THE RESPONSE OF DWARF WHEAT VARIETIES (*Triticum aestivum* L.) TO DIFFERENT WATER STRESS LEVELS, DATES OF SOWING AND NITROGEN FERTILIZATION

BY

Ahmed Mustapha FALAKI

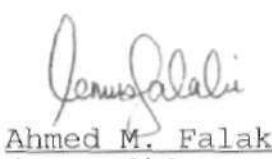
A dissertation submitted to the Postgraduate school, Ahmadu Bello University, Zaria, in partial fulfillment of the degree of Doctor of Philosophy in Agronomy

DEPARTMENT OF AGRONOMY
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

OCTOBER, 1994

DECLARATION

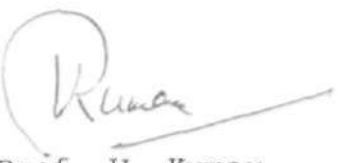
I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.



Ahmed M. Falaki
(Candidate)

Date: 24/11/94

The above declaration is confirmed



Prof. V. Kumar
(Major Supervisor)

Date: 2/12/94

CERTIFICATION

This thesis entitled **"THE RESPONSE OF DWARF WHEAT VARIETIES (Triticum aestivum L.) UNDER DIFFERENT WATER STRESS LEVELS, DATES OF SOWING AND NITROGEN FERTILIZATION"** by Ahmed Mustapha **FALAKI** meets the regulations governing the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

Prof. V. Kumar
Chairman,
Supervisory Committee
Date: 2/12/94

Prof. M.K. Ahmed
Member,
Supervisory Committee
Date: 2-12-1994

Dr. A.A. Ramalan
Member,
Supervisory committee
Date: 2/12/94

Prof. S.T.O. Lagoke
Head,
Department of Agronomy.
Date: 2/12/94

Prof. D. Mohammed
Dean,
Postgraduate School.
Date: 6/12/95

AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

DEDICATION

This work is dedicated to my late brother, Alhaji Husaini Mustapha Falaki for his brotherly love and care and for living an exemplary life worth emulating.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to Professor Vijay Kumar, my Major Supervisor for his invaluable assistance, useful suggestions and guidance throughout the period of this study and in the preparation of this manuscript. The same sincere gratitude goes to the other members of my Supervisory Committee, Prof. M.K. Ahmed and Dr. A.A. Ramalan as well as Prof. J.Y. Yayock and P.R. Muarya who served on my supervisory committee before their departure, for their outstanding contribution to the successful completion of this study.

Sincere appreciation is extended to Prof. S.T.O. Lagoke, Head of Department of Agronomy for his untiring encouragement and invaluable assistance and to all my colleagues in the Department who, in various ways, contributed to the success of this work. Sincere thanks go to Mr. W.C. Mayaki, the then Officer-in-charge of the Irrigation Research Station (IAR), Kadawa and to the Farm Manager of the Station for their assistance in ensuring the success of the field investigations. The contributions of my able assistants Mr. N.C. Nimzing, E.D. Abimbola and U.S. Okwubunka all of Department of Agronomy are well appreciated.

I wish to thank Professor L.B. Olugbemi, the Director IAR, for his continuous support and encouragement throughout the period of this work.

The investigations were partly carried out with the assistance of EEC through the Danish Land Development Service (DANIDA). I wish to thank the EEC for sponsoring my research study at the Royal Veterinary and Agricultural University (RVAU), Copenhagen, Denmark.

I wish to express my sincere appreciation for the encouragement I received from my brothers Dr. A. Mustapha, Prof. S.U. Abdullahi, Dr. I.N. Sada, Dr. A.A. Hussaini, Dr. H. Bobboyi, Ustaz S.S. Abubakar and Aminu M. Daneji. I sincerely thank you all.

I wish to express my sincere appreciation to Mal. Sani A. Idrisu who typed the draft and to the ITN (Zangon Shanu) that assisted in producing the final copies of the manuscript.

I am grateful to my Senior wife (Hajiya Gadatu) for her love, care and encouragement and to my beloved wife Safiya for her patience and understanding. Also, my appreciation is extended to all my brothers and sisters, relations and my children for their understanding and encouragement.

I wish to thank Allah for His Mercy and Protection to see me complete this work.

ABSTRACT

Two field experiments involving (a) Sowing date x Water Stress x Variety and (b) Nitrogen level and Water stress were conducted at the Irrigation Research Station, Kadawa **(11°** 39'N, 08° 02'E and 500m above sea level), Institute for Agricultural Research, Ahmadu Bello University, Zaria. The Irrigation station is located in the Sudan Savanna ecological zone of northern Nigeria. The investigations were carried out for three consecutive years during 1983/84 to 1985/86 dry seasons (October to March) to study the effect of time of planting, water stress on two varieties in the first experiment and nitrogen fertilization and water stress in the second experiment. A supporting experiment was also conducted under growth chamber condition at the Hydrotechnical Laboratory of Royal Veterinary and Agricultural University, Copenhagen (Denmark) to monitor crucial parameters related to soil and plant water status.

Delay in sowing wheat from 10th November to 1st and 22nd December significantly reduced grain yield by 14.8 and 20.8 percent, respectively. Grain yield and yield components were significantly reduced by increase in water stress using IW/CPE (Irrigation water/Cummulative pan evaporation) ratio of 1.00 (no stress), 0.75 (moderate stress) and 0.50 (severe stress). Moderately and severely stressed crop produced 19.7 and 46.0

percent lower grain yield respectively when compared with unstressed control (IW/CPE ratio = 1.0). Response of the grain yield to N fertilization was quadratic. The optimum level of N worked out to be 120kg/ha. Wheat variety 'Siete Cerros' significantly outyielded 'Sonalika' in terms of grain yield, yield components and water-use efficiency (WUE), which decreased with delay in sowing and with increased water stress. Nitrogent application increased WUE linearly up to 150kg/ha.

In the sowing date x water stress experiment, there was a positive and very close association between grain yield with 1000-grain weight followed by spikes/m^2 and number of grains/spike. Whereas in nitrogen x water stress experiment, a high association was observed between grain yield with number of grains/spike followed closely by spikes/m^2. The correlation between the grain yield and 1000-grain weight was not as strong compared with the other two components

Except in one experiment, in both sowing date and water stress treatments, there was a negative linear response between the grain yield and the two treatments, whereas in nitrogen x water stress treatment a quadratic response was found to be significant for nitrogen in all the 3 years and combined data analysis. The response to water stress level was quadratic in the first two seasons and linear in the third season and combined analysis.

In the growth chamber experiment, the rate of transpiration decreased with increase in soil matric potential in descending order from the least to the most stressed plants. 'Sonalika' showed a higher rate of transpiration throughout the season than 'Siete Cerros'. Stomatal resistance, total water, osmotic and pressure potentials, water content and relative water contents in leaves decreased with increasing soil matric potential throughout the period of observation. 'Siete Cerros' showed a lower stomatal resistance, total water and osmotic potential, but higher water content, relative water content and pressure potential in leaves than 'Sonalika' which recorded a negative pressure potential (- 1.2MPa) in the severely stressed crop. Moisture stress also reduced number of spikes/pot, spike length, number of grains/spike, grain weight/spike and 1000-grain weight but gave lower number of grains/spike. Moisture stress significantly reduced both straw and grain yields.

TABLE OF CONTENTS

		Page
Title Page		i
Declaration		ii
Certification		iii
Dedication		iv
Acknowledgement		v
Abstract		vii
Table of Contents		x
INTRODUCTION		1
LITERATURE REVIEW		5
2.1	Plant water balance	5
2.2	Water stress and crop performance	9
2.2.1	Growth and development	9
2.2.2	Yield components, yield and water-use efficiency	11
2.3.	Irrigation scheduling	14
2.3.1	Growth stages	14
2.3.2	Available soil water	15
2.3.3	IW/CPE ratio	15
2.3.4	Ratio of Eta/Etp	17
2.4	Nitrogen	19
2.4.1	Yield and yield components	19
2.5	Nitrogen and Irrigation	20
2.5.1	Yield and yield components	20
2.6	Sowing date	22
MATERIALS AND METHODS		27
3.1	Growth experiment	27
3.1.1	Physical properties of soil	27

3.1.2	Soil moisture characteristic curve..	27
3.1.3	Treatment and design.....	29
3.1.4	Weather parameters in growth chamber.	29
3.1.5	Seeds and sowing.....	30
3.1.6	Moisture stress.....	30
3.1.7	Observations, measurements, calculations and analysis.....	31
3.1.7.1	Plant growth and development.....	31
3.1.7.2	Transpiration and soil matric potential.....	31
3.1.8	Crop water status.....	31
3.1.8.1	Stomatal resistance.....	32
3.1.8.2	Leaf water status.....	32
3.1.8.3	Total leaf water potential.....	32
3.1.8.4	Leaf water content (W) and relative water content (RWC).....	33
3.1.8.5	Leaf osmotic potential.....	34
3.1.8.6	Leaf pressure potential.....	34
3.1.9	Yield and yield components.....	34
3.2	Field Experiments.....	35
3.2.1	Field Experiment 1-Effect of water - stress, sowing date and variety.....	35
3.2.1.1	Experimental design and treatments.....	35
3.2.1.2	Land preparation.....	36
3.2.1.3	Soil analysis.....	36
3.2.1.4	Fertiliser application.....	36
3.2.1.5	Seeds and sowing.....	36
3.2.1.6	Weed control.....	37
3.2.1.7	Meteorological date.....	37
3.2.1.8	Observations.....	37
3.2.1.9	Water-use efficiency.....	41
3.2.2.0	Statistical analysis.....	41

3.2.3	Field Experiment II-Effect of water - stress and nitrogen fertilization.....	42
3.2.3.1	Experimental design and treatments.....	42
3.2.3.2	Other experimental details.....	43
3.2.3.3	Fertilizer application.....	43
RESULTS	.....	44
4.1	Growth chamber experiment.....	44
4.1.1	Plant height.....	44
4.2	Crop water relations.....	44
4.2.1	Transpiration.....	44
4.2.2	Stomatal resistance.....	46
4.2.3	Leaf total water potential.....	46
4.2.4	Leaf osmotic potential.....	52
4.2.5	Leaf pressure potential.....	52
4.2.6	Leaf water content.....	52
4.2.7	Relative water content.....	57
4.3	Crop water status of two varieties in relation to soil matric potential.....	57
4.3.1	Transpiration.....	57
4.3.2	Stomatal resistance.....	57
4.3.3	Leaf total water potential.....	60
4.3.4	Leaf osmotic potential.....	60
4.3.5	Leaf pressure potential.....	63
4.3.6	Leaf water and relative water content..	63
4.4	Yield and yield components.....	67
4.4.1	Primary spikes.....	67
4.4.2	Secondary spikes.....	68
4.4.3	Total spikes.....	70
4.5.	Fields Experiments I.....	72
4.5.1	Growth parameters.....	72
4.5.1.1	Plant height.....	72
4.5.1.2	Dry matter accumulation.....	73

4.5.1.3 Number of tillers/m²..... 76
4.5.2 Yield parameters..... 78
4.5.2.1 Length of spike..... 78
4.5.2.2 Number of spikes/m²..... 82
4.5.2.3 Number of grains/spike..... 84
4.5.2.4 Grain weight/spike..... 86
4.5.2.5 1000-grain weight..... 88
4.5.2.6 Straw yield..... 90
4.5.2.7 Grain yield..... 91
4.5.2.8 Correlation studies(1983-84 season)..... 96
4.5.2.9 Correlation studies(1984-85 season)..... 96
4.5.3.0 Correlation studies(1985-86 season)..... 98
4.5.3.1 Correlation studies(1983-86 season)..... 99
4.5.3.2 Path-coefficient analysis(1983-84 season. 100
4.5.3.3 Path-coefficient analysis(1984-85 season. 102
4.5.3.4 Path-coefficient analysis(1985-86 season. 103
4.5.3.5 Path-coefficient analysis(1983-86 season. 105
4.5.3.6 Polynomial response to sowing date and water stress..... 109
4.5.3.7 Water-use efficiency..... 111
4.6 Field Experiment II: Response of dwarf wheat 'siete cerros' to water stress and nitrogen levels..... 114
4.6.1 Plant height..... 114
4.6.1.2 Dry matter production..... 116
4.6.1.3 Number of tillers/m²..... 116
4.7.1 Yield parameters..... 119
4.7.1.1 Length of spike..... 119
4.7.1.2 Number of spikes/m²..... 120
4.7.1.3 Number of grains/spike..... 121
4.7.1.4 Weight of grains/spike..... 124
4.7.1.5 1000-grain weight..... 124
4.7.1.6 Straw yield..... 127

5.5.2 Nitrogen fertilization..... 172
5.5.3 Simple correlation studies..... 175
5.5.4 Path-coefficient..... 176
5.5.5 Polynomial response of grain yield to water stress and nitrogen..... 177
5.5.6 Water-use efficiency..... 177

SUMMARY AND CONCLUSION..... 179
6.1 Summary..... 179
Conclusion..... 182

REFERENCES..... 184

APPENDICES..... 200

CHAPTER 1.

1.0 INTRODUCTION

Nigeria has within the past two decades, developed a lot of water resources through the large-scale dam constructions by the River Basin Authorities to irrigate about 0.8 million hectares. Out of the 135,000ha envisaged to be developed by 1990, only about 48,000 ha (36%) has actually been developed for irrigation. Majority of the developed area (65%) is under wheat and the rest is used for dry season vegetables, maize, rice and sugarcane. With funds coming from the World Bank for Fadama Development Programme, it is envisaged that small scale farmers will put more land under wheat production in order to bridge the gap between local production and actual requirement (Appendix 1).

Effective irrigation scheduling is necessary for successful wheat production especially on a limited hecterage and under water limited environment. Under such situation, yield reduction from variable soil moisture deficit throughout the crop life circle must be known and quantified. Several workers have quantified such yield reductions by imposing water stress through a fixed irrigation schedule based upon growth stages.

In recent efforts to increase yield and water-use efficiency of dwarf wheat varieties, several scientists have based their irrigation schedule on irrigation water/

cummulative pan evaporation (IW/CPE) ratio approach which reduces stress compared with the fixed irrigation schedule based on growth stages. Pan evaporation measures the drying ability of air which is a function of radiation, wind, temperature and vapour pressure deficit. Meteorological factors are known to have a similar effect on evaporation from free water and moist soil surface and transpiration from plant surfaces. Differences in the rate of water loss may be expected from:

(a) variable crop coverage during the growing season.

(b) availability of water for evaporation from the soil surface, and

(c) differences in the energy absorption characteristics of the crop and open water surface.

The optimum time for wheat planting is mid-November. The late sown crops suffers severely from environmental stress during the reproductive stage due to their variable responses to water stress. Late sown wheat was observed to be exposed to mean temperature of 24°c at jointing stage and maximum temperature of 32.5°c during flowering and grain development, which reduced reproductive stage by about 18 days (Kumar and Yayock, 1980). The low grain yield of late sown wheat was due to decrease in number of productive shoots by 30 percent compared with timely sown crop as a result of crop being exposed to high temperature stress.

The response of wheat to various combinations of irrigation and fertility levels has been a subject of minimum studies. The response function usually showed a positive interaction of irrigation and fertility level. In general, response of wheat to irrigation is increased at higher nitrogen level (Shimshi and Kafkafi, 1978; Singh and Kumar, 1981 and Singh et al. 1987). Such response however, depended upon the water availability and time of sowing.

With the existing facilities and equipment at Irrigation Research Station Kadawa, it was not possible to study and monitor the water status in the plant as well as in the soil in order to get a good picture of the crop performance under different stress levels. This entails studying the internal water balance which controls various physiological processes in wheat crop that affect the growth, development, yield components and ultimately the yield. Such studies needed to be undertaken under controlled condition. The studies were therefore undertaken in growth chambers at the Hydrotechnical Laboratory, Royal Veterinary and Agricultural University, Copenhagen, Denmark for one season.

Based on the above background, this work was undertaken to:

(a) study the effect of water stress and time of planting on the yield components, yield and water-use efficiency of two dwarf wheat varieties 'Siete Cerros' (SAMWHIT-5) and

'Sonalika' (SAMWHIT-8).

(b) evaluate the effect of water stress and nitrogen fertilization on the yield and water use efficiency of wheat variety 'Siete Cerros' (SAMWITH-5).

(c) assess and monitor crucial soil moisture parameters of SAMWITH-5 and 8 in relation to total water, osmoticand pressure potential and other plant processes in relation to growth, yield components and grain yield under growth chamber conditions.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Plant Water Balance

Moisture stress is the result of an imbalance between the supply furnished by the soil water and the amount transpired by the crop as determined by the atmosphere, assuming a complete crop cover. The minimum water potential gradient developed during the day will be a function of the soil moisture supply as it determines the base level of turgor, the evaporative demand and the capacity of the soil to supply water. Thus water stress occurs in crops because the rate of water loss (Transpiration) often exceeds the rate of absorption by roots.

Although the two processes are partly independent, absorption is controlled chiefly by soil factors including soil water potential and the unsaturated conductivity and transpiration chiefly by atmospheric factors such as radiation, air temperature, relative humidity and wind speed which often occur at different rates. According to Taylor and Ashcroft (1972), a crop's response to water is evidently more closely related to soil water potential than to any other single factor.

A progressive change in soil and crop water potential as the soil dries out, based on the assumption that the same evaporative demand conditions prevail daily was first

presented by Slayter (1967). He hypothesized that the upper limiting curve representing soil water potential progressively declined, indicating that the crop water status is mainly governed by soil water stress. It is also apparent that the positive turgor would not be maintained regardless of the length of the recovery period.

Crop water deficit induced by soil moisture and atmospheric stresses affects the crop in several ways such as (a) change in rate of transpiration, (b) crop water relations, (c) stomatal conductance, (d) photosynthesis, (e) respiration, (f) growth characteristics, (g) photosynthetic area and (h) dry matter accumulation which in turn affects the yield and yield components. Giunta et al. (1993) reported that severe water stress affected all grain yield components in wheat particularly number of fertile ears per unit area (- 60%) and grain number per ear (- 48%). Harvest index was also significantly reduced. Thus, in order to quantify the effect of short and long term moisture stress in crops, knowledge to relate crop water status with growth and yield is vital.

The status of water in plant parts is dynamic and changes in response to many environmental and indigenous factors, (Turner and Begg, 1973; Hatfield, 1975). Likewise leaf water potential is affected by the later factors (Recosky et al. 1975; Nel and Berliner, 1990).

Crop growth is directly associated with internal crop

water status and consequently affected by internal crop water deficits because they affect numerous internal processes and conditions such as turgidity, cell enlargement; photosynthesis and respiration (Begg and Turner, 1976). Changes in these processes and conditions modify both the quantity and quality of crop growth.

Sionit et al. (1980) showed that wheat plants had little osmotic adjustment to rapid development of water stress and further indicated that they were most sensitive to low leaf water potential during anthesis resulting in negative pressure potential because of low ability of the tissue to accumulate osmotically active solutes for adjustments as compared to the other stages. Li et al. (1993) suggested that osmotic adjustment could result from an imbalance between production, consumption and translocation of photosynthates under stressed conditions. Also, Gunasekera and Berkowitz (1992) reported that wheat genotypes osmotic adjustment was important acclimation mechanism which could allow for the maintenance of relatively greater metabolic function at low leaf water potential.

Leaf water potential, over the past decade has gained wide acceptance as a fundamental measure of crop water status and when quantified can even be used for scheduling irrigation of wheat under specific soil and climate conditions (Nel and Berliner, 1990). Leaf water potential could also be an

important index for predicting soil water potential of the root zone and thus a useful means for water management and irrigation (Hassan and Al-Anbary, 1989). Li, et al. (1992) reported that soil water stress increased the leaf water potential, relative water content and grain yield decreased and the osmotic adjustment ability and stomatal resistance increased.

The most promising indices of water stress in field conditions are leaf water potential (Brady et al. 1974; Misra and Pant, 1981), leaf water potential and stomatal conductance (Shimshi and Ephrat, 1975; Sivakumar and Shaw, 1978, and Oosterhuis 1984) leaf osmotic potential (Clarke and Simpson, 1978), water potential, pressure potential and stomatal resistance (Kirkham, 1978 and Singh and Singh, 1989), changes in leaf angle (Peinetti and Ledent, 1988). Oosterhuis and Walke (1987) reported that the sensitivity of stomatal response to moisture stress in wheat, ease of measurement with steady state porometer, consistency or stomatal diffusive resistance (r_s) values, low variability between well-watered wheat plants and lack of need for a control, makes r_s potentially useful and reliable plant indicator of crop moisture stress.

2.2 Water stress and crop performance

2.2.1 Growth and development

Crop growth and development are influenced by temperature, soil-water availability, crop-water status and atmospheric evaporative demand. Soil moisture stress during the growth period affects morphological and physiological processes like shoot height, number of leaves, number of tillers, leaf area, spikelet size, number of grains/spike, grain filling, dry matter accumulation/distribution, grain yield and quality.

Singh et al. (1979) reported that water stress at crown root initiation (CRI) was critical for tillering and grain yield. Gajri and Prihar (1983) and Lawlor et al. (1981) reported that early season (30 days from seeding) water stress decreased the rate of dry matter accumulation in wheat as well as reduced the number of tillers/m^2 row length and stem length.

Water stress at tillering has been found to cause losses in yield (Bhardwaj et al. 1971 and Kumar and Singh, 1977) due to reduction in number of spikes/plant as a result of increased tiller and stem senescence. Choudhury and Kumar (1980) revealed that sowing to maximum tillering period was the most sensitive to water stress, while Hochman (1982) reported tillering to anthesis stress reduced leaf area index.

During jointing, moisture stress reduced crop yield due to reduction in plant size, photosynthetic area, fewer spikes/unit area and seeds/spike (Day and Intalap, 1970 and Surma et al. 1980). Davidson (1987) revealed that increased moisture stress reduced tiller production/plant and in general moisture stress brought forward flowering and maturity.

Choudhury and Kumar (1980) found that at all stages moderate and severe moisture stress decreased plant height, tiller numbers and leaf area of dwarf wheat in comparison to mild and control treatments. However, reduced number of tillers and reduced growth and development organs (already initiated) were observed due to imposition of severe stress at seeding to maximum tillering stage.

Kumar (1979) reported that CRI and heading were most critical stages in wheat. He indicated that irrigation at these stages will give maximum water-use efficiency (WUE) under limited irrigation. On the other hand, Choudhury and Kumar (1980) found higher reduction in grain yield and water use efficiency of wheat to be caused by reduction in number of spikelets and grains/spikelet when severe water stress was imposed during seeding to maximum tillering.

Crop yield is directly controlled by moisture stress occurring at critical stages of growth. Numerous studies concerning the critical growth stages have been reported by

many workers. These include crown root inititation (Cheema et al. 1973) seedling growth to maximum tillering (Choudhury and Kumar, 1980), jointing (Mogensen, 1980), booting (Campbell et al. 1981), heading (Morgan and Riggs, 1981), flowering (Bello, 1983), booting to early grain filling (Hochman, 1982), milk and dough (Patel et al. 1971) and flowering to grain filling (Sionit et al. 1980; Morgan and Riggs, 1981).

2.2.2 Yield Components, yield and water-use efficiency

Irrigating crops to avoid yield reduction as a result of moisture stress may not be the most natural use of water in the economic sense. An alternative way is to use less water per unit area and irrigate more land to compensate for lower yields and thus get higher returns overall. Several workers have studied the effect of soil water stress on yield and yield components of wheat in pots, greenhouses and fields under different agroclimatic environments.

Salter and Goode (1967) reviewing the results of earlier workers (1900 - 1965), reported that the reproductive organs were severely damaged and the number of grains was reduced when stress was given during the heading and flowering stages. The booting stages was also found to be sensitive to water stress which reduced the number of spikes, spikeslets and florets in the spike and thus reduced the total number of grains. Soil moisture stress at the early growth and development of crop has been found to be less sensitive to

grain yield, thereby producing better yield and increase in water use efficiency.

Lawlor et al. (1981) revealed that moisture stress at the early growth period decreased tillering, tiller ear production and grains/ear of barley, whereas water stress at the reproductive phase reduced the grain size due to significant reduction in photosynthetic surface area. Rab et al. (1984) reported that when moisture stress was imposed in the early development stages, late tillers developed subsequently and maximum reduction in grain yield occurred with imposition of stress during and after heading. Water stress at this stage resulted in fewer spikes, fewer spikelets/spike and fewer grains/spike. The 1000-grain weight was generally reduced when stress was imposed at the soft dough stage. The suggestion of avoiding soil moisture stress from booting to grain filling stages has been supported by many more investigators (Fischer, 1973; Frank et al. 1973; Angus and Moncur, 1977; Innes and Blackwell, 1981 and Singh, 1981).

Increasing or decreasing moisture stress at different growth stages had little effect on the number of florets/head or the mean kernel weight, but the number of heads and percent seed set were the main components influencing grain yield. Singh et al. (1980) observed reduction in yield and water-use efficiency of wheat when repeated soil moisture stress at 25 percent available soil moisture based on IW/CPE ratio of 0.75

was given at 0-60 cm soil profile throughout the entire growth period.

Hochman (1982) reported that stress from booting to grain filling reduced the grain yield of wheat (36 percent) and water-use efficiency by reducing the grain number and 1000-grain weight. However, stress from tillering to anthesis reduced the grain yield (28 percent) mainly due to reduction in leaf area index and grain number.

Hassan (1983) found that moisture stress at any of the physiological growth stages will reduce the growth, yield components and yield of wheat. While tillering, jointing and flowering were found to be the critical stages to moisture stress, the jointing was the most critical stage. However, in his findings, Bello (1983) revealed that missing irrigation at flowering stage had more serious effect on grain yield reduction (31 percent) than either missing irrigation at milk stage (15.5 percent) or at milk-dough stage (15.0 percent).

Al-Janabi (1988) reported a decrease in water-use efficiency (WUE) of wheat with increase in moisture stress while Heithholt (1989) observed that mild moisture stress did not consistently affect WUE of wheat, but a more severe stress consistently decreased WUE especially under sub-optimal nitrogen supply.

2.3 Irrigation Scheduling

To achieve better productivity in wheat, it is important to work out an efficient and economic irrigation schedule for use under any given agroclimatic conditions. Since response of wheat to irrigation is influenced by soil, plant and atmospheric factors, the potential advantages of scheduling irrigation in wheat production, based upon soil-crop-climate data have been suggested by several workers (Jensen et al. 1971; Singh, 1978; Green and Kirkham, 1980).

Several methods exist for scheduling irrigation to crops. Investigations have been made on the effects of different irrigation schedules based on various concepts and approaches in yield and water-use efficiency of wheat. The common approaches that have been used as criteria for scheduling irrigation to crops are based upon crop growth stages; depletion of available water in the root zone to a given level, the ratio of a fixed amount of irrigation water (IW) to the cummulative pan evaporation (CPE) i.e. IW/CPE and the ratio between the actual evapotranspiration (ETa) to the potential evapotranspiration (ETp).

2.3.1 Growth Stages:

The approach for scheduling irrigation according to the growth and development stages is mainly concerned with the most sensitive stage (critical) at which any water stress has a very pronounced effect. These stages are classified in

order of their magnitude for a particular crop.

From the results of both pot and field experiments, it has been reported that in most of the cases the booting to milk ripe stages were found to be most critical for water stress. Although, in some other studies early stages like crown root intitiation and jointing were also reported to be critical (Misra et al. 1969; Day and Intalap, 1970; Sepaskhah and Ardekani, 1976; Mogensen, 1980; Sionit et al. 1980; Morgan and Riggs, 1981; Singh, 1981; Green and Kirkham, 1980; El-Rab et al. 1988).

2.3.2 Available Soil Water

The effect of irrigation scheduling based upon depletion of available water in a certain depth of soil has also been investigated (Chauhan and Tripathi, 1972; Bapna and Khuspe, 1980). From their findings, it appeared that highest yield and water-use efficiency of wheat can be obtained by irrigating at 20 - 25 percent depletion of soil at active root zone. However, Singh et al. (1980) reported that irrigation at 50 percent available soil water resulted in the highest yield per cm water use by crop and consumptive use of water was maximum when irrigation was applied at 70 percent available soil moisture.

2.3.3 IW/CPE ratio

Numerous investigations have been carried out in scheduling irrigation of wheat based on various ratios of

IW/CPE in relation to optimum yield and water-use efficiency. Several workers reported maximum grain yield and WUE with IW/CPE ratio of 0.75 and 1.0 and 6cm irrigation depth (Govind et al. 1983; Majumdar and Mandal, 1984; Pendey et al. 1986; Sinha et al. 1986; Panda et al. 1988; Chavan and Pawar, 1988 and Gill and Lenvain, 1992). However, Sandhu et al. (1984) reported that grain yield and WUE were highest with IW/CPE ratio of 0.75 with 9cm irrigation depth. Similarly, Singh et al. (1987) found that grain yield and yield attributes of wheat were highest and irrigation efficiency maximum with IW/CPE ratio of 0.75 but with 6cm depth of irrigation. Sharma et al. (1987) revealed that grain yields were highest with irrigation at 5.0cm CPE than with 7.0cm CPE, but the different was not significant. However, they indicated that WUE was highest with irrigation at 5.00cm CPE. Chavan and Pawar (1987) reported that grain yields and water-use efficiency increased with increase in the IW/CPE ratio and decreased with increase in the irrigation depth when it was irrigated at IW/CPE ratio of 0.6, 0.8, 1.0 and 1.2 with irrigation depth of 6.0 or 8.0cm.

Chari (1980) using IW/CPE ratios of 0.8, 1.0 and 1.2 at irrigation depth of 2.0, 4.0 and 6.0cm to schedule irrigation for wheat at Bakura (Sokoto State), reported that grain yield and WUE were highest at 2.0cm depth of irrigation water and decreased significantly as the depth of irrigation water

increased. The effect of IW/CPE ratio was significant for grain yield in the second season only when IW/CPE ratio was 1.20 which was superior to IW/CPE ratio of 1.00 or 0.8. He concluded that in the savanna areas of Nigeria, pan evaporation could form a useful tool in decision making on the irrigation frequency but the operational methods to make use of these tool need to be experimented further to develop a rational approach.

2.3.4 Ratio of Eta/Etp

Some investigators (Agarwal, 1977, Stegman et al. 1977; Rafey et al. 1978) have suggested the approach of relative evapotranspiration (ETa/Etp) for scheduling wheat irrigation. In these studies, irrigation at Eta/Etp of 0.5 to 0.7 gave optimum yield and water-use efficiency. However, the general concept of this approach to obtain maximum yield is to irrigate by maintaining Eta almost equal to Etp (Eta/Etp≈1).

There are two important aspects to be taken into consideration while scheduling irrigation for wheat. The first is scheduling for maximum yield under optimum moisture supply conditions. The second aspect is scheduling for optimum yield with maximum water-use efficiency under limiting and expensive water supply conditions.

For maximum wheat production while moisture supply is not a limiting factor, the concept of irrigation at IW/CPE of 1.0 or irrigation at field capacity or at 20 percent available

soil moisture depletion (ASMD) in 0-60cm soil depth, throughout growth period can be used as a guide for scheduling irrigation. However, the general concept of irrigation for maximum wheat production under abundant water supply is to irrigate at the field capacity in maintaining the evapotransipiration rate at the potential level (Eta/Etp = 1) throughout the growth period, although many workers have reported no significant increase in grain yield and water-use efficiently for irrigation at the early and the last stages of growth except in severe soil water stress conditions (Salter and Goode, 1967).

In scheduling irrigation under limiting water supply conditions, the various concepts of scheduling irrigation in wheat production might be combined together with special attention to the critical stages of plant growth and development for water stress and water supply in order to obtain the maximum water-use efficiency with acceptable level of grain yield. Under limiting water supply conditions, increasing water-use efficiency is of prime importance. However, there must be a satisfactory compromise between yield and water-use efficiency.

2.4 Nitrogen

2.4.1 Yield and Yield Components

Fertilization of high yielding dwarf wheat varieties should take into consideration how much of the various nutrients have been depleted by the previous crop. With the intensification of wet season cropping, fertilizer requirement especially nitrogen is likely to increase in the irrigated areas of the savanna.

El-Sharkawy et al. (1977) reported a linear increase in ear length, number of grains/ear and the average grain weight/ear as well as 1000-grain weight with increase in N-level. Several workers have also reported a significant response of wheat to N fertilization in respect of 1000-grain weight (Hussaini et al. 1976; Ibrahim and Assey, 1976; Patra, 1990).

It is commonly reported that nitrogen application increases the number of spikes produced which has a direct bearing on the yield since grains develop on the spikes (Gomaa et al. 1977; Ellen and Spiertz, 1980 and Patra, 1990). In their work, Villanuera and Montjoy (1973) reported that increased nitrogen application significantly increased spike length which is usually accompanied by increase in the number of fertile spikelets/spike. Rathore and Singh (1973) observed that increased nitrogen uptake generally resulted in increased dry matter production.

An increase in wheat yield with increase in N-levels from 60 to 150kgN/ha was reported by a number of researchers such as 60kg/ha (Muir, 1989 and Woldeab, 1989), 90kg/ha (Chaudhry et al. 1987), 100kg/ha (Singh and Balasubramanian, 1982; Olugbemi, 1984 and Behura and Sharma, 1990), 120kg/ha (Singh et al. 1980; Gami et al. 1986; Bharti et al. 1987; Davidkov and Stamboliev, 1987; Dubey et al. 1987; Panda et al. 1988; Pawar et al. 1988; Sarkar et al. 1989 and Pradhan et al. 1990), 150kg/ha (Amer et al . 1989).

Mayaki and Kumar (1982) reported the response of wheat to nitrogen upto 180kg/ha boosted the grain yield by 230 percent above control. Corresponding yield increase by 120 and 180kgN over the preceding N level was 22 percent and 10 percent only. Optimum N level of wheat worked out to be 150kg/ha. Goffart et al . (1992) reported that excessive N application reduced uptake and increased nitrate leaching to soil depths below 1.5m where the wheat roots do not usually penetrate.

2.5 Nitrogen and Irrigation

2.5.1 Yield and Yield Components

Nitrogen and irrigation normally interact to exert their influence on growth and development of crops. Soil moisture to a greater extent determines the uptake of nitrogen.

El-Sharkawy et al. (1977) reported a significant interaction between nitrogen and irrigation on grain yield and the number of grins per plant. Grain size and 1000-grain weight increased as nitrogen rates increased but decreased with water stress. Shimshi and Kafkafi (1978) reported that the absence of nitrogen decreased soil moisture extraction during the grain filling stage. Patra (1990) revealed that increase in fertilizer and irrigation rates, increased the number of ears/m^2, grains/ear and 1000-grain weight.

Singh (1978) reported that grain yields with 60kgN/ha were the highest when irrigated at 75mm CPE and with 120 kgN/ha when irrigated at 75mm CPE up to the earing stage and thereafter at 50mm CPE upto maturity. Singh et al. (1980) revealed that yield of wheat was significantly affected by irrigation water and N treatments. Maximum yield was obtained with irrigation at 50 percent available soil moisture and addition of 120kgN/ha. On the contrary, Malik et al . (1986) reported that wheat grain yields were not significantly affected by irrigation frequencies when 4 nitrogen rates were used (0, 60, 120 and 180kgN/ha). The highest yield of 4.68t/ha was obtained with 120kgN/ha.

Aremu (1983) using five levels of N (0, 50, 100, 120, and 150kg/ha and three irrigation intervals (5, 7 and 9 days) at Bakura, reported significant increases in grain yield of wheat with the application of 100kgN/ha after which there was no

appreciable increase. Effect of moisture regime was significant but the interaction between nitrogen and moisture was not significant. Further, the crop yield decreased with nitrogen application as irrigation interval from 5 to 7 days caused a yield reduction of 14 percent while further delay of irrigation to 9 days resulted in 25 percent yield reduction. Chari et al. (1980) testing wheat crop response to nitrogen levels (0, 5, 100, 150 and 200kg/ha) under two irrigation intervals (7 and 14 days) at Kadawa, reported a maximum yield of 3.3t/ha with 150kgN/ha under 7-day irrigation schedule.

2.6 Sowing Date

The quality as well as the yield obtained from a crop depends upon the various agronomic practices employed during the growth and development period of the crop. Amongst all the practices, date of sowing appears to be the most important single factor limiting yield especially in wheat. The wheat season in Nigeria is characterized by wide fluctuation of day and night temperatures. The temperature decreases from October to January and increases from February. The rising temperature thus limits the growing season and the wheat yield in relation to planting dates (Kumar et al. 1982). Date of sowing, depending on the temperature conditions influences the maturation period and the leaf area duration (LAD) of crops. Date of sowing (depending on the prevailing weather

conditions) significantly affected the days to maturity, protein percentage and grain yield of wheat (Briggs and Attinaw, 1979). Doyle and Marcellos (1974) associated low grain yield of wheat from late sown crop to lower leaf area and duration obtained after flowering. Nerson et al. (1979) showed that early sowing increased the number of days to anthesis but decreased the number of tillers/m^2 resulting in lower grain yield.

Singh and Dixit (1985) reported that 5 wheat cultivars shown between 10 and 25 November and 10 and 25 December gave average grain yields of 5.18, 5.64, 5.09 and 3.90t/ha, respectively. The number of grains/ear and 1000-grain weight decreased in the late sown crops. Afzal and Nazir (1986) working with 2 wheat cultivars sown on December 12 and January 4 reported that yield was greater in both cultivars from sowing in December rather than January. However, there was no significant difference in straw yield between sowing dates or cultivars. The 1000-grain weight was greater in early sown wheat (December) and in cultivar LU26 and the number of grains/spike was greater from sowing in December and in cultivar SA 75.

Delaying sowing date decreased yield (Ibrahim et al. 1976 and Drewit et al. 1978) as a result of smaller number of grains/ear, fewer ears/m^2 and a lower grain weight. Also, concerning delay in sowing date, Singh and Kumar (1981)

reported a decrease in water-use efficiency in wheat with delay in sowing date. Ansari et al. (1989) reported a decline in the number of tillers/plant, grains/spike, 1000-grain weight and grain yield as sowing was delayed from November 1, 10, 20 to December 1, 10 and 20. Various other reports (Larter et al. 1971; Lensik, 1971; Anonymous 1979; Jain et al. 1992) have also shown that late sowing decreased grain yield by decreasing tillering and the number of grains/plant.

Kumar (1985) reported low grain yield of 0.81 - 1.92t/ha with 5 wheat cultivars grown under late sown conditions (December 19 and 31). Kalyan et al. (1985) in their trials with 3 new wheat cultivars sown on November 6, November 21 and December 6, reported that the crops sown on November 21 resulted in 6.9 and 18.0 percent higher yields than those sown on December 6 in the two seasons, respectively. This sowing date also produced an increase of 11.5 percent in yield over the November 6 sowing date. Chaudhary et al. (1988) reported that for wheat sown at biweekly intervals from late October to early January, the yield showed a quadratic relationship with the number of days after sowing on 23 October; the optimum sowing date was around 12 November. Crops sown at the optimum date induced greater rooting in the profile.

Sharma et al. (1989) in assessing grain and straw yields of 4 varieties of wheat at 3 sowing dates (10 and 30 November and 15 December), reported that variety WH 711 gave

significantly higher yields than the other varieties when sown on the normal date (10 November). There were no significant differences when the varieties were sown on 30 November. The varieties PBW 34 and DWL 5023 were significantly better than the others with late sowing.

Sandhu et al. (1978) working on 3 sowing dates (November 10, December 5 and 30) of wheat, reported that maximum grain yield of 3.76t/ha was obtained by sowing on November 10; which declined to 2.90 and 1.54t/ha when sowing was delayed to December 5 and 30, respectively. Similarly, Habib and Makki (1979) in their trials with wheat cultivar Super-X sown on 4 sowing dates between November 1 and January 9, revealed that the optimum sowing date of wheat was in November giving average grain yield of 4.40 to 6.76t/ha. Yield and yield components decreased greatly with later sowings. Prasad (1979) also found that delay in sowing at 2-week intervals between November 15 and January 11 produced decreases in grain yields of wheat from 3.48 to 1.25t/ha. Kumar and Mayaki (1982) also reported significant decline in grain yield with delay in planting beyond November which was attributed to reduction in head length and 1000-grain weight. Similarly, Palmer-Jones (1978) also working at Kadawa reported that planting wheat in November gave significantly higher grain yield compared with the December planting. Kumar and Yayock (1980) reported a grain yield of 4640kg/ha for timely sown

(mid-November) wheat as against 59 percent lower grain for late sown (mid-December) crop. This reduction was as a result of the decrease by 35, 24 and 23 percent in the 3 yield components of number of grains per head, 1000-grain weight and the number of productive shoots per unit area, respectively.

Cooper (1992) in his work revealed that yield reduction increased with later sowing date. For each day later than 15 November, the mean grain yield fell by 1.3% or about 68kg/ha/day. Rising temperatures not moisture stress seemed to be the factor causing the decreases in yield with late sowing. However, Winter and Musick (1993) attributed the reduction in grain yield in relation to late sowing of wheat to insufficiet rooting to fully extract soil water from blow the root zone.

CHAPTER 3.

3.0 MATERIALS AND METHODS

3.1 Growth Chamber Experiment

A growth chamber experiment was conducted at the Hydrotechnical Laboratory, Royal Veterinary and Agricultural University, Copenhagen (Denmark) between June and November, 1984. The object of the experiment was to evaluate the performance of two dwarf wheat varieties under 4 moisture stress treatments with emphasis on crop and soil water status.

3.1.1 Physical properties of soil

Some physical properties of the soil used for the growth chamber experiment are given in Appendix 1. the texture of the soil was determined after passing the air dried soil through a 4mm sieve. Texturally the soil was loamy sand similar to Kadawa soil which was moderately deep sandy clay loam with loamy sand tops.

3.1.2 Soil moisture characteristic curve

The soil moisture at Field Capacity (FC), permanent wilting point (PWP), and available moisture content for the soil used was determined from moisture characteristic curve using pressure plate (Fig. 1). The FC and PWP of the soil were 14.00 and 3.60 percent respectively on dry wet basis.

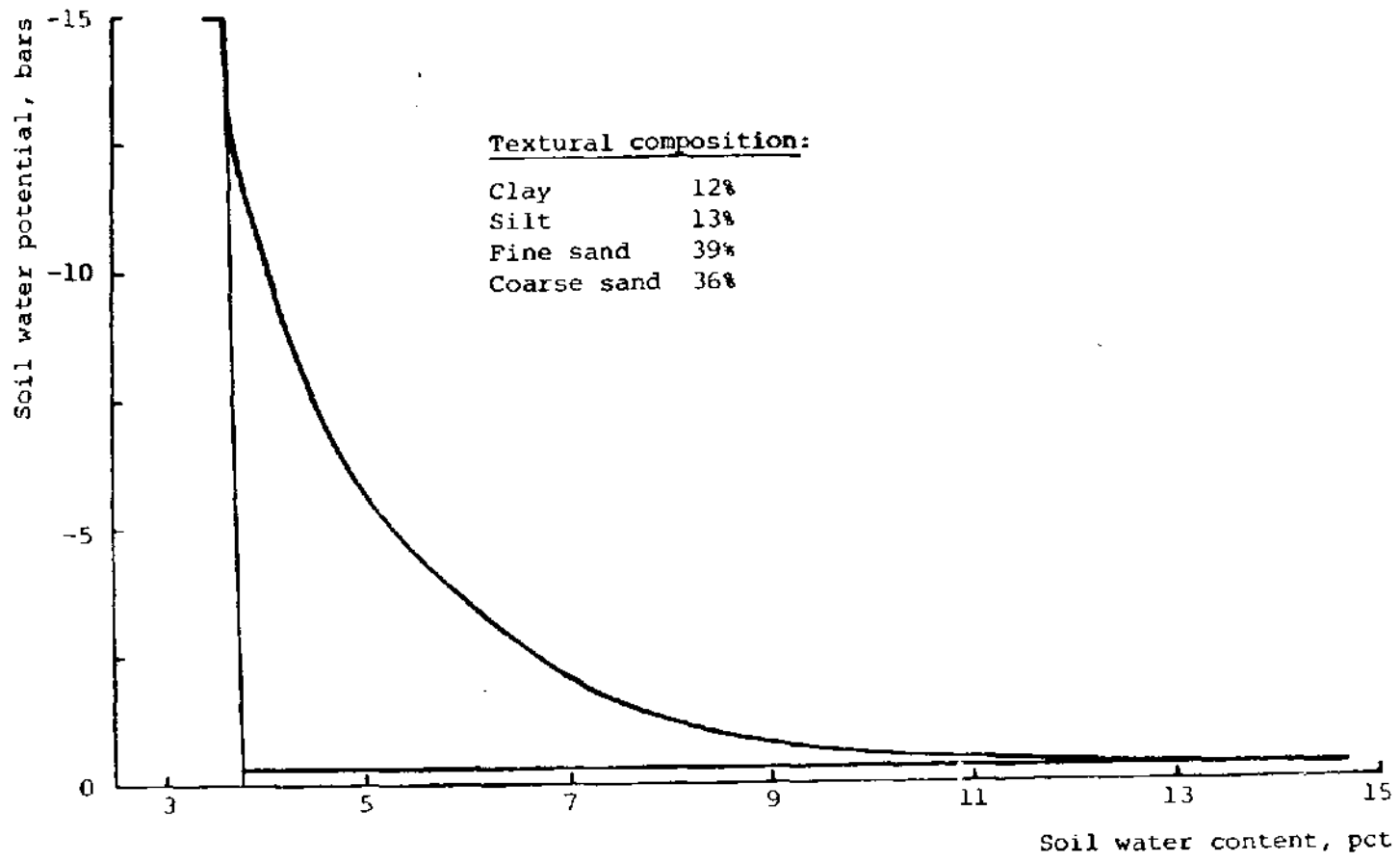


Fig. 1. Soil moisture characteristic curve for loamy sand soil used in growth chamber experiment.

3.1.3 Treatment and design

Two dwarf spring wheat (Triticum aestivum L.) varieties 'Sonalika' and 'Siete Cerros' were subjected to three stress treatments (0.0, 0.25, 0.50 and 0.75 FC loss) making 8 treatments. Each treatment was repeated 6 times in completely randomised design.

The wheat plants were grown in pots 23cm in diameter and 27cm in height. The pots were randomly placed in two growth chambers and were rotated frequently in order to eliminate any effect due to their positioning in the chambers. Two set of pots (16 pots) were used for sampling for the plant water relation studies and soil moisture determination. Thus, four sets (32 pots) were used for growth, yield components and grain yield determination.

Each pot contained 21kg of air dry soil to which 11.0g $(NH_4)_2 HPO_4$; 6.0g urea $(NH_2)_2 C0$; 12.2g $MgS0_4 . 7H_20$; 3.0g $CaC0_3$; 0.9g $MnS0_4 . H_20$; 0.5g $CuS0_4 . 5H_20$ and 11.5g K_2S0_4 coressponding to 5.1g N; 2.6g P; 1.0g Mg; 1.2g Ca; 0.16g Mn; 0.13g Cu and 5.0g K, respectively were applied.

3.1.4 Weather parameters in growth chamber

The day and night mean temperatures were maintained at 22 and 12°C, respectively. The day light intensity used was 400uE/S/m^2 (400 - 700nm) which corresponded with the photosynthetically active rediation (PAR), the only light waveband to which plants respond. The dark and light periods

used were 14 and 10 hours, respectively.

3.1.5 Seeds and sowing

Prior to sowing, 2.5 litres of distilled water was applied to each pot to bring the soil to saturation level. Twenty four hours after saturation, 50 seeds were sown on 25th July and 10 days later the seedlings were thinned to 25. Before sowing, the seeds were soaked in distilled water and kept under aeration for 24 hours to ensure good germination. The pots were covered with aluminium paper for 2 days to prevent evaporation loss until the seeds began to germinate under screen house condition. Four days after seedling emergence, the pot surface was covered with 2.0cm thick layer of perlite to minimize the direct evaporation loss from the soil surface.

3.1.6 Moisture Stress

Moisture stress was imposed from the third week after germination up to two weeks before harvest. the stress was imposed by withholding water application until the moisture in the soil reached the desired level (0.0(no stress), 0.25, 0.50 and 0.75 of the field capacity of the soil) and thereafter water was added to return the soil moisture content to field capacity level. This was accomplished by taking pot weights daily using an electric balance. Based on soil moisture deficit, irrigation was scheduled out daily in the control or fully irrigated treatments throughout the entire crop growing

period in order to maintain optimum soil moisture condition. Similarly, all other pots were irrigated after attaining the desired moisture depletion level.

3.1.7 Observations, measurements, calculations and analysis.

3.1.7.1 Plant growth and development

Plant height was measured weekly from soil level to the tip of the tallest leaf before jointing stage and the top of plant/ear after jointing and heading excluding awns.

3.1.7.2 Transpiration and soil matric potential

The transpiration rate was determined daily by weighing the pots about 2 hours after the light was switched on. The daily change in soil water content during the stress period was calculated by subtracting the daily transpiration from the field capacity level.

The soil matric potential corresponding to the respective soil water content was determined by collecting soil samples from the whole soil profile (0-1 and 15-27cm) using a small auger at the end of each stress cycle.

3.1.8 Crop water status

Stomatal resistance, total water and osmotic potentials, water content and relative water content of the second youngest leaves (next to the flag leaf) were studies from 6th week to 13th week about 4 hours after the light was switched on. The same leaves were used for measuring the following parameters.

3.1.8.1 Stomatal resistance (r_s)

Stomatal resistance against water vapour diffusion on the abaxial leaf surface was measured weekly by a diffusion porometer L1 - 700 (Lambda Instruments Corp., USA). The diffusive rate porometer gave direct readings for counts. From the counts using the calibration curve of the porometer obtained from counts against known resistance, the stomatal resistance was determined. Since the calibration of the porometer varied with level of humidity and with changes in air temperature, the porometer was kept for some time in the same condition as the plants. The measurement for stomatal resistance was made on both upper and lower surfaces of 3 fully expanded leaves per pot under each treatment.

3.1.8.2 Leaf water status

In order to obtain some information on leaf water status under various treatments, the total leaf water potential (ψl_t) leaf osmotic potential ($\psi l\pi$), leaf water content (W) and relative water content (RWC), were measured in the same leaves per pot used for measuring stomatal resistance.

3.1.8.3 Total leaf water potential (ψl_t)

The total leaf water potential was measured on the detached leaf with the leaf sheath by pressure chamber method as described by Slavik, (1974) and Miller and Hansen, (1975).

One fully 2nd expanded leaf from each treatment was cut with a sharp blade and carried in a plastic box immediately to the pressure chamber for measuring the total water potential.

3.1.8.4 Leaf water content (W) and relative water content (RWC)

Soon after measuring total leaf water potential, the leaves were kept in a specially designed highly humid box in order to prevent leaf evaporation. The RWC in leaves were determined as per the procedure given by Barrs and Weatherly (1962). Within minutes two segments of the fresh leaf each of about 2.0cm were cut and weighed (Wt_f) and then placed in a water bath at 18°C (almost similar to leaf temperature) for 4 hours under weak light intensity in order to obtain turgid weight. After saturation and taking the turgor weight (Wt_t), the leaf segments were oven dried at 80°C for 24 hours and were weighed again to obtain dry weight (Wt_d). Leaf water content (W) and relative water content (RWC) were then calculated as follows:

$$\text{Water content, } W = \frac{W^t_f - {}^{wt}d}{{}^{wt}d} \times 100$$

$$\text{Relative water content, RWC} = \frac{W^t_f - {}^{wt}d}{{}^{wt}t - {}^{wt}d} \times 100$$

3.1.8.5 Leaf osmotic potential ($\psi^1\pi$)

After taking the samples for W and RWC, the rest of the fresh leaf segment was frozen at - 20°C for 3 days in order to kill the tissue. After thawing and squeezing, the osmotic potential of the extracted leaf sap was determined by a vapour pressure osmometer using the thermocouple psychrometric method as described by Slavik, (1974).

3.1.8.6 Leaf pressure potential (ψ^1_p)

Leaf pressure potential or leaf turgor pressure was calculated from the measured values of total leaf water potential and leaf osmotic potential according to the equation:

$$\psi^1_t = \psi^1_p + \psi^1\pi$$

3.1.9 Yield and yield components

The wheat crop was harvested at two stages. Post harvest parameters namely length of spike, grains/spike and grain weight were determined from 5 spikes/pot prior to harvest about 100 days after sowing, and the secondary tillers were harvested 10 days later. The stalks were harvested 4 days after secondary spikes were harvested. The produce was oven dried for 24 hours at 70°C. Seeds were threshed, winnowed, separated and weighed for 1000-grain weight and grain yield per pot.

3.2 Field Experiments

3.2.1 Field Experiment I - Effect of water stress, sowing date and variety

3.2.1.1 Experimental Design and Treatments

Field experiments were conducted in a split-plot design using 3 water stress levels x 3 sowing dates as main treatment in a factorial arrangement and two dwarf varieties as subtreatments. Water stress levels were based upon Irrigation water/Cummulative pan evaporation (IW/CPE) ratio of 0.50, 0.75 and 1.00 allowing CPE to build up to 120, 80 and 60mm for the 3 stress treatments, respectively. Sixty millimeters (6.0cm) depth of water was supplied at each irrigation using water flow meter and based upon the soil moisture characteristics given in Appendix 2. The 3 sowing dates were 10th November (early), 1st December (medium) and 22nd December (late). The two dwarf wheat varieties used were 'Sonalika' (early maturing) and 'Siete Cerros' (medium maturing). The size of the subplot was 5 x 2m. To avoid any seepage effect, an unirrigated strip of 1.5m width was left between all main treatment. The subplot accommodated nine rows out of which 3 were treated as border rows, 2 for destructive sampling and for yield estimation, 4 rows were harvested (1x5m) as net plot. A representative field layout sketch during 1983/84 is shown in Appendix 3.

3.2.1.2 Land preparation

The land was irrigated, ploughed and harrowed twice to a fine tilth and was divided into subplots of 5m x 2m with vacant strips of 1.5m around all main plots. Provision for irrigation channel to lead water to each subplot was also made.

3.2.1.3 Soil analysis

Soil samples were taken at the beginning of each season at random throughout the field at a depth of 0 - 60cm prior to fertilization and the fertility status of the field determined from a composite sample of all random samples of the field. The soil samples were analysed for N, P and K using Kjeldhal, Bray 1 and Ammonium acetate (PH = 7.0) methods, respectively (Appendix 4).

3.2.1.4 Fertilizer application

The recommended dose of 50kgN, 45kg P_2O_5 and 30kg K_2O/ha were broadcast and incorporated into the soil using CAN, single superphosphate and muriate of potash. A second dose of 50kgN/ha was top-dressed at 4 weeks after sowing using urea (46%N).

3.2.1.5 Seeds and sowing

The recommended seedrate of 100kg/ha was dressed with Aldrex T and sown as per the sowing date treatments. The seeds were sown by hand in a drill at 2.5cm depth and 25cm between rows.

3.2.1.6 Weed control

Weeds were controlled twice by hand weeding at 4 and 7 weeks after planting. Thereafter, there was no weed problem as the crop canopy gave a good ground cover. However, later in the season (mid-February), with rise in temperatures, a few broadleaved weeds appeared in the field but did not pose any problem to the crop.

3.2.1.7 Meteorological data

Meteorological data recorded for the 3 experimental seasons is given in Appendix 6. The daily pan evaporation values recorded were used in scheduling irrigation as described earlier.

3.2.1.8 Observations

The detailed procedures for recording various soil and plant parameters in the two field experiments are described below:

(a) Pre-harvest crop observations

For periodic observations during the crop growth, 10 samples plants were used for some parameters, while inothers as in tillers and spike counts, 0.5m linear length was used and the number was estimated/m^2 therefrom.

(i) Plant height

Height of the main shoot from the sampled plant was recorded in cms from soil to the tip of spike excluding awns at maturity.

(ii) Number of tillers

Number of tillers was recorded from each subtreatment at 7 and 8 weeks after planting for 'Sonalika' and 'Siete cerros' and the number of tillers/m^2 calculated. The two varieties completed tillering at this age.

(iii) Dry matter accumulation

The plants were sampled at 3, 6, 9 and 12 weeks after sowing, sun-dried and then transferred to an oven and dried at 75°C till they attained a constant weight which was recorded. The dry matter content was determined/m^2 therefrom.

(iv) Number of spikes/m^2

The number of spikes were counted from 0.5m row and the number of spikes/m^2 determined therefrom.

(b) Post-harvest crop observations

(i) Length of spike

Length of spike was measured in cm from 10 sampled plants in each treatment and recorded.

(ii) Weight of grains/spike

Weight of grains from 10 sampled plants in each treatment was recorded in grains and weight of grains/spike was worked out therefrom.

(iii) Number of grains/spike

The number of grains from 10 sampled plants were counted and grain number/spike worked out therefrom.

(iv) 1000-grain weight

Three samples of 250 seeds each were counted from each subplot and weighed. One thousand grain weight in grams was estimated therefrom.

(v) Straw yield

The plants were cut from the base as close to the ground as possible, dried in the field and followed by drying in the oven at 75°C until they attained a constant weight. The weight of straw from sampled plants was also added to the weight of straw/plot. The data was converted from g/plot to kg/ha.

(vi) Grain yield

Yields of subplot inclusive of 10 sampled plants was dried until they attained a constant weight. The yields in g/plot were converted into kg/ha.

(c) Soil moisture observation

Soil moisture determinations were made by gravimetric method from sowing up to two weeks before harvest at periodic intervals to get some basic parameters. These studies were done in one replication only therefore was not analysed statistically. Soil samples were taken from three different

soil depth namely 0-30, 30-60 and 60-90cm by means of an auger. Soil moisture percentage was determined by oven drying the soil samples at 105°C for 24 hours and the moisture content calculated on dry weight basis with the help of the following formula:

$$PW = \frac{WS_1 - WS_2}{WS_2} \times 100$$

Where:
PW = percent soil water
WS_1 = weight of wet soil
WS_2 = weight of dry soil

The loss in moisture was expressed as percentage of oven dry soil.

(i) <u>soil moisture depletion pattern</u>

Soil moisture depletion was worked out layerwise for three different depths (SMD_1 - SMD_3) for the period between two successive soil samplings during the crop growth. After this, the total moisture depleted (SMD) from the root zone depth (0 -90cm) was calculated using the expression:

$$SMD^t = SMD_1 + SMD_2 + SMD_3$$

Moisture depletion for each layer was expressed as percentage of total soil moisture depletion in each period.

3.2.1.9 Water-use efficiency (WUE)

WUE of the crop was calculated viz:

$$WUE = \frac{\text{Weight of the grains (Y) in kg/ha}}{\text{Consumptive use (CU) of water in mm/ha}}$$

3.2.2.0 Statistical analysis

The date collected were subjected to statistical analysis of variance as described by Snedecor and Cochran (1967). Regression analysis was done to determine yield potential using response of different degrees of polynomials for dates of sowing, water stress and nitrogen levels as per the procedure described by Little and Hills (1978).

Path-coefficient analysis was conducted to establish the relative importance of major determinants of grain yield in each of the two field experiments as well as in combined analysis. Three variables were included in the path-coefficient analysis namely (1) 1000-grain weight (2) grain number/spike (3) spikes number/m^2 and their relative contribution was examined on grain yield (4). The nature of the causal system was also represented in path diagrams with double arrowed lines indicating mutual associations measured through simple correlation coefficients (r_{12}, r_{13} and r_{23}) and single arrowed lines representing direct influence as measured by path coefficients constants (P_{14}, P_{24} and P_{34}). The direct and indirect coefficients with grain yield for all possible

comparisons were worked out and tabulated as described by Johnson (1973).

Polynomial response or multiple correlation measures the combined relation between a dependent and a series of independent variables. It is the correlation between the observed values of the dependent variable and its estimated values for the independent variate values, estimated with the help of the multiple regression equation.

If the deviations between observed and expected of a response will not fit in, the deviations between observed and expected of the next degree of polynomial is tested. If the deviations are not significant using a chi-square test, it signifies the goodness of fit of that particular degree of polynomial response.

3.2.3 Field Experiment II - Effect of water stress and nitrogen fertilization.

3.2.3.1 Experimental Design and Treatments

The experiments were conducted in a randomised block design involving 4 nitrogen levels (0, 75, 150 and 225kg/ha) and 3 water stress levels of 0.50, 0.75 and 1.00 based upon IW/CPE ratios as in Field experiment I. Thus, 4 x 3 factorial combinations were allocated randomly to each replications (Appendix 7). The gross plot size was 5 x 2m with a strip of

1.5m wide all around the individual treatment plot to avoid seepage. Out of the nine rows in each gross plot, 3 rows were treated as border, 2 rows for destructive sampling and the remaining 4 rows were harvested as net plot (1 x 5m) for yield estimation.

3.2.3.2 Other Experimental Details

Land preparation, soil analysis, seeds and sowing, weed control measures, irrigation, meteorological data and procedures for taking observations were described in detail in experiment I. Only one variety (Siete cerros) was used in this experiment.

3.2.3.3 Fertilizer application

The two fertilizer, single superphosphate (18% P_2O_5) and muriate of potash (60%K_2O) were applied uniformly to the experimental plots before sowing. Nitrogen was applied in two equal splits at sowing and 4 weeks after sowing through Urea (46%N) to the plots as per the layout of the experiment.

CHAPTER 4

4.0 **RESULTS**

4.1. Growth Chamber Experiment

4.1.1. Plant height

Taller plants were produced by the control (no stress) followed by 0.25 field capacity loss (mild stress), than the moderate and severe stress levels, respectively. Water stress effects were found to be more pronounced on 'Siete Cerros' than on 'Sonalika' (Fig.2 and 3).

Plant height in 'Sonalika' reached its maximum at 77 days after emergence although the 0.50 FC loss (Fig.2). The control and 0.50 FC loss stress produced taller plants that continued growing even after 77 days from emergence in 'Sonalika'. Similar response was recorded in 'Siete Cerros'. Growth was generally higher in 'Siete Cerros' at all levels of stress except the control indicating its better response to water stress as compared to 'Sonalika'.

4.2. Crop Water Relations

4.2.1 Transpiration

Both varieties grown under no stress transpired more water than stressed conditions. A general trend of appreciable decrease in transpiration rate was observed at 70 days after sowing irrespective of stress level or variety. During the peak transpiration period, 100 days after sowing (DAS), under

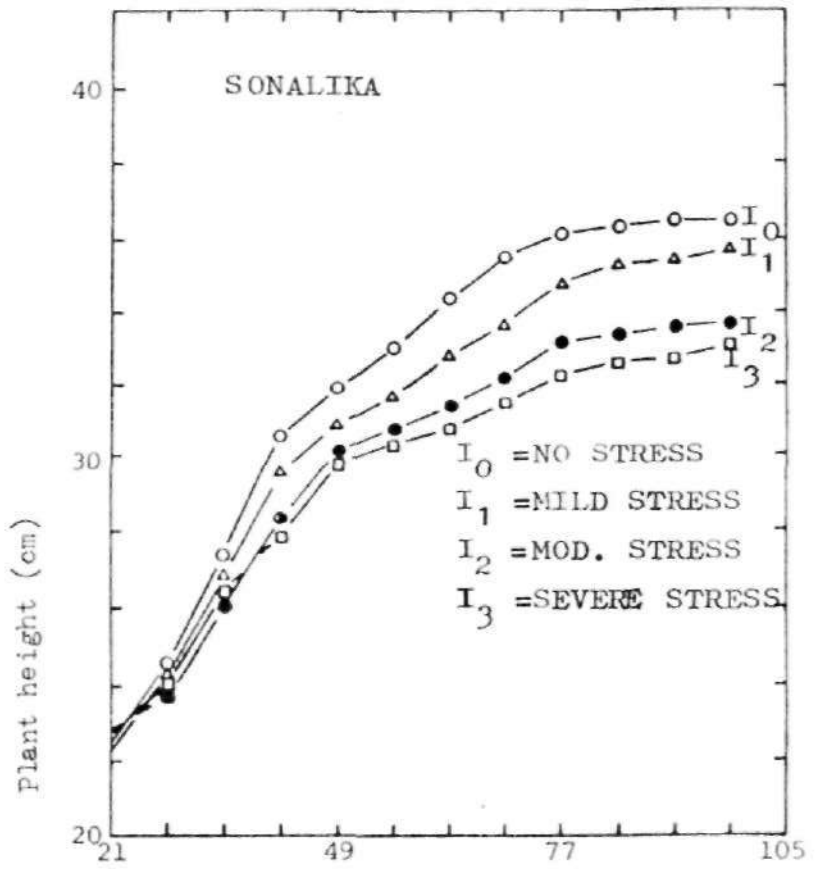


Fig. 2

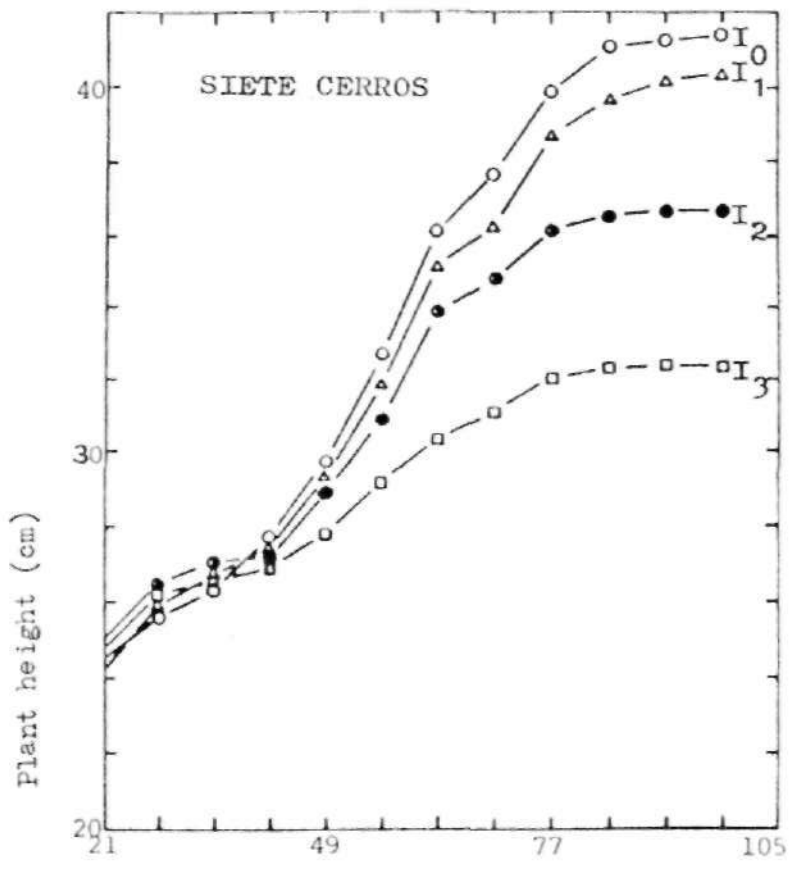


Fig. 3

Plant height of wheat varieties as affected by soil moisture stress under growth chamber condition at RVAU Copenhagen, Denmark, 1984.

no stress condition, 'Sonalika' transpired 1170g/pot/day while 'Siete Cerros' transpired 850g/pot/day (Fig. 6). 'Sonalika' transpired more water than 'Siete Cerros' especially from 60-100 DAS after which a general decline in transpiration was observed. A comparison of transpiration rate of the two varieties at different stress levels is shown in (Fig. 4-9).

4.2.2. Stomatal Resistance(r_s)

Stomatal resistance was higher in stressed plants (25-28 S cm^{-1}) as compared with no stressed plants (4-7s cm^{-1}) irrespective of variety (Fig. 10 and 11). The stomatal resistance increased from about 14s cm^{-2} to 27s cm^{-1} with increase in moisture stress from mild (0.25 FC loss) to severe (0.75 FC loss). 'Sonalika' exhibited higher stomatal resistance (7-28s cm^{-1}) compared to 'Siete Cerros' (4-25s cm^{-1}) through all the growth stages.

4.2.3 Total Water potential in Leaves (ψ^1_t)

Irrespective of varieties, leaf water potential was generally lower by -1.0MPa in severely stressed plants compared with the control treatment at 48 days after emergence (Fig 12 and 13). This difference increased from -1.75MPa in 'Siete Cerros' to -2.5MPa in 'Sonalika' at 90 days after emergence. A gradual decrease in leaf water potential was recorded in 'Sonalika' as from 55 days after emergence (Fig.12).

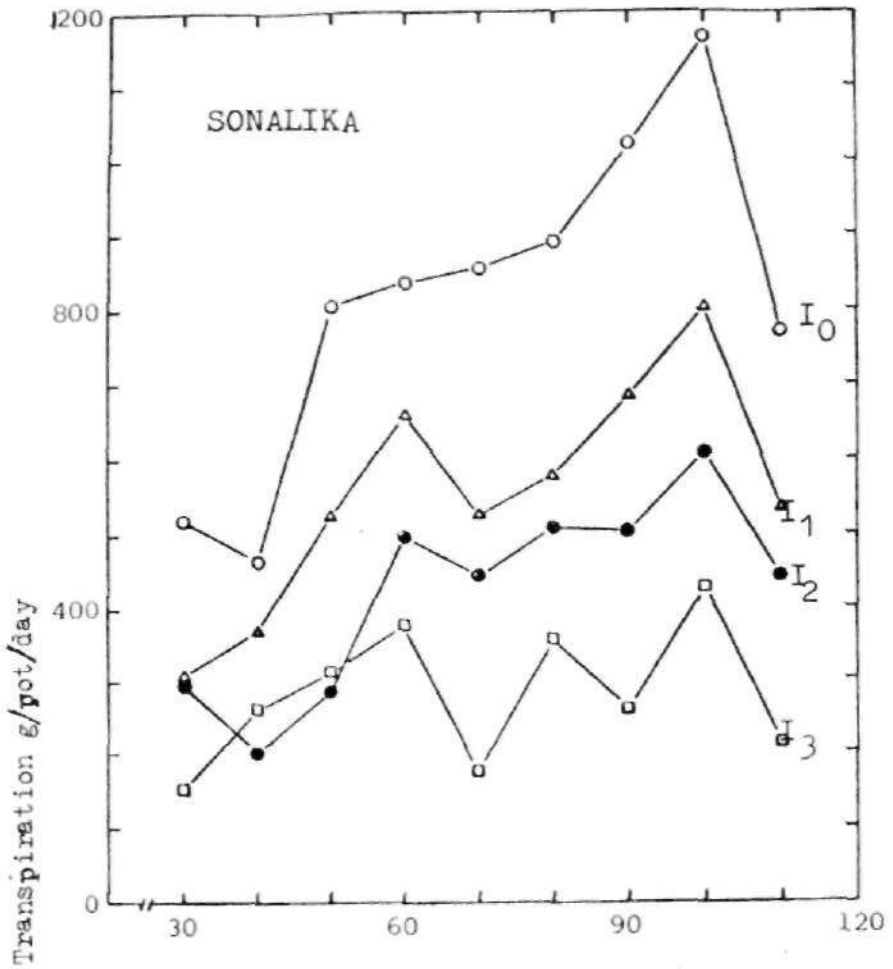


Fig.4

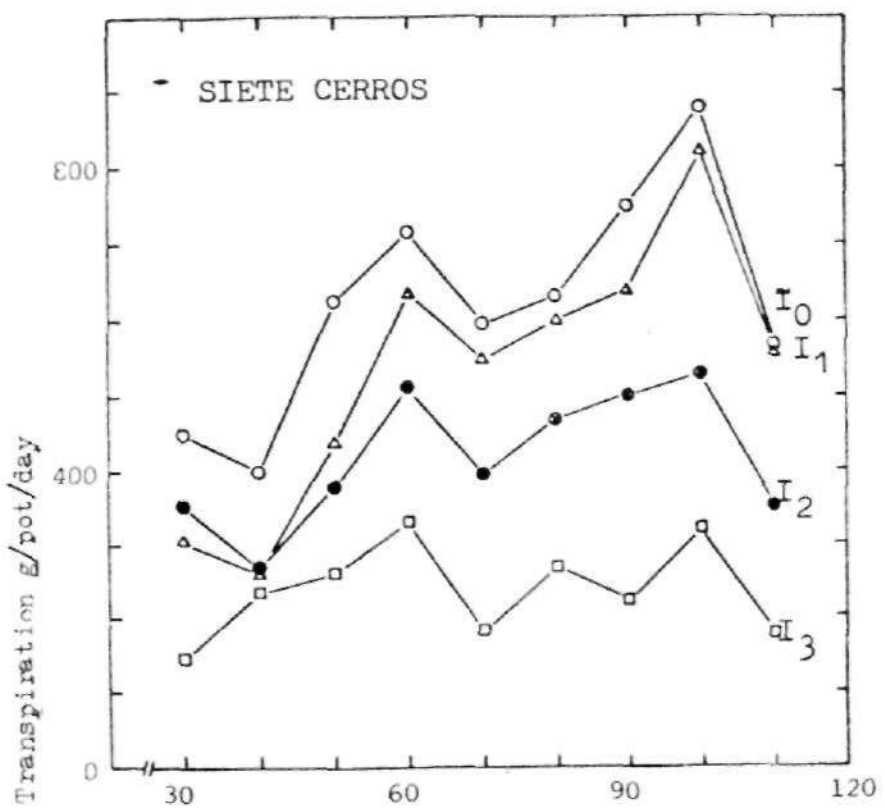


Fig. 5

Change in transpiration rate of wheat varieties as affected by soil moisture stress under growth chamber condition at RVAU Copenhagen, Denmark, 1984.

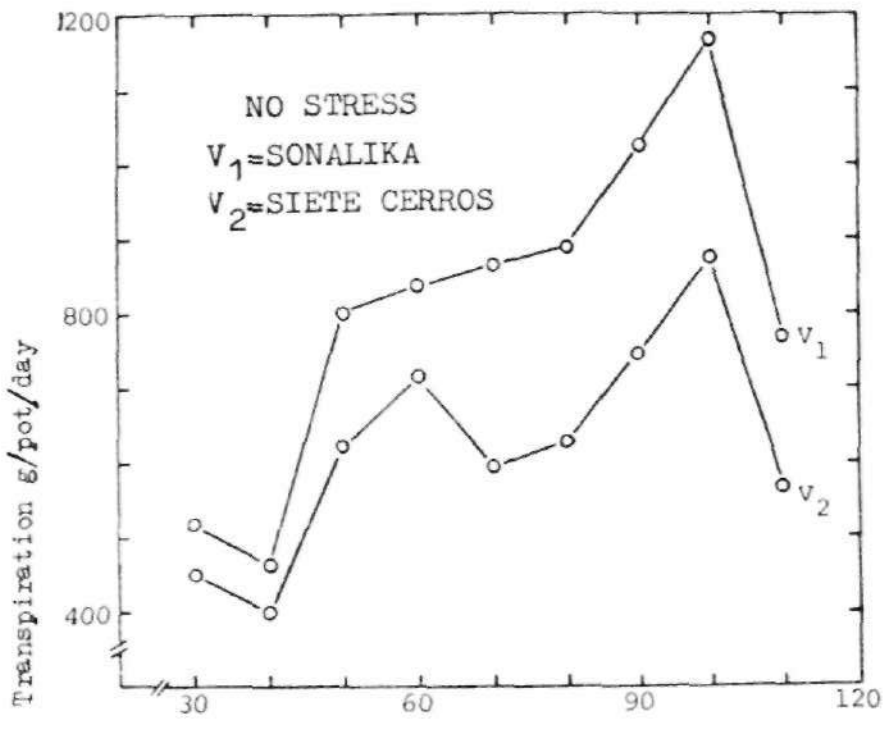


Fig. 6

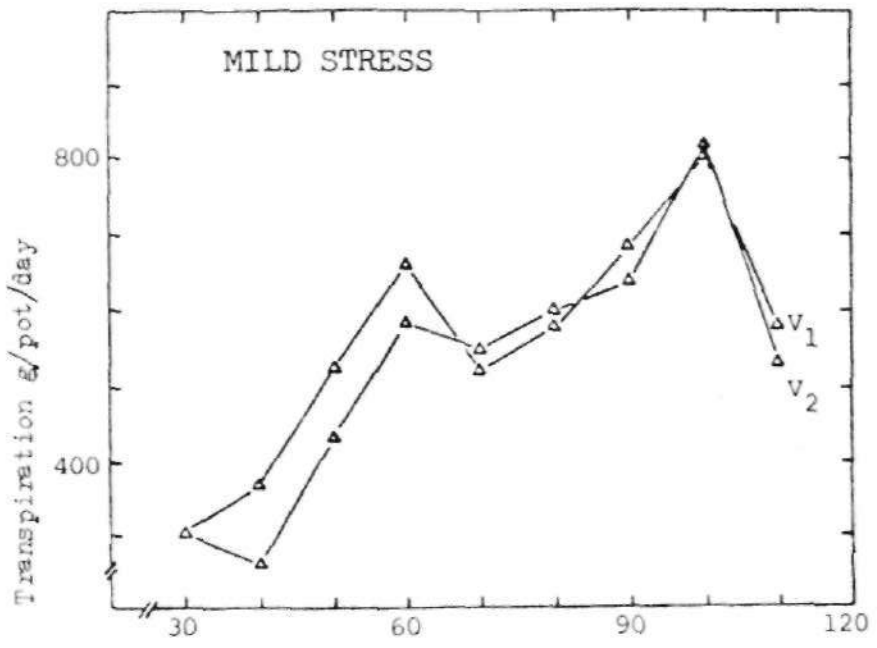


Fig. 7

Transpiration rate of wheat varieties at different moisture stress levels under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

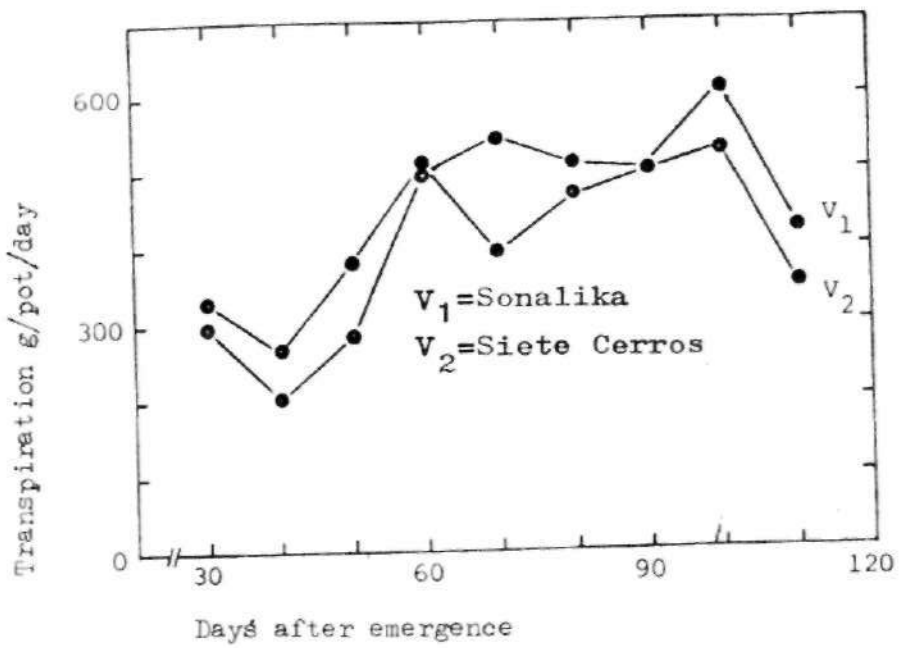


Fig. 8 (Moderate)

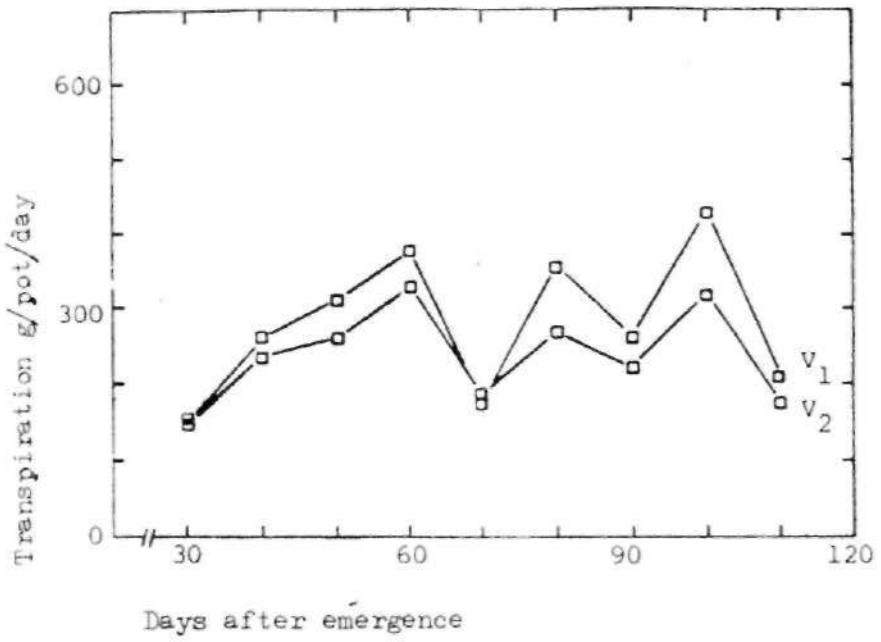
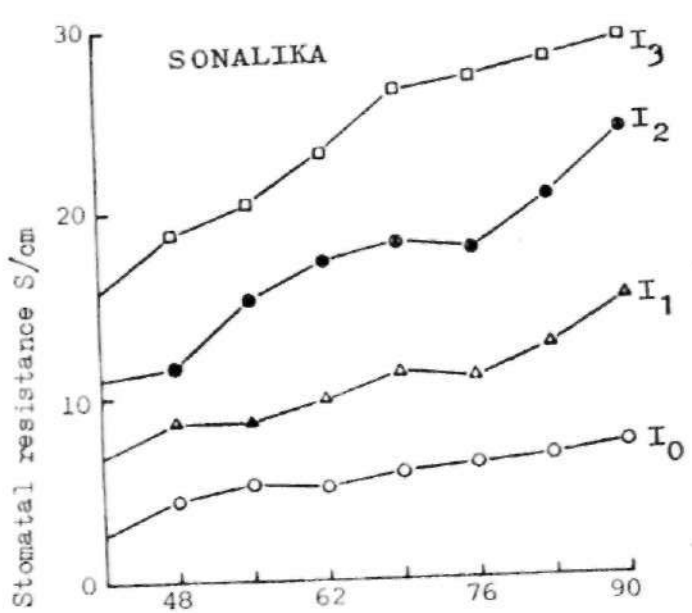


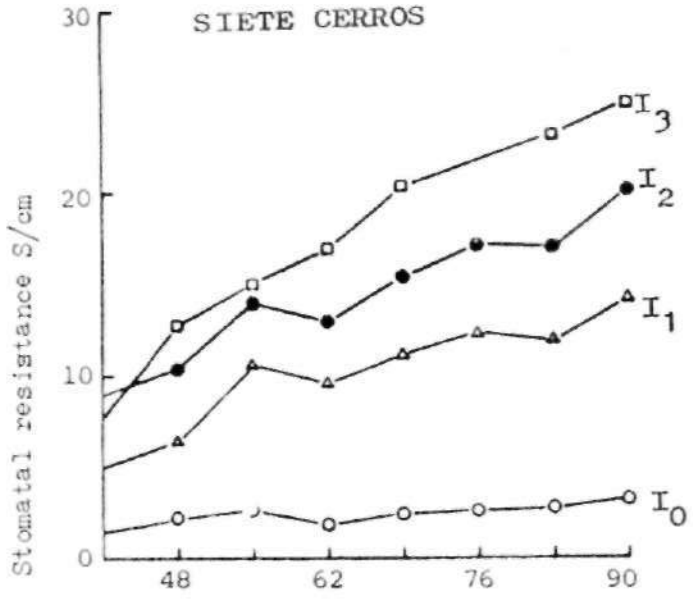
Fig. 9 (Severe)

Transpiration rate of wheat varieties at moderate and severe stress levels under growth chamber condition at RVAU, Copenhagen, Denmark. 1984.



Days after emergence

Fig. 10



Days after emergence

Fig. 11

Stomatal resistance of wheat varieties as influenced by moisture stress under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

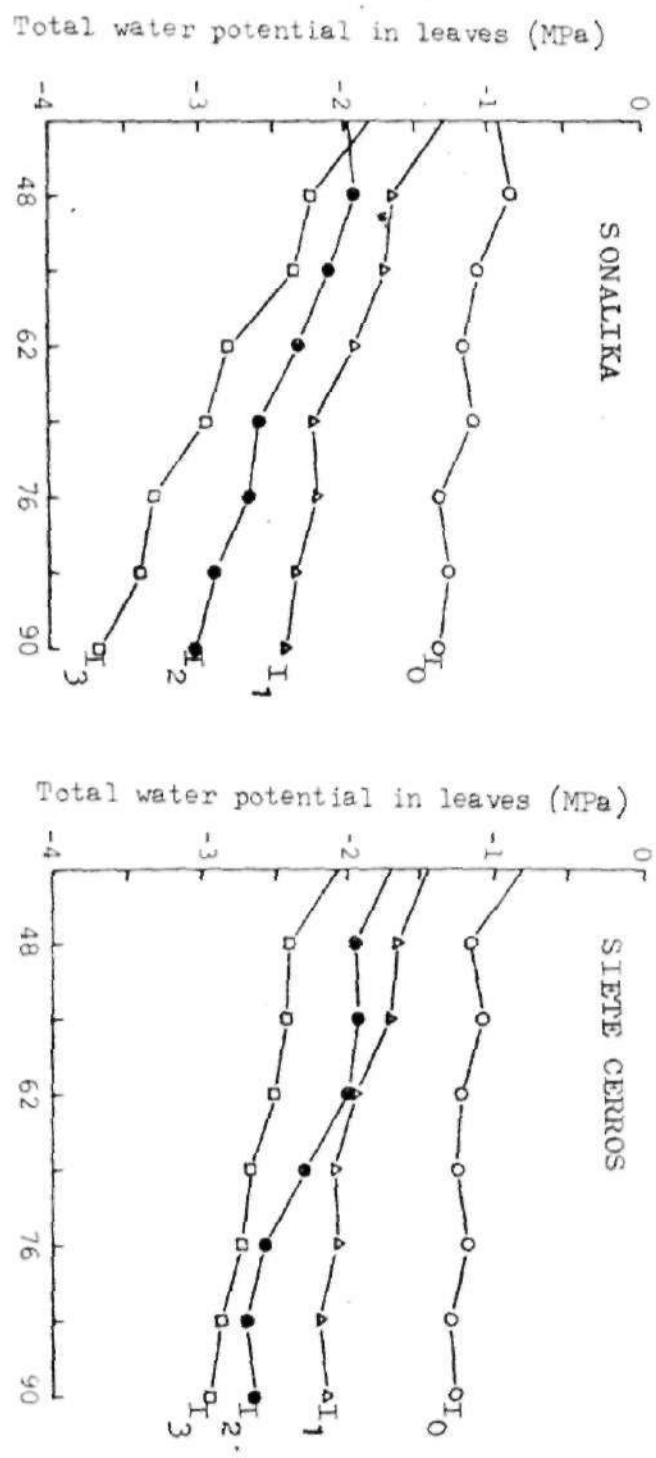


Fig. 12

Changes in total leaf water potential of wheat varieties as influenced by moisture stress under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

Fig. 13

4.2.4 Leaf Osmotic Potential ($\psi^1\pi$)

Severely stressed plants exhibited lower osmotic potential of -1MPa at 48 DAS and -2MPa at 69 DAS compared with no stress (control) treatments (Fig. 14 and 15). The difference in $\psi^1\pi$ between stressed and control treatment was more prominent in 'Sonalika' than 'Siete Cerros'. Sonalika produced higher $\psi^1\pi$ in moderate and severe stress treatments, with the highest $\psi^1\pi$ of -4.1MPa at the severe stress level of 0.75 FC loss at 69 days stage.

4.2.5 Leaf Pressure Potential (ΨL_p)

As expected, there was an increase in ψl_p with increase in water stress with the highest ψ^1_p of -0.2MPa recorded in 'Sonalika' at 0.75 FC loss. 'Siete Cerros' recorded lower ψ^1_p at all stress levels as compared with 'Sonalika' by a range of 0.5 to -1MPa (Fig. 16 and 17).

4.2.6 Leaf Water Content (W)

Leaf water content of unstressed plants remained fairly constant throughout the growth stages in both varieties. However, there was a decrease in W especially in moderate to severely stressed plants (0.50 FC loss and 0.75 FC loss). 'Sonalika' had lower W by about 1g/g as compared with 'Siete Cerros' at 90 days stage (Fig. 18 and 19).

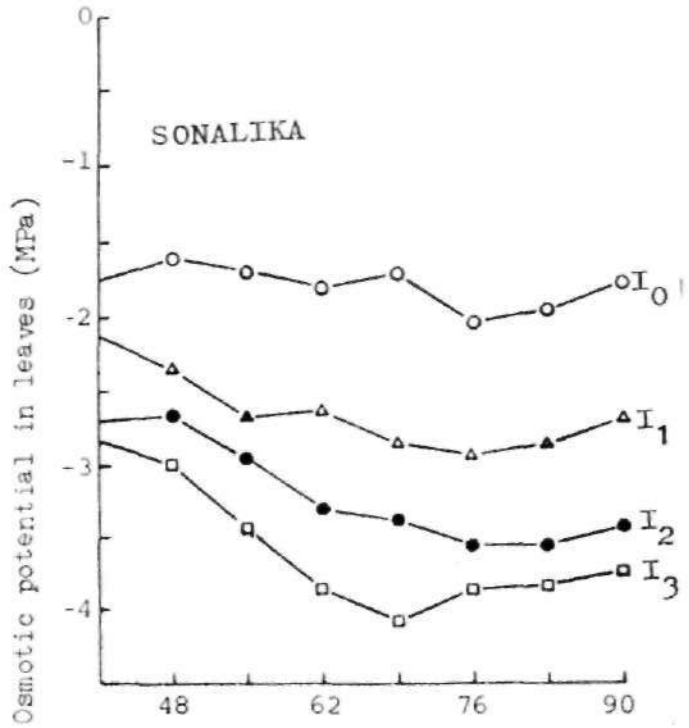


Fig. 14

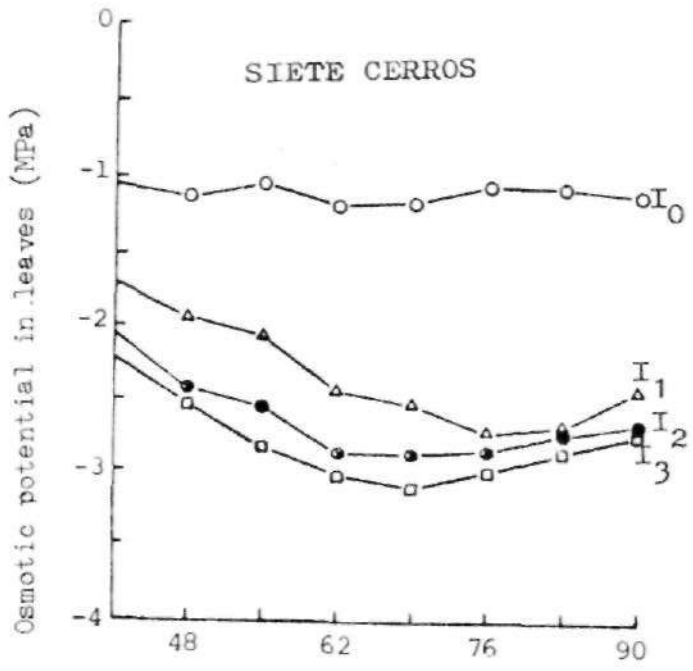
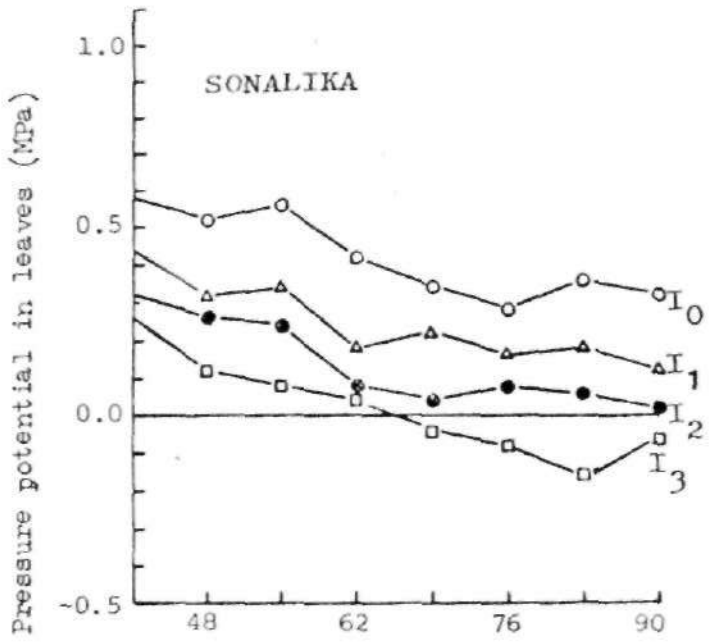


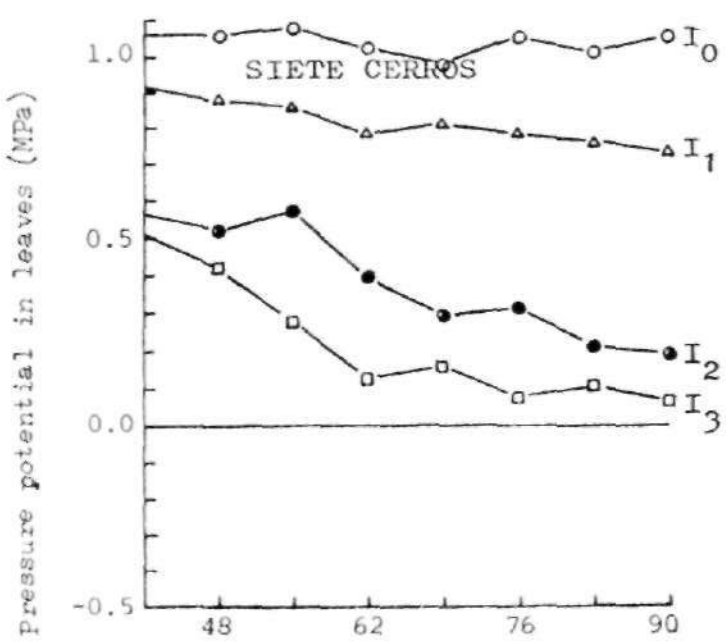
Fig. 15

Changes in leaf osmotic potential of wheat varieties as influenced by moisture under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.



Days after emergence

Fig. 16



Days after emergence

Fig. 17

Changes in pressure potential in leaves of wheat varieties as influenced by moisture stress under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

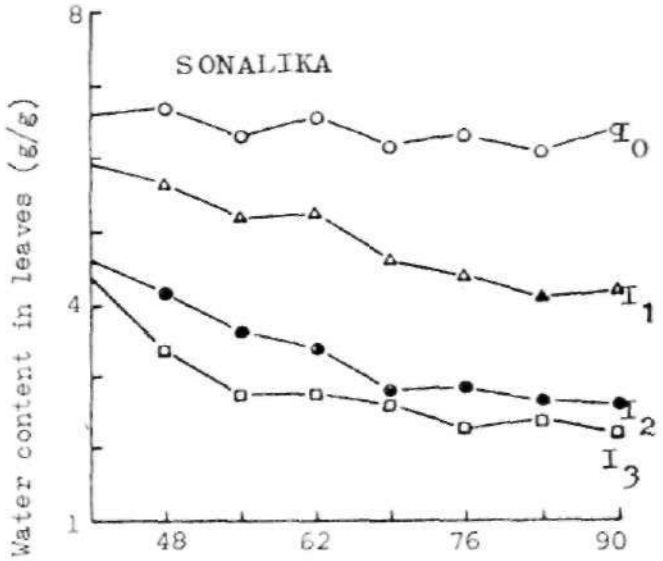


Fig.18

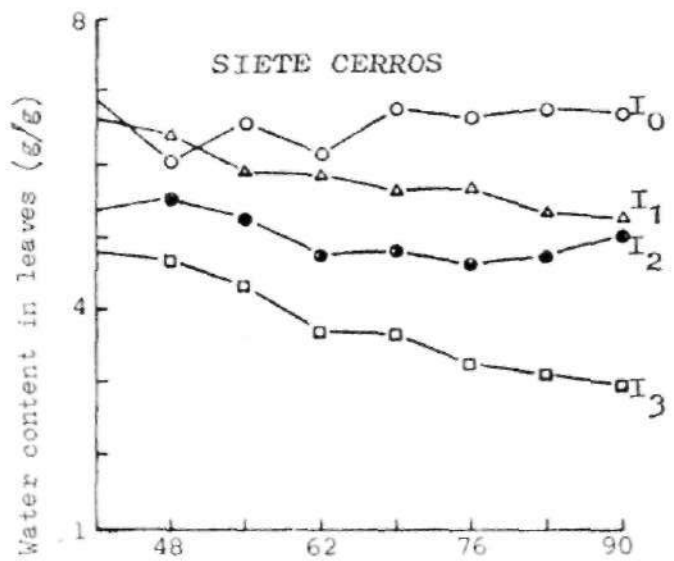


Fig. 19

Changes in water content in leaves of wheat varieties as influenced by moisture stress under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

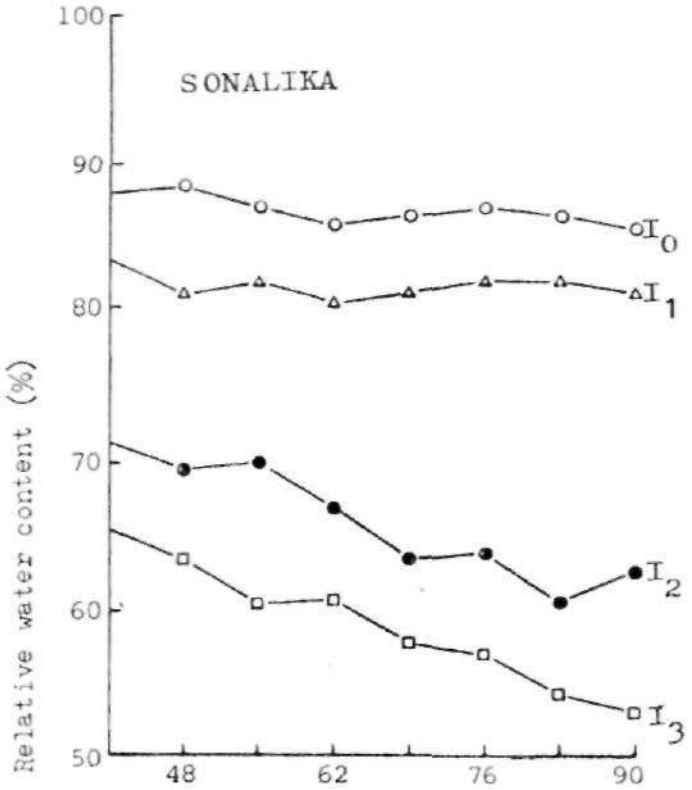


Fig. 20

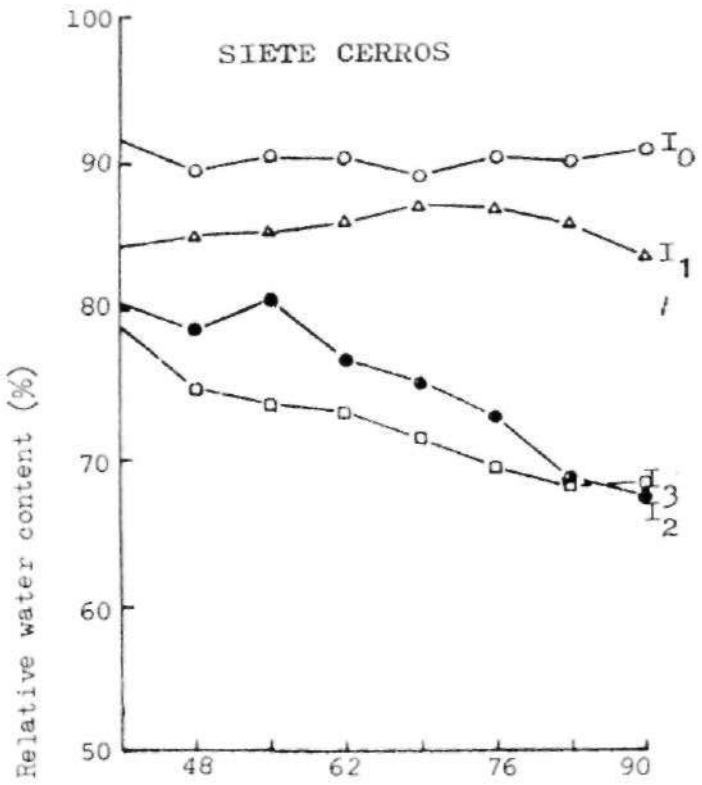


Fig. 21

Changes in relative water content in leaves of wheat varieties as influenced by moisture stress under growth chamber condition at RVAU, Copenhagen, Denmark.

4.2.7 Relative Water Content (RWC)

The RWC of unstressed and mildly stressed plants remained almost constant throughout the season (Fig. 20 and 21). There was a general decrease in RWC with increase in water stress. The lowest RWC of 53% of was recorded in 'Sonalika' compared with 68% in 'Siete Cerros' at 0.75 FC (Severe stress) level.

4.3 Crop Water Status of Two Varieties in Relation to Soil Matric Potential (Ψs_m)

4.3.1 Transpiration

Comparing the two varieties with respect to the rate of transpiration in relation to leaves, the decrease in 'Sonalika' was not as marked as in 'Siete Cerros'. In 'Sonalika' (Fig.22) the transpiration rate decreased to 175g/day/pot at (Ψs_m) of -1.3MPa under severe stress. In the case of 'Siete Cerros', (Fig. 23) the decrease in transpiration as down to 310, 210 and 150g/day/pot for mild, moderate and severe stress treatments, respectively.

4.3.2 Stomatal Resistance (r_s)

Stomatal resistance increased from 8-29s cm^{-1} with increasing (Ψs_m) from -0.3 to -1.5MPa (Fig.24 and 25). The increase was very rapid in the case of moderate/severe stress treatments (0.5 to 0.75 FC) in both varieties. In case of

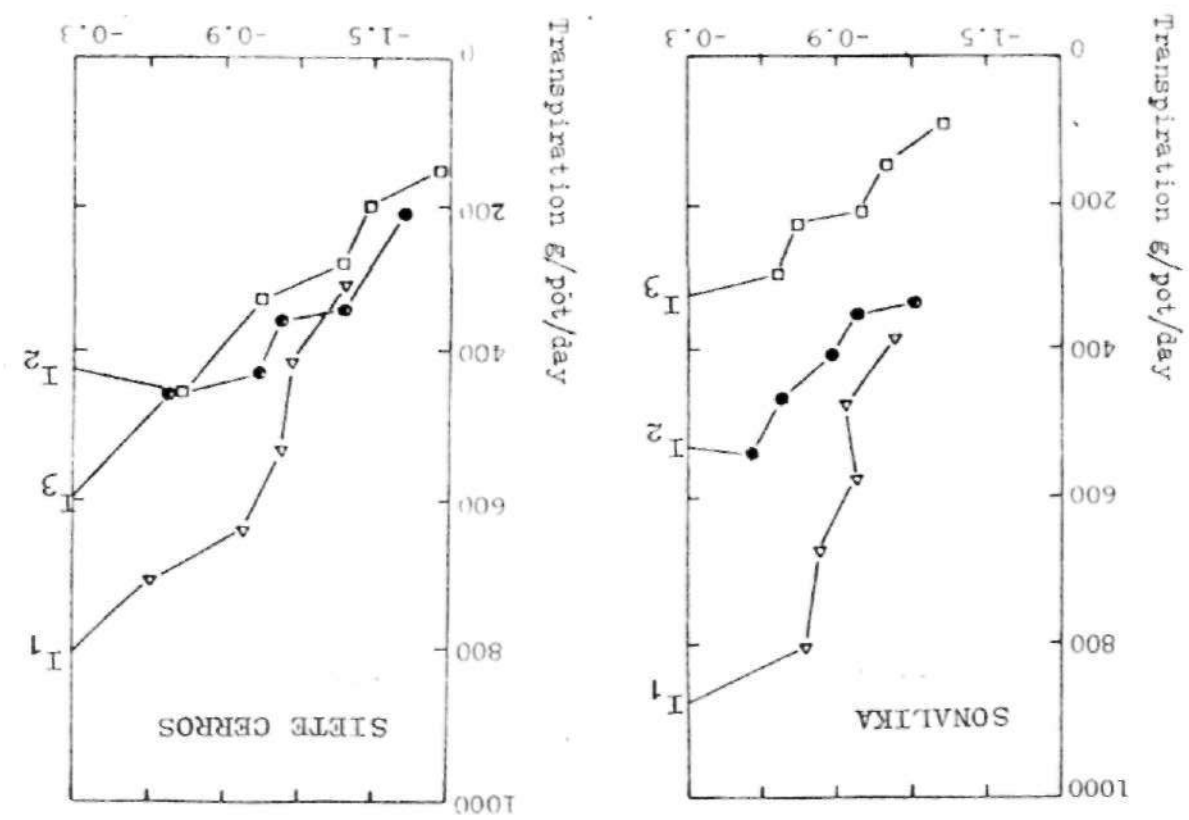


Fig. 22 Fig. 23

Transpiration rate of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

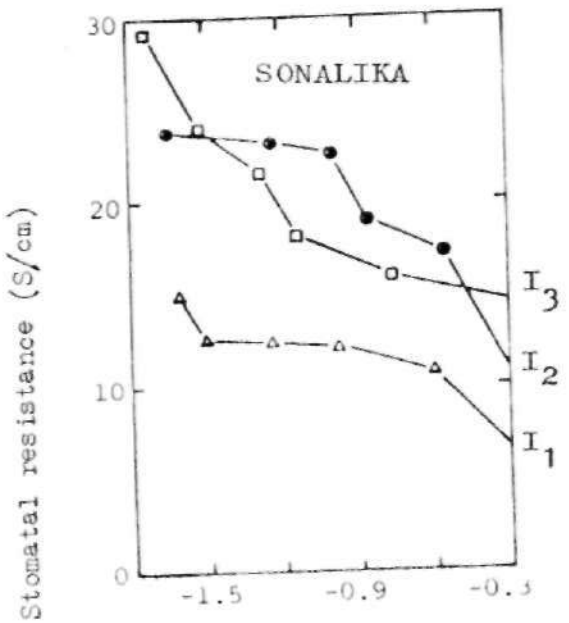


Fig. 24

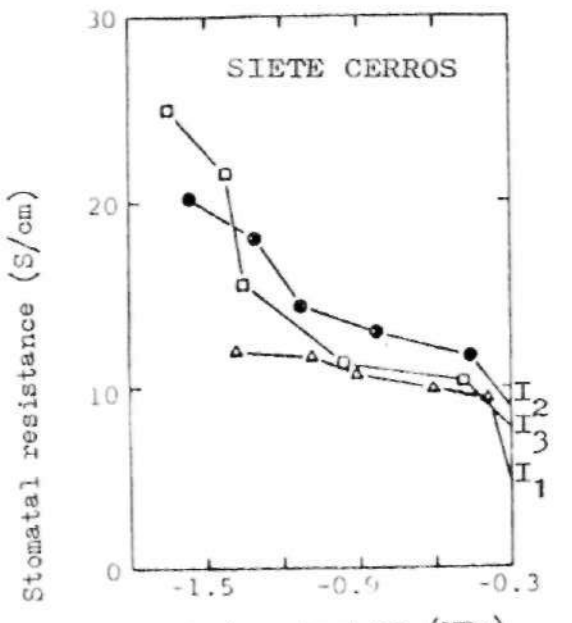


Fig. 25

Stomatal resistance in leaves of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

'Sonalika' the stomatal resistance for moderate and severe stress treatments increased to 24 and 29s cm^{-1} with corresponding (ψ^s_m) of -1.65 and -1.73MPa respectively (Fig.24). The increase in r_s in mild stress treatment was not as rapid even with increasing (ψ^s_m) to about -1.60MPa. However in 'Siete Cerros' (Fig. 25) even with increased (ψ^s_m) the severely stressed plants (0.75 FC loss) attained r_s of 25s cm^{-1} while mildly stressed plants reached a maximum of only 12s cm^{-1} showing that 'Siete Cerros' in comparison with 'Sonalika' can maintain lower atomatal resistance even under increased (ψ^s_m) (-1.65MPa).

4.3.3. Leaf Total Water Potential (ψL_t)

Increase in leaf total water potential was more pronounced in severe stressed plants in both varieties (Fig.26 and 27). Variety 'Siete Cerros' showed less increase in leaf total water potential in comparison to 'Sonalika' under all stress treatments indicating the variety to be more stress resistant than 'Sonalika'.

4.3.4 Leaf Osmotic Potential ($\psi^l\pi$)

The Osmotic potential in leaves of 'Sonalika' remained stable under soil matric potential of -0.3 to -1.0MPa in all the stress treatments (Fig.28), and only began to increase after attaining a soil matric potential of -1.2MPa. In contrast 'Siete Cerros' (Fig.29) exhibited a more rapid increase (-1.75 to -0.3MPa) in osmotic potential up to soil

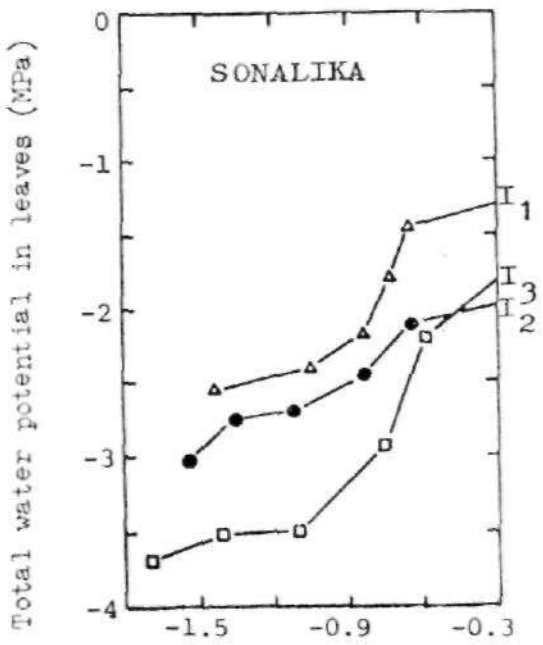


Fig. 26

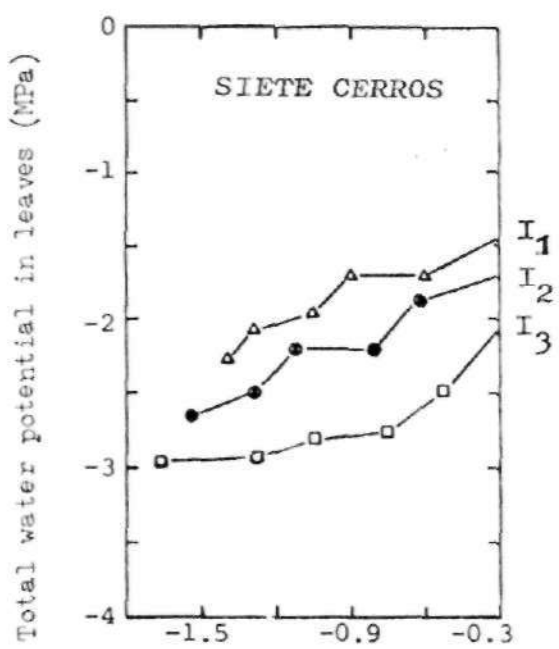


Fig. 27

Total water potential in leaves of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

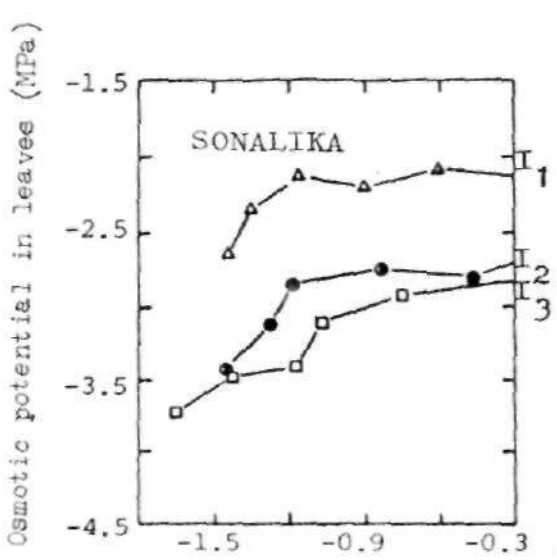


Fig. 28

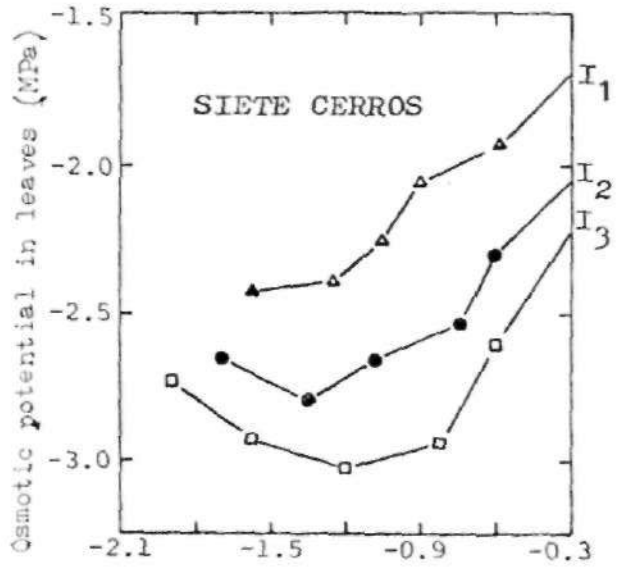


Fig. 29

Osmotic potential in leaves of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

matric potential of about -1.2MPa beyond which the osmotic potential decreased.

4.3.5 Leaf Pressure Potential (ψ^1_p)

The leaf pressure potential increased to a maximum of -0.18MPa at soil matric potential of -0.3MPa in the severe stress treatment of Sonalika (Fig.30), beyond which the pressure potential showed marginal decrease. In 'Siete Cerros', the (ψ^1_T) increased with increasing soil matric potential except under mild stress treatment (Fig. 31). Other treatments, moderate stress in 'Sonalika' (Fig.30) and severe stress in 'Siete Cerros' (Fig.31) showed pressure potential close to zero MPa, thereby indicating water stress close to permanent wilting point.

4.3.6. Leaf Water and Relative Water Content

Leaf water and relative water contents decreased with increasing soil matric potential and the decrease in water content was more rapid in the severely stress treatments (Fig. 32 and 33). Variety 'Sonalika' under mild stress was able to maintain a fairly high water content up to 4.2g/g at soil matric potential of -1.2MPa (Fig. 32). Similarly, mild and moderate stress in 'Siete Cerros' maintained their leaf water content at 5.26 and 5.05g/g at soil matric potentials of -1.13 and 1.43MPa, respectively.

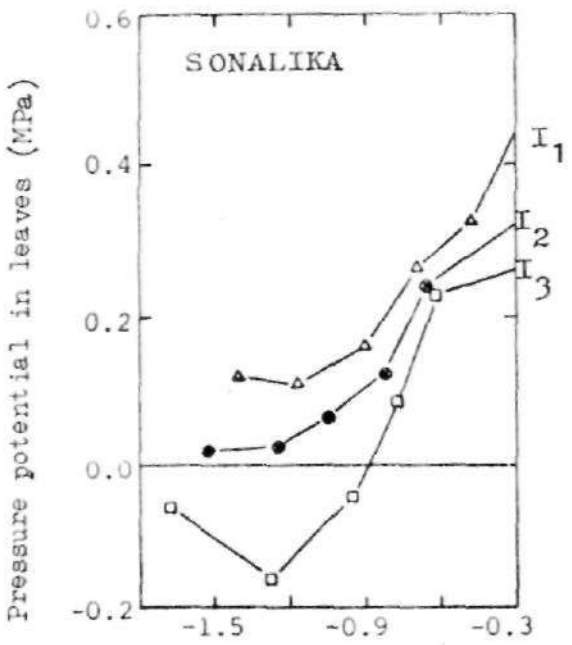


Fig. 30

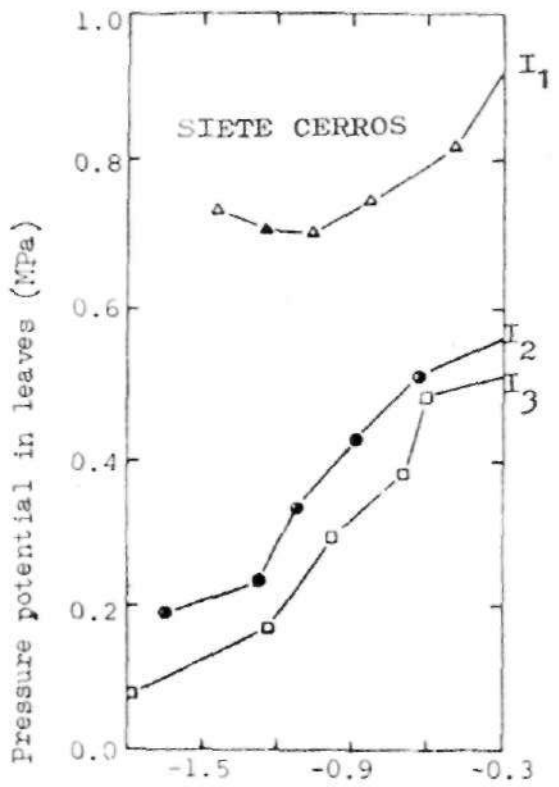


Fig. 31

Pressure potential in leaves of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

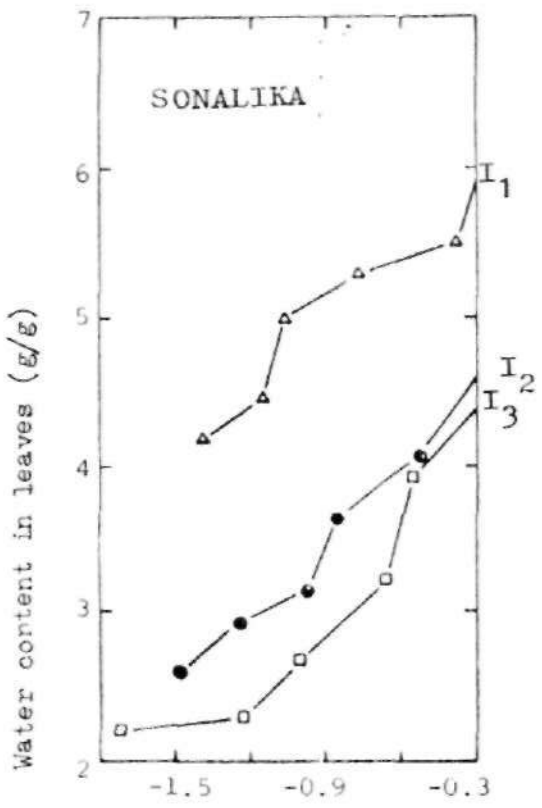


Fig. 32

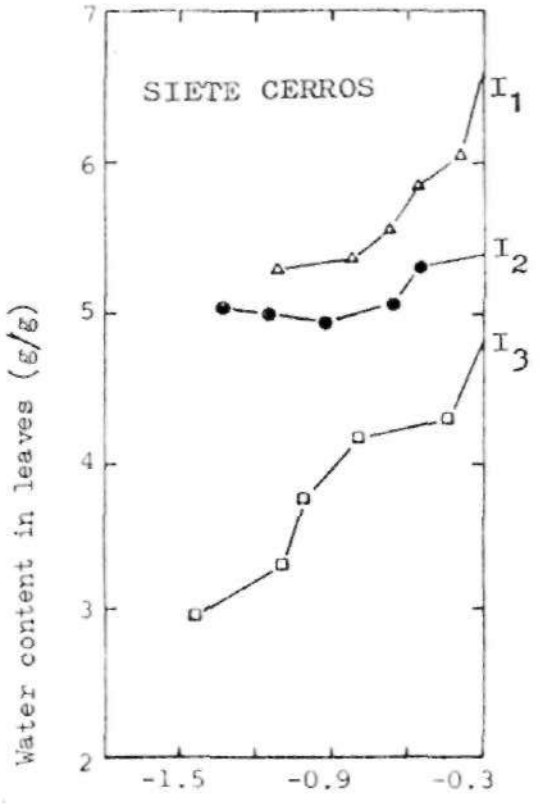


Fig. 33

Water content in leaves of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

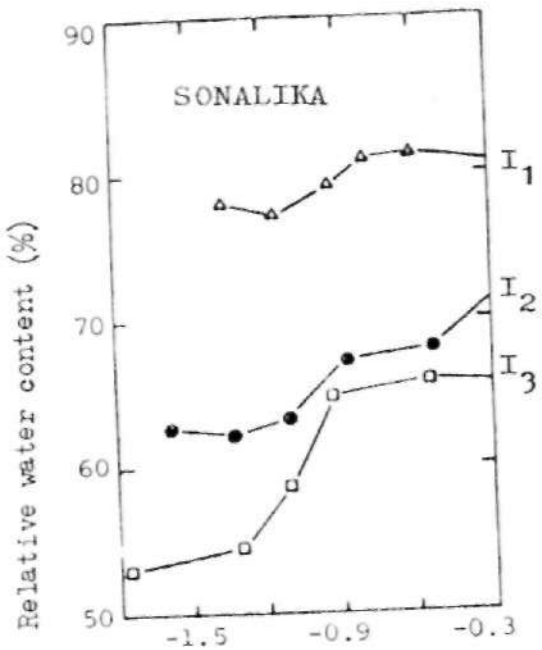


Fig. 34

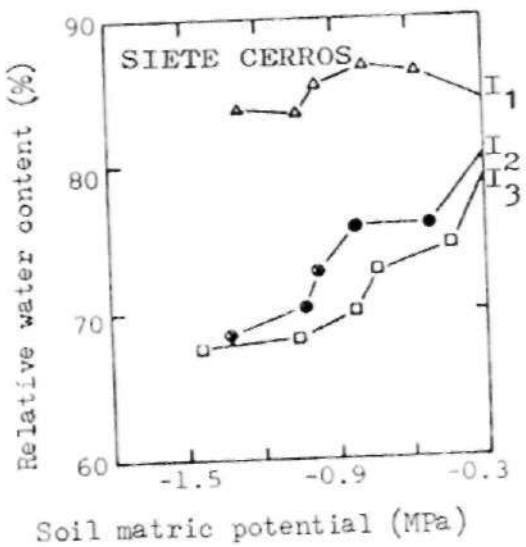


Fig. 35

Relative water content in leaves of wheat varieties as influenced by soil matric potential under growth chamber condition at RVAU, Copenhagen, Denmark, 1984.

The decrease in relative water content was more rapid in moderate and severe stress of both varieties as compared with mild stress (Fig. 34 and 35). Mild stress treatments in 'Sonalika' and 'Siete Cerros' maintained a relative water content of 80.0 and 84.0 percent at -1.4 and -1.3MPa, respectively.

4.4 Yield and Yield Components

The effect of moisture stress on the yield and yield components of the two wheat varieties for primary, secondary and total spikes is presented in Tables 1-3.

4.4.1 Primary Spikes

'Siete Cerros' produced significantly higher number of spikes, 1000-grain weight and grain yield than 'Sonalika'. The difference between the two varieties in other yield parameters such as spike length, number of grains/spike, grain weight/spike and straw yield/pot was not statistically significant (Table 1).

Wheat grown under no stress (control) produced significantly heavier 1000-grain weight over the severe stress (0.75 FC). The 1000-grain weight produced with mild and moderate stress levels were statistically the same. The straw yield produced by the control and mild stress (0.25 FC) were statistically at par but significantly higher than the yield obtained on imposition of moderate to severe stress (0.50 and

0.75 FC). Wheat plants that were grown under no stress gave statistically higher grain yield/pot over stressed treatments. There was a general trend of significant decrease in grain yield with every increase in moisture stress from mild to severe stress level (0.75 FC).

Table 1: Yield and Yield Components of primary spikes of wheat as affected by variety and moisture stress under *growth chamber conditions during July - October, 1984.*

Treatment	Yield and Yield Components						
	No of Spikes/ pots	Spike length (cm)	No. of grains/ spike	Grain weight/ spike(g)	1000-grain weight(g)	Grain yield (g/pot)	Straw yield (g/pot)
Varieties							
Siete Cerros	44.92a	7.65	21.22	0.22	46.04a	36.51a	16.03
Sonalika	34.17b	6.91	24.33	0.19	35.92b	24.75b	17.67
SE (±)	2.96	0.89	6.29	0.19	1.19	3.37	1.77
Moisture Stress							
Control (No Stress)	45.34	7.84	24.69	1.12	45.36a	42.77a	21.75a
0.25 (Mild)	40.05	7.27	23.52	1067	43.35ab	34.34b	19.89a
0.50 (Moderate)	38.84	7.42	23.98	1.08	40.22ab	26.44c	14.88b
0.75 (Severe)	33.50	6.59	18.89	0.73	34.99b	18.97d	10.89b
SE (±)	3.79	0.92	5.26	0.22	0.98	2.35	1.75
Interaction	NS	NS	NS	NS	NS	NS	NS

Means followed by same letter(s) within each factor and character are not significantly different at 5% level using DMRT.
NS = Not significant.

4.4.2 Secondary Spikes

Variety 'Siete Cerros' produced significantly heavier 1000-grain than 'Sonalika' from secondary spikes. The difference between the two varieties in terms of other parameters like number of spikes/pot, spike length, number of grains/spike, grain weight/spike, grain and straw yields was

not statistically significant (Table 2).

When the number of spikes/pot were considered, increasing stress level either to mild or moderate did not decrease the spikes/pot significantly. When the stress was increased to severe level, there was a significant decrease in the number of spikes/pot. When the 3 levels of stress were considered, it was observed that there was no significant decrease in the number of spikes/pot. Similarly, in the case of 1000-grain weight, severely stressed plants produced lighter grain weight when compared with the control. When mild and moderate stress was imposed, it was observed that, they are statistically at par both with the control and with the severely stressed plants. There was a significant decrease in straw yield with every increase in moisture stress up to the moderate level (0.50 FC). A further increase in the stress to severe level however, did not decrease the straw yield significantly. With respect to all other yield parameters like spike length, number of grains/spikes, grain weight/spike and grain yield, no significant differences were recorded when stress was imposed.

Table 2: Yield and Yield Components of secondary spikes of wheat as affected by variety and moisture stress under growth chamber conditions during July-October, 1984.

Treatment	Yield and Yield Components						
	No of Spikes/ pots	Spike length (cm)	No. of grains/ spike	Grain weight/ spike(g)	1000-grain weight(g)	Grain yield (g/pot)	Straw yield (g/pot)
Varieties							
Siete Cerros	14.42	6.08	15.44	0.88	34.25a	12.59	10.67
Sonalika	19.16	5.25	18.19	0.64	25.42b	14.60	13.73
SE (±)	2.55	0.80	4.83	0.14	2.78	1.60	1.42
Moisture Stress							
Control (No Stress)	22.50a	6.45	19.73	0.90	33.83a	15.37a	16.67a
0.25 (Mild)	20.00ab	5.94	16.34	0.81	30.90ab	15.17	13.59b
0.50 (Moderate)	15.00ab	5.54	17.55	0.75	29.30ab	16.18	10.02c
0.75 (Severe)	9.67b	4.74	13.65	0.66	25.31b	7.67	8.51c
SE (±)	3.28	0.75	4.15	0.15	1.39	2.54	1.07
Interaction	NS	NS	NS	NS	NS	NS	NS

Means followed by same letter(s) within each factor and character are not significantly different at 5% level using DMRT.
NS = Not significant.

4.4.3 Total spikes

Combining the data on primary and secondary tillers (Table 3) for varieties, it was observed that 'Siete Cerros' produced heavier grain than 'Sonalika'. The difference in the means of all other parameters did not reach the level of significance including the grain yield.

When the result of the stress levels were considered for the combined analysis, number of spikes, 1000-grain weight, grain and straw yields were found to be significant statistically. As in the secondary spikes, increasing stress up to moderate level, did not decrease the spikes/pot significantly. A further increase in stress to severe level significantly decreased the number of spikes when compared

with control and mild stress. The difference in the mean number of spikes/pot between moderate and severe stress levels was not statistically significant (Table 3).

Table 3: Yield and Yield Components of wheat total spikes as influenced by variety and water stress under growth chamber conditions during July-October, 1984.

Treatment	Yield and Yield Components						
	No of Spikes/ pots	*Spike* length (cm)	*No. of* grains/ spike	*Grain* weight/ spike(g)	*1000-grain* weight (g)	*Grain* yield (g/pot)	*Straw* yield (g/pot)
Varieties							
Siete Cerros	59.17	13.73	36.65	1.96	40.15a	49.09	59.16
Sonalika	53.84	12.16	42.49	1.53	30.67b	39.36	53.33
SE (±)	2.72	1.24	9.79	0.25	0.91	15.60	2.72
Moisture Stress							
Control (No Stress)	67.50a	14.29	44.42	2.02	39.60a	58.14a	67.50a
0.25 (Mild)	60.51a	13.21	39.85	1.87	37.13ab	49.51ab	60.49ab
0.50 (Moderate)	54.83ab	12.96	41.54	1.82	34.76b	42.62b	53.83bc
0.75 (Severe)	43.17b	11.32	32.48	1.28	30.15c	26.64c	43.17c
SE (±)	4.69	1.09	7.18	0.25	1.18	3.74	4.69
Interaction	NS	NS	NS	NS	NS	NS	NS

Means followed by same letter(s) within each factor and character are not significantly different at 5% level using DMRT.
NS = Nog significant.

Considering 1000-grain weight in relation to moisture stress, imposing mild stress did not decrease the grain weight significantly. A further increase to moderate or severe stress significantly decreased the grain weight. The grain weight of mild and moderate stress levels was at par and significantly higher than severe stress level. The response of grain yield was very similar to 1000-grain weight when stress was imposed. When the effect of moisture stress on straw yield was considered, there was no significant difference between

control nd mild stress, mild and moderate stress or moderate and severe stress. However, no stress plants gave significantly higher straw yield than moderate and severe stressed plants and mildly stressed higher than severely stressed. No significant interaction was recorded between varieties and moisture stress levels.

4.5 Field Experiment I.

Responses of dwarf wheat varieties to sowing dates and water stress.

4.5.1 Growth parameters.

The means of 3 factors of sowing date, water stress and variety are shown in table under each parameter for 3 experiments and for grain yield, and also the pooled means. In case of an interaction of first order is significant, the means are shown in further tables separately.

4.5.1.1. Plant height

Sowing date:

There were no significant differences in the height of wheat plants as a result of sowing on different dates in all the 3 years studied (Table 4).

Water stress:

The plant height was significantly and similarly increased with decrease in water stress in 1983/84 and 1985/86 seasons. Plant height did not increase significantly with

decrease of water stress as monitored by IW/CPE ratio from 0.75 to 1.00. The differences in plant heights during 1984/85 did not reach the level of significance.

Variety: The plant height did not differ significantly between the two varieties in all the seasons.

4.5.1.2. Dry matter accumulation

Sowing date:

Dry matter accumulation was not significantly affected by various sowing dates in all the seasons (Table 5).

Water stress:

Dry matter production increased with a decrease in water stress level. In 1983/84, the differences in dry matter production between the CPE ratio of 0.50 and 0.75, and 0.75 and 1.00 were not significant. The no stress treatment (IW/CPE = 1.00) produced significantly higher dry matter over 0.50 ratio. In 1984/85 seasons, decreasing the stress level

Table 4: Effect of sowing date, water stress and variety on plant height (cms) at Kadawa.

Treatment	Plant height (cms)		
	1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early)	81.8	77.6	69.5
1st Dec. (Medium)	82.9	75.4	66.5
22nd Dec. (Late)	80.6	77.5	66.9
SE (±)	0.84	1.20	1.20
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	71.2b	74.9	64.9b
0.75 (Moderate)	84.0a	77.4	68.1a
1.00 (No stress)	84.1a	78.2	70.8a
SE (±)	0.84	1.21	1.22
Variety (V)			
Siete Cerros (Late)	82.1	77.0	67.4
Sonalika (Early)	81.5	76.6	67.8
SE (±)	0.70	1.00	1.00
Interaction	NS	NS	NS

Means within a column and a factor followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

from 0.50 to 0.75 ratio significantly increased the dry matter production, but a further increase in the ratio to 1.00 did not produce higher dry matter.

Table 5: Effect of sowing date, water stress and variety on dry matter accumulation (g/m²) at 12 WAS in Kadawa.

Treatment	Dry matter accumulation (g/m²) 1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early)	568.8	591.9	625.8
1st Dec. (Medium)	550.5	566.9	620.7
22nd Dec. (Late)	651.1	672.0	629.7
SE (±)	38.5	40.1	21.0
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	489.9b	501.1b	596.7b
0.75 (Moderate)	587.0ab	620.3a	613.0b
1.00 (No stress)	692.7a	701.2a	667.0a
SE (±)	38.5	40.1	21.1
Variety (V)			
Siete Cerros (Late)	632.9	654.2	624.3
Sonalika (Early)	547.1	566.9	626.6
SE (±)	31.5	32.8	17.2
Interaction	NS	NS	NS

Means within a column and a factor followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
WAS = Weeks after sowing.
NS = Not significant

In 1985/86 season, on the contrary, increasing the ratio from 0.50 to 0.75 did not increase the dry matter production, but a further increase in the ratio to 1.00 significantly increased the dry matter compared with the other two stress levels.

Variety

No significant differences were recorded from the two varieties in respect of dry matter accumulation in all the three seasons.

4.5.1.3 Number of tillers/m^2

Sowing date

Sowing wheat on different dates (early or late) in 1983/84 and 1984/85 seasons did not produce any significant difference in tiller numbers/m^2. However, in 1985/86 season, sowing wheat early (10th November) significantly increased tillers/m^2 over late sowing (22nd November). Sowing wheat either early and medium or medium and late gave statistically the same number of tillers/m^2 (Table 6)

Water stress

Tiller number/m^2 significantly increased with increasing irrigation levels from IW/CPE ratio of 0.5 to 1.00 during 1983/84 and 1985/86 seasons. The differences in tiller number produced during 1984/85 season did not show any significant difference between the three irrigation levels.

Table 6: Effect of sowing date, water stress and variety on number of tillers/m² of wheat at Kadawa.

Treatment	Number of tillers/m² 1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early)	753.0	707.3	841.5a
1st Dec. (Medium)	732.0	769.2	787.6ab
22nd Dec. (Late)	766.2	815.9	740.6b
SE (±)	18.60	9.98	23.81
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	719.4c	768.6	693.8c
0.75 (Moderate)	738.0b	768.0	798.4b
1.00 (No stress)	793.8a	755.6	877.5a
SE (±)	18.60	9.98	23.81
Variety (V)			
Siete Cerros (Late)	773.4a	787.9a	794.1a
Sonalika (Early)	727.2b	740.3b	785.6b
SE (±)	14.94	8.17	19.44
Interaction			
I x V	*	NS	*

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant
* = Significant at 5% level.

Variety

Variety 'Siete Cerros' produced significantly higher number of tillers/m^2 in all the three experiments.

Interaction

Water stress into variety interaction was found to be significant during 1983/84 and 1985/86 seasons (Table 6a and 6b). Variety 'Siete Cerros' did not respond to water stress levels in both seasons. Tiller production of 'Sonalika' increased significantly, when irrigated at no stress over moderate and severe in 1983/84 season. Reversed was however, true for variety 'Sonalika' in 1985/86.

In 1983/84 variety 'Siete Cerros' out yielded 'Sonalika' significantly under severe stress, while in 1985/86 variety 'Siete Cerros' out yielded 'Sonalika' under no stress.

4.5.2 Yield parameters

4.5.2.1 Length of spike

Sowing date

The length of spike progressively decreased with delay in sowing in 1983/84 (Table 7). The length of spike was the same for 10th November and 1st December sowing dates and also for 1st and 22nd December sowing dates in 1983/84 season. In 1984/85, the decrease in length of spike with delay in sowing dates was not significant.

Table 6a: Interaction between water stress and variety as it affected the number of tillers/m² of wheat at Kadawa during 1983/84.

Water stress (I) (IW/CPE ratio)	Variety	
	Siete Cerros	Sonalika
I_1 0.50 (Severe)	789.0ab	658.8c
I_2 0.75 (Moderate)	759.0ab	717.0bc
I_3 1.00 (No stress)	781.8ab	805.2a
SE (±) 25.86		

Table 6b: Interaction between water stress and variety as it affected the number of tillers/m² of wheat at Kadawa during 1985/86.

Water stress (I) (IW/CPE ratio)	Variety	
	Siete Cerros	Sonalika
0.50 (Severe)	908.6a	846.5a
0.75 (Moderate)	901.8a	863.7a
1.00 (No stress)	943.0a	672.2b
SE (±) 33.67		

Interaction means followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water.
CPE Cumulative pan evaporation.

Table 7: Effect of sowing date, water stress and variety on length of spikes (cm) at Kadawa.

Treatment	Length of spikes (cm) 1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early)	8.2a	8.5	7.5a
1st Dec. (Medium)	8.0ab	8.3	7.4a
22nd Dec. (Late)	7.9b	8.1	7.0b
SE (±)	0.06	0.22	0.12
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	8.0	8.0	6.9c
0.75 (Moderate)	8.0	8.4	7.2b
1.00 (No stress)	8.1	8.5	7.9a
SE (±)	9.06	0.22	0.12
Variety (V)			
Siete Cerros (Late)	8.1	8.2	7.3
Sonalika (Early)	8.1	8.8	7.3
SE (±)	0.05	0.18	0.10
Interaction			
S x V	*	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant
* = Significant at 5% level.

In 1985/86, when sowing was delayed from 10th November to 1st December, the length of spike remained the same. However, sowing on 22nd December produced significantly shorter spikes than the other two sowing dates.

Water stress

The spike length was not significantly affected by stress levels during 1983/84 and 1984/85 seasons. However, during 1985/86 season, the length of spike significantly increased with each increment in IW/CPE ratio from 0.50 to 1.00.

Variety

The two varieties produced spikes of the same length within a season in all the 3 experiments.

Interaction

Sowing date X variety interaction was found to be significant during 1983/84 season (Table 7a). Late maturing variety 'Siete Cerros' produced non-significant decrease in spike length at all sowing dates. The early maturing variety 'Sonalika' produced significantly longer spikes when sown on 1st December (medium) than the other sowing dates (early or late). When the two varieties are considered at the same stress levels, 'Siete Cerros' produced longer spikes only when sown early (10th November).

Table 7a: Sowing date X variety interaction as it affected length of spikes (cm) of wheat at Kadawa during 1983/84.

	Variety	
Sowing date (S)	Siete Cerros	Sonalika
10th Nov. (Early)	8.2ab	7.8cc
1st Dec. (Medium)	8.1abc	8.3a
22nd Dec. (Late)	7.9bc	8.0bc
SE (±) 0.09		

Interaction means followed by the same letter(s) are not significantly different using DMRT at 5% level.

4.5.2.2 Number of spikes/m²

Sowing date

Number of spikes did not differ significantly in relation to dates of sowing in all the season studied (Table 8).

Water stress

The no stress and moderate water stress, being at par produced significantly higher number of spikes over severe stress in all the three seasons.

Variety

Late maturing variety 'Siete Cerros' produced significantly higher number of spikes than 'Sonalika' in all the three seasons.

Interaction

Water stress into variety interaction was found to be significant during 1984/85 season (Table 8a). Variety 'Siete Cerros' produced higher number of spikes than 'Sonalika' only

at no-stress level (IW/CPE ratio = 1.00). At the other two stress levels, the number of spikes produced were statistically the same. Both varieties produced significantly lower spikes at the severe stress level when compared to the other levels.

Table 8: Effect of sowing date, water stress and variety on number of spikes/m² at Kadawa.

Treatment	Number of spikes/m²		
	1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early)	380.5	378.2	408.2
1st Dec. (Medium)	359.6	365.3	373.4
22nd Dec. (Late)	355.0	372.0	366.5
SE (±)	14.1	14.8	14.8
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	312.7b	311.0b	333.7b
0.75 (Moderate)	392.1a	401.8a	405.7a
1.00 (No stress)	389.8a	403.2a	408.7a
SE (±)	14.1	14.8	14.8
Variety (V)			
Siete Cerros (Late)	391.2a	400.8a	410.6a
Sonalika (Early)	338.7b	343.2b	354.8b
SE (±)	11.4	12.1	12.3
Interaction I x V	NS	*	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant
* = Significant at 5% level.

Table 8a: Interaction between stress level and variety as it influenced number of spikes/m² of wheat at Kadawa during 1984/85 season.

Water stress (I) (IW/CPE ratio)	Variety	
	Siete Cerros	Sonalika
0.50 (Severe)	321.6d	300.0d
0.75 (Moderate)	419.0ab	387.8bc
1.00 (No stress)	462.2a	342.8cd
SE (±) 20.90		

Interaction means followed by the same letter(s) are not significantly different using DMRT at 5% level.

4.5.2.3 Number of grains/spike

Sowing date

Grain number per spike did not significantly decrease by delay in sowing dates during 1983/84 season. In 1984/85 season, delay in sowing from 10th November to 1st December or 22nd December significantly decreased the number of grains per spike. In 1985/86 season, the number of grains per spike produced by 10th November sowing date was significantly higher than 22nd December sowing. The differences in other sowing dates in respect to number of grains per spike in the latter two seasons were not significant (Table 9).

Water stress

Stress level did not significantly affect grains per spike during 1983/84 season. In 1984/85, severe stress at IW/CPE ratio of 0.50 resulted in significantly lesser grains per spike compared with the other two irrigation levels, which

were at par. However, in 1985/86 at no stress level of IW/CPE ratio of 1.00, the number of grains per spike was significantly higher than the other two stress levels.

Variety

Variety 'Siete Cerros' produced significantly more grains per spike than 'Sonalika' in 1983/84 and 1984/85 season. In 1985/86, the number of grains per spike produced by the two varieties was statistically at par.

Table 9: Effect of sowing date, water stress and variety on number of grains/spikes at Kadawa.

Treatment	Number of grains/spike		
	1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early	42.5	43.4a	71.9a
1st Dec. (Medium)	41.0	39.4b	68.7ab
22nd Dec. (Late)	40.2	40.2b	67.1b
SE (±)	0.83	0.90	1.10
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	39.9	38.9b	65.9b
0.75 (Moderate)	41.7	42.1a	68.0b
1.00 (No stress)	42.0	42.0a	73.8a
SE (±)	0.83	0.90	1.10
Variety (V)			
Siete Cerros (Late)	49.6a	49.3a	68.4
Sonalika (Early)	32.9b	32.7b	70.0
SE (±)	0.68	0.73	0.90
Interaction	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

4.5.2.4 Grain weight/spike (g)

Sowing date

Sowing wheat on 10th November and December 1st, which were at par, resulted in significantly heavier grain weight per spike over 22nd December sowing in 1984/85 (Table 10). For the other two seasons, there was no differential response of grain weight per spike to sowing dates.

Water stress

The effect of water stress level was found to be significant only during 1983/84 and 1985/86 seasons. The severe water stress level (IW/CPE ratio 0.50) produced significantly lower grain weight per spike compared with the other stress levels, which were at par in both seasons.

Variety

The variety 'Siete Cerros' significantly produced heavier seeds than 'Sonalika' in all the 3 experiments (Table 10).

Interaction

When each sowing date was examined for varying stress levels, it was observed that higher the water stress, lower was grain weight/spike in all the 3 dates of sowing during 1985/86 season. Similarly, when each stress level was examined at different sowing dates, it was revealed that earlier the sowing, higher was the grain weight/spike (Table 10a).

Table 10: Effect of sowing date, water stress and variety on grain weight/spikes (g) at Kadawa.

Treatment	Grain weight/spike(g) 1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early)	1.8	1.6a	2.2
1st Dec. (Medium)	1.8	1.6a	1.9
22nd Dec. (Late)	1.9	1.3b	1.7
SE (±)	0.05	0.09	0.06
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	1.6b	1.5	1.6b
0.75 (Moderate)	1.9a	1.5	2.0a
1.00 (No stress)	1.9a	1.5	2.2a
SE (±)	0.04	0.09	0.06
Variety (V)			
Siete Cerros (Late)	2.0a	1.6a	2.1a
Sonalika (Early)	1.7b	1.4b	1.8b
SE (±)	0.04	0.08	0.05
Interaction			
S x I	NS	NS	*

Means within a column and a factor followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant
* = Significant at 5% level.

Table 10a: Interaction between sowing date and irrigation level as it effects Grain weight/spike of wheat at Kadawa during 1985/86 season.

Sowing date (S)	Water stress (I) (IW/CPE ratio)		
	0.50	0.75	1.00
10th Nov. (Early)	1.7g	2.2b	2.6a
1st Dec. (Medium)	1.6h	2.1c	2.0d
22nd Dec. (Late)	1.5i	1.8f	1.9e
SE (±) 0.01			

Interaction means followed by the same letter are not significantly different using DMRT at 5% level.

4.5.2.3 1000-grain (g)

Sowing date

The 1000-grain weight differences due to sowing dates were found to be significant only in 1984/85 season. The grain weight of early sowing date (10th November) was significantly heavier than late sowing (22nd December). The difference between other sowing dates were not significant (Table 11).

Water stress

Decreasing water stress progressively increased the grain weight. However, effect of water stress in 1985/86 was not significant. It was also observed that in 1984/85 season, moderate and severe stress being at par produced significantly higher grains than no stress. In 1983/84 season, the grain weight under severe stress was significantly Ligher than mild and moderate stress which were at par.

Variety

'Siete Cerros' yielded heavier grains than 'Sonalika' in 1983/84 and 1984/85 seasons. The two varieties were statistically comparable in their grain weight in 1985/86 season.

Table 11: Effect of sowing date, water stress and variety on 1000-grain weight (g) at Kadawa.

Treatment	1000-grain weight (g)		
	1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early	45.0	40.5a	35.0
1st Dec. (Medium)	44.6	40.0ab	35.3
22nd Dec. (Late)	46.3	39.6b	35.3
SE (±)	1.10	0.30	0.25
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	39.2b	39.5b	34.8
0.75 (Moderate)	47.1a	39.8b	35.4
1.00 (No Stress)	49.6a	41.0a	35.4
SE (±)	1.10	0.30	0.25
Variety (V)			
Siete Cerros (Late)	51.9a	40.4a	35.3
Sonalika (Early)	38.6b	39.7b	35.0
SE (±)	0.90	0.25	0.20
Interaction	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation.
NS = Not significant

4.5.2.6 Straw yield

Sowing date

Sowing early on 10th November or mid-season on 1st December, produced straw without any significant difference. However, these two sowing dates resulted in significantly higher straw yield than late sowing on 22nd December in 1983/84 season (Table 12). The difference between the sowing dates in other seasons were not significant.

Water stress

Straw yield significantly increased by irrigating at IW/CPE ratio of 0.75 and 1.00 compared with the 0.50 ratio in 1983/84 and 1984/85 seasons. However, in 1985/86 season, the straw yield increased significantly and linearly with each decrease in the water stress level between 0.5 and 1.00 IW/CPE ratio.

Variety

Variety 'Siete Cerros' significantly out yielded 'Sonalika' in 1983/84 season only. In the other seasons, the straw yield from the two varieties was comparable statistically.

Table 12: Effect of sowing date, water stress and variety on straw yield (hg/ha) at Kadawa.

Treatment	Straw yield (kg/ha) 1983/84	1984/85	1985/86
Sowing date (S)			
10th Nov. (Early	7184a	5232	5936
1st Dec. (Medium)	6768a	5088	6080
22nd Dec. (Late)	5792b	4848	6032
SE (±)	288.0	325.0	273.0
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	5440b	3520b	5129c
0.75 (Moderate)	7408a	5440a	5888b
1.00 (No stress)	6896a	6208a	7024a
SE (±)	288.0	325.0	274
Variety (V)			
Siete Cerros (Late)	7008a	5280	6064
Sonalika (Early)	6144b	4816	5968
SE (±)	235.0	266.0	244.0
Interaction	NS	NS	NS

Means within a column and a factor followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

4.5.2.7 Grain yield

Sowing date

The delay in sowing dates did not significantly reduce the grain yield in 1983/84. However, during 1985/86 season and the pooled data analysis, delay in sowing date between 10th November and 22nd December, linearly and significantly reduced the wheat grain yield. In 1984/85, early sowing on 10th November significantly out-yielded medium (1st December) and

late (22nd December) sowing dates significantly. The latter two dates were at par in 1984/85 season (Table 13).

Water stress

Wheat grain yield responded linearly and significantly to frequent irrigations monitored by IW/CPE ratio between 0.5 and 1.00 in 1983/84 as well as pooled data analysis. During 1984/85 season, IW/CPE ratio of 0.75 and 1.00, being at par, significantly excelled severe water stress ratio of 0.5.

Variety

Variety 'Siete Cerros' significantly outyielded 'Sonalika' in 1984/85, 1985/86 as well as in combined data analysis over the three seasons.

Table 13: Effect of sowing date, water stress and variety on grain yield (kg/ha) at Kadawa.

Treatment	Grain yield (kg/ha)			
	1983/84	1984/85	1985/86	Pooled mean
Sowing date (S)				
10th Nov. (Early	4143	1105a	2496a	2581a
1st Dec. (Medium)	4007	949b	1640b	2199b
22nd Dec. (Late)	3986	920b	1230c	2045c
SE (±)	184.7	46.8	134.3	51.7
Water stress (I) (IW/CPE ratio)				
0.50 (Severe)	2977c	606b	737c	1440c
0.75 (Moderate)	4048b	1127a	1266b	2147b
1.00 (No stress)	5113a	1242a	1663a	2673a
SE (±)	184.7	46.8	66.4	177.8
Variety (V)				
Siete Cerros (Late)	4263	1091a	1323a	2216a
Sonalika (Early)	3828	893b	1121b	1940b
SE (±)	150.8	38.2	57.4	54.5
Interaction				
S x I		NS	*	NS
S x V		NS	*	NS
S x V		NS	*	NS

Means within a column and a factor followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant
* = Significant at 5% level.

Interaction

Interaction between sowing date and water stress level was significant in 1984/85 (Table 13a). Under moderate and severe water stress, early and medium sowing dates were without any significant difference but they significantly outyielded later sown crop. However, as water supply increased (IW/CPE ratio = 1.00), the grain yield decreased linearly and significantly as sowing date was delayed from 10th November to 22nd December.

Interaction between sowing date and varieties was also significant in 1984/85 (Table 13b). Sowing variety 'Siete Cerros' early (10th November), significantly outyielded medium and late sown crop including variety 'Sonalika' sown early, medium and later, which were all at par.

The interaction between water stress and varieties was significant in 1984/85 (Table 13c). As water stress increased from no stress (IW/CPE ratio = 1.00) to severe stress (IW/CPE = 0.5), the grain yield decreased significantly in 'Siete Cerros'. However, with variety 'Sonalika', the decrease in no stress and medium stress (IW/CPE = 0.75) gave statistically the same grain yield. The severe stress level (IW/CPE = 0.5) in both varieties, gave significantly lower grain yield. At severe stress, the two varieties yielded at par but at moderate and no stress level, 'Siete Cerros' yielded higher than 'Sonalika'.

Table 13a: Interaction between sowing date and water stress at it affected Grain yield (kg/ha) of wheat at Kadawa, 1984/85.

Sowing date (S)	Water stress (I) (IW/CPE ratio)		
	0.50	0.75	1.00
10th Nov. (Early)	1147b	1128b	1594a
1st Dec. (Medium)	1037b	1094b	1108b
22nd Dec. (Late)	577c	624c	616c
SE (±) 81.0			

Table 13b: Sowing date x variety interaction as it affected grain yield (kg/ha) of wheat at Kadawa, 1984/85.

Sowing date (S)	Variety	
	Siete Cerros	Sonalika
10th Nov. (Early)	1313a	897b
1st Dec. (Medium)	1021b	877b
22nd Dec. (Late)	937b	903b
SE (±) 66.1		

Table 13c: Interaction between water stress and variety as it influenced grain yield (kg/ha) of wheat at Kadawa, 1984/85.

Water stress (I)	Variety	
(IW/CPE ratio)	Siete Cerros	Sonalika
0.50 (Severe)	561d	651d
0.75 (Moderate)	1247b	1008c
1.00 (No stress)	1464a	1019c
SE (±) 66.1		

Interaction means followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water.
CPE = Cumulative pan evaporation.

4.5.2.8 Correlation studies (1983-84 season)

The coefficient of correlation between yield and yield components,within yield components and their association with a number of other characters studied during 1983/84 season are shown in Table 14.

Grain yield was positively correlated with the 3 yield components of 1000-grain weight, spikes/m^2 and grains/spike. In terms of significance, the former two were significant at 1 percent and 5 percent, respectively while the third parameter was insignificant. Other characters which were found to be significant with yield were length of spike and dry matter production. When the correlations within yield components were examined, 1000-grain weight was positively and significantly (at 1%) correlated with spikes/m^2. It's correlation with number of grains/spike was also positive but insignificant. The association between spikes/m^2 and grains/spike was negative and insignificant. A significant and positive correlation was also observed between 1000-grain weight and length of spike. The association between grains/spike and grain weight/spike was highly significant and negative.

4.5.2.9 Correlation studies (1984-85 season)

When the correlation of coefficients were examined between the yield components in 1984-85 season, the 3 yield components of 1000-grain weight, number of grains/spike and

Table 14: Simple correlation analysis between the parameters studies in Field Experiment I during 1983-84 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.993**	1.00								
3. No. of grains/spike	.211NS	.191NS	1.00							
4. Grain weight/spike	.223NS	.226NS	-.370**	1.00						
5. Length of spike	.291*	.261*	.194NS	.242*	1.00					
6. Straw yield	.137NS	.137NS	.202NS	.103NS	-.096NS	1.00				
7. No. of spikes/m²	.252*	.359**	-.106NS	.289*	.050NS	-.151NS	1.00			
8. No. of tillers/m²	.166NS	.179NS	.203NS	-.110NS	.122NS	-.181NS	.082NS	1.00		
9. Plant height	.143NS	.171NS	.028NS	.133NS	.039NS	.156NS	.115NS	.002NS	1.00	
10. Dry matter accumulation	.246*	.191NS	.180NS	.310**	.131NS	.032NS	.273*	.160NS	.127NS	1.00

NS = Not significant
* & ** = Significant at 5 and 1% levels, respectively.

spikes/m² were all positively correlated with grain yield. Out of 3 components only 1000-grain weight was correlated at 1 percent level of significance. Critical examination of correlations within yield components revealed that spikes/m² was associated at 1 percent level of significance with 1000-grain weight, but the correlation between 1000-grain and grains/spike was insignificant and positive. The association between grains/spike and spikes/m² was negative and insignificant. When the association of yield was examined with other characters studied, it was found to be positive and significantly associated with grain weight/spike. The 1000-grain weight was correlated with grain weight/spike at 5 percent level (Table 15).

Table 15: Simple correlation analysis between the parameters studied in Field Experiment I during 1984-85 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.987**	1.00								
3. No. of grains/spike	.107NS	.121NS	1.00							
4. Grain weight/spike	.232*	.246*	.193NS	1.00						
5. Length of spike	.093NS	.084NS	-.074NS	.221NS	1.00					
6. Straw yield	.090NS	.090NS	-.077NS	.141NS	.041NS	1.00				
7. No. of spikes/m²	.036NS	.376**	-.008NS	.199NS	.001NS	.076NS	1.00			
8. No. of tillers/m²	.088NS	-.126NS	.037NS	-.421**	.016NS	-.164NS	-.260*	1.00		
9. Plant height	.030NS	.106NS	.054NS	.161NS	-.010NS	-.079NS	.147NS	-.098NS	1.00	
10. Dry matter accumulation	.166NS	.024NS	.129NS	.024NS	-.032NS	.083NS	-.108NS	.209NS	-.050NS	1.00

NS = Not significant
* & ** = Significant at 5 and 1% levels, respectively.

4.5.3.0 Correlation studies (1985-86 season).

The correlation of coefficient between yield, yield components and other characters during 1985-86 season are given in Table 16. The 3 yield components of 1000-grain weight, grains/spike and spikes/m² were found to be positive and highly significant in this season. The correlation between grain weight with grains/spike and spikes/m² were also found to be positive and highly significant. The association between grains/spike and spikes/m² was negative and highly significant.

Table 16: Simple correlation analysis between the parameters studied in Field Experiment I during 1983-86 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weighT	.997**	1.00								
3. No. of grains/spike	.377**	.371**	1.00							
4. Grain weight/spike	.223NS	.224**	.260*	1.00						
5. Length of spike	.682**	.596**	.470**	.389**	1.00					
6. Straw yield	.197NS	.198NS	.418**	.090NS	.313**	1.00				
7. No. of spikes/m²	.429**	.437**	-.348**	.339**	.290*	-.023NS	1.00			
8. No. of tillers/m²	.176NS	.174NS	.135NS	.492**	.254*	-.177NS	.376**	1.00		
9. Plant height	.191NS	.198NS	-.013NS	.362**	.177NS	.434**	.068NS	.146NS	1.00	
10. Dry matter accumulation	.391**	.369**	.185NS	.489**	.451**	.027NS	.507**	.380**	.310*	1.00

NS = Not significant
* & ** = Significant at 5 and 1% levels, respectively.

Grain yield was also found to have highly significant correlation with length of spike and dry matter accumulation. The association between 1000-grain weight with length of spike and dry matter accumulation was highly significant and with grain weight/spike significant. The correlation of grains/spike with length of spike and straw yield was significant at 1 percent level and with grain weight/spike was significant at 5 percent level.

4.5.3.1 Correlation studies on combined data (1983-86)

When the correlation coefficients were worked out from the combined data of 3 years (1983-86), the grain yield was found to be positively correlated with it's 3 yield components. The association of yield with 1000-grain weight, spikeS/m² and grains/spike were highly significant, significant and not significant, respectively. The grain yield was also found to be significantly correlated with number of tillers/m² and negatively correlated with grain weight/spike. The number of spikes/m² was highly correlated with dry matter

accumulation (Table 17).

Table 17: Simple correlation analysis between the parameters studied in Field Experiment I during 1983-86 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.988**	1.00								
3. No. of grains/spike	.149NS	.143NS	1.00							
4. Grain weight/spike	.215NS	.222NS	-.656**	1.00						
5. Length of spike	-.099NS	-.102NS	.039NS	.177NS	1.00					
6. Straw yield	.124NS	.122NS	-.110NS	-.077NS	-.065NS	1.00				
7. No. of spikes/m²	.290*	.294*	-.293*	.328**	-.141NS	.155NS	1.00			
8. No. of tillers/m²	.234*	.236*	.436**	-.402**	.096NS	.201NS	.070NS	1.00		
9. Plant height	.207NS	.209NS	.016NS	-.125NS	-.049NS	.112NS	.131NS	-.043NS	1.00	
10. Dry matter accumulation	.181NS	.181NS	-.225NS	-.200NS	-.027NS	-0.115NS	.419**	-.110NS	.120NS	1.00

NS = Not significant
* & ** = Significant at 5 and 1% levels, respectively.

4.5.3.2 Path-Coefficient Analysis (1983-84 season)

A schematic path diagram and coefficient of factors affecting grain yield is shown in figure 36. Using the coefficient of factors (P) and the coefficients of correlation (r) through the path coefficients for 1983-84 revealed that 1000-grain weight directly contributed 1.04% and it's contribution through number of grains/spike was very negligible (0.008). The contribution of spikes/m² was negative and 4.27%.

44693

Table 18: Direct and indirect contribution of yield components on yield of wheat subjected to moisture stress different sowing dates during 1983/84 seasons.

Calculation of Direct and Indirect Effects

(a)	(i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	1.0359
	(ii)	Indirect effect via grain number/spike (X_2) ($P_{24}r12$)	0.00008
	(iii)	Indirect effect via spikes/m² (X_3) ($P_{34}r13$)	-0.0427
		Total effect (Direct + Indirect)	0.993
(b)	(i)	Grain number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	0.00043
	(ii)	Indirect effect via spikes/m² (X_3) ($P_{34}r25$)	0.0127
	(iii)	Indirect effect via spikes/m² (X_3) ($P_{34}r12$)	0.1979
		Total effect (Direct + Indirect)	0.211
(c)	(i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	-0.1199
	(ii)	Indirect effect via seed number/spike (X_2) ($P_{24}r23$)	-0.00046
	(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r13$)	0.3719
		Total effect Direct + Indirect)	0.252

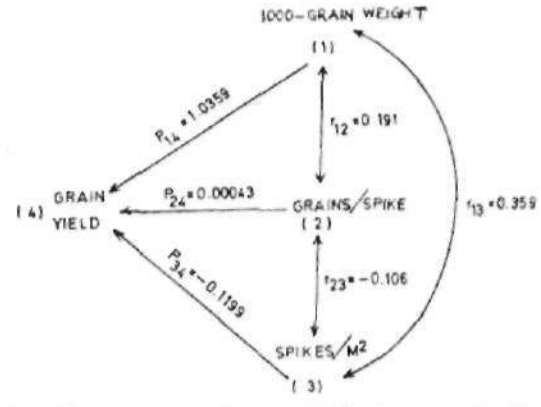


Fig.36. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress at different sowing dates during 1983/84 season.

When the grain yield was examined in relation to number of grains/spike, out of a total (direct and indirect contribution) of 21/1% by grains/spike, a major contribution was via grain weight (19.79%). Number of spikes/m^2 contributed 1.27% and direct contribution of grain number/spike was only 0.04%. Total contribution of spikes/m^2 was 25.2% of which 31.1% was contributed via grain weight. Direct effect of spikes number/m^2 was negative and 11.99%. The effect of grains/spike was also negative and its contribution was 0.046% only (Table 18).

4.5.3.3. Path-Coefficient Analysis (1984-85 season)

The path analysis diagram showing the coefficient factors (P) and respective (r) values for 1984-85 are given in Fig. 37 and direct and indirect contribution of yield components on grain yield in Table 19. Out of a total contribution of 98.7% by grain weight, the direct contribution was 113.85%. The indirect effect via the number of grains/spike and spikes/m^2 were negative and 0.4 and 14.75%, respectively. The total effect of grain number/spike on yield was 10.7% of which its direct effect was negative and 3.39%. The indirect effect of grain number/spike via spikes/m^2 on grain weight were 0.31 and 13.78%, respectively.

When the direct and indirect effects of spike/m^2 and grain yield were considered, out of a total of 3.6%, the direct effect was negative and 39.24%. The contribution of

spikes/m² via grains/spike was very insignificant (0.02%) whereas, via 1000-grain weight it contributed 42.8%.

4.5.3.4 Path-Coefficient Analysis (1985-86 season)

The path diagram giving the coefficient of factors (P) and the coefficient of correlation (r) values are shown in Fig. 38 and their respective direct and indirect contributions in Table 20 for 1985-86 season.

Out of a total effect of 99.7%, grain weight directly contributed 99.74% and its contribution via number of grains/spike was only 0.25%. The effect of grain weight via number of spike was negative and 0.29%. When the direct and indirect contributions of grain number/spike on yield was considered, out of a total of 37.67% contribution, grains/spike contributed 0.68% directly and 37% indirectly via grain weight. The effect of grain number/spike via spikes/m² was negative and very small (0.01%). The total effect of spikes/m² was 42.9% of which direct effect was negative and very small (-0.67%). The indirect effect via number of grains/spike was also negative and very small (-0.015%). The major indirect contribution of spikes/m² was via grain weight which as 43.59%.

Table 19: Direct and indirect contribution of yield components on yield of wheat subjected to moisture stress at different sowing dates during 1984/85 season.

Calculation of Direct and Indirect Effects

(a)	(i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	1.1385
	(ii)	Indirect effect via grain number/spike (X_2) ($P_{24}r12$)	-0.0041
	(iii)	Indirect effect via spikes/m² (X_3) ($P_{34}r13$)	-0.1475
		Total effect (Direct + Indirect)	0.987
(b)	(i)	Grain number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	-0.0339
	(ii)	Indirect effect via spikes/m² (X_3) ($P_{34}r23$)	0.1031
	(iii)	Indirect effect via 1000-grains weight (X_1) ($P_{14}r12$)	0.1378
		Total effect (Direct + Indirect)	0.107
(c)	(i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	-0.3924
	(ii)	Indirect effect via seed number/spike (X_2) ($P_{24}r23$)	0.0002
	(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r13$)	0.4280
		Total effect (Direct + Indirect)	0.036

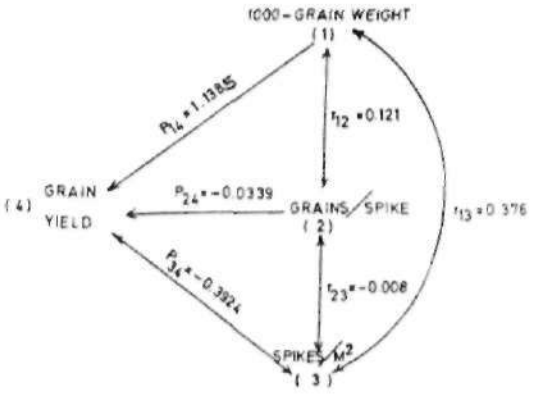


Fig.37. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress at different sowing dates during 1984/85 season.

4.5.3.5 Path-coefficient Analysis on Combined Data (1983-86 seasons)

The path-coefficients of factors (P) and coefficient of correlations (r) for 1983-86 are shown in Fig.39 and their respective direct and indirect contributions in Table 21.

When the combined effect over three seasons of yield components over yield was worked out irrespective of the season, it was found that out of a total effect of 99.8%, 1000-grain weight contributed 99.76% and less than 0.047% was contributed via number of grains/spike and spikes/m^2. When the contribution of grains/spike was examined, out of 14.3%, 14.2% was via 1000-grain weight and very small contribution was either direct (0.217%) with grain number/spike or via spikes/m^2 (-0.046%) of which the latter was negative. The direct contribution of spikes/m^2 on yield was 0.5% and negative. It contributed via grain number/spike only 0.06% while its main contribution was 29.3% via grain weight.

Table 20: Direct and indirect contribution of yield components on yield of wheat subjected to moisture stress at different sowing dates during 1985/86 season.

Calculation of Direct and Indirect Effects

(a) (i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	0.9974
(ii)	Indirect effect via grain number/spike (X_2) ($P_{24}r12$)	0.00253
(iii)	Indirect effect via spikes/m² (X_3) ($P_{34}r13$)	-0.00293
	Total effect (Direct + Indirect)	0.997
(b) (i)	Grain number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	0.00681
(ii)	Indirect effect via spikes/m² (X_3) ($P_{34}r23$)	-0.000154
iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r12$)	0.3700
	Total effect (Direct + Indirect)	0.377
(c) (i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	0.00671
(ii)	Indirect effect via seed number/spike (X_2) ($P_{24}r23$)	-0.000156
(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r13$)	0.43586
	Total effect (Direct + Indirect)	0.429

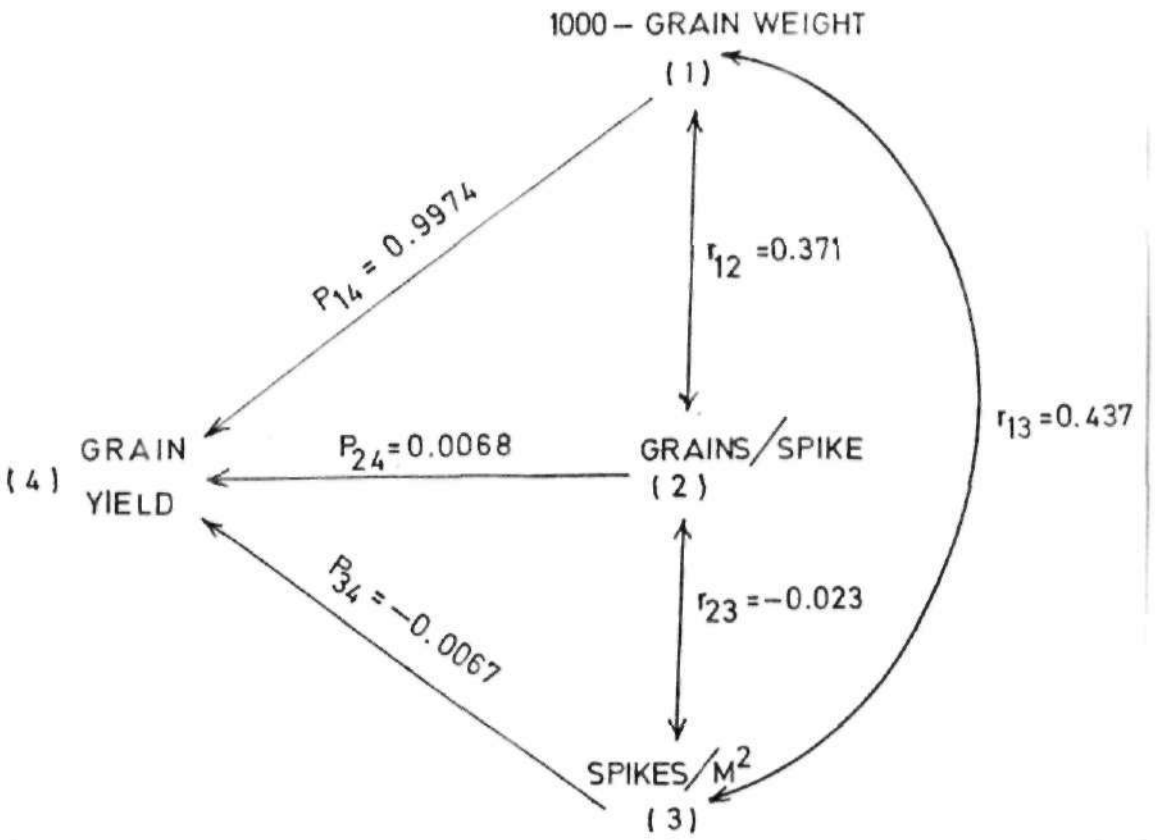


Fig. 38. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress at different sowing dates during 1985 /86 season.

Table 21: Direct and indirect contribution of yield components on yield of wheat subjected to moisture stress at different sowing dates during 1983-86 seasons (combined).

Calculation of Direct and Indirect Effects

(a) (i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	0.9976
(ii)	Indirect effect via grain number/spike (X_2) (P_{24}r12)	0.00031
(iii)	Indirect effect via spikes/m² (X_3) (P_{34}r13)	-0.00046
	Total effect (Direct + Indirect)	0.998
(b) (i)	Grain number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	0.002172
(ii)	Indirect effect via spikes/m² (X_3) (P_{34}r23)	-0.000463
(iii)	Indirect effect via 1000-grain yield (X_1) (P_{14}r12)	0.14265
	Total effect (Direct + Indirect)	0.1430
(c) (i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	-0.005795
(ii)	Indirect effect via grain number/spike (X_2) (P_{24}r23)	0.000636
(iii)	Indirect effect via 1000-grain weight (X_1) (P_{14}r13)	0.29330
	Total effect (Direct + Indirect)	0.290

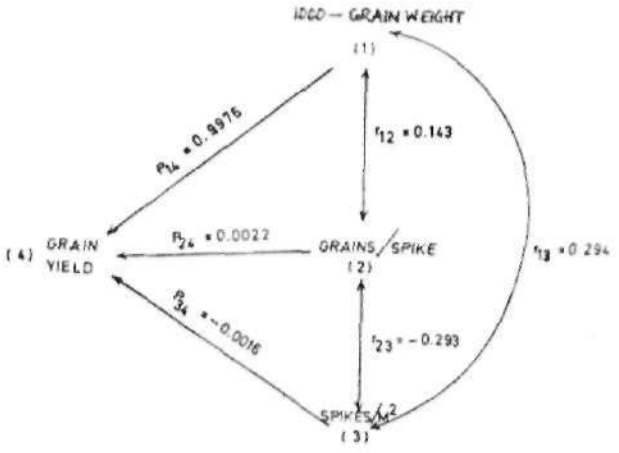


Fig.39. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress at different sowing dates during 1983/86 seasons (combined).

4.5.3.6 Polynomial Response of Sowing Date and Water Stress

The predication equations for linear and quadratic response during 1983-84 and the estimated yields are shown in Table 22. When the deviation between observed and expected were tested using a chi-square test, it was revealed that neither the deviations due to sowing dates nor any water stress levels were found to be significant in this season.

Significance of deviation in sowing date x water stress experiment during 1984-85 season is shown in Table 23. Comparison of calculated X^2 values with the tabular values revealed that none of the deviations in sowing date treatments were found to be significant. In the water stress treatments, severe and moderate were found to be highly significant. The deviation due to linear response at no-stress was found to be insignificant. The total X^2 (28.75) due to water stress in the experiment was found to be highly significant which is mainly attributed to the two moisture stress levels discussed above.

Table 22: Polynomial response of sowing date and water stress during 1983-84 season.

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Total X^2
Sowing date (S)						
S_1 = 10th Nov. (Early)	4143	4123.8	0.089	4143	0.0	0.098NS
S_2 = 1st Dec. (Medium)	4007	4050.0	0.457	4007	0.0	0.457NS
S_3 = 22nd Dec. (Late)	3986	3966.5	0.096	3986	0.0	0.096NS
						0.651NS
Water stress (I) (IW/CPE ratio)						
I_1 = 0.50 (Severe)	2977	2978	0.0003	2977	0.0	0.0003NS
I_2 = 0.75 (Moderate)	4048	4046	0.0010	4048	0.0	0.0010NS
I_3 = 0.00 (No stress)	5113	5114	0.0002	5113	0.0	0.0002NS
			0.0015			0.0015NS

NS = Not significant
Equations
Sowing dates $Y_L = 4045.3-78.5x$; $Y_Q = 4007.0-78.5x+57.5x^2$
Water stress $Y_L = 4046.0+1068x$; $Y_Q = 4048.0+1068x-3x^2$

Table 23: Polynomial response of sowing date and water stress during 1984-85 season.

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Total X^2
Sowing date (S)						
10th Nov. (Early)	1105	1083.8	0.42	1105	0.0	0.42NS
1st Dec. (Medium)	949	991.3	1.81	949	0.0	I.81NS
22nd Dec. (Late)	920	898.8	0.50	920	0.0	0.50NS
						2.73NS
Water stress (I) (IW/CPE ratio)						
0.50 (Severe)	606	673.7	6.80	606	0.0	6.80**
0.75 (Moderate)	11127	991.7	18.45	1127	0.0	18.45**
0.00 (No stress)	1242	1309.7	3.50	1242	0.0	3.50NS
						28.75**

NS = Not significant
** = Significant at 1% level.
Equations
Sowing dates $Y_L = 991.3-92.5x$; $Y_Q = 949.0-92.5x+63.5x^2$
Water stress $Y_L = 991.7+318x$; $Y_Q = 1127+318x-203x^2$

Unlike in 1984-85, the deviations in yield of observed and expected by linearity is highly significant and significant on 1st and 22nd December sowing dates, respectively. All other deviations in the 3 water stress

levels and early sowing of 10th November were found to be insignificant (Table 24).

Chi-square values of the deviations between observed and expected yield due to 1st and 2nd order of polynomial and their respective equations are shown in Table 25 for combined analysis. Comparing the calculated chi-square values with tabular value revealed that none of the deviations were statistically significant indicating a good fit of the expected values when compared with linear observed values.

4.5.3.7 Water-use Efficiency

The water-use efficiency (WUE) of the crops in 1983/84 dry season as observed to increase with delay in sowing. However, in 1984/85 and 1985/86 trials, the WUE decreased significantly when sowing was delayed from November to December (Table 26).

Throughout the 3-year trial, the WUE of the crop was found to decrease with increase in water stress. The control treatment produced crop with the highest WUE, while the severely stressed crop had the least WUE.

Amongst the two varieties, 'Siete Cerros' consistently maintained a higher level of WUE throughout the 3 seasons in comparison with 'Sonalika'.

Table 24: Polynomial response of sowing date and water stress during 1985-86 season.

Treatment	*Observed* yield (kg/ha)	*Expected yield (kg/ha)* Linear	X^2	Quadratic	X^2	Total X^2
Sowing date (S)						
10th Nov. (Early)	2496	2421.6	2.29	2496	0.0	2.29NS
1st Dec. (Medium)	1640	1788.6	12.35	1640	0.0	12.35**
22nd Dec. (Late)	1230	1155.6	4.79	1230	0.0	4.79*
						19.43**
Water stress (I) (IW/CPE ratio)						
0.50 (Severe)	737	759	0.64	737	0.0	0.64NS
0.75 (Moderate)	1266	1222	1.58	1266	0.0	1.58NS
0.00 (No stress)	1663	1685	0.29	1663	0.0	0.29NS
						2.51NS

NS = Not significant
* and ** = Significant at 5 and1% levels,respectively.
Equations
Sowing dates $Y_L = 1788.6-633x$; $Y_Q = 1640.0-633x+223x^2$
Water stress $Y_L = 1222+463x$; $Y_Q = 1266+463x-66x^2$

Table 25: Polynomial response of sowing date and water stress during 1983-86 seasons (combined).

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Total X^2
Sowing date (S)						
10th Nov. (Early)	2581	2543	0.57	2581	0.0	0.57NS
1st Dec. (Medium)	2199	2275	2.54	2199	0.0	2.54NS
22nd Dec. (Late)	2045	2007	0.72	2045	0.0	0.72NS
						3.83NS
Water stress (I) (IW/CPE ratio)						
0.50 (Severe)	1440	1470.1	0.62	1440	0.0	0.62NS
0.75 (Moderate)	2147	2086.6	1.75	2147	0.0	1.75NS
0.00 (No stress)	2673	2703.1	0.34	2673	0.0	0.34NS
						2.71NS

NS = Not significant
Equations
Sowing dates $Y_L = 2275-268x$; $Y_Q = 2199-268x+114x^2$
Water stress $Y_L = 2086.6+616.5x-90.5x^2$; $Y_Q = 2146.9+616.5x-90.5x^2$

Table 26: Total water use (mm) and WUE (kg/ha-mm) of wheat as affected by sowing date and water stress at Kadawa - 1983-86 seasons.

Treatment	1983-84			1984-85			1985-86		
	Yield (kg/ha)	Total water use (mm)	WUE (kg/ha) (mm)	Yield (kg/ha)	Total water use (mm)	WUE (kg/ha) (mm)	Yield (kg/ha)	Total water use (mm)	WUE (kg/ha) (mm)
Sowing date (S)									
10th Nov. (Early)	4143	326	12.7	1105	312	3.5	2496	406	6.1
1st Dec. (Medium)	4007	308	13.0	949	280	3.4	1640	382	4.3
22nd Dec. (Late)	3986	280	14.2	920	278	3.3	1230	360	3.4
SE (±)	184.7			46.8			134.3		
Water stress (I) (IW/CPE ratio)									
0.50 (Severe)	5113	408	12.5	1242	358	3.5	1663	326	5.1
0.75 (Moderate)	4048	375	10.8	1127	332	3.4	1266	295	4.3
0.50 (No stress)	2977	314	9.4	606	280	2.2	737	253	2.9
SE(±)	184.7			46.8			66.4		
Variety(V)									
Siete Cerros	4263	345	12.4	1091	285	3.8	1323	262	5.0
Sonalika	3828	420	9.1	893	312	2.9	1121	290	3.8
SE (±)	150.8			38.2			57.4		

WUE = Water-use efficiency

4.6 Field Experiment II

Response of dwarf wheat 'Siete Cerros' to water stress and nitrogen level

4.6.1 Plant height

Water stress

Decreasing water stress level from 0.50 to 0.75 IW/CPE ratio did not increase the plant height in 1983/84 (Table 27). However, when the irrigation level was increased to IW/CPE ratio of 1.00, there was significant increase in plant height. The difference between 0.75 and 1.00 IW/CPE ratio was also not significant.

In 1984/85, increasing irrigation level from 0.50 to 0.75 IW/CPE ratio increased the plant height significantly. A further increase in irrigation level from 0.75 to 1.00 IW/CPE ratio, gave no significant increase in the plant height. The plant height increase as affected by irrigation level did not attain the level of significance in1985/86 season (Table 27).

Nitrogen levels

Nitrogen levels favorably and significantly increased the plant height with increase in N level up to 150kg/ha in 1983/84 season, beyond which no increase was recorded at 225kg N/ha. However, during 1984/85 season, the difference between plant height of control and 75kg N/ha was not statistically significant.

Table 27: Effect of water stress and nitrogen level on plant height (cm) at Kadawa.

Treatment	Plant height (cm)		
	1983/84	1984/85	1985/86
Water stress (I) (IW/CPE ratio)			
0.50 (Severe)	77.9b	75.8b	69.4
0.75 (Moderate)	78.7ab	79.4a	74.0
1.00 (No stress)	79.8a	80.1a	74.0
SE (±)	0.43	0.52	1.18
Nitrogen (kg/ha)			
0	67.2c	71.4b	63.8b
75	81.7b	73.2ab	73.3a
150	83.1a	75.5a	76.0a
225	83.2a	74.2a	76.3a
SE (±)	0.50	0.81	1.37
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

A further increase in N level to either 150 or 225kg resulted in plants of similar height, but the latter two levels were taller than the control. The differences among all the three treatments of applied N was not significant in 1985/86 season, but they significantly excelled the control (Table 27).

4.6.1.2 Dry matter production

Water stress

The no stress level (IW/CPE ratio = 1.00) resulted in significantly higher dry matter production compared with the 0.50 ratio but statistically at par with the 0.75 ratio in 1985/86 only. Likewise the difference between 0.75 and 0.50 IW/CPE ratio was not significant (Table 28).

Nitrogen levels

In the first two seasons (1983/84 and 1984/85), the three applied N levels, being at par, significantly increased the dry matter production over control. In 1985/86 season, N levels significantly and linearly increased the dry matter production with each level of applied nitrogen (Table 28).

4.6.1.3 Number of tillers/.m^2

Water stress

Number of tillers/m^2 did not differ significantly with variable water stress levels during 1983/84 and 1984/85 seasons. However, in 1985/86 season, IW/CPE ratio 1.00 (no stress) produced significantly higher number of tillers/m^2 compared with the 0.50 ratio. The differences between 0.50 and 0.75 and the 0.75 and 1.00 ratio were statistically not significant (Table 29).

Table 28: Effect of water stress and nitrogen level on dry matter production (g/m²) at Kadawa.

Treatment	Dry matter production (g/m²)		
	1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	646.6	607.9	607.0b
0.75 (Moderate)	648.0	673.5	671.1ab
1.00 (No stress)	683.5	698.6	701.9a
SE (±)	46.61	41.35	19.92
Nitrogen (kg/ha)			
0	457.9b	492.1b	543.5d
75	667.8a	633.3a	599.5c
150	722.5a	740.0a	694.1b
225	791.8a	744.6a	802.8a
SE (±)	53.62	47.75	23.00
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
WAS = Weeks after sowing
NS = Not significant

Table 29: Effect of water stress and nitrogen level on number of tillers/m² at Kadawa.

Treatment	Number of tillers/m²		
	1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	594.1	591.7	566.8b
0.75 (Moderate)	596.3	600.2	612.0ab
1.00 (No stress)	615.5	614.1	627.1a
SE (±)	7.09	7.59	17.12
Nitrogen (kg/ha)			
0	557.9c	550.9 c	479.4d
75	587.7b	583.2bc	579.2c
150	597.4b	605.1b	640.7b
225	664.9a	660.6a	707.7a
SE (±)	8.19	8.77	19.76
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water.
CPE = Cumulative pan evaporation.
NS = Not significant

Nitrogen level

Nitrogen fertilization linearly and significantly increased the tiller number/m² during the three seasons. However, differences between 75 and 150kg N in 1983/84, control and 75kg N and 75 and 150kgN/ha in 1984/85 were not significant.

4.7.1 Yield Parameters

4.7.1.1 Length of spike

Water stress

Spike length variation due to irrigation levels were significant in 1985/86 season only. Irrigation at IW/CPE ratio of 0.75 and 1.00, being at par, significantly increased the length of spike over the 0.5 ratio (Table 30).

Nitrogen levels

Various N levels (75 to 225kg/ha), being at par, significantly increased length of spike over the control (N_o) during 1983/84 and 1985/86 seasons. However, during 1984/85 season, both 150 and 225kg N/ha being at par, significantly excelled in respect of spike length over control and 75kg N/ha, which were also at par with each other.

Table 30: Effect of water stress and nitrogen level on length of spike (cms) at Kadawa.

Treatment	Length of spikes (cms)		
	1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	7.8	**8.1**	7.5b
0.75 (Moderate)	7.7	**8.2**	7.8a
1.00 (No stress)	7.9	8.1	8.1a
SE (±)	0.08	0.06	0.14
Nitrogen (kg/ha)			
0	7.1b	7.9b	6.8b
75	81.7b	73.2ab	7.9a
150	83.1a	75.5a	8.3a
225	83.2a	74.2a	8.1a
SE (±)	0.09	0.07	0.16
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water.
CPE = Cumulative pan evaporation.
NS = Not significant.

4.7.1.2 Number of spikes/m²

Water stress

Differences in the number of spikes/m² in relation to irrigation levels were not significant during the three seasons (Table 31).

Nitrogen levels

Application of 150 and 225kg N/ha resulted in

significantly more spikes/m² over the control in all the three seasons. However, application of 75 and 150 and control and 75kg N/ha produced statistically the number of spikes/m², while 225kg N/ha yielded significantly higher number of spikes than 150kg N/ha.

4.7.1.3 Number of grains/spike

Water stress

There was no significant difference recorded in the number of grains/spike produced by wheat due to different irrigation levels in the three seasons (Table 32).

Nitrogen levels

The number of grains/spike increased significantly by N application only in 1984/85 and 1985/86 seasons, although the difference between 150 and 225kg N/ha was not significant statistically (Table 32).

Table 31: Effect of water stress and nitrogen level on number of spikes/m² of wheat at Kadawa.

Treatment	Number of spikes/m²		
	1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	483.9	482.8	493.0
0.75 (Moderate)	468.8	471.9	481.2
1.00 (No stress)	467.1	465.2	445.6
SE (±)	5.57	5.97	13.46
Nitrogen (kg/ha)			
0	438.5c	439.4c	376.8c
75	461.9bc	458.4bc	455.3bc
150	469.6b	475.6b	503.6b
225	522.6a	519.2a	556.3a
SE (±)	2.42	6.89	15.53
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

Table 32: Effect of water stress and nitrogen level on number of grains/spike of wheat at Kadawa.

Treatment	Number of grains/spike		
	1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	39.6	44.5	53.0
0.75 (Moderate)	43.2	45.7	53.3
1.00 (No stress)	40.2	48.0	55.8
SE (±)	6.22	1.00	0.74
Nitrogen (kg/ha)			
0	37.9	39.2c	46.6c
75	39.8	45.4b	52.5b
150	41.9	49.2a	57.4a
225	44.4	50.4a	59.7a
SE (±)	7.17	1.16	0.85
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

4.7.1.4 Weight of grains.spike

Water stress

In the first season (1983/84), no significant increase in weight of grains/spike was recorded, when irrigation level was increased from IW/CPE ratio of 0.50 to 0.75. However, a significant increase in grain weight/spike was recorded, when the irrigation level was raised to IW/CPE = 1.00. In the following two seasons, no significant difference was recorded in the weight of grains/spike (Table 33).

Nitrogen levels

Nitrogen levels, being at par significantly excelled control in 1984/85 and 1985/86 (Table 33). In 1983/84, only 225kg N/ha was significantly superior to rest of the N levels (0 - 150kg/ha), which were at par.

4.7.1.5 1000-grain weight

Water stress

The variations in 1000-grain weight with the frequency of irrigation was not significant in all the years of study (Table 34).

Nitrogen levels

Nitrogen levels (75 - 225kg/ha), being at par, significantly excelled the control in respect of 1000-grain weight during 1984/85 seasons. In 1983/84, nitrogen at 150 and 225kg/ha significantly increased 1000-grain over control.

Table 33: Effect of water stress and nitrogen level on weight of grains/spike(g) at Kadawa.

Treatment	Weight of grains/spike(g) 1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	1.8b	1.6	1.7
0.75 (Moderate)	1.8b	1.5	1.8
1.00 (No stress)	2.0a	1.6	2.0
SE (±)	0.04	0.06	0.09
Nitrogen (kg/ha)			
0	1.8b	1.4b	1.4b
75	1.8b	1.5a	1.9a
150	1.9b	1.7a	2.1a
225	2.0a	1.7a	2.0a
SE (±)	0.05	0.07	0.11
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

Table 34: Effect of water stress and nitrogen level on 1000-grain weight of wheat (g) at Kadawa.

Treatment	1000-grain weight (g)		
	1983/84	1984/85	1985/86
Water stress (IW/CPE ratio			
0.50 (Severe)	45.3	45.8	35.7
0.75 (Moderate)	43.8	44.4	35.7
1.00 (No stress)	44.5	44.6	35.1
SE (±)	0.96	0.89	0.31
Nitrogen (kg/ha)			
0	41.6b	41.8b	34.2b
75	44.7ab	44.8a	35.3a
150	45.6a	46.7a	36.2a
225	46.2a	46.3a	36.2a
SE (±)	1.11	1.02	0.36
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water.
CPE = Cumulative pan evaporation.
NS = Not significant.

However, application of N at 75kg/ha was at par with control as well as higher levels of N (150 and 225kg/ha).

4.7.1.6 Straw yield

Water stress

There was definite and consistent increasing trend in straw yield as irrigation frequency increased from IW/CPE ratio of 0.5 to 1.00, but the differences were not significant (Table 35).

Nitrogen levels

Nitrogen fertilization linearly and significantly increased the straw yield of wheat in all the three seasons. The difference between 0 and 75kg/ha was significant in 1983/84 and 1984/85 but at par in 1985/86 season. Increase in N level from 150 to 225kg/ha were at par in all the seasons.

4.7.1.7 Grain yield (kg/ha)

Water stress

During 1983/84, 1984/85 seasons and in the combined analysis over 3 experiments, no stress irrigation level (IW/CPE = 1.00) produced significantly higher grain yield than the 0.5 and 0.75 ratios, which were at par. However in 1985/86 season, the grain yield produced by IW/CPE ratio = 1.00 was significantly higher than the ratio = 0.5 only (Table 36).

Table 35: Effect of water stress and nitrogen level on straw yield of wheat (kg/ha) at Kadawa.

Treatment	Straw yield (kg/ha) 1983/84	1984/85	1985/86
Water stress (IW/CPE ratio)			
0.50 (Severe)	4536.0	5102.7	5091.8
0.75 (Moderate)	4872.0	5537.9	5806.1
1.00 (No stress)	5172.0	6375.7	6232.3
SE (±)	184.80	647.36	327.16
Nitrogen (kg/ha)			
0	1644.0c	4177.9b	3651.8b
75	5196.0b	4721.9b	5748.5ab
150	6192.0a	6734.7a	6658.6a
225	6420.0a	7050.2a	6785.3a
SE (±)	213.60	374.3	377.9
Interaction			
N x I	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

Table 36: Effect of water stress and nitrogen level on grain yield (kg/ha) of wheat at Kadawa.

Treatment	Grain yield (kg/ha) 1983/84	1984/85	1985/86	Pooled mean
Water stress (IW/CPE ratio)				
0.50 (Severe)	2045.3b	2319.8b	2604.8b	2336.9b
0.75 (Moderate)	2058.7b	2399.2b	2748.6ab	2409.6b
1.00 (No stress)	2361.6a	2825.8a	2822.5a	2699.0a
SE (±)	104.12	142.02	72.26	99.10
Nitrogen (kg/ha)				
0	1441.6b	1727.5b	1952.5b	1711.4b
75	2228.6a	2623.3a	2740.5a	2552.6a
150	2627.0a	3006.7a	3067.1a	2962.7a
225	2323.2a	2701.8a	3142.2a	2728.1a
SE (±)	143.52	163.9	170.28	204.48
Interaction				
N x I	NS	NS	NS	NS

Means within a column and a factor followed by the same letter(s) are not significantly different using DMRT at 5% level.
IW = Irrigation water
CPE = Cumulative pan evaporation
NS = Not significant

Based on three seasons pooled mean, the no stress (ratio = 1.00) yielded significantly higher grain than the other two ratios (0.5 and 0.75), which were at par (Table 36).

Nitrogen Levels

Throughout the three seasons of experimentation and in the combined analysis of 3 year data, the various N levels yielded significantly higher grain over the control. The nitrogen levels, however, were statistically at par in all the seasons and in combined analysis (Table 36).

4.7.1.8 Correlation studies (1983-84 season).

A study of correlation coefficient between the grain yield and yield contributing factors revealed that the association was significant with the grain weight and with number of grains/spike and number of spikes/m^2 was highly significant in 1983-84. The association of yield with other characters also indicated that its correlation with straw yield, plant height and dry matter accumulation was also highly significant. When the relationship within yield components was examined, the 1000-grain weight was not significantly associated with either number of grains/spike or number of spikes/m^2 but the association between the number of spikes/m^2 and number of grains/spike was significant at 5 percent.

Table 37: Simple correlation analysis between the parameters studied during 1983/84 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.318*	1.00								
3. No. of grains/spike	.507**	.226NS	1.00							
4. Grain weight/spike	.010NS	.160NS	.784**	1.00						
5. Length of spike	.112NS	.192NS	.431**	.126**	1.00					
6. Straw yield	.581**	.320*	.461**	.224NS	.777**	1.00				
7. No. of spikes/m²	.413**	.079NS	.328**	.210NS	.382**	.497**	1.00			
8. No. of tillers/m²	.226NS	.318*	.375**	.238NS	.331**	.532**	.470**	1.00		
9. Plant height	.596**	.374**	.425**	.170NS	.844**	.892**	.421**	.135NS	1.00	
10. Dry matter accumulation	.462**	.063NS	.070NS	.123NS	.352*	.449**	.169NS	.634**	.709**	1.00

NS = Not significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability.

Grain weight was also found to be significantly correlated with straw yield, number of tillers/m² and plant height. Number of grains/spike was found to be correlated at 1 percent level of significance with grain weight/spike, length of spike, straw yield, number of tillers/m² and plant height (Table 37).

4.7.1.9 Correlation studies (1984-85 season)

During this season, grain yield/ha was significantly correlated with number of spikes/m² and its association with the other two yield contributing characters of 1000-grain weight and number of grains/spike was highly significant. In addition, grain yield was found to be significantly correlated with dry matter accumulation and highly significantly correlated with straw yield and plant height. When the correlation within the yield components was examined, 1000-grain weight was not significantly correlated with both number of grains/spike and number of spikes/m². The association of grain weight was highly significant with grain weight/spike

and length of spike. The correlation between number of spikes/m² and number of grains/spike was highly significant. The number of grains/spike was found to be either significant or highly significant with all the characters studied in this season except length of spike (Table 38).

Table 38: Simple correlation analysis between the parameters studied during 1984/85 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.377**	1.00								
3. No. of grains/spike	.453**	.260NS	1.00							
4. Grain weight/spike	.223NS	.447**	.294*	1.00						
5. Length of spike	.197NS	.418**	.090NS	.294*	1.00					
6. Straw yield	.429**	-.023NS	.339*	.073NS	-.384**	1.00				
7. No. of spikes/m²	.337*	.135NS	.492**	.046NS	-.177NS	.376**	1.00			
8. No. of tillers/m²	.176NS	.212NS	.459**	.059NS	-.228NS	.385**	.529**	1.00		
9. Plant height	.391**	.185NS	.489**	.211NS	.027NS	.507**	.380**	.447**	1.00	
10. Dry matter accumulation	.338*	.269NS	.290*	.372**	.368**	.027NS	.131NS	.043NS	.109NS	1.00

NS = Not significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability.

4.7.2.0 Correlation studies (1985-86 season)

In 1985-86 season, the correlation of yield with its components and within yield components themselves revealed that association of yield was significant with 1000-grain weight and highly significant with both number of grains/spike and spikes/m². The association of 1000-grain weight was highly significant with number of grains/spike and not significant with number of spikes/m². The association between number of spikes/m² and number of grains/spike was also highly significant. When the association of yield components was examined with the other characters studied, grain weight was

found to be negatively correlated with straw yield. Number of grains/spike was found to be associated with grain weight/spike and straw yield (Table 39).

4.7.2.1 Correlation studies (1983-86 seasons combined)

In the combined analysis of 3 experiments, the grain yield was significantly correlated with all characters under study except number of tillers/m^2 (Table 40). Grain weight was correlated with number of grains/spikes but not significantly associated with number of spikes/m^2. The association between number of grains/spike and number of spikes/m^2 was highly significant. When the association of yield and yield components was examined, it was significantly correlated with all other parameters except number of tillers/m^2.

Table 39: Simple correlation analysis between the parameters studied during 1985/86 seasons.

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.290*	1.00								
3. No. of grains/spike	.507**	.656**	1.00							
4. Grain weight/spike	.215NS	.017NS	.138NS	1.00						
5. Length of spike	.124NS	.110NS	.077NS	.138NS	1.00					
6. Straw yield	.149NS	-.293*	.328*	.123NS	.155NS	1.00				
7. No. of spikes/m²	.436**	.234NS	.402**	-.089NS	-.201NS	.070NS	1.00			
8. No. of tillers/m²	-.134NS	.047NS	-.153NS	-.247NS	-.145NS	.139NS	.359*	1.00		
9. Plant height	.181NS	-.225NS	.200NS	-.002NS	-.015NS	.419**	-.110NS	.220NS	1.00	
10. Dry matter accumulation	-.063NS	-.294*	.120NS	-.080NS	.057NS	-.035NS	-.139NS	-.197NS	.113NS	1.00

NS = Not significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability.

Table 40: Simple correlation analysis between the parameters studied during 1983/86 seasons (combined)

	1	2	3	4	5	6	7	8	9	10
1. Grain yield/ha	1.00									
2. 1000-grain weight	.627**	1.00								
3. No. of grains/spike	.587**	.443**	1.00							
4. Grain weight/spike	.306*	.262NS	.285NS	1.00						
5. Length of spike	.384**	.288NS	.530**	.372**	1.00					
6. Straw yield	.813**	.173NS	.647**	.436**	.469**	1.00				
7. No. of spikes/m²	.499**	.221NS	.444**	.001NS	.261NS	.158NS	1.00			
8. No. of tillers/m²	.257NS	.346*	.439**	.242NS	.433**	.512**	.206NS	1.00		
9. Plant height	.450**	.347*	.621**	.320*	.573**	.392**	.505**	.421**	1.00	
10. Dry matter accumulation	.463**	.352*	.715**	.151NS	.505**	.591**	.278NS	.641**	.402**	1.00

NS = Not significant
* = Significant at 5% level of probability
** = Significant at 1% level of probability.

Grain weight was found to be correlated with number of tillers/m², plant height and dry matter accumulation. Number of grains/spike was found to be highly correlated with length of spike, straw yield, number of tillers/m², plant height and dry matter accumulation.

4.7.2.2 Path-coefficient analysis (1983-84 season).

Path diagram of coefficient of factors (P) and coefficient of correlation (r) of yield components affecting grain yield is shown in (Fig.40) and the corresponding direct indirect and total contribution of these components is shown in Table 41 for 1983-84 season.

The total contribution of 1000-grain weight for grain yield was 31.8 percent. Out of this figure, seed weight contributed 21.3 percent directly and it contributed indirectly 8.3 and 2.2 percent via number of seeds/spike and spikes/m^2. The total contribution of number of seeds/spike was 50.7 percent out of which 36.9 percent was direct and 4.8 and 9.0 percent through seed weight and number of spikes/m^2. When the contribution of number of spike/m^2 was examined on grain yield, out of a total contribution of 41.3 percent, 27.5 percent was direct and 1.7 and 12.1 percent were via seed weight and seeds/spike, respectively (Table 41).

Table 41: Direct and indirect contribution of yield components on grain yield of wheat subjected to moisture stress under different N fertility level during 1983/84 season.

Calculation of Direct and Indirect Effects

(a)	(i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	0.213
	(ii)	Indirect effect via seed number/spike (X_2) ($P_{24}r12$)	0.083
	(iii)	Indirect effect via spikes/m² (X_3) ($P_{34}r13$)	0.022
		Total effect (Direct + Indirect)	0.318
(b)	(i)	Seed number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	0.369
	(ii)	Indirect effect via spikes/m² (X_3) ($P_{34}r23$)	0.090
	(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r12$)	0.048
		Total effect (Direct + Indirect)	0.507
(c)	(i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	0.275
	(ii)	Indirect effect via seed number/spikes (X_2) ($P_{24}r23$)	0.121
	(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r13$)	0.017
		Total effect (Direct + Indirect)	0.313

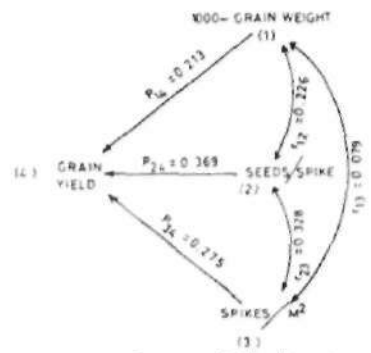


Fig.40. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress under varying N levels during 1983-84 season.

4.7.2.3 Path-coefficient analysis (1984-85 season)

Path diagram of coefficients of factors (P) and correlation (r) are shown in (Fig.41) and the corresponding direct, indirect and total contribution of each factor in Table 42 for 1984-85 season. When the path coefficient analysis was examined, out of a total of 37.7, 1000-grain weight directly contributed 27.7 percent and indirectly contributed 8 and 2 percent via number of seeds/spike and number of spikes/m^2. Number of seeds/spike directly contributed 30.8 percent and indirectly 7.2 and 7.3 percent through seed weight and number of spike/m^2. Like in 1983-84, the highest total contribution of 45.3 percent was from number of seeds/spike. The total contribution of number of spikes/m^2 for grain yield was 33.7 percent with 14.8 percent directly and 3.7 and 15.2 percent through seed weight and seeds/spike (Table 42).

4.7.2.4 Path-coefficient analysis (1985-86 season)

Coefficients of factors (P) and correlation (r) are shown in path diagram Fig.42 and the corresponding direct, indirect and total contributions in Table 43 for 1985-86 season.

Table 42: Direct and indirect contribution of yield components on grain yield of wheat subjected to moisture stress under different N fertility level during 1984/85 season.

Calculation of Direct and Indirect Effects

(a)	(i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	0.277
	(ii)	Indirect effect via seed number/spike (X_2) ($P_{24}r12$)	0.080
	(iii)	Indirect effect via spikes/m² (X_3) ($P_{34}r13$)	0.020
		Total effect (Direct + Indirect)	0.377
(b)	(i)	Seed number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	0.308
	(ii)	Indirect effect via spikes/m² (X_3) ($P_{34}r23$)	0.073
	(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r12$)	0.072
		Total effect (Direct + Indirect)	0.453
(c)	(i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	0.148
	(ii)	Indirect effect via seed number/spike (X_2) ($P_{24}r23$)	0.152
	(iii)	Indirect effect via 1000-grain weight (X_1) ($P_{14}r13$)	0.037
		Total effect (Direct + Indirect)	0.377

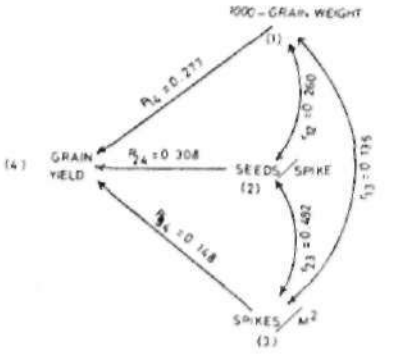


Fig.41. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress under varying N levels during 1984-85 season.

Table 43: Direct and indirect contribution of yield components on grain yield of wheat subjected to moisture stress under different N fertility level during 1985/86 season.

Calculation of Direct and Indirect Effects

(a) (i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	1.135
(ii)	Indirect effect via seed number/spike (X_2) (P_{24}r12)	1.033
(iii)	Indirect effect via spikes/m² (X_3) (P_{34}r13)	0.188
	Total effect (Direct + Indirect)	0.290
(b) (i)	Seed number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	1.574
(ii)	Indirect effect via spikes/m² (X_3) (P_{34}r23)	0.323
(iii)	Indirect effect via 1000-grain weight (X_1) (P_{14}r12)	-0.744
	Total effect (Direct + Indirect)	0.507
(c) (i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	0.803
(ii)	Indirect effect via seed number/spike (X_2) (P_{24}r23)	-0.636
(iii)	Indirect effect via 1000-grain weight (X_1) (P_{14}r13)	0.266
	Total effect (Direct + Indirect)	0.436

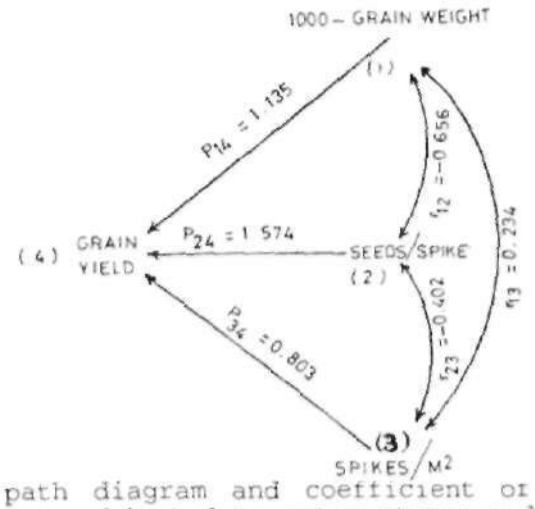


Fig.42. A path diagram and coefficient or factors influencing grain yield of wheat subjected to water stress under varying N levels during 1985-86 season.

A total contribution of 29 percent on grain yield was due to seed weight. The direct effect of seed weight was 113.5 percent and indirect effect due to number of spikes/m^2 was 18.8 percent. The number of seeds/spike was found to have a negative effect of -103.3 percent on yield during the season. The parameter 1000-grain weight and number of spikes/m^2 had a negative effect of -74.4 and -32.3 percent on yield, respectively (Table 43). A total contribution of 50.7 percent was on account of number of seeds/spike of which 157.4 percent was through direct effect. When the direct and indirect effects of number of spikes/m^2 was examined on grain yield, 80.5 percent was as a result of direct effect and 26.6 percent through seed weight. The indirect effect via number of seeds/spike as negative (-63.3 percent).

4.7.2.5 Path-coefficient analysis (1983-86 seasons combined).

The path coefficient analysis done on the combined data of 1983-86 and the factor coefficient (P) and correlation coefficient of (r) are shown in diagram (Fig.43) and their direct, indirect and total contribution shown in Table 44. The results revealed that irrespective of years, the highest percentage of 62.7 percent was found to be contributed by seed weight of which 44.8 percent was direct from 1000-grain weight and 11.6 and 6.3 percent though number of seeds/spike and number of spikes/m^2.

Table 44: Direct and indirect contribution of yield components on grain yield of wheat subjected to moisture stress under different N fertility level during 1983-86 seasons (combined).

Calculation of Direct and Indirect Effects

(a) (i)	1000-grain weight (X_1) and grain yield (X_4) Direct effect (P_{14})	0.448
(ii)	Indirect effect via seed number/spike (X_2) (P_{24}*12)	0.116
(iii)	Indirect effect via spikes/m² (X_3) (P_{34}*13)	0.063
	Total effect (Direct + Indirect)	0.627
(b) (i)	Seed number/spike (X_2) and grain yield (X_4) Direct effect (P_{24})	0.263
(ii)	Indirect effect via spikes/m² (X_3) (P_{34}*23)	0.126
(iii)	Indirect effect via 1000-grain weight (X_1) (P_{14}*12)	0.198
	Total effect (Direct + Indirect)	0.587
(c) (i)	Spikes/m² (X_3) and grain yield (X_4) Direct effect (P_{34})	0.283
(ii)	Indirect effect via grain number/spike (X_2) (P_{24}*23)	0.117
(iii)	Indirect effect via 1000-grain weight (X_1) (P_{14}*13)	0.099
	Total effect (Direct + Indirect)	0.499

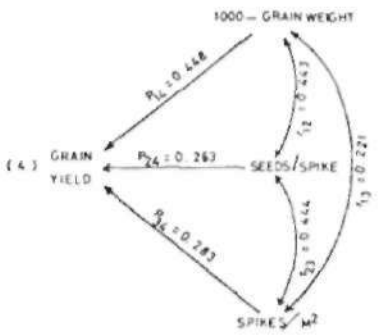


Fig.43. A path diagram and coefficient of factors influencing grain yield of wheat subjected to water stress at different sowing dates during 1983/86 season (combined).

The next contribution came from number of seeds/spike with 26.3 percent from direct effect and 19.8 and 12.6 percent indirectly via 1000-grain weight and number of spikes/m^2. Total of direct and indirect effect on yield was 58.7 percent. The direct effect of number of spikes/m^2 on yield was found to be 28.3 percent of which 9.9 and 11.7 percent were indirectly via 1000-grain weight and spikes/m^2 (Table 44).

4.7.2.6 Polynomial response of water stress and nitrogen levels.

Deviations between observed and predicted yields using the equations developed (Table 45), revealed that in water stress treatment, deviations due to linearity in moderate stress level only was significant during 1983-84 season. When the nitrogen level was considered, all deviations between observed and expected by linear regression were found to be highly significant indicating that linear response does not fit.

Results of 1984-85 season were very similar to that of 1983-84 (Table 46). Deviation due to moderate water stress was significant at 5% level, whereas, in nitrogen levels all deviations between observed and expected yield in linear response were found to be highly significant.

Table 45: Polynomial response of water stress during 1983-84 season.

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Cubic	X^2	Total X^2
Water stress (IW/CPE ratio)								
0.50 (Severe)	2045.3	1997.1	1.16	2045.3	0.00	-	-	1.16NS
0.75 (Moderate)	2058.7	2155.2	4.32	2558.7	0.00	-	-	4.32*
0.00 (No stress)	2361.6	2313.4	1.00	2361.6	0.00	-	-	1.00NS
Nitrogen levels (kg/ha)								
0	1441.6	1698.6	38.88	1425.8	0.18	1441.3	0.00	39.06**
75	2228.6	2002.9	25.43	2275.6	0.97	2228.6	0.00	26.40**
150	2627.0	2307.3	44.30	2580.0	0.86	2627.0	0.00	45.16**
225	2323.2	2611.6	31.85	2338.9	0.11	2323.1	0.00	31.96**
								142.58**

NS = Not significant
* and ** = Significant at 5% and 1% levels, respectively.
Equations
Water stress $Y_L = 2155.2+158.15x$; $Y_Q = 2058.7+158.15x+144.75x^2$
Nitrogen $Y_L = 2155.1+152.16x$; $Y_Q = 2496.0+152.2x-68.18x^2$;
$Y_C = 2496.0+205.73x-68.20x^2-6.53x^3$.

Table 46: Polynomial response of water stress during 1984-85 season.

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Cubic	X^2	Total X^2
Water stress (IW/CPE ratio)								
0.50 (Severe)	2319.8	2261.9	1.48	2319.8	0.00	-	-	1.48NS
0.75 (Moderate)	2399.2	2514.9	5.32	2399.2	0.00	-	-	5.32*
0.00 (No stress)	2825.8	2767.9	1.21	2825.8	0.00	-	-	1.21NS
								8.01*
Nitrogen levels (kg/ha)								
0	1727.5	2018.8	42.03	1718.7	0.05	1727.7	0.05	42.08**
75	2623.3	2349.5	31.91	2649.7	0.26	2623.3	0.00	32.17**
150	3006.7	2680.1	39.80	2980.3	0.23	3006.7	0.00	40.03**
225	2701.8	3010.8	31.71	2710.5	0.03	2702.3	0.00	31.74**
								146.02**

NS = Not significant
* and ** = Significant at 5% and 1% levels, respectively.
Equations
Water stress $Y_L = 2514.9+253x$; $Y_Q = 2399.2x+173.6x^2$
Nitrogen $Y_L = 2514.8+165.33x$; $Y_Q = 2890.0+165.30x-75.04x^2$;
$Y_C = 2890.0+195.38x-75.00x^2-3.66x^3$.

When the deviations between observed and expected due to linear response were considered, none of the response due to water stress was significant statistically during 1985-86 season (Table 47). However, such deviation due to nitrogen levels were highly significant at all the four levels of nitrogen.

The results of combined analysis were very similar to that of 1985-86 season. None of the X^2 values due to water stress were significant and all X^2 values on account of nitrogen levels were highly significant (Table 48).

4.7.2.7 Water use efficiency (WUE)

The WUE of the crops was observed to decrease with increased water stress. This was observed in the 1983/84 and 1984/85 seasons, respectively. However, in the 1985/86 trial, the control treatment had crops with the least WUE while the severely stressed crops had the highest WUE. Generally WUE increased with increase in water stress (Table 49).

Nitrogen application significantly influenced WUE of wheat crop. WUE was found to increase linearly when nitrogen application was increased only from 0 to 150kg/ha; thereafter, addition of nitrogen resulted in a decrease in WUE of the crops. This trend was observed in all the 3 year trials.

Table 47: Polynomial response of water stress during 1985-86 season.

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Cubic	X^2	Total X^2
Water stress (IW/CPE ratio)								
0.50 (Severe)	2604.8	2616.4	0.05	2604.2	0.00	-	-	0.05NS
0.75 (Moderate)	2748.6	2725.3	0.20	2748.6	0.00	-	-	0.02NS
0.00 (No stress)	2822.5	2834.2	0.05	2822.5	0.00	-	-	0.05NS
								0.12NS
Nitrogen levels (kg/ha)								
0	1952.5	2141.2	16.63	1962.6	0.05	1952.7	0.00	16.68**
75	2740.5	2530.8	17.38	2709.0	0.37	2740.6	0.00	17.75**
150	3067.1	2920.4	7.37	3098.6	0.32	3067.1	0.00	7.69**
225	3142.2	3310.0	8.51	3131.4	0.04	3142.1	0.00	8.55**
								50.69**

NS = Not significant
* and ** = Significant at 5% and 1% levels, respectively.
Equations
Water stress $Y_L = 2725.3+108.9x$; $Y_Q = 2748.6+108.9x-34.95x^2$
Nitrogen $Y_L = 2725.6+194.8x$; $Y_Q = 2948.4+194.8x-44.6x^2$;
$Y_C = 2948.0+158.9x-44.6x^2+3.37x^3$.

Table 48: Polynomial response of water stress during 1983-84 season.

Treatment	Observed yield (kg/ha)	Expected yield (kg/ha) Linear	X^2	Quadratic	X^2	Cubic	X^2	Total X^2
Water stress (IW/CPE ratio)								
0.50 (Severe)	2336.9	2300.8	0.57	2336.9	0.00	-	-	0.57NS
0.75 (Moderate)	2409.6	2481.8	2.10	2409.6	0.00	-	-	2.10NS
0.00 (No stress)	2699.0	2662.9	0.49	2699.0	0.00	-	-	0.49NS
								3.16NS
Nitrogen levels (kg/ha)								
0	1711.4	1969.7	33.87	1700.7	0.07	1711.4	0.00	33.94**
75	2552.6	2315.7	24.24	2584.6	0.40	2552.6	0.00	24.64**
150	2962.7	2661.7	34.04	2930.6	0.35	2962.7	0.00	34.39**
225	2728.1	3007.7	25.99	2738.7	0.04	2728.1	0.00	26.03**
								119.00**

NS = Not significant
* and ** = Significant at 5% and 1% levels, respectively.
Equations
Water stress $Y_L = 2481.83+181.05x$ $Y_Q = 2409.60+181.05x+108.35x^2$
Nitrogen $Y_L = 2488.70+173.01x$; $Y_Q = 2824.90+173.01x-67.24x^2$;
$Y_C = 2424.90+209.49-67.2x^2-4.45x^3$.

Table 49: Total water use (mm) and WUE (kg/ha-mm) of wheat as affected by water stress and nitrogen at Kadawa (1983-86).

Treatment	1983-84			1984-85			1985-86		
	Grain Yield (kg/ha)	Total water use(mm)	WUE (kg/ha) (mm)	Grain Yield kg/ha)	Total water use(mm)	WUE (kg/ha) (mm)	Grain Yield (kg/ha)	Total water use(mm)	WUE (kg/ha) (mm)
Water stress (IW/CPE ratio)									
1.00 (No stress)	2361.6	410	5.8	2825.8	372	7.5	2822.5	380	7.4
0.75 (Moderate)	2058.7	361	5.7	2399.2	334	7.2	2748.6	318	8.6
0.50 (Severe)	2045.3	360	5.6	2319.8	330	7.0	2604.8	280	9.3
SE(±)	104.1			142.0			72.3		
Nitrogen(kg/ha)									
0	1441.6	278	5.2	1727.5	285	6.1	1952.5	272	7.2
75	2228.6	293	7.6	2623.3	310	8.5	2740.5	320	8.6
150	2627.0	309	8.5	3006.7	340	8.8	3067.1	338	9.1
225	2323.2	312	7.4	2701.8	360	7.5	3142.2	370	8.5
SE (±)	143.5			163.9			170.3		

WUE = Water-use efficiency

CHAPTER 5

5.0 DISCUSSION

Although a lot of work has been conducted on water scheduling and fertilizer requirements of wheat elsewhere, very little attention has been given to soil-water-crop relation of wheat as to supply adequate information on crop growth and yields especially under Nigerian conditions. Thus it has not been possible to predict what level of soil water stress will limit wheat growth and development unless atmospheric conditions are taken into consideration. Most Of the work conducted for scheduling irrigation have been based on critical stages and on fixed days interval. These approaches may prove irrelevant in view of such factors as rise in water table as a result of poor subsoil drainage or excess irrigation and changes in climatic factors which can cause variations in irrigation requirement. Pan evaporation, which is the index of evaporative demand of the weather, is becoming acceptable as a reliable tool for scheduling irrigation under limited water condition.

Early sown wheat gave better yield because the young seedlings are exposed to low temperature and had low weed infestation and hence less competition. Wheat sown early (November.10) and during medium planting date (December 1) did not encounter any weed infestation, but late sown (December 22) crop encountered some broadleaved weed

infestation from mid-February when temperatures increased considerably. A small incidence of bird infestation across the field was recorded during the second season (1984/85).

The wheat growing season in northern Nigeria extends from November to March for a period of 110 - 120 days marked by suitable temperatures of between 18-24°C. Under assured irrigation during this period. temperature appears to be the most important factor determining the potential of wheat production.

The optimum temperatures differ for different growth stages of wheat. It is 20-24°C for germination, 18-24°C for growth, flowering and grain development (Kumar and Owonubi, 1987). In order to exploit the potential productivity of wheat, however, the growth stages and reproductive phases should coincide with optimum temperatures. In Nigeria, wheat requires at least 55 days of mean air temperatures ranging between 18-24°C for growth, grain development and economic production (Cheema and Kumar, 1993).

Comparing the three growing seasons, grain yield of wheat during 1983/84 were higher over 1985/86 and 1984/85 by 39 and 47%, respectively. The mean air temperature during 1983/84 reproductive phase of the crop (55 DAS) was 20°C and 22.1°C in 1985/86 seasons, respectively. It thus appears that air temperature plays a strong modifying role on grain yield of wheat. This observation is in line with the findings of

Kumar (1993) who reported that every 1°C increase in air temperature during the reproductive phase between the range of 24-28°C at Kadawa, Kano State decreased the grain yield by 633kg/ha.

Irrigation was timely scheduled to impose appropriate moisture stress by means if IW/CPE ratio throughout the three growing seasons. During 1984/85 dry season, however, situations forced the cutting off of irrigation a week earlier (3 weeks before harvest) due to closure of water by the River Basin Authority. The additional one week of water stress has lowered the grain yield during this season.

5.1 Development of internal water deficit in wheat plant

In the absence of added soil water to wheat, and as transpiration from wheat plants in initially wet soil (whose water potential = 0) proceeds from day to day, it progressively reduces soil water content and soil water potential. Since there must necessarily be a gradient of decreasing potential through the water pathway from soil to atmosphere to provide the driving force for water flow, there is also an accompanying decline in plant water potential and plant water content, and consequently an internal water deficit develops and increases in magnitude until the plants wilt.

5.2 Crop water relations of wheat subjected to soil moisture stress.

The rate of increase in plant height was observed to decline as from the 7th week in 'Siete Cerros' (Fig. 3 and 4). This decline coincided with the booting/heading and flowering /grain formation periods respectively which were reported by Sandhu and Horton (1977) to be more sensitive to moisture stress. Similarly, Campell and Davidson (1979) and Talukder (1983) reported that plant height was reduced when moisture stress occurred from the last leaf visible to flowering stage of wheat grown in growth chamber.

'Siete Cerros' compared to 'Sonalika' produced taller plants in all treatments except under severe stress indicating the sensitivity of the variety to increasing height under such stress level. Due to the dwarf nature Of the varieties, no plant height exceeded 42cm.

All treatments except in the case of severely stressed and mildly stressed 'Sonalika' plants showed a sudden decline in rate of transpiration from the 4th to the 6th week after emergence. A second decline was also recorded during 8th and 12th week (Fig.4 and 5). The initial decline can be attributed to the correction of the moisture level applied to all the treatments as the plants were initially stressed. Since the application was uniform, the curves have exhibited similar decline in the rate Of transpiration. The immediate

rise in transpiration after watering indicates that when plants are rewatered after imposition of stress at various growth stages, they show an increase in transpiration rate due to gradual stomatal openings as well as increased growth of plants parts responsible for transpiration. The initial stress also led to the development of secondary tillers (Rab et al.1984) which used water for two weeks longer than the primary tillers.

The rate of water use by the no-stress plants (control) in both varieties occurred at a period (100 days) which coincides with grain filling period. The rise in water use during the period might be as a result of contributed transpiration from ears and awns.

Although both varieties were exposed to the some magnitude of stress, variety 'Sonalika' showed higher increase in stomatal resistance(r_s) in all treatments when compared with 'Siete Cerros'. The maximum stomatal resistance was observed at a period which coincides with the filling stage. In 'Siete Cerros' a decrease in stomatal resistance was also observed during the heading period (9th week).

Recent findings indicate that stomata remains normal and unaffected until the Leaf water potential (ΨL_t) decreases to a critical threshold value (Hsiao, 1973; Millar and Denmead, 1976 and Xu and Ishii, 1991). While Millar and Denmead (1976) defined the critical threshold value as - 1.9MPa

(ψl_t) when the top leaves close their stromata depending on rate Of stress development. Nel and Dijkhuis (1991) defined the value for maximum WUE as -1.82MPa (ψl_t) and -1.44MPa (ψl_t) for maximum yield. Takulder (1983) reported that maximum r_s occurred when wheat crop was stressed at heading and again stressed at the grain formation stage while minimum stomatal resistance was observed at the booting. However, he could not identify the critical threshold value of leaf water potential as the rate of stress development in his work was very fast. Similarly, Agarwal and Koundal (1988) have reported that all physiological processes responded to change in leaf water potential but there was no evidence of a threshold response to change in leaf water potential.

General findings indicate that stomatal closure caused by critical leaf water potential decreases transpiration and photosynthesis under controlled environmental conditions and thus affecting the growth as well as yield of the crop. On the other hand, Leach (1980) reported that stomatal resistance and photosynthesis were not affected in barley under field conditions as a result of moisture stress throughout the growth period. However, stomatal resistance still constitutes a tool used as a moisture indicator particularly in areas of limited water supply since it is known to be the main mechanism for controlling the pathway of gases and water (Hsiao, 1973; Sivakumar and Shaw, 1978).

The total water potential shows a general decline throughout the period of observation (Fig.12 and 13). From the results, the decline varies with the physiological characteristics of the two varieties under all the stress treatments. The cause of the differences in the total leaf water potentials can be attributed to the differences in soil matric potential as a result of stress as well as variation in varietal characteristics. Even after irrigation at the end of the stress cycles the total leaf water potential was continuously higher in the control treatments possibly as a result of cummulative delay in regaining stomatal conductance (Hsiao, 1973).

There was a general decrease in osmotic potential with increasing soil water stress. A higher increase in osmotic potential in leaves was recorded in 'Solanika' when compared to'Siete Cerros'.A decrease in leaf osmotic potential was recorded from the 11th and 12th week in 'Solanika' and 'Siete Cerros', respectively. Talukder (1983) reported a similar decrease at grain formation stage which he attributed to osmotic adjustment in maintaining the Leaf turgor.

From the results, the leaves have maintained positive pressure potential except in the case of severe stress imposed on 'Sonalika' (Fig.16) which gave a negative pressure potential. The negative potential observed in this work agrees with the findings of Hoque (1979), Sionit et al.

(1980), Jensen (1981), Imtiyaz et al, (1983) and Talukder (1983). Sionit et al (1980) reported such minimum values of pressure potential at the flowering stage of wheat in growth chamber which he attributed to possible lack of osmotic adjustment probably due to severe development of water stress. Other workers like Tyree(1976) have suggested that the negative pressure potential may be attributed to errors in measurements of osmotic potential or as a result of neglecting a significant value of the matric potential(Shepherd, 1975).

The effects of the soil moisture stress on leaf water content appear to be in line with other parameters studied in relation to plant water status. As the imposition Of the stress advanced, there was a gradual decline in leaf water content in all the stress treatments. But the control treatments in both varieties maintained a fairly favourable range of leaf water content (6.25g/g in 'Sonalika' and 6.75g/g in 'Siete Cerros') with little fluctuations only.

The unstressed (control) and mildly stressed wheat plants maintained some stable relative water content of 81-88 and 85-90 percent in 'Sonalika' and 'Siete Cerros'; respectively. the more stressed plants showed lower relative water content with the lowest recorded percentage of 53 from the most stressed plants in 'Sonalika' (Fig.20).

The results obtained from the study of various parameters related to water status in plants, it is evident that when

wheat plants are subjected to continuous moisture stress through their growth and development period, they exhibited continuous sensitivity commensurable to the degree of cummulative stress which ultimately affected the yield components and yield. However, due to differences in physiological characteristics of varieties, some maintain low sensitivity even under severe stress condition.

5.3 Crop water parameters in relation to soil matric potential

The quantity of moisture available to plants is highly correlated with the plant water status and the potential gradient that exist between soil and plant. Because the entire growth, development and yield of plants are associated with plant water status, It is essential to have knowledge of the change in water status in the soil so as to plan, allocate and use water efficiently.

The decrease in transpiration rate with increasing soil matric potential may be attributed to cummulative stress to which the plants were exposed. Imtiyaz et al. (1983) and Talukder (1983) also reported a decrease in transpiration rate with increasing soil matric potential in wheat and barley respectively.

The increase in stomatal resistance (r_s) in mildly stressed plants was not as rapid even with increasing soil matric potential to about -1.60MPa. However, in 'Siete Cerros'

even with increased soil matric potential, the severe stressed plants, attained r_s of 25scm^{-1} while mildly stressed reached a maximum of only 12scm^{-1} showing that 'Siete Cerros' in comparison to 'Sonalika' can maintain low r_s even under increased soil matric potential. Lu (1988) in his work, also reported that when soil matric potential of wheat increased, r_s increased and even faster especially on the abaxial side of the leaves.

Total water, osmotic and pressure potentials in leaves decreased with cummulative increase in soil matric potential. However, the total water potential decreased more rapidly especially in all stress treatments on 'Sonalika', with more pronounced decrease in the severe stressed plants of both varieties. 'Siete Cerros' showed lower decrease in total water potential in comparison to 'Sonalika' under all stress conditions indicating the variety to be more stress resistant than 'Sonalika'. Adjei and Kirkham (1980) reported that drought resistant wheat cultivars maintained higher leaf water potential than drought sensitive wheat cultivars.

The result obtained with regards to osmotic potential in leaves indicated that probably due to differences in varietal physiological response to stress, 'Sonalika' was able to maintain a stable osmotic potential up to a certain level of soil matric potential (-1.0MPa). However, 'Siete Cerros' could not maintain an initial stability in osmotic potential

of its leaves, but exhibited the ability to increase the osmotic potential in its leaves under high soil matric potential.

The pressure potential decreased with increasing soil matric potential except in the severely stress plants of 'Siete Cerros' in which the decrease was not so pronounced. The decrease in pressure potential to a negative value in 'Sonalika' may be attributed to the physiological characteristics of the variety. Talukder (1983) reported pressure potential of leaves reaching zero at the grain formation stage under a soil matric potential of -0.14MPa. Imtiyaz et al. (1981) also reported similar results in barley while Sionit et al. (1980) reported a negative ψ^{1}_{p} in wheat during anthesis which they attributed to inability of the tissue to accumulate osmotically active solutes for adjustment as compared to other stages.

Both water content and relative water content also decreased with increasing soil matric potential suggesting that wheat plants are sensitive to cummulative stress due to increasing soil matric potential all through the season. The parameters studied in relation to the water status have been used for sometimes as yardsticks in finding water deficit limits (Huzulak and Matejka, 1989) as well as scheduling irrigation to increase crop production in areas where water constitutes a limiting factor to crop production (Nel and

Berliner, 1990).

It is evident from the results that all the yield components studied were reduced by the various stress treatments, the magnitude of which depended on the intensity of the stress as well as the variety. Several workers have reported such reductions either in some physiological growth stages or even when the stress was imposed throughout the crop growth period (Cheema et al. 1973; Singh et al. 1979; Kumar and Singh, 1978; Kumar, 1979; Surma et al. 1980; Bello, 1983 and Al-Janabi, 1988).

The reductions in yield components of wheat as a result of imposition of water stress have contributed to a large extent in the reduction of straw and grain yield. From the findings, there was progressive reduction in 1000-grain weight, straw and grain yields with increase in moisture stress from mild to severe level. This is in line with what several workers reported (Lawlor et al. 1981; Choudhury and Kumar, 1980; Hassan, 1983; Rab et al. 1993).

5.4. Response of dwarf wheat varieties to sowing date and water stress

5.4.1 Sowing Date

Dry matter production was not affected by the sowing dates in all the 3-season experiments. The growth and development of wheat crop are influenced by prevailing day and

night temperatures. Both the growth and yield are higher with low temperatures. Sowing in late December allowed for only one and a half months period of low temperatures. With rise in temperatures by mid-February especially at night, most of the photosynthates during the day are used by high rate of respiration as a result of high temperatures which resulted in poor dry matter accumulation. Kumar et al. (1982) reported similar result.

Tillering in wheat is affected by both genetic and environmental factors. Among environmental factors, temperature, soil moisture and fertility are important. From the experiments, November sown crop reached the active tillering stage in December when the temperatures were low and this encouraged tillering. Nerson et al. (1979) reported similar results of increased number of tillers/unit area when wheat crop is sown in November.

The spike length decreased with delay in sowing which is attributed to the favourable temperatures at primordial and elongation stages. These stages under late planting are characterized by high temperatures which result in shorter spikes. The findings of Jain et al. (1992) and Kumar and Mayaki (1982) have also shown that delay in planting after November reduced the length of spike. Similarly, the number of spikes/m^2 was reduced with delay in planting for the same reasons stated above.

Delay in sowing decreased number of grains/spike throughout the study. This was as a result of reduced number of spike lets/spike due to temperature fluctuations associated with delayed planting. As the number of spikelets/spike decreased, the number of filled grains per spike also decreased. Ibrahim et al. (1976), Drewit et al. (1978) and Jain et al. (1992) also reported reduction in number of grains/spike with delay in sowing.

Grain weight/spike decreased when planting was delayed to late December. This could be attributed to rise in the night temperature during the grain filling stage. Much of the photosynthates produced during the day was utilised during the night for respiration as a result of high temperature. This finding agreed with the work of Ansari et al. (1989) and Drewit et al. (1978).

The decrease in 1000-grain weight with delay in sowing is also attributed to the same reason advanced above. Ansari et al. (1989) reported reduction in 1000-grain weight delay in sowing date.

The reduction in straw yield with delay in sowing was generally observed. Early and mid season sowing dates provided conducive conditions for proper growth and development of the crop for a much longer period than late sown crop. This resulted in profused tillering, larger leaf area, taller plants with higher dry matter production compared

to late planted crop. These increases in growth might have accounted for higher straw yield in early and mid-season sowing dates when compare with late sowing. Afzal and Nazir (1986) reported similar findings.

Grain yield of wheat decreased with delay in sowing. It is evident from the results that early planting of wheat favours profused tillering, spikes/m^2, spike length, number and weight of grains/spike and 1000-grain weight, all of which directly or indirectly influenced the final grain yield. Wheat being a temperate crop, low temperatures that were prevalent for a much longer duration in early sown wheat could be responsible for higher grain yield in early sown crop. Sandhu et al. (1978), Habib and Makki (1979), Kalyan et al. (1985) and Jain et al. (1992) all reported reduction in grain yield of wheat with delay in sowing.

5.4.2 Water stress

The decrease in plant height with increase in water stress observed in these experiments was expected as water stress limits the vegetative growth at all stages especially jointing stage which significantly affects plant height. Similar results were reported by Lawlor et al. (1981), Gajri and Prihar (1983) and Schalbroeck and Antrique (1988).

The increase in dry matter accumulation with decrease in water stress in all the 3 experiments indicated the

significant role of moisture on growth parameters such as leaf area, tiller number and plant height which have a direct influence on the production and accumulation of dry matter. This result agreed with the work of Lawlor et al. (1981).

There was Linear and significant increase in the number of tillers/m^2 with decrease in water stress. This trend is expected because water stress in wheat decreases virtually all growth parameters including tillering. The growth of crop is directly associated with internal water status and consequently water stress affects numerous internal activities such as turgidity, cell enlargement, photosynthesis and consequently tillering. Similar results were reported by Begg and Turner (1976) who noted that changes in soil water potential cause changes in internal processes resulting in changes in growth.

A progressive increase in length of spike with respect to decrease in water stress occurred in the present investigation. It was attributed to the availability of water to crops which affected the general vigour and most of the growth and yield parameters. Even a mild stress on an established crop was found to cause a marked reduction in a number of growth attributes, including spike length. Bhardwaj et al. (1971) reported similar findings.

Number of spikes/m^2 decreased with increase in water stress throughout the study. It was as a result of water

stress causing tiller mortality and sterility and consequently decreasing the number of effective tillers/plant and per unit area. However, moderate water stress could sustain the crops to produce spikes, though the grains are either shrivelled or spikelets are completely empty. This result is in agreement with the findings of Lawlor et al. (1981) who similarly reported reduction in number of heads/m^2 with increasing water stress. Water stress decreased grain number/spike. This indicated the effect of water on assimilate production, number of spikelets/spike and length of spike, all of which affected grain number/spike. Rab et al. (1984) and Schalbroeck and Antrique (1988) also reported reduction in grain number/spike with increase in water stress.

Imposition of water stress reduced grain weight/spike. It is logical because water stress decreases important growth and yield components due to decreased production of photosynthates. Water stress decreased leaf area, length of spike and number of grains/spike which ultimately resulted in low grain weight/spike. Day and Intalap (1970) and Surma et al. (1980) all reported decrease in grain weight/spike with increase in water stress.

The parameter of 1000-grain weight was reduced with water stress. This is an indication of the negative effect of water stress particularly on grain filling stage. Water stress also affected grain number and weight/spike as well as the size

and weight of grains that filled the spikelets. All these parameters ultimately have direct effect on 1000-grain weight. Hochman (1982) and Schalbroeck and Antique (1988) also recorded reductions in 1000-grain weight with increased water stress.

The straw yield increased linearly with decrease in water stress. These observations indicated the effect of water stress on growth characters as leaf area and dry matter production, tillering, and jointing which have direct bearing on straw yield. Similar results were reported by Gajri and Prihar (1983) and Lawlor et al. (1981).

Grain yield linearly decreased with increase in water stress. This indicated the negative effect of water stress on the general growth, development and yield components of crop, which invariably affected the grain yield. Choudhury and Kumar (1980) and Singh et al. (1980) reported reduction in grain yield with increase in water stress.

5.4.3. Variety

The two dwarf wheat varieties did not differ significantly in relation to height indicating that they are of the same height being dwarf in nature. Also the varieties did not respond differently to either water stress or sowing date. The varieties also did not differ significantly with respect to dry matter being slightly late maturing. 'Siete Cerros' produced higher tillers/m^2 than 'Sonalika'. 'Siete

Cerros' also produced higher number of spikes/m^2 than 'Sonalika' indicating 'Siete Cerros' to have genetic superiority over 'Sonalika'. 'Siete Cerros' produced higher grain number/spike than 'Sonalika' suggesting 'Siete Cerros' to again be genetically superior over 'Sonalika'. Also 'Siete Cerros' had higher 1000-grain weight than 'Sonalika'. This is expected because the former variety also produced heavier grains/spike.

The varietal difference in relation to straw yield indicated that 'Siete Cerros' produced more tillers/plant, taller plants and higher leaf area and number of leaves which ultimately resulted in higher straw yield than 'Sonalika'.

'Siete Cerros' consistently out performed 'Sonalika' in most of the growth and yield components and consequently yielded higher grains. Amaregouda et al (1990) reported greater yield in some varieties which they associated to greater yield contributing characters which was the case in the present investigation.

5.4.4 Simple Correlation Studies

When the association of grain yield with its yield contributing factors was considered, grain weight was found to be very closely associated with the grain yield and all 'r' values were highly significant indicating its pronounced effect on yield. Grain weight was followed by spikes/m^2 wherein its significance with grain yield was at 1% in one

experiment and 5% level in one another and combined analysis and insignificant in one season. The number of grains/spike was found to be associated with grain yield at the lowest degree in date of sowing x water stress experiment as it was found to be significant in one (1% level) out of 4 analyses.

When the correlation coefficients were critically examined within the yield components themselves, it was observed that 1000-grain weight was associated with spikes/m^2 at 1% level in 3 seasons and 5% in the combined analysis. This indicates that factors which favour spikes/m^2 also favour 1000-grain weight when the crop is subjected to water stress and sowing date. The association between grains/spike and 1000-grain weight was positive and significant only in one year whereas, all associations between grains/spike and spikes/m^2 were negative and significant (1%) only in one season.

5.4.5. Path Coefficients

When the total contribution of 1000-grain weight was considered directly and via grains/spike and spikes/m^2, it ranged from 98.7 to 99.8 percent in the 3 experiments and combined analysis. A similar contribution of grains/spike indicated that it contributed very little directly (1%) and sometimes even negative. Contribution of grains/spike via spikes/m^2 was also negligible (about 1%) and 50% of the cases as negative. The main contribution of grains/spike was via

1000-grain weight which gave a total contribution from 10.7 to 37.7 in the 3 experiments. The direct contribution of spikes/m^2 was erratic and most of the cases as negative and ranged from 0.7 to - 39.2%. Similar was the case of spikes/m^2 via grains/spike, but the contribution of spikes/m^2 via 1000-grain weight was significant. The total contribution of spikes/m^2 to the grain yield ranged from 3.6 to 42.9% in the investigations reported.

5.4.6. Polynomial response of grain yield to sowing date and water stress.

In the sowing date x water stress experiments, the deviations between observed and expected as tested using x^2 test of goodness of fit for the polynomial response, linear response (first degree polynomial) was found to fit in two out of 3 seasons and in the combined analysis for the sowing date treatments. In 1985/86 the deviations from linearity were highly significant indicating that in this season, the quadratic response shall fit into the data. When polynomial responses were fitted to the water stress treatment, except in 1984 - 85 season, the first degree of polynomial (linear response) fitted the date, and in 1984 - 85 the second degree of polynomial (quadratic response) was found to be appropriate.

5.4.7 Water Use Efficiency (WUE)

The progressive decrease in WUE with delay in sowing date throughout the 3-year trial is indicative of the fact that delay in sowing resulted in reduced growth and development as the crop growth cycle is shortened due to a sudden rise in temperature at the tail end of the growth span of the crops. This resulted in decreased grain yield, while the total water use did not differ much, consequently resulting in decreasing trend in WUE.

Similar trend was recorded throughout the periods of study in relation to water stress. The reduction in WUE with increased water stress in expected as water stress limits general growth and development as well as the final grain yield. The total water use was also noted to decrease with increase in water stress, consequently resulting in decreased WUE. Similar results were recorded by Singh and Malik (1983).

The WUE of 'Siete Cerros' was higher than that of 'Sonalika' throughout the 3-year study, indicating 'Siete Cerros' to have genetically higher efficiency in converting water absorbed into harvestable grain or dry matter production. Generally, 'Siete Cerros' performed higher than 'Sonalika' in terms of growth and yield attributes consequently having higher grain yield despite using lesser quantity of water than 'Sonalika'.

5.5 Response of dwarf wheat 'Siete Cerros' to water stress and nitrogen fertilization.

5.5.1 Water stress

The linear increase in plant height with decrease in water stress in all the 3-year trial was indicative of the fact that water availability to crops is a function of growth, with particular reference to jointing process in wheat, which influences plant height.

The progressive increase in dry matter production in the 3-year trial indicated the importance of water in photosynthesis, which has a direct bearing on dry matter production. Water stress, even when other growth factors are not limiting, decreases rate of photosynthesis and consequently dry matter accumulation. This was supported by the works of Lawlor et al. (1981) and Gajri and Prihar (1983) who separately reported that was stress decreased the rate of dry matter production in wheat.

The decrease in the number of tillers/m^2 with increased water stress could be attributed to increased tiller senescence or mortality as reported by Bhardwaj et al. (1971) as well as Kumar and Singh (1978). Tillering is genetically controlled, but could also be influenced by environmental factors such as water availability. Water stress generally reduces plant size, photosynthetic area and tiller production/plant as reported by Davidson (1987).

Length of spike in wheat is genetically controlled but could also be influenced by moisture availability and temperature fluctuations. The reduction in length of spike as a result of increased water stress could be attributed to reduced physiological activities of the crop, which consequently affected the proper development of the spikes. Similar finding was reported by Surma et al. (1980).

The lack of significant difference in the number of spikes/m^2 in relation to irrigation levels in the 3-season trial could be explained to the fact that water stress may not necessarily reduce the number of spikes produced per unit area, but may affect the size, length and the number of grains that filled the spikes as water stress reduces the number of spikelets/spike as well as size and number of grains/spike. Rab et al. (1984) in their work on wheat reported similar findings.

The lack of significant difference in the number of grains/spike in relation to water stress can exert its effects on grain filling process either by affecting the number, size or weight of the filled grains in the spikes. The results obtained in the 3-season trial indicated an increase in number of grains/spike with decrease in water stress though the increase was not significant. This result is in agreement with the findings of Lawlor et al . (1981).

The no-stress treatment in all the 3 experiments produced higher grain weight/spike than the stress treatments indicating the significance of water in virtually all physiological activities of the crop, including nutrient uptake, assimilate production and partitioning towards the grain filling process. Lawlor et al. (1981) also reported similar results and attributed this reduction in grain weight/spike as water stress increases, to reduced grain size due to a significant reduction in photosynthetic surface area.

The 1000-grain weight did not respond to water stress treatment in all the 3 seasons, though it was expected to decrease with increasing moisture stress, particularly at soft dough stage as reported by Singh (1981) and Hochman (1982).

Although the difference in straw yield was not significant in all experiments, the increase in straw yield with decrease in water stress was observed and this could be due to the fact that increased water stress resulted in decreased tillering, jointing and leaf area/plant which consequently decreased the straw yield. This result agreed with the findings of Bello (1983).

The progressive decrease in grain yield in relation to increased water stress in the 3-season of study indicated that water supply to crops directly affected all growth and yield parameters of wheat, which subsequently influenced the final grain yield. However, the insignificant difference in grain

yield between moderate and severe water stress indicated that water stress in wheat crop irrespective of its severity and particularly when imposed throughout the crop life cycle, may have serious repercussion on the grain yield. This findings agreed with the work of Singh et al. (1980) who recorded a reduction in grain yield with increasing water stress.

5.5.2 Nitrogen Fertilization

In general, wheat crop, for its growth and development responds to the application of nitrogenous fertilizer as most of the tropical soils lack sufficient quantities of N to meet the requirements of the crop. The progressive increase in plant height as nitrogen level was increased from 0 to 150kg/ha was due to the effects of N on the vegetative growth of the crop, particularly at the jointing process. Beyond 150kgN/ha, the effect of N on plant height was insignificant, indicating 150kgN/ha to be the maximum for increase in height.

The significant difference observed in the dry matter production with increase in N from 0 to 75kg/ha was as a result of the positive effect of N on growth characters such as shoot height, tillering and leaf area/plant. However, the insignificant increase in dry matter production as a result of increased N application from 75 to 225/ha could only be attributed to either leaching, volatilization or alternatively 75kgN/ha could be optimum for dry matter production. Dry matter production increased linearly with increase in N levels

upto 225kg/ha, suggesting that the highest N level produced larger photosynthetic surface, resulting in higher rate of photosynthesis and consequently higher dry matter production. Rathore and Singh (1973) reported similar findings.

Adequate N fertilization coupled with low temperatures as recorded during tillering stage during the 3 experiments favoured profused tillering. This explained the significant difference in the number of tillers produced/m^2 amongst the various N treatments. Similar result was reported by Ibrahim and Assey (1976).

The application of increasing rates of nitrogen from 0 to 75kg/ha significantly increased the length of spike in all the 3-year trial. This observation is not unconnected with the positive effects of N on shoot height, leaf area/plant and the general vigour of the crops. Crops supplied with N become vigorous, capable of producing larger and longer spikes. This observation is in conformity with the findings of El-Sharkawy et al. (1977).

The linear increase in the number of spikes/m^2 in relation to increasing levels of N could be due to the effects of N through promotion of tillering, increasing tiller size, reducing tiller mortality and consequently increasing the number of effective tillers that bear spikes. This observation is in line with the findings of Goma'a et al. (1977), Ellen and Spiertz (1980) and Patra (1990) who reported

an increase in number of spikes/m^2 with increase in N level.

The increase in the number of grains/spike with increasing N levels upto 150kg/ha in all the 3 years is indicative of the positive effect of N on length of spike, leaf area, shoot height and the number of spikelets/spike, which has a direct bearing on the number of grains/spike. Subsequent N increase to 225kg/ha had no effect on this parameter, indicating 150kgN/ha to be optimum. Singh et al. (1980); Gami et al. (1986) and Bharti et al. (1987) all reported 150kgN/ha to be the optimum for number of grains/spike.

Significant increase in grain weight/spike as N level was increased could be due to the favourable effects of nitrogen on the photosynthetic apparatus that resulted in higher rate of assimilate production and partitioning to the grains, which made them fully developed, larger and heavier. Increasing N level beyond 75kg/ha had no significant effect, indicating 75kgN/ha to be optimum. Muir (1989), had reported similar results.

Increasing N level from 0 to 75kg/ha significantly increased 1000-grain weight throughout the years of study. This revealed the positive effect of N on leaf area and dry matter production which have direct bearing on grain filling and subsequently 1000-grain weight. The insignificant difference between 75, 150 and 225kgN/ha in relation to 1000-

grain weight indicated 75kgN/ha to be sufficient for heavier grains. This result confirmed the findings of El-Sharkawy et al. (1977) and Patra (1990).

The significant increase in straw yield with increase in N level up to 150kg/ha during the 3-season of study suggested the influence of N on growth parameters as leaf area, plant height, tillering and dry matter production all of which influenced straw yield. This also revealed that 150kgN/ha to be maximum for straw yield. This observation has conformed with the findings of Singh et al. (1980), Gami et al. (1986) and Bharti et al. (1987) who suggested 150kgN/ha to be optimum for maximum straw yield.

The significant increase in grain yield with increase in N level from 0 to 75 and 150kg/ha is as a result of N favourably increasing all the yield contributing characters like leaf area, number of grains/spike, number of spikes/m^2, grain weight/spike and 1000-grain weight which have direct and indirect influence on grain yield. Application of 120kgN/ha was found to be optimum for grain yield as further addition did not significantly increase the grain yield. This result confirmed the findings of Muir (1989) and Woldeab (1989).

5.5.3 Simple Correlation Studies

In the nitrogen x water stress experiments, number of grains/spike was found to be highly associated with grain yield as all 'r' values were positive and significant at 1%

level. It was closely followed by spikes/m² in which out of 4 analyses 3 were highly significant and one season was significant at 5% level. The third yield contributing factor 1000-grain weight was found not to be as closely associated as the other two yield contributing factors of grains/spike and spikes/m² and one season each was significant at 5% and not significant, respectively. When the correlations within the yield components were examined between spikes/m² and grains/spike, it was highly significant in two cases, significant and not significant in one season each. It was followed by 1000-grain weight with grain weight/spike which was highly significant and not significant in two cases each and between 1000-grain weight and spikes/m² which was highly significant in one and not significant in 3 cases.

5.5.4 Path-Coefficients

A total contribution of grain weight ranged from 29.0 to 62.7% in the 3 seasons and combined analysis, out of which a significant portion was a direct contribution. Number of grains/spike contributed 45.3 to 58.7% out of which direct contribution ranged from 26.3 to 157.4%. Contribution from spikes/m² ranged from 37.7 to 49.9% out of which the direct contribution was between 14.8 to 80.3%. It's contribution via number of grains/spikes in general was higher than via 1000-grain weight. In this experiment, the highest total contribution towards yield was from number of grains/spike

which was closely followed by number of spikes/m^2. The total contribution of 1000-grain weight was found to be the least.

5.5.5 Polynomial response of grain yield to water stress and nitrogen.

When the polynomial response of water stress levels were examined using an X^2 test of goodness of fit over 3 seasons and the combined data analysis, it was observed that second degree of polynomial (quadratic) fitted to the first two season data (Chaudhury et al. 1988), whereas linear response fitted to the third season and the combined analysis data. The deviations between observed and expected using X^2 test were found to be highly significant for N levels in all the 3 seasons and combined analysis for linearity, indicating that the first degree of polynomial response does not fit to this data. Whereas, all deviations between observed and expected at the second degree of polynomials (quadratic) were found to be insignificant for N levels indicating that the quadratic response fits well to the data in 3 seasons and combined analysis.

5.5.6 Water Use Efficiency

The progressive decrease in WUE of the crops with increasing water stress can be attributed to the fact that crops that had no water stress were able to efficiently utilize water to grow normally and vigorously, thus producing higher grain despite higher evapotranspiration (ET) losses.

Al-Janabi (1988) and Heithholt (1989) all reported similar observation. In the 1985/86 trial, however, the increase in WUE with increase in water stress could be due to the fact that the grain yields for the different water stress treatments were comparable while the difference between their respective ET could be highly significant with the severely stressed crops having the least, consequently having the highest, WUE. This was in agreement with the findings of Singh and Kumar (1981).

The significant increase in WUE with increasing N levels upto 150kg/ha in all the 3-year study could be attributed to the fact that crops that were adequately fertilized were able to efficiently utilize water in relation to assimilate production and consequently higher grain yield and WUE despite higher rates of ET. This findings has conformed with the findings of Rathore and Patel (1991). However, the fall in WUE as nitrogen was increased to 225kg/ha could be explained on the basis that this rate (225kgN/ha) might have supported vegetative growth at the expense of reproductive phase, consequently resulting in reduced grain yield, despite a comparable ET with 150kgN/ha treatment.

CHAPTER 6

6.0 SUMMARY AND CONCLUSION

6.1 Summary

Two field experiments were conducted at the Irrigation Research Station, Kadawa for three consecutive seasons during 1983/84, 1985/85 and 1985/86 dry seasons to study the effect of water stress (no stress, moderate and severe) and time of planting (early, medium and late) on the yield components, yield and water-use efficient of two dwarf wheat varieties ('Siete Cerros' and 'Sonalika'); evaluate the effect of water stress and nitrogen fertilization (0, 75, 150 and 225kg/ha) on the yield and water-use efficiency of wheat variety 'Siete Cerros'. A supporting Growth Chamber experiment was also conducted to assess and monitor crucial soil moisture parameters of 'Siete Cerros' and 'Sonalika' in relation to transpiration, stomata resistance, total water, osmotic and pressure potential and other plant processes in relation to growth, yield components and grain yield of the two dwarf wheat varieties.

In Experiment I, variety 'Siete Cerros' out-yielded 'Sonalika' by 10.2, 18.1, 15.3 and 12.5 percent in 1983/84, 1984/85, 1985/86 and mean of the three years, respectively. This findings is as a result of significantly higher number of tillers/m^2, spikes/m^2, grain weight/spike and 1000-grain weight of 'Siete Cerros'. Delay in sowing wheat over the

three seasons from November 10 to December 1 and 22nd significantly reduced grain yield by 14.8 and 20.8 percent, respectively. Increasing water stress using IW/CPE ratio from 1.00 (no stress) to 0.75 (moderate stress) and to 0.50 (severe stress), significantly reduced grain yield and yield components. Moderately and severely stressed wheat produced 19.7 and 46.1 percent mean lower grain respectively over the three seasons.

A positive and close association existed between grain yield with 1000-grain weight, spikes/m^2 and grains/spike whereas, there was a negative linear response between grain yield and the two characters. WUE decreased with delay in sowing and with increase in water stress.

In Experiment II, the three season mean grain yield of 'Siete Cerros' was significantly increased with nitrogen level upto 75kg/ha and 150kg/ha which were at par. Further increase of nitrogen level to 225kg/ha gave a declining yield. Increasing N rate from 0 to 75, 150 and 225kg/ha produced 33.0, 42.2 and 37.3 percent higher wheat grain yield, respectively. The optimum economic level of N worked out to be 120kg/ha. Increases in nitrogen level over the three seasons caused significant increases in straw yield, dry matter production, 1000-grain weight, grain weight/spike and spikes/m^2.

Increasing water stress using IW/CPE ratio from 1.00 to 0.75 significantly reduced grain yield, but a further increase in water stress to 0.50 (severe) did not give any significant reduction in grain yield. Moderately and severely stressed 'Siete Cerros' plants produced 10.7 and 3.0 percent mean lower grain respectively over the three seasons.

A high association was recorded between grain yield with number of grains/spike followed closely by spikes/m^2, whereas the correlation with 1000-grain weight was also as strong. A quadratic response was found to be significant for nitrogen in all the three seasons and the combined data analysis. The water stress response was quadratic in 1983/84 and 1984/85 but linear in 1985/86 and the combined analysis for three seasons. WUE decreased with increased water stress but N application increased WUE linearly up to 150kg/ha.

In the growth chamber experiment, decrease in transpiration rate with increase in soil matric potential was recorded in descending pattern from the least (mild) to the severely stressed plants. 'Siete Cerros' showed a lower rate of transpiration throughout the season when compared to 'Sonalika'. Throughout the trial period, stomatal resistance, total water, osmotic and pressure potentials, water content and relative water content in leaves decreased with increasing soil matric potential. Variety 'Siete Cerros' exhibited lower stomatal resistance, total water and osmotic potential, higher

pressure potential, water content and relative water content when compared to 'Sonalika'. Eventhough moisture stress reduced most of the yield attributes as well as straw and grain yield, variety 'Siete Cerros' in comparison with 'Sonalika' produced higher number of spikes/pot, spike length, grain weight/spike and 1000-grain weight but lower number of grains/spike. Imposition of moisture stress from control to mild, moderate and severe level reduced grain yield by 14.8, 26.6 and 54.2 percent, respectively.

6.2 CONCLUSION

Based on the results of the experiments conducted, the following conclusions are drawn:

1. Imposition of water stress (depending on severity) causes various degrees of reduction in yield and yield components of wheat. Dwarf wheat varieties can withstand some degree of mild to moderate stress and give reasonable grain and straw yields.
2. Delay in sowing dwarf wheats beyond mid-November causes reduction in yield and WUE. For early planting, variety 'Siete Cerros' is preferred.
3. Dwarf wheat variety 'Siete Cerros' is more tolerant to water stress imposed throughout the season by exhibiting lower transpiration rate but higher osmotic potential, water content and relative water content in leaves;

producing significantly higher grain number/ spike, heavier grains/spike, spikes/m^2, tillers/m^2, 1000-grain weight, grain yield and WUE when compared to 'Sonalika'.

4. In scheduling irrigation for the two dwarf wheat varieties, 'Siete Cerros' be irrigated at 50% depletion while 'Sonalika' be irrigated at 25% depletion in order to maximize their efficient use of water.
5. Dwarf wheat respond to N application between the range of 75 to 150kg/ha with the optimum level at 120kg/ha.
6. Increasing water stress to dwarf wheat decreases water-use efficiency.
7. Under different sowing date and water stress levels, 1000-grain weight gave the highest contribution directly to grain yield while the contributions of spikes/m^2 and grains/spike were indirect via 1000-grain weight. However, under variable nitrogen and water stress levels, the highest contribution to grain yield was from grain weight, followed by grains/spike and than spikes/m^2.

REFERENCES

Adjei, G.B. and M.B. Kirkham (1980). Evaluation of winter wheat cultivars for drought resistance. Enphytica 29: 155 - 160.

Afzar, M. and M.S. Nazir (1986). Response of two semi-dwarf wheat varieties to sowing dates. J. Agric. Research Pakistan 24 (2): 109 - 115.

Agarwal, J.P. (1977). Studies on scheduling irrigation to wheat crop in Kabar soil of Bundelkhand. Ind. J. Agron. 22: 123 - 124.

Agarwal, P.K. and K.R. Koundal (1988). Relative sensitivity of some physiological characteristics to plant water deficits in wheat. Plant physiology and Biochemistry, India 15 (1).

Al-Janabi, A.S. (1988). The effect of supplemental irrigation on water use and yield of wheat under dryland farming. J. Agric. Water Res. Soil and water Res. 7 (2): 239 - 255. Dept. Soil Sci. Mosul Univer., Iraq.

Amaregouda, A., Y.C. Panchal, M.B. Chetti and S. Manjunath (1990). Physiological basis of yield variation in wheat genotypes. J. of Research APAU 18 (3): 280 - 283.

Amer, F., W. El-Ghamry, M. El-Rouby and A. Emara (1989). Optimizing water management and nitrogen fertilization under shallow water table conditions I. Wheat. Egyptian J. Soil Sci. 29 (4) 345 - 357.

Angus, J.F. and M.W. Moncur (1977). Water stress and Phenology in wheat. Aust. J. Agric. Res. 28: 177 - 181.

Anonymous (1979). Report on wheat production and marketing in Nigeria. Published by Agricultural Extension and Research Liaison Services, Ahmadu Bello University, Zaria, Nigeria, pp.5.

Ansari, A.H., A.M. Khushk, M.A. Sethar., N.A. Avain and M.Y. Memon (1989). Effect of sowing dates on the growth and yield of wheat cultivars. Pakistan J. of Scientific and Industrial Research (1989) 32 (1) : 39 - 42.

Aremu, J.A. (1983). Irrigation and nitrogen requirement of wheat in progress report on irrigation research programme. Institute for Agric. Res., Ahmadu Bello University, Zaria, 1983, pp. 79.

Ashcroft, G.L. (1972). Physical edaphology: the physics of irrigated and non irrigated soils. Published by W.H. Freeman and Company San Francisco, U.S.A.

Bapna, J.S. and V.S. Khuspe (1980). Effect of different soil moisture regimes and nitrogen levels on moisture use by dwarf wheat. The Mysore J. Agric. Sci. 14 (2): 211 - 214.

Barrs, H.D. and P.E. Weatherley (1962). A re-examination of the relative turgidity technique for estimating water deficits in leaves Aust. J. Biol. Sci. (15): 413 - 428.

Begg. J. E. and N.C. Turner (1976). Crop water deficits. Adv.Agron. 28: 161 - 217.

Behura, A.K. and N.N. Sharma (1990). Performance of Pure Mixed stands of two wheat varieties at varying nitrogen levels. Environment and Ecology 8 (1A): 127 - 129.

Bello, U.B.J. (1983). Effect of water stress on grain development stage of wheat (Triticum aestivum L.) under different levels of nitrogen and phosphorus fertilizers. M.Sc. Thesis, Fac. of Agric. Ahmadu Bello University, Zaria, Nigeria.

Bhardwaj, R.B. L., R.C. Gautam and A. Singh (1971). Irrigate your wheat crop at critical stages of growth. Ind. Farm 20 (10): 11 - 13.

Bharti, A; T. Singh, H. Singh and A.S. Faroda (1987). Response of late sown wheat varieties to nitrogen. Ind. J. Agron. 32 (3): 250 - 252.

Brady, R.A., W.L. Powers, L.R. Stone and S.M. Goltz (1974). Relation of soyabean leaf water potential to soil water potential. Agron. J. (66): 795 - 798.

Briggs, K.C. and A. Attinaw (1979). The effects of seeding rate, sowing date and location of grain yield, maturity, protein percentage and yield of some spring wheat in Central Alberta. Can. J. Plant Sci. 59 (4): 1139 - 1145.

Campbell, C.A. and H.R. Davidson (1979). Effect of temperature, nitrogen fertilization and moisture stress on yield and yield components, protein content and moisture use efficiency of manitou spring wheat. Cand. J. Plant Sci. 59: 963 - 974.

Campbell, C.A.; H.R. Davidson and G.E. Winkleman (1981). Effect of nitrogen, temperature, growth stage and duration of moisture stress on yield components and protein content of manitou spring wheat. Can. J. Plant Sci. 61: 549 - 563.

Chaudhary, M.R., R. Khera and C.J., Singh (1988). Effect of sowing time on yield attributes, root growth and accumulated heat units of wheat. Intern. J. of Trop. Agric. 6 (3 - 4): 241 - 259.

Chaudhy, G.A., S.J.A.S. Shirazi, N.M. Cheema and G.Mohy-ud-din (1987). Fertilizer requirements of different wheat genotypes in Barani areas. Pakistan J. Agric. Res. 8(3):241-244

Chauhan, R.K.S. and B.R. Tripathi (1972). Effect of soil moisture regimes and N and P on "Sanora 64" wheat. Ind. J. Agric. Sci. 42: 1103 - 1109.

Chari, A.V. (1980). Irrigation scheduling for wheat crop under different agroclimatic conditions of northern Nigeria. Paper presented at the 4th NAFPP. Sorghum Millet and Wheat Workshop, Zaria, April 14 - 16, 1980.

Chavan, D.A. and K.R. Pawar (1987). Scheduling Irrigation to dwarf wheat based on pan evaporation. Journ. Maharashtra Agric. Univ. 12 (1): 49 - 51.

Chavan, D.A. and K.R. Pawar (1988). Dry matter accumulation pattern of wheat as influenced by Irrigation levels based on pan evaporation. J. Maharashtra Agric. Univ. 13 (2): 180 - 182.

Cheema, S.S., K.K. Dhingra and G.S. Gill (1973). Effect of missing irrigations at different stages of growth on dwarf wheat. J. Res. Punjab Agric. Univ. 10 (1): 41 - 44.

Choudhury. P.N. and V. Kumar (1980). The sensitivity growth and yield of dwarf wheat to water stress at three growth stages. Irrig. Sci. 1: 223 - 231.

Clarke, J.M. and G.M. Simpson (1978). Leaf Osmotic potential as an indicator of crop water deficit and irrigation need in rape seed (Brassica Napus L.). Agric. Water Management. 1: 351 - 356.

Cooper, J.L. (1992). Effect of time of sowing and cultivar on the development and grain yield of irrigated wheat in the Mazquarie Valley, New South Wales. Aust. J. Exp. Agriculture 32 (3): 345 -353.

Davidkov, E. and M. Stamboliev (1987). Dependence of wheat yields on the rates and dates of nitrogen application under different meteorological conditions. Ponchvoznanie, Agrokhimiyai Rastitelna Zashchita (22): 13 - 18. In Soil and Fertilizers Abstracts (1990) 53 (4): 614.

Davidson, D.F. (1987). The influence of water deficits on tiller production and survival in spring wheat (Triticum aestivum L.) Dissertation Abstracts International B. (Sciences and Engineering) 47 (10): 4011B.

Day, A.D. and S. Intalap (1970). Some effects of moisture stress on the yield and quality of flour from wheat. Agron. J. 63: 115.

Doyle, A.D. and H. Marcellos (1974). Time of sowing and wheat yield in northern New South Wales. Australian J. Exp. Agric. and Anim. Husbandry 14 (66): 93 - 102.

Drewit, F., G. Roddy and J.K. Mall (1978). Effect of sowing date on spring wheat and barley. Agric. Technica 38 (4): 91 - 96.

Dubey, O.P., J.K. Sharman. D.N. Shrivas and N.P. Sharman (1987). response of dwarf wheat varieties to nitrogen fertilization. Ind. J. Agron. 32 (3): 288 - 289.

Ellen. J. and J.H.J. Spiertz (1980). Effect of rate and timing of nitrogen dressing on grain yield formation of winter wheat (Triticum aestivum L). Fertilizer Research 1 (3): 177 - 190.

El-Sharkawy, M.A., F.A. Sorour., M.I. Sha'adan and A. El-kall (1977). Effect of N level and soil moisture stress on growth, yield and yield components of "Sidi Misri wheat and (Triticum aestivum L). Libyan, J. Agric. 6 (1): 69 - 78.

El-Rab, G.M.G., N.G. Ainer and H.M. Eid (1988). Water stress in relation to yield of wheat and some water relations in wheat. Egyptian J. Soil Sci. 28 (4): 433 - 445.

FAO (1993). Quarterly bulletin of statistics. Vol. 6 No. 1 and 2,, pp. 26 and 31.

Fischer, R.A. (1973). The effect of water stress at various stages of development of yield processes in wheat. Plant response to climatic factors. Proc. Uppsala symp. UNESCO, 233 - 241.

Frank, A.B., J.F. Power and W.O. Willis (1973). Effect of temperature and plant water stress on photosynthesis, diffusion resistance and leaf water potential in spring wheat. Agron. J. 65 : 777 - 780.

Gajri, P.R. and S.S. Prihar (1983). Effect of small irrigation amounts on the yield of wheat. Agric. Water Mgt. 6: 31 - 41.

Gami, j.K., M.T. Parmar., T.C. Patel and D. Malavia (1986). Effect of rates, time and method of N application on dwarf wheat, Ind. J. Agron. 31 (4): 401-402.

Gill, K.S. and J.S. Lenvain (1992). Wheat response to open pan evaporation based irrigation scheduling on two oxic paleustalts. Communications in Soil Science and Plant Analysis 23 (9 - 10): 1089 - 1103.

Giunta, F., R. Motzo and M. Deidda (1993). Effect of drought on yield and yield components of durum wheat and triticale in a Mediterranean environment. Field Crops Research 33 (4): 399 - 409.

Goffart, J.P., L. Couvreur, C. Roisin, J. Guiot, J.P. Destain and K. Meeus - Verdinne (1992). Nitrogen nutrition of cereals and the environment. Application to winter wheat. Revuede Agriculture 45 (2): 331 - 348.

Goma'a A. A.; O.H.S. Khalil, R.A. Aba-Elanein and S.E. El-Kalla (1977). Effect of planting density and nitrogen fertilization on yield components of two wheat varieties. Agric. Res. Rev. 55: 13 -25.

Govind, R.M., Y. Yogeswara Rao, S. Rao and K. Ramaseshaiah (1983). A preliminary study on scheduling irrigation with can evaporimeters. Agric. Water Manag. 6: 403 - 407.

Green, D.M. and M.B. Kirkham (1980). Water conserving wheat irrigation schedules based on climate records. Irrig. Sci. 1: 241 - 246.

Gunasekera, D. and G.A. Berkowitz (1992). Evaluation of contrasting cellular-level acclimation responses to leaf water deficits in three wheat genotypes. Plant Science (Limericu) 86 (1): 1 - 12.

Habib, M.M. and Y. M. Makki (1979). Effect of seeding rate and sowing date on yield of wheat grown in Central region of Saudi Arabia. Proceed Saudi Biol. Soc. 3: 15 - 24.

Hassan, K.M. and A. H. A. Al-Anbary (1989). Relationship between soil water potential and leaf water potential of wheat plants. J. of Agric. and Water Research, Soil and Water Res. 8 (1):9-19. Dept of Soil Science. Mosul Univer., Iraq.

Hassan, U.A. (1983). The effect of moisture stress at different growth stages under various seed rates on wheat (Triticum aestivum L.). M.Sc. Thesis, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria.

Hatfield, J. L. (1975). Relationship of photosynthetically active radiation to apparent photosynthetic distribution within Soybean canopies. Ph.D. dissertation, Iowa state University, Ames, Iowa.

Heithholt, J.J. (1989). Water use-efficiency and dry matter distribution in nitrogen and water-stressed winter wheat. Agron. J. 81 (3): 464 - 469.

Hochman, Z. (1982). Effect of water stress with phasic development on yield of wheat grown in semi-arid environment growth stages, in relation to plant water status, wilting and dry matter yield of wheat. Dept. of Plant Physiology. The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Hoque, M.R. (1979). Adaptation of mild water stress during the critical period of growth in wheat. Bangladesh J. Agric. Sci. 18 (2): 243 - 248.

Hsiao, T.C. (1973). Plant responses to water stress Ann. Rev. Pl. Physiol. 24: 519 - 570.

Hussain, M.R., M.S. Bajwa., M.A. Gill and M.I. Bajwa (1976). Effect of different levels of nitrogen and seeded rate on

the yield of Mexican wheat Pakistan J. Agric. Sci. 13 (7): 49 - 52.

Huzulak, J. and F. Matejka (1989). Physiological indicators of the date of irrigation of winter wheat. Rostlinna vyroba 35 (4): 347 - 352.

Ibrahim, A.A. and A.A. Assey (1976). Response of Mexican wheat cultivars to N and Phosphate fertilizers. Annals Agric. Sci. Moshtohor, Egypt (5): 11 - 20.

Ibrahim, A.A.; E.M. Zeidan and A.A. Assey (1976a). Response of Mexican wheat cultivars to N and phosphate fertilizers. Annals Agric. Sci. Moshtohor (5): 11 - 20.

Ibrahim, A.A., E.M. Zeidan and A.A. Assey (1976b). determination of optimum sowing time for Mexican wheat cultivars. Annals Agric. Sci. Moshtohor (5): 29 - 37.

Imtiyaz, M.; H.E. Jensen and J.M. Wielsen. (1983). Plant water status, nutritional status and drought sensitivity at various growth stages of spring, barley in relation to soil water status. Proc. Int. conf. Agric. Eng., and Agro. Ind. in Asia. Asian Inst. of Techn., Bangkok. pp.239.

Innes, P. and R.D. Blackwell (1981). The effect of drought on the water use and yield of two spring wheat genotypes. J. Agric. Sci., Comb. 96: 603 - 610.

Jain, M.P., J.P. Dixit; P.V.A. Pillai; R.A. Khan (1992). Effect of sowing date on wheat (Triticum aestivum L.) varieties under late sown irrigated condition Ind. J. Agric. Sci. 62(10): 669-671.

Jensen, C.R. (1981). Influence of soil water stress on wilting and water relations of different osmotically adjusted wheat plants. New Phytol. 89: 15 - 24.

Jensen, M.E. J.L. Wright and B.J. Pratt (1971). Estimating soil moisture depletion from climate, crop and soil data. Trans. ASAE. 14: 954 - 959.

Johnson, G.R. (1973). Relationship between yield and several yield components in a set of maize hybrids. Crop Science 13: 649-651.

Kalyan, S.; H.D. Verma., P.P. Singh and D.K. Jasmini (1985). Effect of sowing date and N on growth and yield of some new wheat varieties. Ind. J. Agron. 30 (1): 72 - 74.

Kirkham, M.B. (1978). Water potential and turgor pressure as a selection basis for wind-grown winter wheat. Agric. Water Mgt. 1: 343 - 349.

Kumar, A. (1985). Response of wheat cultivars to N fertilization under late sown condition. Ind. J. Agron. 30 (4): 464 - 467.

Kumar, V. (1979). Water stress and crop growth. Agronomy Departmental Seminar paper, July, 1979. Ahmadu Bello University, Zaria, Nigeria.

Kumar, V. and T. Singh (1977). Evapotranspiration and Pan evaporation ratio of barley as affected by crop stages and water stress. Ind. J. Ecology 4 (2): 188 - 193.

Kumar, V. (1993). Cropping pattern for dry season farming in the savanna ecological zone of Nigeria with special reference to wheat. Paper presented at the National Seminar on wheat in Nigeria, Daula Hotel, Kano, February, 18, 1993.

Kumar, V., O.P. Bishnoi and M.K. Moolani (1977). Evapotranspiration of 'HD 1941' dwarf wheat as related to pan evaporation and emirical methods. Ind. J. Agric. 47 (3): 143 - 147.

Kumar. V. and J.Y. Yayock (1980). Growth stages and productivity of wheat at two dates of planting at Samaru. Proceed. 7th National Irrig. seminar, Kano, Nigeria, Sept. 1980.

Kumar, V. and W.C. Mayaki (1982). Effect of different maturity dates of proceeding cotton on growth yield and yield components of wheat. Trop. Agric. (Trinidad) 59: 202 - 206.

Kumar, V. and J.J. Owonubi (1987). Crop-climate implications on irrigated cropping pattern in northern Nigeria. Paper presented at 10th National Irrigation and Drainage Seminar, National Water Research Institute, Kaduna, 23 - 26 November.

Kumar, V., J.J. Owunubi and J.A. Aremu (1982). Optimum planting time for crops during the dry season in the Sudan and northern Guinea Savanna zones of Nigeria. Report prepared for Irrigation Research Committee, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. October, 1982.

Larter, E.N., P.J. Kaltsikes and R.C. McGinnis (1971). Effect of date and rate of seeding on the performance of triticale in comparison to wheat. Crop Sci. 11: 593 - 595.

Lawlor, D.W., W. Day., A.E. Johnston, B.J. Legg and K.J. Parkingson (1981). Growth of spring Barley under drought: Crop development, photosynthesis, dry matter accumulation and nutrient content. J. Agric. Sci. Camb. 96: 167 - 186.

Leach, J.E. (1980). Photosynthesis and growth of spring barley: Some effects drought. J. Agric. Sci. Camb. 94: 623-635.

Lensik, (1971). Response of some wheat cultivars to sowing intensity and sowing date in the agro-ecological conditions of the southern Bamat. Arhiz za Poljopriredue Nank 30 (110): 43 - 55.

Li, D.Q., Y.Q., Zhang, Q. Zou and B.S. Cheng (1992). Effect of soil water stress on water status, photosynthesis and yield of wheat with drought resistance. J. Shaudong Agric. Univ. 23 (2): 125 - 130.

Li, X.M., Y.S. Feng and L. Boersma (1993). Comparison of osmotic adjustment responses of water and temperature stresses in spring wheat and sudan grass. Annals of Botany 71 (4): 303 - 310.

Little, T.M. and F.J., Hills (1978). Agricultural Experimentation Design and Analysis. John Wiley and Sons, New York, pp. 350.

Lu, Z.M. (1988). The sensitivity of adaxial and abaxial stomal resistance in wheat leaf to soil water stress. Acta phytophysiologica sinica 14 (3): 223 - 227.

Mayaki, W.C. and V. Kumar (1982). Productivity of various crops interplanted with may-sown cotton and their effect on nitrogen requirement of wheat under irrigated rotation. Paper presented at the 18th Annual Conference of Agric. Soc. Nigeria, Calabar, August, 1982.

Majumdar, D.K. and M. Mandal (1984). Effect of irrigation based on pan evaporation and nitrogen levels on the yield and water use in wheat. Indian, J. Agric. Sci. 54 (7): 613 - 614.

Malik, B.S. M.L. Batra and J. Singh (1986). Nitrogen and irrigation needs of wheat under shallow ground water table conditions. Haryana Agric. Univ. J. Res. 16 (1): 25 - 29.

Maurya, P.R. and R.S. Sachan (1985). Irrigation scheduling in relation to salt build-up under varying ground water table conditions. Proc. Filth Afro-Asian Regional Conference. ICID, Townsville, Australia.

Millar, B.D. and O.T. Denmead (1976). Water relations in wheat leaves in the Field. Agron. J. 68: 303 - 307.

Miller, B.D. and G.K. Hansen (1975). Exclusion error in pressure chamber estimates of leaf water potential Ann. Bot. 39: 915 - 920.

Misra, R.D., K.C. Sharma, B.C. Wright and V.P. Singh (1969). Critical stages in irrigation and irrigation requirement of wheat variety 'Larma Rojo'. Indian J. Sci. 39 (9): 898 - 907.

Misra, R.D. and P.C. Pant (1981). Criteria for scheduling the irrigation of wheat. Expt. Agric. 17: 157 - 162.

Mogensen, V.O. (1980). Drought sensitivity at various growth stages of barley in relation to relative evapo-transpiration water stress. Agron. J. 72: 1033 - 1038.

Morgan, A. G. and J.J. Riggs (1981). Effect of drought on grain and malt characters in spring barley. J. Sci. Food Agric. 32: 339 - 346.

Muir, J.H. (1989). Influence of applied nitrogen and seeding rate on winter wheat. Research series, Arkansas Agric. Experim. Sta. 385: 69 - 71.

Nel. A.A. and P.R. Berliner (1990). Quantifying leaf water potential for scheduling irrigation of wheat under specific soil-climate conditions. S.African J. Plant and soil. (1): 68 - 71.

Nel, A.A. and F.J. Dijkhuis (1991). Use of estimated leaf potential for irrigation timing in wheat. S. Afric. J. of Plant and Soil 8(2): 88-92.

Nerson, H.M., A. Edilstein and M. Meirchick (1979). Effect of sowing date on development and yield of wheat. Hassadeh 59 (6): 1113 - 1117.

Olugbemi, L.B. (1980). Bread: The road to self-sufficiency in Nigeria. Paper presented at Ahmadu Bello university, Lecture, 12 March, 1990.

Olugbemi, L.B. (1984). Effects of varieties and nitrogen fertilizer on yield of irrigated wheat in northern Nigeria. Samaru J. Agric. Res. 2 (1 and 2): 25 - 32.

Oosterhuis, D.M. (1984). Stomatal responses to water stress in field crops. Crop production 13: 1 soil and Irrig. Res. Inst. Pretoria, S. Africa.

Oosterhuis, D.M. and S. Walke (1987). Stomatal resistance measurement as an indicator of water deficit stress in wheat and soybean. S.African J. Plant, Sci. 4 (3) 113 - 120.

Palmer-Jones, R.W. (1978). The effects of water frequency, land preparation and planting date of irrigated wheat at Kadawa. Report to the Board of Governors, Inst. for Agric. Research, Ahmadu Bello University, Zaria, Nigeria.

Patel, C.S., V. Singh and D. Prasad (1971). Critical stages of irrigation in dwarf wheat variety "Kalyan Sona". Ind. J. Agron. 16: 265 - 267.

Panda, S.C., J.M.L. Gulati and B. Misra (1988). Effect of water regimes and nitrogen on wheat. Ind. J. Agron. 33 (4): 364 - 367.

Pandey, D.S., R.D. Mishra and K.C. Sharma (1986). Effect of irrigation based on pan evaporation and nitrogen on wheat. Ind. J. AGron. 31 (4): 370 - 373.

Pantra, S.S. (1990). Response of wheat varieties to fertilizer and irrigation. Ind. J. Agron. 35(3): 302-303.

Pawar, V.S., A.C. Joshi and N.K. Umrani (1988). Effect of sowing fertilizer and seedrate on wheat. Ind. J. Agron. 33 (3): 276 - 278.

Peinetti, R. and J.F. Ladent (1988). Effect of water stress on leaf angle in wheat (Triticum aestivum L.) Archives Internationales de physiologie et de Biochimie 96 (1): 25.

Pradhan, L., D. Rout, T.N. Barik and G.K. Patro (1990). Response of wheat to Nitrogen, Potash and Zinc under irrigated conditions. Environment and ecology 8(2): 777-779.

Prasad, N.K. (1979). Effect of late seeding on wheat and barley. Ind. J. Agron. 24 (3): 331 - 332.

Rab, A., H.E. Jensen and V.O. Mogensen (1984). Dry matter production of spring wheat subjected to water stress and various growth stages. Cereal Res. Comm. 12: 19 - 25.

Rafey, A., B.N. Mittra and H.K. Pande (1978). Performance of "Kalyan Sona" wheat under different soil moisture regimes at critical growth phases. Ind. J. Agric. Sci. 48 (12): 736-741.

Rathore, A.L. and S.L. Patel (1991). Studies on nitrogen and irrigation requirement of late sown wheat. Indian J. Agronomy 36 (2): 184 - 187.

Rathore, S.S. and R.M. Singh (1973). Effect of different soil moisture and fertility levels on growth and yield of Sonora 64. Ind. J. Agric. Sci. 43 (7): 713 - 717.

Recosky, D.C., R.B. Campbell and C.W. Doty (1975). Diurnal fluctuation of leaf water potential of corn as influenced by soil matric potential and microclimate. Agron. J. 67: 380 - 384.

Salter, P.J. and J.E. Goode (1967). Crop responses to water at different stages of growth. Res. Review 2: 3 - 48.

Sandhu, B.S. and M.L. Horton (1977). Response of Oats to water deficit II. Growth and yield characteristics. Agron. J. 69: 361 - 364.

Sandhu, H.C., S.S. Dhillon and G.S. Gill (1978). Response of timely and late sown wheat to different levels of nitrogen. Ind. J. Agric. Sci. 48 (4): 225 - 228.

Sandhu, B.S., S.S. Prihar and K.L. Khera (1984). Irrigating wheat with limited amount of water in Punjab. Ind. J. Ecology 11 (2): 243 - 248.

Sankara, R.G.H. and M.N. Reddy (1977). Efficient use of irrigation water for wheat and groundnut. Mysore J. Agric. Sci. 11: 22 - 27.

Sarkar, A.K., J.M.L. Gulati and J.K. Mohanty (1989). Response of wheat to varying levels of nitrogen and time of application. Environment and Ecology 7 (4): 994 - 995.

Schalbroeck, J.J. and A. Autrique (1988). The effect of sowing date on growth and yield of wheat in the Mugamba region, Burundi. Agronomic Tropicale 43 (4): 289 - 300.

Sepaskhah, A.R. and E.R. Ardekani (1976). Effect of irrigation regimes on yield, yield components and grain quality of torsh barley. Iran J. Agric. Res. 4: 89 - 98.

Sharma, K.C., R.D. Misra,D.S. Pandey and O.P.S. Bama (1987). Response of wheat to irrigation based on CPE. Ind. J.Agron. 32 (2): 121 - 123.

Sharma, K.N., A.L. Bhandari, D.S. Rama, J.S. Sodhi and M.L. Kapur (1989). Nitrogen requirement of wheat (Triticum aestivum L.) varieties as influenced by date of sowing. Ind. J. Agric. Sci. 59 (4): 266 - 268.

Shepherd, W. (1975). Matric potential of leaf tissue. Measurements and significance. J. Exp. Bot. 26: 465 - 469.

Shimshi, D. and D. Ephrat (1975). Stomatal behaviour of wheat cultivars in relation to their transpiration photosynthesis and yield. Agron. J. 67: 326 - 331.

Shimshi, D. and V. Kafkafi (1978). The effect of supplemental irrigation and nitrogen fertilization of wheat (Triticum aestivum L.). Irrig. Sci. 1 (1): 27 - 38.

Sinha, N.H., R.D. Singh, and R.K. Singh (1986). Effect of irrigation and nitrogen on wheat. Ind. J. Agron. 31 (4): 326 - 330.

Singh, A. (1978). Response of late sown wheat to N fertilization and irrigation management in Western Rajas than In. J. Agron. 23 (1): 44 - 48.

Singh, D.P. (1978). Relation of soil moisture and air conditioning irrigation to plant water balance growth characteristics and nutrients uptake in rye and wheat. Biologia plantarum (Praha) 20 (3): 161 - 166.

Singh, S.D. (1981). Moisture sensitive growth stages of dwarf wheat and optimal sequencing of evapotranspiration deficits. Agron. J. 73: 387 - 391.

Singh, L. and V. Balasubramanian (1979). Effects of continuous fertilizer use on a ferruginous soil (Haplustalf) in Nigeria. Expl. Agric. 15, (in press).

Singh, L. and V. Balasubramanian (1982). Moisture sensitive growth stages of dwarf wheat and optimal sequencing of evapotraspiration deficits. Agron. J. 73: 387 - 391.

Singh, L. and V. Balasubramanian (1982). Efficiency of nitrogen fertilizer use under rainfed maize and irrigated wheat at Kadawa, northern Nigeria. Fertilizer Res. (in press).

Singh, S.B. and R.S. Dixit (1985). Effect of sowing dates on wheat varieties. Ind. J. of Agron. 30 (4): 512 - 513.

Singh, K.P. and V. Kumar (1981). Water use and water efficiency of wheat and barley in relation to seeding dates, levels of irrigation and nitrogen fertilization. Agric. Water Manag. 3 (4): 305 - 316.

Singh, T. and D.S. Malik (1983). Effect of water stress at three growth stages on the yield and water-use efficiency of dwarf wheat. Irrig. Sci. 4 (4): 239 - 245.

Singh, H. and O. Singh (1987). Response of late sown wheat to seed rate and nitrogen. Ind. J. Agron. 32 (3): 290 - 291.

Singh, G; P.N. Singh and L.S. Bhushan (1980). Water use and wheat yields in northern India under different irrigation regimes. Agric. Water Magt. 3: 107 - 114.

Singh, P.N., B.P. Joshi and G. Singh (1987). Water use and yield response of wheat to irrigation and nitrogen on an alluvial soil in north India. Agric. Water Magt. 12 (4): 311 - 321.

Singh, T. and H. Singh (1989). Leaf water potential and stomatal conductance of wheat (Triticum aestivum L.) as affected by water stress. Ind. J. Plant physiol. 32 (3): 278 - 280.

Singh, N.T., A.C. Vig., R. Singh and M.R. Chaudhary (1979). Influence of different levels of irrigation and nitrogen on yield and nutrient uptake by wheat. Agron. J. 71: 401 - 404.

Singh, N.T., R. Singh, P.S. Mahahajan and A.C. Vig (1979). Influence of supplemental irrigation and pre-sowing water storage of wheat. Agron. J. 71: 483 - 486.

Sionit, N.I., W. Teare and P.J. Kramer (1980). Effect of repeated application of water stress on water status and growth of wheat. Physiol, Plant 50: 11 - 15.

Sivakumar, M.V.K. and R.H. Shaw (1978). Relative evaluation of water stress indicators for soybean Agron. J. 70:619-623.

Slatyer, R.D. (1967). Plant-water relationship. Academic Press, New York.

Slavik, B. (1974). Methods of studying plant water relationships. Ecology. Studies 9, (Zechoselovak Acad. Sci., Prague, Springer - Verlag Berlin, Heidelberg and New York, 70 - 74.

Surma, D.A.; U.S. Gupta and L.B. Olugbemi (1980). On the possibility of economizing irrigation water in two distinct varieties of wheat. Paper presented at 7th National Irrigation Seminar, September, 1980, Kano, Nigeria.

Stegman, E.C., A. Eauer J.C. Zubricki and J. Bander (1977). Crop curves for water balance irrigation scheduling in S.E. North Dakota. Res. Report, Agric. Expt. Station, North Dakota State Univ., 66: 1 - 11.

Talukder, M.S. (1983). Growth and development of wheat as affected by soil moisture stress. Ind. J. Agric. Sci. 57 (8): 556 - 558.

Taylor, S. A. and G.L. Ashcroft (1972). Physical edapology, W.H. Freeman, San Francisco.

Turner, N.C. and J.E. Begg (1973). Stomatal behaviour of water status of maize, sorghum and tobacco under field conditions I. At high soil water potentials. Ibid. 51: 31 - 36.

Tyree, M.T. (1976). Negative turgor pressure in plant cells: Fact or Fallacy. Can J. Bot. 54: 2738 - 2746.

Villanuera, N.R. and G.O. Montjoy (1973). Response of three wheat cultivars to different levels of fertilizers N and P. Turrialba, 23 (1): 84 - 90, Field Crop Abstr. 28 (9): 5238.

Winter, S.R. and J.T. Musick (1993). Wheat planting date effects on soil water extraction and grain yield. Agron, Journal 85 (4): 912 - 916.

Woldeab, A. (1989). The response of bread wheat to rate and time of nitrogen application. Proceed. 6th Regional Wheat Workshop for Eastern, Central and Southern African, Addis Ababa, Ethiopia, 2 - 6 October, 1989, pp. 146 - 152.

Xu, H.L. and R. Ishii (1991). Effects of water deficit on photosynthesis in wheat plants. VI. Capacitance and resistance of transpiratory water flux in different plant parts. Japanese Journal of Crop Science 60 (1): 75 - 81.

Appendix 1: Wheat Production, Importation and Consumption in Nigeria (1980 and 1993)

Year	Area under wheat '000ha	Local Production of wheat m-tons	Local Production as % of Quantity Imported	Quantity Imported (m-metric-tons)	Cost $	Cost ₦	Consumption (g/head/day) Average	Consumption (g/head/day) Urban	Exchange rate
1980	19.3	29,000	2.1	1.40	290m	435m	50.0	180.0	1$ = ₦1.50
1993	33.2	50,000	5.2	0.95	785m	37.7bn	28.0	105.0	1$ = ₦48.0

Olugbemi, (1980) FDA (1993) and FAO (1993).

Appendix 2: Soil Moisture characteristics of Kadawa Soil

Texture	Bulk density g/cm	Field Capacity (-0.02MPa)	Permanent wilting point (-1.5MPa)	FC - PWP (Available water)
Loamy sand	1.50	19.10	5.75	13.35

Depth of irrigation water in CM (di) = $\frac{di = Fci-Fbi}{100}$ x Asi x Di

Where: di = depth of irrigation water (cm)

Fci = Field capacity of the ith layer

Fbi = Moisture percentage before irrigation

Asi = apparent specific gravity of ith layer

Di = depth of ith layer in cm (active root zone assumed in this case to be 60cm).

di = $\frac{19.10 - 5.75 \times 1.50}{100}$ x 60cm

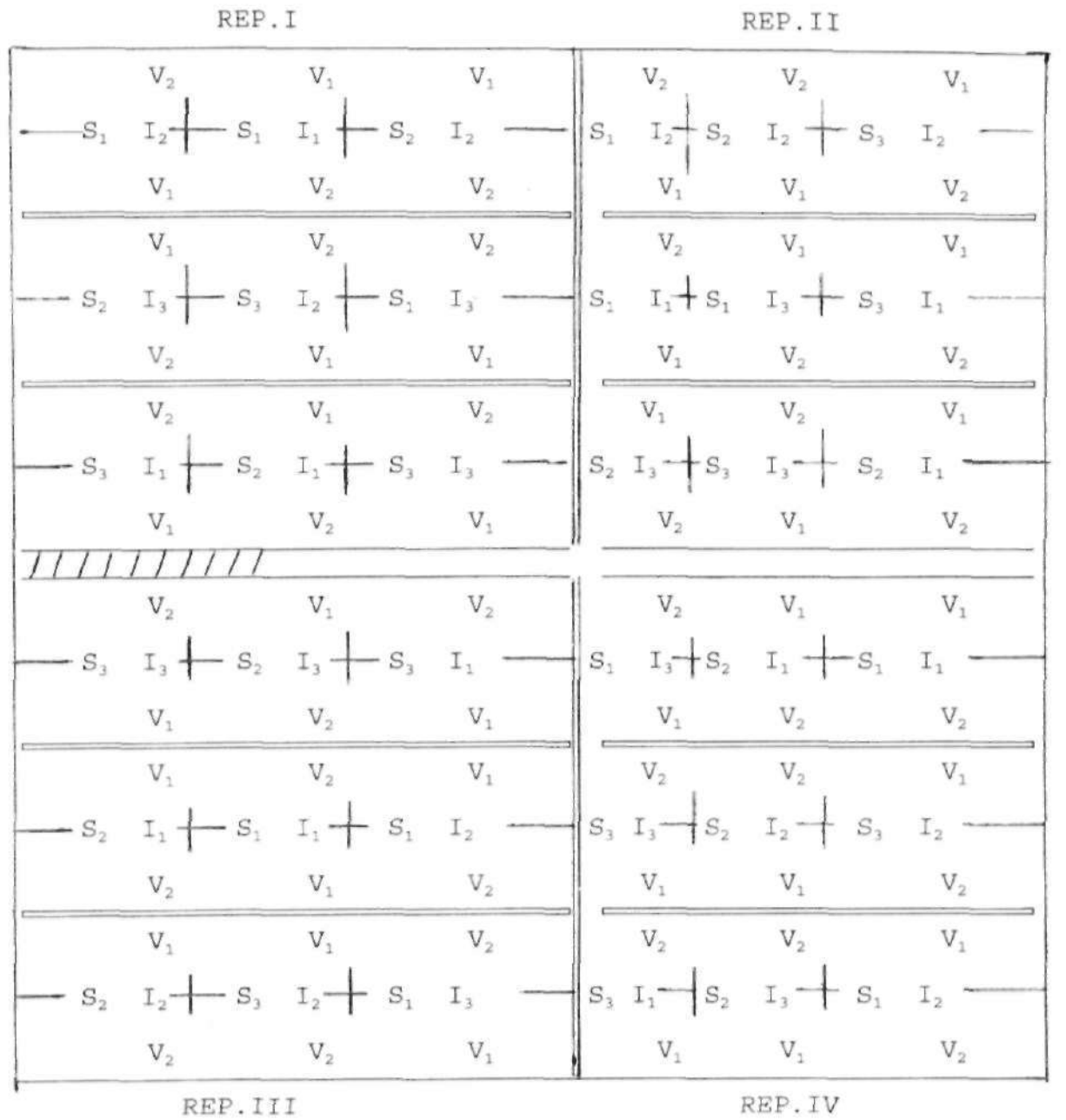
= $\frac{13.35 \times 1.50}{100}$ x 60cm

= 12.00cm

Irrigation at 50% depletion of available water = $\frac{12 \times 50}{100}$ = 6.00cm (60mm)

Depth of Irrigation (D) mm	IW/CPE ratio (R)	Cummulative pan evaporation CPE (mm) (D + R)
60mm	0.50	120mm (I_1)
	0.75	80mm (I_2)
	1.00	60mm (I_3)

Appendix 3: Experiment I: Field Layout Sketch in 1983/84



Key:

Varieties	Sowing dates	Irrigation (IW/CPE)
V_1 - Siete Cerros	S_1 = Nov. 10 (Early)	I_1 = 0.50 (Severe)
V_2 - Sonalika	S_2 = Dec. 1 (Medium)	I_2 = 0.75 (Moderate)
	S_3 = Dec. 22 (Late)	I_3 = 1.00 (No Stress)

Appendix 4: The physical and chemical properties of the soil at the experimental site collected to a depth of 0-60cm at Kadawa.

Soil properties	Characteristics		
	1983-84	1984-85	1985-86
Physical properties			
Sand %	84.3	81.5	82.9
Silt %	6.2	6.8	6.5
Clay %	9.5	11.7	10.6
Texture class	Loamy sand	Loamy sand	Loamy sand
Chemical properties			
pH (in H_2O)	6.7	6.9	6.5
pH (in 0.01m $CaCl_2$)	5.9	6.4	6.0
Exchangeable cations			
Na	0.152	0.143	0.138
K	0.195	0.237	0.314
Ca	3.250	3.573	3.667
Mg	1.671	1.392	0.989
Total P (ppm)	31.23	28.58	34.72
Total N (%) in 0.048N H_2SO_4	0.021	0.049	0.037
CEC (Meq/100g)	5.82	5.93	5.82

Appendix 5: Previous cropping history of the experimental site at Kadawa.

Season		Crop	
Wet	Dry	Wet	Dry
1980	1980/81	Fallow	Tomato
1981	1981/82	Fallow	Wheat

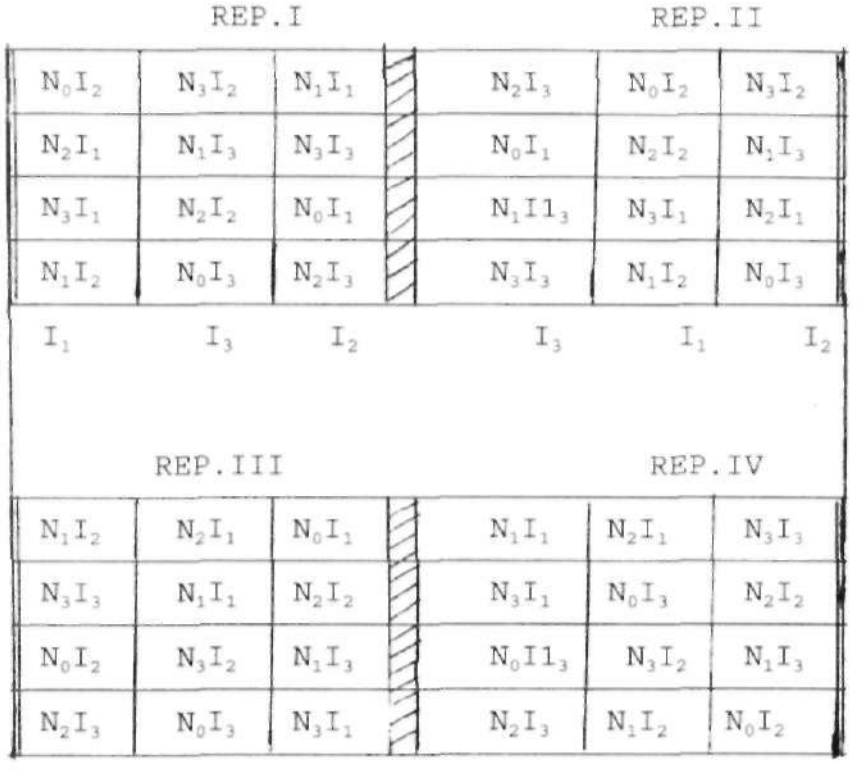
1982 1982/83 Fallow Tomato

Appendix 6: Mean monthly air temperature (°C) rainfall and relative humidity during 1983-86 dry seasons at Kadawa.

Monthly and year	Temperature°C Mean Max.	Mean Min.	Average	Rainfall (mm)	Relative humidity (%)
November, 1983	34.0	15.2	20.2		
December, 1983	27.0	13.0	20.0		
January, 1984	26.8	12.4	19.6	-	38.8
February, 1984	30.2	14.7	22.7	-	45.7
March, 1984	36.2	19.5	27.9	-	47.2
April, 1984	37.4	22.6	30.0	57.4	51.8
November, 1984	30.7	15.7	23.2	-	45.7
December, 1984	30.9	14.7	21.8	-	59.5
January, 1985	28.2	14.8	21.2	-	65.0
February, 1985	28.9	13.8	21.4	-	51.7
March, 1985	35.6	20.6	28.1	28.0	46.9
April, 1985	34.4	21.3	27.9	6.5	46.2
November, 1985	30.2	14.3	22.3	22.3	50.2
December, 1985	28.3	13.3	20.8	-	43.6
January, 1986	28.6	12.3	20.5	-	45.2
February, 1986	33.8	16.1	25.0	-	44.7
March, 1986	35.9	19.6	27.8	-	45.7
April, 1986	38.3	23.4	30.9	-	50.2

Source: IAR Meteorological Unit.

Appendix 7: Experiment II: Field Layout Sketch in 1983/84



Key:

Irrigation (IW/CPE ratio)

I_1 = 0.50 (Severe)No
I_2 = 0.75 (Moderate)
I_3 = 1.00 (No Stress)

Nitrogen levels

N_0 = 0kgN/ha (control)
N_1 = 75kgN/ha
N_2 = 150kgN/h
N_3 = 225kgN/ha

Appendix 8: Structure of ANOVA for Experiment I

Source of variance	DF	SS	MS	F
Replication (r - i)	3			
Main treatment (m - i) water stress (w - i) = 2 sowing date (s - i) = 2 water stress x sowing date (w-i)(s-i) = 4	8			
Error (a) (E-i) (m-i)	24			
Variety (v-i)	1			
Variety x water stress	2			
Variety x sowing date	2			
Variety x water stress x sowing date	4			
Error (b) m (r-i) (v-i)	27			
Total r.w.s.v-i	71			

Appendix 9: Structure of ANOVA for Experiment II

Source of variance	DF	SS	MS	F
Replication (r-i)	3			
Treatment (t-i) Nitrogen level (n-i) = 3 Water stress (w-i) = 2 Nitrogen x water stress = 6	11			
Error (r-i) (ni-i)	33			
Total r.n.i.1	47			

B I O G R A P H Y

Name : Ahmed Mustapha FALAKI

Date of Birth: 13th June, 1951.

Place of Birth : Kano City.

State of Origin : Kano

Home Address : No. 203 Daneji Quarters, Kano City.

Previous Qualifications: B.Sc. (Agric.) A.B.U., Zaria
M.Sc (Agron) ABU, Zaria.

Institutions Attended	From	To	Certificate/Degree
Dandago Primary School, Kano.	1957	1964	Pri. Sch. Certificate
Govt. College Keffi.	1965	1969	West African School Certificate.
School of Basic Studies A.B.U., Zaria.	1970	1972	S.B.S. Certificate.
Ahmadu Bello University	1973	1976	B.Sc. (Agriculture)
Ahmadu Bello University	1979	1980	M.Sc. (Agronomy)

Positions held since the award of First Degree

Organisation	From	To	Position
NYSC, County Grammer School, Ikwerre-Etche, Rivers State	1976	1977	Agric. Sci. Teacher
Min. of Agric., Kano.	1977	1977	Agric. Officer
Hadejia-Jama'are River Basin, Kano.	1977	1978	Irrigation Agronomist
Ahmadu Bello University, Zaria.	1978	Date	Grad. Asst. to Lecturer I.

Ph.D. Registration Number: PhD/Agric./6849/82-84