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FINAL

RESEARCH REPORT

COTTON GROWTH AND SEED COTTON YIELD IN RELATION TO PLANT WATER DEFICIT

(USAID/ISMR-CGP RESEARCH PROJECT III)

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1. DETAIL OF PROJECT

1.	Project Title	:	Cotton Growth and Seed Cotton Yield in Relation to Plant Water Deficit.
2.	Project No.	:	ISMR-CGP- Research Project-III
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8.	Date of Termination	:	December 17, 1991
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2. SUMMARY

Field experiments were conducted for two seasons 1990 to 1992 on clay loam soil at Multan (Latitude 30° 12N, Longitude 71° 28'E, alt. 123 m) to find out cotton growth and yield response to plant water deficit of ≥ -25 bar, imposed at squaring, early flowering and peak flowering phases of crop. There was a check treatment, crop receiving water ≤-16 bar throughout the season. Studies revealed that pressure chamber measurements of leaf water potential provide a useful mean to quantify plant responses to water stress. Plant water deficit of -25 bar at either stage of plant development caused reduction in all parameters of expansive and reproductive growth viz., plant height, total assimilatory capacity, net assimilation rate, production of potential fruiting sites and actual boll load. Flower bud and boll shedding was higher in water stressed crop. These crop conditions led to lower seed cotton yield and it ranged from 3009 to 3477 kg/ha in different treatments. The reduction in seed cotton yield due to water stress was 13 percent at squaring, 11 percent in early flowering and 5 percent at peak flowering stage. The decrease in boll number and small boll size were responsible for reduction in seed cotton yield. Fibre quality was a similar in all treatments. Crop earliness remained unchanged.

Consumptive use in control treatment was 63 cm and the crop stressed at squaring, early flowering and peak flowering used 50 cm, 55 cm and 61 cm of water, respectively. Maximum water use occurred in the months of August and September. Roots extracted about half of the total water from top 30 cm soil layer. Seed cotton yield was a linear function of evapotranspiration ($r = 0.54$) and water use efficiency was 36 kg cm^{-1}.

Plant indicators such as terminal green length of main stem and distance of white bloom from top could serve as useful criteria for scheduling irrigation.

Crop maintaining a leaf area index of 4.5 at peak flowering stage produced highest yield. Yield was a quadratic function of leaf area index ($r = 0.78$).

Cotton crop required on an average 90, 480, 860, 1500 and 2050 degree days (Base temp. 15.5°C) for emergence, squaring, bloom, boll split and maturity from planting date. Cotton boll required about 500 degree days to mature. About 2/3 of total boll load contributing to yield was formed in the month of September and these bolls have large size than those appearing either early or late in the season.

The old practice of delaying first irrigation to cotton crop was very deterimental to various processes of yield formation. The ranking of cotton phases in terms of sensitivity to water stress are (1) squaring (2) early flowering and (3) peak flowering. Early water stress in consonance with high temperature (Max. temp. 42°C; Min. temp. 33°C) causes deleterious effects on cotton growth and development and it should be avoided at all costs to achieve maximum yield.

3. INTRODUCTION

Cotton is grown in some 78 countries of the world. It is source of livelihood to several million farming families around the globe. Besides, it provides job and trade to substantial portion of world population. Cotton is among the sharpest instrument of change in human life world over.

Pakistan is known in the world as a major cotton producing nation. In 1991-92, cotton occupied an area of 2.8 million ha or 14 percent of total cropped area. It produced 10.27 million bales of lint (1 bale = 170 kg) and 628 kg of lint yield per ha. Pakistan ranked second in export among cotton growing countries of the world.

The share of cotton and made ups in the total exports was 59.27 per cent in 1990-91. It contributed more than Rs. 34 billion in national exchequer in form of foreign exchange.

The textile sector comprises the largest segment of Pakistan's GDP and cotton yarn and cloth production accounts for 66 percent of all large scale manufacturing in the country. There are 6 million spindles and 75000 rotors in Pakistan. These machines consume about 8 million bales of lint. Cotton also provides raw material to 1035 ginning factories and 1250 oil mills. Pharmaceutical, soap, chemical and feed industries also depend on cotton bye-products. In social sector, cotton is an occupation of 1.5 million farming families and provides job to 54 percent of labour force. Cotton has now attained a position of vertiable "Alladin Lamp" in Pakistan's economy and its success makes a difference between poverty and prosperity.

Pakistan has an arid to semi arid climate. Rainfall is scanty and agriculture is carried by supplemental irrigation. The largest contagious irrigated area in the world of about 20 million hectare lies in the Indus Plain. About 3/4 of arable land is irrigated compared with 18 percent in the world (Stewart and Nelson, 1990). Pakistan ranks second

next to Egypt in irrigated agriculture. Cotton is grown almost with full irrigation. This has made it a high input crop in terms of fertilizers, pesticides and fuel. The total energy input increased so yield increased with time. Notwithstanding, yield level obtained in Pakistan is still very low compared with other irrigated areas of the world. (Fig.1).

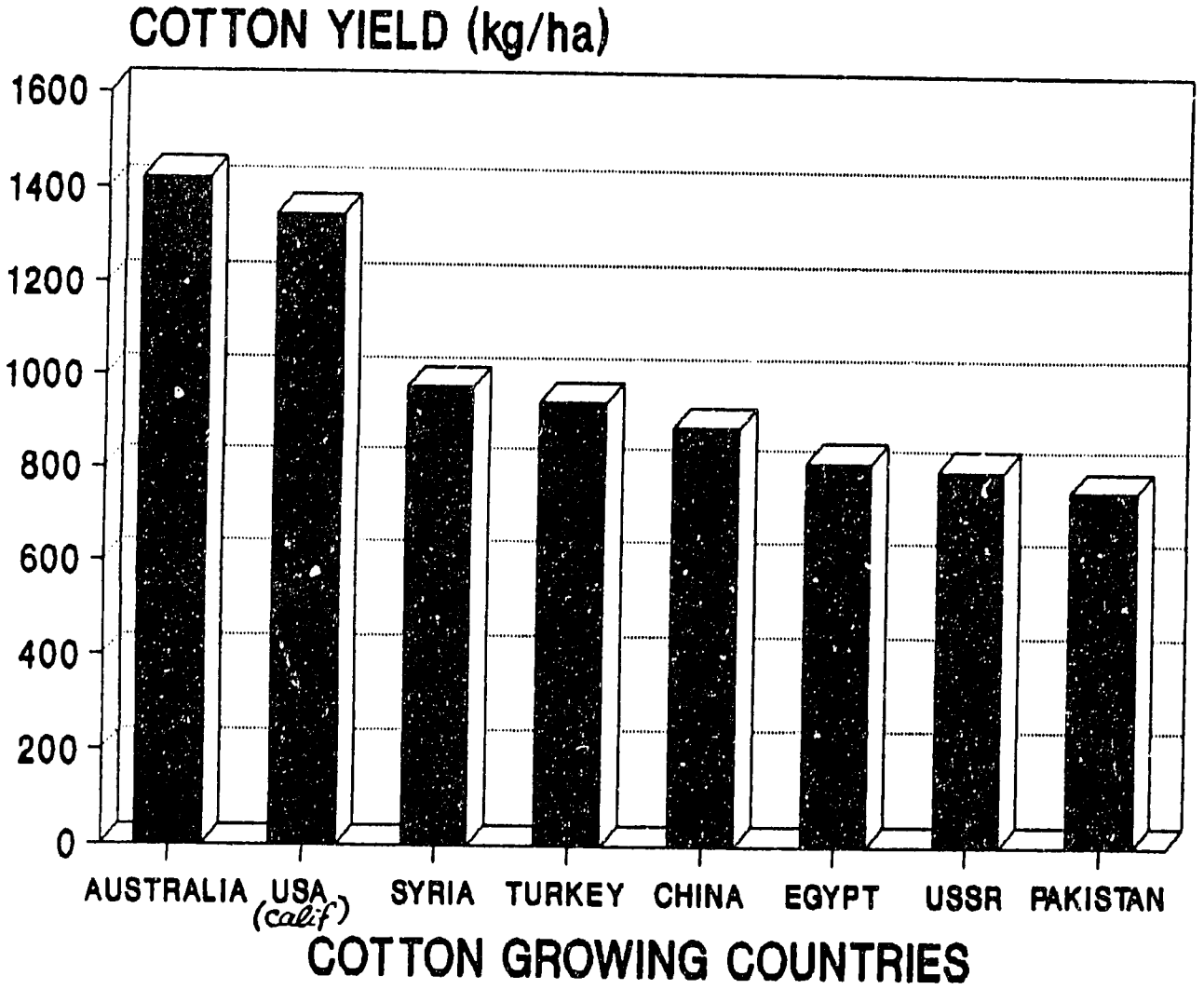
Water is scarce and costly commodity. Water for irrigation is becoming more and more valuable due to increasing cost of irrigation projects and limited supply of good quality water. Pakistan is facing great difficulty in increasing irrigated land so as to feed and clothe human population which is increasing at the rate of 3 percent per annum. Thus there is need to improve irrigation practices for maximum crop production and avoid both water excesses and deficits at field level. This could be done by providing irrigation water based on plant water status measurements which is an integration of soil-plant-atmosphere continum. This experiment tends to investigate usefulness of pressure chamber measurements of leaf water potential as a criteria for scheduling irrigation in the cotton crop and also to identify crop phases which are sensitive to water stress so as to avoid yield losses due to water shortages.

4. MATERIALS AND METHODS

4.1 Site selection and characterization

Field studies were conducted for two seasons 1990-92 at experimental farms of Central Cotton Research Institute, Multan. The soils were clay loam which are classified as Haplic Yermosols, according to FAO system of soil classification. The soil samples were removed in steps of 30 cm upto the depth of 1.2 m to determine physico-chemical characteristics of the experimental site. Soil constants like textural class, bulk density, porosity, moisture retension characteristics were determined as per methods described by Klute (1986). Chemical analysis for major nutrients alongwith pH etc were also carried out as per methods of Black (1965).

Fig.1. AVERAGE COTTON YIELD IN COTTON GROWING AREAS OF THE WORLD (DATA FOR YEAR 1991)



SOURCE: WORLD AGRI.PROD. USDA,MAY,1992

4.2 Layout of the Experiment

Cotton cultivar CIM-109 (*Gossypium hirsutum* L.) was planted during early June in a randomized complete block design with four replications. Crop was sown in rows and had plant configuration of 75 x 30 cm. Crop received 150 kg N, 50 kg P_2O_5 and 50 kg K_2O per hectare. The whole quantity of phosphorus, potassium and 1/4th of nitrogen fertilizers were broadcast and incorporated in soil at seedbed preparation. The remaining quantity of nitrogen was splitted into three and added after the appearance of first white flower.Crop husbandry practices were standard of the area.

4.3 Imposition of Irrigation Treatments

Field received a pre-plant irrigation of 8 acre inches and stress treatments were imposed beginning from first post-plant irrigation. These treatments are depicted in Fig.2 and details are provided below:

Irrigation Treatments

Growth stage (Period of water stress)*	LWP threshold for irrigation	Total water applied during crop season (Mean of two seasons)
Squaring (27 - 48 DAP**)	$\geq$ -25 bar	74 cm.
Early flowering (48 - 68 DAP)	$\geq$ -25 bar	83 cm.
Peak flowering (76 - 96 DAP)	$\geq$ -25 bar	85 cm.
Planting to maturity (No water stress)	$\leq$ -16 bar (Control)	97 cm.

* Crop at particular phase was stressed only once to attain a LWP of $\geq$ -25 bar and thereafter stress was released by providing full irrigation.

** Days after planting.

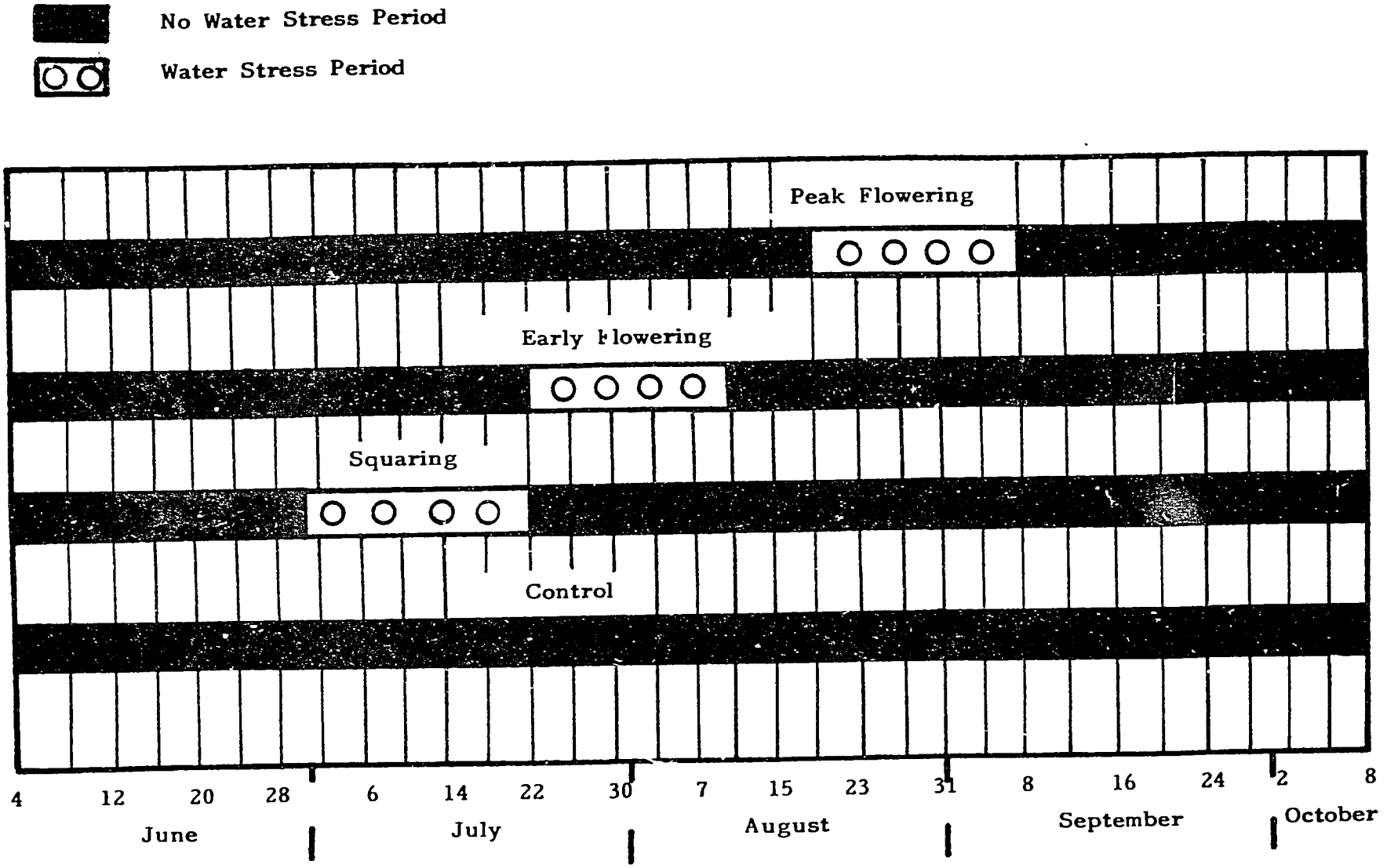


Fig.2. Plan Showing Phases of Water Stress in Cv. CIM-109

4.4 Measurement of Plant Water Status

Water stress treatments were imposed by regularly maintaining leaf water potential (LWP) of recently matured main stem leaves by pressure chamber technique (Scholander et al 1965; Jordan, 1970; Grimes & Yamada, 1982, Zelinski, 1988). Five random leaves, usually fourth node down from the terminal were excised with sharp razor blade from the base of petiole between 12.30 to 14.30 hours. The leaves selected were fully expanded, unshaded and free of any damage. Leaf water potentials thus determined represent the maximum value for the day and were termed the plant water potential value for scheduling irrigation.

4.5 Soil Moisture Determination and Consumptive Use

Soil water content was determined by gravimetric method. Soil samples were removed from the random spots in each plot at an increment of 30 cm upto the depth of 1.2 m before and after each irrigation. The composite sample of five cores was put in aluminium cans and weighed immediately to avoid evaporation losses. Samples were dried in an oven at 105°C to constant mass (18-24 h drying). The samples were reweighed and water content on a dry mass basis was calculated from

$$\theta m = \frac{ms + w - ms}{ms} = \frac{ms + w}{ms} - 1$$

θm = Water content on dry mass basis

$ms+w$ = Weight of wet soil

ms = Weight of oven dry soil

The volumetric water content was calculated from the gravimetric water content according to the following formula:

$$\theta v = (\rho s/\rho w)\ \theta m$$

ρs = Bulk density of the soil

ρw = Density of water

Consumptive use of water was estimated by summation of amount of water depleted from 1.2 metre depth during irrigation intervals. Water use during water application and for a time thereafter during downward movement of water was estimated before and after irrigation to a point midway in the time interval. The amount of water used by crop from planting to final harvest was thus termed as consumptive use during the season. Rainfall, of any was also taken into consideration while calculating the consumptive use.

4.6 Growth and Development

Crop development was followed during the season by harvesting four consecutive plants in each experimental unit at five physiological stages of growth, viz., (i) the initiation of square, "DAP 30" (ii) flower formation; "DAP 60" (iii) peak flowering; "DAP 90" (iv) splitting of bolls; "DAP 120" and (v) maturity; "DAP 150". The samples were brought to the laboratory and measurements were taken on plant height, number of nodes on main stem and internodal length. Fruiting positions were categorized as having either aborted or retained the fruiting forms. Bolls were characterized as immature, mature and open. After recording these measurements, plants were partitioned into leaves, stalks and fruit. Leaf area was determined with an automatic leaf area meter. Plants biomass was dried to a constant weight at approximately $70^{o}C$ for dry weight determinations.

Formulae used to calculate growth parameters were as presented by Radford (1967):

(i) Crop Growth Rate $(\overline{CGR}) = \frac{W_2 - W_1}{t_2 - t_1}$
($g/m^2/day$)

(Where W_1 and W_2 are the values of total dry weights at times t_1 and t_2, respectively)

(ii) Relative Growth Rate ($\overline{RGR}$) (g/g/day) = $\dfrac{\log_e W_2 - \log_e W_1}{(t_2 - t_1)}$

(Where $\log_e W_1$ and $\log_e W_2$ are the values of total dry weights at times t_1 and t_2, respectively).

(iii) Net Assimilation Rate ($\overline{NAR}$) (mg/dm^2/day) = $\left\{\dfrac{(W_2 - W_1)}{(A_2 - A_1)}\right\} \cdot \left\{\dfrac{(\log_e A_2 - \log_e A_1)}{(t_2 - t_1)}\right\}$

(Where W_1, W_2 and A_1, A_2 are total dry weights and leaf areas at times t_1 and t_2, respectively).

(iv) Leaf Area Duration ($\overline{LAD}$) (time) = $\dfrac{(A_2 - A_1)}{(\log_e A_2 - \log_e A_1)} \cdot (t_2 - t_1)$

(Where A_1, A_2 are the values of leaf area at times t_1 and t_2, respectively).

4.7 Earliness Indices

Earliness was determined by recording data on phenological events, morpho-physiological indicators and product quantity measures of crop during the season. (Munro, 1971).

4.8 Plant Mapping

Plant mapping was done to quantify production, survival and growth of fruit on cotton for explaining differences created by irrigation treatments. Five random plants were selected representing the majority of population in each experimental plot. Tags were attached below pedicels of flowers on the data of anthesis. Flowers were tagged daily from initial flowering until flowering was negligible late in the season. Plants were diagrammed at maturity. Positions which were not accompanied by a tag were recorded as having aborted before anthesis (as a square). Positions which had a tag but no boll were categorized as aborting as young bolls.

4.9 Seed Cotton Yield and Fibre Quality

Seed cotton yield was obtained by harvesting each plot measuring 450 m^2, three times from mid-October to end December. Open bolls were counted on ten consecutive plants at each harvest. A sample of 100 bolls taken from each plot at each harvest was used to determine boll weight, lint percentage, seed index and lint quality. Seed index was determined by weighing three random samples of 100 seeds and lint index was calculated from lint percentage and seed index data. The weighted mean of all the harvests was calculated for boll number, boll weight, lint percentage and seed index.

Lint quality determinations were made on the composite samples of all the harvests. Fibre length, was measured on a fibrograph, tensil strength by "Pressley Tester", fineness by Wira Cotton Fineness Meter and fibre maturity by Shirley Fineness/ Maturity Tester. All measurements were made under controlled temperature ($25 \pm 2^{o}C$) and humidity (65 ± 2 percent R.H.).

Analysis of variance was calculated by standard procedures for randomized block design (Steel & Torrie, 1980).

5. RESULTS AND DISCUSSIONS

5.1 Crop and Weather

The experimental site (30° 12 N, 71° 28 E, alt. 123 m) occurs in an arid subtropical continental climate where cotton cultivation is possible only with supplemental irrigation. The main features of climate are very hot summer and great range of diurnal temperatures. May, June and July are the hottest months of the year. Dust storms are very common during this period. Wind direction is mostly from north in early part of season and south easter-lies in the later part of season. The rainfall occurs during monsoon period (mid-July to mid-September) in the form of high density downpour. The relative humidity becomes high during monsoon

and these conditions are conducive to out break of pest. Crop needs 3 to 5 insecticides sprays to over-come pests damage. There is no dearth of sunshine hours and energy during cotton growing season.The extreme heat and high light intensity rather constitutes major limitation to cotton productivity in this region.

Climatological data averaged over two seasons are depicted in Table-1. Climate remained mostly favourable to cotton growth and development. June, July and August were the hottest months of the year. The absolute maximum temperature of 46.5^{o}C was recorded in the month of June and absolute minimum temperature of 32°C during months of June and July. These hot temperatures caused mortality of seedlings and shedding of early fruiting forms. It was only in August that effective fruiting started in cotton crop. The intense heat gave way to sporadic dust storms. On an average, precipitation of 41 mm was received during crop season. The precipitation was evenly distributed in the season and did not interfere the imposition of water stress treatments. The pest level was normal of location. Heat units (DD) accumulated from June to December were 2548. These daily heat units are illustrated in Fig.3.

5.2 Soil Characterization

5.2.1 Textural Class and Fertility Status

The soils are alluvial, calcareous, clay loam and alkaline in reaction (Table-2). Organic matter and nitrogen are main limitation to cotton production. The phosphorus supply is medium and potassium supply is adequate. Drainage is fair and there is no restriction on root growth. Roots may grow 2 metre deep. Because of arid climate, adequate water supply ensures good cotton production.

Table-1. Meteorological data recorded at Central Cotton Research Institute, Multan - Pakistan

Parameters	June	July	August	September	October	Noyember	December
Mean maximum temperature	41.0	39.1	35.9	33.9	31.5	27.3	21.8
Range	36.0-46.5	33.0-42.5	29.0-39.5	27.0-37.5	25.5-36.0	22.0-31.0	14.0-25.5
Mean minimum temperature	28.4	30.3	28.6	25.7	17.4	11.5	8.2
Range	23.0-32.0	27.0-33.0	26.0-32.0	20.0-29.5	12.0-21.5	6.0-18.0	1.0-13.0
Relative humidity							
8 AM	55.1	68.8	76.1	80.8	81.1	88.0	95.0
5 PM	34.1	44.2	60.3	64.3	67.7	65.5	67.4
Total sunshine hours	292.4	291.6	298.6	283.0	290.4	253.4	204.8
Rainfall (mm)	1.5	3.2	18.6	17.8	-	-	4.4
Heat units	578.1	615.7	522.3	415.1	265.6	119.0	32.4

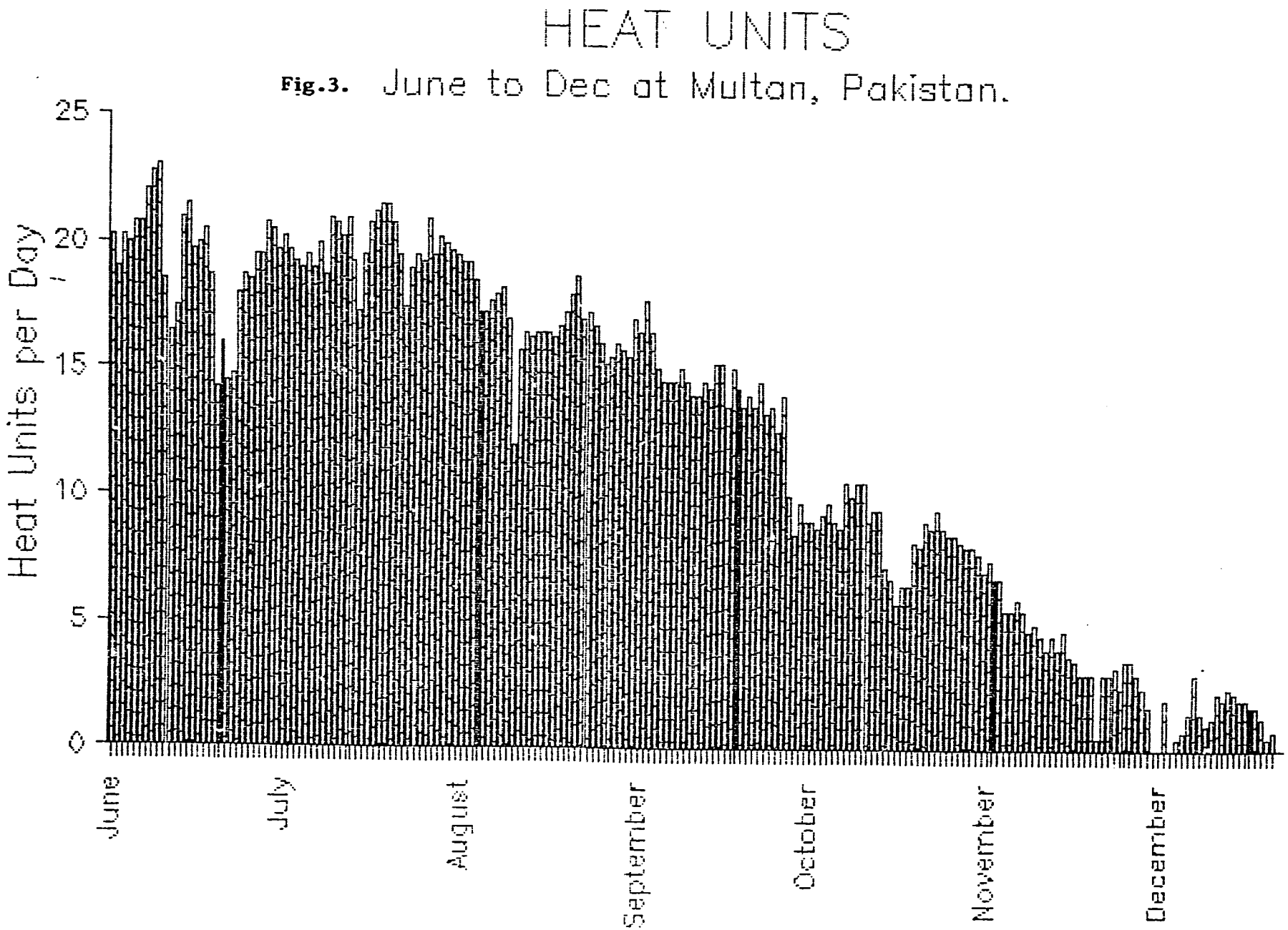


Fig.3. June to Dec at Multan, Pakiston.

Table-2. Physio-chemical characteristics of the experimental site

Soil characteristics		Soil depth (cm) 0-15	15-30
pHs		8.2	8.2
Organic matter (%)		0.46	0.40
$CaCO_3$ (%)		8.7	9.9
ECe (d Sm^{-1})		1.7	1.3
Available nutrients (mg kg^{-1})	NO_3-N	15	12
	P	9	7
	K	179	163
Particle size distribution (%)	Clay	34	
	Silt	30	
	Sand	36	
Textural class		Clay loam	

5.2.2 Soil Moisture Curves

Soil moisture tension curves show that available moisture decreased with soil depth (Fig.4). Available moisture showed a steep drop from field capacity at-1/3 bar to a section of -1 bar and almost flattened after -6 bar. The moisture held at lower suctions is more available to plant than that held at higher suctions.

5.2.3 Soil Moisture Constants

Field capacity (at-1/3 bar suction) wilting point (at-15 bar suction), bulk density and available water decreased with increasing depth (Fig.5). Field capacity ranged from 29.8% to 33.8%, wilting point ranged from 4.3 to 5.2 and bulk density ranged from 1.38 to 1.52 for various soil depths.

5.3 Dry Matter Production

The dry matter yield per unit land area is a useful tool to evaluate crop production potential in a given environment. It is an approximate expression of net photosynthesis over a season. Dry matter accumulation patterns in plant organs helps in understanding processes of yield formation and general crop behaviour. Data illustrated in Fig.6 show that cotton plant follows familiar sigmoid growth curve. The dry matter accumulation was slow during vegetative phase and exponential increase occurred during flowering bud formation to first boll split. The supply of assimilates became limiting as plant aged and growth activity ceased at maturity. The dry matter yield showed significant decrease due to water stress treatments.The squaring and flowering phases were more sensitive to water stress than peak flowering phase. This shows that early season water management was more important than late. A good water supply throughout the season ensured higher dry matter yield. Cotton responds to water stress by reduction in rate of cell expansion and closing of the stomata (Hearn, 1979; Hearn and Constable, 1981). The effect of these

FIG- 4 SOIL MOISTURE CONTENT AT DIFFERENT TENSIONS

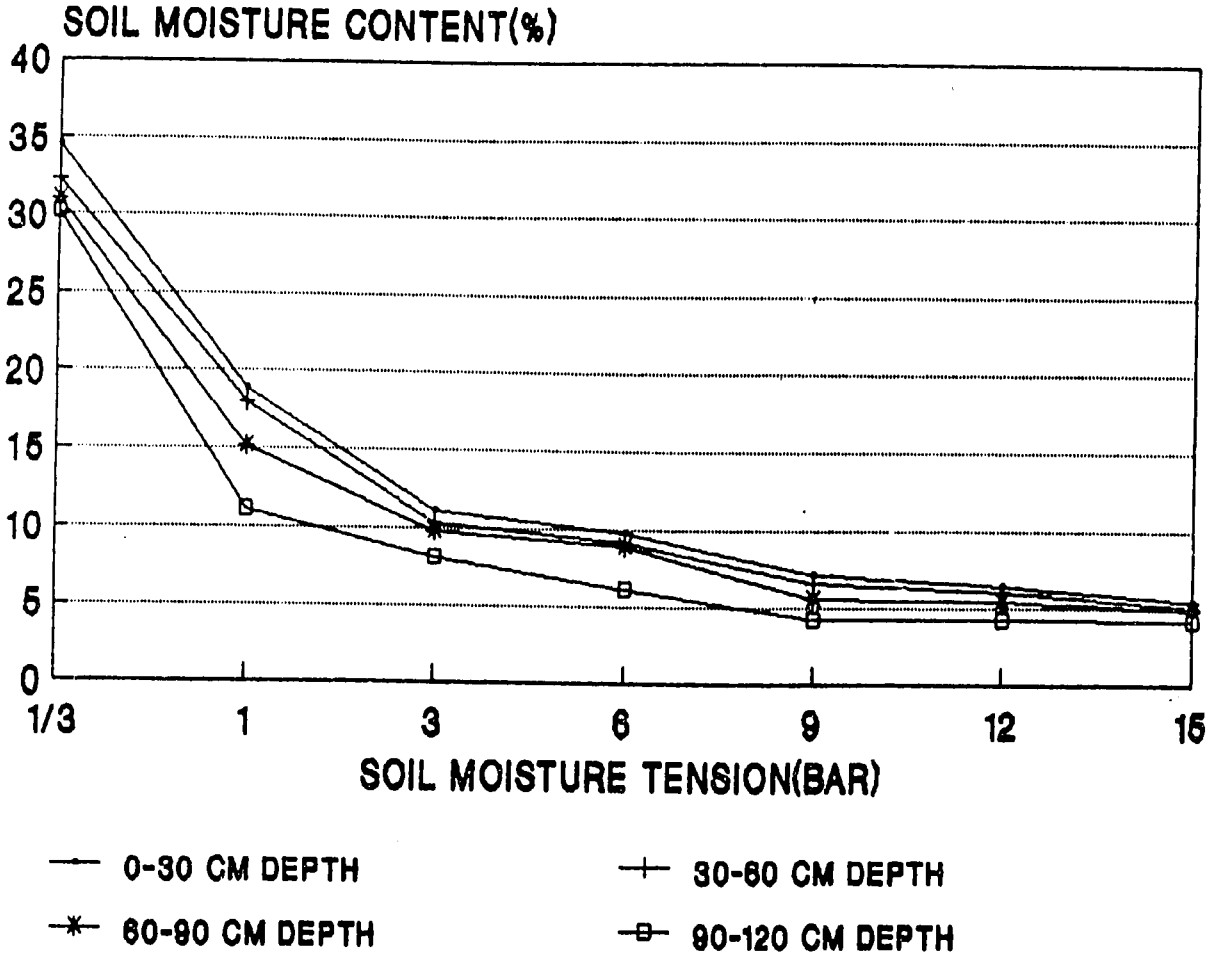


Fig.5. Soil Moisture Characteristics

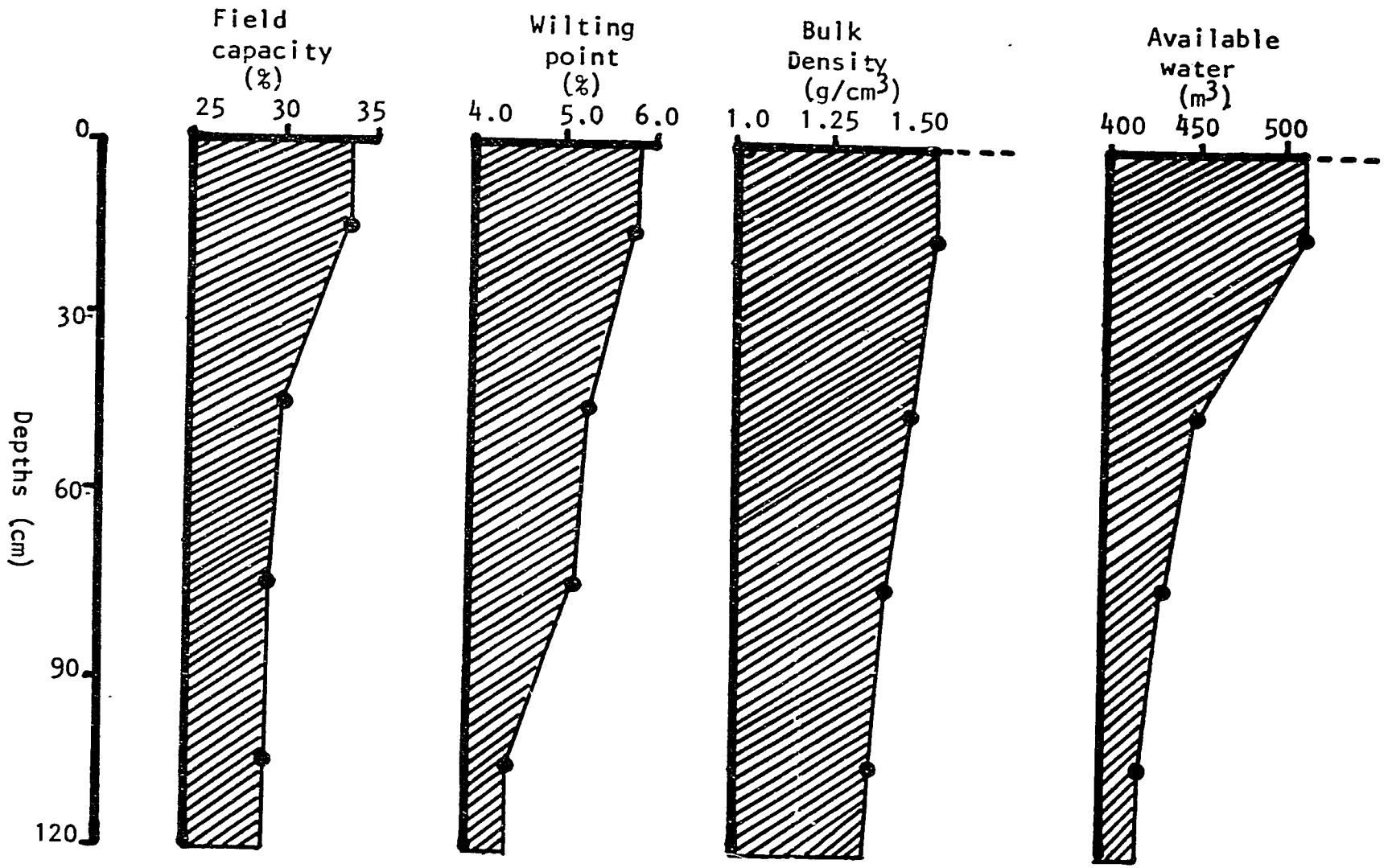
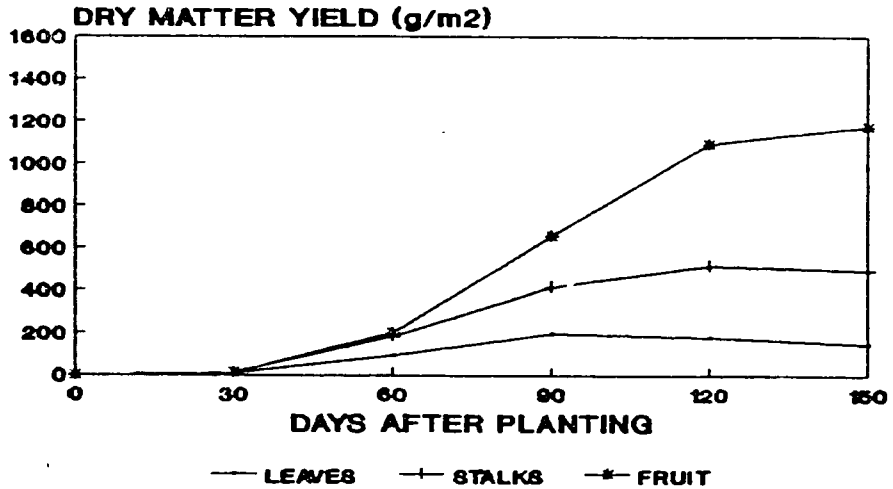
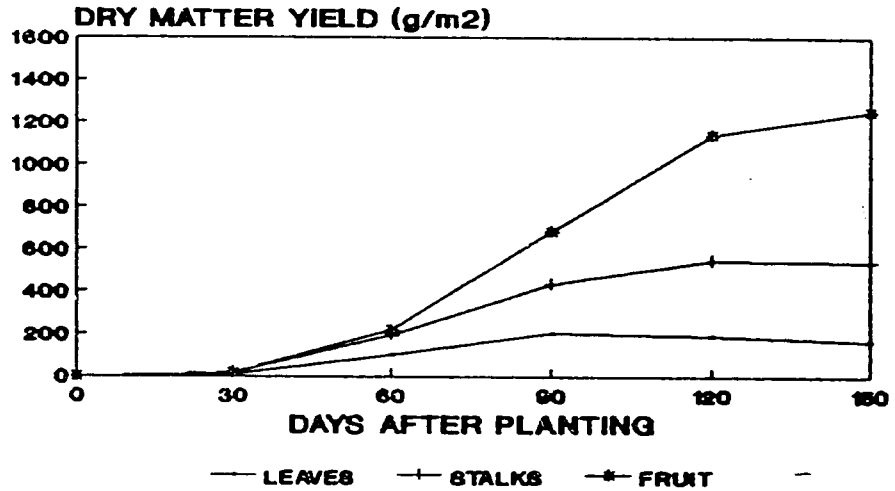


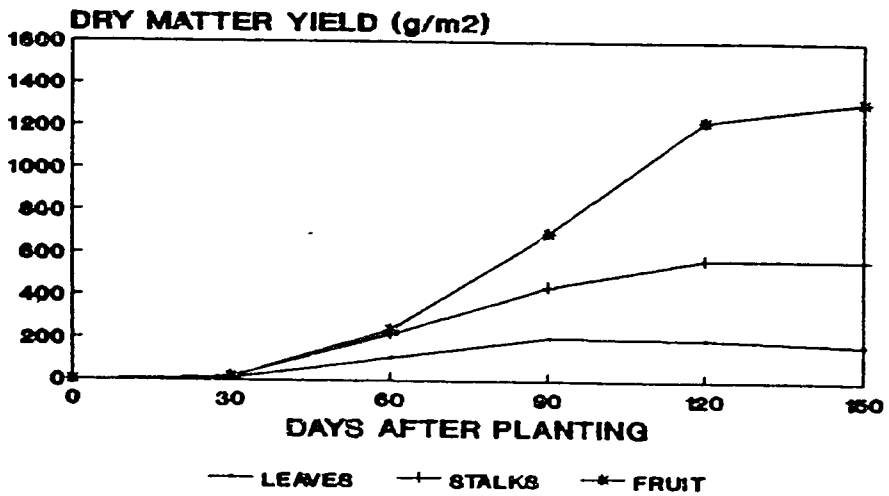
Fig.6. Effects of Water Stress on Dry Matter Yield



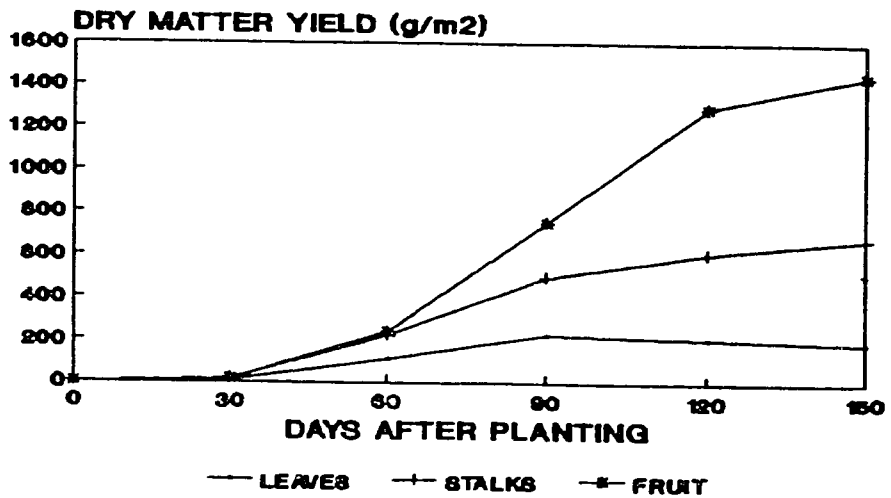
1- STRESS AT SQUARING



2- STRESS AT EARLY FLOWERING



3- STRESS AT PEAK FLOWERING



4- CONTROL (NO STRESS)

phenomena are expressed in plants in terms of reduced leaf area, lower number of fruiting positions and shorter main stem height. These conditions were eventually reflected as reduction in the total dry matter yield and loss ranged from 10 to 20 percent.

5.4 Plant Structure

Plant structure measurements taken at maturity are provided in Table-3.

Table-3. Effects of water stress on plant structure at maturity

Parameters	Treatments				LSD (0.05)
	Stress at:				
	Squaring	Early flowering	Peak flowering	No stress	
Main stem height (cm)	142	146	150	158	6.1
Nodes/plant	37	38	38	39	0.9
Internodal length (cm)	3.84	3.74	3.94	4.10	0.3

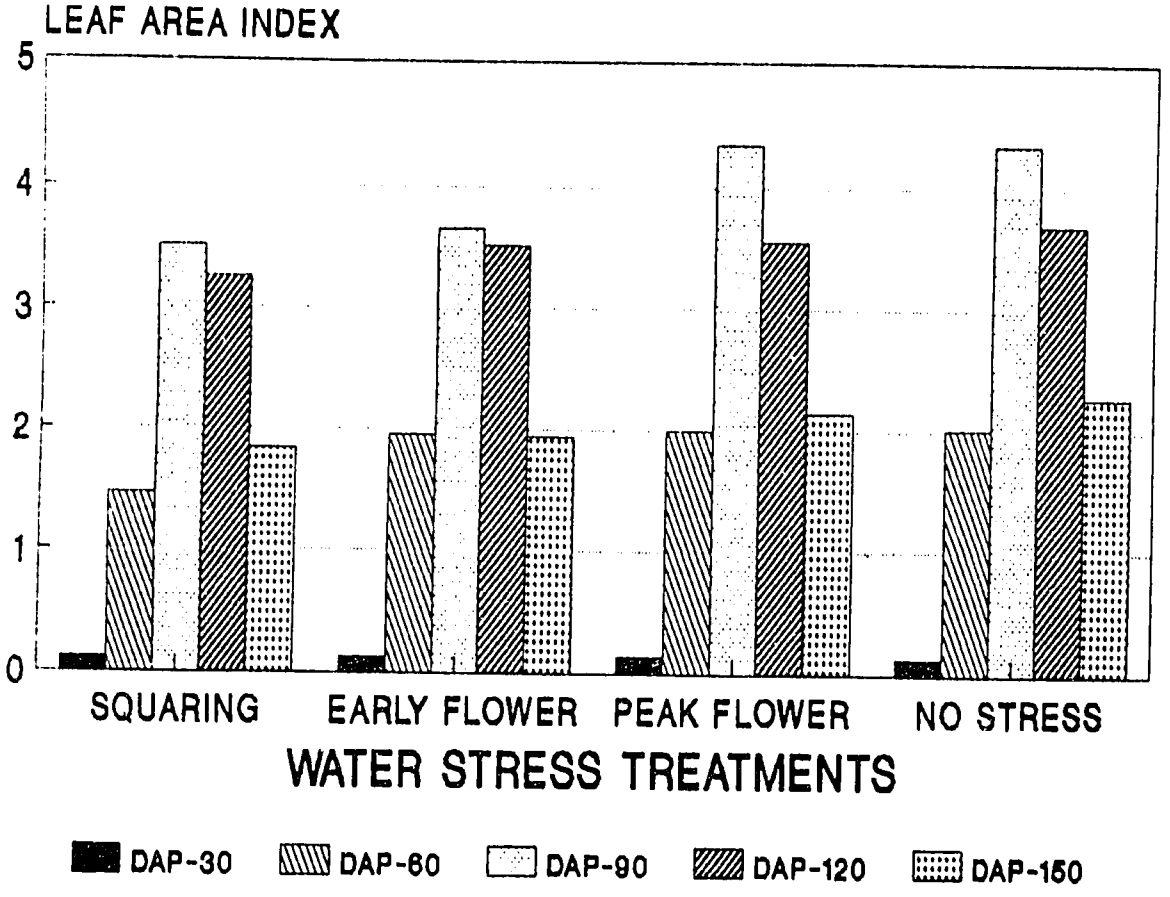
Water stress was associated with reduced main stem height,lower number of nodes per plant and shorter internodes. The squaring phase of cotton seemed more prune to water stress. It seemed that cotton plant in the Punjab plains because of extreme heat prevalent in these areas after relief of water stress could not compensate in growth. The smaller size of plant due to lower water supply is well recorded in literature (Grimes et al, 1978; Grimes and Yamada, 1982; Grimes and El-Zik, 1990). However, the reduction in plant height generally occurs due to shorter internodal length rather than node number per plant. (Crowther, 1934). Water stress in present case reduced both parameters of plant height that is main stem node and internodal length. This shows that water regulates also cell differentiation besides cell expansion.

5.5 Leaf area index

Leaves constitute main organ of photosynthesis and leaf area index (LAI) is considered the most useful measures of capacity of a crop to produce yield. Leaf area index measured at different stages of growth is presented in Fig.7. Leaf area index followed sigmoid pattern of growth. It increased slowly from planting to squaring and then showed rapid expansion reaching its maximum at peak flowering phase. LAI became almost static from peak flowering to mid maturity when it showed rapid decline due to accelerated leaf fall. The maximum LAI of 4.78 was achieved in non-stressed crop. It seemed that from peak flowering, the increase in leaf surface area was counter balanced by leaf senescence. The maximum leaf area index in cotton has been reported to occur at peak flowering phase by Hearn and Constable (1984). The assimilate use in bolls limits formation of new leaves and senility further exaggerates the situation. These conditions results in fall of leaf area index.

Water stress treatments caused significant decrease in leaf area index. The earlier was the crop stressed, greater was the loss in leaf area index. Crop that suffered from water stress could not compensate its loss in leaf area index notwithstanding the removal of water stress. The first measurable effects of water stress on cotton crop are suppression of leaf expansive growth and slower canopy development (Marani and Levi, 1973; Costerhuis, 1989: Hsiao et al,1982; Grimes, 1991). The reduction in expansive growth continues for several days despite the removal of water stress (Hsiao et al,1982). The water stressed plants partitioned a small proportion of their new acquired dry matter to the leaves than did the watered plants (Fisher et al, 1982).

Fig.7. EFFECTS OF WATER STRESS ON LEAF AREA INDEX



DAP = DAYS AFTER PLANTING FOR HARVEST

5.6 Leaf Area Duration

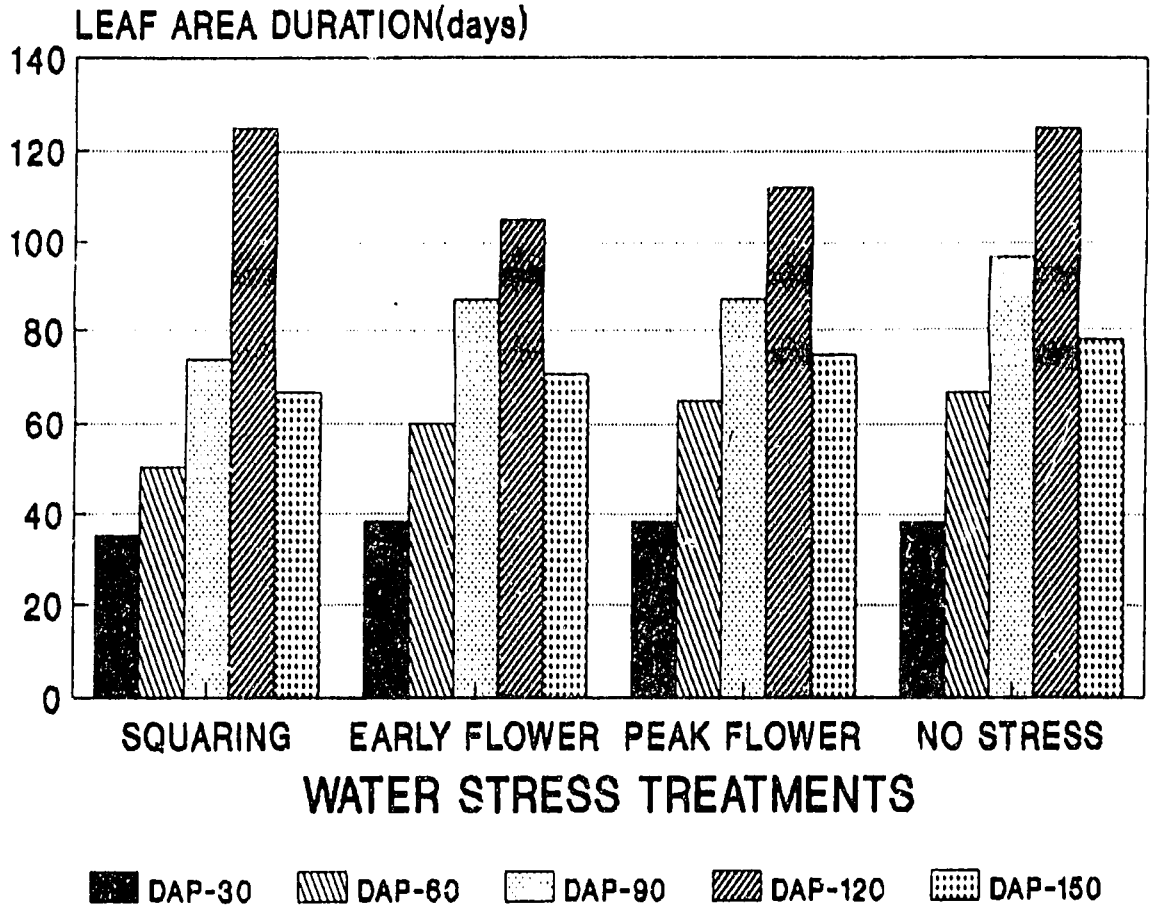
Leaf area duration (LAD) represents an integration of leaf area over time (Watson, 1952). It takes into account both the magnitude of leaf area and its persistance in time. Among various physiological processes influenced by water supply, LAD has great relevance in understanding the process of yield formation. Data illustrated in Fig.8 indicate that maximum LAD reached at 125 days from planting; at boll split phase. The LAD thereafter declined due to senescence of leaves. The average life of leaf is about 56-60 days (Hearn, 1976). However plant water deficit shortens leaf age (Marani and Levi, 1973, Fisher et al, 1982) and this effect was noted in present experiment. The greater the amount of water, the longer the crop continues to produce leaves. Cotton crop in general attained maximum LAD at about boll splitting phase and expansion of new leaves almost slowed down at this stage (Hutchinson et al, 1958). Water stress at any stage of growth was deterimental to leaf persistance. The crop stressed at squaring phase did compensate leaf loss but that was too late in the season.

5.7 Net-Assimilation-Rate

The increase in dry weight of crop depends primarily on the balance between photosynthesis and respiration called net photosynthesis (Net Assimilate Rate). The economic yield of crop depends on distribution of dry matter so produced by net photosynthesis between vegetative and reproductive organs. Thus net assimilation rate plays an important role in growth and yield formation of a crop.

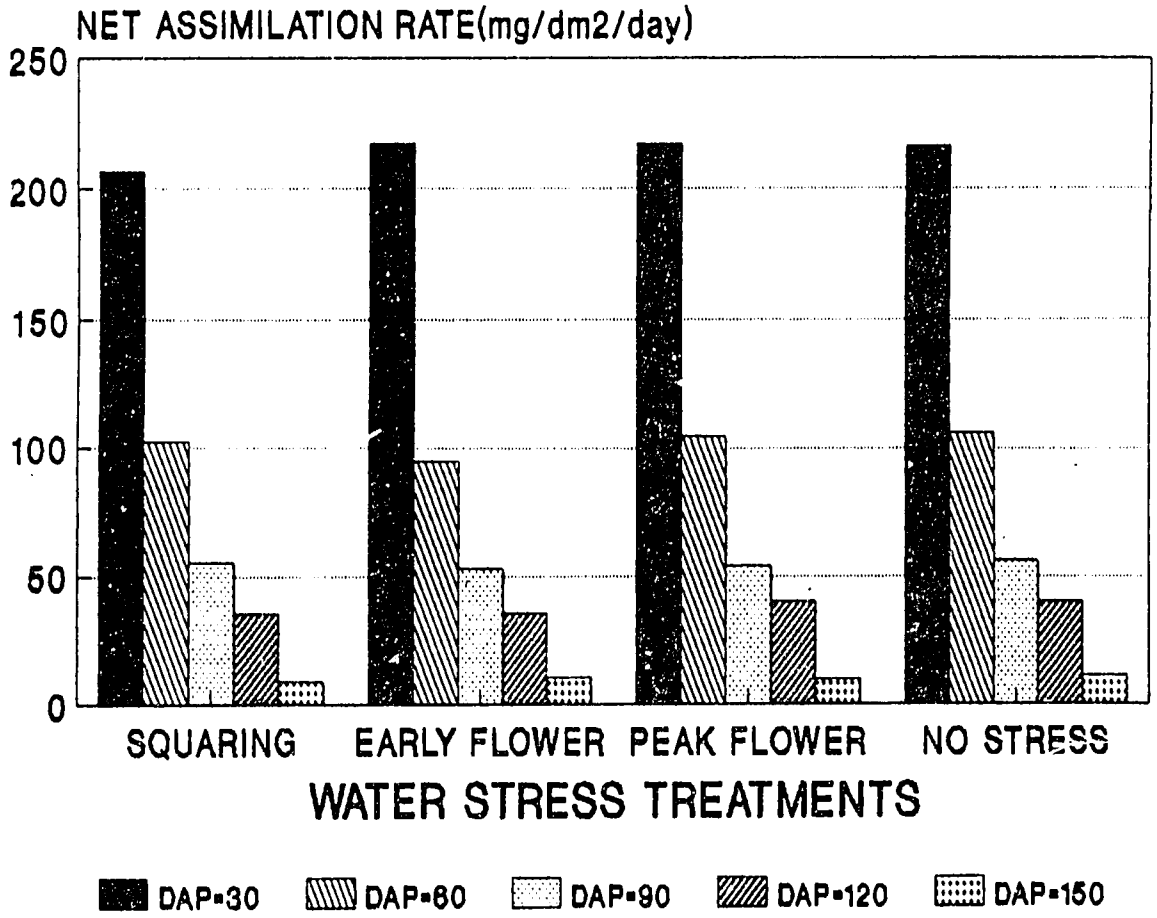
Net assimilation rate of $\geq$ 200 mg dm^2 day^{-1} was found at squaring stage and it showed decline with age, attaining a value of 10mg dm^2 day^{-1} at maturity (Fig-9).The decrease in net assimilation rate was more pronounced between squaring to white flower.This emphasizes the need for adoption of management practices favourable to early vegetative growth. The accumulation of old leaves and bolls as crop aged resulted in loss of net assimilation rate (Malik, 1977). A 50 days old leaf has about half the maximum rate of photosynthesis (Hearn and Constable, 1984).

Fig.8. EFFECTS OF WATER STRESS ON LEAF AREA DURATION



DAP=DAYS AFTER PLANTING FOR HARVEST

Fig.9. EFFECTS OF WATER STRESS ON NET ASSIMILATION RATE



DAP = DAYS AFTER PLANTING FOR HARVEST

Water stress at any stage of growth curtailed net assimilation rate and early stress was more deterimental than later ones. There is linear decline in net assimilation rate below -20 bar LWP (Parsons et al. 1979; Karami et al, 1980; Grimes and Yamada, 1982; Turner, 1990). Both stomatal and non stomatal inhibition of photosynthesis occurs under water stress. Almost all metabolic reactions are influenced by water deficits. There is decrease in Hill reaction, synthesis of ATP (adenosine triphosphate) and increase in leaf resistance to carbon dioxide exchange besides stomatal closure (Jordan et al. 1972; Cutler and Rains, 1977; Ackerson et al. 1977; Hutmacker and Krieg, 1981, Krieg, 1986; Jordan, 1986).

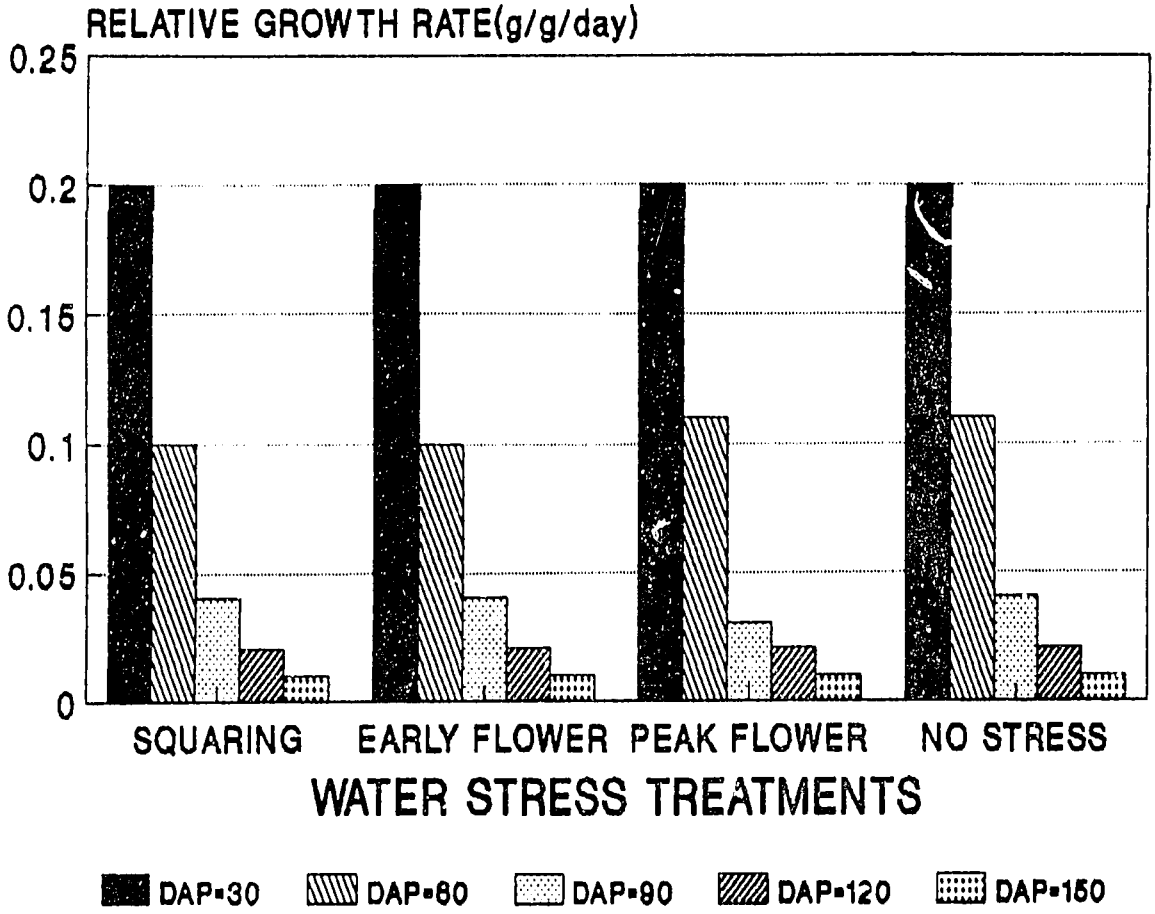
5.8 Relative growth rate

Relative growth rate (RGR) is defined as the increase of plant material per unit of material present per unit of time. RGR is a product of photosynthetic efficienty and leaf area ratio. Results indicate that RGR decreased as crop advanced in age and downward drift was accentuated at bloom stage (Fig-10). This may be due to slowing of new leaf development and cessation of leaf growth during peak boll formation phase. Water stress caused a little differences in RGR. Since RGR has been calculated on whole plant basis rather than on unit organ, whereas water restricts expansive growth more than other organs, the effects of water on RGR are likely to be obscured on whole plant basis. In general any departure from an adequate supply of inputs such as light, temperature, mineral nutrients or water produces an adverse effect on RGR (Hunt, 1982).

5.9 Crop Growth Rate

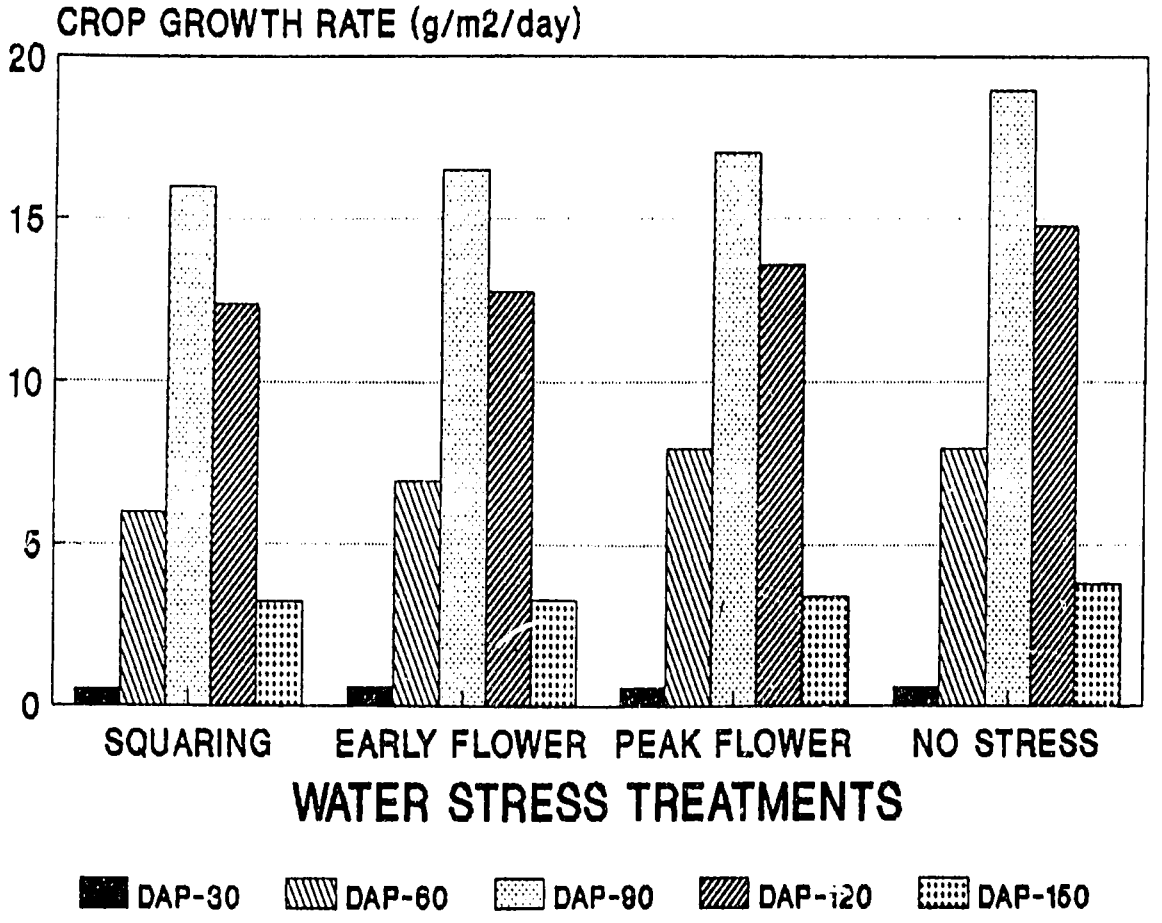
Crop growth rate (CGR) is the instantaneous rate of dry matter production per unit area of land, a simple and an important index of agricultural productivity. Crop growth rate was slow during vegetative phase, steadily rose-up with the onset of squaring phase, attaining a maximum of 16-17 gm^{-2} day^{-1} at peak flowering phase (Fig-11). Crop growth rate was slow in the beginning because canopy was not fully intercepting light early in the season.

Fig.10. EFFECTS OF WATER STRESS ON RELATIVE GROWTH RATE



DAP = DAYS AFTER PLANTING FOR HARVEST

Fig.11. EFFECTS OF WATER STRESS ON CROP GROWTH RATE



DAP = DAYS AFTER PLANTING FOR HARVEST

Water stress at any stage decreased crop growth rate. This could be accrued to the sensitivity of various physiological processes of growth to supply of water. Results similar to this have been reported by various authors (Hearn, 1976; Jordan, 1982; Hearn and Constable, 1984; Mauney, 1986).

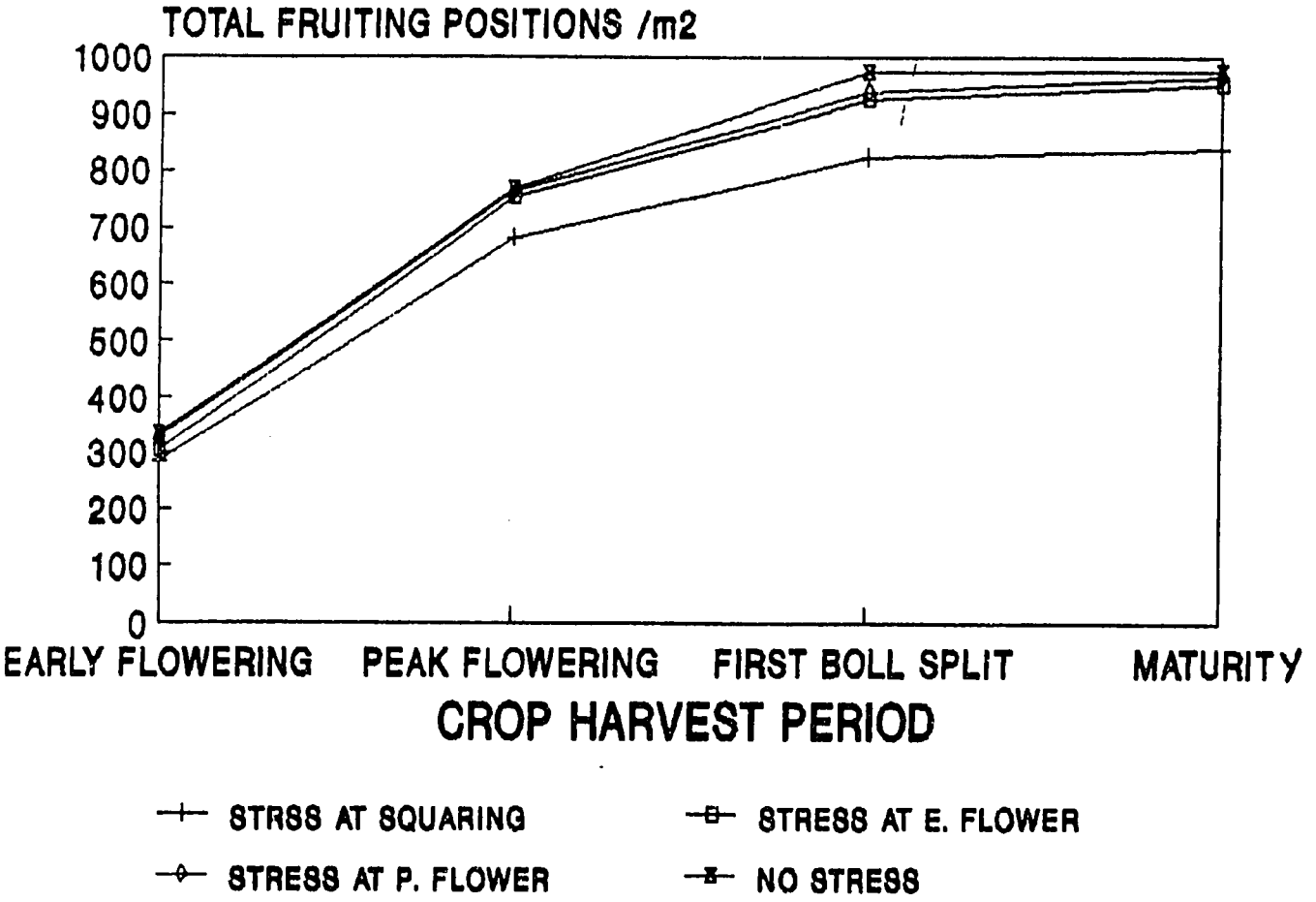
5.10 Production of Fruiting Sites

Fruiting sites are the first stepping stone of yield building processes and are indicative of potential yield. The total number of fruiting sites are determined by the rate of production of nodes along main stem and sympodia. Since reduction in vegetative growth and plant size are common sequence of water stress (Jordan, 1970, Hsiao, 1973; Taylor and Klepper, 1974; Ackerson et al, 1977; Grimes et al, 1978), the potential number of fruiting sites must also be reduced. Data presented in Fig.12. clearly demonstrate the detrimental effects of water stress on production of fruiting sites. Earlier the stress greater was the reduction of fruiting sites. This happended due to water stress at early stage of growth in coincidance with high temperatures in months of July and August; was more harmful to plant growth than that imposed at peak flowering phase. There is need for rapid early growth to provide sufficient frame work for heavy fruiting (Longenecker and Erie,1968). In general water stress restricts formation of both the monopodia and sympodia and thus the end result is lower number of fruiting sites and potential for yield (Mauney, 1979; Jordan, 1986).

5.11 Production of Bolls

Bolls constitute on effective yield sink. A large portion of fruiting forms are shed and only fraction of these is carried through to maturity as bolls. This happens due to gap between photosynthate supply and demand for competitive sinks.

FIG -12 EFFECTS OF WATER STRESS ON TOTAL FRUIT PRODUCTION

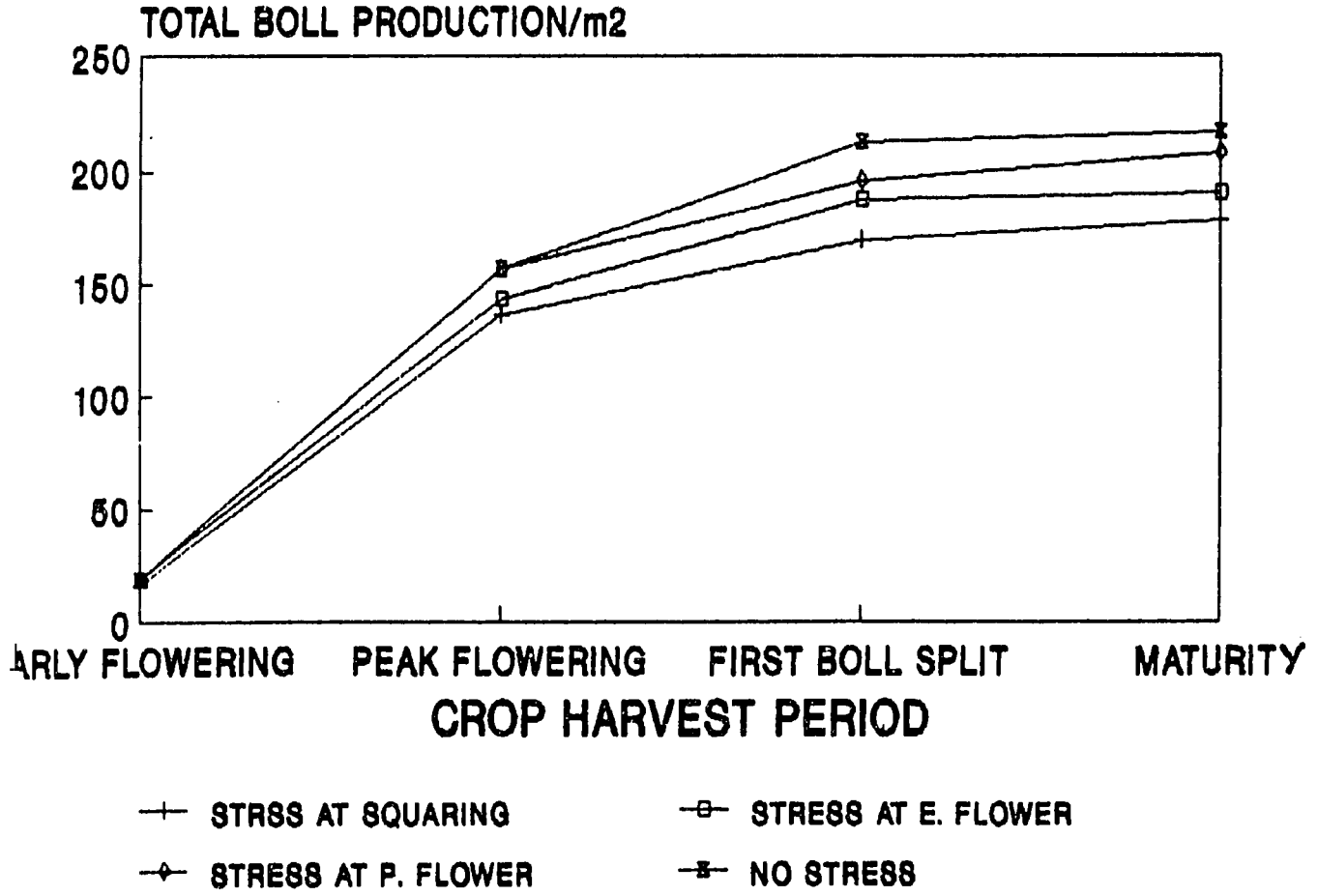


Data presented in Fig.13 demonstrates this phenomenon as in all treatments number of boll set at any given date is far low than number of fruiting sites produced. Besides natural shedding, water stress at any stage of growth decreased boll load compared with control. Earlier the crop was subjected to water stress, greater was its damage. Crop did not compensate despite full water supply after a brief period of stress. The number of bolls produced ranged from 179 to 217 m^2 in different water stress treatment. Maximum rate of boll formation was observed in the first 4-5 week of flowering and alomost full boll load was achieved by the time crop has reached first boll split phase. Grimes and El-Zik(1990) stated that cotton plant sets 80 percent of its boll load in the first 6 weeks of flowering. The conversion of flowers to bolls that will be retained by the plant is more effective in the early than in the late part of season. The decrease in boll load due to water stress in present experiment may be explained as per Eaton (1955) argument that within a variety and climatic complex the no.of bolls that are set tend to be proportional to the strength of source i.e. vegetative reproductive balance.

Water stress in present experiments reduced plant size, assimilatory leaf surface area (LAI) and net assimilation rate; thereby leading to lower number of bolls. These results substantiate the observations of other workers (Crowther, 1934; Rijks, 1965; Shimshi and Marani 1971; Ch Nahl et al·1979; Turner et al·1986; Marrow and Krieg 1990) that water supply regulated boll load in cotton plant.

However, some researchers (Grimes et al·1970; Marani and Amirav; 1971, Singh 1975; Guinn et al·1981) have found stress at squaring phase beneficial for boll production. The differences in results could be ascribed to mild climatic conditions prevailing in those areas early in the season. Water stress at peak flowering

FIG -13 EFFECTS OF WATER STRESS ON TOTAL BOLL PRODUCTION



stage was less harmful than earlier ones because atmospheric stress was less late in the season and the plants possibily had already passed a critical fruiting stage sensitive to water stress. These results agree with work done in Israel (Amir and Bileorai, 1969; and USA Grimes et al. 1970; McMichael and Hesketh, 1982).

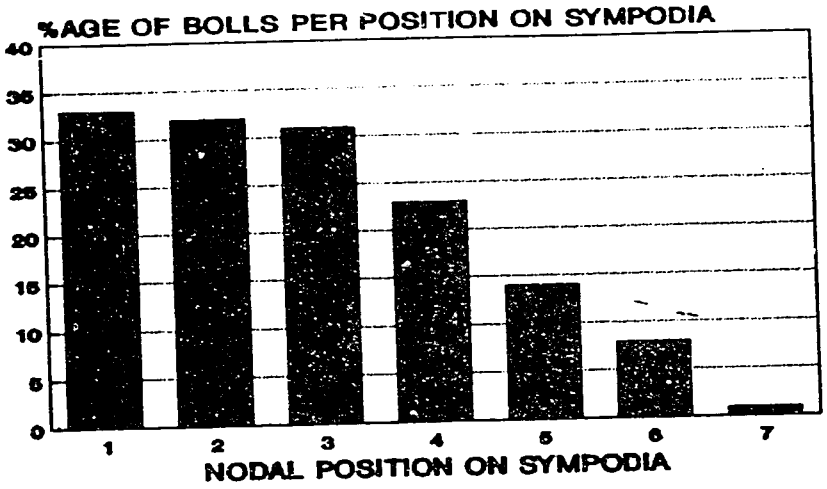
5.12 Plant mapping and effectiveness of fruiting sites

Plant mapping defines fruiting partterns in response to crop management. Water is an important crop management tool and its supply is likely to cause differences in effectiveness of specific fruiting sites and location of bolls on plant. Data presented in Fig.14 indicate that first three fruiting positions along sympodia has higher survival rates compared with subsequent fruiting positions. The survival rate of fruiting positions at bottom 15 stem nodes was small than the middle of plant. Crop subjected to water stress showed lower survival rate of fruiting positions along sympodia than the control. Water stress at squaring particularly seemed more damaging than the other treatments.

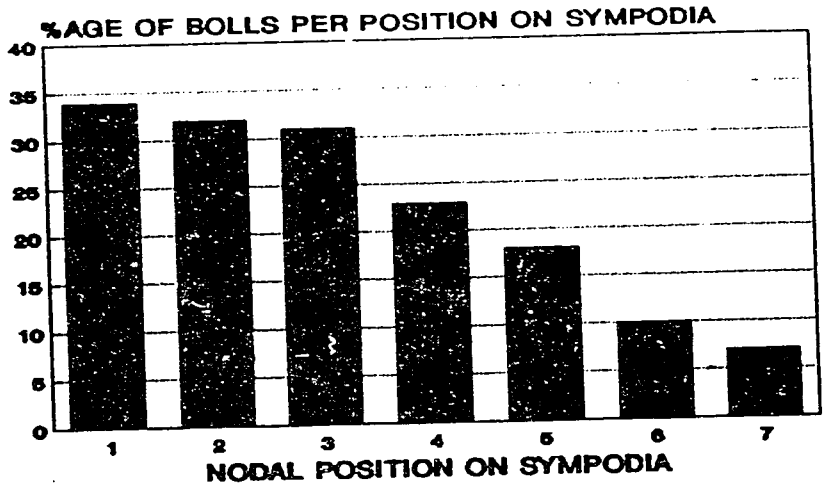
The upper portion of cotton plant exhibited a wide contrast among treatments. The fruiting sites appearing at stem nodes 36 to 40 in control treatment showed 34% survival as compared with 10-18% success in water stressed crop. A lack of assimilate supply presumbly resulted in enhanced abortion of fruiting position in water stressed crop.

A good water supply maintains growth for longer period and there is likely to be better coordination of assimilatory capacity with reproductive sink activity (Jenkins et al, 1990). These conditions would favour greater retention of fruit in non-stressed cotton crop.

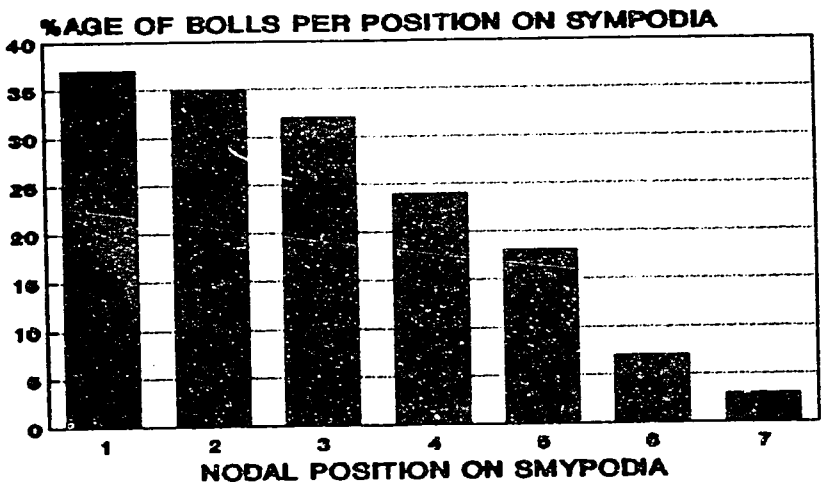
Fig.14(a). Plant Mapping and Effectiveness of Fruiting Sites Along Sympodia



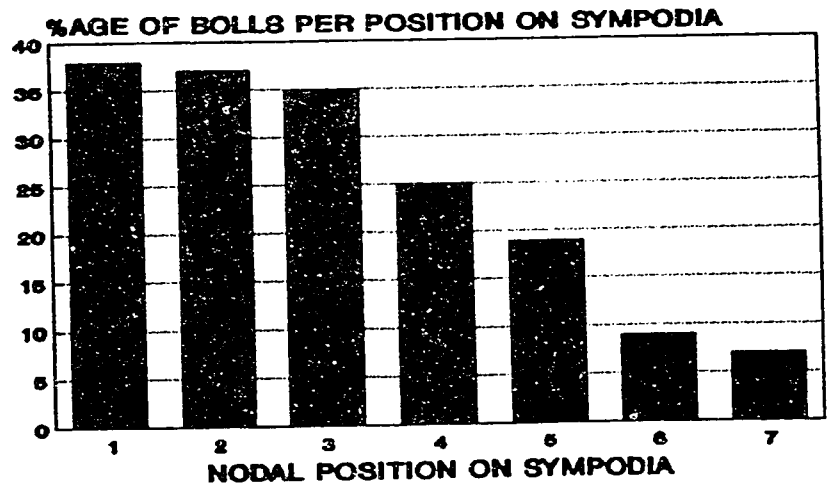
1-STRESS AT SQUARING



2-STRESS AT EARLY FLOWERING

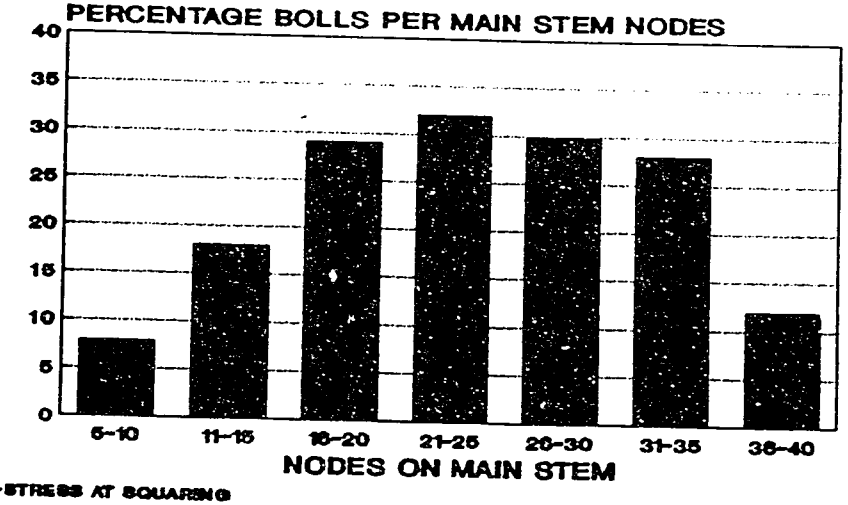


3-STRESS AT PEAK FLOWERING

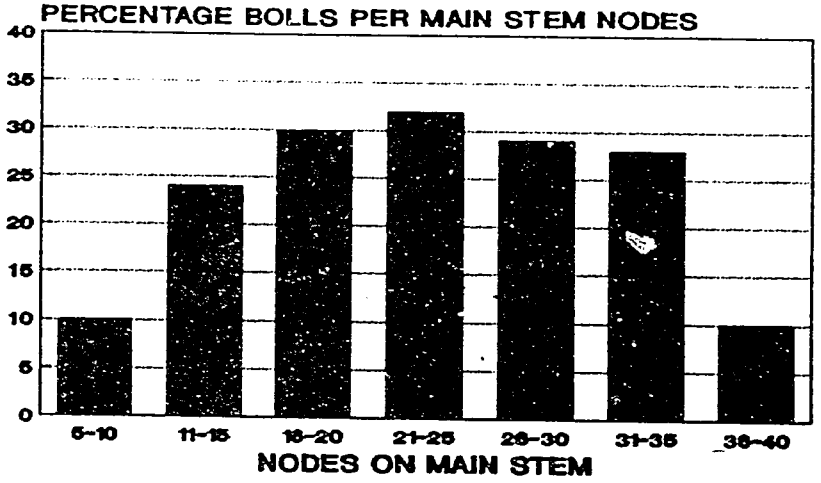


4-CONTROL(NO STRESS)

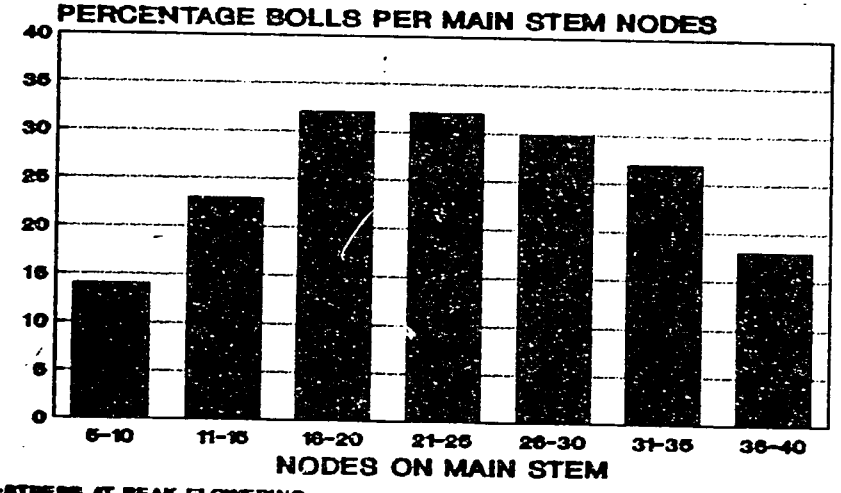
Fig.14(b) Plant Mapping and Effectiveness of Fruiting Sites Along Main Stem



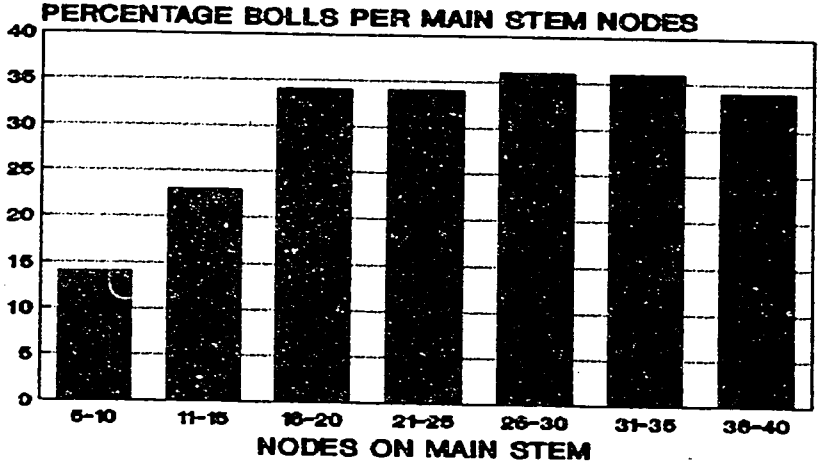
1-STRESS AT SQUARING



2-STRESS AT EARLY FLOWERING



3-STRESS AT PEAK FLOWERING



4-CONTROL (NO STRESS)

5.13 Fruit shedding

Cotton plant initiates two to three times as many fruit as it can support. The remainder fruit are shed as a result of internal and external stresses. Among external stresses, water stress is considered greatest single hazard to cause shedding of fruit. Data on flower bud and boll shedding are presented below.

Table-4 EFFECTS OF WATER STRESS ON FLOWER BUD SHEDDING (%).

Water stress phases	Stages of growth			
	White flower	peak flower	Boll split	Maturity
	60 *	90	120	150
Squaring	18	46	38	41
Early flowering	13	44	42	44
Peak flowering	12	38	47	47
Control (no srress)	12	38	45	45

* Days after planting

Crop receiving no water stress showed less flower bud shedding than receiving stress at any stage of growth. Shedding increased with advancement in season. This was the effect of increaring boll load (Guinn,1982). Water stress both at pre-flowering and postflowering stage has been found to increase fruit bud shedding and thus decrease flowering rate (Grimes et at, 1970; Bhatt, 1978; Guinn and Mauney.1984).

As flower bud develops from pin head stage to anthesis, a time period of 21 to 22 days, their sensitivity to water stress decreases. Flower buds which do not abscise up to the age of 6 to 9 days generally mature as flowers. These flowers become boll on blossoming day as they get fertilized in the morning hours. Most authorities agree that open flowers or flowers at anthesis rarely, if ever, shed. Most of shedding in cotton occurs as bolls. Data on boll shedding are presented below.

Table-5 EFFECTS OF WATER STRESS ON BOLL SHEDDING (%).

Phases of water stress	Stages of growth		
	Peak flower	Boll split	Maturity
	90*	120	150
Squaring	13	38	39
Early flowering	13	34	36
Peak flowering	11	31	32
Control (No stress)	11	28	31

* Days after planting

Boll shedding was more in treatments exposed to water stress than control. Boll shedding showed tremendous increase from peak flower to boll split phase and thereafter it became al-most constant. This is because boll load stress decreased at boll split phase. Leaf water potential- 1.9 MPa has been shown to increase shedding of bolls. (Mc Michael et al.1973; Guinn, 1982, Guinn and Mauney, 1984).

The shedding of flower buds and bolls was of same magnitude in present experiment. Most workers ignore the shedding of flower buds.

This is because flower bud abscission is not obvious (Hall, 1958). Flower buds abortion take place when these are few millimeters broad and hardly noticeable.

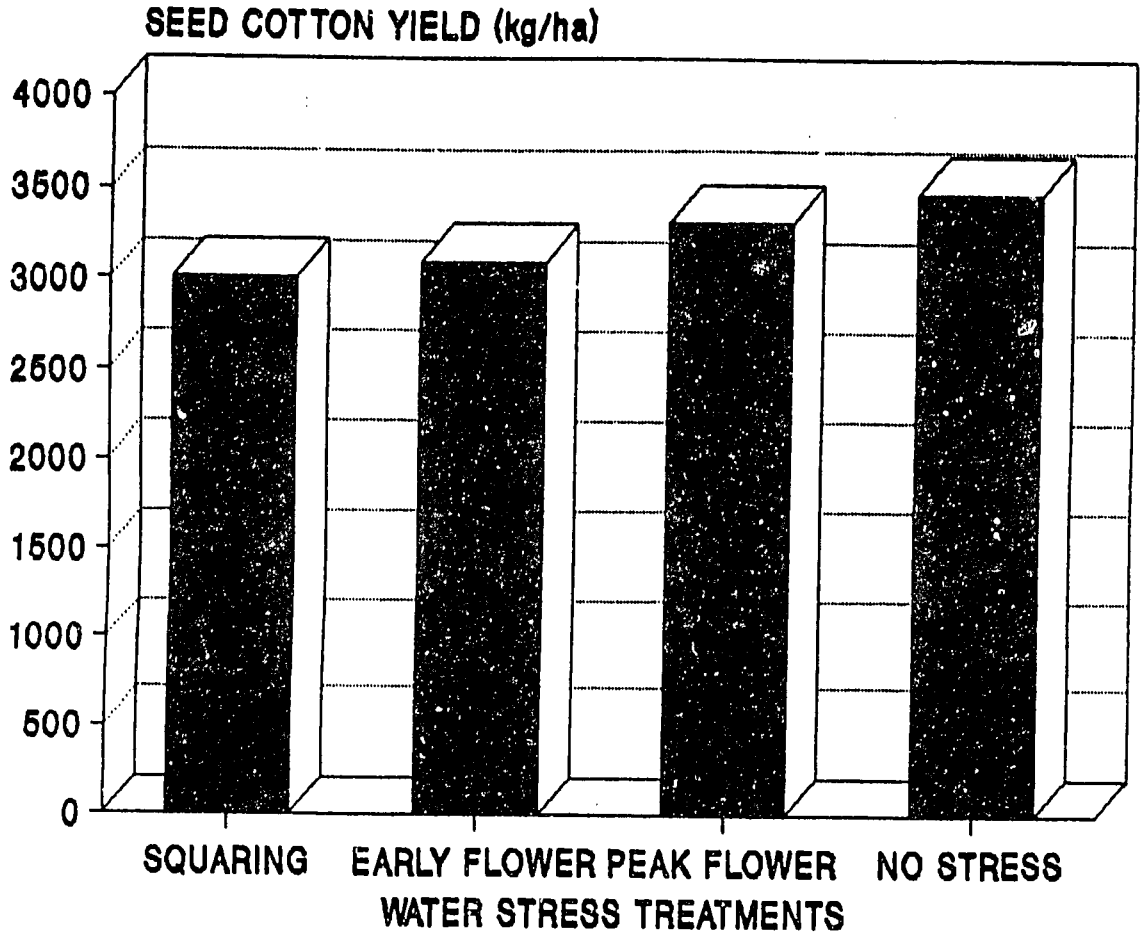
5.14 Seed Cotton Yield and Its Components

Seed cotton yield is an outcome of interaction of all plant processes to environment. Water is the major component of environment besides atmospheric conditions and essential mineral nutrients. Cotton plant shows an orderly morphological development within certain range of environment and yield variations occurs only in extreme situations.

Plant per unit land area, bolls per plant, seed cotton per boll, lint percentage and seeds per boll are main components of yield. The data on seed cotton yield and its components in response to water stress are presented in Fig.15. These data show significant decrease in seed cotton yield, boll number and seed cotton weight / boll due to water stress. Earlier the stress imposed greater was the loss in yield. The period from square appearance to early flowering was most sensitive to water stress. The water stress during this period caused more than 10 percent loss in seed cotton yield. The stress at peak flowering phase was less damaging and caused only half loss to that occuring earlier in the season (Fig.16). The seed cotton yield ranged from 3009 to 3477 in different water stress treatments.

The effects of water stress on cotton yield occurred through (a) decrease in morphogenesis (b) decline in assimilate supply and net assimilation rate and (c) reduced sink capacity due to high shedding of buds and bolls. These studies reveal the importance of well watered crop throughout the season. Several workers have placed high emphasis on the relationships between vigorous plant size and good yield. The minimal water stress should be imposed particularly during early part of reproductive phase (Longenecker and Erie, 1968; Grimes and El-Zik, 1982, 1990; Hearn and Constable, 1984; Johnson et al.1989; Senft 1992). There are reports, however, that too early irrigation in the season and vigorous plant growth may lower yield (Grimes et al: 1978;Guinn et al.1981; Guinn and Mauney, 1984). But this determiment to yield due to early irrigation was attributed to reduced soil and canopy temperature and lack of insects control. The temperature in the Indus Plain is very high and early irrigation mitigates heat damage to cotton plant. The lower susceptibility of cotton plant to water stress and peak flowering may be attributed to deep root penetration and slow down in generation of new fruiting positions due to increase boll load. This characteristic allows greater tolerance to water stress late in the season.

Fig.15. EFFECTS OF WATER STRESS ON SEED COTTON YIELD



YIELD COMPONENTS

Water Stress Phases	Bolls/m2	Seed Cotton per boll (g)	G.O.T. (%)	Seed Index (g)	Lint Index (g)	Seed/ boll
Stress at squaring	30	3.18	33.4	8.0	4.1	26
Stress at early flowering	31	3.20	33.8	8.1	4.1	26
Stress at Peak flowering	33	3.23	33.6	8.2	4.1	26
No stress	34	3.25	33.7	8.2	4.2	26
LSD (0.05)	1.01	0.05	N.Sig.	N.Sig.	N.Sig.	N.Sig.

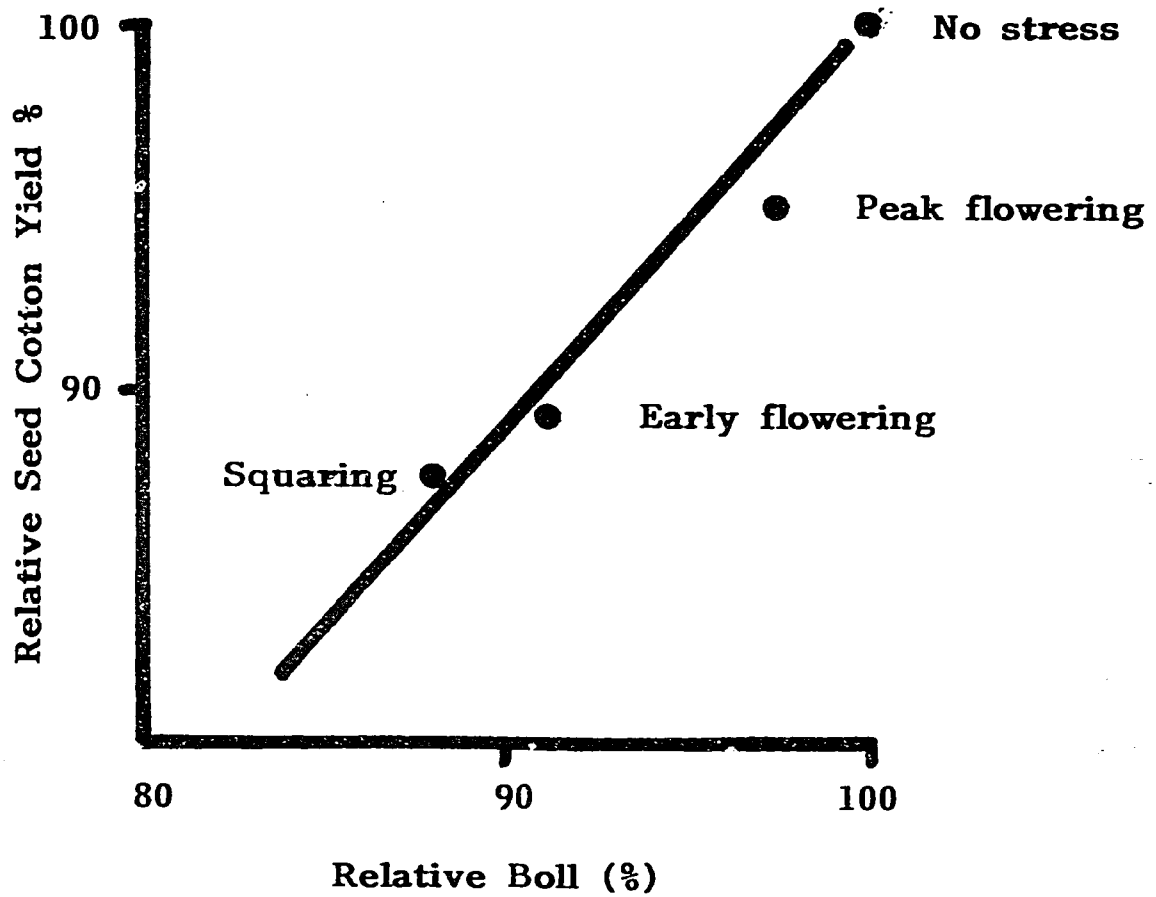


Fig.16. Relative Seed Cotton Yield and Boll Production Associated with Different Stress Conditions

5.15 Water Yield Production Functions

Water production function describes relationships between evapotranspiration and or total water applied and crop yield. It helps planners to determine the economic impact of various alternate water allocation decisions, In addition, water production functions provide guidelines for determining the capacity of irriagtion systems, procedures for sheduling irrigation and means of comparing relative water use efficiencies. The data on water response functions pertaining to evapotranspiration and total water applied in relation to seed cotton yield are presented below.

5.15.1 Evapotrasnpiration and seed cotton yield

The water response function between evapotranspiration and seed cotton yield (Fig.17) indicate linear relationship (r=0.54). The correlation coefficient, although highly significant, is not large due to scattering of data for two seasons. Sammis (1981) reported linear relation for cotton although long term studies (Grimes et al. 1969; Grimes and Elzik, 1982) suggested a slight curvature to the function. Cotton crop in the Indus Plains grows in extreme heat and soil water supply hardly maintains crop turgidity. The crop is always under water stress at mid-noon and linear function is expected under these growing conditions. The higher water supply and more frequent irrigations may lead to curvilinear function. The water use efficiency was 36 kg ha^{-1}.

5.15.2 Applied water and seed cotton yield

As shown in Fig.18 the relationships between applied water and seed cotton yield is curvilinear (r= 0.70). This type of function indicates that water was not used beneficially; some became drainage water and other evaporated from soil surface due to sealing characteristics of Pakistan's soils. The poor soil structure causes water stagnation and temporary water logged conditons. This lead to poor water use efficiency. These results agree closely with those of Grimes et al.(1969, 1982) in California.

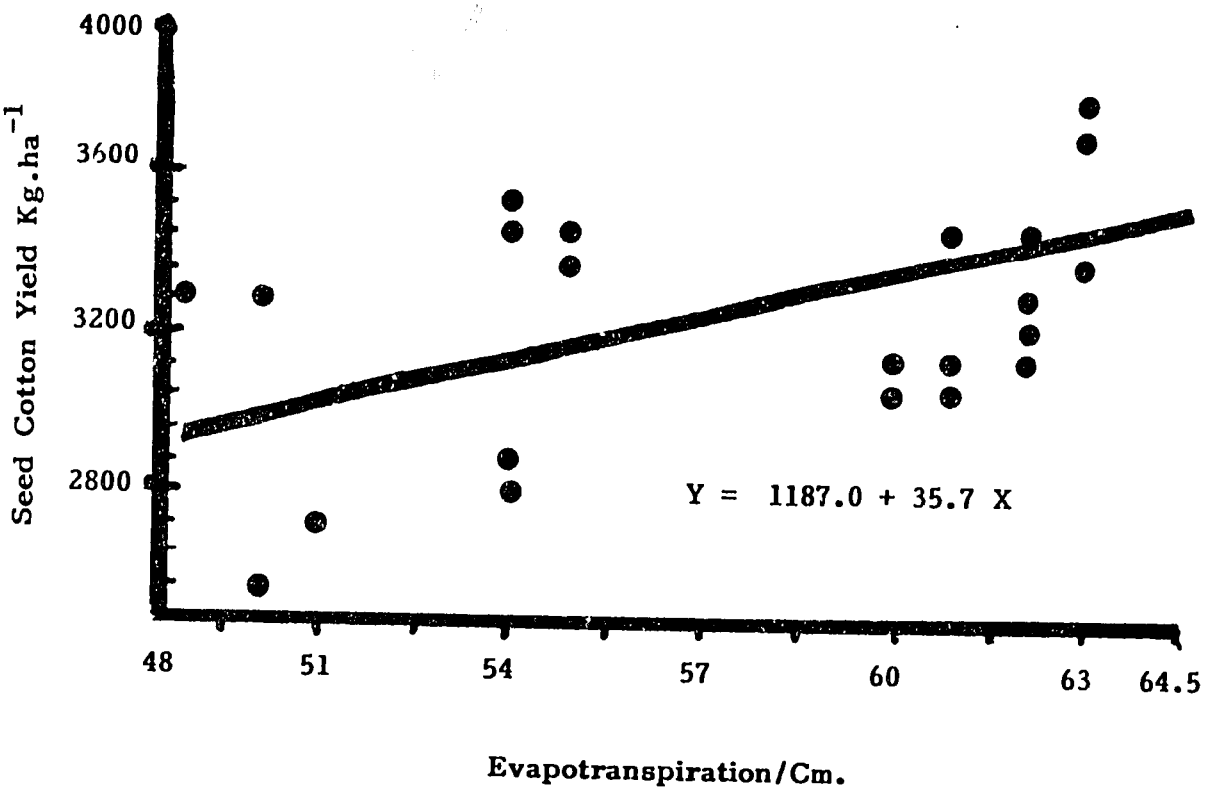


Fig.17. Relationships between Evapotranspiration and Seed Cotton Yield

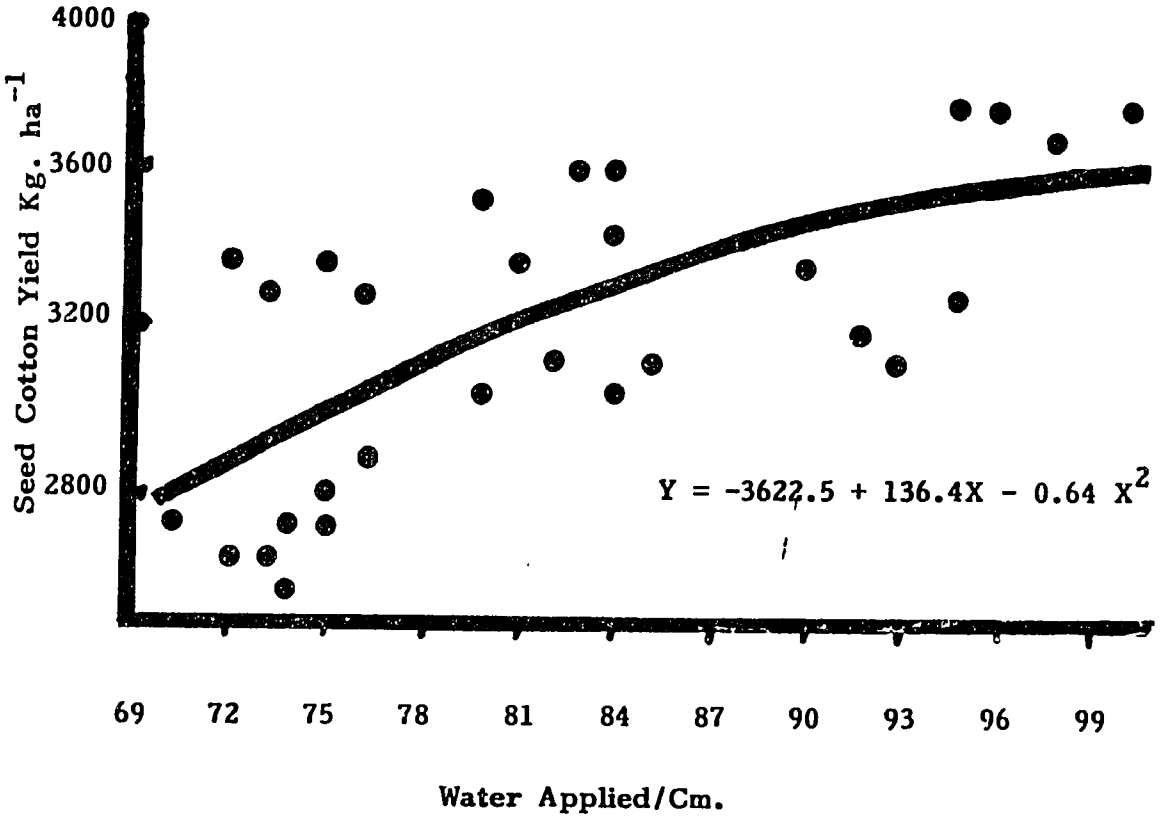


Fig.18. Relationships between Applied Water and Seed Cotton Yield

5.16 Relations of Cotton Leaf Area Index to Seed Cotton Yield

Leaves are primary source for photosynthesis and have strong bearing on production of crops. The relationships between leaf area index measured at peak flowering phase and seed cotton yield are illustrated in Fig.19. A high degree of correlation(r=0.78) was measured between LAI and seed cotton yield. The relationships was curvilinear and LAI of 4.5 gave maximum seed cotton yield. These results agree with those of Ashley et al. (1965) that an LAI of 4.5 to 5.0 was required to harvest good yield.

5.17 Fiber Quality

The influence of water stress on fiber properties appears to be slight (Table-6). Shedding of young bolls due to water stress seemed partially responsible for thelack of response. Moreover many fiber characteristics are determined primarily by the genetic make-up of variety (Malik and Baluch, 1978 ; Grimes and El-Zik,1990). According to Eaton and Ergle (1952), the cotton plant, when subjected to water stress increases its carbohydrate level and thereby tends to offset the disadvantages of reduced water supply. This provides a mechanism whereby the cotton plant develops normal fiber when it is subjected to drought. Micronaire of water stressed crop was slightly higher than the non-stressed crop in the present investigation. Micronaire was generally reduced by water management practices which delayed maturity.

Table-6 Effects of water stress on fiber quality

Fiber characteristics	Treatment				
	Water stress at				
	Squaring	Early f;owering	Peak flowering	No stress	LSD (0.05)
Fibre length(mm)	26.9	26.9	27.0	27.1	N.Sig.
Fiber uniformity ratio	46.3	46.6	46.6	46.3	N.Sig.
Fiber maturity ratio	0.93	0.92	0.93	0.92	N.Sig.
Fiber fineness ug/inch	4.46	4.43	4.45	4.32	N .Sig.
Fiber strength 000 lbs/ sq.inch.	91.3	91.0	91.0	91.5	N.Sig.

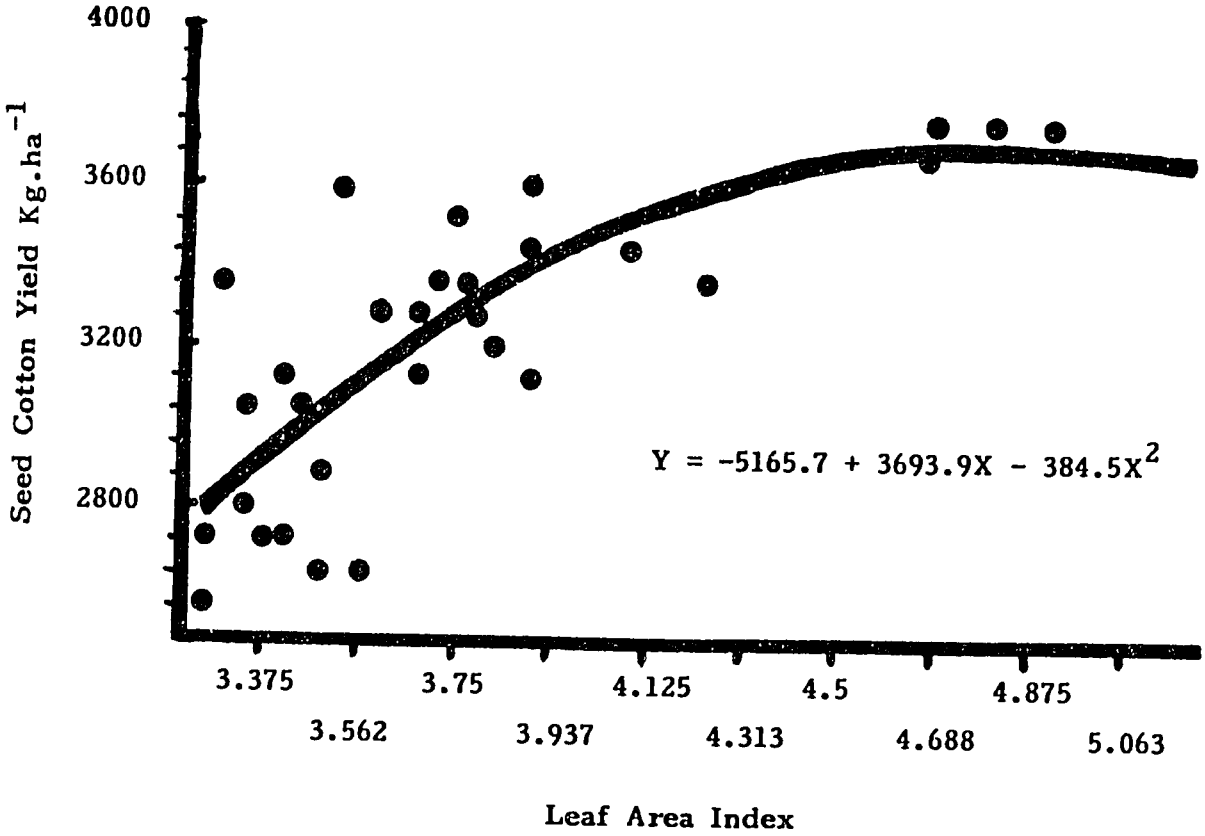


Fig.19. Relationships Between Leaf Area Index and Seed Cotton Yield

5.18 Crop Earliness

Earliness is a crop expression to set fruit in relation to age. It has gained an importance in recent years to assess crop performance. Water being the main instrument regulating crop growth is likely to influence the various parameters of cotton earliness. Results obtained in present investigation are given below.

Table 7 Effects of water stress on phenological events

Parameters	Treatments: Water stress at Squaring	Early flower	Peak flowering	No stress	LSD (0.05)
Days from plantong to:					
First flower bud	32	33	33	33	0.96
First white flower	55	57	58	59	0.92
First boll split	98	97	96	99	1.36

Water stress caused significant differences in phenological criteria of earliness. Water stress at peak flowering phase particularly made crop early by about 3 days compared to no stress treatments. Since boll opening is mainly dehydration process and water stress at a stage when some bolls have attained maturity was likely to accelerate early opening of bolls.

Table 8 Effects of water stress on morpho-physiological measures

Parameters	Treatments: Water stress at Squaring	Early flowering	Peak flowering	No stress	LSD (0.05)
i) First sympodial node number	10	10	10	10	N.Sig.
ii) First sympodial height (cm)	13	15	15	15	0.80
iii) Flowering interval(days)					
Horizontol	5.8	5.8	5.7	5.7	N.Sig.
Vertical	2.5	2.4	2.4	2.5	N.Sig.

The main stem node number of first sympodium and flowering interval were not affected by water stress treatments (Table 8). These characters of cotton plant were affected more by genotype and to a lesser extent by environmental components like water (Low et al. 1969; Tiffany and Malm, 1981). However, water stress at squaring shortened height of first sympodium. Water stress is known to restrict internodal length and this reduced height of first sympodium.

Table 9 Effects of water stress on product quantity measures

Parameters	Treatments				LSD (0.05)
	Water stress at				
	Squaring	Early flowering	Peak flowering	No stress	
Percentage of seed cotton harvested at first pick.	48	54	57	44	
Mean maturity date (days)*	164	164	160	166	1.06
Production rate index (kg ha^{-1} day^{-1})	19	19	20	21	0.72
Fruit production efficiency(days)	88	88	91	92	1.51

Mean maturity date (MMD) = $\frac{W_1H_1+W_2H_2+ \ldots W_nH_n}{W1+W2 + \ldots Wn}$

Where W = Weight of seed cotton. H = number of days from planting to harvest and 1,2, ... n = consecutive periodic harvest number (Christidis and Harreson,1955).

Production rate index (PRI) = $\frac{(W_1+W_2+\ldots\ldots W_n)^2}{W_1H_1+W_2H_2+\ldots W_nH_n}$

Where W = Weight of seed cotton kg ha^{-1}

H = number of days from planting to harvest; and 1,2..... n = consecutive periodic harvest number (Bilbro and Quisenberry, 1973).

Fruit Production Efficiency (FPE) = Number of days required from sowing to produce flowers at a given number of fruiting site where a is a constant having a value of 9.6., x_1 is the number of days to standard flower, x_2 is the node number of first

fruiting branch, x_3 is the vertical flowering index and x_4 is the horizontal flowering index (Malik et al· 1978). The formula used was as follow.

$$F.P.E. = a + x_1 + x_2\ x_3 + 9\ x_3 + x_4$$

The product quantity measures of earliness showed significant variations due to water stress treatments (Table 9). The percentage of crop harvested at first pick and mean maturity date were delayed in crop experiencing no water stress. Since increased water supply results in more vegetative plant; this resulted in later crop. The production rate index and fruit production efficacy were higher in crop experiencing no water stress.

These results indicate that those earliness indices which do not take into account yield (phenological events, height of first sympodium, percentage crop harvested at first pick and mean maturity date) were affected differently by water stress treatments than those which combined yield and earliness into single index (production rate index, fruit production efficiency). Water stress made crop early without regard to yield. The major consideration here was more yield in minimum time. Earliness by withholding water could be achieved with corresponding reduced seed cotton yield (Grimes and Dickens, 1977). The indices which encompass both yield and earliness (production rate index, fruit production efficiency) were positively influenced by good water supply. Bilbro and Quisenberry (1973) and Malik et al. (1978) found production rate index and fruit production efficiency most valuable tools to delineates factors involved in crop earliness.

5.19 Consumptive Use of Water

The rate of water used by the cotton plant will vary throughout the growing season. From emergence to appearance of flower bud, the rate of water use is very low. The onset of fruiting phase and heavy flowering period correspond to the period of maximum daily use rate. The period of maximum growth and water use at Multan occur in the month of August and September. Water use ranged between 8 to 10 cm per fortnight during peak growth period. Taha et al. (1982) arrived at the similar consumptive use of 7-10 cm during the period of August and September. The water use declined in the month of October, when crop had attained the age of mid-maturity. Consumptive use in control treatment was 63 cm and crop stressed at squaring, early flowering and peak flowering used 50 cm, 55 cm and 61 cm of water respectively (Fig.20). Evapo-transpiration rate was function of water supply and plant growth.

Cotton crop used about half of total water from top 30 cm layer and extraction of water declined with depth (Fig.21). The amount of water extracted from 91to 120 cm layer was 1/5th of that extracted from top 30 cm layer. These results agree with those of Malik and Chaudhry (1984).

5.20 Plant Indicators for Irrigation Management

Various plant parameters are utilized to indicate a level of water stress. Among various plant processes, expansive growth of stem and positioning of white flower provide an indication to water stress. Green coloration of stem can indicate growers to determine when to irrigate. The measurement of green stem portion can easily be followed with a ruler. The position of white flower can also guide irrigator to schedule irrigation accordingly.

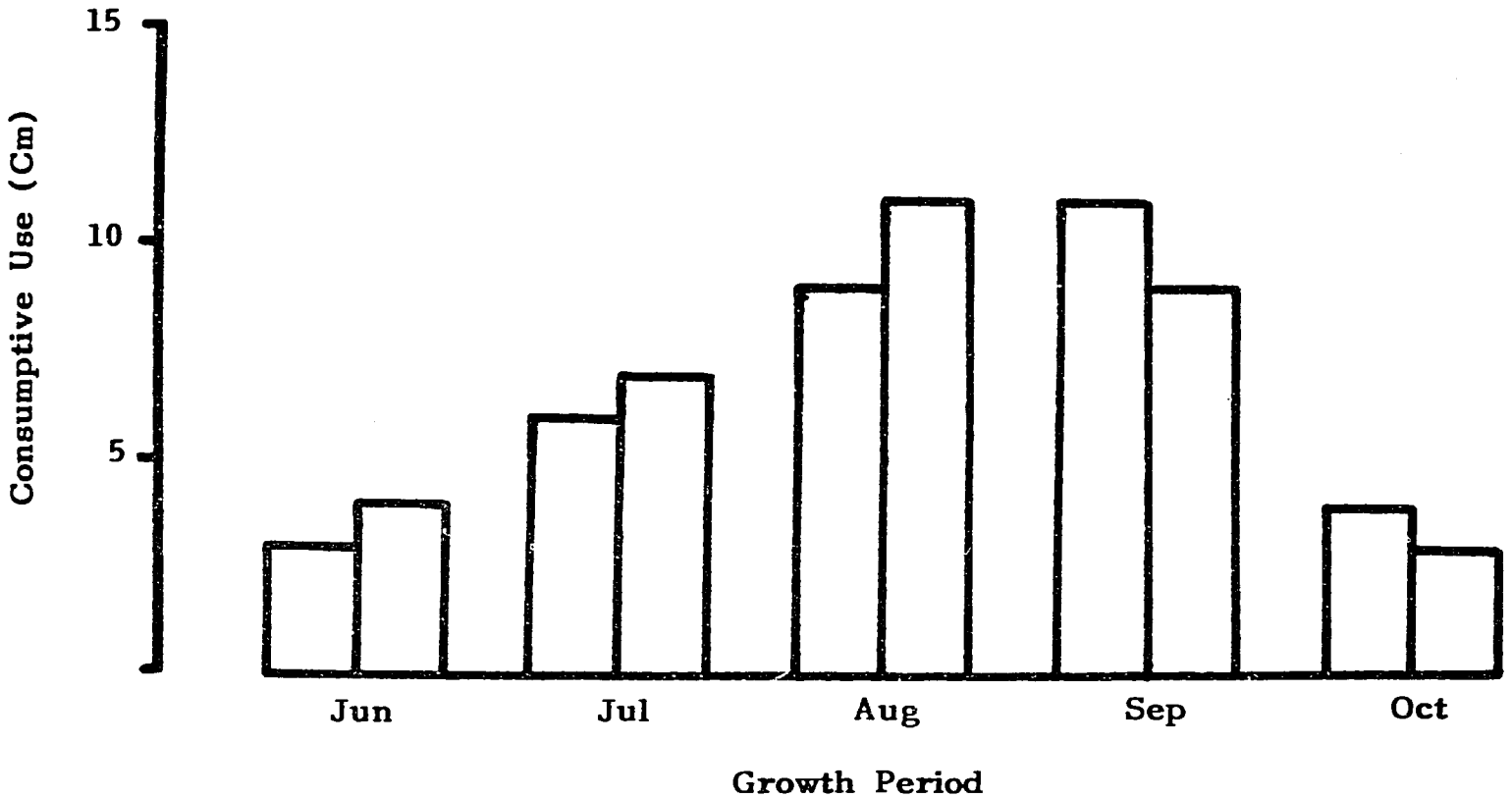
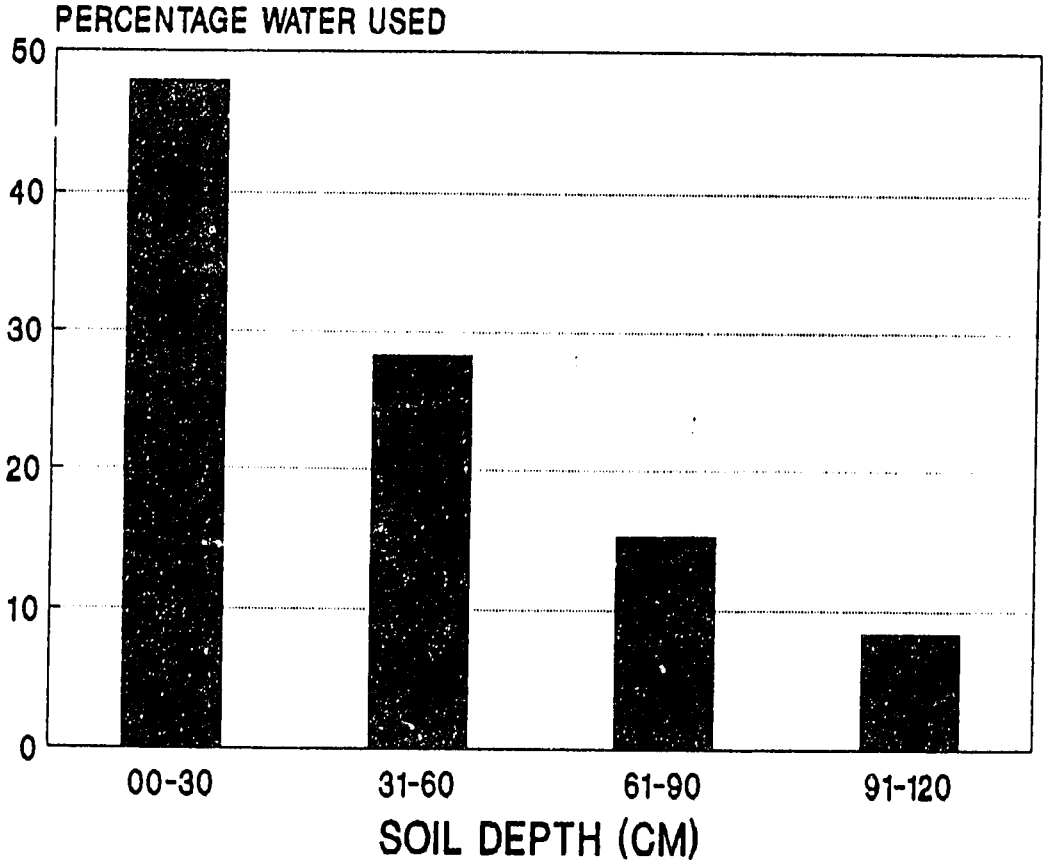


Fig.20. Fortnightly Consumptive Use of Water in Cotton

FIG.21 WATER EXTRACTION BY COTTON PLANT WITH SOIL DEPTH



Research studies indicate that crop receiving full irrigation (no stress treatments) always showed higher terminal green length of main stem and setting of flowers at lower nodes than that stressed during any part of season (Fig.22). Crop stressed at squaring stage had about two third green portion compared to that fully irrigated crop. The maximum seed cotton was obtained in treatment where terminal green length of main stem was maintained from 16-9 cm upto mid-September. The results are similar with those of Hutchinson et al. (1986) who obtained good yield in range of 9-7 cm green stem portion values by scheduling irrigation application at these values. Chaudhry et al. (1988) and Chrisco (1982) also noted reduction in terminal green length and distance of white bloom from the terminal due to water stress.

5.21 Comparison of Boll Weight and Boll Maturation Period at Different Times of the Year

Bolls set during the month of September attained larger size than those set either in August or October. Boll maturation period in terms of calendar days increased with advancement in season and it ranged between 34 to 68 days (Fig.23). However, boll maturation period showed lesser variation in terms of degree days. This is because, the boll development was regulated by thermal units and bolls would dehisce after attaining a definite physiological age.

5.22 Cotton Phenology

An understanding of the growth and development of cotton plant based on energy input is essential for designing and implementing crop management programme to produce cotton more efficiently and profitably (Malik, 1991). The major features of cotton phenology in terms of calendar days, heat units and degree days are presented in Table 10. Heat units are summation of daily mean maximum and minimum

Fig.22. PLANT INDICATORS AS CRITERIA FOR IRRIGATION MANAGEMENT

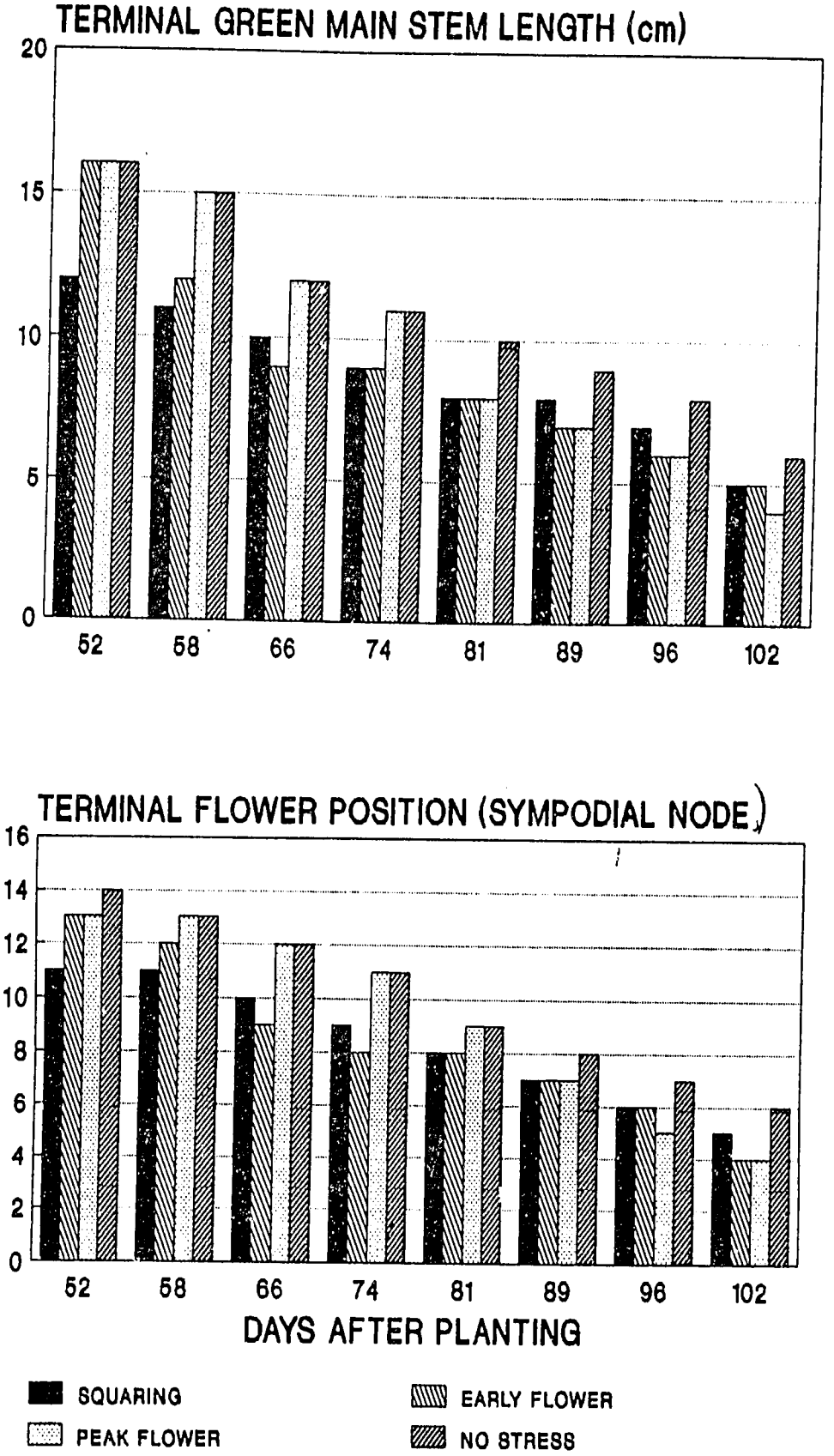
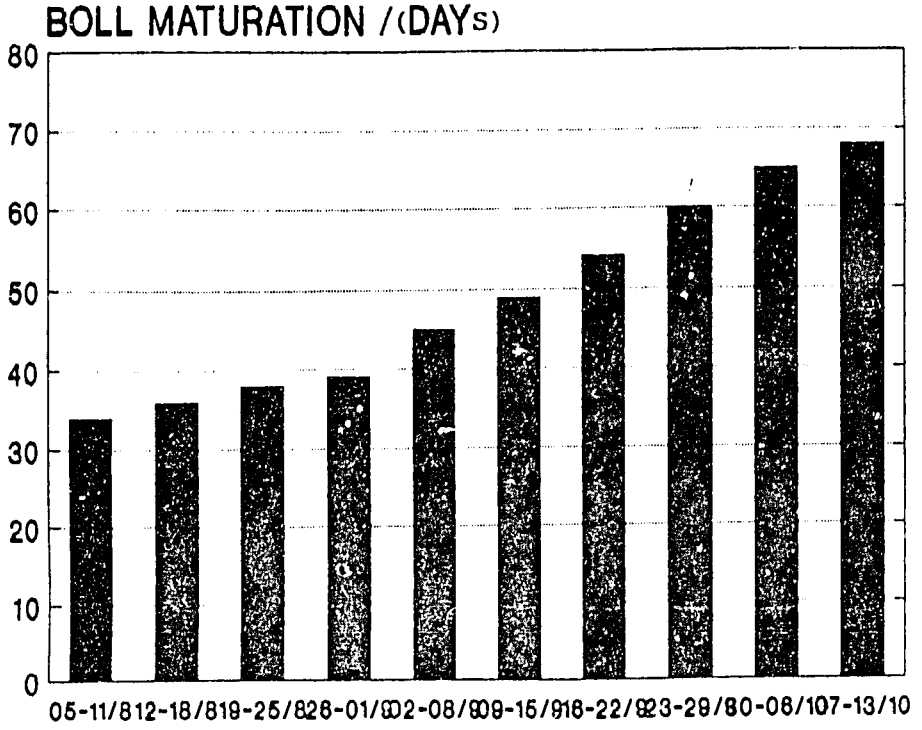


Fig.23.

(A)

BOLL MATURATION PFRIOD AT DIFFERENT TIME OF THE YEAR



(B)

BOLL WEIGHT AT DIFFERENT TIME OF THE YEAR

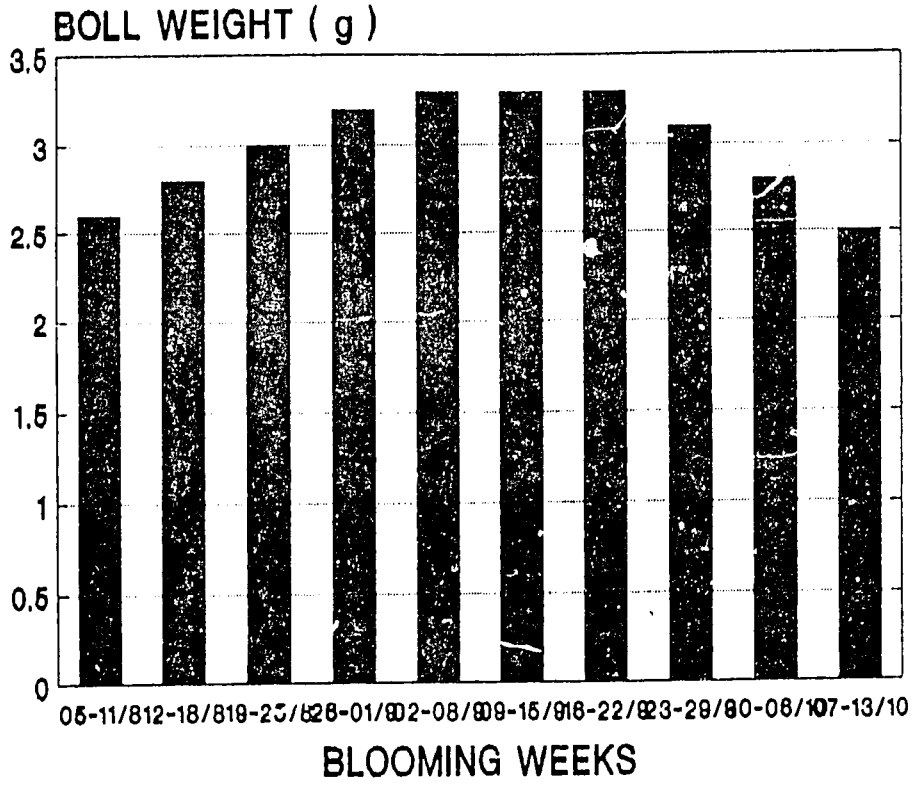


Table 10 Phenology of Cv.CIM-109 at Multan-Pakistan

Phenological events (Planting to)	Calendar days		Mean of treatments	
	Range	Average	Heat units	Degree days
Emergence	4-8	5	135	90
First flower bud	25-35	33	675	480
First white flower	55-65	60	1200	850
First boll split	95-110	100	1950	1500
Maturity	150-165	155	2700	2050

temperature; minus developmental threshold of 15.5°C. Degree days take into account percent sunshine hours, percent dark hours threshold of both maximum temperature (32°C) and minimum temperature (23.5°C) and base temperature (15.5°C). These methods have been used to describe cotton phenology in Israel (Wallach et al. 1978) and Pakistan (Malik, 1991).

The main features of cotton phenology at Multan are:

1. The first true leaf appears seven days after emergence and plastachron index is two to three days till the inception of squaring phase.
2. The first flower buds are produced on sympodial branches at 7th to 10th main stem nodes. The height of first flower bud from cotyledonary node ranges between 14 to 18 cm.
3. Crop growth rate and canopy development are slow in early sown crop.
4. Leaf area index is 4-5 during peak flowering phase.
5. High temperatures are primary reason for delay in both first effective square and boll.
6. Rank growth is result of excessive fruit shedding whether it is due to insects damage or hot weather.
7. After the few bolls are set, the growth rate of main stem slows down and flowering interval increases between and along sympodia.

8. Temperature regulates all processes leading to bud, flower, boll information and maturation. Flower buds and bolls of small age are more sensitive to abscission stimuli. There is hardly any shedding after 9 to 12 days. Flowers seldom shed except due to mechanical injury.

9. The first three positions on the fruiting branches account for about 70 to 90 percent yield.

10. Month of September is most crucial for yield potential.

11. The boll maturation period ranges between 35 to 70 days. Bolls formed during August take substantially less number of days than those bolls formed in October.

12. Bolls formed in August have less boll weight and poor lint quality. Smilar is the case for October formed bolls.

13. Bolls reaches full size three week after flowering and boll weight ranges between 3 to 4 gms.

14. Approximately 250 to 320 bolls are required to produce one kg of seed cotton.

15. Approximately 15 to 20 bolls per plant are required in 30x75 cm configuration to harvest 1000 kg seed cotton per acre.

16. It takes about 180-195 days to mature cotton crop.

17. Heat units requirements of cotton crop from planting to emergence are 135; for first flower bud 675, for first flower 1200; for first boll split 1950 and more than 2700 for maturity. On an average, it takes 550 heat units to mature a cotton boll during a season.

18. Degree days requirement from planting to emergence are 90; for first flower bud 480; for first flower 850 for first boll split 1500 and more than 2050 for maturity. On an average, it takes 500 degree days to mature a cotton boll during a season.

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Annexure-I

Project Objectives

The objectives of the project were set out as under:

i) To increase productivity and quality of raw cotton by making better use of irrigation water.

ii) To quantify the effects of water stress imposed at different physiological stages of growth on cotton yield and lint quality.

iii) To develop yield response function to water supply.

iv) To determine consumptive use of water and develop methodology based on plant measurements for proper scheduling of cotton irrigation.

v) To develop recommendations package to increase water use efficiency in cotton.

Annexure-II

Project Planning Chart

No.	A C T I V I T Y	1989-90					1990-91			
		01	02	03	04		01	02	03	04
1.	Preparation of work plan									
2.	Operation and layout of trials in fields									
3.	Logistic for layout and operation of experiments									
4.	Supervision of data collection of field and laboratory experiments.									
5.	Laboratory analysis work									
6.	Handling and processing of data and computer simulation									
7.	Preparation of annual reports and technical material									
8.	Report schedule	I	P	P	P		P	P	P	T

I = Inception Report P = Progress Report T = Terminal Report

Annexure-III

Research and Technology Development Plan

The selected field received a pre-plant irrigation of eight acre inches of water and stress treatments were imposed beginning from first post plant irrigation. Water stress treatments were imposed by regularly maintaining leaf water potential (LWP) of recently matured main stem leaves by pressure chamber technique. Five random leaves, usually fourth node down from the terminal were excised with sharp razor blade from the base of petiole between 1230 to 1430 hours. The leaves selected were fully expanded, unshaded and free from damage. Leaf water potentials thus determined represent the maximum value for the day and were termed the plant water potential value for scheduling irrigation.

Annexure-IV

Setting-up of laboratory and testing facilities for the Project

Cotton Research Institute, Multan conduc s research on all facets of cotton production viz., Agronomy, Breeding, Cytogenetics, Entomology, Physiology and Chemistry, etc. The research approach is multidisciplinary and all activities are carried out in a coordinated manner.

The Physiology/Chemistry Section conducts research on plant nutrition/fertility, soil-plant-water relationships and stress physiology. It has necessary equipments to carry out soil-plant-water investigation which include Leaf Area Meter, Soil Pressure Membrane Apparatus, Pressure Chamber, Automatic Porometer, Atomic Absorption Spectrophotometer, Spectrophotometer, Electro-ultrafiltration and Kjeldhal Apparatus, etc. In addition to these, aluminium cans and soil augers were procured to determine soil moisture content by gravimetric technique.

Annexure-V

Exploration/Field Evaluation

The soils are alluvial, calcareous, clay loam and alkaline in reaction. Carbon level and nitrogen supply are main limitation to cotton production. The phosphorus supply is medium and potassium supply adequate. Drainage is fair and there is no restriction on root growth. Roots may grow 2 metre deep.

Soil moisture tension curves showed that available moisture decreased with soil depth. The moisture held at lower suctions is more available to plant than that held at higher suctions.

Field capacity, wilting point, bulk density and available water decreased with increasing depth. Field capacity ranged from 29.8% to 33.8%, wilting point ranged from 4.3% to 5.2% and bulk density ranged from 1.38 to 1.52 for various soil depths.

Annexure-VI

Pre-feasibility Studies

It was proposed that the research project may be carried out in the cotton belt and where research facilities are also available. Cotton Research Institute, Multan was choosen as the best site, which is located in the heart of cotton belt.

Cotton Research Institute, Multan has the infra-structure viz., building, electricity, gas, essential equipment, technical manpower and experience of collaboration with FAO/UNDP, Asian Development Bank and Overseas Development Assistance, United Kingdom.

The research work done on cotton irrigation in Pakistan and other cotton growth countries of the world was reviewed.

Annexure-VII

Scope of Application and Post Research Development

1. The scope of the project will be increased cotton yield, better management of limited water resources and generation of technology for scheduling irrigation.

2. Cotton production gains will result in an increase in foreign exchange earning of the country. Raw material supply will increase to textile mills, ginning factories and edible oil mills.

3. The major output will be in cotton irrigation system. The scarce source of water will be utilized efficiently. Water will be applied to soil as per physiological need of cotton crop. It will also help to overcome the menace of water logging and salinity.

4. Research capability of Cotton Research Institute, Multan will be improved.

5. The portable Pressure Chamber may be manufactured locally on commercial basis and should be available to farmers on subsidized rate. The use of pressure chamber will help in better management of limited water resources.

Annexure-VIII

A) BIODATA OF PRINCIPAL INVESTIGATOR

Name	:	Dr. Muhammad Nawaz A. Malik
Father's Name	:	Malik Khan Mulk
Place of birth	:	
Date of birth	:	
Citizenship	:	Pakistani
Marital status	:	Married

Education :

Degree	Subject	Institution
Ph.D.	Agriculture	University of Queensland Australia.
M.Sc.	Agri.Chemistry	University of Sind, Sind, Pakistan.

Research Publications	:	102
Field of research	:	Environmental stress, Soil-plant-water relationships, Nutrition and Soil Fertility, Growth Hormones and Defoliants, Growth and Development.
Membership of professional societies	:	Australian Society of Plant Physiologists Pakistan Soil Science Society Pakistan Scientific Society
Address	:	Head, Plant Physiology/Chemistry Section, Central Cotton Research Institute, Multan, Pakistan.
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B) BIODATA OF PRIMARY INVESTIGATOR

Name	:	Fazal Illahi Chaudhry
Father's Name	:	Ch. Fateh Muhammad
Date of birth	:	
Nationality	:	Pakistani
Marital status	:	Married
Education	:	

Name of Institution	Degree	Subjects
Board of Intermediate and Secondary Education, Lahore.	Matriculation	Physics, Chemistry, Mathematics, English, Social Studies, Arabic.
University of Sind.	B.Sc.(Agri.)	Soil Science, Agriculture, Horticulture, Veterinary, Plant Pathology, Agri. Engineering, Animal Husbandry.
University of Sind.	M.Sc.(Agri.)	Agricultural Chemistry.

Research Publications	:	50
Field of Research	:	Environmental Stress, Soil-plant-water relationship, Plant Nutrition, Growth Hormones, Growth and Development.
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ANNEXURE-IX

Future Plans For Similar Research

Water requirement of cotton in Pakistan is mostly based on number of irrigations in the season and has no relevance to soil and plant water status measurements. Plant based measurement of leaf water potential is considered the most reliable and accurate method of scheduling cotton irrigation. Results achieved in present project indicate that water stress at any growth stage curtailed seed cotton yield but early stress was more deterimental then later ones. Therefore, minimal water stress should be imposed before flowering. The intensive research investigations are therefore needed for further improvement of water management practices in cotton. The researchable areas are:

1. Different water stress treatments may be studied based on plant water status measurement during different growth stages to determine the most suitable threshold of leaf water potential for scheduling irrigation.

2. Studies should be conducted on different soil types and management practices across the cotton belt.

3. Research studies should be undertaken on plant water deficits induced by low available soil water and/or high evaporative demand during early growth period.

4. Varietal differences should be studied with respect to early season water management.