EFFECT OF APPLIED NITROGEN AND WATER STRESS ON THE YIELD AND QUALITY OF BARLEY

(Hordeum vulgare L.)

By .

NANCHAK CHIRDAN NIMZING

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FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY
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CERTIFICATION

This thesis entitled 'Effects of Applied Nitrogen and Water Stress on the Yield and Quality of Barley (*Hordeum vulgare* L.)' by Nanchak Chirdan Nimzing meets the regulations governing the degree of Master of Science of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

DR. M.K. AHMED
Chairman, Supervisory Committee

DR. R.M.O. AGUNBIADE
Member, Supervisory Committee

DR. Y. YUSUF
Head, Department of Agronomy

PROF. G.E. OSUIDE
Dean, Postgraduate School

Date: 16-2-88

AHMADU BELLO UNIVERSITY
Z A R I A

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.

NANCHAK CHIRDAN NIMZING
(Candidate)

Date: 10/07/87

The above declaration is confirmed.

DR. M.K. AHMED
(Major Supervisor)

Date: 10-7-1987

DEDICATION

To my wife, Nanre

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ABSTRACT

Field trials were conducted at the Irrigation Research Station, Kadawa if Institute for Agricultural Research, Ahmadu Bello University, during the 1984/85 and 1985/86 dry seasons, to study the effects of moisture stress imposed at various growth stages under different nitrogen levels on yield and quality of malting barley,

Moisture stress imposed ,by missing irrigation at any growth stage before dough stage reduced most of the growth parameters viz: plant height, number of tillers per plant, leaf area per plant, leaf area index, flag leaf area ana dry matter production. However, N application increased these growth parameters, Missing irrigation at jointing and heading stages reduced the mean number of days to maturity whereas nitrogen application upto 60 kg N/ha increased the number of days to maturity.

Missing irrigation during early stages from tillering to heading reduced the number of spikes per metre square and number of grains per spike.

The final grain yield was adversely affected by withholding irrigation at any stage of growth except heading stage. The maximum yield reductions of 13 and 32 per cent were observed when irrigation was missed at jointing stage in 1985 and 1986, respectively.

A nitrogen fertilizer rate of 60 kg N/ha was found to be •ptimum for efficient water utilization and acceptable grain protein content in malting barley.

TABLE OF CONTENTS

Chapter			Page
		Dedication	i
		Acknowledgements	ii
		Abstract	iii
		Table of Contents	v
		List of Tables	ix
		List of Appendices	xi
1		INTRODUCTION	1
2		LITERATURE REVIEW	5
	2.1	Effects of Moisture Stress at Different Growth Stages on Yield of Barley	5
	2.2	Effect of Moisture Stress on Yield and Yield Components	10
	2.3	Recovery from Moisture Stress and Consequent Compensatory Growth....	11
	2.4	Effect of Moisture Stress on Grain Protein Content	11
	2.5	Effect of Nitrogen on Yield and Yield Components	12
	2.6	Effect of Nitrogen on Grain Protein Content	15
	2.7	Moisture and Nitrogen Interaction on Yield and Yield Components	15
	2.8	Water Use Efficiency	17
3		MATERIALS AND METHODS	18
	3.1	Experimental Site	18
	3.2	Treatments	18
	3.2.1	Moisture Stress	18
	3.2.2	Nitrogen levels	19

Chapter		Page
3.3	Cultural Practices	19
3.3.1	Land Preparation	19
3.3.2	Fertilizer Application	19
3.3.3	Sowing	19
3.3.4	Irrigation	20
3.3.5	Weeding	20
3.3.6	Harvesting	20
3.4	Assessment of Growth, Yield and Yield Characters	21
3.4.1	Growth Characters	21
3.4.1a	Plant height (cm)	21
3.4.1b	Number of tillers per plant	21
3.4.1c	Leaf area per plant (cm^2)	21
3.4.1d	Leaf area Index	22
3.4.1e	Dry matter production (g/m^2)	22
3.4.1f	Maturity	22
3.4.1g	Length of Spikes (cm)	22
3.5	Post Harvest Yield and Yield Components	22
3.5.1	Number of grains per spike	22
3.5.2	One thousand kernel weight (g)	22
3.5.3	Grain yield (kg/ha).....	23
3.5.4	Straw yield (kg/ha)	23
3.5.5	Grain Protein content	23
3.5.6	Cummulative depth of water used	23
3.5.7	Water Use Efficiency	24
3.6	Statistical Treatment of Data	24

Chapter			Page
4		RESULTS	25
	4.1	The Effect of Moisture Stress at Different Growth Stages and Nitrogen Levels on The Growth of Barley	25
	4.1.1	Plant height	25
	4.1.2	Number of tillers per plant	31
	4.1.3	Leaf Area per Plant	37
	4.1.4	Flag leaf Area	42
	4.1.5	Leaf Area Index	43
	4.1.6	Dry matter accumulation	47
	4.2	Effects of Moisture Stress at Different Growth Stages and Nitrogen Levels on Yield Components and Yield of Barley	51
	4.2.1	Number of grains per spike	51
	4.2.2	Grain weight	53
	4.2.3	Spikes per unit area	54
	4.2.4	Grain yield (kg/ha)	56
	4.2.5	Straw yield (kg/ha)	57
	4.3	The Effects of Moisture Stress and Nitrogen Levels on Number of Days to Maturity	60
	4.4	Water Use Efficiency	63
	4.5	Crude Protein Content	67
	4.6	Correlation Studies	67
5		DISCUSSION	70
	5.1	Effects of Moisture Stress at Different Growth Stages and Nitrogen Levels on the Growth of Barley	70
	5.1.1	Moisture stres	70

Chapter			Page
	5.1.2	Nitrogen	72
	5.1.3	Moisture stress and nitrogen interaction on vegetative growth....	75
	5.2	Effects of Moisture Stress at Different Growth Stages and Nitrogen Levels on Yield Components and Yield of Barley.....	77
	5.2.1	Moisture stress	77
	5.2.2	Nitrogen	79
	5.2.3	Moisture stress and nitrogen interaction on yield components and yield	81
	5.3	Effects of Moisture Stress and Nitrogen on Grain Quality	82
	5.3.1	Moisture stress	82
	5.3.2	Nitrogen	82
	5.4	Water Use Efficiency (WUE).....	83
	5.4.1	Interaction between moisture stress and nitrogen on the number of days to maturity and WUE	83
6		SUMMARY AND CONCLUSIONS	85
		REFERENCES	88
		APPENDICES	96
		BIOGRAPHY	

LIST OF TABLES

Table		Page
4.1	The effect of moisture stress and nitrogen levels on plant height (cm) of barley at different growth stages in 1985 and 1986 seasons at Kadawa . .	26
4.2	Effect of moisture stress x Nitrogen levels on plant height during tillering stage in 1984/85 dry season at Kadawa..	27
4.3	Effect of moisture stress x Nitrogen levels on plant height during heading stage in 1984/85 and 1985/86 dry seasons at Kadawa.....	30
4.4	The effect of moisture stress and nitrogen levels at different growth stages on number of tillers of barley in 1985 and 1986 at Kadawa	32
4.5	Effect of moisture stress x Nitrogen levels on number of tillers at heading in 1984/85 and 1985/86 dry seasons at Kadawa	35
4.6	The effect of moisture stress at different growth stages and nitrogen levels on leaf area of barley in 1985 and 1986 and flag leaf area in 1986 at Kadawa	40
4.7	Effect of moisture stress x Nitrogen levels on leaf area at heading in 1984/85 and 1985/86 dry seasons at Kadawa	41
4.8	The effect of moisture stress at different growth stages and nitrogen levels on leaf area index of barley in 1985 and 1986 at Kadawa	45
4.9	Effect of Moisture stress x Nitrogen levels on leaf area index during tillering stage in 1984/85 dry seasons at Kadawa.	46
4.10	Effect of moisture stress x Nitrogen levels on leaf area index during heading stage in 1985/86 dry season at Kadawa....	46

Table		Page
4.11	The effect of moisture stress at different growth stages and nitrogen levels on dry matter accumulation (g) of barley in 1985 and 1986 at Kadawa....	48
4.12	Effect of moisture stress x Nitrogen levels on dry matter accumulation (g) at heading stage in 1984/85 dry season at Kadawa.	50
4.13	The effect of moisture stress at different growth stages and nitrogen levels on spike length (cm) at harvest in 1985 and 1986 dry seasons at Kadawa.....	52
4.14	The effect of moisture stress at different growth stages and nitrogen levels on spikes m^{-2}, number of grains per spike and 1000-grain weight.....	55
4.15	The effect of moisture stress at different growth stages and nitrogen levels on the grain and straw yields of barley in 1985 and 1986 dry seasons at Kadawa.	58
4.16	Effect of moisture stress x Nitrogen levels on grain yield of barley in 1984/85 dry season at Kadawa	59
4.17	The effects of moisture stress at different growth stages and nitrogen levels on W.U.E., Days to maturity and grain protein content at Kadawa.	61
4.18	Effect of moisture stress x Nitrogen levels on mean number of days to maturity of barley in 1985/86 dry season at Kadawa....	62
4.19	Effect of Moisture stress x Nitrogen levels on W.U.E. in 1984/85 dry season at Kadawa.	66
4.20	Simple and partial correlation coefficients between yield and yield components and within yield components...	68

LIST OF APPENDICES

Appendix		Page
A-1	Mean monthly air temperature (°C) and evaporation (mm) during the barley growing period at Kadawa in 1984/85 dry season	96
A-2	Mean monthly air temperature (°C) and evaporation (mm) during the barley growing period at Kadawa in 1985/86 dry season	96
B	The physical and chemical properties of the soil collected at upto a depth of 30 cm from the experimental site at Kadawa	97
C	Previous cropping history of the experimental site at Kadawa	97
D	Variation in soil moisture reading (%) from tillering to dough stages before and after irrigation at Kadawa, in 1984/85 and 1985/86 dry seasons	98
E-1	Analysis of variance table for grain yield in 1984/85 dry season	99
E-2	Analysis of variance table for grain yield in 1985/86 dry season.	99

Chapter 1

INTRODUCTION

Barley (*Hordeum vulgare* L.) which belongs to the grass family, is one of the oldest cereals known to man. Basically, it is a crop which thrives well in the temperate regions and it is also grown in hotter and drier regions of Asia Minor, North Africa and the Mediterranean. However, barley grown in Nigeria at present is mainly on experimental scale, and entirely under irrigation in the savanna ecological zone.

Barley contains 68 and 12 per cent of carbohydrate and protein, respectively. As a human food and animal feed, protein is one of the important constitutents. For brewing industry, a high protein content is undesirable as it replaces starch which is converted to maltose and imparts disagreeable odour and taste to the material brewed from it.

In Nigeria, barley is mainly used for malt preparations. However, all the existing brewing and distilling industries rely entirely on imported malt as their source of raw material. For example, one of the thirty-two breweries, the Nigerian Breweries Limited (NBL) alone imported about 80,000 tons of malt at an estimated value of 38 million Naira in 1979 (Asenime *et al.*, 1980). Similarly the number of breweries keep increasing almost at a geometrical rate.

The increasing demand for malt products, with the consequent increase in the amount of foreign reserves

needed to import sufficient malt for the numerous breweries constitutes a major drain on the country's foreign reserves. The brewing industry is therefore largely affected by government directives of obtaining their raw materials internally, particularly in terms of malting barley. However, locally produced cereal substitutes which have been tried such as sorghum (Sorghum bicolor) and maize (Zea mays) may not compete with barley successfully for malting purposes because of their low enzymatic content and absence of hull which protects the micropile during malting process. For example, North Breweries Limited, Kano has only been able to use sorghum for substitution upto 10 per cent level (Fowowe, 1983). In order to maintain the quality of product, the only alternative is to embark on the local production of malting barley in Nigeria. Ahmed et al. (1977), Falaki (1980) Ikwelle (1985) have successfully grown and reported on the performance of several elite malting varieties in two locations in the Nigerian savanna.

Although some work on varietal adaptability, fertilizer and other management requirements of malting barley are at various stages of investigation in Nigeria, there is paucity of information regarding the yield and quality response of the crop to moisture stress, and its interaction with nitrogen fertilization.

Since barley cultivation is entirely under irrigation in Nigeria, available soil moisture could be a major yield determining factor. Moreover, the consistent rise of water table at Kadawa and its surroundings during the irrigation cropping season (Nwa, 1978) poses a threat of water logging conditions in future if irrigation water is not judiciously applied. Consequently, water economy for crop production under irrigation will therefore, be inevitable when more area is brought under irrigation.

The judgement of the farmer about the time of irrigation and the amount of water needed with each irrigation is an important factor contributing to low average yields as well as poor crop quality. Inspite of the fact that plants have a number of ways of avoiding the build up of water deficits (Levitt, 1972) some growth stages have been found to be more sensitive to moisture stress than others (Aspinall et al., 1964; Lahane and Staple, 1962). Such a sensitive stage is also referred to as the critical stage. Yield suffers if one or two irrigations are missed at a critical stage of growth, and if the drought experienced is severe the crop may fail.

Nitrogen is considered the most important single nutrient element affecting both the grain yield and quality of the crop. The initial soil nitrogen content, its degree of availability and the quantity of

externally applied nitrogen are among important factors which determine the level of barley productivity as well as the quality of the grain. Thus, knowledge regarding the above mentioned factors is necessary in achieving high productivity of barley grain of high quality for industrial use.

In the light of the above background, the present study was undertaken with the following objectives:

1. To study the influence of moisture stress at certain critical stages of crop growth on grain yield, grain protein and seed weight.

2. To study the interaction of nitrogen levels and moisture stress at critical stages of growth on grain yield and the above seed quality aspects.

Chapter 2

LITERATURE REVIEW

Barley research in Nigeria is in its infancy and virtually no work has been carried out on the effects of moisture stress and nitrogen levels on the crop. However, there is some work published on this subject in other barley producing parts of the world. The literature on irrigation is scanty as barley is mostly grown as a rainfed crop in other parts of the world.

2.1 Effects of Moisture Stress at Different Growth Stages on Yield of Barley

Soil moisture is considered the single most important factor limiting crop yields. Moisture stress results from an inbalance between the supply of moisture furnished by the soil and the amount needed by the plant as determined by atmospheric demand (Singh and Kumar, 1979). It is generally agreed that even the plant water deficit that develops at any point in time is the result of a complex combination of soil, plant and atmospheric factors, all of which interact to control the rates of water absorption and water loss (Kramer, 1963 and Vaadia, et al., 1961).

Although it is generally established that moisture stress reduces yields, the degree of yield reduction, however, depends on environmental

conditions, soils, crop variety and the growth stage at which the stress occured. Lahane and Staple (1962) reported that plant characteristics, stage of development, soil and climatic conditions are important variables in determining the relationship between moisture and crop production.

Germination and seedling emergence are the first two critical stages of growth in dryland farming. Obtaining an adequate crop stand for optimum crop production is difficult in many dryland conditions because of the adverse effects of low soil moisture content on germination and seedling emergence of crops. On the other hand, however, excessive moisture supply decreased the rate of germination of wheat (Dasberg and Mendel, 1971). In their study with many grasses, Wright et al. (1978) also observed that both rate and total emergence of seeds declined with soil moisture deficit. However, Doneen and McGillworay (1943) concluded that seed germination was proportionately delayed as the initial soil moisture percentage was decreased, and the germination percentage for some crops is lowered as the soil moisture is decreased towards the wilting coefficient.

Moisture stress during tillering reduces yields. Kumar and Singh (1977) observed that water stress between active tillering and the flag leaf stages was

most critical for reducing grain yields. Yield decreased significantly with stress occuring at the onset of tillering (Heapy et al., 1976 and Day et al., 1978). Mkamanga and Singh (1976) observed that avoiding moisture stress at the tillering stage increased grain yield of malting barley. Day et al. (1979) also reported that variations in number of ears per unit area was largely accounted for by the soil moisture deficit which occured at tiller production and spikelet initiation periods.

During jointing, moisture stress reduced wheat grain yield due to reduction in plant size, photosynthetic area, heads per unit area and fewer seeds per spike (Day and Intalap, 1970 and Falaki et al., 1979), and research with barley by Stanberry and Schrieber (1965) and Stanberry and Lowrey (1965) also indicated a behaviour similar to that of wheat. However, Day and Thompson (1975) observed that withholding irrigation water during the jointing stage of spring barley did not reduce grain yield and in some cases increased it. They found that stressing barley for water at jointing resulted in shorter plants, less lodging, and more tillering and more heads per unit area. In contrary with this finding, however, it was found that the number of ears per unit area reduced with moisture stress at jointing (Day et al., 1978).

Moisture stress at heading has been reported to cause reduction in number of grains per ear. Sepaskah (1978) found that grain yield of barley was highest with irrigation at heading and flowering stages. Navas (1975) observed heading stage to be one of the most sensitive periods for moisture stress in barley. He further observed that stress during heading greatly induced tiller production, and stress at any stage but especially during heading decreased grain yields. Safely (1974) reported that in general, for all crops, stress at almost any stage between floral initiation and maturity was likely to result in yield variation.

Day and Thompson (1975) reported that water stress at flowering and dough stages decreased grain yield, at flowering stage decreased number of grains per ear and at dough stage decreased seed-weight. Moisture stress at tiller and spikelet death, and anthesis was found to cause yield variation in the number of grains per spike and moisture stress at grain filling caused reduction in mean grain mass (Day, et al., 1979). Working in Southern Iran, Sepaskah (1978) found that one irrigation at the flowering stage resulted in an average grain yield increase of 35% compared with no irrigation treatment and was found to be preferable to irrigations at any other stages of growth with respect to both grain yield production and water use efficiency. He also reported that lower grain yields

due to moisture stress at dough stage resulted mainly from lower seed weight. Robins and Domingo (1962) observed that the greatest yield reductions were obtained when stress was imposed during and after heading stage. Salim et al. (1965) reported that the most critical period for most small grains was during the heading stage; and stress at the flowering and dough stages hastened maturity (Day and Intalap, 1970).

As regards which stage of growth is the most critical to moisture stress, Navas (1975) reported that tillering stage was the most critical for moisture stress as regards dry matter production and that stress during earing and pollination gave the greatest decrease in grain yield. Similarly, Sepaskah and Raeissi-Ardekani (1976) and Sepaskah (1978) found that both grain yield and water use efficiency were highest with irrigation at flowering stage. On the contrary, however, the heading stage has been identified as most critical (Salim et al., 1975 and Robins and Domingo, 1962) whereas Day and Intalap (1970) reported jointing stage to be the most critical stage because moisture stress at this stage resulted in fewer days from planting to flowering and reduced yield. They concluded, however, that moisture stress at any stage decreased yield, but that the jointing stage was the most critical.

2.2 Effect of Moisture Stress on Yield and Yield Components

Both yield and yield components of barley are affected by moisture stress at varying degrees.

Day et al. (1978 and 1979) reported that moisture stress occuring during tillering and ear formation reduced number of grains per ear and for the reduction of number of spikes per unit area, the relevant period included stem extension and tiller death whereas grain weight reduction is caused by water stress at grain filling.

Sepaskah (1978) revealed that 1000-grain weight was reduced when drought occured at the dough stage. Day and Thompson (1975) reported that water stress imposed for seven days at the jointing stage tended to reduce plant height, increased tillering and ears per unit area. They also observed that water stress at flowering stage decreased number of grains per ear and at dough stage decreased seed weight. Water stress at the jointing stage has been found to result in fewer heads per unit area and fewer seeds per head. Also lighter seed weight was observed with moisture stress occuring at flowering and dough stages.

2.3 Recovery from Moisture Stress and Consequent Compensatory Growth

A more rapid rate of growth and development than in unstressed controls is frequently observed in plants recovering from stress (Gates, 1974, 1968). Similarly, leaf enlargement has also been found to be higher for the stressed than for control plants on recovery (Boyer, 1970; Hsiao et al., 1970; Acevedo et al., 1971). Acevedo et al. (1971) reported that full recovery is possible if the stress is brief, but with long or severe stress full recovery did not occur (Boyer, 1970; Acevedo et al. 1971). Also, photosynthetic rate of leaves subjected to stress has been found to be greater on recovery than for leaves of similar chronological age that had not undergone stress (Ludlow and Ng. 1974).

As regards yield compensation, Nicholls and May (1963) observed that the rate of primodia production of the apex was reduced by soil water deficit, but alleviation of stress caused an accelerated rate of primodium formation so that the final number of primodia and the apex length were the same as the controls.

2.4 Effect of Moisture Stress on Grain Protein Content

Grain protein content is one of the most important quality parameters of malting barley.

The grain protein content of malting barley was found to decrease under irrigation when compared to barley grown under rainfed conditions (Hooda et al., 1977; Navas, 1975). The work of Fedak and Mack (1977) was in agreement with this finding. They reported that increasing moisture levels resulted in decreased grain protein content. Protein content was found to increase with increase in moisture tension from 0.45 to 0.75 bars, but reduced grain yield.

2.5 Effect of Nitrogen on Yield and Yield Components

Nitrogen is considered the most important single element affecting both yield and quality of malting barley.

Several researchers have reported a positive and significant yield in malting barley to application of nitrogen fertilizers. Mkamanga and Singh (1976) reported that grain yields of barley cultivar clipper increased from 2.32 tonnes per hectare without nitrogen to 2.78 and 2.99 t/ha with 20 and 40 kg N/ha, respectively. In a three-year barley study with irrigation and nitrogen Stanberry and Lowrey (1965) reported that nitrogen rate increased barley yields appreciably and moisture utilization efficiency was favoured by higher nitrogen rates and the drier moisture regimes. Menta and Shakhawat (1970) have found that application of nitrogen fertilizer increased grain yield of barley.

Average-grain weight is one of the characters contributing to grain yield. However, opinions seem to vary about the effect of nitrogen application on 1000-grain weight of malting barley. For example, Badan and Poehlman (1968) reported a negative response of this character to 40 and 80 kg N/ha but not lower rates; Jevtic (1973) also reported a negative response at all levels of nitrogen beyond 60 kg N/ha. Other workers reporting similar reductions in 1000-grain weight as the level of nitrogen is increased include Reisenauer and Dickson (1961); Day et al. (1963); Poulsen and Skov (1973) and Gothard et al. (1978). Contrary to these findings however, Dubetz and Wells (1965), Stanberry and Schrieber (1965), Misra (1976) and Falaki (1980) found that this yield character was increased with increasing level of nitrogen while Baghott et al. (1968) and Ahmed et al. (1983) found no significant response irrespective of nitrogen level.

The number of effective tillers or the number of spikes produced per plant or per unit area of land is also influenced by the application of nitrogen fertilizer. Dubetz and Wells (1965); Stanberry and Lowrey (1965) found a significant increase in the number of spikes per unit area with application of nitrogen fertilizer in spring malting barley. Similarly, Badan and Poehlman (1968) ; Jevtic (1973); Misra (1976) and Falaki (1980) reported a positive and significant increase in number of spikes per unit area with nitrogen fertilizer application on malting barley.

2.6 Effect of Nitrogen on Grain Protein Content

Nitrogen fertilizer application has a considerable influence on the grain protein content of malting barley.

Most researchers have reported increase in grain protein content of malting barley with nitrogen fertilizer application. Kandera and Zatko (1976) found that grain protein content was increased by 1.5% with 90 kg N/ha as compared with P and K fertilizer alone. Hooda et al. (1977) Kopecky (1981) and Pomeranz et al. (1976) all reported that grain protein content increased linearly with increasing nitrogen rate. Grain protein content was closely correlated with important malt parameters (Pomeranz et al., 1976).

2.7 Moisture and Nitrogen Interaction on Yield and Yield Components

Nitrogen and irrigation normally interact in dry land farming to exert their influence on growth and development of crops. Soil moisture is known to determine the uptake of nitrogen to a great extent.

Yield increase in malting barley due to interaction effects of nitrogen and irrigation has been reported by Krishchenko and Dashdendev (1978). Jenkins et al. (1979) also reported a large irrigation x nitrogen interaction. Recently in India, Jain and Jain (1979) reported that application of 40 kg N/ha was optimum for lower levels

of irrigation, but 70 kg N/ha was required for higher levels. They found that the highest yields for two years were given by applications of 130 kg N/ha with 9 irrigations and 100 kg N/ha with 7 irrigations. Singh et al. (1978) also reported a significant irrigation x nitrogen level interaction. However, they found that yields with one irrigation and 40 kg N/ha and two irrigations and 20 kg N/ha were similar. Besides, Singh (1973) found that application of 120 kg N/ha increased grain yields of spring barley from 1.39 t/ha without nitrogen to 4.17 t/ha under rainfed conditions and from 1.16 to 4.93 t/ha with irrigation, indicating that irrigation without nitrogen decreased yields. Kuszelewski and Labetawicz (1974) in their study of interactions between fertilizer application and irrigation found that yields of spring barley grain were increased by 5-10% with irrigation and applied NPK as compared with NPK fertilizer alone.

The uptake of several other elements has also been shown to be reduced by water stress (Greenway and Klepper, 1969; Gates, 1974). These results clearly suggest that the reduced growth observed as a result of moderate water deficit may, in part, arise from a disturbance in mineral nutrition as well as any direct effect of water deficits (Turner and Begg, 1978).

Water Use Efficiency

Water use efficiency (WUE) in terms of the grain yield per unit of water used in evapotranspiration is very important when the supply of water is limited.

Irrigation at certain stages of crop growth has a marked effect on both yield and WUE. Sepaskah (1978) observed that grain yield of barley was highest with irrigation at heading and flowering, but wue was highest with irrigation at the flowering stage only. However, Malhotra and Cheema (1976) reported that wue was highest with presowing irrigation, which increased barley yield by 31%. When barley cultivar K 18 was subjected to various soil moisture stresses of 0.15, 0.30, 0.45, 0.60 and 0.75 atmospheric tension, throughout the crop growth period, it was found that plants maintained at 0.45 atm tension had the best Wue (Singh et al., 1979). Similarly, Singh (1978) found that wue per unit water was reduced with increase in water supply. He also reported that adequately nourished plants showed a reduction in the width of the stomatal aperture and used water more efficiently than poorly nourished plants. Improvement in wue was particularly favoured by higher nitrogen rates and drier regimes (Stanberry and Lowrey, 1965); and only the judicious use of water and fertilizer would improve each other's efficiency.

Chapter 3

MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted under irrigation during the 1984/85 and 1985/86 dry seasons at the Irrigation Research Station of the Institute for Agricultural Research, Ahmadu Bello University, Kadawa ($11^{o}39^{o}$N, 08^{o} 02' E and 500 metres above sea level) located in the savanna ecological zone of Nigeria. The climatic and soil conditions of the location and the cropping history of the field in which the experiment was conducted are given in appendices A1, A2, B and C.

3.2 Treatments

3.2.1 Moisture stress

Moisture stress was created at different growth stages by missing one irrigation at Tillering, Jointing, Heading and Dough stages and compared with a control in which normal irrigation was supplied at all growth stages. Normal irrigation was given whenever Cummulative Pan Evaporation (CPE) deficit builds upto 90 mm. The moisture stress treatments were:

So - Irrigating at all growth stages (control)

S_1 - Stress at tillering

S_2 - Stress at jointing

S_3 - Stress at heading

S_4 - Stress at Dough stage.

3.2.2 Nitrogen levels

Three levels of applied nitrogen of 30, 60 and 90 kg/ha along with a control were used.

Thus a total combination of twenty treatments (5 x 4), were replicated four times in a randomized complete block design. The gross and net plot sizes were 5 x 2 m and 4.5 x 1.5 m, respectively.

3.3 Cultural Operations

3.3.1 Land preparation

The experimental area was ploughed once and harrowed twice before making basins. The basins were hand levelled for uniform irrigation.

3.3.2 Fertilizer application

Single superphosphate was applied uniformly to supply 40 kg P_2O_5/ha before second harrowing. Nitrogen was applied as per the treatment at sowing through calcium ammonium nitrate (CAN, 26% N).

3.3.3 Sowing:

The seed of barley variety 'Ketch' was sown by hand drilling at the rate of 100 kg/ha on 2nd and 10th December, 1984 and 1985, respectively; in 5 m rows 20 cm

apart on the well prepared basins. The plots were immediately irrigated.

3.3.4 Irrigation:

Irrigation was done by gravitational method. Water was conveyed from the main channel into sub-channels that led into plots using plastic pipe siphons. Two general irrigations were given, one immediately after sowing and another 9 days after sowing to ensure good germination and establishement of seedlings. Thereafter, differential irrigation as per treatment started, applying 6 cm of water during each irrigation. Soil moisture content was recorded before and after each irrigation (appendix D).

3.3.5 Weeding:

The crop was manually weeded once at four weeks after sowing, in both years.

3.3.6 Harvesting:

The barley crop was harvested at fully ripe stage at 90 and 93 days after sowing in 1985 and 1986 seasons, respectively. Net plots were harvested for yield assessment; while the rest of the plot was harvested in bulk. Manual labour was used for harvesting, threshing winnowing and cleaning of seeds. The seeds were carefully weighed in the laboratory and grain yield per hectare was calculated.

3.4 Assessment of Growth, Yield and Yield Characters

3.4.1 Growth characters:

For the purpose of determining various growth characters, samples were either taken from 25 cm row of the crop or from ten plants randomly (excluding the net plot area) at four sampling dates (at 20-25; 35-40; 50-55 and 70-75 days after sowing) coinciding with tillering, jointing, heading and dough stages, respectively in the two seasons.

(a) Plant height (cm): Plant height was measured from the soil surface to shoot apex or tip of the ear after heading excluding awns. A metre rule was used for this exercise.

(b) Number of tillers per plant: The number of tillers was counted from 25 cm row to determine the number of tillers per plant. The number of effective tillers (ear-bearing tillers) was also recorded at harvest for each treatment. The number of tillers was calculated per metre square there from.

(c) Leaf area per plant (cm^2): Leaf area per plant was measured by sampling ten plants from each treatment and measuring length and width (widest point) of all leaves. Only functional (green) leaves were used for this measurement. Leaf area per plant was then calculated by multiplying the product of length and width of each

leaf with a factor of 0.72 (Hassan, 1983) on each of the plants. The flag leaf area was determined similarly after 100 per cent heading.

(d) Leaf Area Index (LAI): This was determined by multiplying the number of plants per m^2 by leaf area per plant and dividing the result by 10,000.

(e) Dry matter production (g/m^2): The aerial portion of the crop from 25 cm row of each treatment were oven dried at 70°C until constant weight to determine the dry matter per square metre.

(f) Maturity: Number of days to maturity for each plot was recorded when the plant rachis was dried in 50% of the spikes.

(g) Length of spikes (cm): Ten spikes were measured randomly from each plot using a metre rule.

3.5 Post Harvest Yield and Yield Components

3.5.1 Number of grains per spike:

Ten spikes were sampled randomly per plot and the number of grains per spike counted. The mean number of grains per spike was then calculated.

3.5.2 1000-Kernel weight:

Two samples of 250 seeds were counted from each treatment to determine the 1000-kernel weight on the basis of mean of two samples.

3.5.3 Grain yield (kg/ha):

The crop from the net plot was cut close to the ground bundled in sheaves and properly sun dried in a protected area until they attained a constant weight. The crop was threshed, winnowed and the clean seeds were carefully weighed. From this the grain yield per hectare was calculated.

3.5.4 Straw yield (kg/ha):

Straw yield was determined by obtaining the difference between the total dry matter (excluding roots) and the grain yield for each net plot.

3.5.5. Grain protein content:

The grains were analysed for nitrogen using micro-Kjeldahl method as described by Jennings (1961). Nitrogen content was multiplied by 6.25 to convert into crude protein content (Jackson, 1962).

3.5.6. Cummulative depth of water used:

This was obtained by multiplying the water applied during each irrigation (6 cm) by the total number of irrigations for the crop duration.

3.5.7 Water Use Efficiency (WUE):

Water use efficiency was estimated as:

$$WUE = \frac{\text{Grain yield (kg/ha)}}{\text{Cummulative depth of water used (cm)}}$$

(Hoque, 1981).

3.6 Statistical Treatment of Data

The data collected were subjected to analysis of variance as described by Snedecor and Cochran (1967). Duncan's Multiple Range Test (DMRT) was used to compare the means for significant differences as described by Duncan (1955).

Chapter 4

RESULTS

4.1 The Effect of Moisture Stress at Different Growth Stages and Nitrogen Levels on The Growth of Barley

4.1.1 Plant height

The effects of moisture stress and nitrogen levels on plant height at different stages of growth are presented in Table 4.1.

Imposing moisture stress during tillering in 1985 produced significantly shorter plants than the other four stress treatments which produced plants statistically of the same height. In 1986, there was no significant effect of moisture stress on plant height at tillering stage.

There were highly significant differences in plant height due to the application of nitrogen in both 1985 and 1986 seasons, at tillering stage. The highest dose of nitrogen (90 kg/ha) produced significantly taller plants than the other two rates (30 and 60 kg/ha) which produced plants of the same height. The control treatment (0 kg N/ha) produced the shortest plants. This trend was the same for both years.

Table 4.1 : The effect of moisture stress and nitrogen levels on plant height (cm) of barley at different growth stages in 1985 at Kadawa.

Treatment	Stage of growth			
	Tillering	Jointing	Heading	Dough
MOISTURE STRESS AT				
Control	17.15a	40.80a	51.25	58.91a
Tillering	12.14b	37.72b	51.49	52.03b
Jointing	17.69a	34.00c	51.38	52.79b
Heading	17.34a	40.78a	50.03	54.93ab
Dough	17.46a	40.70a	50.00	53.79b
SE (±)	1.002	0.846	0.769	0.042
Significance	**	**	N.S	*
N-levels (kg/ha)				
0 (control)	9.67c	32.00d	2.25d	47.76b
30	13.36b	34.65c	9.48c	57.72a
60	14.49b	37.49b	2.26b	55.87a
90	27.90a	50.52a	9.33a	56.61a
SE (±)	0.897	0.757	0.688	1.827
Significance	**	**	**	**
Interaction				
Nitrogen x stress	*	N.S	*	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically. N.S. = Not significant; *and ** = significant at 5 and 1 per cent, respectively.

Table 4.2 : The effect of moisture stress and nitrogen levels on plant height (cm) of barley at barley at different growth stages in 1986 at Kadawa.

Treatment	Stage of growth			
	Tillering	Jointing	Heading	Dough
MOISTURE STRESS AT				
Control	26.59	46.33a	58.44a	66.15
Tillering	27.01	44.72b	59.67a	64.31
Jointing	24.55	41.93c	53.56b	62.33
Heading	28.00	46.43a	50.04c	65.83
Dough	27.43	46.46a	58.39a	65.40
SE (±)	1.759	0.635	00.789	2.325
Significance	N.S	**	**	N.S
N-levels (kg/ha)				
0 (control)	17.53c	35.90d	41.91d	52.04c
30	26.72b	41.12c	48.73c	64.57b
60	29.62b	48.17b	62.41b	68.24b
90	32.99a	55.51a	71.04a	74.36a
SE (±)	1.573	0.568	0.706	2.079
Significance	**	**	**	**
Interaction				
Nitrogen x stress	N.S	N.S	*	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically. N.S = Not significant; * and ** = significant at 5 and 1 per cent, respectively.

Table 4.3: Effect of moisture stress x Nitrogen levels on plant height during tillering stage in 1985 dry season at Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	10.35cdef	8.83f	10.75cdef	8.98ef	9.45def
30	12.50bcdef	13.28bcdef	14.25bcd	13.83bcde	12.95bcdef
60	15.00bc	11.45bcdef	15.00bc	15.30bc	15.70b
90	30.75a	15.00bc	30.75a	31.25a	31.75a

SE ± 2.005

However, there was a significant interaction between moisture stress and nitrogen levels in 1985 season (Table 4.3). When the effect of moisture stress at different growth stages was studied at the same nitrogen level, it was observed that stress at tillering produced significantly shorter plants than all other stress treatments, indicating that this is the most critical stage in respect of plant height. There was no difference within all other nitrogen levels when looked at the different growth stages.

At jointing stage for both years, control and stress at heading and dough stage treatments produced plants of statistically same heights and were taller than plants which were stressed at tillering or jointing. Stress at tillering resulted in taller plants than jointing.

There was a progressive increase in plant height with increase in the level of nitrogen upto the highest dose of 90 kg/ha in both years. Each increase in nitrogen significantly increased the height. No interaction between nitrogen levels and moisture stress was observed for plant height in the two seasons.

Missing irrigation at heading did not produce a significant effect on plant height in 1985, but in 1986 it was significantly affected. The control and stress at tillering and dough stages produced plants of the same

heights and were taller than those stressed at jointing and heading in that order.

The effect of nitrogen levels on plant height was highly significant and similar in both 1985 and 1986. In both years, plant height significantly increased with each increase in nitrogen upto the highest level of 90 kg/ha.

The interaction between moisture stress and nitrogen levels on plant height at heading was significant in both years. In 1985 (Table 4.4), there was no significant difference in the height of plants from the applied nitrogen rates of 30 and 60 kg/ha in no stress as well as stress at tillering and jointing treatments. But with stress at heading and dough stages, plants from 60 kg N/ha were significantly taller than those of 30 kg N/ha. In all the stress treatments, 90 kg N/ha produced the tallest and 0 kg N/ha resulted in the shortest plants. In 1986 (Table 4.4) plant height generally increased with each increase in nitrogen level from 0 to 90 kg/ha in control and stress at tillering, heading, and dough stages, but with stress at jointing, there was response to nitrogen application only upto 60 kg/ha.

The effect of moisture stress on plant height at dough stage of growth (Table 4.1) was statistically

Table 4.4: Effect of moisture stress x Nitrogen levels on plant height of barley during heading stage in 1985 and 1986 dry seasons at Kadawa.

1985

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	60.85e	63.15de	63.50cde	62.60e	61.15e
30	71.8b	70.8b	71.20b	66.60cd	67.00cd
60	72.9b	71.15b	71.25b	73.20b	72.80b
90	79.5a	80.85a	79.55a	77.70a	79.05a

SE (±) = 1.538

1986

0	43.5h	40.68i	42.0hi	40.0i	43.38hi
30	51.0f	48.38fg	48.25fg	45.0gh	51.0f
60	64.0d	69.13c	60.25d	54.93e	63.75d
90	75.25b	80.50a	63.75d	60.25d	75.45b

SE (±) = 1.580

significant in 1985. The control produced taller plants than all other stress treatments in which irrigation had been missed , except stress at heading. The effect of missing irrigation on plant height was not significant in 1986.

Mean heights due to nitrogen levels were highly significant in both 1985 and 1986. In 1985, all the three levels of applied nitrogen, which were at par, produced significantly taller plants than the control. In 1986, 90 kg N/ha produced significantly taller plants than 60 and 30 kg /ha which were at par and produced taller plants than the control. There was no significant interaction between moisture stress and nitrogen levels on plant height at the dough stage.

4.1.2 Number of tillers per plant

The data showing the mean number of tillers per plant at different growth stages as influenced by moisture stress and nitrogen levels are presented in Table 4.5.

In 1985, missing irrigation significantly reduced the number of tillers per plant at tillering stage. The other stress treatments in which irrigation was not missed before taking the observation were at par. The same trend and significance were observed in 1986.

Table 4.5: The effects of moisture stress and nitrogen levels at different growth stages on number of tillers per plant of barley in 1985 at Kadawa.

Treatments	Growth stage			
	Tillering	Jointing	Heading	Dough
Moisture stress at				
Control	4.06a	3.44	4.69b	2.43
Tillering	2.01b	3.37	4.90a	2.13
Jointing	4.03a	3.38	4.91a	2.36
Heading	4.03a	3.43	4.93a	2.00
Dough	4.19a	3.51	4.94a	2.41
SE (±)	0.395	0.915	0.083	0.249
Significance	**	N.S	*	N.S
N-levels (kg/ha)				
0 (control)	1.95d	2.48d	3.57d	1.52b
30	3.40c	3.06e	4.46c	2.28a
60	4.25b	3.62b	5.06b	2.72a
90	5.06a	4.56a	6.40a	2.54a
SE (±)	0.353	0.082	0.074	0.223
Significance	**	**	**	**
Interaction				
Nitrogen x stress	N.S	N.S	*	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

Table 4.6: The effects of moisture stress and nitrogen levels at different growth stages on number of tillers per plant of barley in 1986 at Kadawa.

Treatments	Growth stages			
	Tillering	Jointing	Heading	Dough
Moisture stress at				
Control	4.38a	4.49	4.88b	4.64ab
Tillering	3.35b	4.44	5.30a	4.39b
Jointing	4.27a	4.30	4.83b	4.31b
Heading	4.31a	4.36	4.84b	4.46b
Dough	4.28a	4.41	4.84b	5.16a
SE (±)	0.345	0.091	0.107	0.281
Significance	*	N.S	*	*
N-levels (kg/ha)				
0 (control)	2.00c	2.5d	2.55d	3.03c
30	4.26b	3.98c	4.34c	4.66b
60	4.99a	5.01b	5.64b	5.02b
90	5.22a	6.10a	7.23a	5.66a
SE (±)	0.308	0.082	0.096	0.252
Significance	**	**	**	**
Interaction				
Nitrogen x stress	N.S	N.S	*	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.
fo
N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

As regards response to nitrogen, highly significant differences were observed in both years. In 1985, each increase in nitrogen level significantly increased the number of tillers. In 1986, however, the response to nitrogen was significant only upto 60 kg /ha, which was statistically the same with 90 kg /ha. The interaction between moisture stress and nitrogen levels was not significant for number of tillers in both seasons.

At jointing stage of growth, response to moisture stress was not significant in both seasons. The differences in mean number of tillers due to nitrogen were highly significant. The response of nitrogen was exactly the same in both seasons. Each increase in nitrogen significantly increased the number of tillers per plant. There was no significant interaction between moisture stress and nitrogen levels on tiller per plant in either year.

Moisture stress at heading significantly affected the number of tillers per plant in both seasons. In 1985, the number of tillers per plant was the same in stress at tillering, jointing and heading, in which irrigation had been missed and these were also the same with stress at dough stage in which irrigation was not missed. No stress treatment produced significantly lower number of tillers than

all other stress treatments. In 1986, missing irrigation at tillering stage produced more tillers than the other four stress treatments which produced statistically the same number of tillers per plant.

The differences in the mean number of tillers due to nitrogen levels were highly significant. The different treatments followed the same pattern of significance as at jointing stage, for both years.

Significant interactions between moisture stress and nitrogen levels were observed for both years. In 1985 (Table 4.7), when the effect of nitrogen levels was studied at the same stage of moisture stress, it was observed that in control and stress at tillering, the nitrogen levels of 30 and 60 kg/ha which were at par, and higher than 0 kg N/ha, produced significantly less tillers than 90 kg N/ha. However, in stress at jointing, heading and dough stages, each increase in nitrogen level significantly increased the number of tillers per plant. When the effect of moisture stress was studied at the same level of nitrogen, it was observed that at the zero level moisture stress at any stage did not produce a significant change in the number of tillers per plant. At 30 kg N/ha, no stress, stress at tillering and jointing were statistically at par with each other, but stress at jointing was also statistically the same with stress at heading and dough stages.

Table 4.7: Effect of moisture stress x Nitrogen levels on number of tillers at heading in 1984/85 and 1985/86 dry seasons at Kadawa.

1985

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	3.25j	3.70i	3.60ij	3.65ij	3.65ij
30	4.70efg	4.65efg	4.50fgh	4.15h	4.30gh
60	4.85ef	4.80ef	4.95de	5.30cd	5.40c
90	5.95b	6.45a	6.60a	6.60a	6.40a
SE (±) = 0.166					
1986					
0	2.55f	2.55f	2.50f	2.55f	2.58f
30	4.30e	4.40e	4.33e	4.35e	4.33e
60	5.58d	6.20c	5.50d	5.53d	5.40d
90	7.08b	8.05a	7.0b	6.95b	7.05b
SE (±) = 0.214					

At 60 kg N/ha, the control, stress at tillering and jointing were statistically the same. Stress at jointing and heading were also found to be the same. Stress at heading and dough stages were statistically the same and stress at dough stage produced significantly higher number of tillers than jointing. At 90 kg N/ha, stress at tillering, jointing, heading and dough stages were statistically at par with each other and higher than control. In 1986 (Table 4.7), when the effect of moisture stress was studied at the same level of nitrogen, it was found that at 0 and 30 kg N/ha, all the stress treatments were statistically at par with each other. At 60 and 90 kg N/ha, no stress, stress at jointing, heading and dough stages were statistically at par with each other and significantly less than stress at tillering. When the effect of nitrogen levels was studied at the same stage of stress, it was observed that the mean number of tillers per plant significantly increased with each increase in nitrogen level from 0 to 90 kg/ha.

At dough stage (Table 4.6), the effect of moisture stress on number of tillers per plant was significant only in 1986. At the time of taking observation at dough stage, irrigation has previously been missed at tillering, jointing and heading stages. Stress at dough stage, in which irrigation

missed
had just been / produced higher number of tillers per plant than the other treatments except no stress treatment. However, the number of tillers per plant in control and stress at tillering, jointing and heading was statistically the same.

The effect of nitrogen was highly significant at the dough stage both in 1985 and 1986. In 1985, application of nitrogen significantly increased the number of tillers per plant, but the differences among the three levels of applied nitrogen were not significant. In 1986, the highest level of 90 kg N/ha produced significantly higher tillers than 30 and 60 kg/ha which were statistically at par and in turn higher than control. The interaction between moisture stress and nitrogen levels was not significant in either year.

4.1.3 Leaf Area per Plant

The effects of moisture stress and nitrogen levels on leaf area per plant at different growth stages are shown in Table 4.8

At tillering stage, the effect of moisture stress on leaf area was significant in 1985, but not significant in 1986. In 1985, stress at tillering in which one irrigation was missed produced significantly smaller leaf area than the other treatments wherein irrigation was not missed.

Table 4.8 : The effect of moisture stress at different growth stages and nitrogen levels on leaf area of barley in 1985 at Kadawa.

Treatments	Growth stages		
	Tillering	Jointing	Heading
Moisture stress at			
Control	67.43a	77.86a	112.24a
Tillering	61.37b	71.80b	99.89b
Jointing	66.49a	68.23b	92.49c
Heading	66.49a	77.86a	85.73d
Dough	66.46a	77.77a	112.39a
SE (±)	1.327	2.013	2.423
Significance	*	*	*
Nitrogen levels (kg/ha)			
0 (control)	59.47c	60.72d	65.43d
30	63.97b	67.13c	90.77c
60	65.89b	74.43b	113.97b
90	73.28a	96.54a	132.03a
SE (±)	1.187	1.800	2.167
Significance	**	**	**
Interaction			
Nitrogen x stress	N.S	N.S	*

Mean followed by the same letter within a treatment group for a particular character are not significant statistically. N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

Table 4.9 : The effect of moisture stress at different growth stages and nitrogen levels on leaf area of barley and flag leaf area in 1986 at Kadawa.

Treatments	Growth stages				Flag leaf area
	Tillering	Jointing	Heading	Dough	
Moisture stress at					
Control	70.72	78.73a	113.61a	53.66	12.23a
Tillering	69.89	73.11b	100.65b	53.91	12.19a
Jointing	70.19	68.75c	93.72c	54.18	12.16a
Heading	70.19	78.77a	98.46bc	53.97	11.54b
Dough	68.86	78.83a	113.83a	52.40	12.18a
SE (±)	.497	0.791	2.857	1.424	0.23
Significance	N.S	*	*	N.S	*
Nitrogen levels (kg/ha)					
0 (control)	61.57d	61.01d	65.73d	20.49d	8.70d
30	68.44c	68.04c	91.68c	32.00c	11.13c
60	72.87b	75.97b	115.74b	64.45b	13.32b
90	77.01a	97.54a	143.08a	97.55a	15.12a
SE (±)	1.339	0.708	2.555	1.273	0.20
Significance	**	**	**	**	**
Interaction					
Nitrogen x stress	N.S	*	*	N.S	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

Nitrogen application significantly increased leaf area per plant in both 1985 and 1986, seasons. In 1985, significantly higher leaf area was recorded at the highest dose of 90 kg N/ha. This was followed by 60 and 30 kg N/ha which were statistically at par with each other but significantly higher than control. In 1986, each increase in nitrogen level significantly increased the leaf area. There was no significant interaction between moisture stress and nitrogen levels in both seasons.

At jointing stage, the differences due to stress treatments were significant in 1985 and highly significant in 1986 season. Stress at tillering and jointing in which irrigation had been missed, produced smaller leaf area than the other three stress treatments in both seasons wherein irrigation had not yet been missed upto jointing stage. However, stress at tillering and jointing differed significantly in 1986. Stress at jointing producing smaller leaf area than tillering.

The effect of nitrogen application at jointing stage both in 1985 and 1986 followed the same trend as at tillering stage in 1986. There was no significant interaction between moisture stress and nitrogen levels on leaf area at jointing stage.

At the time of measuring leaf area per plant at heading stage (Table 4.8), irrigation had been missed at three stages, namely tillering, jointing and heading. These stages produced leaves smaller than the other two treatments, (control and Stress at dough stage) in which irrigation was not missed, both in 1985 and 1986. However, in 1985, leaf area decreased with missing irrigation at tillering, jointing and heading, in that order, whereas in 1986, the reduction in leaf area was highest when stress occured at jointing although this was not statistically different from stress at heading.

The differences in leaf area due to nitrogen were highly significant in both years. Each increase in nitrogen level significantly increased the leaf area, in both years. The same trend was observed at tillering in 1986 and jointing in both 1985 and 1986.

There were signific ant interactions between moisture stress and nitrogen levels on leaf area per plant at heading stage in 1985 and 1986. In 1985 (Table 4.10), there was a general tendency of increasing leaf area as the nitrogen level was increased upto 90 kg/ ha. However, in control and stress at dough stage, in which irrigation was not missed upto heading stage nitrogen level progressively increased leaf area per plant from 0 to 90 kg N/ha. In other stress treatments wherein irrigation has previously been missed either during tillering, jointing or heading, there was no significant difference in leaf areas of 60 and 90 kg N/ha.

Table 4. 10: Effect of moisture stress x N-levels on leaf area at heading in 1985 and 1986 dry season at Kadawa.

1985

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	68.13fgh	65.08gh	63.25h	62.63h	68.05fgh
30	100.25de	96.13e	80.70f	75.50fg	101.25de
60	120.18b	118.88b	110.75bcd	99.80de	120.25b
90	160.40a	119.50b	115.25bc	105.cde	160a

SE ± 4.845

1986

0	69.55ef	66.10f	63.13f	60.88f	69.0f
30	102.13c	96.75d	83.25de	74.80ef	101.45c
60	122.13b	118.25b	114.0bc	101.80c	122.50b
90	160.63a	121.50b	114.50bc	156.38a	162.38a

SE ± = 5.713

In 1986 (Table 4.10), in no stress and stress at dough stage, leaf area increased as the level of nitrogen increased from 0 to 90 kg/ha. However, there was response to nitrogen application upto 60 kg/ha in stress treatments at tillering and jointing. Leaf area was significantly increased at all levels of applied nitrogen when stress was applied during heading.

At dough stage (Table 4.8), leaf area was recorded only during 1986. The differences in leaf area means for the various irrigation treatments were not statistically significant.

The effect of nitrogen on leaf area was the same as the trend observed for nitrogen effects at heading, jointing, and tillering in 1986. There was no significant interaction between moisture stress and nitrogen levels at the dough stage.

4.1.4 Flag leaf area

Flag leaf area (Table 4.9), was recorded in 1986. Missing irrigation at heading stage just before flag measurement leaf area/produced significantly smaller flag leaves than the other four stress treatments which were statistically the same.

Each level of nitrogen significantly increased flag leaf area from 0 to 90 kg/ha. The interaction between moisture stress and nitrogen levels was not significant.

4.1.5 Leaf Area Index (L.A.I.)

The data relating the effects of moisture stress and nitrogen levels on L.A.I. at different growth stages are presented in Table 4.11.

The analysis of data revealed that the differences in stress treatment means were not significant statistically at tillering and jointing stages but they reached a level of significance at 5 per cent level at heading and dough stages in all experiments. L.A.I. values were significantly lower when stress was applied at heading and the differences in the means of all other stress treatments were not statistically significant during 1985 and 1986 seasons. The L.A.I. was significantly lower when the stress was applied at the dough stage and other means were statistically at par with each other in 1986. Thus, upto jointing stage the L.A.I. was not significantly influenced and thereafter it was found to be lower for the stage during wnich stress treatment was applied.

The effect of nitrogen levels on L.A.I. was highly significant at all stages of growth for both years. Nitrogen application significantly increased L.A.I. at

Table 4.11 : The effects of moisture stress at different growth stages and nitrogen levels on leaf area index (I.A.I.) of barley in 1985.

Treatment	Growth stage			
	Tillering	Jointing	Heading	Dough
Moisture stress at				
Control	1.31	2.28	3.21a	0.84a
Tillering	1.35	2.27	3.21a	0.84a
Jointing	1.31	2.25	3.22a	0.83a
Heading	1.31	2.27	3.11b	0.83
Dough	1.31	2.27	3.24a	0.74b
SE (±)	0.012	0.012	0.031	0.024
Significance	N.S	N.S	*	**
Nitrogen levels (kg/ha)				
0 (control)	0.40d	1.45d	1.52d	0.31
30	0.99c	2.01c	2.84c	0.79
60	1.29b	2.60b	3.42b	0.97
90	2.59a	3.00a	5.01a	1.20
SE (±)	0.011	0.011	0.028	0.022
Significance	**	**	**	**
Interaction				
Nitrogen x stress	*	N.S	N.S	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.
N.S. = Not significant; * and ** =significant at 5 and 1 percent, respectively.

Table 4.12: The effects of moisture stress at different growth stages and nitrogen levels on leaf area index (I.A.I.) of barley in 1986 at Kadawa.

Treatments	Growth stage		
	Tillering	Jointing	Heading
Moisture stress at			
Control	1.45	2.51	3.12a
Tillering	1.6	2.45	3.12a
Jointing	1.45	2.41	3.11a
Heading	1.61	2.45	2.85b
Dough	1.45	2.46	3.11a
SE (±)	0.057	0.058	0.033
Significance	N.S	N.S	*
Nitrogen levels (kg/ha)			
0 (control)	0.45d	1.51d	1.51d
30	1.026	2.29c	2.83c
60	1.51b	2.84b	3.17b
90	2.89a	3.18a	4.74a
SE (±)	0.051	0.052	0.030
Significance	*	**	**
Interaction			
Nitrogen x stress	*	N.S	*

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; * and ** = Significant at 5 and 1 percent, respectively.

each level upto 90 kg /ha from tillering to dough stage in both 1985 and 1986 experiments.

All interactions between moisture stress and nitrogen levels were not statistically significant except at tillering in 1985 and at heading in 1986. At tillering in 1985 (Table 4. 13) all stress treatments were found to have a very similar pattern of significance. When the data was analysed for the same stress treatment at varying levels of nitrogen, it was observed that each increase in nitrogen level significantly increased L.A.I. within a stress treatment. When the data was examined at the same level of nitrogen for different stages of stress treatments, the differences were not significant within a nitrogen level except 60 and 90 kg N/ha at tillering stage which recorded higher. L.A.I. than the other stress treatments in each nitrogen level.

The interaction between moisture stress and nitrogen levels at heading stage in 1986 (Table 4.14) indicated that each increase in nitrogen level significantly increased the L.A.I. within each stress treatment. When the same nitrogen level was studied at varying stages of stress treatments, no significant difference was observed within zero level and 30 kg N/ha. Both in 60 and 90 kg N/ha, stress at heading stage resulted in significantly lower L.A.I. than jointing, tillering and control and all other stress treatments, respectively.

Table 4.13: Effect of moisture stress x N-levels on LAI during tillering stage in 1985 dry season at Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	0.41f	0.37f	0.41f	0.41f	0.41f
30	1.00e	0.99e	1.00e	1.00e	0.98e
60	1.30c	1.22d	1.00e	1.00e	0.98e
90	2.54b	2.81a	2.54b	2.53b	2.53b

SE ± = 0.024

Table 4.14: Effect of moisture stress x N-levels on LAI during heading stage in 1986 dry season at Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	1.52f	1.54f	1.52f	1.46f	1.53f
30	2.85e	2.85e	2.85e	2.74e	2.85e
60	3.23c	3.21c	3.20c	3.02d	3.18cd
90	4.88a	4.87a	4.86a	4.19b	4.89a

SE ± = 0.067

4.1.6 Dry matter accumulation

The mean dry matter accumulation (g/plant) at different stages of growth as influenced by moisture stress and nitrogen levels are presented in Table 4.15.

Analysis of the data reveals that the differences due to moisture stress were not significant at tillering in both seasons and at heading and dough stages in 1986. At jointing in 1985, moisture stress produced the lowest dry matter, but this was statistically the same with stress at tillering. However, mean dry matter of plants in which irrigation was not missed upto jointing stage were statistically at par with control. In 1986, stress at jointing also produced significantly lower dry matter than all other stress treatments which were statistically at par with each other. Stress at heading stage significantly produced the lowest dry matter in 1985. The dry matter accumulation in stress at dough, tillering and control were found to be the same but stress at jointing produced lower dry matter than control and stress at dough stage. Moisture stress at dough stage in 1985, accumulated the lowest quantity of dry matter per plant. The mean dry matter values of plants previously stressed at heading, jointing or tillering stages were the same but that of control was statistically higher than heading and dough stages.

Table 4.15: The effects of moisture stress at different growth stages and nitrogen levels on dry matter accumulation (g) of barley in 1985 at Kadawa.

Treatments	Growth stages			
	Tillering	Jointing	Heading	Dough
Moistures at				
Control	119.87	166.09a	281.10a	415.25a
Tillering	109.50	161.28ab	273.44ab	405.75ab
Jointing	118.69	152.43b	268.94b	413.50ab
Heading	118.91	168.06a	231.00c	397.00b
Dough	118.38	166.13a	280.93a	377.88c
SE (±)	3.867	4.676	4.974	8.122
Significance	N.S	*	**	*
Nitrogen levels (kg/ha)				
0 (control)	94.72c	107.29d	185.72d	243.65d
30	99.88c	128.58c	230.60c	334.50c
60	128.60b	183.98b	280.30b	451.50b
90	145.08a	231.35a	371.70a	577.85a
SE (±)	3.459	4.182	4.449	7.265
Significance	**	**	**	**
Interaction				
Nitrogen x stress	N.S	N.S	*	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

Table 4.16: The effects of moisture stress at different growth stages and nitrogen levels on dry matter accumulation (g) of barley in 1986 at Kadawa.

Treatments	Growth stages			
	Tillering	Jointing	Heading	Dough
Moisture at				
Control	120.38	185.06a	318.00	442.88
Tillering	114.16	179.81a	317.56	443.56
Jointing	121.06	167.06b	317.38	442.69
Heading	120.69	180.13a	316.38	443.00
Dough	120.84	180.25a	314.19	442.50
SE (±)	5.769	4.018	6.765	0.701
Significance	N.S	*	N.S	N.S
Nitrogen levels (kg/ha)				
0 (control)	98.38e	119.95d	200.15d	250.35d
30	100.60e	148.25e	256.90e	390.25c
60	129.30b	198.80b	360.00b	490.55b
90	149.43a	246.85a	449.75a	640.55a
SE (±)	5.159	3.594	6.051	0.627
Significance	**	**	**	**
Interaction				
Nitrogen x stress	N.S	N.S	N.S	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

The effect of nitrogen application on dry matter accumulation was highly significant at all stages of sampling and in both years. The response of dry matter was statistically the same when the nitrogen level was increased from 0 to 30 kg N/ha, but the dry matter production was significantly higher when nitrogen level was increased either to 60 or 90 kg N/ha. However, at jointing, heading and dough stages each increase in nitrogen level significantly increased the dry matter accumulation in both years.

The interaction between moisture stress and nitrogen levels on dry matter accumulation was only significant at heading in 1985 (Table 4.17). When the effect of moisture stress was studied at the same level of nitrogen, it was observed that moisture stress at any stage did not significantly affect dry matter production at 0 kg N/ha. However, with 30 and 90 kg nitrogen /ha, moisture stress significantly reduced dry matter production at heading stage only. At 60 kg N/ha, no stress and stress at dough stage produced statistically the same dry matter values, and stress at tillering produced higher dry matter than stress at heading which is at par with stress at jointing. When the effect of nitrogen was studied at the same stage of moisture stress, it was observed that each increase in nitrogen level

Table 4. 17: Effect of moisture stress x N-levels on dry matter accumulation (g) at heading in 1985 dry season at Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	192.15gh	187.75gh	186gh	171.75h	190.95gh
30	240.25f	239.75f	229.75f	202.50g	240.75f
60	300.75b	277cd	272.75de	249.75ef	301.25b
90	391.25a	389.25a	387.25a	300bc	390.75a

SE (±) = 9.949

significantly increased the dry matter accumulation in all stages of moisture stress.

4.1.7 Length of spike

The effects of moisture stress at different growth stages and nitrogen levels on length of spike (cm) measured at maturity (two weeks before harvesting) are presented in Table 4.18.

Moisture stress did not significantly influence spike length in 1985. In 1986, missing irrigation at tillering and jointing produced significantly shorter spikes than dough stage. The differences among the spike lengths of control, and stress at heading and dough stages were statistically at par with one another.

In both seasons, each increment in nitrogen significantly increased the spike length, except in 1986 wherein 30 kg N/ha produced statistically same spike length as 60 kg /ha. The interaction between moisture stress and nitrogen levels was not significant.

4.2. Effects of Moisture Stress at Different Growth Stages and Nitrogen Levels on Yield Components and Yield of Barley

4.2.1 Number of grains per spike

The effects of moisture stress at different growth stages and nitrogen levels on number of grains per spike are presented in Table 4.19.

Table 4.18: The effect of N-levels and moisture stress at different growth stages of barley on spike length at harvest (cm) in 1985 and 1986 dry seasons at Kadawa.

Treatments	Spike length (cm) 1984/85	1985/86
Moisture stress		
Irrigating at all growth stages (control)	17.18	19.61ab
Missing irrigation at tillering.	17.14	18.85b
Missing irrigation at jointing.	17.21	18.88b
Missing irrigation at heading.	17	19.33ab
Missing irrigation at dough	17.69	20.11a
SE (±)	0.27	0.37
Significance	N.S	*
N-levels (kg/ha)		
0 (control)	14.30d	16.71c
30	14.88c	19.65b
60	19.62b	20.11b
90	20.17a	20.95a
SE (±)	0.24	0.34
Significance	**	**
	**	**
Interaction		
N x S	N.S	N.S

* and ** = significant at 5 and 1 per cent, respectively

N.S = not significant.

In 1985, moisture stress had no significant effect on the number of grains per spike. In 1986, missing irrigation at dough stage produced the highest number of grains, but this was statistically the same as no stress treatment Stress at tillering, jointing and heading produced the same number of grains per spike. However, stress at jointing produced significantly lower grains per spike than the control.

In 1985, application of nitrogen significantly increased grain number, but differences among the three applied levels of nitrogen were not statistically significant. In 1986, the control resulted in significantly lower number of grains per spike than all other nitrogen treatments. Increasing nitrogen level from 30 to 60 kg /ha did not increase the number of grains per spike, however, a further increase in the nitrogen level to 90 kg /ha significantly increased the grain number per spike. There was no significant interaction between moisture stress and nitrogen levels in either season.

4.2.2 Grain weight

The effects of moisture stress at different growth stages and nitrogen levels on thousand grain weight (g) are presented in Table 4.19.

The effect of moisture stress on 1000-grain weight was not significant in the two experiments.

In 91985, increasing the nitrogen level either to 30 or 60 kg/ha did not increase the grain weight. The highest level of 90 kg N/ha, however, significantly increased grain weight more than all other nitrogen levels. The response of grain weight to nitrogen levels was not significant in 1986. There was no significant interaction between moisture stress and nitrogen levels in this parameter.

4.2.3 Spikes per Unit area

The data relating the effects of moisture stress at different growth stahes and nitrogen levels on the number of spikes per is presented in Table 4.19.

The effect of moisture stress was not significant on the number of spikes in 1985. In 1986, moisture stress significantly influenced the number of spikes produced at 5% level of significance. Stress at dough stage produced significantly more spikes per unit area than stress at all other stages except no stress treatment. However, the control and stress at tillering, jointing and heading were statistically at par with each other.

The effect of nitrogen levels on number of spikes produced was highly significant in both seasons. In 1985, the three applied nitrogen levels were statistically at par and higher than control. In 1986, the 90 kg nitrogen/ ha level resulted in significantly higher number of spikes than 60 and 30 kg/ha which were at par and higher than control.

Table 4.19: The effect of moisture stress at different growth stages and nitrogen levels on spikes m^{-2}, number of grains per spike and 1000-grain weight.

Treatments	Spikes m^{-2}		No of grains per spike		1000-grain weight	
	1985	1986	1985	1986	1985	1986
Moisture stress at						
Control	137.73	263ab	13.00	16.89ab	50.88	58.88
Tillering	120.73	248.83b	11.13	15.25bc	50.19	59.13
Jointing	133.76	244.29b	11.14	14.91c	53.13	57.63
Heading	113.36	252.79b	11.65	15.30bc	51.25	57.75
Dough	136.60	292.47a	11.63	17.35a	52.44	57.50
SE (±)	10.464	17.244	0.730	0.701	1.121	1.720
Significance	N.S	*	N.S	*	N.S	N.S
Nitrogen levels (kg/ha)						
0 (Control)	66.15b	171.74c	10b	11.96c	50b	56.50
30	129.23a	264.13b	12.59a	16.37b	50.50b	59.50
60	154.17a	284.53b	11.72a	16.95b	50.40b	57.30
90	143.97a	320.81a	12.52a	18.48a	55.40a	59.40
SE (±)	52.922	55.014	0.660	0.630	1.001	1.530
Significance	**	**	**	**	**	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; *and ** = significant at 5 and 1 percent, respectively.

4.2.4 Grain yield (kg/ha)

The data relating the effects of moisture stress at different growth stages and nitrogen levels are presented in Table 4.20.

Analysis of the data revealed that the differences due to moisture stress were significant at 5% level in both years.

In 1985, missing irrigation at the jointing stage produced significantly lower grain yield than all other treatments. The differences in yield of the other stress treatments were statistically at par with one another. Similarly, in 1986, stress at jointing resulted in the lowest yield and it was significantly at par with stress at tillering and dough stage. Grain yield of no stress, stress at tillering and dough stages were statistically the same, but significantly lower than stress at heading. The yields of control and stress at heading and dough stages constitute the same significant group.

The differences in the mean grain yield of nitrogen levels were highly significant in both years. In 1985, nitrogen application increased grain yield upto 60 kg /ha. A further increase of nitrogen from 60 to 90 kg did not increase the yield

Table 4.20 : The effects of moisture stress at different growth stages and nitrogen levels on the grain and straw yields of barley in 1985 and 1986 dry seasons at Kadawa.

Treatments	Grain yield (kg/ha)		Straw yield (kg/ha)	
	1985	1986	1985	1986
Moisture stress at				
Control	2092a	2599ab	7378	11,313
Tillering	2125a	2093bc	6098	11,219
Jointing	1827b	1780c	5379	10,156
Heading	2206a	2876a	7314	11,500
Dough	2350a	2358abc	6024	11,344
SE (±)	129.00	291.210	921.441	1429.468
Significance	*	*	N.S	N.S
Nitrogen levels (kg/ha)				
0 (control)	1658c	1135b	3453c	4725c
30	2041b	2628a	5684b	11,175b
60	2496a	2830a	7827a	13,700ab
90	2289a	2772a	8791a	14,825a
SE (±)	115.401	260.470	824.160	1278.551
Significance	**	**	**	**
Interaction				
Nitrogen x stress	*	N.S	N.S	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.
N.S. = Not significant; * and ** = significant at 5 and 1 per cent, respectively.

significantly. In 1986, all the three levels of applied nitrogen were at par and produced significantly higher grain yield than control.

Interaction between moisture stress and nitrogen levels was only significant in 1985 (Table 4.16). When the effect of moisture stress was considered at the same level of nitrogen upto 60 kg /ha, it was observed that stress at jointing resulted in significantly lower yield than all other stress treatments within the same level of nitrogen. However, at 90 kg N/ha, there was no difference in grain yields of all stress treatments.

4.2.5 Straw yield (kg/ha)

The data relating the effects of moisture stress at different growth stages and nitrogen levels on straw yield is presented in Table 4.20.

Moisture stress did not influence straw yield in either season. However, the differences were highly significant for nitrogen levels in both seasons. Nitrogen increased straw yield significantly upto 60 kg /ha. There was no significant difference in straw yield between 60 and 90 kg N/ha. This trend was similar for 1986. In 1986 also there was significant increase in straw yield upto 60 kg nitrogen /ha. The difference between 60 and 90 or 60 and 30 kg/ha was not statistically

Table 4.21: Effect of moisture stress x N-levels on grain yield (kg/ha) in 1985 dry season, Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	1561de	1580de	982f	2067bcde	2100bcde
30	1963cde	2141bcde	1665de	2183bcd	2254abc
60	2523abc	2603ab	2196bc	2292abc	2866a
90	2335abc	2178bcde	2465abc	2283abc	2182bcd

SE (±) = 257.995

significant. The interaction between moisture stress and nitrogen levels was not significant in both years.

4.3. The Effects of Moisture Stress and Nitrogen Levels on Number of Days to Maturity

The data relating the effects of moisture stress and nitrogen levels are presented in Table 4.21.

Moisture stress significantly affected the mean number of days to maturity in both years. In 1985, withholding irrigation at jointing produced plants which matured significantly earlier than those of the other stress treatments, which matured at about the same time. In 1986, plants stressed for water at jointing and heading stages reached maturity at the same time but were significantly earlier than plants of other treatments, which were at par.

The effect of nitrogen on the mean number of days to maturity was highly significant for both years. In both 1985 and 1986, control and 30 kg nitrogen/ha matured at the same time and were significantly shorter than those of 60 and 90 kg /ha which were also at par with each other.

There was a significant interaction between moisture stress and nitrogen levels on mean number of days to maturity in 1986 (Table 4.23). When the data was examined for the same stage of moisture stress at

Table 4.22: The effects of moisture stress at different growth stages and nitrogen levels on W.U.E., Days to maturity and Grade protein content at Kadawa.

Treatments	W.U.E (kg/ha/cm water)		Days to maturity		Crude Protein content (%)	
	1985	1986	1985	1986	1985	1986
Moisture stress at						
Control	3.88c	6.26ab	86.56a	87.00a	9.31	10.87
Tillering	4.43b	5.14bc	86.50a	87.56a	8.50	9.59
Jointing	3.80c	4.34c	83.31b	85.13b	8.52	9.75
Heading	4.59ab	7.05a	86.69a	85.44b	8.31	9.72
Dough	4.90a	5.79b	86.56a	86.69a	9.22	10.73
SE (±)	0.263	0.705	0.657	0.603	0.583	0.635
Significance	**	**	**	**	N.S	N.S
Nitrogen levels (kg/ha)						
0 (control)	3.38c	3.02c	83.75b	84.00b	6.56c	8.60c
30	4.16b	6.33b	84.45b	84.50b	6.82c	9.07c
60	5.08a	6.85a	87.50a	88.20a	8.50b	10.72b
90	4.66a	6.65a	88.00a	88.75a	13.20a	12.13a
SE (±)	0.235	0.631	0.587	0.539	0.521	0.568
Significance	**	**	**	**	**	**
Interaction						
Nitrogen x stress	*	N.S	N.S	*	N.S	N.S

Means followed by the same letter within a treatment group for a particular character are not significant statistically.

N.S. = Not significant; * and ** = significant at 5 and 1 percent, respectively.

Table 4.23: Effect of moisture stress x Nitrogen levels on mean number of days to maturity of barley in 1986 dry season at Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	84.25gh	84.25gh	83.0h	84.25hg	84.25gh
30	84.0gh	85.25fgh	84.25gh	84.75gh	84.25gh
60	88.50bcde	88.75bcd	86.50defg	87.0cdefg	90.25abc
90	91.25ab	92.0a	86.75defg	85.75efgh	88.0cdef

SE (±) = 1.205

varying levels of nitrogen at no stress and stress at dough stage, 90 and 60 kg nitrogen/ha resulted in significantly longer period to mature than 30 and 0 kg/ha, which were statistically at par with each other. At tillering stage, 90 kg nitrogen/ha took the longest period to mature. This was followed by 60 kg/ha which also matured in significantly longer period than 30 and 0 kg N/ha. At jointing stage, 90 and 50 kg nitrogen/ha were statistically at par and resulted in more days to mature than 30 and 0 kg/ha which were also statistically at par. At heading, there w was no significant difference in number of days to maturity at all levels of nitrogen. When the data was studied for the same level of nitrogen at different stages of moisture stress, no significant difference was recorded in the mean number of days to maturity within control and 30 kg N/ha. At 50 kg N/ha, stress at dough stage resulted in significantly longer period to reach maturity than stress at jointing. At 90 kg nitrogen/ha the mean number of days to maturity of plants in no stress and stress at tillering was statistically at par and more than stress at jointing, heading and dough stages which were also statistically not different from each other.

4.4 Water Use Efficiency (WUE)

The effects of moisture stress at different growth stages and nitrogen levels on W.U.E. is given on Table 4.22.

The effects of moisture stress treatments on W.U.E. was highly significant in both years. In 1985, the control and stress at jointing produced similar W.U.E. values which were significantly lower than other stress treatments. Stress at tillering resulted in lower W.U.E. than stress at dough stage but this was significantly at par with stress at heading. The W.U.E. of plants stressed at heading and dough stages were also statistically at par with each other. In 1986, moisture stress at jointing produced the lowest W.U.E. and was statistically at par with stress at tillering and dough stages. This was followed by stress at dough, tillering and no stress treatments which constituted the same significant group. The next significant group constituted no stress and stress at dough and heading stages.

Nitrogen application significantly increased W.U.E. in both 1985 and 1986. In 1985, response of W.U.E. to nitrogen was significant upto 60 kg ./ha, whereas in 1986, the response was significant only upto 30 kg ./ha.

The interaction between moisture stress and nitrogen levels on W.U.E. was significant only in 1985 (Table 4.24). When the data was studied at the same nitrogen level for the different stress treatments, the lowest and highest applied nitrogen levels had

statistically the same W.U.E. values for all stress treatments. However, at the medium level of 60 kg nitrogen/ha, W.U.E. value of plants stressed at dough stage was the same with plants stressed at tillering and heading, but it was significantly higher than those stressed at jointing and control. The W.U.E. values of plants stressed at tillering, jointing, heading and no stress were statistically same at the 60 kg nitrogen/ha. Within 0 kg nitrogen/ha, moisture stress at jointing had the lowest W.U.E. value, but this was statistically the same with no stress. Moisture stress at tillering, heading and dough stages also produced statistically the same W.U.E. values with no applied nitrogen. The W.U.E. of plants stressed at tillering and no stress were also found to be the same.

When the mean W.U.E. values were studied at the same stress level there was no difference among the three levels of applied nitrogen in no stress and stress at tillering, jointing and also heading which had no difference among all nitrogen levels. However, with stress at dough stage, 60 kg nitrogen/ha, was statistically at par with 30 kg/ha and was significantly higher than 0 and 90 kg/ha. In no stress treatment, there was no significant difference between 0 and 30 kg nitrogen/ha. At jointing, all the applied levels of nitrogen produced significantly

Table 4.24: Effect of moisture stress x Nitrogen levels on W.U.E. in 1985 dry season at Kadawa.

N-levels (kg/ha)	Moisture stress at				
	Control	Tillering	Jointing	Heading	Dough
0	2.89fg	3.29ef	2.04g	4.31bcde	4.27bcde
30	3.64cdef	4.46bcde	3.47def	4.53bcde	4.70abcd
60	4.67bcd	5.42ab	4.57bcde	4.77abc	5.97a
90	4.32bcde	4.54bcde	5.13ab	4.76abcd	4.55bcde

SE (±) = 0.526

higher W.U.E. values than control. However, when stress was imposed at tillering or dough stages, 30 and 90 kg nitrogen /ha produced statistically the same W.U.E. values as the control.

4.5 Crude Protein Content

The data relating the effects of moisture stress at different growth stages and nitrogen levels on grain crude protein content (%) are shown in Table 4.22.

In both seasons, moisture stress treatment did not significantly influence grain crude protein content. However, the differences due to nitrogen levels were highly significant in the two experiments. In both years increasing the nitrogen level from 0 to 30 kg ../ha did not increase the protein content. However, a further increase from 30 to 60 or 60 to 90 kg of nitrogen /ha significantly increased the crude protein content. The difference between 60 and 90 kg ../ha was also significant.

Interaction between moisture stress and nitrogen levels on crude protein content was not significant in either season.

4.6. Correlation Studies

Correlation studies were carried out between yield, yield components and within yield components themselves (Table 4.25.)

Table 4.25: Simple and Partial Correlation Coefficients between Yield and Yield components and within yield components.

Components	Correlation Coefficient	
Simple correlation	1985	1986
Yield Vs. grain weight	0.39**	0.29*
Yield Vs. number of grains/spike	0.33*	0.66**
Yield Vs. number of spikes/m^2	0.35**	0.65**
Grain weight Vs. number of grains/spike	0.20NS	0.21NS
Grain weight Vs. number of spikes/m^2	0.41**	0.10NS
Grain number Vs. spikes number	0.31*	0.80**
Partial Correlation		
Yield Vs. grain weight, keeping grain number constant	0.36**	0.16NS
Yield Vs. grain weight, keeping spikes number constant	0.29*	0.24NS
Yield Vs. grain number, keeping grain weight constant	0.28*	0.82**
Yield Vs. grain number, keeping spikes number constant	0.25*	0.31*
Yield Vs. spikes number, keeping grain weight constant	0.98**	0.82**
Yield Vs. spikes number, keeping grain number constant	0.28*	0.27*

NB: NS = Not significant; ** and * = Significant at 1 and 5% levels, respectively.

All simple correlations between yield, yield components and within yield components were positive and highly significant except correlation between yield and grain weight in 1986, yield and number of grains per spike, grain number and spike number both in 1985 were significant at 5% level; grain weight versus number of grains per spike was not significant in both years and grain weight versus number of spikes per square metre was also not significant statistically in 1986.

The partial correlation coefficients between yield and grain weight, keeping grain number as constant was highly significant in 1985 and not signifi cant in 1986. Similarly, yield versus grain weight, keeping spike number constant was found to be significant in 1985 and not significant in 1986. The partial correlation between yield and grain number, keeping grain weight constant was significant in 1985 and highly significant in 1986. Partial correlation coefficients between the same factors keeping spike number constant was found to be significant at 5 per cent level in both years.

The partial correlation coefficient between yield and spike number was found to be highly significant in both years when grain weight was kept constant and significant when the grain number was kept constant.

Chapter 5

DISCUSSION

5.1 Effects of Moisture Stress at Different Growth Stages and Nitrogen Levels on the Growth of Barley

5.1.1 Moisture stress

Water being a constituent of protoplasm, solvent for nutrients and a reagent, is the most important factor for crop growth, development and yield, especially for dry season crops such as wheat and barley.

Moisture stress at early critical sta ges which include tillering, jointing and heading was found to affect plant height markedly. However, when the stress was applied at the dough stage, the effect on height was not observed. The reduction in height as a result of stress treatment in the early growth stages was also reported by Musick and Dusek (1980), Datiri (1982) and Hassan (1983).

The number of tillers per plant reduced with moisture stress at various growth stages. On tillering the effect of moisture stress was greater when it was applied during tillering and jointing. This is because stress was imposed at the time of tiller initiation and stem elongation which supressed the vital process of tillering. This probably affected nutrient uptake and distribution

within the plant. The staggered or delayed tillering stimulation after resumption of irrigation was clearly observed in treatments that suffered moisture stress during the tillering stage. In fact, these same treatments had significantly higher number of total tillers than even the control in both 1985 and 1986 seasons. According to Gardner and Nieman (1964), cell division may continue during moisture stress, though their enlargement is arrested, until quite severe conditions exist. Angus and Muncor (1977) further observed that when water supply is resumed, a temporary rapid rate of development resulted. This enabled the stressed plants to catch up with no stress crop at jointing and continue tillering even during heading stage.

Withholding irrigation at any growth stage from tillering to heading reduced growth as measured by the leaf area, L.A.I. and dry matter production. The number of tillers per plant determine the number of leaves produced. Imposing moisture stress at tillering had reduced the plant height and number of tillers per plant. These reductions caused general reduction in size and number of leaves per plant, low leaf area index and consequently smaller dry matter accumulation. During the moisture stress periods, protoplasmic dehydration reduced certain physiological activities of the cells, particularly in tissues which require water supply crucially for their development. Similar results were

also reported by Salter and Goode (1967), Panek (1976), Musick and Dusek (1980) and Hassan (1983) who supported the view that moisture stress had similar effect as observed in the present investigation on these growth characters.

Among leaves, the flag leaf area is an important parameter in estimating the grain yield of cereal crops. The flag leaf accounts for 40 per cent of the grain dry matter and variation in grain yield and dry matter accumulation was found to be greatly correlated with the mean flag leaf area (Milthorpe, 1956). Moisture stress at the heading stage significantly reduced the growth of flag leaves due to the adverse effect of stress on flag leaf development.

Moisture stress significantly affected the duration of maturity in barley. Moisture stress occuring at jointing or heading reduced the period of vegetative growth and consequently shortened the mean time to maturity. Other workers who reported similar findings include Aspinall et al. (1964) and Day and Intalap (1970).

5.1.2 Nitrogen

The effect of nitrogen could be seen very clearly on the colour of leaves. The control treatment produced plants which were light green in appearance while those from plots with 90 kg N/ha were dark green in colour.

The light green leaves senesced earlier than the dark coloured leaves, indicating the fact that nitrogen prolongs the productive period of leaves.

Nitrogen deficiency affects the vegetative growth examined in the different growth parameters. There was a pronounced effect of nitrogen on plant height measured at different growth stages. Plant height was found to increase progressively with an increase in nitrogen rate upto 90 kg nitrogen per ha. Similar effect of nitrogen on plant height has been reported by Aspinall et al. (1964) and Bello (1983).

The production of tillers is another important parameter to examine in the vegetative growth because of its impact on yield. The number of tillers per plant increased progressively with increase in nitrogen rate upto the highest dose of 90 kg/ha. A reduction in mean number of tillers per plant was noticed at dough stage, probably due to tiller mortality. Nitrogen fertilization thus stimulated the production of tillers at all levels tested in this investigation.

There were significant responses of nitrogen on leaf area and L.A.I. at all sampling periods from tillering to dough stages of growth. Plant height and tiller number per plant were increased by nitrogen application. These two characters decide the number of leaves per plant which in turn leads to higher leaf area per plant and

consequently larger L.A.I. As with tiller number, both leaf area and L.A.I. increased upto heading and thereafter decreased at dough stage. The amount of decrease also differed under different nitrogen levels. This indicated the favourable effect of nitrogen in keeping larger phostosynthetic surface for longer period. The results of the present investigation was found to be in conformity with those reported by Evans et al. (1975) and Cooper (1980).

As a consequence of the favourable effect of nitrogen on plant height, number of tillers and leaf area, the dry matter accumulation recorded at different growth stages was also favourably influenced. Other workers who reported similar increase in dry matter to nitrogen application include Khalifa (1973); McNeal et al. (1966) and Singh and Gupta (1970).

The role of the flag leaf in the contribution of assimilates towards the spikes cannot be overemphasized. Rawson and Bremner (1978) conclusively showed that grain filling was overwhelmingly the product of current assimilation which means materials stored before grain setting play comparatively a little role. Thus, areas and duration of organs most active in photosynthesis during the grain filling such as the flag leaf, the ear and the upper part of the stem are very important. The flag leaf contributes the main source of carbohydrate to the grains. In this study, nitrogen increased the

flag leaf area at all levels from 0 to 90 kg per ha due to its favourable effect on leaf growth.

Spike length indicates the number of the grains which may be produced in the spike. Application of nitrogen significantly increased spike length (Table 4.18). The positive response observed was upto 90 kg nitrogen per ha. This observation support the general idea that nitrogen application increased plant height, leaf areas and general vigor of the plants. These vigorous plants are, therefore, capable of producing larger spikes. This is confirmed by the work of Verma, et al. (1970) Goma'a, et al. (1977) and Bello (1983) who also reported that spike length increased with increasing rate of nitrogen.

5.1.3 Moisture stress and nitrogen interaction on vegetative growth

During the vegetative growth, nitrogen and moisture stress interaction significantly affected plant height of barley at tillering in 1985 and at heading in both 1985 and 1986 seasons. At tillering in 1985 (Table 4.7), the height of plants responded to the increase in nitrogen level in a similar manner in all stress treatments except when the irrigation was withheld at tillering. In the stress treatment at tillering it was observed that the effect of nitrogen on plant height was not significant in all the applied levels. This suggests that moisture stress during tillering suppressed the favourable effect

of nitrogen fertilizer on plant height. Similarly, at heading (Table 4.4) moisture stress suppressed the influence of nitrogen on plant height. However, at higher nitrogen rates of 60 and 90 kg/ha, plants stressed at tillering were observed to be significantly taller than those of other stress treatments. This indicates that with adequate nitrogen fertilization, moisture stress at early stage of growth (tillering) stimulates tillering on rewatering. Similarly, Gates (1968 and 1974) reported that a more rapid rate of growth and development than in unstressed controls is frequently observed in plants recovering from stress; and Ludlow and Ng (1974) also observed that the photosynthetic rate of leaves subjected to stress was greater on recovery than for leaves of similar chronological age that had not undergone stress.

The interaction between moisture stress and nitrogen levels was also significant in some other parameters examined during the vegetative growth. These include leaf area per plant at heading stage in both 1985 and 1986, L.A.I. at tillering in 1985 and at heading in 1986 and dry matter accumulation at heading in 1985. Moisture stress consistently reduced the favourable effect of nitrogen on all of these parameters. A critical study of the data revealed that throughout the investigation, any interaction between moisture stress and nitrogen during the vegetative growth occured either early at tillering stage, or at the attainment of maximum growth

at heading. This indicates that nitrogen applied to barley at seeding was actively utilized throughout the vegetative growth period. This suports single dose application of nitrogen to barley.

5.2 Effects of Moisture Stress at Different Growth Stages and Nitrogen Levels on Yield Components and Yield of Barley

5.2.1 Moisture stress

The number of spikes per unit area, the number of grains per spike and the seed weight are considered to be the most important yield components of the 2-row malting barley.

The number of spikes per square metre is a function of ear bearing tillers and this determines the quantity of grains to be carried, hence the yield. The number of spikes per unit area was reduced by moisture stress occuring at early growth stages, particularly from tillering to heading, while moisture stress imposed only at the dough stage increased this parameter. This is because effective tillers was decided between tillering and heading stages; stress at dough stage, could not do much to reduce the number of effective tillers. This finding conforms with the work of Day et al. (1979) who also observed that variations in number of ears per unit area was largely accounted for by the soil moisture deficit which occured at tiller production and spikelet

initiation periods; and Day and Thompson (1975) and Day et al. (1978) also reported the reduction in number of ears per unit area with moisture stress at jointing.

The number of grains per spike (Table 4.19) was not affected by moisture stress in 1985, but significantly affected by moisture stress in 1986. The number of grains per spike is established during inflorescence development. In fact, any moisture stress during these decisive stages will affect the number of grains per spike. Moisture stress at any stage from tillering to heading reduced the number of grains per spike, the most deterimental effect being at jointing stage. The reduction caused by stress at tillering could be due to reduction in spike length, whereas the reduction caused by moisture stress during jointing and heading could be associated with its adverse effects on spikelet initiation and formation of gametes. Aspinal et al. (1964) also made similar observations.

The effect of moisture stress on 1000-grain weight was not significant in both years of trial. Thus grain weight was fairly constant regardless of the period of imposing moisture stress during the crop growth in this investigation. This is because the stress during dough stage was probably not very severe as irrigation was missed only once.

Grain yield was significantly affected by moisture stress treatments in both years (Table 4.20). Withholding irrigation during the early stages of growth reduced grain yield considerably. Moisture stress occuring during the jointing stage was most deleterious. In 1985, grain yield decreased by 13 per cent when irrigation was withheld at the jointing stage. Similarly grain yield decreased by 32 per cent over the control in 1986. Losses in grain yield at tillering and jointing were due to reductions in the number of spikes per unit area and number of grains per spike. Losses in grain yield due to moisture stress at dough stage was due to lighter grains caused by incomplete grain filling or maturation. Similar findings have been reported by many workers (Aspinall et al., 1964; Stanberry and Schreiber, 1965; Stanberry and Lowrey, 1965; Day and Intalap, 1970; Falaki, 1980; Datiri, 1981 and Hassan, 1983).

Straw yield was not affected by moisture stress in both years of this investigation. This is probably because growth resumed on rewatering and moisture stress affects grain yield and its attributes more than vegetative development.

5.2.2 Nitrogen

Nitrogen application significantly increased the number of spikes per square metre in two years of investigation. This indicates that nitrogen nutrition reduces tiller mortality.

The number of grains per spike and 1000-grain weight were also increased by nitrogen application. Similar increases in number of grains per spike due to nitrogen application have been reported by Stanberry and Lowrey (1965), Hefni (1976) and Falaki (1980). Since nitrogen deficiency has been recognised as the most probable cause of failure of upper florets (Evans et al., 1975; and Rawson and Bremner, 1978), the increased spike grain number was due to increase in fertile spikelets which contained the grains. Similar results were observed by Dubetz and Wells (1965), Stanberry and Schrieber (1965), Misra (1976) and Falaki (1980). The non-significant response of 1000-grain weight irrespective of nitrogen level in 1986 is in conformity with the findings of Baghott et al. (1968) and Ahmed et al. (1983).

Grain yield significantly responded to the application of nitrogen upto 60 kg per ha, although this was not statistically different from 30 and 90 kg in 1986. The application of 60 kg nitrogen per ha increased the grain yield over the control by about 51 and 149 per cent in 1985 and 1986, respectively. Other workers who recorded grain yield increase due to application of nitrogen include Schilbach (1969); Bengston (1970); Jevtic (1973); Sergeeva (1973); Poulsen and Skov (1973), Mkamanga and Singh (1976), Wilten and Vermaire (1976); Falaki (1980) and Christensen and Killorn (1981).

As earlier shown, the application of nitrogen increased all growth parameters in this study, hence, it is expected that straw yield was also significantly increased by its application. Nitrogen increased plant size by increasing number of tillers, number of leaves and plant height, consequently the straw yield was similarly increased by nitrogen. Similar findings have been reported by Mc Neal et al. (1966) and Christensen and Killorn (1981).

5.2.3 Moisture stress and nitrogen interaction on yield components and yield

There was no interaction between nitrogen and moisture stress for all the yield components in the two years of study. However, grain yield responded significantly to the interaction between moisture stress and nitrogen levels in 1985 only (Table 4.21). The lowest grain yield was recorded with stress at jointing stage at 0 kg nitrogen/ha. Plants in this group also hurriedly reached maturity and this probably reduced the period of assimilate accumulation. Similar findings have been reported by Aspinall et al. (1964) and Day and Intalap (1970).

5.3 Effects of Moisture Stress and Nitrogen on Grain Quality

5.3.1 Moisture stress

Grain protein and 1000-grain weight are two important characters of the grain frequently considered for malting purposes. Moisture stress treatments did not influence these two characters even at the 5 per cent level of significance.

5.3.2 Nitrogen

Malsters prefer plump seeds because of their high starch and high germinative capacity. Grain weight was not influenced by nitrogen upto 60 kg/ha, but was significantly increased by nitrogen at 90 kg per ha.

Grain protein content increased significantly with each increase in applied nitrogen upto the highest nitrogen dose of 90 kg per ha. Many workers have similarly reported increases in grain protein content due to nitrogen application (Hooda et al., 1977; Kopecky, 1981; Falaki, 1980 and Ahmed et al., 1985). One of the most desirable characters in malting barley is low protein content. This is because barley protein is reflected in malt and wort nitrogen. A high barley protein as reported by Ahmed et al.(1985) results in low malt extract and reduces barley and malt quality. Thus, based on the findings in this investigation, 60 kg N/ha is preferred in relation to grain protein content.

5.4 Water Use Efficiency

Data for water use efficiency are presented in Table 4.22. The control treatment received 48 cm total irrigation water, whereas stress treatments (minus one irrigation) received 42 cm.

Although W.U.E. was generally low in this study, withholding irrigation at jointing has produced the most unfavourable effect of stress. Stress at jointing as earlier reported had caused reduction in number of tillers and leaf area per plant and also reduced plant height. These consequently reduced the W.U.E. of the crop, which depends so much on the general vigor of the plant.

Nitrogen application also significantly affected the W.U.E. The application of nitrogen increased W.U.E. due to its favourable effects on the general growth and vigor of the plant.

5.4.1 Interaction between moisture stress and nitrogen on the number of days to maturity and WUE

The interaction between moisture stress and nitrogen significantly affected the mean number of days to maturity (Table 4.23). This interaction reveals that plants hurriedly reached maturity at 0 and 30 kg nitrogen per ha regardless of the period of moisture stress occurence. However, moisture stress had a pronounced effect of

shortening duration of maturity at higher nitrogen rates, particularly 90 kg nitrogen per ha.

Interaction between moisture stress and nitrogen was significant for W.U.E. The application of 60 kg/ha was favourable to WUE when irrigation was missed preferably at the dough stage. Missing one irrigation at jointing without nitrogen application produced the most adverse effect on WUE of barley. However, nitrogen application upto 90 kg per ha compensated for the lack of nitrogen at this stage of growth. Thus, adequate nitrogen fertilization improved the WUE of malting barley under limited water supply.

Chapter 6

SUMMARY AND CONCLUSIONS

Field trials were conducted at the Irrigation Research Station, Kadawa, of Institute for Agricultural Research, Ahmadu Bello University during the 1984/85 and 1985/86 dry seasons to study the effects of moisture stress imposed at various growth stages under different nitrogen levels on yield and some quality aspects of malting barley.

Moisture stress was created at different growth stages by missing irrigation at tillering, jointing, heading and dough stages which were compared with a control in which normal irrigation was supplied at all growth stages whenever Cummulative Pan Evaporation (CPE) deficit built upto 90 mm. Three levels of applied nitrogen of 30, 60 and 90 kg N/ha along with a control constituted the second factor.

The differences in mean plant height, number of tillers per plant, leaf area, flag leaf area, leaf area index and dry matter production were significantly decreased by moisture stress at different stages of growth. Nitrogen application significantly increased the above mentioned parameters. The flag leaf area and spike length were also found to increase with increase in nitrogen level, but moisture stress at

heading stage significantly decreased the spike length. Withholding irrigation at jointing and heading stages reduced the mean number of days to maturity whereas nitrogen application upto 60 kg N/ha increased the number of days to maturity.

Missing irrigation during early stages from tillering to heading reduced the number of spikes per square metre and number of grains per spike. Nitrogen application significantly increased all the yield components viz: number of spikes per square metre, number of grains per spike and 1000-grain weight.

The grain yield was adversely affected by withholding irrigation at any growth stage except heading stage. The maximum yield reduction levels of 13 and 32 per cent were observed when irrigation was missed at jointing stage in 1985 and 1986, respectively. Nitrogen application significantly increased grain yield upto 60 kg N/ha. Grain yield increased by about 51 and 149 per cent in 1985 and 1986 over the control, respectively due to nitrogen application of 60 kg/ha. Straw yield also responded to nitrogen application only upto 60 kg/ha in both years.

Grain yield was found to be strongly associated with all the yield components which were positive and highly significant.

The water use efficiency (WUE) was more adversely affected by withholding irrigation at jointing stage in both years. However, nitrogen application increased the mean WUE values only upto 60 kg N/ha.

Grain protein content increased significantly with each increase in applied nitrogen upto the highest dose of 90 kg/ha, but was not affected by moisture stress.

Based on the present investigations, it is concluded that moisture stress at any growth stage results in reduction in growth, yield components and yield of barley. If one has to unavoidably economise irrigation by missing one irrigation, it is safer to miss it after jointing. Jointing, tillering and dough stages were found to be the most critical stages in that order to soil moisture stress. Also, a nitrogen fertilizer rate of 60 kg/ha applied at sowing is recommended for optimum grain yield with acceptable grain protein content for malting barley.

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Appendix A-1: Mean monthly air temperature (^{o}C) and evaporation (mm) during the barley growing period at Kadawa in 1984/85 dry season.

month	Temperature		
	Mean maximum	Mean minimum	mean evaporation(mm)
November, 1984	33.67	15.70	9.51
December, 1984	28.23	12.90	7.66
January, 1985	28.13	15.16	8.53
February, 1985	26.79	13.79	9.01
March, 1985	35.58	20.00	8.02
April, 1985	34.43	21.20	8.76

Appendix A-2: Mean monthly air temperature (^{o}C) and evaporation (mm) during the barley growing period at Kadawa in 1985/86 dry season.

Month	Temperature		
	Mean maximum	Mean minimum	Mean Evaporation(mm)
November, 1985	33.07	14.30	7.68
December, 1985	28.26	13.29	7.18
January, 1986	28.78	15.29	7.24
February, 1986	26.98	14.01	8.56
March, 1986	37.26	21.00	7.99
April, 1986	38.27	23.4	9.30

Appendix B: The physical and chemical properties of the soil collected at upto a depth of 30 cm from the experimental site at Kadawa.

Soil Properties	Characteristics
Physical properties	
Sand%	51.58
Silt%	35.40
Clay%	8.10
Textural class	Sandy loam
Chemical properties	
pH in H_2O	6.5
pH in 0.01 m $CaCl_2$	5.8
Exchangeable Cations (meg/100n g of soil)	
Na	0.148
K	0.117
Ca	3.250
Mg	0.989
Total P (ppm)	100.00
Total N (%) in 0.048 N H_2SO_4	0.021
CEC (meg/100 g)	5.93

Appendix C: Previous cropping history of the experimental site at Kadawa.

Season		Crop	
Wet	Dry	Wet	Dry
1983	1983/84	Fallow	Wheat
1984	1984/85	Fallow	Barley
1985	1985/86	Fallow	Barley

Appendix D: Variation in soil moisture reading (%) from tillering to dough stages of barley before and after irrigation at Kadawa, in 1984/85 and 1985/86 dry seasons.

Moisture stress treatment	Moisture content (%)			
	Before	After	Before	After
	1985		1986	
So - Adequate moisture maintained at all stages (control).	7.90	12.10	8.12	11.0
S_1 - Stress at tillering	6.50	10.50	6.70	9.80
S_2 - Stress at jointing	6.20	9.80	6.95	9.45
S_3 - Stress at heading	6.00	9.00	7.40	12.00
S_4 - Stress at dough	8.75	12.95	6.82	9.40

Appendix E-1: Analysis of variance table for grain yield in 1984/85 dry season.

Sources	DF	SS	MS	F
Replications	3	114899	382996	-
Stress	4	235334	588334	4.421*
Nitrogen	3	779113	2597040	19.515**
Stress x Nitrogen	12	322679	268899	2.021*
Error	57	758565	133082	-

* and ** - significant at 5 and 1 perccent, respectively.

Appendix E-2: Analysis of variance table for grain yield in 1985/86 dry season.

Source	DF	SS	MS	F
Replications	3	266846	889486	-
Stress	4	116560	2913990	4.295*
Nitrogen	3	3924 8700	13082900	19.284**
Stress x Nitrogen	12	10124100	843676	1.244 NS
Error	57	38670400	678428	-

* and ** - significant at 5 and 1 per cent, respectively.
NS - Not significant.

BIOGRAPHY: Nanchak Chirdan Nimzing

Name:	:	N.C. Nimzing
Date of Birth	:	25 February, 1958
Business Address	:	Agronomy Department, Faculty of Agriculture, Ahmadu Bello University, Zaria.
Home Address	:	c/o C.O.C.I.N. Church Pil-Gani, P.O. Langtang, Plateau State.

Previous Qualifications

Institutions attended	From	To	Cert/Degree
Government Secondary School, Dengi.	1973	1978	W.A.S.C.
School of Basic Studies, Ahmadu Bello University Zaria.	1978	1979	I.J.M.B.
Ahmadu Bello University, Zaria.	1979	1983	B.Sc. (Agriculture)

Posts Held since the Award of First Degree

Organization	From	To	Position
Institute for Agricultural Research, A.B.U., Zaria.	1983	1984	N.Y.S.C. (Research Assistant)
Ahmadu Bello University, Zaria.	1984	Date	Graduate Assistant.

Year of Admission for Postgraduate Studies: 1985

Admission Number : M.Sc/Agric./8942/1984-85.