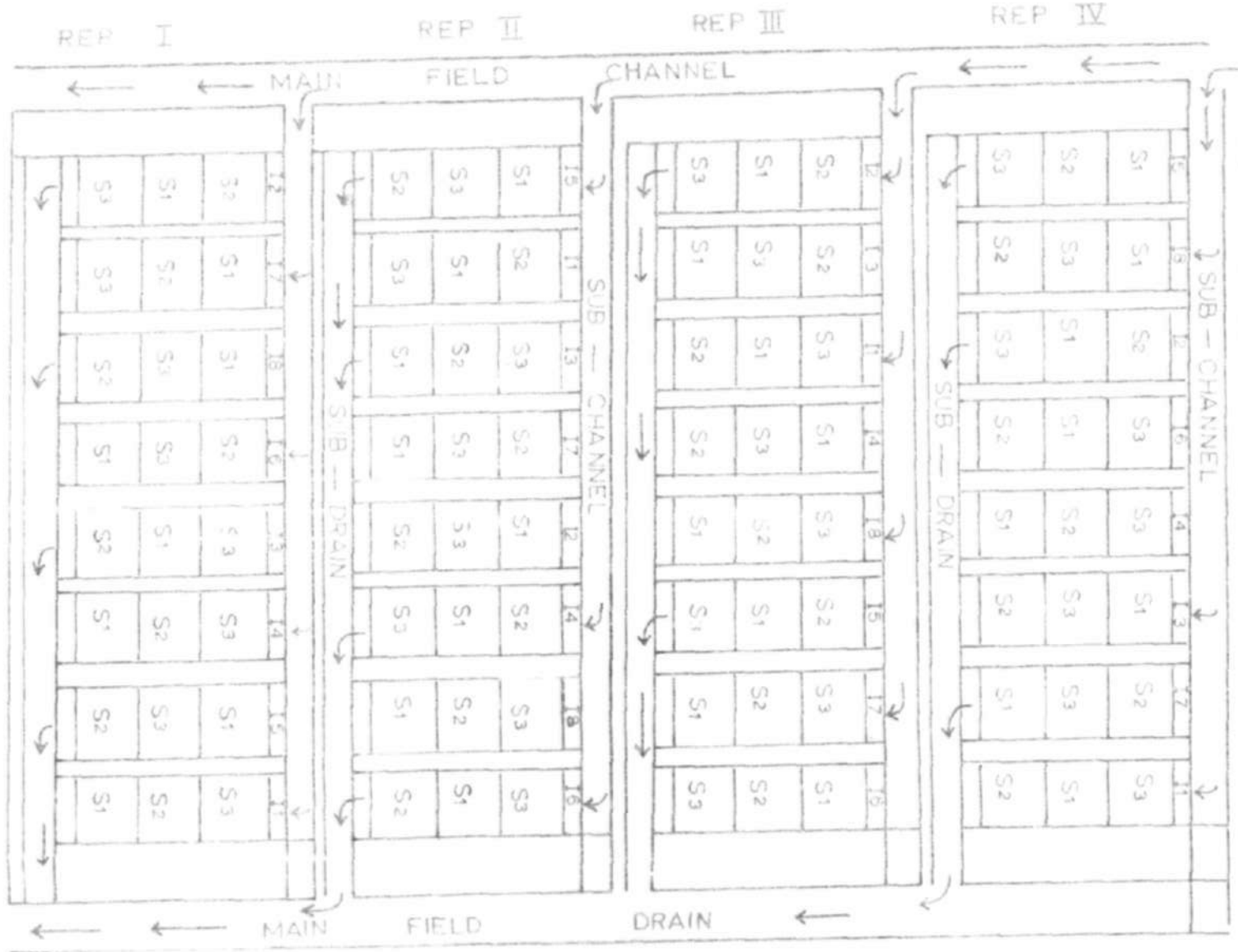


FIG 2. LAYOUT OF EXPERIMENTAL PLOTS

I_7 - Missing two irrigations at jointing (40 & 50 DAS).

I_8 - Missing two irrigations at heading and flowering (60 and 70 DAS).

Seed rate treatments: Three levels:

S_1 - 75 kg ha^{-1}

S_2 - 100 kg ha^{-1}

S_3 - 150 kg ha^{-1}

Table 3.1 The maximum, minimum and mean temperatures during wheat growing season (from November 20, 1981 to March 10, 1982) at Samaru.

Period	Days after sowing	Temperature (Co)		
		Max.	Min.	Mean
20 - 30 November	5	26.8	13.1	19.9
1 - 10 December	15	30.1	13.4	21.7
11 - 20 December	25	28.8	12.4	20.6
21 - 31 December	36	31.7	12.3	22.0
1 - 10 January	46	27.8	11.8	19.8
11 - 20 January	56	31.9	15.0	23.4
21 - 31 January	67	29.5	14.7	22.1
1 - 10 February	77	26.8	12.9	19.85
11 - 20 February	87	32.6	14.8	23.7
21 - 28 February	95	35.4	19.3	27.35
1 - 10 March	105	31.5	16.2	23.85

Table 3:2 The Physical and chemical properties of the soil collected up to a depth of 30cm from the experimental site at Samaru.

Soil Properties	Characteristics
Physical Properties	
Sand percentage	48.8
Silt percentage	42.6
Clay percentage	9.4
Textural class	Loamy sand
Chemical Properties	
P^H in $^H20$	5.5
Exchangeable cations (meq/100g soil)	
Na	0.3
K	0.21
Ca + Mg	3.8
Cation exch. capacity (C.E.C.)	6.4
Base saturation percentage	68.7
Organic carbon percentage	0.8

Land Preparation

The experimental area was ploughed, harrowed and levelled. Final levelling of 96 plots was done manually with hand.

Fertilizer application

According to the recommendation of AERLS (1979) calcium ammonium nitrate at 50 kg ha^{-1}, single super phosphate at 45 kg P_2O_5 ha^{-1} and muriate of potash at 30 kg K_2O ha^{-1} were broadcast and incorporated into the soil at the time of sowing. A second dose of calcium ammonium nitrate at 50 kg N ha^{-1} was top-dressed four weeks after sowing.

Sowing

Wheat variety "Siete Cerros" was sown on November 25, 1981 by hand drilling in rows 20cm apart on the well prepared basin beds. Before sowing, the seeds were dressed with Aldrex-T at 20g per 10 kg of seed.

Irrigation

Two general irrigations were given on the first and tenth day after sowing to ensure good germination and establishment. Differential irrigations as per treatment started on the 20th day after sowing.

Harvesting

The wheat crop was harvested at dead ripe stage, on March 10, 1982, (105 days after sowing). Harvesting, threshing, winnowing and cleaning of seeds were all done manually.

Assessment of Growth, Yield Characters and Yield

Germination Count

In each plot, two rows were randomly selected and in each row one meter length was marked out. The plants were counted on 15 days after sowing and from these figures the number of plants m^{-2} was determined for each plot.

Growth characters

For the purpose of determining the following growth characters, samples of five plants were taken at three sampling dates (at 40, 50 and 60 days after sowing) coinciding with early jointing, late jointing and booting stages, respectively.

i) Plant height (cm)

The lengths of stems were measured from the ground level to the base of top leaves to determine the plant height.

ii) Number of tillers per plant

The number of stems was counted and the number of

tillers per plant was determined.

iii) Leaf area per plant (cm^2)

Fresh leaves were removed from their base on each plant, their number, length and breadth (from the widest point) were measured with a ruler. A factor of 0.72 was used in calculating the leaf areas (Bello, 1983).

iv) Leaf area index (LAI)

This was determined by multiplying the number of plants per m^{-2} into leaf area per plant and dividing the result by 10,000.

v) Dry matter production (g m^{-2})

The plants and leaves (including dead ones) from each plot were oven-dried and weighed. The dry matter per square metre was determined.

Apart from the above characters, flag leaf area (cm^2) was also determined after complete ear emergence (at 70 days after sowing). Ten flag leaves were sampled per plot and from this the average flag leaf was determined as described above.

Growth and development of grains at grain filling stages

Three samples, each of 20 spikes, were taken at

random from each plot at 10-day intervals during grain filling (70, 80 and 90 days after sowing) and from these average grain weights were determined.

Yield components

The following yield components were studied:

i) Number of spikes m^{-2}

After complete ear emergence at 70 days after sowing, the numbers of spikes from the two central rows were counted, and the number of spike bearing tillers per square metre was calculated from these.

ii) Spike length and number of spikelets per spike

A sample of 10 spikes was taken at random from each plot at harvest and the spike length (cm) was recorded, from these spikes, the numbers of fertile and sterile spikelets per spike were counted and recorded.

iii) Grain number per spike

A sample of 20 spikes was also taken at random from each plot at harvest and the number of grains present was counted.

iv) Weight of grain per spike

Weight of grains were taken from the above samples.

v) 1000-grain weight

From the same samples 1000-grain weight (in grams) was determined.

Grain and straw yields

i) Grain Yield

This was obtained after threshing, winnowing and cleaning the seeds harvested from the net plot area (2m x 0.8m) and from this the grain yield per hectare was determined.

ii) Straw yield

This was determined by obtaining the difference between the total dry matter and the grain yield.

Statistical analysis

The data collected were subjected to statistical analysis of variance as described by Snedecor and Cockran (1967). Main and sub-treatment means were compared using the least significant difference (LSD) and Duncan multiple range test (DMRT) for the comparison of interaction means.

CHAPTER IV

RESULTS

A. EFFECTS OF IRRIGATION AND SEED RATES ON THE GROWTH OF WHEAT

i) Germination count

The effect of seed rates on the number of plants per square meter recorded at 15 days after sowing (DAS) is shown in Table 4:1.

It is evident from the data in the table that the number of plants per square meter was significantly increased with increasing seed rate.

ii) Plant height

The data relating plant height at different stages of growth (40, 50, 60 and 105 DAS) to irrigation and seed rates are presented in Table 4:2.

At early jointing stage (40 DAS) treatment I_6, with missing two consecutive irrigations at crown root initiation and tillering stages (20 and 30 DAS) produced significantly shorter plants than the other seven treatments, which produced plants of about the same height.

At the late jointing stage (50 DAS), all the treatments where irrigation was missed once or twice before that time

Table 4:1 The effect of seed rates on number of plants m^{-2} at 15 DAS during 1981/82 dry season at Samaru.

Seed rates kg ha^{-1}	Number of plants m^{-2}
S_1 - 75	207.75
S_2 - 100	260.06
S_3 - 150	303.17

SE $\pm$ 2.29

L.S.D. (0.05) = 6.35

DAS - Days after sowing

Table 4.2 Effect of moisture stress at different growth stages under various seed rates on plant height of wheat at Samaru, 1981/82

Treatments	40 DAS	50 DAS	60 DAS	105 DAS
Irrigation				
I_1 - Control (irrigating every 10 days)	24.13	32.42	41.65	73.57
I_2 - Missing irrigation at CRI	24.01	30.78	35.75	68.49
I_3 - Missing irrigation at early jointing	23.72	26.95	33.91	67.23
I_4 - Missing irrigation at heading	23.57	31.86	40.64	69.44
I_5 - Missing irrigation at milk-ripe	25.01	31.28	39.61	73.42
I_6 - Missing irrigations at CRI & Tillering	17.44	27.14	36.58	59.93
I_7 - Missing two irrigations at jointing	25.49	28.31	34.65	59.70
I_8 - Missing irrigations at heading & flowering	25.47	31.19	41.09	70.11
SE(±)	0.99	0.51	0.31	0.57
LSD (0.05)	2.90	1.50	1.10	1.69
Seed rate (kg ha^{-1}				
S_1 - 75	23.60	29.82	38.12	67.71
S_2 - 100	24.14	29.80	38.15	67.55
S_3 - 150	23.07	30.36	37.68	67.95
SE(±)	0.6	0.25	0.10	0.29
LSD(0.05)	N.S.	N.S.	0.28	N.S.
Interaction				
I ×				
I × S	N.S.	SIG.	SIG.	SIG.

DAS - Days after sowing, CRI - Crown root initiation, SIG. - Significant
N.S. - Not Significant.

of taking observation (Treatments I_3, I_6 and I_7) produced significantly shorter plants than the treatments where irrigation was not missed (I_1, I_4, I_5 and I_8).

At about the booting stage (60 DAS) the picture was almost the same as at late jointing stage (50 DAS). All the treatments where irrigation was not missed before 60th days after sowing (I_1, I_4, I_5 and I_8) produced taller plants than in the treatments where irrigation was missed once or twice before that date (I_2, I_3, I_6 and I_7).

At harvest (105 DAS), treatments I_1 (normal irrigation at 10 days interval) and I_5 (missing one irrigation at milk-ripe, 80 DAS) produced significantly taller plants than the other treatments. Treatments with missing two consecutive irrigations at jointing stages (40 and 50 DAS - I_7) and at CRI and tillering (20 and 30 DAS - I_6), being at par produced the shortest plants. The effects of other treatments were between these two extremes. Among these treatments, those having irrigation missed at later stages, viz at heading and flowering (60 and 70 DAS - I_8) and at heading (60 DAS - I_4) produced taller plants than when irrigation was missed at early jointing (40 DAS - I_3). Missing irrigation at CRI (20 DAS - I_2) was at par with I_3, I_4 and I_8.

The effect of seed rate on plant height was only significant at the booting stage (60 DAS) when the highest

seed rate (150 kg ha^{-1}) produced shorter plants than the other two rates (75 and 100 kg ha^{-1}), both of which were at par.

There was significant interaction between irrigation and seed rate at late jointing (Table 4:3), booting (Table 4:4) and at harvest (Table 4:5), but with no definite trend.

iii) Number of tillers per plant

The data showing the number of tillers per plant as influenced by irrigation and seed rate at different stages of growth (40, 50 and 60 DAS) are presented in Table 4:6.

At early jointing (40DAS), missing one irrigation at CRI (20 DAS - I_2), and missing two consecutive irrigations at CRI and tillering stages (20 and 30 DAS - I_6) significantly reduced the number of tillers per plant, with I_6 being the most consequential on this parameter. The other six treatments, where irrigation was not missed before taking that observation, produced more tillers than treatments I_2 and I_3; however there were no significant differences among these six treatments.

At late jointing stage (50 DAS), all the treatments without missing any irrigation before the 50th day after sowing (I_1, I_4, I_5 and I_8) were at par and produced

Table 4:3 The interaction of moisture stress at different growth stages and seed rate on plant height of wheat at late jointing (50 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	33.44ab	29.92def	33.92a
I_2 - Missing irrigation at CRI	30.80cde	28.75efg	32.80abc
I_3 - Missing irrigation at early jointing	24.46i	27.56fgh	28.84efg
I_4 - Missing irrigation at heading	30.18bcd	33.40ab	31.00bcd
I_5 - Missing irrigation at milk-ripe	32.30abc	30.79cde	30.76cde
I_6 - Missing irrigations at CRI & tillering	27.02gh	28.60fg	25.80hi
I_7 - Missing two irrigations at jointing	28.82efg	28.86efg	27.24gh
I_8 - Missing irrigations at heading & flowering	30.50cde	30.53cde	32.50abc

SE ± 0.72

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter (s) within a treatment group are significantly different at the 5 per cent level.

Table 4:4 The interaction of moisture stress at different growth stages and seed rate on plant height of wheat at booting (60 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	43.38 b	39.81efg	41.76c
I_2 - Missing irrigation at CRI	34.93k	37.02i	35.30k
I_3 - Missing irrigation at early jointing	35.53jk	33.401m	32.81m
I_4 - Missing irrigation at heading	40.62de	44.98a	36.33ij
I_5 - Missing irrigation at milk-ripe	41.54cd	39.03gh	38.27h
I_6 - Missing irrigations at CRI & tillering	34.84k	35.13k	29.78efg
I_7 - Missing two irrigations at jointing	33.78L	36.41ij	33.77L
I_8 - Missing irrigations at heading and flowering	40.32ef	39.48fg	43.46b

SE ± 0.28

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:5 The interaction of moisture stress at different growth stages and seed rate on plant height of wheat at harvest (105 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	71.25cdef	77.97a	71.49cde
I_2 - Missing irrigation at CRI	68.49fg	65.08	71.92cde
I_3 - Missing irrigation at early jointing	65.51h	65.11h	71.07cdef
I_4 - Missing irrigation at heading	69.08efg	72.94bc	66.29gh
I_5 - Missing irrigation at milk-ripe	73.90bc	75.16ab	71.19cdef
I_6 - Missing irrigations at CRI & tillering	60.06i	59.88i	59.84i
I_7 - Missing two irrigations at jointing	61.73i	55.84j	61.53i
I_8 - Missing irrigations at heading & flowering	71.68cde	68.41fg	70.25def

SE $\pm$ 0.83

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:6 Effect of moisture stress at different growth stages under various seed rates on tiller number per plant of wheat at Samaru, 1981/82.

Treatments	40 DAS	50 DAS	60 DAS
Irrigation			
I_1 - Control (Irrigating at every 10 days)	4.44	5.22	4.87
I_2 - Missing irrigation at CRI	3.79	4.12	3.87
I_3 - Missing irrigation at early jointing	4.30	4.35	4.02
I_4 - Missing irrigation at heading	4.35	5.12	4.88
I_5 - Missing irrigation at milk-ripe	4.56	5.38	4.73
I_6 - Missing irrigations at CRI & tillering	2.83	3.33	3.48
I_7 - Missing two irrigations at jointing	4.38	4.33	3.87
I_8 - Missing irrigations at heading & flowering	4.37	5.13	4.68
SE(±)	0.18	0.19	0.11
LSD(0.05)	0.52	0.56	0.33
Seed rate (kg ha^{-1})			
S_1 - 75	3.70	5.03	4.50
S_2 - 100	4.02	4.60	4.42
S_3 - 150	4.55	4.23	3.98
SE(±)	0.06	0.07	0.06
LSD(0.05)	0.18	0.19	0.17
Interaction			
I x S	SIG.	SIG.	SIG.

DAS - Days after sowing, CRI - Crown root initiation, SIG - Significant.

significantly more tillers per plant than I_3 (missing one irrigation at early jointing), I_2 (missing one at CRI) and I_7 (missing two at jointing) which were identical in their effects. Missing two consecutive irrigations at CRI and tillering stages (I_6) gave fewest tillers per plant.

At booting stage (60 DAS) the different irrigation treatments followed the same trend as at the late jointing stage.

A study of tillering at the three different stages (Table 4:6) has clearly shown that the number of tillers per plant increased from early jointing to late jointing and then declined at the booting stage with the exception of treatment I_6.

With respect to seed rates, at late jointing and booting stages, the highest and lowest seed rates produced significantly the lowest and highest number of tillers per plant, respectively. At early jointing the trend was reversed.

Significant irrigation x seed rate interactions were observed at all the vegetative stages. At early jointing (Table 4:7), in treatments where irrigation was missed before that stage i.e. I_2 and I_6, there was no significant differences with different seed rates. On the other hand, in treatments where irrigation was not missed (except I_5),

Table 4:7 The interaction of moisture stress at different growth stages and seed rate on tiller number per plant of wheat at early jointing (40 DAS) at Samaru, 1981/82

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	3.87de	4.25bcd	5.19a
I_2 - Missing irrigation at CRI	3.74de	3.70e	3.02e
I_3 - Missing irrigation at early jointing	3.79de	4.12cde	5.00a
I_4 - Missing irrigation at heading	3.87de	4.08cde	5.10a
I_5 - Missing irrigation at milk-ripe	4.25bcde	4.59abc	4.85ab
I_6 - Missing irrigations at CRI & tillering	2.55f	2.89f	3.06f
I_7 - Missing two irrigations at jointing	3.65e	4.36bcd	5.17a
I_8 - Missing irrigations at heading and flowering	3.91de	4.17cde	5.02a

SE $\pm$ 0.18

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

the highest seed rate produced highest number of tillers per plant, and there was no significant difference between the two lower seed rates. At late jointing stage (Table 4:8) among the treatments where irrigation was missed once or twice before this observation was taken there was no effect of seed rate on number of tillers per plant in the case of I_6. In I_3 and I_2, the lowest seed rate produced the most and the fewest tillers, respectively, whereas the highest seed rate produced the fewest tillers in I_3 and I_7. Among the treatments where irrigation was not missed, the lowest seed rate produced the most tillers per plant in three treatments (I_1, I_4 and I_8) and in I_5, though the trend was the same but not significant. Almost the same trend was observed at booting stage (Table 4:9) as at late jointing stage.

iv) Leaf area per plant

The effects of irrigation and seed rate on leaf area per plant at different stages of growth (40, 50 and 60 DAS) are presented in Table 4:10.

At the early jointing stage (40 DAS) treatments I_2, with one missing irrigation at 20 DAS and I_6, with missing two consecutive irrigations at 20 and 30 DAS, produced significantly smaller leaf area than the other six treatments, in which irrigation was not missed. Treatments I_2 and I_6 differed significantly, I_6 producing smaller leaf areas.

Table 4:8 The interaction of moisture stress at different growth stages and seed rate on tiller number per plant of wheat at late jointing (50 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	6.10a	5.00def	4.55efg
I_2 - Missing irrigation at CRI	3.55h	4.40fg	4.40fg
I_3 - Missing irrigation at early jointing	5.20cde	4.30g	3.55h
I_4 - Missing irrigation at heading	6.00ab	4.80defg	4.55efg
I_5 - Missing irrigation at milk-ripe	5.70abc	5.40bcd	5.05def
I_6 - Missing irrigations at CRI & tillering	3.00h	3.40h	3.60h
I_7 - Missing two irrigations at jointing	4.80defg	4.60efg	3.50h
I_8 - Missing irrigations at heading & flowering	5.90ab	4.90defg	4.60efg

SE $\pm$ 0.20

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:9 The interaction of moisture stress at different growth stages and seed rate on tiller number per plant of wheat at booting (60 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	5.5ra	4.85bcd	4.20efg
I_2 - Missing irrigation at CRI	3.48h	4.13efg	4.00fgh
I_3 - Missing irrigation at early jointing	4.00fgh	4.21efg	3.85gh
I_4 - Missing irrigation at heading	5.20abc	4.95bcd	4.50def
I_5 - Missing irrigation at milk-ripe	5.30ab	4.70cde	4.20efg
I_6 - Missing irrigations at CRI & tillering	3.25i	3.63gh	3.55h
I_7 - Missing two irrigations at jointing	4.00fgh	4.05fgh	3.55h
I_8 - Missing irrigations at heading & flowering	5.25abc	4.80bcd	4.00fgh

SE ± 0.17

CRI - Crown root initiation; S_1, S_2, and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:10 Effect of moisture stress at different growth stages under various seed rates on leaf area per plant (cm^2) of wheat at Samaru, 1981/82.

Treatments	40 DAS	50 DAS	60 DAS
Irrigation			
I_1 - Control (Irrigating at every 10 days)	178.43	233.22	254.00
I_2 - Missing irrigation at CRI	130.93	151.80	164.80
I_3 - Missing irrigation at early jointing	190.69	164.23	190.00
I_4 - Missing irrigation at heading	179.31	206.14	197.80
I_5 - Missing irrigation at milk-ripe	198.23	216.90	203.50
I_6 - Missing irrigations at CRI & tillering	83.59	104.76	157.20
I_7 - Missing two irrigations at jointing	185.04	164.13	175.60
I_8 - Missing irrigations at heading & flowering	178.17	200.67	215.10
SE(±)	8.11	6.00	8.00
LSD(0.05)	23.80	17.75	23.61
Seed rate (kg ha^{-1})			
S_1 - 75	163.40	167.83	175.20
S_2 - 100	181.80	201.45	208.90
S_3 - 150	151.33	152.20	200.20
SE(±)	3.21	2.44	3.68
LSD(0.05)	8.90	6.77	10.20
Interaction			
I x S	SIG.	SIG.	SIG.

DAS - Days after sowing, CRI - Crown root initiation, SIG. - Significant.

At the time of measuring leaf areas at the late jointing stage (50 DAS) irrigation had been missed in four treatments, namely I_2, I_3, I_6 and I_7. These treatments produced leaves smaller than the other four treatments (I_1, I_4, I_5 and I_8) in which irrigation was not missed. Among the missing irrigation treatments, two consecutive irrigations were missed in I_6, which produced the smallest leaf areas. The remaining three treatments, though with smaller effects, were superior to I_6 but inferior to all those treatments (I_1, I_4, I_5 and I_8) in which irrigation had not been missed.

The performances of all the eight irrigation treatments at the booting stage (60 DAS) were similar to those at the late jointing.

Significant differences were observed among the three seed rates (Table 4:10). At early and late jointing stages the medium seed rate of 100 kg ha^{-1} produced the largest leaf areas, followed by the lowest seed rate of 75 kg ha^{-1} and then the highest seed rate of 150 kg ha^{-1}. At booting stage the medium and highest seed rates had identical effects, producing larger leaf area than the lowest seed rate.

Significant interactions were observed at all the stages of vegetative sampling. At early jointing (Table 4:11), there were no significant differences among the seed rates for the treatments with missing irrigations

Table 4:11 The interaction of moisture stress at different growth stages and seed rate on leaf area per plant (cm^2) of wheat at early jointing (40 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	184.60abcde	199.58abcd	151.12fg
I_2 - Missing irrigation at CRI	134.30g	130.99g	127.50gh
I_3 - Missing irrigation at early jointing	179.00bcdef	215.66a	176.40cdef
I_4 - Missing irrigation at heading	174.46cdef	194.65abcd	168.81def
I_5 - Missing irrigation at milk-ripe	199.92abcd	209.31ab	185.47abcde
I_6 - Missing irrigations at CRI & tillering	67.90j	101.22hi	81.65ij
I_7 - Missing two irrigations at jointing	190.00abcde	198.52abcd	166.60ef
I_8 - Missing irrigations at heading & flowering	176.93cdef	204.49abc	153.09fg

SE ± 9.08

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

(I_2 and I_6). On the other hand, in the treatments where irrigation was not missed, the highest seed rate generally produced the lowest leaf area per plant but the two lower seed rates produced similar leaf areas. At late jointing the medium seed rate in treatments where irrigation was not missed (I_1, I_4, I_5 and I_8) produced a larger leaf area than the higher and lower seed rates (Table 4:12). When irrigation was missed at 40 DAS (I_3 and I_7) the lowest seed rate produced the smallest leaf area. When one irrigation was missed at 20 DAS (I_2) the different seed rates did not differ in their leaf area values, but when two consecutive irrigations were missed at 20 and 30 DAS (I_6) the lowest and highest seed rates produced smaller leaf areas than the medium seed rate. At booting stage in all the treatments where irrigation was not missed by that time (I_1, I_4, I_5 and I_8), the medium seed rate of 100 kg ha^{-1} was found to produced greater leaf area than did the two other seed rates (Table 4:13). In treatments with missing irrigation (I_2, I_3, I_6 and I_7), however, the different seed rates differed significantly in their leaf area values, but without a definite trend.

v) Leaf area index (LAI)

The data on leaf area index (LAI) of wheat as affected by irrigation and seed rates at different stages of growth are presented in Table 4:14.

Table 4:12 The interaction of moisture stress at different growth stages and seed rate on leaf area per plant (cm^2) of wheat at late jointing (50 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	235.20abc	246.25a	218.20bcde
I_2 - Missing irrigation at CRI	158.00jk	154.oojk	143.30k
I_3 - Missing irrigation at early jointing	136.60k	179.00ghi	177.10ghij
I_4 - Missing irrigation at heading	208.15def	240.58ab	169.70nij
I_5 - Missing irrigation at milk-ripe	214.60cde	234.80abc	201.30ef
I_6 - Missing irrigations at CRI & tillering	79.88L	137.90	96.50L
I_7 - Missing two irrigations at jointing	135.80K	190.00fgh	166.60hij
I_8 - Missing irrigations at heading & flowering	174.46hij	229.00abcd	198.60efg

SE ± 6.91

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:13 The interaction of moisture stress at different growth stages and seed rate on leaf area per plant (cm^2) of wheat at booting (60 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	199.25bcdef	270.72a	254.00a
I_2 - Missing irrigation at CRI	163.56fg	159.02g	171.74fg
I_3 - Missing irrigation at early jointing	163.93fg	218.73bcd	187.34cdefg
I_4 - Missing irrigation at heading	185.21defg	225.17b	187.11efg
I_5 - Missing irrigation at milk-ripe	194.23bcdef	203.35bcde	213.03bcd
I_6 - Missing irrigations at CRI & tillering	135.72h	170.62efg	165.34fg
I_7 - Missing two irrigations at jointing	161.90g	198.33bcdef	166.44fg
I_8 - Missing irrigations at heading & flowering	198.03bcdef	224.99b	222.33bc

SE $\pm$ 10.40

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:14 Effect of moisture stress at different growth stages under various seed rates on leaf area index (LAI) of wheat at Samaru, 1981/82.

Treatments	40 DAS	50 DAS	60 DAS
Irrigation			
I_1 - Control (Irrigating at every 10 days)	4.16	5.67	6.05
I_2 - Missing irrigation at CRI	3.36	3.90	4.73
I_3 - Missing irrigation at early jointing	4.17	4.39	4.94
I_4 - Missing irrigation at heading	4.22	5.01	5.56
I_5 - Missing irrigation at milk-ripe	4.14	4.96	5.79
I_6 - Missing irrigations at CRI & tillering	2.33	2.74	3.77
I_7 - Missing two irrigations at jointing	4.21	4.75	4.56
I_8 - Missing irrigations at heading & flowering	4.24	5.32	5.51
SE(±)	0.11	0.11	0.09
LSD(0.05)	0.33	0.34	0.26
Seed rate (kg ha^{-1})			
S_1 - 75	2.71	3.47	3.82
S_2 - 100	4.23	5.25	5.38
S_3 - 150	4.62	5.54	6.14
SE(±)	0.04	0.04	0.05
LSD(0.05)	0.11	0.12	0.15
Interaction			
I x S	SIG.	SIG.	SIG.

DAS - Days after sowing, CRI - Crown root initiation, SIG - Significant.

At early jointing (40 DAS) by missing one irrigation at CRI (I_2) and two consecutive irrigations at CRI and tillering stages (I_6), LAI was significantly reduced, with treatment I_6 being the most affected. The other six treatments, in which irrigation was not missed before taking that observation, gave higher values of LAI but with no significant differences.

It is evident that at the late jointing stage (50 DAS) all the treatments in which irrigation was not missed (I_1, I_4, I_5 and I_8) and that at which it was missed on 40 DAS (I_7) were found not to differ from one to the other and gave higher LAI values than those treatments in which one irrigation was missed at early jointing (I_3) or at CRI (I_2) and two consecutive irrigations at CRI and tillering stages (I_6).

At booting stage (60 DAS) all the treatments in which irrigation had not been missed by 60 DAS (I_1, I_4, I_5 and I_8) produced higher LAI than those treatments in which irrigation was missed (I_2, I_3, I_6 and I_7). Among the latter set of treatments, I_6 produced significantly the lowest LAI.

Seed rates had significant positive effect on LAI at all the three stages in the vegetative growth phase. There occurred significant increases in LAI with increasing seed rate at all the stages.

There were significant irrigation x seed rate interactions at all the stages of vegetative sampling. At the early jointing (Table 4:15) the two higher seed rates produced higher LAI than the lowest seed rate in those treatment in which irrigation had not been missed at the time of early jointing (I_1, I_3, I_4, I_5, I_7 and I_8). The other two treatments, with missing irrigation (I_2 and I_6), resulted in significant increase in LAI with increasing seed rate. At the late jointing stage the effects of different seed rates under similar irrigation treatments showed no particular trend (Table 4:16). At the booting stage a significant interaction was observed, the higher seed rates producing higher LAI values (Table 4:17).

vi) Dry matter production

The effects of irrigation and seed rates on dry matter production sampled at different stages of growth are presented in Table 4:18.

At early jointing (40 DAS) missing one irrigation at CRI (I_2) and two consecutive irrigations at CRI and tillering (I_6) produced less dry matter than did the other irrigation treatments, in which no irrigation had been missed at that time. Treatments I_6 produced a significantly lower dry matter than I_2.

At late jointing stage (50 DAS) missing two consecutive

Table 4:15 The interaction of moisture stress at different growth stages and seed rate on leaf area index (LAI) of wheat at early jointing (40 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	2.81ef	4.81ab	4.85ab
I_2 - Missing irrigation at CRI	2.65fg	3.15de	4.28c
I_3 - Missing irrigation at early jointing	2.91ef	4.70ab	4.90ab
I_4 - Missing irrigation at heading	3.15ef	4.68ab	4.82ab
I_5 - Missing irrigation at milk-ripe	3.01def	4.61bc	4.80ab
I_6 - Missing irrigations at CRI & tillering	1.32g	2.37e	3.31d
I_7 - Missing two irrigations at jointing	2.95def	4.69ab	5.00ab
I_8 - Missing irrigations at heading & flowering	2.85ef	4.83ab	5.03a

SE $\pm$ 0.12

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:16 The interaction of moisture stress at different growth stages and seed rate on leaf area index (LAI) of wheat at late jointing (50 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	4.31h	5.42cdef	7.28a
I_2 - Missing irrigation at CRI	3.13kl	3.71j	5.04fg
I_3 - Missing irrigation at early jointing	3.22k	4.86g	5.10fg
I_4 - Missing irrigation at heading	3.10kl	5.15fg	6.77bc
I_5 - Missing irrigation at milk-ripe	4.21hi	5.44cde	5.24defg
I_6 - Missing irrigations at CRI & tillering	1.55m	3.89ij	2.79l
I_7 - Missing two irrigations at jointing	4.00hij	5.38cdef	4.86g
I_8 - Missing irrigations at heading & flowering	3.30k	7.01ab	5.66bc

SE $\pm$ 0.13

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:17 The interaction of moisture stress at different growth stages and seed rate on leaf area index (LAI) of wheat at booting (60 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	4.41kl	6.31cd	7.42a
I_2 - Missing irrigation at CRI	3.79m	4.75ij	5.66fg
I_3 - Missing irrigation at early jointing	3.921m	4.95ij	5.94def
I_4 - Missing irrigation at heading	4.71ijk	5.73efg	6.25cde
I_5 - Missing irrigation at milk-ripe	3.88m	6.54bc	6.94ab
I_6 - Missing irrigations at CRI & tillering	2.59N	4.25m	4.48jk
I_7 - Missing two irrigations at jointing	3.45m	5.02hi	5.22ghi
I_8 - Missing irrigations at heading & flowering	3.83m	5.49fgh	7.21a

SE ± 0.16

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:18 Effect of moisture stress at different growth stages under various seed rates on dry matter production (g m^{-2}) of wheat at Samaru, 1981/82.

Treatments	40 DAS	50 DAS	60 DAS
Irrigation			
I_1 - Control (Irrigating at every 10 days)	202.68	415.07	537.16
I_2 - Missing irrigation at CRI	140.03	395.44	413.00
I_3 - Missing irrigation at early jointing	192.86	383.97	484.01
I_4 - Missing irrigation at heading	185.00	435.44	534.63
I_5 - Missing irrigation at milk-ripe	208.31	417.09	530.43
I_6 - Missing irrigations at CRI & tillering	117.52	196.53	301.83
I_7 - Missing two irrigations at jointing	217.54	474.53	547.41
I_8 - Missing irrigations at heading & flowering	188.77	438.98	659.60
SE(±)	3.59	7.29	9.67
LSD(0.05)	10.55	21.43	28.44
Seed rate (kg ha^{-1})			
S_1 - 75	136.05	319.50	403.81
S_2 - 100	196.88	403.86	509.18
S_3 - 150	212.77	460.52	590.07
SE(±)	2.06	4.03	5.11
LSD(0.05)	5.71	11.20	14.21
Interaction			
I x S	SIG.	SIG.	N.S.

DAS - Days after sowing, CRI - Crown root initiation, SIG - Significant, N.S.- Not Significant.

irrigations at jointing (I_7) and at CRI and tillering stages (I_6) produced the most and lowest dry matter, respectively. The relative effects of other treatments were between these extremes.

At booting stage (60 DAS) all the treatments in which irrigation was not missed (I_1, I_4, I_5 and I_8) produced more dry matter than treatments in which irrigation was missed, with the exception of treatment I_7. Among the first set of treatments, those in which no irrigation was missed, treatment I_8 produced the most dry matter. Among the treatments in which irrigation was missed, missing one at early jointing (I_3) produced significantly more dry matter than missing one irrigation at (CRI (I_2), which in turn produced significantly more than the treatment with missing two consecutive irrigations at CRI and tillering stages (I_6).

At all the three samplings during the vegetative growth phase, there was significant increase in dry matter production with increasing seed rate (Table 4:18).

Significant interactions were observed at all the samplings during vegetative phase. At early jointing, the two higher seed rates gave more dry matter than the lowest seed rate in those treatments in which irrigation was not missed (I_1, I_4, I_5, I_7 and I_8; except I_3) (Table 4:19). The remaining two treatments (I_2 and I_6), with missing irrigation, showed significant increase in dry matter with increasing seed rate. At late jointing stage the

Table 4:19 The interaction of moisture stress at different growth stages and seed rate on dry matter production (g m^{-2}) of wheat at early jointing (40 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	143.19j	232.33cd	233.12cd
I_2 - Missing irrigation at CRI	113.91l	166.33hi	139.85jk
I_3 - Missing irrigation at early jointing	189.52fg	173.86gh	215.21de
I_4 - Missing irrigation at heading	121.16kl	226.05cde	207.82ef
I_5 - Missing irrigation at milk-ripe	134.23jk	244.68bc	252.91ab
I_6 - Missing irrigations at CRI & tillering	81.35m	147.59ij	123.62kl
I_7 - Missing two irrigations at jointing	173.51gh	211.89e	267.22a
I_8 - Missing irrigations at heading & flowering	131.56jkl	172.32gh	262.42ab

SE $\pm$ 5.82

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

treatments in which no irrigation was missed (I_1, I_4, I_5 and I_8) produced more dry matter as seed rate was increased from 75 to 150 kg ha^{-1} (Table 4.20). A similar effect was observed for treatment I_2. In the remaining treatments (I_3, I_6 and I_7), significant interactions were observed for dry matter production.

vii) Flag leaf area

The influence of irrigation and seed rates on the flag leaf area of wheat is shown in Table 4:21. The treatments in which irrigation was not missed during the vegetative growth phase, that is up 60 DAS (I_1, I_4, I_5 and I_8) produced larger flag leaves than those of treatments in which irrigation was missed, I_3, I_6 and I_7 with exception of I_2. Flag leaf area was significantly increased as seed rate was increased. No significant irrigation x seed rate interaction was observed for flag leaf area.

B. THE EFFECT OF IRRIGATION AND SEED RATES ON YIELD COMPONENTS AND YIELD OF WHEAT

i) Number of spikes per square meter

The effect of irrigation and seed rate on the number of spikes m^{-2} is shown in Table 4:22.

The normal irrigation (I_1) produced about the same spike number as in treatments I_4, I_5 and I_8, in which

Table 4:20 The interaction of moisture stress at different growth stages and seed rate on dry matter production (g m^{-2}) of wheat at late jointing (50 DAS) at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	321.24f	427.34e	496.44b
I_2 - Missing irrigation at CRI	267.88g	396.72cd	521.71ab
I_3 - Missing irrigation at early jointing	380.48de	421.89c	349.55ef
I_4 - Missing irrigation at heading	354.69ef	412.84cd	538.80a
I_5 - Missing irrigation at milk-ripe	343.16ef	398.22cd	509.89ab
I_6 - Missing irrigations at CRI & tillering	130.58i	253.02g	206.00h
I_7 - Missing two irrigations at jointing	412.63cd	491.49b	519.48ab
I_8 - Missing irrigations at heading & flowering	345.30ef	429.39c	542.26a

SE ± 11.39

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1} respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Table 4:21 *Effect of moisture stress at different growth stages under various seed rates on flag leaf area (cm^2) of wheat at Samaru, 1981/82.*

Treatments	Flag leaf area (cm^2)
Irrigation	
I_1 - Control (Irrigating at every 10 days)	15.63
I_2 - Missing irrigation at CRI	13.99
I_3 - Missing irrigation at early jointing	10.01
I_4 - Missing irrigation at heading	15.26
I_5 - Missing irrigation at milk-ripe	15.15
I_6 - Missing irrigation at CRI & tillering	10.05
I_7 - Missing two irrigations at jointing	11.24
I_8 - Missing irrigations at heading & flowering	16.95
SE ($\pm$)	0.47
LSD (0.05)	1.39
Seed rate (Kg ha^{-1})	
S_1 - 75	13.16
S_2 - 100	13.48
S_3 - 150	13.97
SE ($\pm$)	0.10
LSD (0.05)	0.29
Interaction	
I x S	N.S

CRI - Crown root initiation.

N.S - Not significant.

Table 4:22 Effect of moisture stress at different growth stages under various seed rates on number of spikes m^{-2} of wheat at Samaru, 1981/82.

Treatments	Spike number m^{-2}
Irrigation	
I_1 - Control (Irrigating at every 10 days)	224.75
I_2 - Missing irrigation at CRI	190.98
I_3 - Missing irrigation at early jointing	173.81
I_4 - Missing irrigation at heading	212.60
I_5 - Missing irrigation at milk-ripe	206.52
I_6 - Missing irrigations at CRI & tillering	168.98
I_7 - Missing two irrigations at jointing	166.79
I_8 - Missing irrigations at heading & flowering	209.06
SE ($\pm$)	6.80
LSD (0.05)	20.09
Seed rate (kg ha^{-1})	
S_1 - 75	194.59
S_2 - 100	192.94
S_3 - 150	195.04
SE ($\pm$)	3.42
LSD (0.50)	N.S
Interaction	
I x S	N.S

CRI - Crown root initiation

N.S - Not significant

irrigation was not missed up to heading, producing more spikes m^{-2} than those treatments in which irrigation was missed before heading (I_2, I_3, I_6 and I_7). It was observed that missing one irrigation (I_2 and I_3) produced more spikes m^{-2} than missing two irrigations at jointing (I_7), which was at par with I_6 (missing two irrigations at CRI and tillering).

There was no significant effect of seed rate and interactions on this character.

ii) Spike length

The data on the length of spike as influenced by irrigation and seed rate are presented in Table 4:23.

From the table it is evident that missing irrigation at any stage after CRI up to heading (I_3, I_6 and I_7) significantly reduced the spike length. Among such treatments that in which one irrigation was missed (I_3) produced longer spikes than treatments with two missing irrigations (I_6 and I_7). Treatment I_6, in which two irrigation were missed at earlier stage (20 and 30 DAS) produced longer spikes than I_7, in which two irrigations were missed at later stages (40 and 50 DAS). There were no significant differences among the remaining treatments (I_1, I_2, I_4, I_5 and I_8), which produced significantly longer spikes than I_3.

Table 4:23 Effect of moisture stress at different growth stages under various seed rates on length of spike (cm) of wheat at Samaru, 1981/82.

Treatments	Spike Length (cm)
Irrigation	
I_1 - Control (Irrigating at every 10 days)	8.12
I_2 - Missing irrigation at CRI	7.79
I_3 - Missing irrigation at early jointing	7.48
I_4 - Missing irrigation at heading	7.88
I_5 - Missing irrigation at milk-ripe	7.94
I_6 - Missing irrigations at CRI & tillering	7.12
I_7 - Missing two irrigations at jointing	6.57
I_8 - Missing irrigations at heading & flowering	8.03
SE ($\pm$)	0.09
LSD (0.05)	0.27
Seed rate (kg ha^{-1})	
S_1 - 75	7.48
S_2 - 100	7.74
S_3 - 150	7.62
SE ($\pm$)	0.046
LSD (0.05)	0.130
Interaction	
I x S	N.S

CRI - Crown root initiation

N.S - Not significant

There was neither a significant effect of seed rate on this character nor a significant irrigation X seed rate interaction.

iii) Number of fertile spikelets per spike

The data on number of fertile spikelets per spike at harvest as influenced by irrigation and seed rate are presented in Table 4:24.

The control treatment (I_1), in which no irrigation was missed and treatment I_5, in which one irrigation was missed at milk-ripe stage being at par, gave the highest number of fertile spikelets per spike. Treatments in which one irrigation was missed at early jointing (I_3) and at heading (I_4), and two irrigations at heading and flowering (I_8) being at par were next in the order. Treatments in which one irrigation was missed at CRI (I_2), two consecutive irrigations at jointing (I_7) and at CRI and tillering (I_6) significantly reduced the number of fertile spikelets per spike in decreasing order.

The main effect of seed rate was significant and the medium and lowest seed rates produced the most and fewest fertile spikelets per spike, respectively.

Significant interaction was observed (Table 4:25). In treatments I_3 and I_6, the number of fertile spikelets per spike was increased with increasing seed rate. In

Table 4:24 Effect of moisture stress at different growth stages under various seed rates on the number of fertile spikelets per spike of wheat at Samaru, 1981/82.

Treatments	Fertile Spikelets
Irrigation	
I_1 - Control (Irrigating at every 10 days)	13.85
I_2 - Missing irrigation at CRI	12.12
I_3 - Missing irrigation at early jointing	12.98
I_4 - Missing irrigation at heading	13.37
I_5 - Missing irrigation at milk-ripe	13.83
I_6 - Missing irrigations at CRI & tillering	10.21
I_7 - Missing two irrigations at jointing	11.48
I_8 - Missing irrigations at heading & flowering	13.33
SE ($\pm$)	0.15
LSD (0.05)	0.43
Seed rate (Kg ha^{-1})	
S_1 - 75	12.28
S_2 - 100	13.00
S_3 - 150	12.65
SE ($\pm$)	0.07
LSD (0.05)	0.20
Interaction	
I x S	SIG

CRI - Crown root initiation

SIG - Significant.

Table 4:25 The interaction of moisture stress at different growth stages and seed rate on the number of fertile spikelets per spike of wheat at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	14.15ab	13.86abcd	13.53bcdef
I_2 - Missing irrigation at CRI	11.33j	12.90fg	12.12hi
I_3 - Missing irrigation at early jointing	11.98i	12.70gh	14.25a
I_4 - Missing irrigation at heading	13.18efg	13.85abcd	13.09efg
I_5 - Missing irrigation at milk-ripe	14.33a	13.70abcde	13.48cdef
I_6 - Missing irrigations at CRI & tillering	9.33m	10.051	11.25jk
I_7 - Missing two irrigations at jointing	10.75jk	12.98fg	10.72k
I_8 - Missing irrigations at heading & flowering	13.23defg	14.00abc	12.75g

SE $\pm$ 0.19

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1}, respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

treatments I_4, I_7 and I_8, the lowest and the highest seed rates, being at par, produced fewer fertile spikelets than the medium seed rate. The medium seed rate was also found to be better than the other two rates in I_2. In treatments I_1 and I_5 no significant interactions were observed.

iv) Sterile Spikelets per Spike

The data on number of sterile spikelets per spike as affected by irrigation and seed rate are presented in Table 4:26.

The highest number of sterile spikelets per spike was obtained when two consecutive irrigations were missed at heading and flowering (I_8), followed by treatment I_3, in which one irrigation was missed at early jointing. On the other hand, the fewest sterile spikelets per spike occurred in the treatment in which two consecutive irrigations were missed at CRI and tillering (I_6), followed by the treatment having only one irrigation missed at CRI (I_2). The effects of the remaining treatments (I_1, I_4, I_5 and I_7) were between these two extremes.

The effect of seed rate on this character was significant. The lowest and medium seed rates produced the most and fewest sterile spikelets per spike, respectively.

Significant irrigation x seed rate interaction was also observed (Table 4:27). Increasing seed rate decreased the number of sterile spikelets in I_1 and I_6. In treatment

Table 4:26 Effect of moisture stress at different growth stages under various seed rates on the number of sterile spikelets per spike of wheat at Samaru, 1981/82.

Treatments	Sterile spikelets per spike
Irrigation	
I_1 - Control (Irrigating at every 10 days)	2.192
I_2 - Missing irrigation at CRI	1.600
I_3 - Missing irrigation at early jointing	2.513
I_4 - Missing irrigation at heading	2.242
I_5 - Missing irrigation at milk-ripe	2.300
I_6 - Missing irrigations at CRI & tillering	1.367
I_7 - Missing two irrigations at jointing	2.130
I_8 - Missing irrigations at heading & flowering	3.390
SE ($\pm$)	0.047
LSD (0.05)	0.138
Seed rate (kg ha^{-1})	
S_1 - 75	2.410
S_2 - 100	2.070
S_3 - 150	2.170
SE ($\pm$)	0.0236
LSD (0.05)	0.065
Interaction	
I x S	SIG.

CRI - Crown root initiation.

SIG - Significant.

Table 4:27 The interaction of moisture stress at different growth stages and seed rate on the number of sterile spikelets per spike of wheat at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	2.475def	2.175ghi	1.925jk
I_2 - Missing irrigation at CRI	1.675l	1.325m	1.800kl
I_3 - Missing irrigation at early jointing	2.7000cd	2.575cde	2.263fghi
I_4 - Missing irrigation at heading	2.325fg	2.050ij	2.350efg
I_5 - Missing irrigation at milk-ripe	2.300fgh	2.675cd	1.925jk
I_6 - Missing irrigations at CRI & tillering	1.675l	1.325m	1.00n
I_7 - Missing two irrigations at jointing	2.65cd	1.651	2.09hij
I_8 - Missing irrigations at heading & flowering	3.50b	2.75c	3.93a

SE $\pm$ 0.0667

CRI - Crown root initiation; S_1, S_2 and S_3 = 75, 100 and 150 kg ha^{-1}, respectively.

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

I_3 the trend was similar except that the two lower rates rates were at par. In treatment I_2 and I_4, the lowest and highest seed rates being at par produced more sterile spikelets per spike than the medium seed rate, while in I_7 the lowest and the medium seed rates produced the most and fewest sterile spikelets, respectively. In I_8 the highest and medium seed rates produced the most and fewest sterile spikelets, respectively, whereas in I_5 the medium and highest seed rates produced the most and the fewest sterile spikelets, respectively.

v) Number of grains per spike

The data illustrating the effects of irrigation and seed rate on the number of grains per spike at harvest are shown in Table 4:28.

Normal irrigation (I_1) and missing one irrigation at any stage of plant growth and development (I_2, I_3, I_4 and I_5) produced significantly more grains per spike than with missing two consecutive irrigations (I_6, I_7 and I_8). I_8 was significantly superior to I_6 which was significantly superior to I_7 in producing more grains per spike.

The two higher seed rates produced significantly more grains per spike than the lowest seed rate. There were significant interactions between irrigation and seed rate for number of grains per spike (Table 4:29). In treatment I_1 the lowest seed rate produced more grains per spike.

Table 4:28 Effect of moisture stress at different growth stages under various seed rates on the number of grains per spike of wheat at Samaru, 1981/82.

Treatments	Grains per spike
Irrigation	
I_1 - Control (Irrigating at every 10 days	37.70
I_2 - Missing irrigation at CRI	37.16
I_3 - Missing irrigation at early jointing	36.41
I_4 - Missing irrigation at heading	38.81
I_5 - Missing irrigation at milk-ripe	39.24
I_6 - Missing irrigations at CRI & tillering	30.65
I_7 - Missing two irrigations at jointing	26.72
I_8 - Missing irrigations at heading & flowering	34.98
SE ($\pm$)	0.45
LSD (0.05)	1.31
Seed rate (kg ha^{-1}	
S_1 - 75	34.41
S_2 - 100	35.77
S_3 - 150	35.45
SE ($\pm$)	0.27
LSD (0.05)	0.47
Interaction	
I x S	SIG

CRI - Crown root initiation

SIG - Significant.

Table 4:29 The interaction of moisture stress at different growth stages and seed rate on the number of grains per spike of wheat at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	39.95ab	37.24cde	35.93e
I_2 - Missing irrigation at CRI	38.23bcde	36.41de	36.85de
I_3 - Missing irrigation at early jointing	32.89f	39.81abc	36.53de
I_4 - Missing irrigation at heading	39.93ab	37.85bcde	38.66bcd
I_5 - Missing irrigation at milk-ripe	37.41bcde	38.29bcde	42.01a
I_6 - Missing irrigations at CRI & tillering	30.65fg	29.99g	31.31fg
I_7 - Missing two irrigations at jointing	24.00h	30.40fg	25.75h
I_8 - Missing irrigations at heading & flowering	32.24fg	36.14de	36.55de

SE $\pm$ 0.75

CRI - Crown root initiation

Values followed by unlike letter(s) within a treatment group are significantly different at 5 per cent level.

Missing irrigation from early to late stages influenced the effect of seed rates. There was no significant difference between the three seed rates when irrigation was missed at 20 and 30 DAS (I_2 and I_6). When irrigation was missed from 40 to 50 DAS (I_3 and I_7) the medium seed rate produced more grains than the other two seed rates. With missing two irrigations at late stage i.e. 60 and 70 DAS (I_8) the two higher seed rates produced more grains than the lowest seed rate. Also when one irrigation was missed at a later stage at 80 DAS (I_5) the highest seed rate produced a higher number of grains per spike than the other two rates.

vi) Spike-grain weight

The data on spike-grain weight at ten days interval during the grain filling and at harvest are presented in Table 4:30.

At the early stage of grain development (70 DAS) missing two consecutive irrigations at CRI and tillering (I_6) produced significantly lower spike-grain weight than all other irrigation treatments which were more or less similar. At 80 DAS missing one irrigation at CRI (I_2) joined I_6 in producing the lowest spike-grain weight. Among the other treatments, normal irrigation (I_1) and missing two consecutive irrigations at jointing (I_7) produced heaviest and lightest spike-grain weights,

Table 4:30 Effect of moisture stress at different growth stages under various seed rates on spike-grain weight (gm) of wheat at different growth stages at Samaru, 1981/82.

Treatments	70 DAS	80 DAS	90 DAS	105 DAS
I_1 - Control (Irrigating every 10 days)	0.1157	0.689	1.367	1.330
I_2 - Missing irrigation at CRI	0.0974	0.467	1.1967	1.302
I_3 - Missing irrigation at early jointing	0.1067	0.619	1.185	1.466
I_4 - Missing irrigation at heading	0.1206	0.613	1.3218	1.371
I_5 - Missing irrigation at milk-ripe	0.1069	0.595	1.257	1.387
I_6 - Missing irrigations at CRI & tillering	0.0777	0.442	0.957	1.076
I_7 - Missing two irrigations at jointing	0.1070	0.519	1.007	0.993
I_8 - Missing irrigations at heading & flowering	0.1288	0.614	1.1753	1.352
SE ($\pm$)	0.004	0.0092	0.0253	0.028
LSD (0.05)	0.0117	0.027	0.074	0.082
Seed Rate (kg ha^{-1})				
S_1 - 75	0.1046	0.5534	1.1281	1.182
S_2 - 100	0.1111	0.6004	1.2049	1.369
S_3 - 150	0.1071	0.5556	1.2183	1.302
SE ($\pm$)	0.0024	0.0056	0.0113	0.013
LSD (0.05)	N.S	0.0156	0.0313	0.036
Interaction				
I x S	N.S	N.S	N.S	N.S

DAS - Days after sowing, CRI - Crown root initiation, N.S - Not Significant.

respectively. There were no significant differences among I_3, I_4, I_5 and I_8. At 90 DAS the treatments with missing two consecutive irrigations before heading I_6 and I_7 being at par produced the lightest spike-grains, followed by treatment I_8 with missing two irrigations at heading and flowering. The other irrigation treatments being similar produced heavier spike-grains. Missing two consecutive irrigations at CRI and tillering stages (I_6) or at jointing (I_7) significantly reduced the spike-grain weight at harvest. There was significantly greater reduction in spike-grain weight in I_7 than in I_6. The differences among the remaining irrigation treatments were not significant.

Seed rate effect was significant at 80, 90 and 105 DAS. At 80 DAS the highest and lowest seed rates being at par produced lower spike-grain weight than the medium seed rate. At 90 DAS the two higher seed rates being at par were significantly superior to the lowest seed rate. At 105 DAS (harvest) the medium and lowest seed rates produced the highest and lowest spike-grain weights, respectively.

There was no significant interaction between irrigation and seed rate for this character.

vii) Thousand-grain weight

The effects of irrigation and seed rates on 1000-grain weight recorded at ten days interval during the

grain filling stage and at harvest are presented in Table 4:31.

At the early stage of grain development (70 DAS), treatment I_8 where irrigation was missed at 60 DAS produced significantly lower 1000-grain weight than the other treatments which were more or less statistically similar. At 80 DAS treatment I_7 with missing two consecutive irrigations at 40 and 50 DAS, and treatment I_6 with missing at 20 and 30 DAS produced the highest and lowest 1000-grain weights, respectively. Treatments I_1 and I_5 where irrigation was not missed by that time and I_3 where one irrigation was missed at 40 DAS being statistically similar produced lower 1000-grain weights than I_7. Treatments I_2 and I_4 where irrigation was missed at 20 and 60 DAS, respectively, and I_8 being statistically the same produced lower 1000-grain weights than I_1, I_3 and I_5. At 90 DAS normal irrigation ($_1$) being at par with I_4 (missing one irrigation at heading) produced highest grain weight. Treatments I_3 and I_5 were found to be at par with I_4. Treatments I_2, I_7 and I_8 being at par produced more grain weight than I_6 which produced the lowest weight. At harvest (105 DAS) the highest 1000-grain weight was obtained from treatment I_7, in which two consecutive irrigations were missed at jointing stage; this was followed by treatment I_3, in which only one irrigation was missed at early jointing. Statistically, the effect of I_1 was similar

Table 4:31 Effect of moisture stress at different growth stages under various seed rates on 1000-grain weight (gm) of wheat at different stages at Samaru, 1981/82.

Treatments	70 DAS	80 DAS	90 DAS	105 DAS
Irrigation				
I_1 - Control (Irrigating at every 10 days)	4.77	19.152	35.859	37.99
I_2 - Missing irrigation at CRI	4.21	17.752	32.315	36.88
I_3 - Missing irrigation at early jointing	4.55	18.942	34.032	39.14
I_4 - Missing irrigation at heading	4.46	17.709	34.677	36.25
I_5 - Missing irrigation at milk-ripe	4.81	18.893	33.788	34.50
I_6 - Missing irrigations at CRI & tillering	4.72	15.115	28.530	35.56
I_7 - Missing two irrigations at jointing	4.75	20.681	32.006	40.62
I_8 - Missing irrigations at heading & flowering	3.87	16.972	31.788	33.24
SE ($\pm$)	0.10	0.340	0.44	0.44
LSD (0.05)	0.29	1.010	1.29	1.32
Seed rate (kg ha $^{-1}$)				
S_1 - 75	4.72	18.210	30.709	36.45
S_2 - 100	4.46	17.571	33.185	36.67
S_3 - 150	4.37	18.676	34.734	37.20
SE ($\pm$)	0.05	0.17	0.21	0.23
LSD (0.05)	0.15	0.46	0.57	0.64
Interaction				
I x S	N.S	N.S	N.S	N.S

DAS - Days after sowing, CRI - Crown root initiation, N.S - Not significant.

to that of I_3. Other treatments in which irrigations were missed either before or after jointing produced lighter grains. Either missing one irrigation at milk-ripe (I_5) or two coneecutive irrigations at hoading and flowering (I_8) produced very light grains.

Seed rates were found to influence 1000-grain weight during grain filling and at harvest. An increase in seed rate decreased grain weight at 70 DAS but increased it at 90 DAS. At 80 DAS the highest seed rate produced the heaviest 1000-grains which was followed by lowest seed rate which in turn was followed by the medium seed rate. At harvest (105 DAS) the highest and lowest seed rates produced grains of heavier and lighter weights, respectively. Medium seed rate was at par with both of these.

There was also no significant interaction between irrigation and seed rate for this character.

viii) Grain Yield

The data showing the effect of irrigation and seed rate on wheat grain yield are presented in Table 4:32.

Missing no irrigation (I_1) produced the highest yield. Missing one irrigation (I_2, I_3, I_4 and I_5) produced lower grain yields than I_1, and missing two irrigations (I_6, I_7 and I_8) further reduced grain yields significantly. Among those treatments in which one irrigation was missed, treatment I_4 (missing at 60 DAS)

Table 4:32 Effect of moisture stress at different growth stages under various seed rates on grain yield (kg ha^{-1}) of wheat at Samaru, 1981/82.

Treatments	Grain yield ($Kg\ ha^{-1}$)
Irrigation	
I_1 - Control (Irrigating at every 10 days)	2221.7
I_2 - Missing irrigation at CRI	1927.0
I_3 - Missing irrigation at early jointing	1981.0
I_4 - Missing irrigation at heading	2052.0
I_5 - Missing irrigation at milk-ripe	1990.7
I_6 - Missing irrigations at CRI & tillering	1632.0
I_7 - Missing two irrigations at jointing	769.2
I_8 - Missing irrigations at heading & flowering	1533.0
SE ($\pm$)	38.7
LSD (0.05)	113.9
Seed rate (kg ha^{-1})	
S_1 - 75	1649.8
S_2 - 100	1859.5
S_3 - 150	1788.8
SE ($\pm$)	15.0
LSD (0.05)	41.9
Interaction	
I x S	SIG.

CRI - Crown root initiation

SIG. - Significant.

produced significantly higher yield than I_2 (missing at 20 DAS). Treatments I_5 (missing at 80 DAS) and I_3 (missing at 40 DAS) were found to be at par with treatments I_4 and I_2. Missing two irrigations at jointing (I_7) produced significantly lower yield than the other two treatments, I_6 (missing at 20 and 30 DAS) and I_8 (missing at 60 and 70 DAS), which were at par.

The medium and lowest seed rates produced the highest and lowest grain yield, respectively.

Significant interaction between irrigation and seed rate was observed (Table 4:33). In treatments I_1, I_2 and I_4 the two higher seed rates, though at par, were statistically better in producing grain yields than the lowest seed rate. In treatments I_3 and I_6 the medium seed rate produced the highest grain yields, while in treatments I_5, I_7 and I_8 similar yields were obtained from the three seed rates.

ix) Straw yield

The straw yield data showing the effect of irrigation and seed rate are presented in Table 4.34.

The control treatment (I_1), in which no irrigation was missed, gave the highest straw yield. Treatments in which two consecutive irrigations were missed at CRI and tillering (I_6) and at jointing (I_7), though at par,

Table 4:33 The interaction of moisture stress at different growth stages and seed rate on grain yield (Kg ha^{-1}) of wheat at Samaru, 1981/82.

Irrigation	Seed rates		
	S_1	S_2	S_3
I_1 - Control (Irrigating at every 10 days)	2015.0cdef	2256.0ab	2394.0a
I_2 - Missing irrigation at CRI	1661.0gh	2049.0cde	2072.0cd
I_3 - Missing irrigation at early jointing	1955.0defg	2144.0bc	1844.0g
I_4 - Missing irrigation at heading	1922.0efg	2073.0cd	2161.0bc
I_5 - Missing irrigation at milk-ripe	2018.0cdef	2034.0cdef	1920.0efg
I_6 - Missing irrigations at CRI & tillering	1496.0hij	1896.0fg	1569.0hij
I_7 - Missing two irrigations at jointing	691.0k	815.0k	805.5k
I_8 - Missing irrigations at heading & flowering	1440.0ij	1609.0ji	1549.0hij

SE ($\pm$) 42.7

CRI - Crown root initiation

Values followed by unlike letter(s) within a treatment group are significantly different at the 5 per cent level.

Table 4:34 Effect of moisture stress at different growth stages under various seed rates on straw yield (kg ha^{-1}) of wheat at Samaru, 1981/82.

Treatments	Straw yield ($Kg\ ha^{-1}$)
Irrigation	
I_1 - Control (Irrigating at every 10 days)	5649.0
I_2 - Missing irrigation at CRI	3973.0
I_3 - Missing irrigation at early jointing	3515.0
I_4 - Missing irrigation at heading	4477.0
I_5 - Missing irrigation at milk-ripe	4097.0
I_6 - Missing irrigations at CRI & tillering	2373.0
I_7 - Missing two irrigations at jointing	2394.0
I_8 - Missing irrigations at heading & flowering	4580.0
SE ($\pm$)	136.32
LSD (0.05)	401.00
Seed rate (kg ha^{-1})	
S_1 - 75	3459.0
S_2 - 100	4135.0
S_3 - 150	4053.0
SE ($\pm$)	58.63
LSD (0.05)	162.5
Interaction	
I x S	N.S

CRI - Crown root initiation

N.S - Not significant.

produced the lowest straw yields, followed by the treatment in which one irrigation was missed at early jointing (I_3). The straw yields for other irrigation treatments were found to be in between (I_3) and I_1). Among these were treatments in which two consecutive irrigations were missed at heading and flowering (I_8) and one at heading (I_4) yielded higher than treatments I_5 and I_2, in which one irrigation was missed on 80 and 20 DAS, respectively.

With respect to seed rates, the two higher rates produced higher straw yields than the lowest rate. The most optimum seed rate appears to be about 100 gk ha^{-1}. There was no significant irrigation X seed rate interaction for straw yield.

CHAPTER V

DISCUSSION

A. EFFECT OF IRRIGATION AND SEED RATE ON THE VEGETATIVE GROWTH OF WHEAT

i) Irrigation

Water as a constituent of protoplasm, solvent for nutrients and a reagent, is the most important factor affecting the growth and survival of plants. The effect of moisture stress caused by withholding irrigation at different stages of wheat growth was investigated in this study.

Regular supply of water had increased vegetative growth as measured by height, number of tillers, leaf area per plant and dry matter production.

The vigour of vegetative growth is decided, to a great extent, by the moisture availability. The plant height measured at different periods in vegetative phase and at harvest was influenced favourably by water application. This effect was clear and pronounced during all the sampling periods. It was observed that moisture stress at any growth stage before anthesis (i.e. at CRI, tillering, jointing and heading) reduced plant height considerably. The reduction was more pronounced when two consecutive irrigations were missed before heading (I_6 and I_7).

This is so because these are the stages of active and maximum growth in wheat, normally known as the grand growth period. The results obtained in this study are in conformity with the findings of Singh and Singh (1971/72), Abdel-Gawaad et al. (1979), Ibrahim et al. (1979), Cooper (1980) and Musick and Dusek (1980).

The production of tillers is another important character of vegetative growth as it affects yield. Missing one or two irrigations at CRI and tillering stages adversely affected tiller formation at all the stages of vegetative sampling. This result is in conformity with the findings of EL - Nadi (1969), Singh and Singh (1971/72), Cooper (1980) and Musick and Dusek (1980).

The number of tillers per plant increased from early jointing to late jointing and then decreased by the time the crop reached booting stage. The reduction in the number of tillers per plant at booting stage was due to tiller mortality. This aspect of tiller mortality is very important as about 30 per cent of grain yield might come from tillers (Rawson and Bremner, 1978). It is to be noted here, that the treatment with missing two consecutive irrigations at CRI and tillering stages (I_3) increased the number of tillers per plant even at booting stage. This increase might be due to later production of tillers which indicates that although tillering was earlier suppressed due to moisture stress, water application afterwards stimulate the formation of late tillers.

Imposing moisture stress by withholding irrigation at any stage from CRI to booting stage significantly reduced the growth of wheat as measured by leaf area, leaf area index and dry matter production. Moisture stress had the most adverse effect on these characters when one or two consecutive irrigations were missed at CRI and tillering stages. Plant height and number of tillers per plant determine the number of leaves produced by a plant. Missing one or two consecutive irrigations at CRI and tillering stages had reduced the plant height and number of tillers per plant. These two reductions caused smaller leaf per plant, low leaf area index and consequently smaller dry matter production. During the moisture stress periods, protoplasmic dehydration reduces the physiological activity of the cells, particularly in tissues which require water supply for their development (Salter and Goode, 1967). The findings in this study are also in harmony with those of Panek (1976), Prusty (1976), Ibrahim et al. (1979), Cooper (1980) and Musick and Dusek (1980) who support the view that moisture stress had unfavourable effect on these growth characters.

The last parameter measured during the vegetative phase was the flag leaf area. The role of the flag leaf area in the contribution of assimilates towards the spikes was reported by various workers who only differed in the magnitude of assimilates believed to be contributed.

Archbold's investigations as cited by Rawson and Bremner (1978), conclusively showed that grain filling was overwhelmingly the product of current assimilation (i.e. materials stored before grain setting plays little role). This means that the areas and duration of organs most active in photosynthesis during the grain filling are the flag leaf, the ear and the leaves of the upper part of the stem. The flag leaf contributes the main source of carbohydrate to the grains (Evans et al., 1975 and Rawson and Bremner, 1978). In this study the effect of moisture stress on the flag leaf area was clear. Missing irrigation during the vegetative growth (between tillering and heading) reduced the flag leaf area which might have contributed to the reduction in yield to a certain extent as reported in preceding chapter.

ii) Seed Rate

The number of plants per square meter was significantly increased with increasing seed rate. The finding is in conformity with the general belief that the larger the quantity of seeds sown the more will be the number of plants in earliest stage.

Plant height was significantly affected by different seed rates only at booting stage (Table 4:2), that is, the higher the seed rate, the shorter was the plant. The growth of individual plants is generally governed by the

competition created between plants both in root and shoot development. Increasing the seed rate to 150 kg ha^{-1} might have increased the degree of competition, resulting in shorter plants. Abdul-Galil (1964) and Suput (1966) had reported decrease in plant heights when high seed rates were used.

At late jointing and booting stages the number of tillers per plant was decreased with increase in seed rate. Similar findings have been reported by Abdul-Galil (1964), Chlopecki (1972), Bassiouny (1979) and Ubi (1981).

Increasing the seed rate from 75 kg ha^{-1} to 100 kg ha^{-1} increased the leaf area per plant, but increasing the seed rate beyond this decreased it at both early and late jointing stages. At booting stage the two higher seed rates produced plants with larger leaf areas. The result indicate that the 100 kg ha^{-1} appears to be the optimum seed rate for producing plants with large leaf areas at all the three stages of vegetative sampling (Table 4:10). The maximum leaf area per plant was obtained at booting stage when the flag leaf had fully emerged, as also observed by Evans et al. (1975).

At all the three stages of vegetative sampling the leaf area index (LAI) and dry matter production generally increased with increase in seed rate. The increase in tiller number with low seed rate could not compensate for the fewer number of plants per unit area of land and

consequently the LAI as the ratio between the area of green leaves and land could not be increased. Likewise the increased number of plants under high seed rates could compensate for the decreased leaf area per plant and tiller number resulting in a larger LAI, and higher dry matter accumulated per unit area of land. The medium seed rate lied in between. A minimum leaf area index of four is required for optimum yield in wheat crop (Daphne Lucas and Asana, 1968). This requirement was fulfilled under the conditions of both medium and high seed rates. The findings of this study are in harmony with those of Ibrahim (1972), Foltyn and Skorpik (1974), Ruzha and Adamovich (1976) and Suryanarayana (1979).

The flag leaf area is a function of the vigour of an individual plant. This growth parameter was decreased with increasing seed rate indicating the adverse effect of increasing plant density on growth of the individual wheat plant. Similar findings have been reported by Foltyn and Skorpik (1974), Bassiouny (1979) and Ubi (1981).

iii) Irrigation and seed rate interaction:

From the study of the interaction of irrigation at different stages with varying seed rates at jointing and booting stages, it has been found that a lower seed rate produced lower leaf area per plant, leaf area index and dry matter accumulation. This observation can be

attributed to the lower number of plants per unit area due to lower seed rate.

B. EFFECT OF IRRIGATION AND SEED RATES ON YIELD COMPONENTS AND YIELD OF WHEAT

i) Irrigation

The number of spikes per square meter is a function of tillers and this determines the quantity of grains to be carried, hence the yield. This character was not affected significantly by moisture stress treatment at any stage from heading to milk-ripe, while moisture stress at early stages of growth, particularly when two consecutive irrigations were withheld at CRI and tillering and jointing stages significantly reduced the number of spikes m^{-2}. A reference to the data on tiller number per plant (Table 4:6) may explain the differences in the number of spikes m^{-2}. Similar results have been reported by many investigators, including Storrier (1965), Talha (1966), EL-Nadi (1969), Wilson (1974), Panek (1976), Abdel-Motaleb (1978), Ibrahim et al. (1979) and Cooper (1980).

Spike length indicates the number of grains which may lodge there, and possibly grain size as well. The length of spike was not affected by moisture stress after heading but was severely reduced with prolonged moisture stress during tillering and jointing stages when spike

initiation was taking place (Table 4:23).

The number of fertile spikelets per spike at harvest (Table 4:24) was not affected by moisture stress at milk-ripe, but significant reduction was observed when moisture stress occurred from CRI to heading. The number of fertile spikelets were more prominently reduced in longer stressed treatments during tillering and jointing. Aspinall et al. (1964) reported that such a reduction could be attributed to the process of spikelet initiation which occurs prior to anthesis. The results obtained in this study were found to be similar with the findings of Day and Intalap (1970), Shrotriya et al.(1970), Hussein et al. (1978) and Musick and Dusek (1980).

The number of sterile spikelets per spike at harvest (Table 4:26) was found to be prominently increased by moisture stress at heading and flowering stages, whereas the lowest numbers of sterile spikelets were obtained by withholding two consecutive irrigations at very early stage of growth (CRI and tillering). The increase caused by moisture stress during heading and flowering could be a consequence of an effect associated with the process of spikelet initiation and formation of gametes (Aspinall et al. 1964; Salter and Goode, 1967). They reported that moisture stress during the formation of the reproductive organs, and later at flowering were most sensititive, resulting in aborted or sterile upper or

lower florets.

The numbers of grains per spike at harvest (Table 4:28) were significantly affected by irrigation treatments. It can be observed that prolonged moisture stress at heading and flowering, CRI and tillering, and jointing stages was detrimental to the number of grains per spike particularly at jointing stage. This, of course, may be expected since the number of grains per spike is established during inflorescence development (Slatyer, 1973; Fischer, 1973). Abdel-Motaleb (1978) and Musick and Dusek (1980) have also reported that there should not be any moisture stress during these decisive stages in order to attain maximum number of grains per spike.

Spike grain weight was influenced by the irrigation treatments. Referring to the data on spike-grain weight recorded at different stages of the grain filling period (Table 4:30) would reveal that the rate of flow of the assimilates differed from one treatment to another. It is of interest to note here that the treatment where there was no stress of moisture stopped the flow of assimilates to the grain early and the spike grain weight decreased from 1.37 gm at 90 DAS to 1.33 gm at harvest (by 2.7 per cent). Whereas all other treatments of moisture stress continued to store assimilates in the spikes with varying degrees in the same period (90 - 105 DAS); missing one irrigation at jointing (40 DAS) caused assimilates to flow

to the spikes at higher rates during this maturity stages (90 - 105 DAS). This may be explained on the basis of that the yield component which was adversely influenced by this treatment was number of spikes m^{-2} (Table 4:22) but when no stress was imposed after this stage, the plants were able to recover with less number of spikes, produced relatively high number of grains per spike (Table 4:28) and ultimately produced heavier grain weight per spike. Missing two consecutive irrigations during jointing (40 and 50 DAS) affected the number of spikes m^{-2} (the lowest among irrigation treatments) produced the lowest grain number per spike and also the lowest spike grain weight at the grain filling stage and at harvest, too. This indicates that at early jointing stage spike number is determined and at later stage of jointing (50 DAS), spike size is decided, which in turn determines the number of grains borne on each spike. But plants under moisture stress throughout the jointing stage (missing irrigation at 40 and 50 DAS) were able to recover and permit the early flow of assimilates, which stopped at 90 DAS. Missing two consecutive irrigations at heading and flowering (60 and 70 DAS) seemed not to affect the spike grain weight at any stage but delayed the attainment of the final spike grain weigh till after 90 DAS (increased from 1.18 gm at 90 DAS to 1.35 gm at 105 DAS by 15 per cent). It is to be noted here that this

treatment produced relatively higher numbers of spikes m^{-2} and grains per spike.

It is worth summarising the final effect of irrigation at different growth stages at harvest (105 DAS). Withholding one irrigation at early jointing and milk-ripe stage produced the heaviest spike-grain weight. Withholding two consecutive irrigations at early stages of growth during tillering and jointing produced the lowest spike-grain weight. The increase in spike-grain weight with missing one irrigation at early jointing and milk-ripe may be explained on the basis of 1000-grain weight at 105 DAS (Table 4.31) and number of grain per spike (Table 4.28). The reduction in the spike-grain weight with moisture stress during tillering and jointing may be attributable to the resultant stunted growth as manifested in the reduction of plant height, tiller number per plant, leaf area, leaf area index and spike length.

Regarding the 1000-grain weight as influenced by irrigation treatment (Table 4:31), it is clear from the data collected at different stages during grain filling and at harvest that there was little increase in this character after 90 days in the control treatment (from 35.859 gm at 90 DAS to 37.99 gm at 105 DAS by about 2 per cent only). The treatment of missing two consecutive irrigations at jointing (40 and 50 DAS) showed dissimilar trend to its spike-grain weight. Since a prolonged

moisture stress throughout jointing stage resulted in a decreased spike number m^{-2}, decreased grain number per spike and lowest spike-grain weight, yet the plants could recover and produced with the assimilates available the heaviest grains expressed in terms of 1000-grain weight throughout the grain filling period. Also the movement of assimilates towards the grains continued, till a later stage (from 32.0 gm at 90 DAS to 40.6 gm at harvest i.e. 105 DAS by 27 per cent increase). Skipping one irrigation at early jointing stage (40 DAS) did not affect the 1000-grain weight adversely throughout the grain filling period but only hindered the flow of assimilates by 15 per cent after 90 days. Likewise, missing two consecutive irrigations at CRI and tillering also delayed the formation of full size grain till after 90 days after sowing and there still occurred increase in the grain size after that period and before harvest (90 - 105 DAS) by about 25 per cent. The occurrence of moisture stress at the milk-ripe stage (about 80 DAS) caused some detriment by reducing the final 1000-grain weight as compared with the other irrigation treatments but this hastened maturity. This was clear from the rate of increase in the 1000-grain weight by about 2 per cent after 90 days and till harvest (105 DAS). A prolonged moisture stress at heading and flowering did more harm (the lowest 1000-grain weight throughout grain filling and at harvest), but also hastened the formation of the

final grain size (only 4.5 per cent increase after 90 days). Moisture stress at early jointing (40 DAS) only delayed the attainment of final grain size by 15 per cent but resulted in heavier grains. This is expected since stress at this stage reduced the number of tiller bearing spikes as expressed in term of spike number m^{-2}. Skipping irrigation at heading (60 DAS) hastened the attainment of full grain size (only 4.5 per cent remaining after 90 days) and reduced the size of grains as compared with the control treatment.

It is also worth summarising the final effect of irrigation on the 1000-grain weight at harvest. Withholding two consecutive irrigations at jointing increased grain weight, while withholding one at milk-ripe and two consecutive irrigations at heading and flowering stages produced very lighter grains. A reference to the data on number of tillers per plant, dry matter production and number of grains per spike (Tables 4:6, 4:18 and 4:28) will reveal that missing two consecutive irrigations at jointing influenced favourably the translocation of assimilates into the spike resulting in heavier grains. On the other hand increasing the number of tillers per plant and the number of grains per spike might have intensified the competition for assimilates within the spike with moisture stress at milk-ripe, heading and flowering stages, resulting in

lighter grains. Similar results were reported by Wilson (1969). Other investigators, including Mosaad (1975), Misra et al. (1976) and EL-Dababy et al. (1978), also reported reductions in 1000-grain weight due to moisture stress during grain filling period.

Grain yield (Table 4:32) was influenced significantly by withholding irrigation at all stages of growth and development. The treatment without missing irrigation (control) gave the highest grain yield of 2222 kg ha^{-1}. Missing two consecutive irrigations at any of the stages examined reduced the grain yield considerably, much more than missing only one irrigation. Grain yield was decreased by 27, 65 and 31 per cent by withholding two consecutive irrigations at (CRI and tillering), (jointing) and (heading and flowering), respectively. The treatments which had one irrigation missed during CRI, early jointing, heading and milk-ripe, caused reductions in grain yield by 13, 11, 8 and 10 per cent, respectively. The low yields obtained when two irrigations were missed during (CRI and tillering) and jointing stages could be explained in the light of reduced plant height, tiller number per plant, leaf area per plant, leaf area index, dry matter production, number of spikes m^{-2} number of fertile spikelets per spike, number of grains per spike and spike-grain weight which all combined to bring about a considerable yield reduction. Also the low yields obtained

when two irrigations were missed during heading and flowering could be attributed to the lower number of grains per spike and 1000-grain weight. Slatyer (1973) further explained the reduction in grain yield with moisture stress at flowering as being due to reduced fertilization and grain set, and because of dehydration of pollen grains or probably poor germination of the pollen or failure of growth of the tube from the stigma to the ovules. Based on the reduction in grain yield, tillering, jointing and flowering could be regarded as the critical stages in terms of moisture stress, with jointing being the most critical stage.

Plant height and number of tillers (both effective and ineffective) have a direct bearing on straw yield. Withholding irrigations at early stages of growth i.e. CRI, tillering and jointing affected these parameters, and this was found to be detrimental to straw yield (Table 4:34). About 58 per cent reduction in straw yield was obtained when two consecutive irrigations were missed during these early stages. The normal regular irrigation which increased plant height and tiller number gave the highest straw yield while missing irrigation at ripening stages generally did not cause much reduction in the straw yield.

ii) Seed rates

The three seed rates used in this study did not significantly affect the number of spikes m^{-2}. Referring back to the table on the number of tillers per plant (Table 4:6), may throw some light on this lack of significance effect on spike number per meter square by the different seed rates. Increased seed rates resulted in greater competition between plants and high tiller mortality thus giving rise to similar spike number per unit area.

The results of spike length (Table 4:23) indicated that the lowest seed rate produced the shortest spike while the two higher seed rates produced longer spike which is not in conformity with the findings reported by Foltyn and Skorpik (1974), Abdel-Wahab (1976), Khalil et al. (1979) and Bassiouny (1979). It is difficult to explain why it so happened in the present trial.

Seed rate significantly affected the number of fertile spikelets per spike (Table 4:24). Also due to competition resulting from the higher number of spikes per plant with a low seed rate, it gave the minimum number of fertile spikelets per spike, and the highest seed rate was also found to be inferior to the medium seed rate in producing fertile spikelets per spike. This seems to indicate that the medium seed rate is the optimum seed rate with respect to this character. This finding conforms

with those of Ahmed (1973), Dougherty et al. (1974), Abu Haghaza (1977), Gomaa et al. (1977), Khalil et al. (1977), Bassiouny (1979) and Ubi (1981) who reported significant reductions in the spikelet number per spike with increasing seed rate in wheat.

With respect to number of sterile spikelets per spike, this number increased significantly with increase in seed rate. Similar result was also reported by Bassiouny (1979).

The number of grains per spike and spike grain weight at harvest as influenced by seed rate showed a trend similar to that of length of spike at harvest in which the lowest seed rate produced the lowest number and weight of grains and spike-grain, respectively. The reason could possibly be due to increased competition with higher number of spikes per plant as explained earlier in the discussion on spike length.

Throughout the reproductive phase the values of 1000-grain weight increased as the seed rate increased (Table 4:31). After 90 DAS, about 19, 10 and 7 per cent of assimilates were stored in the grains till the harvest (105 DAS) under 75, 100 and 150 kg ha^{-1} seed rates, respectively. The production of as many spikes by the lowest seed rate (75 kg ha^{-1}) as did the higher seed rates resulted in the inability of the plants to provide adequate assimilates to these spikes and hence the ligher weight per grain. At harvest the final effects of the

three seed rates did not differ much, though the highest seed rate gave the highest weight of 1000-grains and the medium rate was at par with both the higher and the lower seed rates. Abdul-Galil (1964), Singh et al. (1971) Ahmed (1973), Day et al. (1976) and Eissa (1979) also reported no significant effect of varying seed rates from 29 to 240 kg ha^{-1}.

The medium seed rate of 100 kg ha^{-1} gave consistently better results in most of the yield contributing characters as influenced by seed rates and consequently it also produced the highest grain yield than the two other rates. It can be seen from Table 4:32 that this medium seed rate was suitable in producing the maximum grain yield. Similar results were reported by Sinha and Singh (1970), Singh et al. (1971), Ibrahim (1972) and Ubi (1981).

The effect of seed rate on straw yield (Table 4:34) was found to be significant. The two higher rates were superior to the lowest rate, indicating that the higher rates significantly increased the straw yield. A reference to the data on leaf area, leaf area index and dry matter accumulation (Tables 4:10, 4:14 and 4:18) will illustrate this observation. Similar results were reported by Singh et al. (1971), Agarwal et al. (1972), Ibrahim (1972), Ahmed (1973), Ballatore et al. (1975), Abdel-Wahab (1976), Sorour et al. (1977) and Ubi (1981).

iii) Irrigation x Seed rate interaction

The interactions were found to be significant only in three yield - related characters, namely number of fertile and sterile spikelets per spike and number of grains per spike.

The number of fertile spikelets per spike was significantly affected by different seed rates under various moisture conditions. When irrigation was not missed or missed only at a late stage (milk-ripe) the three seed rates had similar effects. However, when irrigation was missed at earlier stages (20 to 40 DAS) the highest seed rate produced the highest number of fertile spikelets, whereas when irrigation was missed at later stage (after 40 days) the medium seed rate produced the highest number of fertile spikelets. In both cases the lowest seed rate produced the lowest number of the fertile spikelets per spike.

The number of sterile spikelets per spike was also affected by different seed rates under various moisture conditions. In most of the cases the results were reversed (number of fertile spikelets) as described immediately above.

From Table 4:29 it can be observed that under normal irrigation, when there was no detectable moisture stress,

the lowest seed rate produced the highest number of grains per spike. When moisture stress was created by omitting one or two irrigations, in most cases, the lowest seed rate produced the lowest number of grains per spike.

These findings clearly indicate that it is the coverage of the land with more plants that had minimized the adverse effect of moisture stress on these yield contributing characters.

The interaction between irrigation and seed rate on grain yield (Table 4:33) has shown that without missing irrigation and when irrigation was missed at early stages the two higher seed rates were superior in producing more grain yields. The three seed rates did not differ significantly in their effects on grain yields when irrigation was missed at late stages. The final grain yield is a complex character based on so many interacting yield components. The results of treatment effects on the yield components have also shown that when irrigation was missed earlier higher seed rates produced better results which are reflected in grain yields.

CHAPTER VI

SUMMARY AND CONCLUSION

A field trial was conducted at the Ahmadu Bello University farm, Zaria, during 1981/82 dry season to study the response of growth, development and yield in wheat to moisture stress imposed at various growth stages under different seed rates.

The treatments consisted of combinations of eight moisture stress conditions and three seed rates. The moisture stress treatments were: normal irrigation at 10 days interval (I_1), missing one irrigation at CRI (20 DAS-I_2), early jointing (40 DAS-I_3), heading (60 DAS-I_4) and milk-ripe (80 DAS-I_5); missing two consecutive irrigation at CRI and tillering (20 and 30 DAS-I_6), jointing (40 and 50 DAS-I_7) and heading and flowering (60 and 70 DAS-I_8). Three seed rates of 75, 100 and 150 kg ha^{-1} were tested.

It was observed that moisture stress effected by withholding irrigation at any growth stage before anthesis (i.e. at CRI, tillering, jointing and heading) reduced most of the growth parameters viz plant height, tiller number per plant, leaf area per plant, leaf area index, flag leaf area and dry matter production.

Missing two consecutive irrigations during early

stages from CRI to jointing reduced the number of spikes m^{-2}, length of spike, number of fertile spikelets per spike, whereas missing two consecutive irrigations at both early and late stages reduced the number of grains per spike. The value of 1000-grain weight was adversely affected by either missing one irrigation at milk-ripe stage or missing two irrigations at heading and flowering stages.

The final grain yield was adversely affected by withholding irrigation at any stage of growth and development. The highest grain yield was obtained with normal irrigation. Missing two consecutive irrigations at any of the stages reduced yield more than missing one irrigation. By missing one and two irrigations grain yields were reduced by levels of 7.6 to 13.3 and 26.5 to 65.4 per cent, respectively. The maximum yield reduction of about 13.3 and 65.4 per cent were observed when one irrigation was missed at CRI and when two consecutive irrigations were missed at jointing, respectively.

Based on the present findings, it may be concluded that moisture stress at any of the various growth stages is likely to reduce the growth, yield component and yield of wheat. If one has to unavoidably miss one irrigation it is safer to miss this after heading, and if two are to be missed consecutively, then they should be missed before jointing. The seed rate of 100 kg ha^{-1} produced higher grain yields

under various moisture stress conditions. Tillering, jointing and flowering were found to be the critical stages to soil moisture stress, with jointing being the most critical stage.

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