YIELD MAXIMISATION IN MAIZE THROUGH AGRONOMIC MANIPULATIONS

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CERTIFICATE

This is to certify that the thesis entitled **"YIELD MAXIMISATION IN MAIZE THROUGH AGRONOMIC MANIPULATIONS"** submitted in part fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** (Agriculture) in **AGRONOMY** to the Tamil Nadu Agricultural University, Coimbatore, is a record of bonafide research work carried out by **Thirumathi. Sherin George** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazinc.

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Dedicated

to my

beloved husband

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ABSTRACT

SHERIN GEORGE. 1998. Yield maximization in maize through agronomic manipulations, Ph.D. **(Dr. P. SUBRAMANIAN)**

Studies were undertaken during summer and *kharif* seasons of 1996 and 1997 to evaluate the response of maize to irrigation, plant population and nitrogen management and to maximise the yield through effective manipulation of these management options at Agricultural College and Research Institute, (TNAU), Madurai.

The thrice replicated experiments were laid out in split-split design with two irrigation levels, viz., I_1-Irrigation to the entire area and I_2 -Irrigation to the effective root zone width, four plant populations, viz., 55,000, 83,000, 1,11,000 and 1,66,000 plants ha^{-1} and three nitrogen levels at 100,135 and 170 kg ha^{-1}.

Irrigation to the effective root zone width resulted in nine per cent savings in irrigation water without affecting grain yield. The soil moisture content was less under high plant population and N levels indicating greater absorption as revealed by increased moisture depletion under such situations.

The leaf proline content, leaf temperature and leaf diffusive resistance increased and the RLWC and transpiration rate decreased under higher population and lower N levels to keep the maize plant physiologically withstand short term moisture stress. However, none of these factors was influenced by irrigation levels indicating the absence of moisture stress to maize.

The LAI, CGR, and interception of PAR were higher under higher plant population. But RGR, chlorophyll content and photosynthetic rate showed a

declining trend at high plant population. All the physiological parameters studied displayed an increasing trend with increase in the rate of N application.

The relative competitive ability of weeds was decreased and the weed interference was less with increase in plant population and N levels.

Tasseling and silking were hastened by low plant population and increased rate of N application.

The uptake of N, P and K by the crop increased markedly with increase in plant population and N levels. Irrigation levels did not influence the nutrient uptake.

All the yield components studied were adversely affected by increased the plant population whereas, N application positively influenced the yield components and yield.

The plant population of 1,11,000 plants ha^{-1} and N application rate of 170 kg ha^{-1} recorded maximum grain yield. A positive interaction was noticed between plant population and nitrogen and a combination of 1,11,000 plants ha^{-1} and 170 kg N ha^{-1} recorded maximum yield.

The grain protein content was adversely affected by increasing the plant population and reducing the N application rate.

Irrigation to the effective root zone width resulted in an increased WUE during summer. Higher water use efficiencies were associated with a population of 1,11,000 plants ha^{-1} and 170 kg N ha^{-1}.

The gross and net returns and benefit - cost ratio were maximum with the population of 1,11,000 plants ha^{-1} and at a N application rate of 170 kg ha^{-1}.

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CHAPTER I

INTRODUCTION

Maize is one of the most important food grain, forage and industrial crops in the world. In India, maize is cultivated over an area of 5.9 lakh ha with a production of 7.98 lakh tonnes of grain. In Tamil Nadu, it is beeing cultivated over an area of 0.27 lakh ha with a production of 0.40 lakh tonnes. Poultry production has been progressively increasing in Tamil Nadu since last decade. Maize, being the chief source of poultry and animal feed industry, is gaining importance with farmers.

The scientists and planners throughout the country are emphasizing the need for the development of an agricultural strategy centering on strong annual increases in food grain production. This is a worthy and attainable goal, but to sustain the momentum of this objective, research programmes based on higher yields must be initiated.

Optimization of plant populations, fertilizer rates and irrigation are management options that can maximise the grain yield and quality. Use of high plant density is a unique technique used to increase the crop yield per unit area. While the yield per plant decreases with the increased plant density, the total light interception by the canopy is maximised and the yield is enhanced. (Karlen and Camp, 1985; Dezfouli and Herbert, 1992).

Water is yet another input contributing towards higher grain yield. The response to soil water availability is dependent on plant population and N levels in the soil (Averbeke and Marais, 1992; Bangarwa *et al.*,1992).

Variations in N supply can affect the growth and development and yield through its effect on various physiological components and yield attributes (Muchow and Davis, 1988).

Considerable data exists on the growth, development and productivity of maize in response to density, nutrients or water applied alone. But much less information are available to describe the interactive effect of these parameters on maize production. Similarly though individual experiments have well documented, an increase in crop growth rate and yield associated with these factors, information on different physiological processes and soil and climatic elements contributing to yield variation as influenced by these factors are scarce.

Keeping the above factors in view, the present study was undertaken with the following objectives.

1. To maximise the grain yield through agronomic manipulations on irrigation, plant population and N management.

2. To explore the possibilities of increasing the water use efficiency through plant population and N management.

3. To study the influence of plant population on solar energy utilization efficiency and its effect on weed dynamics in combination with nitrogen and irrigation management.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Optimization of plant population, fertilizer rates and irrigation are the management options which can affect the grain yield and quality. The efficiency of these management practices may be dependent upon weather conditions prevailing during the crop growing periods. The available literature on growth, development and productivity of maize in response to density, nutrients and water applied alone or in combination are briefly reviewed here.

2.1. WATER USE STUDIES

2.1.1. Water requirement

The crop water requirement of maize varies with crop season, physiological phases and soil, nutritional and environmental variations, (Jeyakumar, 1991).

Panchanathan *et al.* (1986) estimated the water requirement of maize as 464 mm during summer, when irrigation was given through sprinklers. Water requirement of maize cultivar Co.1 was 495 mm and 464 mm during *kharif* and *rabi* reasons respectively at Coimbatore (Selvaraju and Iruthayaraj, 1994). Bosnjak and Pejic (1995) reported that water consumption for maize was at the same level in all the variants of irrigation, regardless of the irrigation rate and ranged from 471.9 to 535.3 mm depending on growing season.

Field trials conducted at Maharashtra with maize, in clay loam soils to assess the impact of irrigation scheduling, mulching and layout revealed that water consumption was higher (345.16 mm) in mulched than in unmulched plots (331.63 mm) and in flat beds than in ridges and was higher at the highest IW/CPE ratio (Jadhav *et al.,* 1994).

2.1.2. Irrigation scheduling for maize

Current constraints on the availability of irrigation water prompted studies aimed at economizing its use without affecting production. Results indicated that soil moisture fluctuations from allowable depletion to permanent wilting point resulted from decreasing moisture regimes based on different irrigation scheduling methods reflected in the performance of maize (Patil *et al.*, 1991; Moentono and Fagi, 1992; Alam, 1995). Optimum soil moisture was to be maintained to a minimum depth of 20-40 cm for maize with an irrigation rate of 20-40 mm and in that depth, it was indispensable to maintain permanent level of readily available water for the better growth and development of maize (Bosnjak, 1996).

Irrigation scheduling for corn requires knowledge on methods for timing the irrigation. Irrigating the crop through narrow furrows (30 cm) up to grand growth stage and thereafter resorting to full depth through widened furrow resulted in 99.3 per cent of grain yield produced under flat bed system with full depth of irrigation with a saving of 38.5 per cent of irrigation water (Ibrahim and Gopalswamy, 1993).

In a field study, different irrigation methods like partial ET replacement, crop water stress index (CWSI of 0.2,0.4, and 0.6), measured soil metric potential (30 and 50 kPa), and growth model (CERES-maize) were compared for estimates of drymatter accumulation and water use (Steele *et al.*, 1994). The reference irrigation timing method was based on allowable root zone available water depletion (40%). All the non reference methods except for CWSI=0.6, offered the potential for significant irrigation water savings without significant yield reductions.

The recent irrigation scheduling concept says that consumptive water use by a crop is governed primarily by meteorological parameters when plant canopy is adequate and moisture supply is not limiting, which paved the way for irrigation scheduling based on IW/CPE ratios, i.e., water use factors (Prihar and Sandhu, 1987).

The IW/CPE concept has been found to be a reliable, economical and practical basis for scheduling irrigation. Verma *et al.* (1987) and Varughese and Iruthayaraj (1996) found that 0.75 IW/CPE ratio was optimum for scheduling maize irrigation. Banga *et al.* (1994) compared three irrigation levels, i.e., 0.3, 0.6 and 0.9 IW/CPE ratios and observed that grain yield was comparable at 0.6 and 0.9 IW/CPE ratios.

2.1.3. Role of ET on water use of maize

The dry matter production (DMP) in several crops in directly proportional to the water transpired by the crop (Prihar and Sandhu, 1987). Panchanathan (1987) observed a linear relationship between ET and yield and ET and dry matter in maize. Water deficit reduced seasonal ET, grain yield and water use efficiency and the yield response factor (relationship between relative yield decrease and relative ET deficit) ranged from 0.2 (in a wet year) to 2.6 in a dry year (Craciun and Craciun, 1994).

Oliveira *et al.* (1993) studied the actual evapotranspiration and water extraction pattern of maize. The total ET during the growth cycle of corn was found to be 455 mm and the water extraction from 0-20, 20-40, 40-60 and 60-80 cm soil depths was 36,39,22, and 3 per cent respectively. Toit and Human (1995) reported that the percentage of available water in the top 30 cm was less than 25 per cent for most of the active growing period, while in the 30-60 cm soil layer available water generally exceeded 25 per cent. Wirosoedarmo *et al.* (1993) developed a mathematical model for predicting water availability and effective rain fall during maize growth from evapotranspiration and changes in soil water content.

The total ET during the cropping period is often decided by the prevailing soil moisture conditions of the soil and evaporative demand caused by weather factors. In maize soil moisture available in the top 0-30 cm layer was contributing more towards evapotranspiration. (Toit and Human, 1995).

Thiyagarajan (1981) reported that other factors being equal, the consumptive use of water increased with age of the crop till maturity. But Panchanathan (1987) and Jeyakumar (1991) observed a low consumptive use rate during the initial stage, gradually reaching the peak by silking and declining thereafter rapidly irrespective of the season.

To predict the stage of peak water requirement of a crop ET/Ep ratio is essential. This derivative is very useful in predicting an optimum irrigation programme under limited water availability (Prihar and Sandhu, 1987). The ET/Ep ratio in maize was progressively increased from knee-high stage to silking and thereafter declined gradually (Stewart *et al.*, 1975; Panchanathan, 1987).

2.1.4. Water Use Efficiency (WUE)

Karim *et al.* (1985) conducted an experiment on water use by maize at three different locations and found that for all the three locations, WUE decreased with increasing irrigations. Ibrahim and Gopalswamy (1993) studied the effect of depths and land shaping methods for irrigation in maize and observed that the highest WUE resulted in the narrow furrow irrigations, followed by normal furrows with 50 per cent depth. Askar *et al.* (1994) reported that both grain yield and WUE were highest in 50 per cent moisture depletion treatment compared to 25 or 75 per cent depletion of available soil moisture. Jadhav *et al.* (1994) studied the WUE in maize as influenced by irrigation scheduling, mulching and layout. It was found that WUE was highest with 0.4 IW/CPE ratio (16.99 - 19.98 kg mm^{-1}) and lowest with IW/CPE ratio of 1.0 (12.06 - 12.77 kg mm^{-1}) and WUE was higher in unmulched but ridges and furrows plots compared to mulched and flat bed plots.

2.1.5. Water relations on maize physiology

2.1.5.1. Leaf temperature

Leaf temperature measurements were found to be a good indicator of stress. The use of leaf temperature to detect water stress is based on the assumption that transpired water evaporates and cools the leaves below the temperature of the surrounding air (Ehrler, 1973). As water becomes limiting, transpiration is reduced and the leaf temperature increases (Jackson, 1981; Ehrler, 1983; Jeyakumar, 1991). The unirrigated plots of maize had a high canopy temperature, which resulted in reduced yield (Claweson and Blad, 1982; Ceulemans *et al.,* 1988). Inoue (1987) observed that the canopy temperature of maize leaf was 2 to 5°C lower than the ambient air temperature, but both decreased linearly with vapour pressure deficit. Steiner (1987) opined that slightly higher leaf temperature in the higher population might have been related to a greater depletion of plant available water than in medium and low population plots. Selvaraju and Iruthayaraj (1994) observed that higher doses of N application reduced the canopy temperature at all stages of the crop.

2.1.5.2. Transpiration rate

Transpiration and its intensity are directly connected to the quantity of easily accessible moisture in the soil (Kabasi, 1988). If a plant is well watered, the transpirational cooling occurs and as the plant experiences water stress due to soil moisture deficits, transpiration reduces progressively (Turner, 1975; Mtui *et al.*, 1981; Ehrler, 1983).

Dwyer and stewart (1985) observed that decreased rate of transpiration in maize decreased the rate of photosynthesis due to reduction in leaf area under water stress conditions. Steiner (1987) reported that narrow row and high population treatments showed greater stress as evidenced by lower transpiration.

Selvaraju and Iruthayaraj (1995) observed that transpiration rate was increased by N application. However, Fernandez *et al.* (1996) were of opinion that water relations of maize (leaf water potential, leaf conductance and transpiration rate) were not affected by reduced nitrogen application.

2.1.5.3. Leaf diffusive resistance

The degree of water stress in maize might be predicted from estimates of minimum or maximum daily stomatal resistance (Dwyer and Stewart, 1985; Pathak and Mathur, 1987). Experimental evidences indicate that stomatal conductance decreases with the increase in soil moisture deficit (Berlinear *et al.*, 1984; Jeyakumar; 1991). Singh and Singh (1992) found that stomatal conductance showed a positive linear relationship with Photosynthetically Active Ratiation (PAR) and negative with turgor potential.

Bennett *et al.* (1986) observed in maize that low-N plants maintained higher stomatal conductance. A similar trend was also noticed by Eghball and Maranville (1991) for N rates ranging from 0-180 kg ha^{-1}. But Selvaraju and Iruthayaraj (1995) reported that N application increased stomatal conductance. Adequate N could adjust osmotic potential by accumulating N compounds and other assimilates with more efficient utilization of available soil moisture (Bataglia *et al.*, 1985).

2.1.5.4. Relative Leaf Water Content (RLWC)

The RLWC is a measure of free energy status of water in plants. The concept of RLWC was first developed by Weatherly (1950) and later modified by Barns and Weatherly (1962). Reduction in RLWC under moisture stress had been used as a measure of drought tolerance and its effect on growth and development was studied by several workers in maize (Tanguiling et al., 1987; Panchanathan, 1987; Jeyakumar, 1991). Sadras *et al.* (1985) observed that water potentials, relative leaf water content or observed plant wilting are used as criteria to determine the timing and duration of moisture stress.

2.1.5.5. Leaf Proline Content

Proline, an aminoacid accumulates in all organs of the intact plant during water deficit. Accumulation of proline in plant parts during periods of water stress is an important indication (Singh *et al.*, 1992). Proline accumulation during moisture deficit might be an adaptive mechanism related to RLWC (Stewart and Hanson, 1980). They also opined that proline accumulated in the plant during moisture stress might be used as a nitrogen or energy tool to support recovery and regrowth after cessation of moisture stress.

The extent of proline accumulation under stress was directly correlated with stress tolerance in maize (Panchanathan, 1987; Jeyakumar, 1991).

2.2. EFFECT OF SOLAR RADIATION ON GROWTH AND DEVELOPMENT OF MAIZE

2.2.1. Radiation

The spatial distribution of plants had a larger effect on the amount of energy absorbed by plants (Aubertin and Peters, 1961). Yao and shaw (1964) stated that higher population rates and narrow spacing reduced the ratio of the net radiation at ground to the net radiation above maize crop. The availability of incoming short wave radiation in a maize canopy decreased from 61 per cent in 60 x 30 cm spacing to 27 per cent in 40 x 22.5 cm spacing (Sandhu and Mavi, 1987). Ottman and Welch (1989) and Watiki *et al.* (1993) found that wider row spacings of maize allowed more incident radiation to strike soil surface compared to narrow row spacings.

Drymatter accumulation rate in maize varied in direct proportion to the amount of intercepted radiation (Kniry *et al.,* 1989). Hurn and Hammes (1992) observed that maize grown under radiation intensities of 100, 75 or 42 per cent of full sunlight produced grain yields of 7.8, 7.5 and 5.6 t ha^{-1}, respectively. Suboptimal and supra optimal densities produced a strong negative effect on the efficiency with which the crop or plant converts intercepted radiation into grain sink capacity (Andrade *et al.*, 1993; Kiniry and Knievel, 1995).

Gallo and Daughtry (1986) reported that PAR absorbed in maize canopies increased as a function of LAI upto silking and then decreased due to absorption by stalks and non-green leaves. Tollenaar and Bruulsema (1988) observed that absorption of PAR varied significantly among the canopies due to its transmittance among canopies and they also stated that transmittance and reflectance of PAR by maize canopies varied substantially with the plant population. Differences in dry matter accumulation among crop cultivars could be attributed to the differences in either the absorbance of incident PAR and / or the conversion of absorbed PAR in to dry matter (Tollenaar and Aguilera, 1992).

Guiducci and Marroni (1992) noticed that PAR was decreased by water deficit to values corresponding to 92 per cent of those recorded in well irrigated treatments. Similarly, N deficiency strongly diminished the leaf expansion rate and reduced intercepted PAR (Muchow, 1994 and Uhart and Andrade, 1995).

2.2.2. Photosynthetic rate

Water stress can affect photosynthesis directly by affecting various biochemical processes involved in photosynthesis and indirectly by reducing the intake of CO_2 through stomata as a result of their closure (Hartt, 1967). A reduction in photosynthesis to varying extents due to different degrees of moisture stress during the growth period was reported by several workers (Tanner and Sinclair, 1981; Panchanathan 1987, Wolfe *et al.*, 1988). Fernandez *et al.*(1996) observed that maximum values of net photosynthesis rate varied from 45.5 μ mol CO_2 $m^{-2}s^{-1}$ one day after irrigation down to 35.5 μ mol CO_2 $m^{-2}s^{-1}$ three days after irrigation.

Carbon stress generally increased with increase in plant density and affected the rate of photosynthesis (Lemcoff and Loomis, 1994). The reduction in the rate of photosynthesis was attributed to greater mutual shading in higher densities and to the decrease in the chlorophyll content of ear leaf (Dezfouli and Herbert, 1992). Cox (1996) observed that as plant density increased, leaf CO_2 exchange rate declined by 10-20 per cent under mild and 20-30 per cent under warm dry conditions.

Sinclair and Horie (1989) and Muchow and Sinclair (1994) presented equations for maize that describe leaf CO_2 assimilation rate as a function of leaf N. Bunce (1990) while working with young maize plants found a reduction in the photosynthetic activity when the plants were supplied with low amounts of N. A number of studies have examined the relationship between leaf N content and leaf CO_2 assimilation rate and found high correlation coefficients (Muchow and Davis, 1988). Dwyer *et al.* (1991) also observed higher leaf CER under low than under high plant densities.

2.3. EFFECT OF DENSITY ON WEED DYNAMICS

The relative competitive ability of maize can be enhanced by increasing plant density. Weil (1982) reported a negative correlation between maize plant density and weed dry matter. Gafar and Watson (1983) observed that biomass of yellow sedge was significantly reduced when maize density was increased from 3-13 plants m^{-2}. The leaf area index of maize usually increased when plant density was increased (Tollenaar, 1992), which reduced the transmission of irradiance by maize canopy which affected the weed growth and development (Tollenaar *et al.*, 1994). Videnovic and Stefanovic (1994) noticed that the increase of plant density to 145,000 plants ha^{-1} resulted in a decreased weed coverage of 22.9 per cent. The relationship between maize plant density and competitive ability of maize with weeds varied with intensity, duration and timing of weed stress (Tollenaar *et al.*, 1994).

2.4. EFFECT OF IRRIGATION ON GROWTH AND DEVELOPMENT OF MAIZE

2.4.1. Growth components

2.4.1.1. Plant height

Decreased plant height was a common phenomenon in maize due to moisture stress (Thakur and Rai, 1984; Al-Niemi and Hassan, 1988), more specifically when it occurred during early growth phase, nearly 6 per cent reduction was noticed (Pathak and Mathur, 1987). Ibrahim and Gopalswamy (1994) established a positive correlation between grain yield and plant height in irrigated maize. Similar results were also reported by Selvaraju and Iruthayaraj (1994) and Jadhav *et al.* (1995).

2.4.1.2. Leaf Area Index (LAI)

Moisture stress at all growth stages markedly reduced the leaf growth (Muchow and Carberry, 1989). Maximum reduction in LAI was noticed when the crop experienced moisture stress during early six weeks period (Dwyer and stewart, 1985; Pathak and Mathur, 1987). Adequate moisture supply resulted in increased leaf elongation and consequently higher LAI in irrigated maize, (Panchanathan, 1987; Jeyakumar, 1991; Selvaraju and Iruthayaraj, 1994).

2.4.1.3. Dry Matter Production (DMP)

Dry matter yield was linearly related to cumulative water use (Prihar and Sandhu, 1987) and the increase was reported to be 13 to 43 per cent with favourable water supply (Mackay and Barber, 1985). Dry matter production was substantially reduced by the degree and duration of moisture stress (Dwyer and Stewart, 1985; Jama and Ottman, 1993).

2.4.1.4. Root Growth

Irrigation affected the total maize root length, weight and distribution (Mayaki *et al.*, 1976; Mackay and Barber, 1985). Aboulroos *et al.* (1992) reported that root growth is unaffected by soil moisture during early stage, while at 60-90 days, shoot and root weights were greater at the higher moisture level. Many researchers observed deep root system with water stress as compared to that in irrigated crop. (Upchurch and Ritchie, 1984; Newell and Wilhelm, 1987).

2.4.1.5. Growth analysis

Varying degrees of moisture stress at different growth stages reduced the NAR, CGR and RGR (Subramanian, 1977; Thiyagarajan, 1981; Panchanathan, 1987). Wolfe *et al.* (1988) reported an increased green leaf area duration in maize due to irrigation.

2.4.2. Yield attributes and yield

2.4.2.1. Yield attributes

Jadhav *et al.* (1995) carried out yield correlation studies in maize irrigated at different IW/CPE ratios and found that irrigation positively influenced cob length, cob girth, number of grains cob^{-1}, test weight and finally the yield. Similar results were also reported by Karlen and Camp (1985), Ibrahim and Gopalswamy (1993), Selvaraju and Iruthayaraj (1994) and Varughese and Iruthayaraj (1996).

According to Gab-Alla *et al.* (1995) grain yield was most positively correlated with number of plants per unit area and 100 grain weight when irrigation was given omitting tasseling stage, with 100 grain weight while irrigating the crop omitting silk stage and with number of grains row^{-1} when irrigation was given at all stages of growth.

Moisture stress at tasseling, silking and grain development stages reduced cob length, cob diameter and test weight (Prasad *et al.*, 1985; Eck, 1986; Pathak and Mathur, 1987).

2.4.2.2. Yield

Grain yield in maize is often directly proportional to the available soil moisture. A linear increase in grain yield with increase in irrigation was reported by many workers (Patil *et al.*, 1991; Simon, 1991; Askar *et al.*, 1994; Banga *et al.*, 1994; Craciun and Craciun, 1994).

Grain yield of maize increased several folds by increasing the depth of irrigation (Karlen and Camp, 1985; Nosier *et al.*, 1986). Panchanathan (1987) reported that grain yield increased from 4.58 to 6.1 t ha^{-1} with increase in number of irrigations from 5 to 8. Silva *et al.* (1992) observed that grain yield ranged from 1.25 t ha^{-1} with 109 mm water to 8.95 t ha^{-1} with 753 mm water. Jadhav *et al.* (1993) noticed that grain yield increased linearly with irrigation from 4.23 t ha^{-1} at 0.4 IW/CPE ratio to 5.29 t ha^{-1} at an IW/CPE ratio of 1.0. Ibrahim and Gopalswamy (1993) found that irrigation with full depth (5cm) in normal furrows (60 cm) produced the highest grain yield.

2.5. EFFECT OF DENSITY ON GROWTH AND DEVELOPMENT OF MAIZE

2.5.1. Growth components

2.5.1.1. Plant height

Madhavi (1987) and Uthayakumar (1987) reported that increasing plant population increased the height of the plants. However, Pissia *et al.* (1993) observed that spacing had no effect on plant height.

2.5.1.2. Leaf area index

The LAI increased with increase in plant population and reached a peak at mid silking stage (Karlen and Camp, 1985; Lemcoff and Loomis, 1994). Plant population influenced the canopy structure and maximum yield was recorded at LAI's of 4.1 - 4.75. Cox (1996) compared different plant densities and found that low plant density had a 40 per cent lower LAI from mid vegetative to early grain filling which offset higher photosynthetic efficiency resulting in less dry matter production at silking.

2.5.1.3. Dry matter production

Dry matter per plant decreased with increase in plant population, but the total DMP per unit area increased markedly with increase in plant population (Karlen and Camp, 1985; Sing *et al.,* 1987; Hari *et al.*, 1995). Tentio-Kagho and Gardner (1988) observed that the kernel, stalk and total dry matter yield per plant decreased reciprocally with increasing plant population. Dense growth tended to decrease vegetative growth at silking and the amount of dry matter accumulated after silking was evenly distributed between grain and other parts of the ear indicating a possible competition between organs especially at lower densities (Yihjan *et al.*, 1995). Cox (1996) reported a 15 per cent lower DMP under low plant density (4.5 plants m^{-2}) compared with the high plant density (9 plants m^{-2}).

2.5.1.4. Growth analysis

Shen *et al.* (1993) reported that eventhough LAI increased with increased plant population, NAR and CGR showed little change with increase in LAI. Cox (1996) observed a lower CGR during vegetative development under low plant density.

2.5.2. Yield attributes and yield

2.5.2.1. Yield attributes

Mean grain yield is a product of three yield components, (1) cobs per unit area (2) grains cob^{-1} and (3) Kernel weight. Plant density has marked influence on these yield components. Compensation does occur among the yield components to minimise yield loss when one component is reduced, but such compensation occurs within a limited plant density range (Karlen and Camp, 1985).

Tentio-Kagho and Gardner (1988) reported that the number of grains row^{-1} number of rows ear^{-1} and number of grains cob^{-1} were influenced by plant density. Increasing plant population decreased kernel number and weight per plant but increased grain yield. Similar trends were also noticed by several workers (Dezfouli and Herbert, 1992; Bozic, 1993 and Cox, 1996).

Berzseny (1992) reported that when density was increased harvest index (HI) was decreased. Hari *et al.* (1995) observed that the HI increased with increasing plant population from 75,000 to 100,000 and then it decreased when the population went upto 125,000. But cox (1996) reported that plant density did not affect harvest index values.

2.5.2.2. Yield

Use of high plant densities is a technique used to increase crop yield per unit area. While the yield per plant decreased with increased plant density, the total yield was increased (Karlen and Camp, 1985).

The response of grain yield per unit area to increase in plant density was parabolic (Mengli *et al.*, 1994; Philip and Gautam, 1995). Subedi (1994) compared three plant densities, viz., 33,333; 53,333 and 73,333 ha^{-1} and found that grain yield increased linearly with increase in plant density. Increase in grain yield with increasing plant density up to 90,000 was reported by Bangarwa *et al.* (1992) and Cox (1996). Liang *et al.* (1993) also found a similar trend, but he opined that the high plant densities if not accompanied by other inputs, decreased yield. A positive trend of increase in grain yield with increase in plant population up to 1,00,000 plants ha^{-1} was reported by several workers (Sufian and Abedin, 1985; Gracia - Barrios and Kohashi, 1994; Hari *et al.*, 1995). However, Philip and Gautam (1995) found that grain yield increased linearly upto 80,000 from 40,000 plants ha^{-1} and thereafter it decreased when the density was further increased to 1,00,0000.

Narayanaswamy *et al.* (1994) reported that the yield was maximum at plant densities of 1,11,000 ha^{-1}. But Thakar *et al.* (1995) noticed a linear increase in yield upto 1,67,000.

Singh *et al.* (1992) reported that plant populations of 56,000, 74,000, 83,000 and 1,11, 000 had no significant effect on yield. Similarly Adhikari (1990) tried four densities, viz., 38,095, 53,333, 66,666 and 80,000 and found that the grain yield was unaffected by the different densities tried.

2.6. EFFECT OF NITROGEN ON GROWTH AND DEVELOPMENT OF MAIZE

2.6.1. Growth components

2.6.1.1. Plant height

Increased maize plant height with increased fertilizer N was reported by several workers (Ali *et al.*, 1990; Walia *et al.*, 1991; Paradkar and Sharma 1993 and 1994).

2.6.1.2. Leaf area index

The LAI increased with increase in the application of fertilizer N (Hibberd and Hall, 1990; Ghosh and Singh, 1993; Selvaraju and Iruthayaraj, 1994). Banga *et al.* (1994) observed that application of each successive increment of N from 0 to 180 kg ha^{-1} increased the LAI significantly throughout the growth period.

2.6.1.3. Dry matter production

Gaur *et al.* (1992) reported an increase in maize DMP with increase in N levels. A similar trend was also noticed by many authors (Dahiya *et al.*, 1991; Grewal *et al.*, 1992; Banga *et al.*, 1994; Vijayapalani and Shanthi, 1995).

2.6.1.4. Root growth

Localized stimulation of root growth in response to N placement (Granato and Raper, 1989) and N source (Anghinoni and Barber 1988; Teyker and Hobbs, 1992) were recorded.

Under field conditions, N fertilization at planting increased root weight in the surface 7cm in 2 out of 3 years (Anderson, 1987). Addition of N fertilizer also created longer roots without changing the weight which resulted in finer roots (Anderson, 1987; Durieux *et al.*, 1994).

2.6.1.5. Growth analysis

Rifin (1988) reported that nitrogen application increased the CGR. Banga *et al.* (1994) and Uhart and Andrade (1995) also found a similar trend with nitrogen application.

2.6.2. Yield attributes and yield

2.6.2.1. Yield attributes

Ghosh and Singh (1993) observed significant improvement of plant growth and yield components in maize with increase in N application. Increased length of cobs, number of grains row^{-1}, cob girth and number of rows cob^{-1} were observed in 120 kg N ha^{-1} which were superior to 40 and 80 kg N ha^{-1} (Khanday *et al.*, 1993). Misra *et al.* (1994) observed significantly increased number of cobs ha^{-1}, grain rows cob^{-1} and 100 grain weight with increased N fertilizer under high population (98,000 plants ha^{-1}) in sandy loam soils with low available N.

Mishra *et al* (1995) reported increased grain rows cob^{-1}, grain number row^{-1} and number of grains cob^{-1} in higher N fertilizer treatment. Similar results of increased yield contributing factors with increased application of N fertilizer were reported by several workers (Bangarwa *et al.*, 1989 Nandal and Agarwal, 1991; Paradkar and Sharma, 1993).

2.6.2.2. Yield

Hibberd and Hall (1990) observed a linear trend between N applied and maize grain yield. Walia *et al.* (1991) concluded that maize grain yield was significantly higher with the application of 120 kg N ha^{-1} compared to 60 kg in sandy loam soil with low available N.

Gaur *et al.* (1992) reported significant increase in maize grain and straw yield and the increase was 10.8 and 11.1 per cent respectively by increasing the N-fertilizer from 80-120 kg ha^{-1}. Paradkar and sharma (1993) reported that N application significantly and steadily increased the grain yield in clay loam soil with low available N.

Banga *et al.* (1994) observed that the response of fertilizer to maize grain yield was linear up to 180 kg ha^{-1}. Gill *et al.* (1994) obtained a consistent increase in grain yield of maize with each increment from 75 to 150 percent of the recommended fertilizer N. A linear relationship between grain yield and applied N was also reported by many workers (Prusty, 1988; Ahamed, 1989; Grewal *et al.*, 1992; Mishra *et al.*, 1995; Pierre *et al.*, 1997).

2.7. INTERACTIVE EFFECT OF IRRIGATION, DENSITY AND NITROGEN ON GRAIN YIELD

Nagy (1996) opined that the irrigation-fertilization and plant density fertilization interactions were positive and accordingly all these factors have to be adjusted simultaneously when production levels were changed.

Silva *et al.* (1992) reported that maize grain yield ranged from 1.25 t ha^{-1} with 105 mm water and no N to 8.95 t ha^{-1} with 753 mm water and 160 kg N ha^{-1}. Similar positive irrigation - nitrogen interactions were also reported by other workers (Wolfe *et al.*, 1988; sharma and Thukral, 1992 ; Selvaraju and Iruthayaraj, 1995).

Dragovic *et al* . (1987) studied the effect of irrigation and density on the yield of corn hybrids and found that when irrigation was given density should be 10-20% greater resulting in better yield. Averbeke and Marais (1992 reported that when water supply was adequate grain yield response to increase in plant density was asymptotic, but when water supply was inadequate, the response of grain yield to increase in plant density was parabolic.

Similarly significant density - nitrogen interactions were also reported Bangarwa *et al.* (1992) found that out of the different plant populations an

N - levels tried, a density of 90,000 plants ha^{-1} along with application of 180 kg N ha^{-1} resulted in maximum grain yield of 7.27 ha^{-1}. Gracia - Barrios and Kohashi (1994) and Subedi (1994) also observed similar interactions.

2.8. EFFECT OF IRRIGATION, DENSITY AND NITROGEN ON N CONTENT AND UPTAKE

Increased uptake of N by maize with increasing moisture level was reported by Thiyagarajan (1981) and Mackay and Barber (1985). Karlen and Camp (1985) and Panchanathan (1987) also reported a higher uptake of N under adequate moisture regimes. But irrigation reduced the concentration of N in the crop as wellas grain (Karczmarczyk *et al.*, 1987; Kniep and Mason, 1991).

Increased crop density resulted in overall reduction in N content of the stem, leaves and husk. But N uptake by the plant was significantly higher in plots with high density than with low density planting (Madhavi, 1987; Uthayakumar, 1987; Mengli *et al.*, 1994).

The uptake of N in the grain and straw of maize increased with increased rates of N application (Karlen and Camp, 1985). An increased grain N content with increased N application was reported by several workers (Albinet, 1993; Liang *et al.*, 1993; Mengli *et al.*, 1994).

2.9. EFFECT OF IRRIGATION, DENSITY AND NITROGEN ON QUALITY OF MAIZE

Changes in corn yield will affect the grain N and protein concentrations, eventually influencing the nutritional quality of corn. Experiments conducted by Kneip and Mason (1991) on the influence of irrigation and nitrogen on grain yield and quality revealed that irrigation increased the yield and decreased the protein content, where as N increased both grain yield and protein content. Karczmarczyk *et al.* (1987) also reported that supplemental watering lowered the accumulation of N and thus the grain crude protein (CP) content.

Albinet (1993) studied the influence of plant density on yield and seed quality and found that seed CP content was optimum under lower density. Akcin *et al.* (1993) reported that increasing plant density decreased the grain CP content.

A direct relationship between applied N and grain CP content was reported by many workers (Karczmarczyk *et al.*, 1987; Albinet, 1993; Liang *et al.*, 1993).

2.10. ECONOMICS

Panchanathan (1987) reported that the gross and net returns were highest when the moisture supply was adequate through out the crop growth period. Jeyakumar (1991) and Ibrahim and Gopalswamy (1993) also reported that net profit as well as return per rupee invested were higher when maize was subjected to no moisture stress. According to Varughese and Iruthayaraj (1996) the physical and economic dose of N was 223 and 211 Kg ha^{-1}, respectively. Similar high physical and economic dose of N for maize was noticed in N deficient soils by Bhaskaran *et al.* (1993).

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

Field experiments were conducted at Agriculture College and Research Institute, Madurai during the summer and *kharif* seasons of 1996 and 1997 to study the effect of irrigation, density and nitrogen management and their interactive effect on growth, physiology and yield of irrigated maize. The details of the materials used and methods adopted during the course of investigations are presented in this chapter.

3.1 Materials

3.1.1. Fields location

The experiments were conducted at the Central Farm, Agriculture College and Research Institute, Madurai (Tamil Nadu Agricultural University) located at 9° 54' N latitude and 78° 54' E longitude with an altitude of 147 m above mean sea level.

3.1.2. Climate and weather

The experimental farm experiences tropical climate with dry summer extending from March to August. The mean annual rainfall is 856 mm, out of which 39.8 per cent is distributed during *kharif* season, i.e., South West Monsoon (SWM), 42 per cent during *rabi* season, i.e., North East Monsoon (NEM), 2.1 per cent during winter and 16.2 per cent during summer. The daily mean maximum and minimum temperatures are 35.5°C and 25.3°C during SWM, 30.9°C and 21.1°C during NEM, 30.9°C and 20.8°C during winter and 36.4°C and 24.7°C during summer respectively.

Table 1 – Mean weekly weather data during the cropping periods (1996)

Std Week	Date and Month		Temperature (°C)		RH (%)		Rainfall (mm)		Pan evaporation (mm day^{-1})	Mean sunshine (h day^{-1})	Wind velocity (Km h^{-1})
	From	To	Max	Min	At 0700 hrs	At 1400 hrs	Total	Rainy days			
9	Feb 26	03	33.8	22.4	76	34	-	-	7.86	10.4	6.1
10	04	10	34.9	21.0	79	27	-	-	7.71	10.7	5.1
11	11	17	35.7	20.7	81	30	-	-	7.46	9.5	2.8
12	18	24	37.7	24.0	78	35	-	-	7.82	9.8	3.1
13	25	31	38.5	25.7	78	39	-	-	7.82	9.8	2.2
14	April 01	07	37.9	26.6	81	46	-	-	7.04	7.4	3.7
15	08	14	36.2	25.0	79	53	116.2	1	5.32	6.1	2.6
16	15	21	34.6	24.8	83	55	33.0	2	4.68	8.2	4.8
17	22	28	37.0	26.6	81	50	1.0	-	6.18	9.8	4.3
18	29	05	37.3	27.3	74	48	7.0	1	5.79	9.4	2.5
19	May 06	12	31.8	27.4	74	48	-	-	6.75	10.5	1.7
20	13	19	39.6	27.2	69	49	-	-	7.29	10.3	1.2
21	20	26	38.2	25.8	74	38	27.0	1	5.46	9.8	1.2
22	27	02	38.3	26.9	75	36	-	-	6.25	9.6	1.7
23	June 03	09	38.7	26.4	71	37	28.0	1	5.89	8.2	1.8
24	10	16	32.0	25.4	76	55	14.0	1	3.64	7.8	4.2
25	17	23	35.1	25.6	72	40	-	-	6.18	8.4	4.8
26	24	30	36.2	24.8	76	42	38.6	2	4.46	7.6	2.9
27	July 01	07	36.4	25.1	70	38	3.6	1	5.80	7.1	1.8
28	08	14	35.2	25.1	69	43	9.8	2	4.39	6.7	1.8
29	15	21	34.6	26.6	63	43	-	-	5.75	8.4	2.6
30	22	28	35.7	26.5	65	41	-	-	6.36	7.2	4.8
31	29	04	37.4	26.6	62	38	-	-	7.29	8.4	2.1
32	Aug 05	11	37.3	26.5	67	43	3.0	1	6.29	8.5	0.9
33	12	18	35.9	25.5	75	48	77..0	2	4.64	8.4	0.6
34	19	25	33.9	24.2	81	54	52.0	4	4.92	9.1	4.7
35	26	01	34.3	25.6	74	51	-	-	5.07	8.6	4.4
36	Sept 02	08	33.6	25.3	80	56	6.0	1	3.43	8.4	2.5
37	09	15	32.6	24.7	82	60	44.0	3	4.39	9.1	3.8
38	16	22	34.5	26.3	76	57	-	-	4.25	9.6	3.3
39	23	29	32.9	24.7	77	64	25	1	3.36	6.3	3.6
40	30	06	34.3	25.5	69	54	-	-	4.86	7.1	4.4
41	Oct 07	13	32.2	24.0	91	66	147.6	4	2.29	6.4	4.4

Table 1a.Mean weekly weather data during the cropping periods (1997)

Std Week	*Date and Month*		Temperature		RH (%)		Rainfall (mm)		Pan evaporation (mm day^{-1})	Mean sunshine (h day^{-1})	Wind velocity (Km h^{-1})
	From	To	Max	Min	At 0700 hrs	At 1400 hrs	Total	Rainy days			
2	1997 Jan 08	14	29.6	22.2	86	61	-	-	3.21	9.4	7.5
3	15	21	30.5	21.6	86	57	-	-	3.89	9.2	5.0
4	22	28	31.1	21.1	84	57	-	-	4.29	9.7	4.3
5	29	04	30.8	19.7	82	53	-	-	4.50	9.5	4.2
6	Feb 05	11	32.9	21.2	83	53	-	-	4.46	8.9	1.9
7	12	18	32.7	20.2	85	51	-	-	4.86	9.4	4.2
8	19	25	33.9	23.1	87	57	-	-	4.80	10.1	1.9
9	26	04	32.9	21.8	84	62	-	-	5.21	10.3	4.2
10	Mar 05	11	34.2	22.9	88	56	-	-	5.68	9.8	1.8
11	12	18	37.1	22.8	89	55	-	-	5.57	9.0	0.2
12	19	25	37.0	24.9	84	49	-	-	5.57	10.1	0.2
13	26	01	35.9	24.5	86	46	29.4	2	5.75	8.9	0.4
14	April 02	08	33.9	24.3	83	47	34.0	2	4.36	8.2	1.0
15	09	15	35.6	25.5	81	41	7.8	1	4.39	9.1	0.3
16	16	22	35.8	25.1	78	36	-	-	5.43	9.8	0.8
17	23	29	35.6	25.4	76	38	-	-	5.29	10.2	0.2
18	30	06	36.2	25.7	78	44	37.0	1	5.43	9.6	0.4
19	May 07	13	34.3	26.1	81	53	48.0	2	3.96	7.5	0.2
20	14	20	36.8	26.5	70	38	-	-	5.39	9.8	1.0
21	21	27	39.3	26.4	67	33	1.6	-	6.11	10.2	1.1
22	28	03	39.3	26.9	65	35	6.2	1	5.68	8.9	0.7
23	June 04	10	38.5	25.9	72	37	-	-	6.11	9.8	1.1
24	11	17	36.2	24.2	81	45	52.2	4	4.71	8.5	0.6
25	18	24	36.8	26.2	69	44	-	-	5.96	8.7	0.4
26	25	01	36.5	27.2	68	45	-	-	6.50	8.5	2.1
27	July 02	08	36.4	26.7	66	43	-	-	6.50	8.2	3.8
28	09	15	37.8	26.4	68	40	-	-	7.18	8.7	1.8
29	16	22	38.0	26.4	72	42	25.0	2	5.68	7.6	1.5
30	23	29	36.0	26.2	68	47	1.4	-	6.28	7.2	2.8
31	30	05	36.5	27.2	68	45	-	-	6.96	7.9	2.0
32	Aug 06	12	36.2	26.2	70	48	2.2	-	5.42	7.7	1.9
33	13	19	36.1	25.6	70	41	52.2	3	5.21	7.3	1.4
34	20	26	37.8	26.8	68	42	-	-	7.0	8.6	3.0
35	27	02	38.0	26.8	67	39	14.0	1	6.22	8.4	2.3
36	Sep 03	09	35.3	24.7	75	48	35.8	3	5.04	7.8	2.2
37	10	16	35.0	25.2	75	46	2.8	1	4.63	9.1	2.1
38	17	23	35.8	25.2	73	44	28	1	5.21	7.9	2.8

Table 2. Abstract of observations on weather parameters and effective rainfall during the cropping periods

Sl.No	Weather parameters	Summer					*Kharif*				
		Mar'96	April '96	May'96	June '96	Total	July '96	Aug'96	Sept'96	Oct '96	Total
1	Total rainfall (mm)	-	150.2	34.0	42.0	226.3	13.4	132.0	75.0	147.6	368.0
2	Rainy Days	-	3	2.0	2	7	3	7	5	4	19
3	Effective rainfall (mm) .	-	59.95	34.0	42.0	135.75	11.0	68.35	52.0	69.50	200.85
4	cumulative pan evaporation (mm)	222.35	172.25	186.25	68.25	649.1	152.00	185.85	115.75	47.75	501.35
5	*Sunshine hours (day^{-1})*	*10.40*	*7.88*	*9.92*	*8.00*	-	*7.56*	*8.60*	*8.35*	*6.75*	-
6	relative humidity (%)	88	81	73	74	-	67	72	78	82	-
7	Maximum temperature (c)	36.4	36.5	38.3	36.3	-	35.5	35.7	33.3	32.3	-
8	Minimum temperature (c)	22.7	25.9	26.8	25.6	-	25.9	25.7	25.3	32.3	-
9	Wind velocity (km h^{-1})	3.6	3.8	1.6	3.3	-	2.8	2.4	3.3	3.8	-
		Jan'97	Feb '97	Marc'97	Apr '97	Total	June '97	July96	Aug'97	Sept'97	Total
1	Total rainfall (mm)	-	-	4.0	68.2	72.2	57.6	36.40	54.4	89.66	228.0
2	Rainy Days	-	-	1	4	5	5	2	2	7	17
3	Effective rainfall (mm)	-	-	4.00	68.20	72.27	24	26.4	22.15	89.6	162.15
4	cumulative pan evaporation (mm)	88.00	135.25	142.00	115.50	480.75	169.25	199.35	192.90	113.95	675.45
5	Sunshine hours (day^{-1})	9.45.	9.67	9.45	9.32	-	-	-	-	-	-
6	relative humidity (%)	84	84	87	79	-	56	56	56	57	-
7	Maximum temperature (c)	30.0	32.9	35.7	35.3	-	37.3	37	37	36	-
8	Minimum temperature (c)	21.5	21.1	23.4	25.0	-	26.0	26.5	26.5	25.1	-
9	Wind velocity (Kmph)	6.2	3.0	0.7	0.4	-	0.9	2.5	2.2	2.3	-

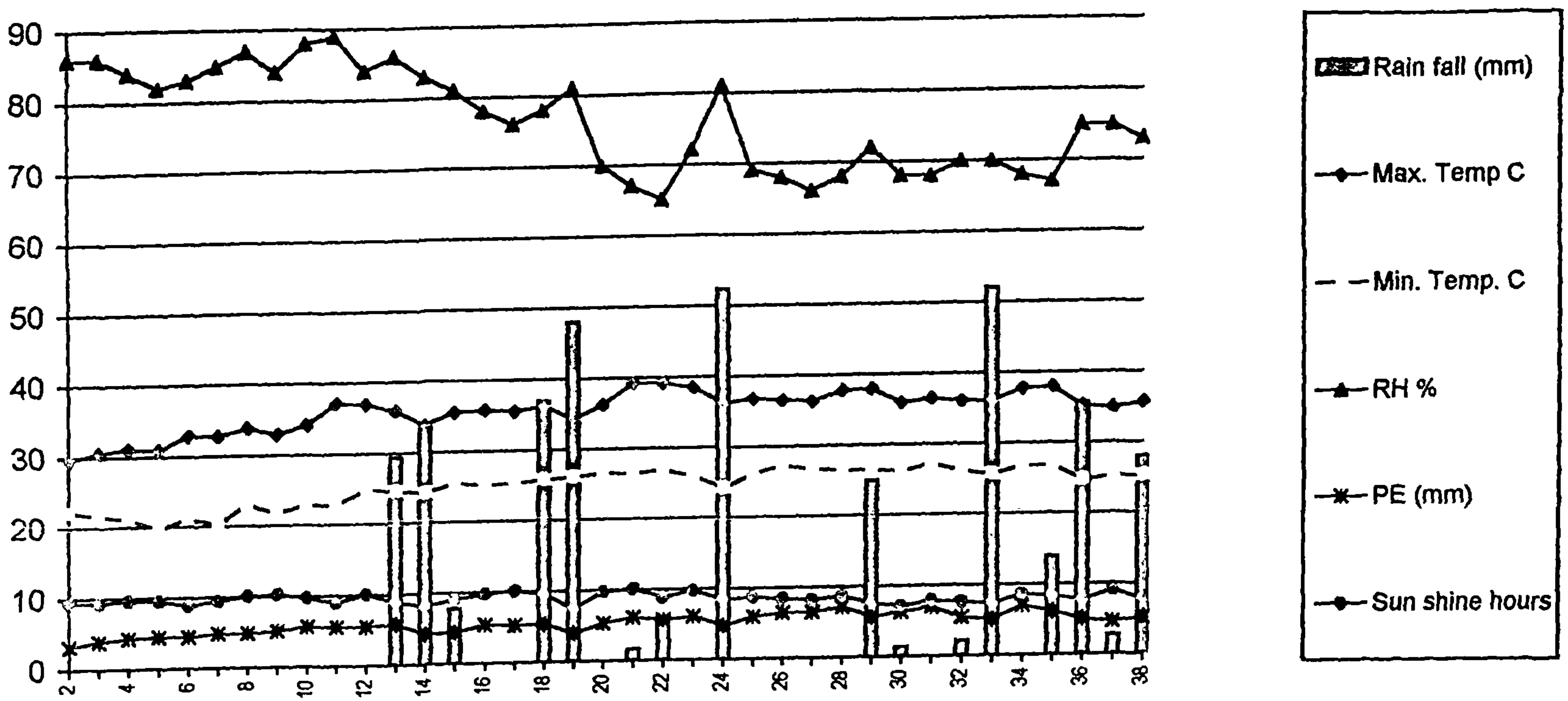

Fig 1. Weather data during the cropping period - 1996

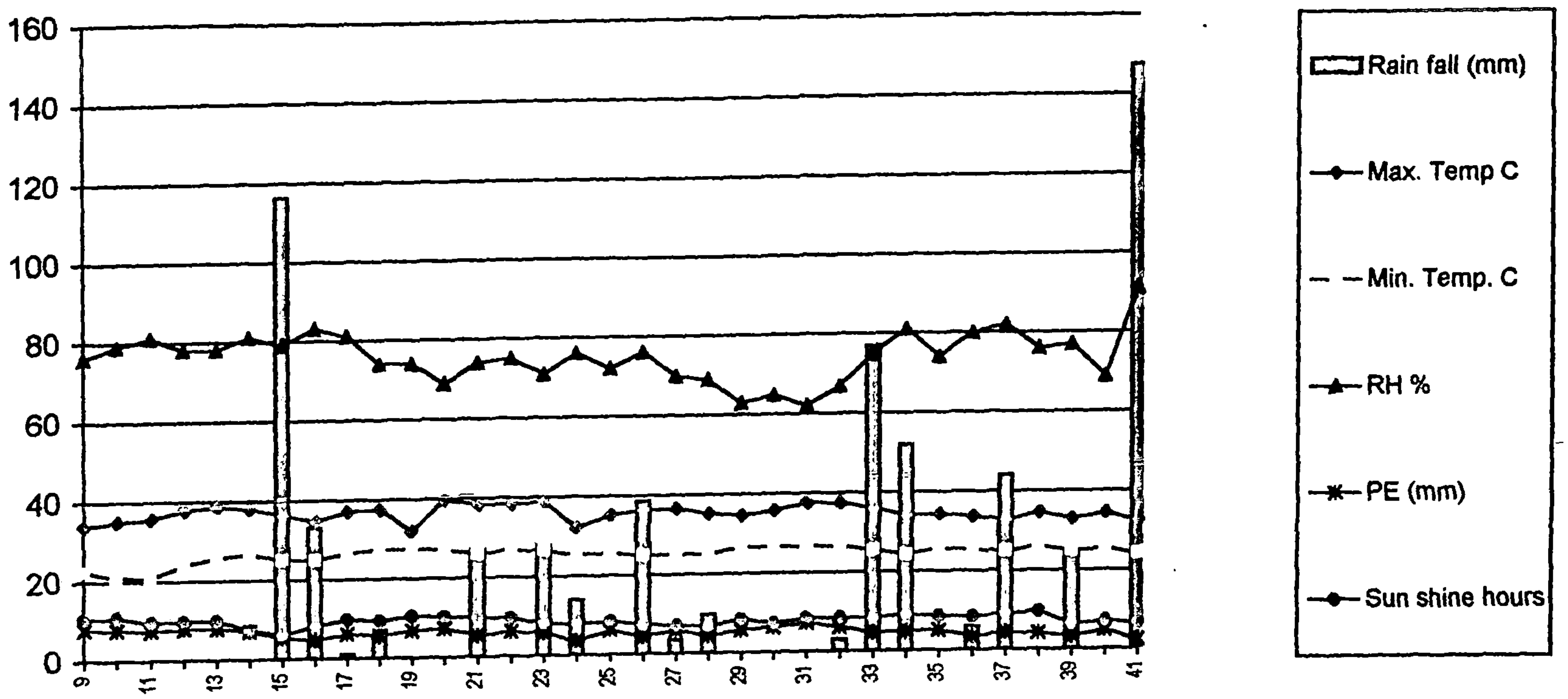

Fig 1a. Weather data during the cropping period - 1997

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The mean weekly weather data that prevailed during the cropping seasons are presented in Table 1. and 1a. and illustrated in Fig.1. and 1a. The abstract of important climatic parameters during the cropping seasons are furnished in Table 2. The effective rainfall during the cropping seasons were 200.85 mm and 162.15 mm during *kharif*, 1996 and 1997 and 135.75 mm and 72.2 mm during summer, 1996 and 1997, respectively. The cumulative pan evoporation during the crop growth periods were 495.85 mm and 617.45 mm during kharif 1996 and 1997 and 649.10 mm and 480.75 mm during summer 1996 and 1997, respectively.

3.1.3. Soil characteristics

The soil of the experimental fields were sandy clay loam in texture with low available N and medium P and K. The detailed soil physicochemical properties are presented in Table 3.

3.1.4. Crops and Varieties

CoH.3, a high yielding hybrid of 100 days duration and having an average yield potential of 5000 kg ha^{-1} was used as the test variety during summer, 1996 and maize cv.Co.1 maturing in 105-110 days with an average yield potential of 3380 kg ha^{-1} was used as the test variety during the rest of the seasons.

3.2. METHODS

3.2.1. Experimental design

The experiments were laid out in split - split design with treatments on irrigation as well as density allotted to the main plots and N levels to the sub plots and replicated thrice. The field lay out plan is given in Fig.2.

Table 3. Initial soil characteristics of the experimental field

A. Textural composition (per cent on moisture free basis) (Piper,1966)		
i)	Course sand	35.80
ii)	Fine sand	26.03
iii)	Silt	15.82
iv)	Clay	22.35
v)	Textual classification	sandy clay loam
B. Chemical properties		
i)	Available `N' (kg ha^{-1}) (Subbaiah and Asija, 1956)	220.00
ii)	Avialable `P' (kg ha^{-1}) (Olsen *et al.*, 1954)	21.00
iii)	Available `K' (kg ha^{-1}) (standford and English,1949)	190.00
iv)	pH (soil : water 1:2.5) (Jackson, 1973)	7.9
v)	EC (Soil : water 1:2.5) (mm mhos cm^{-1}) (Jackson, 1973)	0.38
vi)	Organic carbon (per cent) (Jackson,1973)	0.39
C. Soil moisture constants		
i)	Insitu bulk density (g cm^{-3}) (Dakshinamurthy and Gupta,1968)	1.40
ii)	Hydraulic conductivity (cm h^{-1}) (Dakshinamurthy and Gupta,1968)	2.21
iii)	Field capacity (per cent) (Dastane, 1972)	20.8
iv)	Permanent wilting point (per cent) Misra and Ahmed, 1990)	8.6
v)	Maximum water holding capacity (per cent) (Misra and Ahmed,1990)	33.00
vi)	Infiltration rate (cm h^{-1}) (Dakshinamurthy and Gupta,1968)	2.55

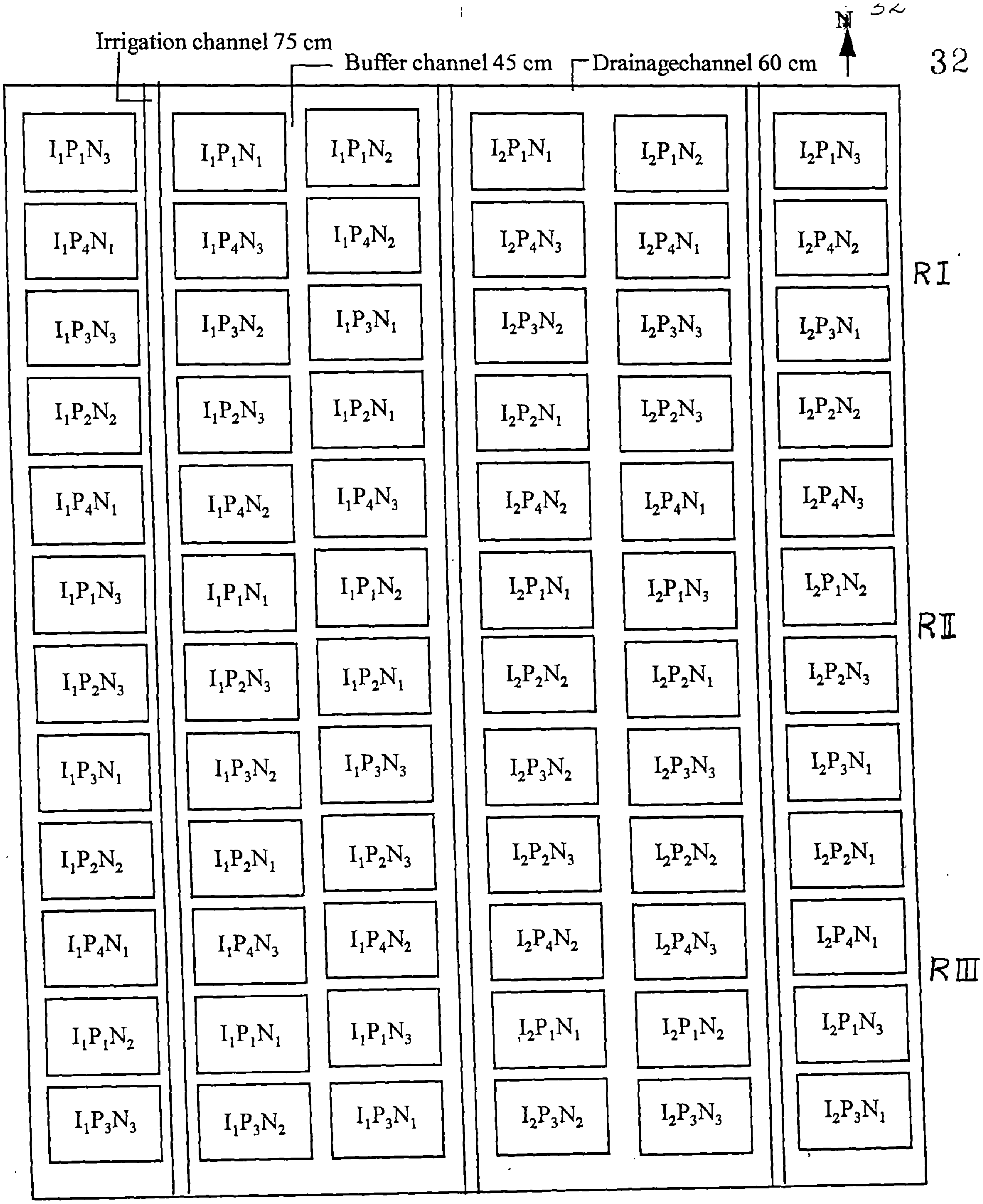

Fig 2. Field lay out plan

3.2.2. Treatment details

While designing the treatments on moisture regimes, the limited water resource situation of Madurai region was taken into consideration. Accordingly, irrigation water management based on the concept of effective root zone width was attempted. Here, while arriving at the quantity of water to be applied at each time, instead of the entire plot area, the area corresponding to effective root zone width alone was taken in to account. Thus two moisture levels based on IW/CPE ratio of 0.75 were arrived at one, irrigation to the entire area and the other, to the effective root zone width.

Treatments

1. Main plots

A. Irrigation

I_1 - Irrigation to the entire area

I_2 - Irrigation to the effective root zone width

B. Plant population

P_1 - 60x20 cm single side sowing (83,000 plants ha^{-1})

P_2 - 60x20 cm double side sowing (1,66,000 plants ha^{-1})

P_3 - 60x30 cm single side sowing (55,000 plants ha^{-1})

P_4 - 60x30 cm double side sowing (1,11,000 plants ha^{-1})

2. Sub plot (N levels)

N_1 - 100 kg ha^{-1} (75 per cent of the recommended dosage)

N_2 - 135 kg ha^{-1} (100 per cent of the recommended dosage)

N_3 - 170 kg ha^{-1} (125 per cent of the recommended dosage)

Plot size

The following plot size was adopted for all the experiments.

Gross plot	-	4.8 x 3.6 m	= 17.28 m^2
Net plot	-	3.6 x 3.0 m	= 10.80 m^2

3.2.3. Cultivation aspects

3.2.3.1. Field preparation

The experimental fields were ploughed thrice, harrowed, levelled and ridges and furrows were formed 60 cm apart. To avoid seepage of water from plot to plot, a buffer space of 45 cm between plots and irrigation channels which were formed with 75 cm width, were provided. All around the experimental field, drainage channels were provided for effective drainage.

3.2.3.2. Seeds and sowing

Maize seeds were obtained from `School of Genetics' Tamil Nadu Agricultural University, Coimbatore. The seeds were treated with bavistin @ 2g kg^{-1} of seeds. The seeds were sown at the required spacing as per the treatment schedule. The plants were later thinned to a single plant per hole. The sowings were done on March 3rd and January 10th for summer 1996 and 1997 and July 6th and June 10th for *kharif* 1996 and 1997, respectively.

3.2.3.3. Fertilizers

A uniform dose of 62.5 kg P ha^{-1} in the form of single super phosphate and 50 kg K ha^{-1} in the form of muriate of potash were applied basally to the crop. The nitrogenous fertilizer was applied as per the treatment schedule in the form of prilled urea. One fourth of the total N was applied basally, half the dose was top dressed at 25 DAS and the remaining 1/4th was applied at 45 DAS.

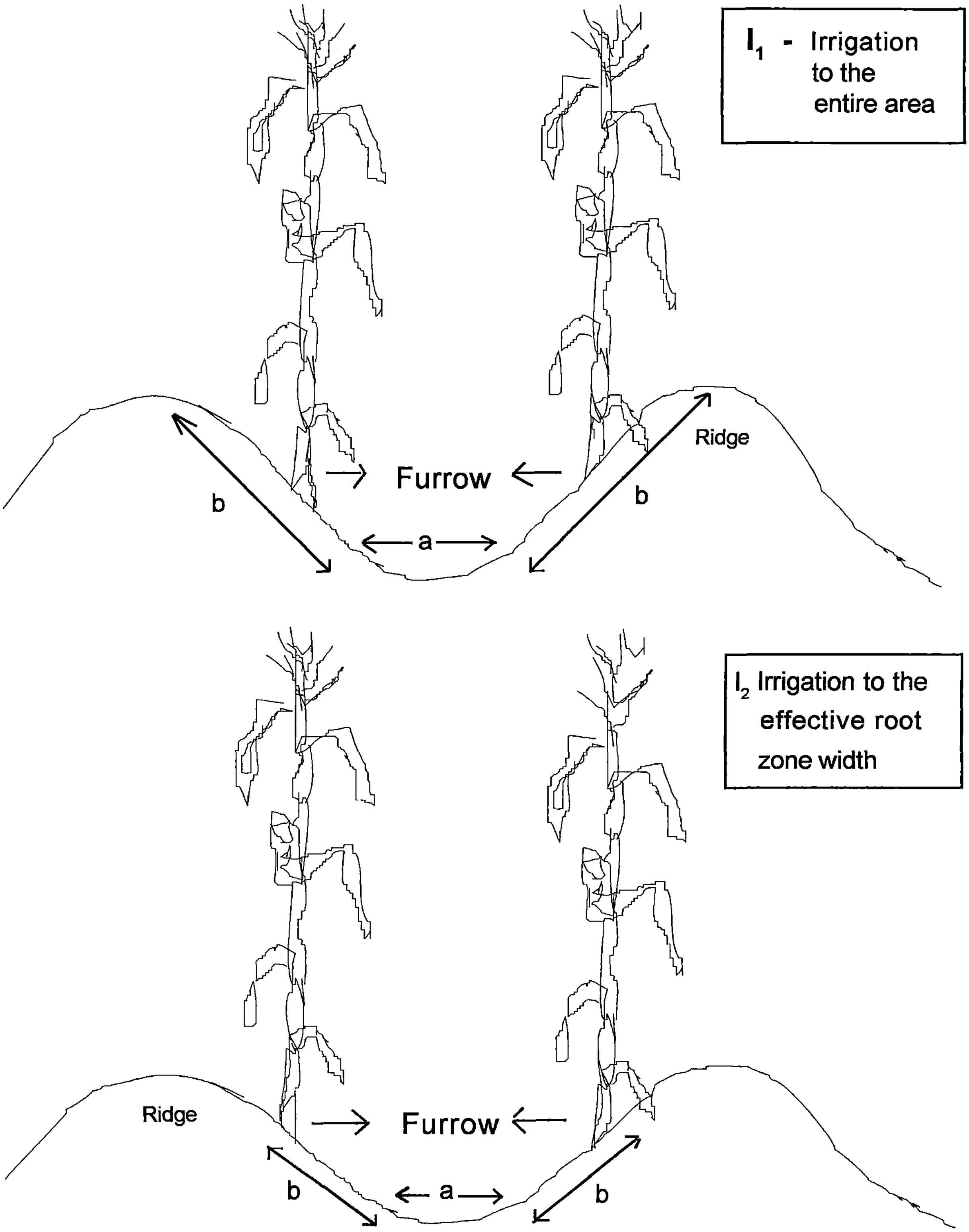

Fig. 3. Methods of irrigation

3.2.3.4. Weed Management

The experiment field was kept free from weeds by the application of preemergence herbicide atrazine 50 per cent WP at 500 g ha^{-1} on 3 DAS followed by hand weeding on 25 DAS and 45 DAS.

3.2.3.5. Irrigation

In all the seasons, the crop received common irrigations for sowing and initial establishment. The depth of required water (60 mm) was multiplied by the entire plot area to arrive at the volume of water required for each plot for I_1. For I_2, the area corresponding to the effective root zone width per plot was calculated using the formula [(a+2b) l] N, where, 'a' is the bed width of the furrow, 'b' is 2/3rd of the side slope, 'l' is the length of the furrow and 'N' is the total number of furrows per each plot (Fig. 3.). The effective root zone width was multiplied by the depth of required water (60 mm) to arrive at the volume of water required per plot for I_2. Irrigation water was measured by regulating its flow through a 7.5 cm throat Parshall flume.

The evaporation data was collected from a USWB - Class 'A' open pan evaporimeter and the different treatments received irrigation as and when their corresponding cumulative pan evaporation values reached 80 mm which is equal to 0.75 I W/CPE ratio with 60 mm water depth. The amount of rainfall if any, received during the irrigation interval was considered while working out the subsequent date of irrigation. Effective rainfall was worked out by balance sheet method as suggested by Misra and Ahmed (1990).

3.2.3.6. Harvest

Grain yield was recorded from the produce collected from the net plot leaving border rows. The cobs were dried, shelled, the grains sun dried to required moisture level and yield recorded. The stalks were cut at the base, sun dried and the stover yield per plot recorded.

3.3. OBSERVATIONS RECORDED

3.3.1. Water use studies

3.3.1.1. Consumptive water use

Consumptive water use in different treatments were computed as given below.

$$Cu = \sum_{i=1}^{n} di + Re$$

Where,

Cu = Consumptive water use in mm.

di = Applied water depth for each irrigation (mm)

Re = Effective rainfall (mm) for the cropping period.

3.3.1.2. Soil moisture content (SMC) before each irrigation

Soil samples were drawn prior to each irrigation from surface to 45 cm depth at an interval of 15 cm and the moisture content was determined gravimetrically on oven dry basis and expressed in per cent.

3.3.1.3. Moisture depletion pattern

The moisture depletion pattern is the difference between the field capacity and the actual moisture content. The average moisture content before each irrigation was used to work out the moisture depletion pattern and expressed in terms of depth units using the formula,

$$MD = \frac{(Fc - Mc)\ lb\ Rz}{100}$$

Where,

MD = Moisture depletion pattern in cm

Fc = Percentage of moisture content after each irrigation

Mc = Percentage of moisture content before each irrigation

lb = Bulk density of the soil g cm^{-3}

Rz = Root zone depth in cm

3.3.1.4. Evapotranspiration / Pan evaporation ratio (ET/Ep)

The ratio between evapotranspiration (ET) and consumptive evaporation (Ep) of water from USWB class `A' open pan evaporimeter for the particular stage was calculated.

3.3.1.5. Rate of water use

The total consumptive water use was divided by the number of days in different stages of maize growth and daily water use rate (mm) was arrived at not only for individual growth stage, but also for the entire cropping season.

3.3.1.6. Water use efficiency

The ratio of grain yield from different treatments and the respective seasonal consumptive water use was calculated and expressed as kg ha^{-1} mm^{-1} of water used.

3.3.2. Water relations on maize physiology

3.3.2.1. Leaf proline content

The proline estimation in the leaves was done by using the method suggested by Bates *et al.* (1973). The third fully expanded leaf from the top was used and the proline content was expressed in mg g^{-1}.

3.3.2.2. Relative leaf water content

The RLWC was estimated according to the method suggested by Barns and Weatherly (1962) as explained by Boote (1983) and expressed in per cent.

$$RLWC = \frac{\text{Fresh weight - dry weight}}{\text{Turgid weight - dry weight}} \times 100$$

3.3.2.3. Leaf temperature (°C)

3.3.2.4. Transpiration rate (μ g cm^{-1} s^{-1})

3.3.2.5. Stomatal diffusive resistance (S cm^{-1})

The above three parameters were recorded at specific stages in expanded young leaf between 11.00 and 13.00 h with the help of LI - 6000 steady state porometer, LIN - coln, Nebraska, USA.

3.3.3. Physiological parameters

3.3.3.1. Chlorophyll content

Chlorophyll `a', `b' and total content were estimated in fully expanded young leaf at specified stages (Yoshida *et al.*, 1976).

3.3.3.2. Light interception

Light interception was recorded with luxmeter just above the canopy and at ground level between 11 a.m. and 2 p.m. on sunny days at specific growth stages and expressed as per cent.

3.3.3.3. Photosynthetically Active Radiation (PAR)

Global solar radiation was monitored with a pyranometer and transformed to PAR by multiplying with 0.48. Per cent PAR interception was calculated as (1- I1/I0) x 100, where I1 is the incident PAR at ground level and I0 is the incident PAR at the top of the canopy. The values for I1 and I0 were obtained with a L1 - COR 180 B radiometer connected to a L1 - COR 180 B Line quantum sensor at mid - day (11.30 - 13.00 h) on sunny days by following the technique described by Gallo and Daughtry (1986). The determinations were made at the time of silking for 1996, summer and *kharif* crops and expressed as per cent PAR interception.

3.3.3.4. Photosynthetic rate

The photosynthetic rate was quantified by the portable photosynthetic system (model LI - 6000 of LI-COR, INC., USA) directly in the field without any destructive sampling at the time of 50 per cent flowering during summer and *kharif*, 1997 and the values expressed as mg CO_2 $cm^{-2}h^{-1}$.

3.3.4. Biometric observations

3.3.4.1. Growth characters

The growth characters, viz., plant height, leaf number and DMP at different stages of crop growth were recorded by adopting standard procedures from five tagged plants.

3.3.5 Growth analysis

3.3.5.1. Leaf Area Index (LAI)

The LAI was estimated by the method suggested by Balakrishnan *et al.* (1987) using the formula

$$LAI = \frac{L \times B \times K \times \text{number of leaves } (cm^2)}{\text{Spacing adopted } (cm^2)}$$

where,

L is length of the leaf (cm)

B is the maximum breadth of the same leaf (cm)

K is the constant (0.796)

3.3.5.2. Crop Growth Rate (CGR)

The CGR during the period was calculated according to Buttery (1970)

$$CGR = \frac{W_2 - W_1}{P(t_2 - t_1)} \text{ g m}^{-2} \text{ day}^{-1}$$

Where,

W_1 and W_2 are the shoot dry weights recorded at time t_1 and t_2

P is the land area occupied by the plant

3.3.5.3. Relative Growth Rate

The RGR was estimated as suggested by Enyi (1962)

$$RGR = \frac{(\log_e W_2 - \log_e W_1)}{t_2 - t_1} \text{ g g}^{-1} \text{ day}^{-1}$$

where,

W_1 and W_2 are the shoot dry weights recorded at time t_1 and t_2.

3.3.6. Root studies

From the plant samples collected for the estimation of DMP at maturity, the following root studies were made as illustrated by Misra and Ahmed (1990).

3.3.6.1. Root length

3.3.6.2. Root weight

3.3.7. Duration of phenological phases

3.3.7.1. Days to midtasseling / silking

When 50 per cent of the plants completely exerted tassels and silks, the plants were considered to have reached 50 per cent tasseling or silking and expressed as days to mid tasseling / silking.

3.3.8. Weed studies

The weed count was taken on 25 and 45 DAS in all the four crops to assess the effect of plant population on the growth and development of weeds.

3.3.8.1. Weed population

The total weed count was recorded by using 0.25 m^2 quadrat in four places in each plot and expressed as number m^{-2}.

3.3.8.2. Weed dry matter production

The weeds in four quadrats were removed, air dried and later oven dried at 80°C till a constant weight was attained. The dried weed weight was recorded and expressed in kg ha^{-1}.

3.3.9. Soil and plant analyisis

3.3.9.1 Soil analysis

Mechanical composition of the soil was determined as suggested by Piper (1966) before laying out the trial.

Composite soil samples collected from 30 cm depth at the pre and post harvest stage of the experimentation were air dried, sieved through 2 mm sieve and analysed for the following nutrients.

Nutrient	**Method**	**Author**
Available N (kg ha^{-1})	Alkaline permanganate	Subbaiah and Asija(1956)
Available P (kg ha^{-1})	Colorimetric	Olsen *et al.* (1954)
Available K (kg ha^{-1})	Neutral normal ammonium acetate	Stanford and English (1949)

3.3.9.2. Plant analysis

The plant samples drawn for dry matter estimation at different growth stages were ground in to fine powder in a Willey mill and used for chemical analysis of nutrient concentration as below.

Nutrient	**Method**	**Author**
Nitrogen	Microkjeldahl	Yoshida *et al.*(1976)
Phosphorus	Tripple acid extract	Jackson (1973)
Potassium	Flame photometer	Jackson (1973)

3.3.10. Yield components

The following yield components and yields were recorded by adopting standard procedures.

3.3.10.1. Cob length (cm)

3.3.10.2. Cob grith (cm)

3.3.10.3. Grain rows cob^{-1}

3.3.10.4. Grain number cob^{-1}

3.3.10.5. Grain number row^{-1}

3.3.10.6. Hundred grain weight (g)

3.3.10.7. Shelling percentage (%)

3.3.10.8. Harvest index (HI)

3.3.11. Economic yields

3.3.11.1. Grain yield (kg ha^{-1})

3.3.11.2. Stover yield (kg ha^{-1})

3.3.12. Quality studies

3.3.12.1. Seed protein content

Grains were analysed for total N content by microkjeldahl method (Yoshida *et al.*, 1976) and this N fraction was multiplied by a factor 6.25 to arrive at protein content of seeds.

3.3.13. Statistical analysis

The experimental data collected from three replications were subjected to statistical scrutiny as per the method suggested by Gomez and Gomez (1984) and whenever the results were found significant, critical differences were worked out at five per cent probability level. Pooled analysis of two year data was done for summer and *kharif* separately.

3.3.14. Economics

Gross and net returns and benefit - cost ratio were worked out based on the cost of cultivation and gross returns with costs adopted in the central Farm during the cropping periods.

3.3.15. Modelling studies

Simple statistical modelling function was run using the computer soft ware 'TABLE CURVE' Jandel Scientific, USA (1993) in which plant population (x) was related with yield (y) using the yield density model.

$$y^{-1} = a + bx^{2.5} + cx^{3}$$

where,

'a' , 'b' and 'c' are parametric constants.

RESULTS

CHAPTER IV

RESULTS

The results of the field experiments conducted at Agriculturalcollege and Research Institute, Madurai to maximise the yield of maize through irrigation, plant population and N management are presented in this chapter.

4.1. WATER USE STUDIES

A perusal of the data on water supply as well as water use may enable to ascertain the optimum quantity of irrigation water to be applied.

4.1.1. Consumptive water use (Table 4)

Consumptive water use was found to be higher during summer than during *kharif* irrespective of the treatments. Irrigation to the effective root zone width (ERW), i.e., I_2 resulted in a lesser consumptive water use compared to irrigation to the entire area (I_1). The consumptive water use was 40mm and 7.5mm less for I_2 than for I_1 during summer and *kharif* respectively.

4.1.2. Soil moisture content before each irrigation (Table 5)

The data showed a reduced soil moisture content during summer compared to *kharif* in all the treatments. However, between the irrigation treatments not much variation was found with respect to seasons and depths.

In both the seasons, the soil moisture content differed distinctly with respect to the different plant populations tried. A higher soil moisture content was observed in 60 x 30 cm and 60 x 20 cm single side sowing (P_3 and P_1 - SSS) compared to 60 x 30 cm and 60 x 20 cm double side sowing (P_4 and P_2 - DSS), the mean values being 11.12 and 10.92 and 11. 43 and 11.12 per cent

Table 4 . Consumptive water use (mm), rate of water use (mm), effective rainfall (mm), and ET/Ep ratio *

Crop growth stages	Consumptive water use				Rate of water use				Effective rainfall				Ep		ET/EP			
	Summer		*Kharif*		Summer		*Kharif*		Summer		*Kharif*		Summer	*kharif*	Summer		*Kharif*	
	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2			I_1	I_2	I_1	I_2
Vegetative	264	254	243	233	8.80	8.50	8.10	7.80	-	-	30	30	172	167	1.53	1.47	1.45	1.39
Flowering	150	140	123	130	5.0	4.10	4.10	4.30	30	40	33	55	169	172	0.90	0.83	0.71	0.75
Grain development	191	171	198	193	4.8	4.3	4.6	4.50	71	71	138	143	223	196	0.85	0.76	1.0	0.98
Total	605	565	564	556	6.0	5.6	5.5	5.4	101	111	201	228	562	535	1.07	1.00	1.05	1.03

* Data not analysed.

Table 5. Mean available soil moisture content (%) before each irrigation *

Treatment	Summer			*Kharif*		
	0-15cm	15-30cm	30-45cm	0-15cm	15-30cm	30-45cm
Irrigation						
I_1 - Entire area	9.63	10.90	11.05	9.88	11.21	11.32
I_2 - ERW	9.50	10.71	10.84	9.71	10.77	11.22
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	10.02	11.27	11.49	10.29	11.45	11.64
P_2 - 60 x 20 cm DSS	8.87	10.17	10.43	9.22	10.60	10.73
P_3 - 60 x 30 cm SSS	10.22	11.56	11.60	10.59	11.77	11.98
P_4 - 60 x 30 cm DSS	9.16	10.23	10.47	9.41	10.65	10.81
N levels (kg ha^{-1})						
N_1 - 100	9.80	11.13	11.30	10.21	11.43	11.57
N_2 - 135	9.52	10.69	10.89	9.81	11.11	11.20
N3 - 170	9.39	10.51	10.81	9.61	10.83	11.06

* Data not analysed

ERW = Effective Root zone Width

SSS = Single Side Sowing

DSS = Double Side Sowing

during summer and *kharif* for P_3 and P_1 respectively, and 9.95 and 9.82 and 10.28 and 10.18 per cent for P_4 and P_2 respectively during summer and *kharif.*

As the N application rate increased, there was a slight reduction in soil moisture content in both the seasons irrespective of soil depths.

4.1.3. Moisture depletion pattern (Table 6)

The knowledge of the amount and rate of moisture depletion by a growing crop is of prime importance in establishing the relationship between moisture depletion and economic yield of crops. Such information is a prerequisite for sound irrigation water management to achieve efficient and economic water use. Soil moisture depletion was noticed from 0-45 cm depth with the top 30 cm layer contributing more.

In general, the moisture depletion was more in summer than in *kharif*. However, the soil moisture extraction was found to be comparable for I_1 and I_2 during both the seasons irrespective of depths.

Among the four plant populations, 60 x 20 cm DSS (P_2) recorded the highest moisture depletion which was comparable with 60 x 30 cm DSS (P_4). The 60 x 20 cm and 60 x 30 cm SSS (P_1 and P_3) registered a comparatively lesser value.

Soil moisture depletion increased with increase in the level of applied N. Application of 170 kg N ha^{-1} (N_3) resulted in more depletion of soil moisture.

4.1.4. Rate of water use (Table 4)

The rate of water use was found to be higher in summer than in *kharif* for both the irrigation treatments during all the stages of growth as in the case of consumptive water use.

Table 6. Moisture depletion pattern (cm) *

Treatment	Summer			*Kharif*		
	0 -15cm	15-30cm	30-45cm	0 -15cm	15-30cm	30-45cm
Irrigation						
I_1 - Entire area	2.34	2.08	2.04	2.29	2.01	1.99
I_2 - ERW	2.37	2.11	2.09	2.32	2.09	2.01
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	2.26	2.00	1.95	2.20	1.96	1.92
P_2 - 60 x 20 cm DSS	2.50	2.23	2.17	2.43	2.14	2.11
P_3 - 60 x 30 cm SSS	2.22	1.94	1.93	2.14	1.89	1.86
P_4 - 60 x 30 cm DSS	2.44	2.21	2.16	2.39	2.13	2.09
N levels (kg ha^{-1})						
N_1 - 100	2.31	2.03	1.99	2.22	1.96	1.93
N_2 - 135	2.36	2.12	2.08	2.30	2.03	2.01
N_3 - 170	2.40	2.16	2.09	2.34	2.09	2.04

* Data not analysed.

Table 7. Leaf proline content (mg g^{-1} fresh weight of leaf) and relative leaf water content (%)

Treatment	Leaf proline content		Relative leaf water content	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	2.17	2.12	67.9	69.3
I_2 - ERW	2.17	2.13	67.8	68.9
SE_D	0.006	0.003	0.26	0.56
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	2.17	2.12	68.5	69.8
P_2 - 60 x 20 cm DSS	2.19	2.16	65.5	67.0
P_3 - 60 x 30 cm SSS	2.15	2.10	70.3	71.6
P_4 - 60 x 30 cm DSS	2.18	2.14	67.0	68.2
SE_D	0.01	0.009	1.33	1.05
CD (P = 0.05)	0.02	0.02	2.72	2.15
N levels (kg ha^{-1})				
N_1 - 100	2.20	2.15	65.70	67.50
N_2 - 135	2.16	2.12	68.70	69.60
N_3 - 170	2.16	2.11	69.00	70.20
SE_D	0.007	0.009	0.68	0.95
CD = (P = 0.05)	0.014	0.02	1.36	1.88

Interaction absent.

4.1.5. ET/Ep ratio (Kc value) (Table 4)

Seasonal variation was found in the ET/Ep ratio among the treatments due to rain effects. ET/Ep ratio recorded for I_1 was more during summer than during *kharif*, whereas for I_2 it was more during *kharif* than in summer. Generally, ET/Ep ratio was more for I_1 than for I_2 irrespective of the seasons.

4.2. WATER RELATIONS ON MAIZE PHYSIOLOGY

4.2.1. Leaf proline content (Table 7)

Leaf proline accumulation was more during summer than in *kharif*. Irrigation levels did not influence the leaf proline content.

The proline content increased with increasing plant population. However, comparable proline contents (2.19 and 2.18 and 2.16 and 2.14 mg g^{-1} in summer and *kharif* respectively) were recorded for 60 x 20 cm DSS (P_2) and 60 x 30 cm DSS (P_4) during both the seasons. Similarly at the lowest population level also the proline contents were comparable (60 x 20 cm SSS and 60 x 30 cm SSS).

A decreasing trend was noticed with increase in N application rate, but the values were comparable for N_2 and N_3 during summer and *kharif*.

4.2.2. Relative leaf water content (Table 7)

The RLWC was higher in *kharif* than in summer. Irrigation treatments failed to exert any significant influence on RLWC.

Plant population and N levels had a significant influence on RLWC. The RLWC decreased progressively with increase in plant population. However, the RLWC was comparable between 60 x 20 cm and 60 x 30 cm SSS (P_1 and P_3)

Table 8. Leaf temperature (°C)

Treatment	Summer			*Kharif*		
	30DAS	60DAS	90 DAS	30 DAS	60 DAS	90 DAS
Irrigation						
I_1 - Entire area	32.2	33.8	32.8	32.4	32.1	31.1
I_2 - ERW	32.3	33.9	32.8	32.3	32.0	31.2
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	31.8	33.3	32.1	31.3	30.9	30.4
P_2 - 60 x 20 cm DSS	33.9	35.8	34.7	34.3	33.8	32.9
P_3 - 60 x 30 cm SSS	30.6	31.9	31.2	30.8	30.5	29.3
P_4 - 60 x 30 cm DSS	32.9	34.3	33.3	33.2	32.9	31.8
N levels (kg ha^{-1})						
N_1 - 100	32.9	34.5	33.4	32.8	32.5	31.2
N_2 - 135	32.2	33.8	32.8	32.3	32.0	31.1
N_3 - 170	31.8	32.3	32.2	31.9	31.6	30.7

* Data not analysed

Table 9 . Leaf transpiration rate (g cm^{-2} s^{-1})*

Treatment	Summer			*Kharif*		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Irrigation						
I_1 - Entire area	16.82	17.93	15.00	15.72	16.85	13.89
I_2 - ERW	16.65	17.78	14.94	15.70	16.78	13.93
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	17.27	18.43	15.88	16.95	17.56	14.84
P_2 - 60 x 20 cm DSS	15.04	16.73	13.77	13.50	14.70	12.05
P_3 - 60 x 30 cm SSS	18.17	19.52	16.07	17.28	18.76	15.28
P_4 - 60 x 30 cm DSS	16.78	17.07	14.31	15.10	16.25	13.58
N levels (kg ha^{-1})						
N_1 - 100	16.15	17.32	14.67	15.51	16.51	13.67
N_2 - 135	16.48	18.06	15.03	15.62	16.83	13.97
N_3 - 170	16.69	18.43	15.08	16.01	17.11	14.10

* Data not analysed

(68.5 and 70.3 in summer and 69.8 and 71.6 in *kharif*) and 60 x 20 cm and 60 x 30 cm DSS (P_2 and P_4) during both the seasons.

The N application favourably influenced the RLWC. However, there was no significant difference between the second and third level (135 and 170 kg N ha^{-1} respectively) of applied N but, they were significantly superior to first level of N (100 kg ha^{-1} -N_1).

4.2.3. Leaf temperature (Table 8)

Leaf temperature did not vary much with irrigation treatments during both the seasons.

With respect to plant population an increasing trend was noticed with increase in plant population and the highest leaf temperature (34.8°C and 33.6°C in summer and *kharif* respectively) was registered for 60 x 20 cm DSS (P_2) during both the seasons at all sages of growth.

Among the N levels, the lowest leaf temperature was maintained by the plants which received the highest level of N (170 kg N ha^{-1}) irrespective the seasons and growth stages.

4.2.4. Transpiration rate (Table 9)

Leaf transpiration rate varied with seasons, the rate being higher during summer than in *kharif*. Transpiration rate increased from vegetative phase to flowering and decreased thereafter upto maturity irrespective of the season.

There was no considerable variation in transpiration rate with respect to the irrigation treatments.

Higher transpiration rates (17.92 and 17.1 g cm^{-2} s^{-1} in summer and *kharif* respectively) were associated with reduced plant population (P_3), which

Table 10. Leaf diffusive resistance (S cm $^{-1}$) *

Treatment	Summer			*Kharif*		
	30DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Irrigation						
I_1 - Entire area	3.92	3.64	4.14	4.40	3.97	4.87
I_2 - ERW	3.90	3.61	4.15	4.42	3.99	4.86
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	3.71	3.45	3.95	4.20	3.79	4.65
P_2 - 60 x 20 cm DSS	4.33	4.15	4.61	4.94	4.54	4.52
P_3 - 60 x 30 cm SSS	3.44	2.95	3.68	3.86	3.35	4.35
P_4 - 60 x 30 cm DSS	4.22	3.89	4.33	4.60	4.22	5.08
N levels (kg ha^{-1})						
N_1 - 100	4.14	3.78	4.46	4.70	4.31	5.20
N_2 - 135	3.93	3.63	4.12	4.42	3.96	4.84
N_3 - 170	3.71	3.42	3.84	4.09	3.66	4.59

* Data not analysed

Table 11. Chlorophyll content (mg g $^{-1}$ fresh weight) in summer maize*

Treatment	30 DAS			60 DAS			90 DAS		
	chlorop hyll.a	chloro phyll.b	Total chloro phyll.	chlorop hyll.a	chloro phyll.b	Total chloro phyll	chloro phyll.a	chloro phyll.b	Total chloro phyll
Irrigation									
I_1 - Entire area	1.24	0.48	1.93	1.47	0.55	2.21	1.19	0.46	1.82
I_2 - ERW	1.22	0.47	1.91	1.48	0.55	2.23	1.20	0.46	1.83
Plant population (ha^{-1})									
P_1 - 60 x 20 cm SSS	1.30	0.50	2.01	1.44	0.54	2.17	1.23	0.47	1.89
P_2 - 60 x 20 cm DSS	1.08	0.43	1.69	1.36	0.51	2.04	1.01	0.41	1.58
P_3 - 60 x 30 cm SSS	1.36	0.52	2.11	1.71	0.64	2.51	1.40	0.53	2.10
P_4 - 60 x 30 cm DSS	1.23	0.48	1.89	1.40	0.54	2.12	1.13	0.43	1.73
N levels (kg ha^{-1})									
N_1 - 100	1.18	0.46	1.83	1.40	0.53	2.11	1.13	0.43	1.72
N_2 - 135	1.25	0.48	1.95	1.49	0.56	2.22	1.20	0.46	1.83
N_3 - 170	1.29	0.50	1.99	1.55	0.58	2.28	1.26	0.48	1.94

* Data not analysed

Table 12. Chlorophyll content (mg g^{-1} fresh weight) in *kharif* maize*

Treatment	30 DAS			60 DAS			90 DAS		
	chlorophyll.a	chlorophyll. b	Total chlorophyll.	chlorophyll.a	chlorophyll.b	Total chlorophyll	chlorophyll.a	chlorophyll.b	Total chlorophyll
Irrigation									
I_1 - Entire area	1.62	0.61	2.41	1.79	0.66	2.62	1.47	0.55	2.22
I_2 - ERW	1.60	0.61	2.42	1.78	0.65	2.61	1.49	0.56	2.24
Plant population (ha^{-1})									
P_1 - 60 x 20 cm SSS	1.71	0.64	2.51	1.87	0.68	2.72	1.44	0.54	2.15
P_2 - 60 x 20 cm DSS	1.36	0.52	2.05	1.51	0.57	2.25	1.30	0.50	1.98
P_3 - 60 x 30 cm SSS	1.78	0.66	2.62	1.96	0.71	2.85	1.71	0.64	2.52
P_4 - 60 x 30 cm DSS	1.62	0.61	2.41	1.78	0.66	2.61	1.51	0.57	2.26
N levels (kg ha^{-1})									
N_1 - 100	1.54	0.58	2.29	1.68	0.62	2.47	1.41	0.54	2.12
N_2 - 135	1.62	0.61	2.41	1.78	0.65	2.61	1.50	0.56	2.22
N_3 - 170	1.69	0.63	2.50	1.88	0.68	2.73	1.56	0.58	2.31

* Data not analysed

got steadily lowered as the plant population was increased in both the seasons at all the stages of crop growth.

Application of N resulted in an increase in leaf transpiration rate, with the maximum value registered for the maize crop receiving 170 kg N ha^{-1}.

4.2.5. Leaf diffusive resistance (Table 10)

Seasons had differential effect on the diffusive resistance of maize canopy. The values were more in *kharif* than in summer.

In general, leaf diffusive resistance decreased from vegetative to flowering stage and thereafter increased upto maturity irrespective of the season.

Irrigation treatments did not have considerable affect on this character during all the stages in summer and *kharif*.

Regarding plant population, the 60 x 20 cm DSS recorded higher values (4.36 and 4.66 S cm^{-1} in summer and *kharif* respectively) than the other treatments during the entire growth period of maize irrespective of the season. The minimum value was registered for 60 x 30 cm SSS. Increased leaf diffusive resistance was noticed at the lowest level of applied N (100 kg ha^{-1}) followed by the second level (135 kg ha^{-1}) and the least value being recorded at the N_3 level (170 kg ha^{-1}).

4.3. PHYSIOLOGICAL PARAMETERS

4.3.1. Chlorophyll content (Table 11;12)

The total chlorophyll content as well as its components were influenced by the seasons with higher values in *kharif* than in summer.

Table 13. Light interception percentage (%)*

Treatment	Summer		Kharif	
	30 DAS	60 DAS	30 DAS	60 DAS
Irrigation				
I_1 - Entire area	48.3	70.4	50.3	73.7
I_2 - ERW	47.4	70.0	51.0	72.4
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	47.7	69.0	49.3	71.3
P_2 - 60 x 20 cm DSS	52.7	74.1	54.7	78.0
P_3 - 60 x 30 cm SSS	44.0	67.3	45.3	69.7
P_4 - 60 x 30 cm DSS	50.0	71.3	52.0	75.7
N levels (kg ha^{-1})				
N_1 - 100	44.3	67.0	47.5	70.0
N_2 - 135	49.5	70.7	51.0	74.3
N_3 - 170	52.0	73.5	53.5	76.8

* Data not analysed.

In general, chlorophyll 'a', chlorophyll 'b' and total chlorophyll content increased from vegetative to flowering stage and declined thereafter to maturity.

The difference with regard to the irrigation treatment was negligible throughout the crop growth period during both the seasons.

A decreasing trend was noticed with increase in plant population. The highest values (2.24 and 2.66 mg g^{-1} in summer and *kharif* respectively) were registered for 60 x 30 cm SSS and the lowest value for 60 x 20 cm DSS at all the stages of crop growth in both the seasons.

Application of N had a positive influence during both the seasons. The N application increased the chlorophyll content irrespective of the stages of growth with the maximum recorded for the application of 170 kg N ha^{-1}.

4.3.2. Light interception (Table 13)

Light interception was more in *kharif* than in summer season. The interception of light increased from vegetative to flowering phase during both the seasons. Irrigation treatments didn't have any notable effect on light interception in all the stages of growth during both the seasons.

Irrespective of the stages and seasons, the 60 x 20 cm DSS (P_2) registered higher light interception percentage (63.4 and 66.4 in summer and *kharif* respectively) and it was minimum in 60 x 30 cm SSS (P_3).

In both the seasons, at all the stages of maize growth, the light interception percentage varied with different levels of applied N. Application of 170 kg N ha^{-1} recorded the highest value and it decreased with lesser quantities of N.

Table 14. Interception of PAR (%) and photosynthetic rate (mg CO_2 dm^{-2} h^{-1}) at the time of flowering

Treatment	Interception of PAR		Photosynthetic rate	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	36.4	39.2	34.8	37.8
I_2 - ERW	37.7	38.3	34.3	37.9
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	31.7	34.39	36.5	39.3
P_2 - 60 x 20 cm DSS	45.2	47.9	28.7	32.5
P_3 - 60 x 30 cm SSS	26.8	28.3	40.0	44.1
P_4 - 60 x 30 cm DSS	42.1	45.5	31.8	35.2
N levels (kg ha^{-1})				
N_1 - 100	32.5	34.7	30.0	34.0
N_2 - 135	36.6	38.6	34.4	38.1
N_3 - 170	40.3	43.7	38.4	41.6

* Data not analysed.

Table 15. Plant height (cm)

Treatment	Summer			*Kharif*		
	30DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Irrigation						
I_1 - Entire area	78.9	178.8	199.5	90.6	190.1	220.5
I_2 - ERW	78.6	177.2	198.3	90.3	189.5	219.7
SE_D	1.3	0.7	1.3	1.2	0.7	0.5
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	78.5	174.9	194.5	85.6	188.8	218.0
P_2 - 60 x 20 cm DSS	82.8	183.6	205.3	101.4	198.8	229.9
P_3 - 60 x 30 cm SSS	75.1	174.8	195.0	81.6	177.8	211.0
P_4 - 60 x 30 cm DSS	78.7	180.6	200.9	93.1	194.1	223.5
SE_D	1.1	0.9	0.8	1.0	1.0	1.4
CD (P = 0.05)	2.3	1.9	1.8	2.0	2.0	2.8
N levels (kg ha^{-1})						
N_1 - 100	71.8	169.9	189.9	80.9	177.6	211.2
N_2 - 135	78.1	179.9	200.6	90.4	190.1	221.5
N_3 - 170	86.4	185.6	206.3	100.1	201.0	229.1
SE_D	0.75	0.62	0.7	0.8	0.8	1.1
CD (P = 0.05)	1.49	1.25	1.4	1.5	1.5	2.1

Interaction present - furnished in Appendix A; (i) to(ii)

4.3.3. Photosynthetically active radiation (Table 14)

There was variation in the PAR interception between seasons. In *kharif* it was more than in summer. Irrigation treatments did not show much variation.

The PAR interception was higher in 60 x 20 cm DSS during both the seasons (45.2 and 47.9 per cent in summer and *kharif* respectively). The interception of PAR decreased with the decrease in plant population and the 60 x 30 cm SSS registered the lowest value in both the seasons.

During summer and *kharif* N application promoted the interception of PAR markedly with the highest interception recorded at the highest level of applied N.

4.3.4. Photosynthetic rate (Table 14)

With regard to season, the photosynthetic rate was higher during *kharif* than in summer.

A notable difference was observed between plant populations during both the seasons. It was more in 60 x 30 cm SSS (40.0 and 44.1 mg CO_2 dm^{-2} h^{-1} in summer and *kharif* respectively) and showed a declining trend with increase in plant population.

The photosynthetic rate progressively increased with increase in the level of N application during both the seasons.

4.4. GROWTH CHARACTERS

4.4.1. Plant height (Table 15)

Generally, the *kharif* maize plants were taller than those from summer season.

Table 16. Dry matter production (kg ha^{-1})

Treatment	Summer			*Kharif*		
	30DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Irrigation						
I_1 - Entire area	556	7086	14420	581	7590	16320
I_2 - ERW	543	6974	14328	569	7404	16174
SE_D	12	127	77	14	149	140
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	524	6700	14233	541	7038	16328
P_2 - 60 x 20 cm DSS	649	8137	16664	678	8610	17439
P_3 - 60 x 30 cm SSS	427	5626	11481	463	6220	14241
P_4 - 60 x 30 cm DSS	598	7657	15108	618	8121	16981
SE_D	16	187	177	21	194	207
CD (P = 0.05)	32	382	264	42	396	423
N levels (kg ha^{-1})						
N_1 - 100	482	6048	13397	514	6509	15170
N_2 - 135	553	7072	14467	574	7532	16426
N_3 - 170	613	7971	15251	637	8452	17146
SE_D	2.5	17	88	5	29	118
CD (P = 0.05)	5.0	33	175	10	58	235

Interaction present - furnished in Appendix B; (i) to (iv)

In both the seasons, at all stages of growth, the plant height was not significantly influenced by irrigation levels.

Plant population had considerable effect on plant height of maize. The 60 x 20 cm DSS (P_2) recorded the maximum plant height which was significantly superior to all other treatments. The 60 x 30 cm SSS (P_3) recorded the lesser plant height in all stages of growth in both the seasons of study.

Plant population and N levels had a distinct interactive effect on plant height of maize, (Appendix A; (i) to (ii)) at 60 DAS during summer and *kharif.* The 60 x 20 cm DSS with 170 kg N ha^{-1} (P_2 N_3) resulted in maximum plant height.

4.4.2. Dry matter production (Table 16)

In general, the DMP was more during *kharif* than in summer.

Irrigation treatments failed to influence the DMP in both the seasons at all stages of maize growth.

The DMP of maize differed significantly between plant populations. The 60 x 20 cm DSS (P_2) produced the highest drymatter (16.6 and 17.4 t ha^{-1} in summer and *kharif* respectively at harvest) while 60 x 30 cm SSS (P_3) produced the least at all the stages of growth in both the seasons.

Among the N levels, a linear response to each level of N application was noticed.

The interaction effect of plant population and different levels of N was significant at 30 and 60 DAS in both the seasons (Appendix B; (i) to (iv)). The DMP was maximum with 60 x 20 cm DSS and 170 kg N ha^{-1} (P_2 N_3) in both the stages and seasons.

Table 17. Leaf area index

Treatment	Summer			*Kharif*		
	30DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Irrigation						
I_1 - Entire area	2.77	4.96	2.49	3.39	5.57	3.10
I_2 - ERW	2.75	4.93	2.50	3.42	5.51	3.11
SE_D	0.03	0.01	0.02	0.02	0.08	0.02
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	2.54	4.16	2.28	3.22	4.52	2.89
P_2 - 60 x 20 cm DSS	3.75	7.04	3.48	4.60	7.86	4.31
P_3 - 60 x 30 cm SSS	1.65	3.06	1.44	1.94	3.75	1.67
P_4 - 60 x 30 cm DSS	3.11	5.52	2.80	3.88	6.06	3.54
SE_D	0.05	0.05	0.04	0.04	0.19	0.05
CD (P = 0.05)	0.10	0.10	0.08	0.08	0.40	0.10
N levels (kg ha^{-1})						
N_1 - 100	2.36	4.42	2.11	3.06	5.16	2.76
N_2 - 135	2.74	4.99	2.49	3.38	5.58	3.07
N_3 - 170	3.19	5.43	2.89	3.78	5.89	3.48
SE_D	0.03	0.04	0.03	0.04	0.15	0.03
CD (P = 0.05)	0.07	0.08	0.05	0.07	0.31	0.06

Interaction present - furnished in Appendix C; (i) to (iii)

Table 18. Crop growth rate (g m^{-2} day^{-1})*

Treatment	Summer		*Kharif*	
	30-60 days	60-90 days	30-60 days	60-90days
Irrigation				
I_1 - Entire area	22.08	16.16	23.76	17.82
I_2 - ERW	21.94	16.17	23.48	17.80
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	20.27	15.65	22.62	17.64
P_2 - 60 x 20 cm DSS	25.16	18.60	26.78	20.13
P_3 - 60 x 30 cm SSS	17.62	13.69	19.95	15.26
P_4 - 60 x 30 cm DSS	23.88	16.72	24.84	18.14
N levels (kg ha^{-1})				
N_1 - 100	18.85	15.05	20.53	16.59
N_2 - 135	22.01	16.31	23.66	17.75
N_3 - 170	24.88	17.16	26.04	19.11

* Data not analysed

4.5. GROWTH ANALYSIS

4.5.1. Leaf area index (Table 17)

Kharif maize recorded higher LAI than the summer maize. The LAI of maize was higher upto 60 DAS and decreased thereafter.

During both the seasons, the irrigation levels failed to exert any significant effect on LAI throughout the crop growth period.

The LAI was significantly varying among different plant populations. It was significantly higher in 60 x 20 cm DSS (P_2) (7.04 and 7.86 in summer and *kharif* respectively at 60 DAS) followed by 60 x 30 cm DSS (P_4). The LAI recorded for 60 X 30 cm SSS (P_3) was minimum.

Application of N increased the LAI significantly at all stages of growth during both the seasons. The response was linear as in the case of plant height and DMP.

Interaction of plant population and levels of N was significant at 60 DAS during summer, and at harvest during summer and *kharif* (Appendix C; (i) to (iii)). The 60 x 20 cm DSS with 170 kg N ha^{-1} (P_2 N_3) recorded maximum LAI, while the minimum was in 60 x 30 cm SSS with 100 kg N ha^{-1} (P_3 N_1) at all the above mentioned stages.

4.5.2. Crop growth rate (Table 18)

A difference in CGR of maize between crop seasons was observed and *kharif* maize was superior to summer.

Irrigation levels had very narrow difference. However, plant populations had wide variation in CGR. The 60 x 20 cm DSS recorded the highest CGR

Table 19. **Relative growth rate (mg g^{-1} day^{-1})**

Treatment	Summer		*Kharif*	
	30-60 days	60-90 days	30-60 days	60-90days
Irrigation				
I_1 - Entire area	80.30	23.00	85.10	24.90
I_2 - ERW	80.20	22.90	85.20	24.70
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	80.20	23.60	85.30	25.10
P_2 - 60 x 20 cm DSS	79.30	21.30	84.50	22.90
P_3 - 60 x 30 cm SSS	81.00	24.90	86.00	27.20
P_4 - 60 x 30 cm DSS	79.80	22.20	85.00	24.10
N levels (kg ha^{-1})				
N_1 - 100	79.10	21.30	84.50	22.90
N_2 - 135	80.20	23.20	85.30	25.10
N_3 - 170	80.80	24.40	85.80	26.30

* Data not analysed

Table 20. **Root length (cm) and root dry weight (g)**

Treatment	Root length		Root dry weight	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	24.00	22.37	1.11	1.03
I_2 - ERW	24.35	22.76	1.13	1.05
SE_D	0.08	0.16	0.004	0.01
CD (P = 0.05)	0.21	NS	0.010	NS
Plant population (ha-1)				
P_1 - 60 x 20 cm SSS	24.42	22.87	1.12	1.07
P_2 - 60 x 20 cm DSS	22.21	20.51	1.02	0.95
P_3 - 60 x 30 cm SSS	26.91	25.26	1.27	1.17
P_4 - 60 x 30 cm DSS	23.17	21.61	1.08	0.99
SE_D	0.20	0.27	0.015	0.017
CD (P = 0.05)	0.42	0.61	0.030	0.038
N levels (kg ha-1)				
N_1 - 100	23.31	21.64	1.08	1.00
N_2 - 135	24.09	22.58	1.12	1.05
N_3 - 170	25.13	23.46	1.17	1.09
SE_D	0.15	0.24	0.009	0.012
CD = (P = 0.05)	0.29	0.49	0.019	0.025

Interaction absent.

(21.88 and 23.45 g m^{-2} day^{-1} in summer and *kharif* respectively) followed by 60 x 30 cm DSS during both the seasons. Lowest CGR value was recorded in 60 x 30 cm SSS.

A linear response to the application of N was noticed at both the stages and seasons of study.

4.5.3. Relative growth rate (Table 19)

The RGR was influenced by cropping seasons with higher values in *kharif.*

Irrigation levels did not show much difference during different stages and seasons.

Irrespective of stages and seasons, the RGR increased when maize was sown under 60 x 30 cm SSS (P_3) (52.95 and 56.6 mg g^{-1} day^{-1} in summer and *kharif* respectively). The lowest RGR was recorded with 60 x 20 cm DSS (P_2).

Application of N had a positive influence on RGR. The RGR increased with increasing levels of N throughout the crop growth period in both the seasons.

4.6. ROOT STUDIES

The root studies on root length and root dry weight showed increased values during summer. Irrigation levels influenced both the parameters during summer only, significantly higher values (24.35 and 22.76 cm and 1.13 and 1.05 g during summer and *kharif* respectively) being recorded when irrigation was given to the effetive root zone width.

Both root length and root weight were found to be reduced when plant population was increased during both the season. The maximum root length

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Table 21. Days to 50 per cent tasseling and silking

Treatment	Days to 50 per cent tasseling		Days to 50 per cent silking	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	50.8	52.1	58.3	60.7
I_2 - ERW	51.2	51.9	58.5	60.6
SE_D	0.29	0.15	0.08	0.26
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	50.1	51.7	57.5	60.8
P_2 - 60 x 20 cm DSS	53.7	54.3	61.2	62.8
P_3 - 60 x 30 cm SSS	48.7	49.4	55.8	58.0
P_4 - 60 x 30 cm DSS	51.6	52.7	58.9	60.9
SE_D	0.40	0.28	0.38	0.45
CD (P = 0.05)	0.82	0.58	0.78	0.92
N levels (kg ha^{-1})				
N_1 - 100	52.3	54.0	60.1	62.9
N_2 - 135	50.7	51.6	57.9	59.9
N_3 - 170	50.0	50.4	57.1	59.1
SE_D	0.30	0.33	0.18	0.44
CD (P = 0.05)	0.59	0.65	0.36	0.88

Interaction present - furnished in Appendix D and root weight (26.91 and 25.26 cm and 1.27 and 1.17 g during summer and *kharif* respectively) were recorded for 60 x 30 cm SSS (P_3).

Nitrogen had a positive influence on both these parameters during summer and *kharif*. The values were maximum with the application of 170 kg N ha^{-1}.

4.7. DURATION OF PHENOLOGICAL PHASES

4.7.1. Days to midtasseling and silking (Table 21)

Tasseling and silking were earlier in summer than in *kharif*. While moisture availability exhibited no significant influence plant population showed a significant influence. The tasseling and silking were earlier in 60 x 30 cm SSS (P_3) and delayed progressively as the plant population was increased and thus 60 x 20 cm DSS (P_2) took maximum days (54 and 62 days on an average) for tasseling and silking.

Both tasseling and silking were earlier in the case of plants which received the highest dose of (170 kg ha^{-1}) N during both the seasons.

Plant population and N levels exhibited significant interaction during *kharif* (Appendix D). Plants with 60 x 30 cm SSS at the highest level (170 kg ha^{-1}) of applied N took minimum days for tasseling. However, it was on par with 60 x 30 cm SSS 135 kg N ha^{-1} (P_3 N_2) and 60 x 20 cm SSS at 170 kg N ha^{-1}).

4.8. WEED STUDIES

The weed studies under varying wetting area, population and N levels may help to understand the weed dynamics under such situations.

Table 22. Weed population m^{-2} at 25 and 45 DAS

Treatment	25 DAS		45 DAS	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	9.06 (83.2)	10.19 (104.7)	11.01 (122.0)	11.95 (143.4)
I_2 - ERW	9.07 (83.3)	10.21 (105.0)	10.96 (121.1)	11.94 (143.2)
SE_D	0.61	0.05	0.06	0.05
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	9.33 (87.9)	10.62 (113.1)	11.25 (127.2)	12.27 (150.9)
P_2 - 60 x 20 cm DSS	8.12 (66.7)	9.20 (85.1)	10.06 (101.6)	11.10 (123.6)
P_3 - 60 x 30 cm SSS	9.86 (98.2)	11.10 (123.6)	11.75 (138.4)	12.69 (161.3)
P_4 - 60 x 30 cm DSS	8.94 (80.4)	9.87 (97.6)	10.89 (118.9)	11.72 (137.5)
SE_D	0.17	0.07	0.08	0.07
CD (P = 0.05)	0.34	0.14	0.16	0.14
N levels (kg ha^{-1})				
N_1 - 100	9.47 (90.8)	10.59 (113.0)	11.35 (129.5)	12.29 (151.6)
N_2 - 135	9.04 (82.8)	10.15 (103.8)	10.97 (121.0)	11.94 (143.2)
N_3 - 170	8.67 (76.3)	9.85 (97.9)	10.64 (114.2)	11.61 (135.2)
SE_D	0.11	0.07	0.07	0.06
CD (P = 0.05)	0.22	0.13	0.13	0.12

Interaction absent.

Table 23. Weed DMP (kg ha^{-1}) at 25 and 45 DAS

Treatment	25 DAS		45 DAS	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	96	119	548	646
I_2 - ERW	93	116	546	649
SE_D	2	1.5	2	4
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	102	128	572	683
P_2 - 60 x 20 cm DSS	78	100	456	558
P_3 - 60 x 30 cm SSS	112	136	626	725
P_4 - 60 x 30 cm DSS	94	112	539	624
SE_D	2	2	6	6
CD (P = 0.05)	4	4	13	12
N levels (kg ha^{-1})				
N_1 - 100	105	128	595	699
N_2 - 135	96	117	539	642
N_3 - 170	87	111	511	601
SE_D	1.5	1.3	4	5
CD (P = 0.05)	3	2.5	8	11

Interaction present - furinshed in Appendix E

Table 24. N uptake (kg ha^{-1})

Treatment	Summer			*Kharif*		
	30DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Irrigation						
I_1 - Entire area	6.8	89.4	137.9	7.1	92.3	152.9
I_2 - ERW	6.8	89.4	140.2	7.1	90.8	152.3
SE_D	0.2	0S.61	1.26	0.04	2.05	0.79
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Plant population (ha^{-1})						
P_1 - 60 x 20 cm SSS	6.1	81.1	133.8	6.3	81.3	153.9
P_2 - 60 x 20 cm DSS	8.3	108.6	163.6	8.6	107.8	172.2
P_3 - 60 x 30 cm SSS	5.2	67.9	99.5	5.5	73.3	123.1
P_4 - 60 x 30 cm DSS	7.7	99.9	159.4	7.9	103.9	161.7
SE_D	0.18	0.48	3.44	0.14	2.78	1.26
CD (P = 0.05)	0.36	0.98	7.02	0.31	5.68	2.57
N levels (kg ha^{-1})						
N_1 - 100	5.5	71.4	121.7	5.8	71.9	135.8
N_2 - 135	6.8	89.1	139.5	7.1	91.8	152.3
N_3 - 170	8.1	107.7	156.1	8.4	111.1	169.8
SE_D	0.15	0.61	1.13	0.16	0.81	1.21
CD (P = 0.05)	0.30	1.22	2.24	0.34	1.62	2.40

Interaction present - furinshed in Appendix F; (i) to (iv)

4.8.1. Weed population (Table 22)

The weed count recorded at 25 and 45 DAS revealed that the weed interference was more during *kharif* than in summer.

Irrigation did not exert any significant influence on weed interference.

The weed interference was minimum in 60 x 20 cm DSS (P_2) and as the population decreased, there was a corresponding increase in weed count. Maximum weed population was observed in 60 x 30 cm SSS (P_3). The weed count decreased as the N application rate was increased.

4.8.2. Weed drymatter production (Table 23)

The weed DMP followed the same trend as that of weed count with respect to seasons, stages of growth and treatments.

However, a significant interaction effect was noticed for plant population and N levels at 45 DAS during *Kharif* (Appendix E). Maximum weed DMP (789 kg ha^{-1}) was recorded by 60 x 30 cm SSS at 100 kg N ha^{-1} (P_1 N_1).

4.9. PLANT NUTRIENT UPTAKE

4.9.1. N Uptake (Table 24)

The N uptake increased steadily from 30 DAS till harvest. Compared to summer season, the N uptake was more during *kharif*.

Variation in irrigation quantities could not exert any significant influence on N uptake by maize crop.

The N uptake was positively influenced by plant population at all the stages in both the seasons. Higher plant population favoured higher N uptake.

The incremental N applications increased its uptake by maize irrespective of the season and growth stages and the response was linear.

Table 25. **P and K uptake at harvest (kg ha^{-1})**

Treatment	P uptake		K Uptake	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	44.8	52.7	205.1	230.1
I_2 - ERW	44.1	52.5	203.3	227.3
SE_D	0.09	0.12	2.66	2.29
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	44.1	51.9	203.7	230.1
P_2 - 60 x 20 cm DSS	51.7	57.5	236.1	249.7
P_3 - 60 x 30 cm SSS	35.7	46.9	164.8	203.3
P_4 - 60 x 30 cm DSS	46.2	54.1	216.9	236.7
SE_D	0.89	0.44	4.38	2.29
CD (P = 0.05)	1.82	0.90	8.95	5.36
N levels (kg ha^{-1})				
N_1 - 100	41.7	49.4	191	217.3
N_2 - 135	44.9	53.1	206	220.1
N_3 - 170	46.7	55.4	210	224.8
SE_D	0.84	0.40	1.29	3.98
CD (P = 0.05)	1.67	0.80	2.56	7.92

Interaction absent.

Table 26. Cob length and Cob girth (cm)

Treatment	Cob length		Cob girth	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	16.1	16.7	12.1	13.1
I_2 - ERW	15.9	16.7	12.0	13.1
SE_D	0.15	0.31	0.20	0.25
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	16.1	17.0	12.2	13.3
P_2 - 60 x 20 cm DSS	14.1	14.8	11.2	12.1
P_3 - 60 x 30 cm SSS	18.2	18.7	12.8	14.1
P_4 - 60 x 30 cm DSS	15.7	16.4	11.9	13.0
SE_D	0.22	0.41	0.23	0.21
CD (P = 0.05)	0.45	0.84	0.46	0.43
N levels (kg ha^{-1})				
N_1 - 100	14.6	15.1	11.0	11.8
N_2 - 135	16.2	16.7	12.4	13.3
N_3 - 170	17.2	18.3	12.8	14.3
SE_D	0.19	0.12	0.13	0.19
CD (P = 0.05)	0.37	0.24	0.26	0.39

Interaction present - furnished in Appendix G

Plant population and N levels has a conspicuous interaction effect at 30 DAS (Appendix F; (i) to (ii)) and at harvest (Appendix F; (iii) to (iv)) during both the seasons. The 60 x 20 cm DSS at 170 kg N ha^{-1} (P_2 N_3) recorded the highest uptake (10.1 and 10.4 kg ha^{-1} in summer and *kharif* respectively) during both the seasons at 30 DAS. At harvest also, the same trend was noticed during *kharif*, but during summer, the treatments 60 x 20 cm and 60 x 30 cm DSS at N_3 level (P_2 N_3 and P_4 N_3) were found to be on par with each other.

4.9.2. P uptake at harvest (Table 25)

The P uptake was higher during *kharif* than in summer season.

Irrigation levels failed to exert any significant influence on P uptake.

Plants with 60 x 20 cm DSS (P_2) displayed the highest P uptake (51.7 and 57.5 kg ha^{-1} summer and *kharif*) during both the seasons. The P uptake recorded by 60 x 30 cm SSS (P_3) was minimum.

Nitrogen application positively affected the P uptake. The P uptake increased progressively with increase in the level of applied N.

4.9.3. K uptake at harvest (Table 25)

The uptake of K followed the same trend as in the case of P. In general, the uptake was more in *kharif*.

4.10. YIELD COMPONENTS

4.10.1. Cob length (table 26)

In general, the maize crop produced longer cobs during *kharif*.

The cob length was not significantly affected by irrigation treatments.

Table 27 . Grain rows cob^{-1} and grain number cob^{-1}

Treatment	Grain rows cob^{-1}		Grain number cob^{-1}	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	12.8	12.9	379	415
I_2 - ERW	12.8	12.9	377	413
SE_D	0.07	0.11	2	3
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	13.3	13.5	412	452
P_2 - 60 x 20 cm DSS	11.6	11.2	282	308
P_3 - 60 x 30 cm SSS	13.6	13.9	465	507
P_4 - 60 x 30 cm DSS	12.5	12.9	354	389
SE_D	0.15	0.17	5.0	4.5
CD (P = 0.05)	0.31	0.32	10.0	9.0
N levels (kg ha^{-1})				
N_1 - 100	11.6	11.6	309	336
N_2 - 135	13.1	13.1	387	424
N_3 - 170	13.6	13.9	440	483
SE_D	0.12	0.11	3	5
CD (P = 0.05)	0.24	0.23	7	10

Interaction present - furnished in Appendix H and I ; (i) and (ii)

With respect to plant population, the 60 x 30 cm SSS (P_3) recorded the maximum cob length (18.2 and 18.7 cm in summer and *kharif*) followed by 60 x 20 cm SSS (P_1) which was comparable with 60 x 30 cm DSS (P_4) during *kharif*. The cob length was minimum for 60 x 20 cm DSS (P_2) during both the seasons.

Irrespective of the season, the N application exerted a positive influence on cob length with longer cobs associated with higher level of N during both the seasons.

Interaction effect of plant population and nitrogen levels were significant during *kharif* (Appendix G) and was maximum in 60 x 30 cm SSS and 170 kg N ha^{-1} ($P_3 N_3$) combination.

4.10.2. Cob girth (Table 26)

kharif plants recorded more cob girth than summer plants. Irrigation treatments had no significant influence on cob girth.

The cob girth was significantly reduced by increasing the plant population, irrespective of the season. The cob girth was the lowest in 60 x 20 cm DSS (P_2) and 60 x 30 cm SSS (P_3) recorded the highest value (12.8 and14.1 cm in summer and *kharif* respectively). The cob girth was maximum when N was applied at the rate of 170 kg ha^{-1}.

4.10.3. Grain rows cob^{-1} (Table 27)

Grain rows per cob was higher in *kharif* maize compared to summer maize.

The effect of irrigation treatments on row number per cob was negligible. Plants with 60 x 30 cm SSS (P_3) recorded more row number, but it was comparable with 60 x 20 cm SSS (P_1) during summer. The response to N application was linear.

Significant interaction effect was noticed in plant population and nitrogen combination (Appendix H). The 60 x 30 cm SSS at 170 kg N ha^{-1} (P_3 N_3) recorded the maximum row numbers (14.7) followed by 60 x 20 cm SSS at the N_3 level (P_1 N_3) during *kharif.* However, during summer these two treatments were on par with each other.

4.10.4. Grain number cob^{-1} (Table 27)

In general, *kharif* crop produced cobs with more grains than summer crop.

Grain number per cob was significantly influenced by plant population and nitrogen levels during both the seasons, but it was unaffected by the irrigation treatments. Number of grains per cob was smaller for plants with higher population. The maximum grain number per cob was recorded for 60 x 30 cm SSS (P_3) during both the seasons.

More number of grains per cob was noticed in the highest level of applied N, viz., 170 kg ha^{-1}.

significant interaction was noticed in plant population and levels of N combination during both the seasons (Appendix I ; (i) to (ii)). In summer, 60 x 30 cm SSS at N_3 level (P_3 N_3) recorded the maximum grain number per cob (548) followed by 60 x 30 cm SSS at N_2 level (P_3 N_2). During *kharif* also, the grain number per cob was the highest in 60 x 30 cm SSS at N_3 level (P_3 N_3) (597) followed by 60 x 30 cm SSS at N_2 level (P_3 N_2) and 60 x 20 cm SSS at N_3 level (P_1 N_3) which were on par with each other.

Table 28. Grain number row^{-1} and 100 grain weight (g)

Treatment	Grain number row^{-1}		100 grain weight	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	29.6	32.0	22.8	24.2
I_2 - ERW	29.3	31.8	22.6	24.0
SE_D	0.42	0.34	0.10	0.18
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	30.6	32.9	23.8	25.2
P_2 - 60 x 20 cm DSS	25.2	28.0	19.9	20.3
P_3 - 60 x 30 cm SSS	34.0	36.3	25.6	27.6
P_4 - 60 x 30 cm DSS	27.9	30.3	21.7	23.7
SE_D	0.53	0.61	0.13	0.36
CD (P = 0.05)	1.16	1.34	0.27	0.75
N levels (kg ha^{-1})				
N_1 - 100	26.6	28.9	20.6	21.9
N_2 - 135	29.6	32.1	23.0	24.6
N_3 - 170	32.2	34.7	24.7	26.1
SE_D	0.49	0.35	0.14	0.27
CD (P = 0.05)	1.00	0.72	0.29	0.54

Interaction present - furnished in Appendix J and K

4.10.5. Grain number row^{-1} (Table 28)

Number of grains per row was influenced by the seasons. *kharif* plants had more grains per row compared to summer plants.

Irrigation treatments failed to exert any significant influence on number of grains per row.

Plant population and N levels had a significant influence on grain number per row. The 60 x 30 cm SSS (P_3) recorded maximum grain number row^{-1} (34 and 36.3 during summer and *kharif* respectively) and the minimum was recorded by 60 x 20 cm DSS (P_2). Similarly maximum number of grains per row was recorded at the highest level of N (170 kg N ha^{-1}).

Significant interaction of plant population and nitrogen levels during *kharif* (Appendix J) showed that 60 x 30 cm SSS at 170 kg N ha^{-1} (P_3 N_3) recorded more number of grains per row followed by 60 x 30 cm SSS at 135 kg N ha^{-1} (P_3 N_2).

4.10.6. Hundred grain weight (Table 28)

kharif plants produced bold grains compared to summer plants.

Variation in 100 grain weight with respect to irrigation treatments was not significant.

A progressive decline in 100 grain weight was noticed with increase in plant population. The 60 x 30 cm SSS (P_3) recorded the highest value (25.6 and 27.6 in summer and *kharif*) followed by 60 x 20 cm SSS (P_1). Heavy grains were associated with increased N levels.

Interaction of plant population and N levels during summer (Appendix K) showed that it was maximum for 60 x 30 cm SSS at the N_3 level (P_3 N_3) followed

Table 29. **Shelling percentage (%) and harvest index**

Treatment	Shelling percentage		Harvest index	
	Summer	Kharif	Summer	Kharif
Irrigation				
I_1 - Entire area	70.2	70.9	0.35	0.38
I_2 - ERW	69.5	70.3	0.35	0.38
SE_D	0.31	0.22	0.002	0.001
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	70.60	71.30	0.35	0.38
P_2 - 60 x 20 cm DSS	68.10	68.30	0.31	0.34
P_3 - 60 x 30 cm SSS	71.8	72.6	0.39	0.40
P_4 - 60 x 30 cm DSS	68.8	69.6	0.37	0.39
SE_D	0.43	0.41	0.005	0.004
CD (P = 0.05)	0.89	0.84	0.01	0.007
N levels (kg ha^{-1})				
N_1 - 100	65.7	66.1	0.34	0.36
N_2 - 135	70.7	71.5	0.36	0.38
N_3 - 170	73.2	74.1	0.37	0.39
SE_D	0.35	0.32	0.003	0.002
CD (P = 0.05)	0.71	0.65	0.005	0.004

Interaction present - furnished in Appendix L; (i) to (ii) by 60 x 30 cm SSS at N_2 level (P_3 N_2) and 60 x 20 cm SSS at N_3 level (P_1 N_3) which were on par with each other.

4.10.7. shelling percentage (Table 29)

In summer and *kharif* seasons, shelling percentage did not differ much along with the treatments eventhough it was slightly higher during *kharif* season.

While the response to irrigation was not significant, a declining trend was noticed with increase in plant population and a raising trend with increase in N applications.

The interaction effect of plant population and N levels was significant during summer and *kharif* (Appendix M (i) to (ii)) and the treatment combinations 60 x 30 cm SSS at N_2 and N_3 level (P_3 N_2 and P_3 N_3) and 60 x 20 cm SSS and 60 x 30 cm DSS at N_3 level (P_1 N_3 and P_4 N_3) had a significant but comparable performance irrespective of the seasons.

4.10.8. Harvest index (Table 29)

Harvest index was found to be higher during *Kharif* than summer.

Irrigation treatments did not appreciably influence the HI during both the seasons.

Variation in plant population significantly influenced the HI during summer and *kharif.* The maximum (0.39 and 0.40 during summer and *kharif* respectively) were recorded under 60 x 30 cm SSS (P_3) followed by 60 x 30 cm DSS (P_4). The minimum was under 60 x 20 cm DSS (P_2).

Table 30. Grain yield and Stover yield (kg ha^{-1})

Treatment	Grain yield		Stover yield	
	Summer	*Kharif*	Summer	*Kharif*
Irrigation				
I_1 - Entire area	4973	6140	9398	10164
I_2 - ERW	4954	6136	9301	10084
SE_D	22.4	32.8	63.1	63.2
CD (P = 0.05)	NS	NS	NS	NS
Plant population (ha^{-1})				
P_1 - 60 x 20 cm SSS	4992	6175	9251	10180
P_2 - 60 x 20 cm DSS	4831	5985	11034	11423
P_3 - 60 x 30 cm SSS	4528	5731	6892	8537
P_4 - 60 x 30 cm DSS	5505	6663	9561	10356
SE_D	39.5	44.6	111.8	123.3
CD (P = 0.05)	80.6	91.0	288.4	251.9
N levels (kg ha^{-1})				
N_1 - 100	4322	5366	9025	9788
N_2 - 135	5108	6303	9340	10141
N_3 - 170	5461	6746	9788	10442
SE_D	26.5	38.8	78.9	83.3
CD (P = 0.05)	52.8	77.2	157.2	165.8

Interation present - furnished in Appendix M; (i) to (ii)

4.11. ECONOMIC YIELDS

4.11.1. Grain yield (Table 30)

The grain yield was higher during *kharif* than during summer. Irrigation levels failed to influence the grain yield during both the seasons. However, substantial variation in grain yield was observed with respect to different plant population and nitrogen levels tried.

Crop sown with 60 x 30 cm DSS (P_4) registered the maximum grain yield (5505 and 6663 kg ha^{-1}) during summer and *kharif,* which were 10.2 per cent and 7.9 per cent higher than the grain yield recorded under the normal recommended spacing (60 x 20 cm SSS - P_1). However raising the plant population further by adopting the spacing of 60 x 20 cm DSS (P_2), resulted in a reduction in grain yield (4831 and 5985 kg ha^{-1} during summer and *kharif* respectively). The minimum grain yield was registered under 60 x 30 cm SSS -P_3 (4528 and 5731 kg ha^{-1} during summer and *kharif* respectively).

Grain yield declined as the N application rate was reduced reaching the minimum at 100 kg N ha^{-1} (N_1).

Interaction of plant population with nitrogen levels had a distinct effect on grain yield (Appendix L; (i) to (ii)). During summer, crops sown with 60 x 30 cm DSS (P_4 N_3) registered higher values (6075 kg ha^{-1}) over other treatment combinations. This was followed by 60 x 30 cm DSS with 135 kg N ha^{-1} (P_4 N_2). During *kharif* also, the maximum grain (7407 kg ha^{-1}) yield was recorded for the same treatment combination, followed by 60 x 20 cm SSS with 170 kg N ha^{-1} (P_1 N_3) and 60 x 30 cm DSS with 135 kg N ha^{-1} (P_4 N_2) which were comparable with each other.

Table 31. Post harvest soil available N (kg ha^{-1})

Treatment	Summer	*Kharif*
Irrigation		
I_1 - Entire area	161.9	151.8
I_2 - ERW	162.2	152.1
SE_D	0.35	2.2
CD (P = 0.05)	NS	NS
Plant population (ha^{-1})		
P_1 - 60 x 20 cm SSS	163.4	152.6
P_2 - 60 x 20 cm DSS	153.1	144.5
P_3 - 60 x 30 cm SSS	175.1	160.4
P_4 - 60 x 30 cm DSS	156.7	150.2
SE_D	2.1	1.7
CD (P = 0.05)	4.2	3.6
N levels (kg ha^{-1})		
N_1 - 100	155.9	145.9
N_2 - 135	162.5	152.0
N_3 - 170	167.8	157.9
SE_D	1.8	1.7
CD (P = 0.05)	3.5	3.3

Interaction absent.

Table 32. Seed protein content (%)

Treatment	Summer	*Kharif*
Irrigation		
I_1 - Entire area	8.5	8.4
I_2 - ERW	8.6	8.4
SE_D	.03	.01
CD (P = 0.05)	NS	NS
Plant population (ha^{-1})		
P1- 60 x 20 cm SSS	8.7	8.6
P_2 - 60 x 20 cm DSS	8.1	7.9
P_3 - 60 x 30 cm SSS	9.1	8.9
P_4 - 60 x 30 cm DSS	8.4	8.3
SE_D	0.06	0.05
CD (P = 0.05)	0.13	0.11
N levels (kg ha^{-1})		
N_1 - 100	8.4	8.2
N_2 - 135	8.6	8.4
N_3 - 170	8.8	8.7
SE_D	0.07	0.04
CD (P = 0.05)	0.14	0.08

Interaction absent.

4.11.2. Stover yield (Table 30)

There was marked difference in stover yield of maize between seasons. Stover yield was more during *Kharif* .

Irrigation treatments had little influence on stover yield during both the seasons.

The highest stover yield was recorded under 60 x 20 cm DSS, viz., 11,034 and 11,423 kg ha^{-1} during summer and *kharif* respectively and the lowest under 60 x 30 cm SSS, viz., 6892 and 8537 kg ha^{-1} respectively during summer and *kharif.* The response to N was linear with the maximum stover yield recorded at the highest level of N, viz., 9788 and 10,442 kg ha^{-1} during summer and *kharif* respectively.

4.12. POST HARVEST ANALYSIS OF SOIL

4.12.1. Soil available N (Table 31)

The soil N status at post harvest stage varied between different seasons. The soil N was more during summer than *kharif.*

Irrigation treatments failed to influence the soil N availability. However, the residual N status was significantly higher in P_3 (175.1 kg ha^{-1}) followed by P_1 during summer.

During *kharif* also, the soil available N content was maximum in P_3 (160.4 kg ha^{-1}) followed by P_1 and P_4 which were comparable with each other. The residual N status increased with increasing levels of N.

4.13. QUALITY STUDIES

4.13.1. Seed protein content (Table 32)

Seed protein content was influenced by crop season. An increased protein content was observed in summer over *kharif.*

Table 33. **Water use efficiency (kg ha^{-1} mm^{-1})**

Treatment	Summer	*Kharif*
Irrigation		
I_1 - Entire area	8.2	10.9
I_2 - ERW	8.8	11.0
SE_D	0.11	0.08
CD (P = 0.05)	0.29	NS
Plant population (ha^{-1})		
P_1 - 60 x 20 cm SSS	8.6	11.00
P_2 - 60 x 20 cm DSS	8.3	10.7
P_3 - 60 x 30 cm SSS	7.8	10.2
P_4 - 60 x 30 cm DSS	9.4	11.9
SE_D	0.06	0.07
CD (P = 0.05)	0.13	0.14
N levels (kg ha^{-1})		
N_1 - 100	7.5	9.6
N_2 - 135	8.7	11.2
N_3 - 170	9.3	12.0
SE_D	0.10	0.07
CD (P = 0.05)	0.20	0.13

Interaction present - furnished in Appendix N

Seed protein content did not differ significantly between irrigation levels. It was higher under 60x 30 cm SSS (P_3) (9.1 and 8.9 per cent in summer and *kharif* respectively) and gradually got reduced with increase in plant population. The trend was the same during both the seasons.

Irrespective of the seasons, the seed protein content was higher with the application of 170 kg N ha^{-1} and the lowest value was registered for the lowest level of N.

4.14. WATER USE EFFICIENCY (Table 33)

The water use efficiency was more during *kharif* than summer.

The WUE was significantly influenced by irrigation levels during summer only with higher value recorded under I_2 (Irrigation to the effective root zone width followed by I_1 (Irrigation to the entire area).

The WUE varied significantly with respect to plant population. The highest WUEs (9.4 and 11.9 kg ha^{-1} mm^{-1} in summer and *kharif* respectively) were registered under 60 x 30 cm DSS (P_4) followed by 60 x 20 cm SSS (P_1) during both the seasons. The lowest value was registered under 60 x 20 cm DSS (P_2). The WUE was positively influenced by N application in both the seasons. An increasing trend in WUE was noticed with increasing levels of applied N.

Plant population and nitrogen levels had a conspicuous interaction during *kharif* only (Appendix N). The 60 x 30 cm DSS at N_3 level (P_4 N_3) registered the maximum WUE. The next best and comparable WUE noticed with 60 x 30 cm DSS at N_2 level (P_4 N_2) and 60 x 20 cm SSS at N_3 level (P_1 N_3) combinations.

Table 34. Economics - Summer*

Treatment	Gross return Rs. ha^{-1}	Cost of cultuvation Rs. ha^{-1}	Net return Rs. ha^{-1}	B.C. ratio	Per day gross return Rs. ha^{-1}
Irrigation					
I_1 - Entire area	22217	8546	13671	2.60	222
I_2 - ERW	22141	8546	13595	2.59	221
Plant population (ha^{-1})					
P_1 - 60 x 20 cm SSS	22268	8506	13762	2.62	223
P_2 - 60 x 20 cm DSS	22070	8706	13364	2.54	220
P_3 - 60 x 30 cm SSS	19837	8446	11391	2.35	198
P_4 - 60 x 30 cm DSS	24395	8526	15869	2.86	244
N levels (kg ha^{-1})					
N_1 - 100	19538	8288	11250	2.36	195
N_2 - 135	22757	8561	14196	2.66	228
N_3 - 170	24294	8835	15459	2.75	243

* Data not analysed.

Table 35. Economics-*Kharif* *

Treatment	Gross return Rs. ha^{-1}	Cost of cultuvation Rs. ha^{-1}	Net return Rs. ha^{-1}	B.C. ratio	Per day gross return Rs. ha^{-1}
Irrigation					
I_1 - Entire area	27085	8482	18603	3.1 9	263
I_2 - ERW	27044	8482	18562	3.18	262.5
Plant population (ha^{-1})					
P_1 - 60 x 20 cm SSS	27225	8442	18783	3.22	264
P_2 - 60 x 20 cm DSS	26790	8642	18148	3.09	260
P_3 - 60 x 30 cm SSS	26790	8382	16667	2.98	243
P_4 - 60 x 30 cm DSS	25049	8462	20765	3:45	283
N levels (kg ha^{-1})					
N_1 - 100	23889	8224	15.665	2.90	232
N_2 - 135	27737	8497	19240	3.26	269
N_3 - 170	29584	8771	20813	3.37	287

* Data not analysed.

4.15. ECONOMICS

4.15.1. Gross and net returns (Table 34;35)

Gross and net returns were higher during *kharif* than during summer.

They did not vary much with irrigation treatments. But plant population and nitrogen levels altered the gross and net returns in both the seasons of study with 60 x 30 cm DSS (P_4) producing higher values followed by 60 x 20 cm SSS (P_1), the net returns per ha being Rs.15,869 and Rs. 20,765 in summer and *kharif*. Minimum values were registered under 60 x 30 cm SSS (P_3) during both the seasons. Higher rates of N application favoured higher values irrespective of season.

4.15.2. Benefit - cost ratio and per day gross returns (Table 34;35)

In general, benefit - cost ratio and per day gross returns conferred to the same trend as that of gross and net returns during both the seasons.

4.16. MODELLING STUDIES

The plant population (x) and grain yield of maize (y) were related using the modelling function

$$y^{-1} = a + bx^{2.5} + cx^3$$

where,

a, b and c are parametric constants.

a = 0.00024 and 0.00019 in summer and *kharif* respectively.

b = - 6.719 e^{-17} and - 4.234 e^{-17} in summer and *kharif* respectively.

c = 1.570 e^{-19} and 9.923 e^{-20} in summer and *kharif* respectively.

The yield density model showed a high regression coefficient value (R^2 = 0.99) and was highly significant.

DISCUSSION

CHAPTER V

DISCUSSION

The results of the investigations on yield maximization of maize presented in the previous chapter are discussed in this chapter with supporting literature to evaluate the experimental results.

5.1. SEASONAL EFFECT

With the advancement of the crop growth, the *kharif* season was characterised by a slow but steady decrease in air temperature while summer was characterised by a steady increase in air temperature (Table 2). During *kharif*, the cumulative pan evaporation and effective rainfall on an average were 535 mm and 214 mm respectively, whereas during summer the same were 562 mm and 106 mm respectively. The relative humidity showed a slow increase during *kharif* from sowing to maturity, while a slow decrease was observed during summer (Table 2). The mean sunshine hours were also less during *kharif* compared to summer.

Prevalence of low temperatures and sunshine hours with the required solar radiation during the crop growth period in the *kharif* season favoured higher growth components like plant height, LAI and DMP. Further, low evaporation coupled with increased availability of effective rainfall through intermittent showers obtained during *kharif* created a minimum environmental stress and thereby maintained favourable plant water relations and enhanced photosynthetic efficiency. These favourable weather conditions favoured the enhancement of yield components like ear size, kernel number and kernel weight leading to effective grain filling process, which in turn led to increased

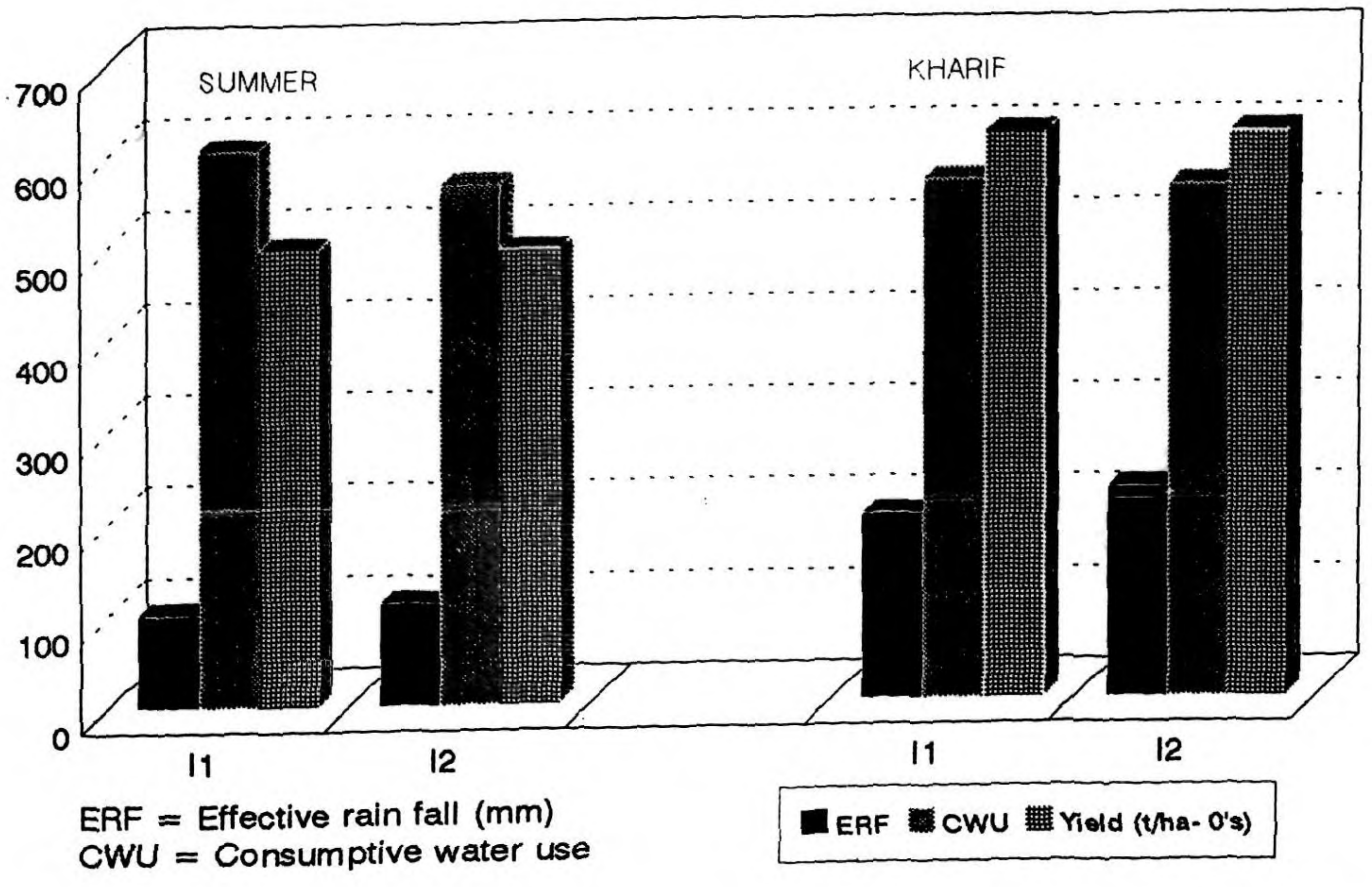


Fig 4. Effect of consumptive water use and effective rainfall on maize grain yield

grain yield from the *kharif* maize compared to summer maize. Similar influence of weather parameters on growth, yield components and yield of maize were also reported by other workers (Neild, 1982; Panchanathan, 1987).

5.2. WATER USE STUDIES

The water use varied from season to season owing to the climate. The water use studies, viz., consumptive use, soil moisture content before each irrigation and moisture depletion pattern helped to arrive at the optimum quantity of irrigation water by reasoning out from the water status.

Consumptive water use is one of the most effective tools in the efficient scheduling and management of irrigation water. The consumptive water use for a given crop would depend upon the plant growth stages as well as prevailing climatic conditions (Prihar and Sandhu, 1987). Irrigation to effective root zone width (ERW) resulted in 9.9 and 9.6 per cent savings in irrigation water during summer and *kharif* respectively compared to irrigation to the entire area.

The marginal variation in consumptive water use between the irrigation treatments during *kharif* as against the marked difference of 40 mm during summer is attributed to the contribution from effective rainfall (Fig.4.). The effective rainfall was 10 mm and 27 mm more for I_2 than for I_1 during summer and *kharif* respectively. The intermittent rain received has also reduced the number of irrigations required to maintain the respective prescribed moisture levels during both the *kharif* seasons. However, irrigations were given during summer as per schedule and the supplementary contribution from effective rainfall was relatively limited.

Resorting to irrigation to ERW resulted in water saving through its effective utilization of available water (both irrigation water and rainfall) without affecting the soil and plant water status as evidenced from soil moisture contents estimated before each irrigation and also from soil moisture depletion pattern (Table 5 and 6). For I_1 the evaporation and percolation losses of water may be higher as a result of larger wetted area over I_2.

Under non-limiting conditions of water supply, ET is largely governed by the dynamics of microclimate rather than the plant and soil factors (Gardner, 1965). But, when weather parameters remain the same, the loss of water through ET becomes a function of soil moisture supply (Prihar and Sandhu, 1987). In the present investigation also, the same trend was noticed. Consumptive water use, the rate of water use and ET/Ep ratio being higher for irrigation to the entire area than for irrigation to the ERW during both *kharif* and summer seasons.

The increased soil moisture depletion and the reduced soil moisture content associated with higher population can be attributed to the increased number of plants per unit area under high plant population, extracting more moisture from the soil. Karlen and Camp (1985) and Uthayakumar (1987) also reported that as the plant population increased, the volume of water absorbed also generally increased.

A perusal of the data on moisture depletion pattern reveals that the top 0-30 cm layer is contributing more towards ET (Table 6) Toit and Human (1995) observed that the percentage of available water in the top 0-30 cm layer was less than 25 per cent for most of the active growing period.

Adequate N could adjust osmotic potential by accumulating N compounds and other assimilates with more efficient utilization of available soil moisture. (Bataglia *et al.*, 1985). This reasoning could be advanced to explain the observed variation in the SMC and depletion associated with N application.

5.3. WATER RELATIONS ON MAIZE PHYSIOLOGY

Whenever, the plants are subjected to adverse conditions, viz., water stress, high temperature, low nutrient situation etc., the plant is likely to accumulate more proline which helps the plant to overcome the adverse conditions. (Patil *et al.*, 1984).

Proline acts as an osmoticum and a source of readily available energy and aminoacids. In the present study, the proline content didn't vary significantly between the irrigation treatments indicating the absence of water stress, but the content is relatively higher under higher population and low level of N indicating the presence of water stress under such conditions.

The RLWC shows a reducing trend under moisture stress conditions (Bardford and Hsiao, 1982; Jeyakumar, 1991). In the present study, the RLWC did not vary much with irrigation levels showing the absence of water stress even while irrigating to effective root zone width alone. However, at higher population, a reducing trend in RLWC was noticed indicating a possible water stress due to the extraction of more moisture by a larger number of plants per unit area.

Higher RLWC maintained by the plants receiving increased rate of N application may be due to higher absorption of water. Bennett *et al.* (1986) suggested that N deficient maize leaves were more sensitive to water deficits than leaves from N sufficient plants.

Cooler canopies are associated with adequate moisture content and leaf temperature was progressively higher with increasing soil moisture stress (Inoue, 1987). The leaf temperature was comparable for I_1 and I_2 pointing towards a favourable plant water relation and desirable transpiration rate for I_2 also. The slightly higher leaf temperature in the higher populaton was due to the greater depletion of available water by maize than under medium and low population rates as reported by steiner (1987).

Higher doses of N application reduced the leaf temperature owing to the higher uptake of water as evidenced from the increased RLWC, resulting in a greater transpirational cooling. Selvaraju and Iruthayaraj (1994) also expressed similar views.

Transpiration rate did not vary much between the irrigation levels indicating a judicious soil moisture supply in the case of I_2 also. Kabasi (1988) reported that transpiration and its intensity are directly related to the quantity of easily accessible moisture in the soil.

In general, whenever moisture stress occured, the stomatal conductance and transpiration rate were decreased and the leaf temperature and stomatal diffusive resistance were increased (Ehrler, 1983; Khera and Sandhu, 1986).

The plants under higher population and reduced N application exhibited a similar trend in physiological water relations.

5.4. PHYSIOLOGICAL PARAMETERS

All the physiological parameters as well as growth indices studied were affected by the plant population and nitrogen levels.

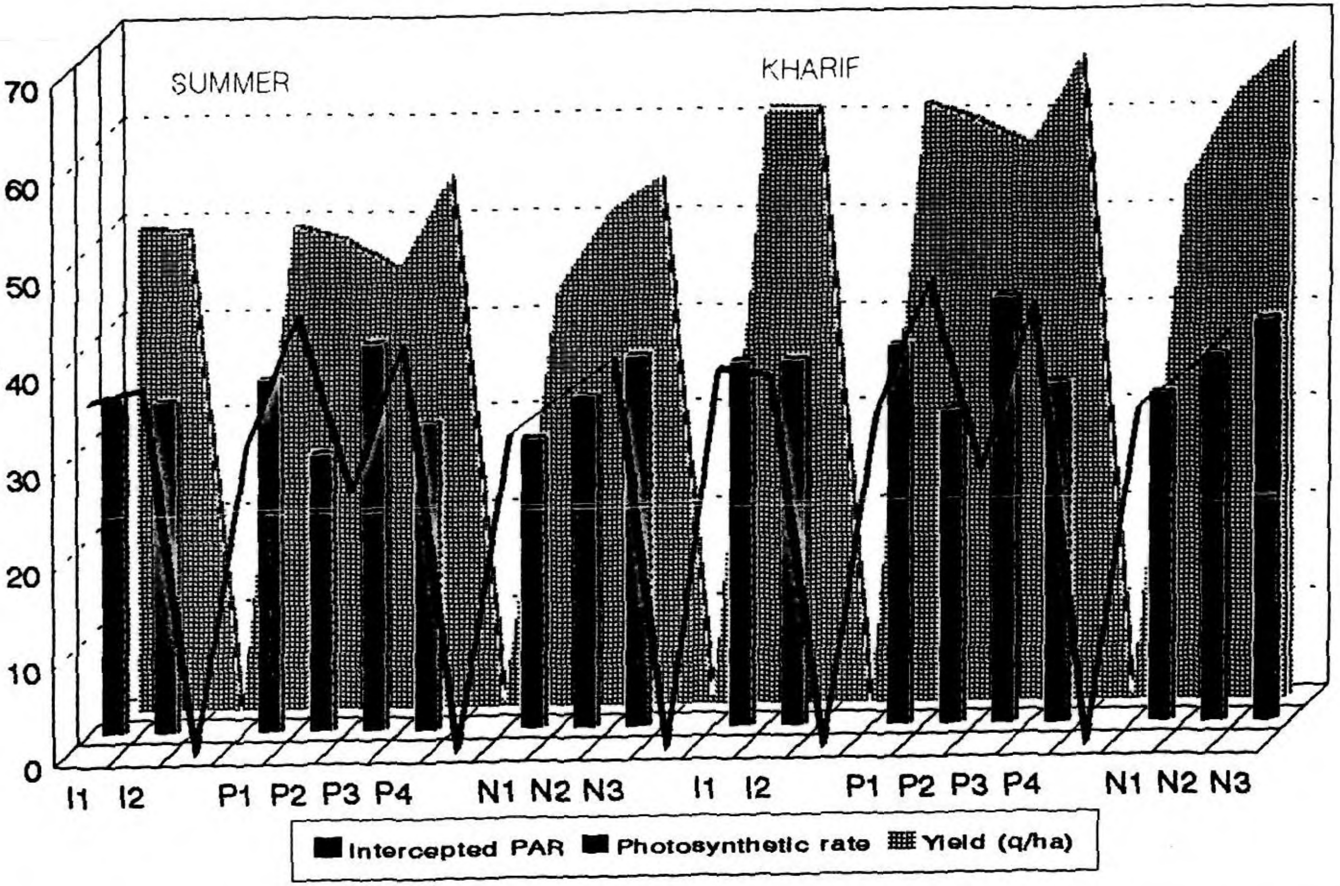


Fig 5. Effect of intercepted PAR and photosynthetic rate on maize grain yield

At the time of flowering, the highest plant population (P_2) had 28.2 per cent lower photosynthetic rate than the lowest plant density (P_3) (Fig.5.). This reduction in the rate of photosynthesis was attributed to mutual shading at higher plant densities and to the decrease in chlorophyll content (Table 11 and 12). Other researchers (Bunce, 1990; Dwyer et al., 1991) also observed higher leaf CER of maize under low than under high plant densities.

Although, the photosynthetic rates were lower at high plant population, the LAI averaged between 7.45 and 5.79 for the high plant population (P_2 and P_4) vs 4.34 abd 3.4 for the low plant population at the flowering stage. The higher LAI under high plant populaton is indicative of much greater absorption of photosynthetic radiation which apparently offset its lower photosynthetic efficiency to such an extent that the high plant population had the highest DM accumulation (Table 16). Likewise, high plant density also had higher CGR compared to low plant densities (Table 18), presumably because of the higher LAI which resulted in higher DMP. Similar results were reported by cox (1996).

All the crop physiological components studied, i.e, chlorophyll content, LAI, photosynthetic rate, percentage of PAR interception, crop growth rate and relative growth rate were increased due to increased N supply. The positive influence of N supply on all these physiological parameters are well documented (Muchow and Davis, 1988; Sinclair and Horie, 1989; and Uhart and Andrade, 1995).

5.5. GROWTH CHARACTERS

Growth of a plant can be manifested in many ways. A simple way to measure the growth is by recording the plant height. Though plant height is genetically controlled, it can be modified by environmental factors.

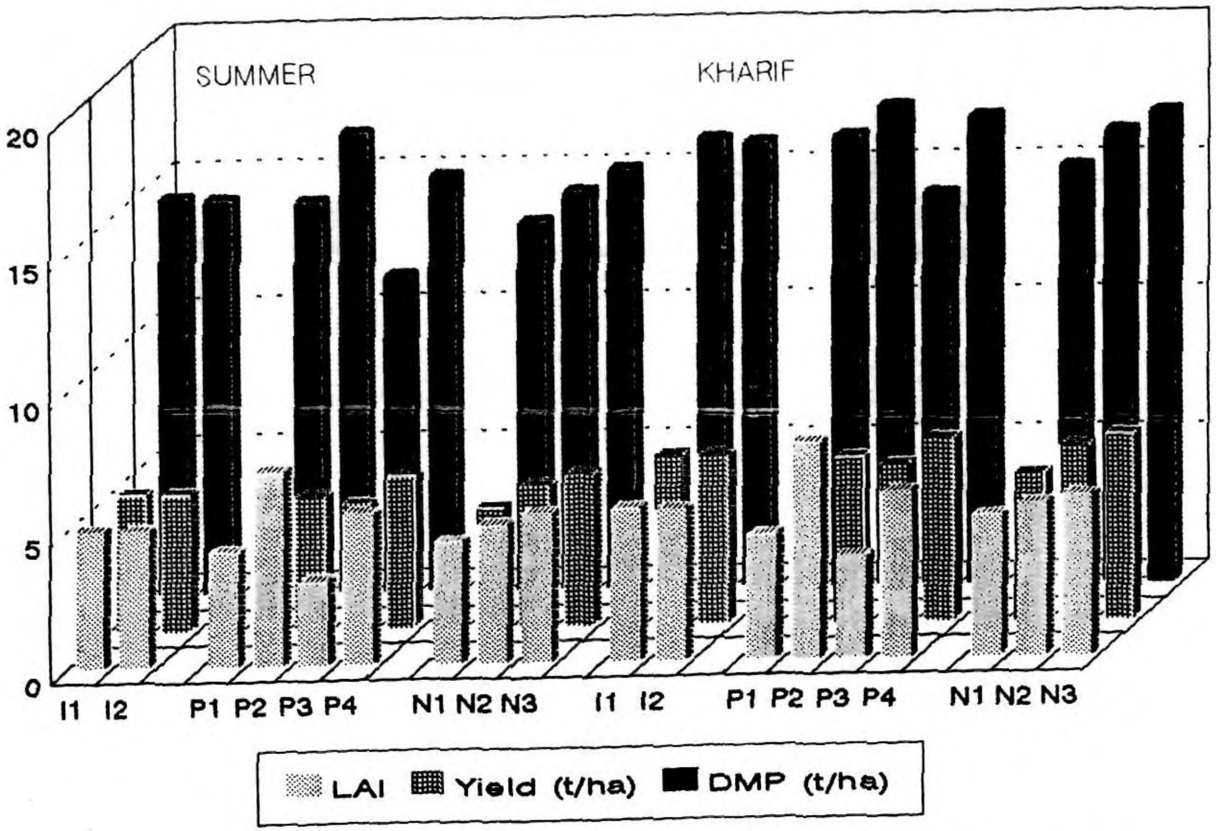


Fig 6. Effect of plant growth charecters on maize grain yield

The overall growth and development through increased plant height and leaf area helped for increased photosynthesis and thereby increased the drymatter accumulation.

The higher plant height recorded at higher population was due to greater competition for light at denser populaton leading to etiolation of stems (Madhavi, 1987). The enhanced plant height recorded under higher rates of N application in the present study is in conformity with the findings of other workers (Walia *et al.*, 1991; Paradkar and Sharma,1993).

The higher LAI (Table 17) and increased plant height at higher population resulted in higher dry matter accumulation at higher population (Fig.6.). Though the dry weight per plant was less at higher population, increase in DMP was achieved mainly by increasing the number of plants per unit area. Similar observations were also made by Hari *et al.* (1995) and Cox (1996).

N supply had a much larger effect on the area of individual leaves and leaf emergence rate (Muchow and Davis, 1988; Uhart and Andrade, 1995) which led to higher DM accumulation as found in the present investigation (Table 16).

Interaction effect of population and fertilizer levels was noticed. In general the highest population (1,66,000) at the N_3 level (170 kg N ha^{-1}) recorded maximum plant height, DMP and LAI. At higher population level, the demand for nutrients was high and this was met by higher level of fertilization.

5.6. ROOT STUDIES

Soil moisture affects the root growth in most of the crops and this becomes an important parameter in evaluating the cultivars for their drought tolerance (Mackay and Barbar,1985).

In general the water deficit induced an absolute increase in the length of root system (Upchurch and Ritchie, 1984). In the present study also an increased root length and weight was noticed during summer where lesser quantity of water was applied (I_2-ERW) whereas during *kharif* significant difference was not noticed between the irrigation levels, because the treatment effect was reduced by the increased contribution through effective rainfall.

Jongho *et al.* (1996) found that the vertical pulling resistance and spread of brace and fibrous roots increased with decrease in plant density. Here also a similar trend was noticed.

Corn root growth is not completely regulated by the shoot. Localized addition of N fertilizer can modify root growth (Durieux *et al.*, 1994). Increased rate of N application resulted increased root length and weight. Similar results were also reported by Anderson (1987).

5.7. DURATION OF PHENOLOGICAL PHASES

Tassel and silk emergence were slightly delayed under higher plant population. The time for 50 per cent silking was delayed by upto five days on an average as the plant population was increased from 55,000 (P_3) to 1,66,000 (P_2). Such delayed flowering pattern under higher plant population was also reported by Dezfouli and Herbert (1992). Jacobs and Pearson (1991) and Uhart and Andrade (1995) found that N stress delayed tasseling and silking. This is in conformity with the present findings.

Plant population and nitrogen levels interacted for the time taken to mid tasseling. The lowest plant populaton (55,000 plants ha^{-1}) at the highest level of applied N (170 kg ha^{-1}) took minimum days for mid tasseling. This was due to the increased N availability at a lesser population.

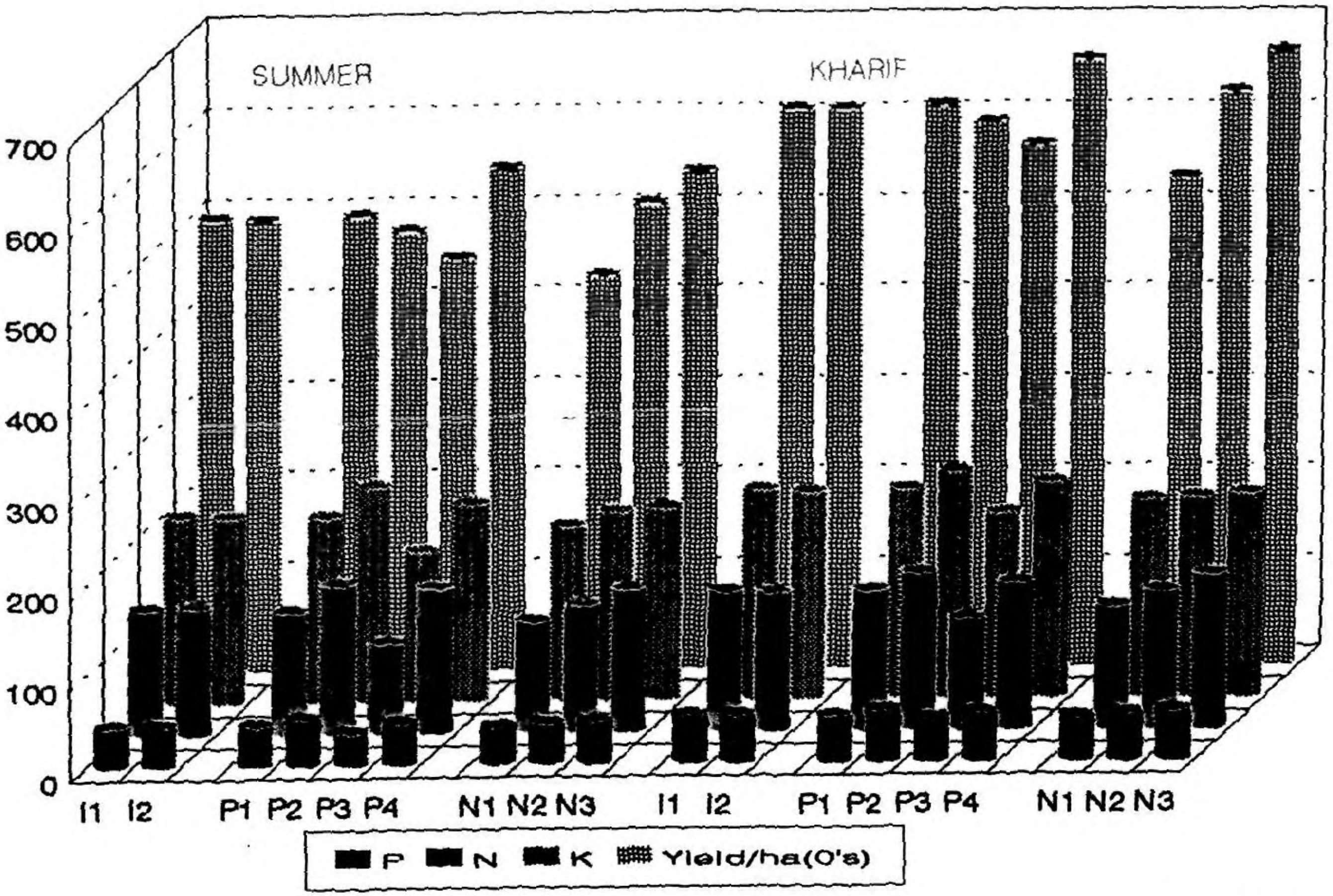


Fig 7. Effect of nutrient uptake on maize grain yield

5.8. WEED STUDIES

The relative competitive ability of maize with weeds can be increased by increasing the plant density. The LAI of maize usually increased when the plant density was increased (Tollenaar, 1992) which inturn reduced the transmission of irradiance by the maize canopy (Ballare et al., 1990) which affected the weed growth and development. Similarly, in the present study also an increase in plant population to 1,66,000 plants ha^{-1} from 55,000 plants ha^{-1} resulted in an average weed coverage decrease of 28 per cent. Weed DMP also followed the same trend.

It was found that the weed population and biomass was lower under higher soil N than under lower N suggesting that higher soil N enhanced the relative competitiveness of maize. This contention is supported by a larger decrease in LAI under low than under high N application. Similar results were also reported by Tollenaar *et al.* (1994).

5.9. PLANT NUTRIENT UPTAKE

The available soil moisture has an important role in the uptake of nutrients either by its direct action through low water potential affecting metabolic processes or by an associated effect of low rates of water flow in the system. when the soil moisture content is reduced, the cross sectional area of the soil accessible to diffussion is reduced (Mackay and Barber, 1985) and thereby reducing the ion transport (Bennett *et al.*, 1986).

In the present invesgation, the uptake of nutrients N, P and K showed comparable values between irrigation levels indicating the absence of stress when irrigation was given to the effective root zone width (Fig.7.).

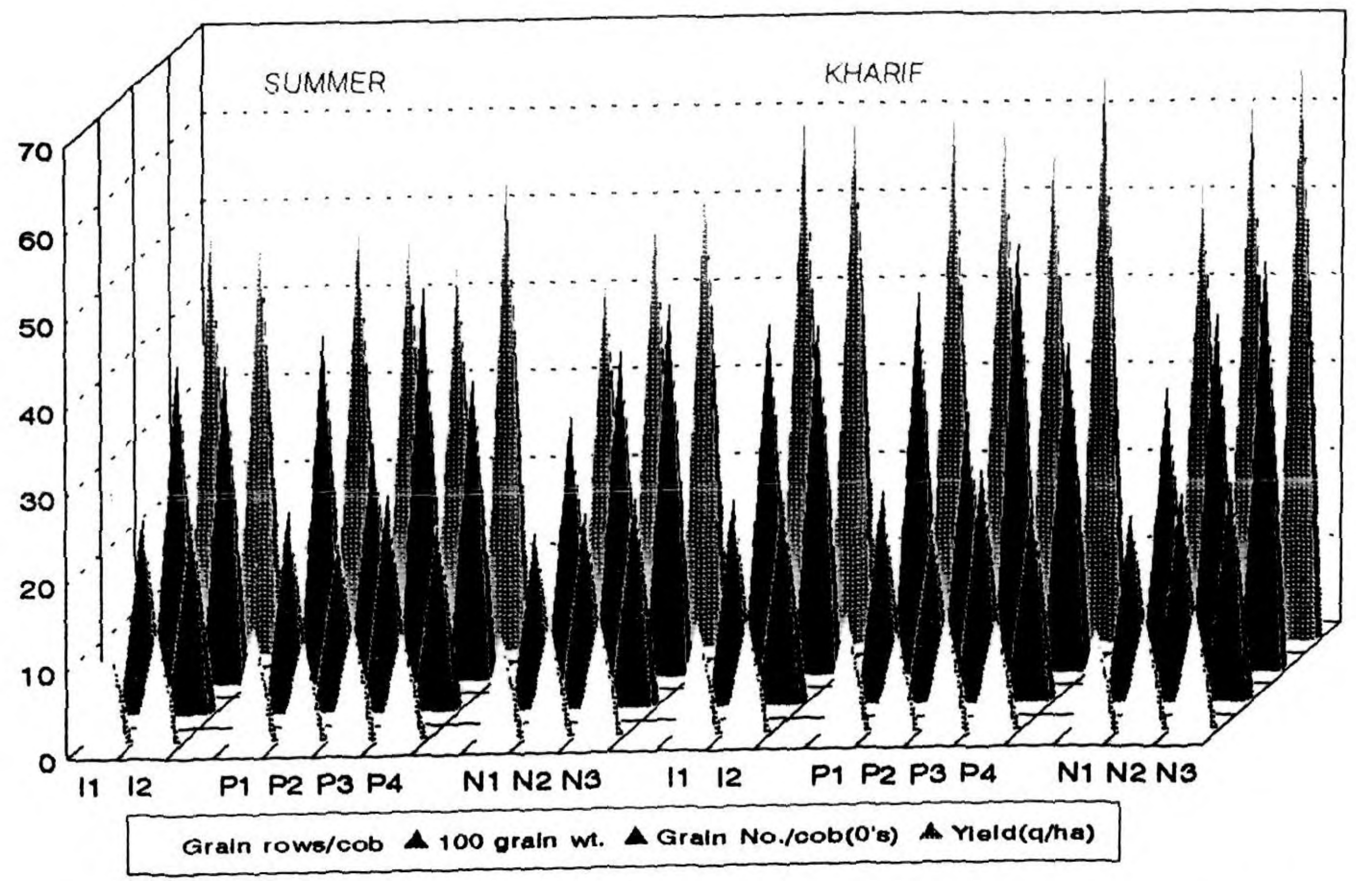


Fig 8. Effect of yield attributes on maize grain yield

Increaing the plant population increased the nutrient uptake. This was due to the fact that the DMP was higher under higher plant population at all the stages of growth (Table 16). The higher uptake of N,P and K at the higher level of applied N was due to the increased DMP at increased levels of applied N. This is in conformity with the findings of Bennett *et al.* (1986) and Selvaraju and Iruthayaraj (1994).

5.10. YIELD COMPONENTS

All the yield components studied (cob length, cob girth, grain rows cob^{-1}, grain number cob^{-1}, grain number row^{-1}, hundred grain weight, shelling percentage and harvest index) were adversely affected by increasing the plant population (Fig.8.). At very high densities, the competition for resources was very severe resulting in the limitation of allocation of photosynthates to the sink. This limited the development of all the yield components. Lemcoff and Loomis (1994) and Cox (1996) observed that kernel number per plant and kernel weight had a negative linear response to increased plant density. Tollenaar (1992) suggested that barrenness and / or reduction in kernel number at higher plant densities may be associated with low photosynthetic rates. Lemcoff and Loomis (1994) opined that kernel number was reduced mainly due to abortion which tended to be more density dependent. They also found that density infleunced both whole ear and individual kernel masses. Similar observations were also made by Dezfouli and Herbert (1992) and Akcin *et al.* (1993).

Harvest index increased when plant population was increased from 88,000 to 1,11,000 plants ha^{-1} but it decreased when the population was further increased to 1,66,000 plants ha^{-1}. Hari *et al.* (1995) observed that the HI increased with increased plant population from 75,000 to 1,00,000 and then it decreased when the population went up to 1,25,000. At higher population, there was a greater proportion of pith resulting in lower shelling percentage (Varughese and Iruthayaraj, 1996). Similar results were observed in the present study also.

Nitrogen had a favourable influence on all the yield components studied. Khanday *et al.* (1993), Ghosh and Singh (1993), and Misra *et al.* (1994) observed significantly increased length of cobs, cob girth, number of grains per row and number of rows per cob with increased rate of N application. Girardin *et al.* (1987) reported that N shortage had affected the kernel number through its effect on potential number of ovules and CGR at flowering.

Uhart and Andrade (1995) reported that N deficiencies dropped the HI. The HI was related to the number and activity of reproductive sinks and the definition of those sinks was associated with CGR at flowering, which inturn was modified by N availability. In the present investigation also a similar trend was observed.

Interaction of plant population and N levels were significant for most of the yield components studied. Lower population with the application of 170 kg N ha^{-1} was the best treatment combination regarding all the yield components. Similar views were also expressed by Bangarwa *et al.* (1992) and Gracia - Barrios and Kohashi (1994).

5.11. ECONOMIC YIELDS

Whatever the basic objectives proposed for any experiments in Agronomy, the final consideration rests on the treatmental effect on yield attributes and its effect on ultimate economic yields.

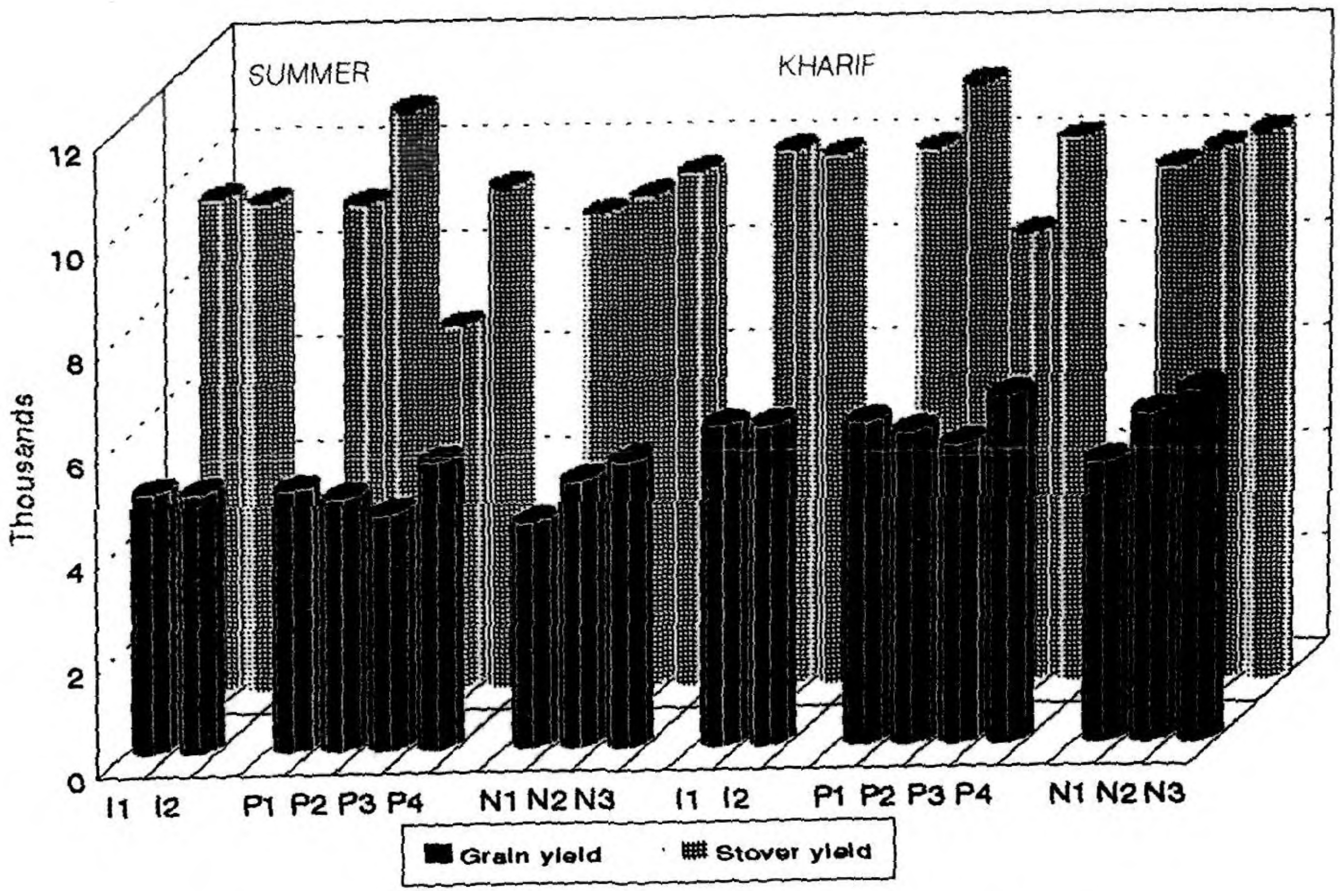


Fig 9. Grain and stover yield (kg/ha)

If the results are carefully scanned, the effect of various parameters studied were interlinked either for enhancing or decreasing the maize production.

Under both irrigation levels, desirable plant water relations were maintained during the entire crop growth period resulting in favourable growth components and yield attributes. Adequate moisture supply favoured the absorption and utilization of nutrients providing condusive situation for assimilate accumulation. Hence the grain yield was not reduced significantly when irrigation was given to the effective root zone width alone in the present study (Fig.9.).

Grain yield differed considerably under different plant populations. Yield increased with increased plant population upto 1,11,000 and thereafter it declined. The percentage of increase in grain yield at 1,11,000 plants ha^{-1} was on an average 18.6 when compared to 55,000 plants ha^{-1} and nine when compared to 83,000 plants ha^{-1} (recommended population).

Eventhough, all the yield components were in favour of low plant population of maize, the increase in yield components failed to compensate the loss in population. Hence, at higher population, more number of ears per unit area contributed to higher maize grain yield.

At the popuation level of 1,66,000 plants ha^{-1}, inspite of more number of ears per unit area, the yield declined because all the yield attributes were very much adversely affected due to high inter plant competition.

At denser populations, the plants exploited the resoures, particularly N to the fullest extent possible due to severe inter-plant competition, resulting in an increased LAI at flowering, increased DMP and N uptake (Table 17,16,24). Consequently, the number of ears per unit area was greater though the yield attributes were adversely affected. Maize is not a tillering crop and so it could not make up any reduction in germination and establishment at lower population, ending up with the production of only lesser number of cobs harvested per unit area and hence reduced yield. Similar parabolic response in grain yield to increasing plant density was also reported by Madhavi, (1987), Mengli *et al.* (1994), Narayanaswamy *et al.*(1994) and Philip and Gautam (1995).

The relative competitive ability of maize can be enhanced by increasing plant density and hence the weed interference is less under high plant population compared to low plant population (Tollenaar, 1992). In the present study also reduced weed interference was noticed under higher population contributing towards increased grain yield.

Nitrogen application increased the grain yield. As already discussed, all the yield contributing components were positively influenced by higher N application. The major effect of N for increasing the grain yield of maize was through increased kernel number and weight (Tabel 27 and 28). The barrenness of maize was effectively reduced by enhanced rate of N application (Table 29). The N application also inceased the LAI (Table 17), CGR at flowering (Table 18), PAR interception, photosynthetic rate (Table 14) and dry matter partitioning to reproductive sink (Table 29). Similar increase in grain yield through increased rate of N application was reported by many workers (Walia *et al.*,1991; Ghosh and Singh, 1993; Mishra *et al.* 1995).

In the present study a positive interaction between higher population and N levels was brought out. At higher population, the competition for N can be *minimised* by higher rates of N supply and thereby reduced the stress on this factor.

By growing the crop in the optimum season with less limitation on solar radiation, the population could be increased for obtaining higher yields to a critical level beyond which the grain yield would start declining due to severe inter plant competition. In the present investigation also, it has been found that optimum population of around 1,11,000 coupled with the application of 170 kg N ha^{-1} increased the yield substantially.

The stover yield increased with increased plant population. At higher plant population an increased plant height and LAI was recorded which might have effectively utilized the intercepted PAR at relatively lesser photosynthetic rates leading to a higher drymatter accumulation and thus the stover yield. Higher stover yield associated with higher population was also reported by Karlen and Camp (1985), Uthayakumar (1987) and Cox (1996).

Variation in N supply affects the growth and development of plants. Nitrogen shortage led to reduced leaf expansion and leaf emergence rate resulting in a reduction in LAI (Muchow and Davis ,1988; Uhart and Andrade, 1995). Increased N supply resulted in increased LAI, CGR, interception of PAR, photosynthetic rate and finally increased dry matter accumulation, which in turn increased the stover yield. This is in conformity with the findings of Muchow (1988) and McCullough *et al.*(1994).

5.12. POST HARVEST SOIL AVAILABLE N

The amount of available N in the soil was significantly reduced under the higher population. The DMP and consequently the uptake of N were higher under higher population and hence the depletion also was higher. But higher rates of N application improved the residual N availability. This was due to greater addition of N at higher level of fertilization. This in conformity with the findings of Madhavi (1987).

5.13. QUALITY STUDIES

Grain crude protein content was not influenced by different irrigation levels. It was due to the fact that the uptake of N was not influenced and hence the irrigation to the effective root zone width alone was enough to maintain favourable plant water relationship. But the CP content decreased with increasing plant population. The quantitative dilution effect due to increase in grain yield at higher population was the reason for such a decline. Liang *et al.* (1993), Albinet (1993) and Akcin *et al.* (1993) also reported higher protein content under reduced plant populations.

Karczmarczyk *et al.* (1987) and Akcin *et al.* (1993) reported that N supply enhanced grain CP content through enhanced grain N content. This is in conformity with the present findings.

5.14. WATER USE EFFFICIENCY

The WUE can be increased either by increasing the yield or by maintaining the yield or by maintaining the yield level and reducing the quantity of water input (Karim *et al.*,1985). In the present study also, reduction in consumptive water use during summer coupled with the maintenance of

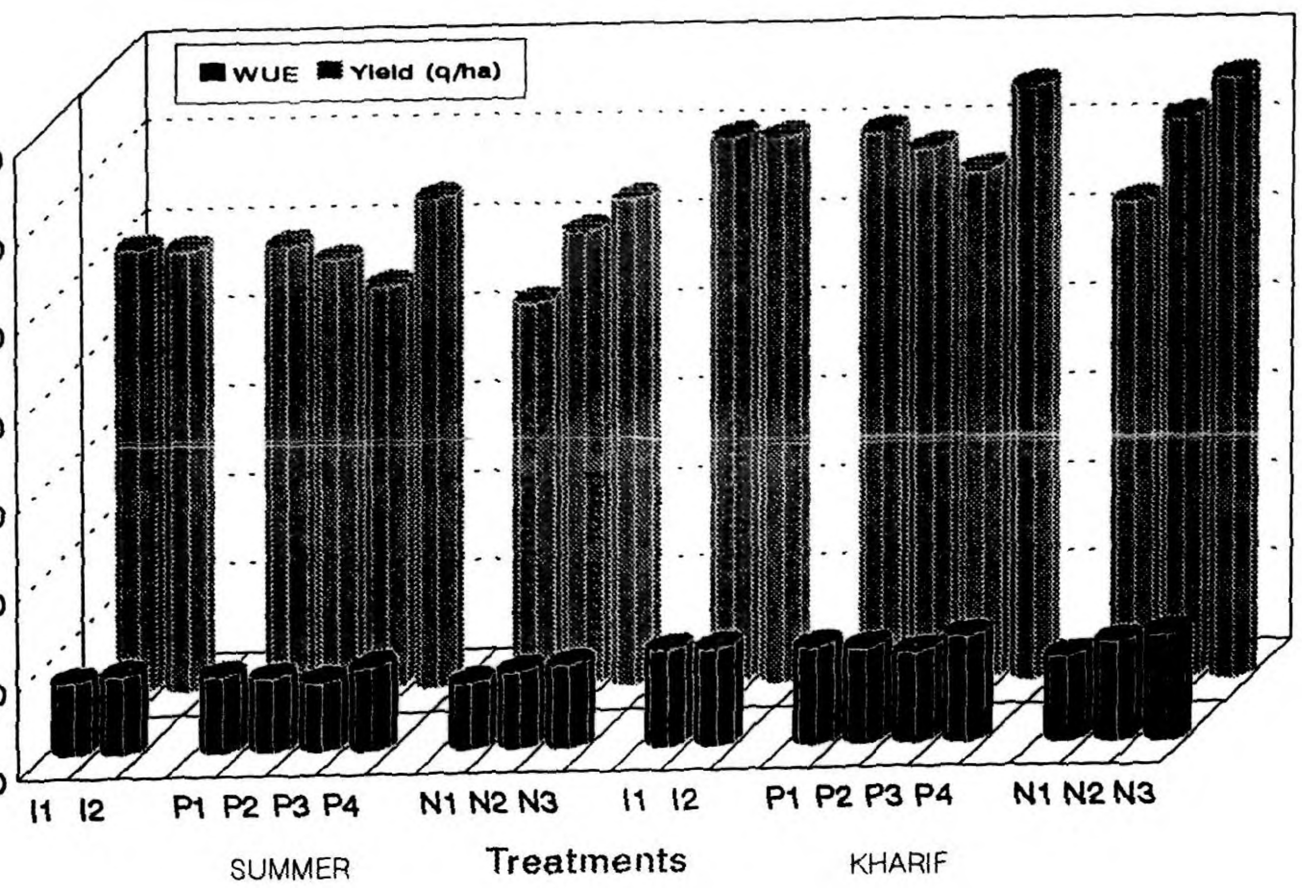


Fig 10. Effect of WUE on maize grain yield

yield at the expected level increased the WUE under irrigation to the effective root zone depth, whereas during *kharif*, difference in consumptive water use between irrigation treatments were narrowed down by the contribution from effective rainfall and the WUE also did not differ much (Fig.10.).

The higher WUE found with the plant population of 1,11,000 plants ha^{-1} and 170 kg N ha^{-1} were due to the increased grain yield. This corroborates with the findings of Dragovic *et al.* (1987) and Silva *et al.* (1992).

Significant interaction effect of plant population and N levels was observed for WUE also. The combination of 1,11,000 plants ha^{-1} and 170 kg N ha^{-1} resulted in maximum WUE due to increased grain yield.

5.15. ECONOMICS

As far as the irrigation levels were concerned, the gross and net returns did not vary much, because the cost of cultivation was the same for both the treatments and the yield also did not vary much between the treatments. The additional expenditure on increasing the plant population was marginal and this coupled with high grain yield at the population level of 1,11,000 plants ha^{-1} enhanced the net returns and B.C ratio for P_4.

The net income as well as B.C. ratio increased with increasing levels of N which indicates that the application of N up to 170 kg ha^{-1} was economical for maize.

Thus, the yield as well as monitary advantages of maize can be considerably enhanced by adopting a plant population of 1,11,000 plants ha^{-1} with the application of 170 kg N ha^{-1} and adopting irrigation to effective root zone width.

Fig. 11 Experimental (symbols) and predicted (line) grain yields for different plant populations - Summer

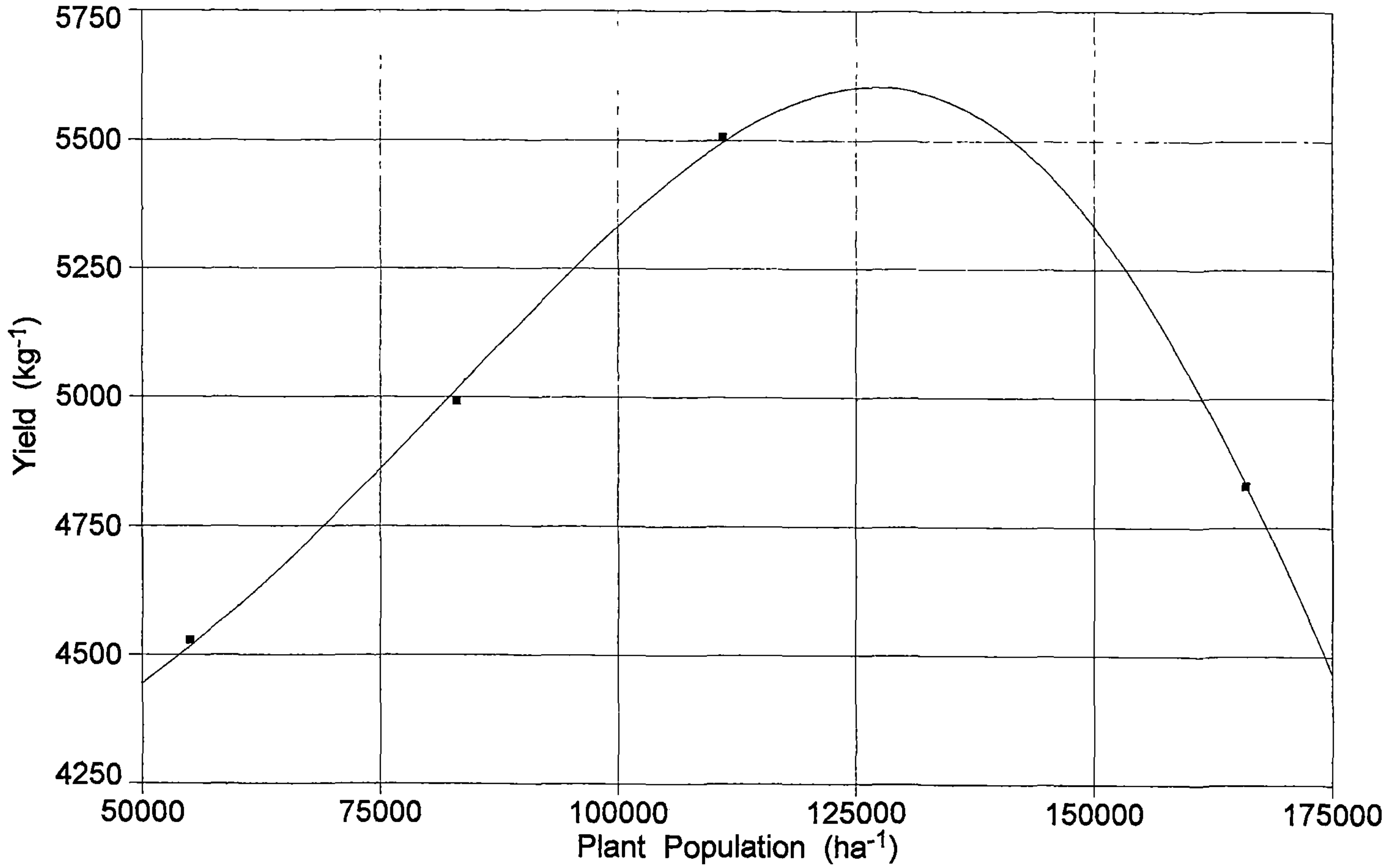
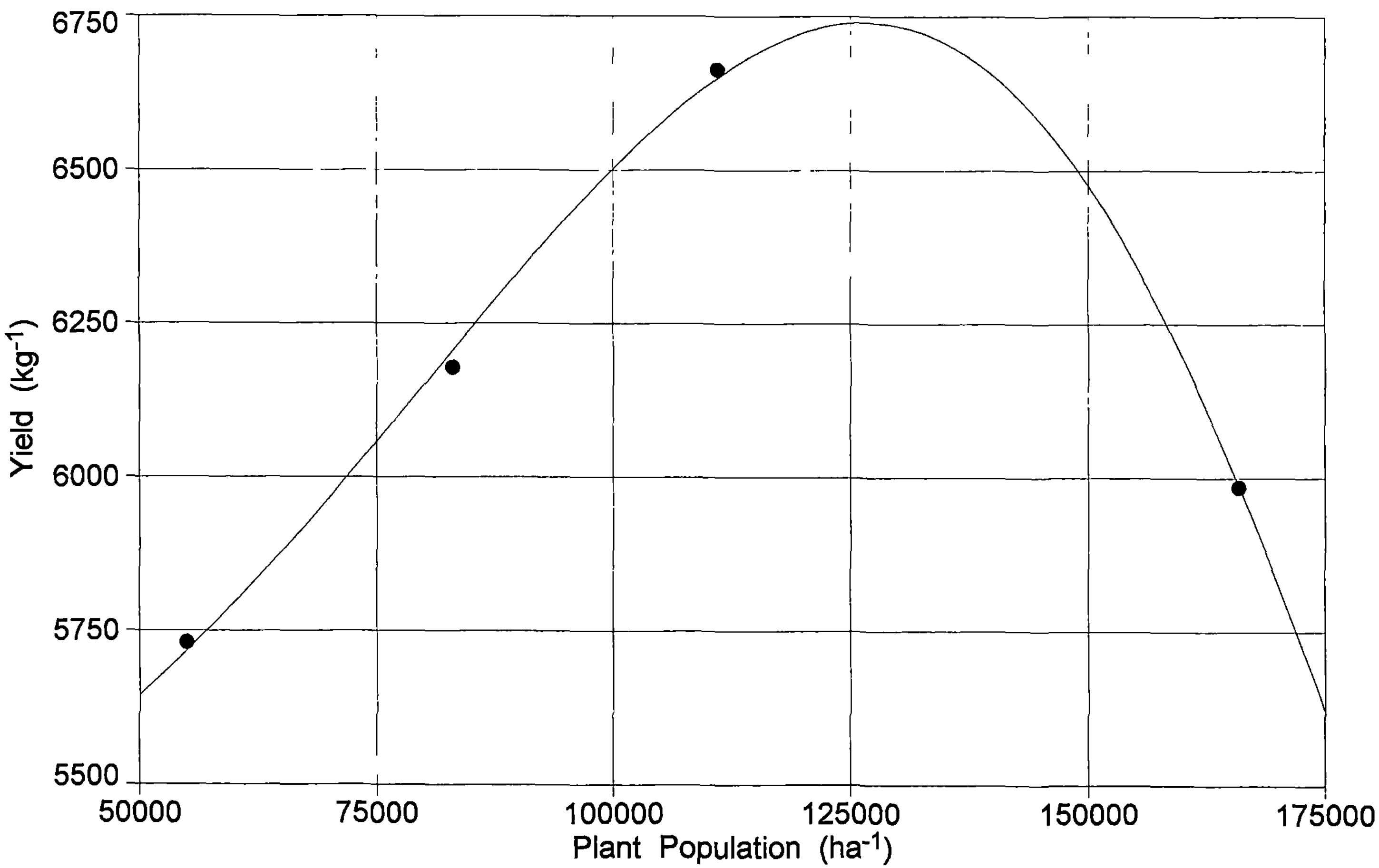


Fig. 11a Experimental (symbols) and predicted (line) grain yields for different plant populations - Kharif



5.16. MODELLING STUDIES

Maize grain yield response to different plant population is shown in Fig.11. and 11a. Comparisons of the experimental observations and simulations through the modelling functions provide a good index of the suitability of the model in mimicking the dynamic response of maize to plant population under the conditions of the present investigation. By differentiating the equation, the optimum population for maximum yield can be predicted beyond which the yield decreases due to severe inter plant competition. The predicted optimum population in the present study is 1,27,000. By using the equation we can also predict the yield for any other plant population by substituting the values for x.

SUMMARY

CHAPTER VI

SUMMARY AND CONCLUSIONS

Field experiments were conducted to evaluate the response of maize to irrigation, plant population and N management and to maximize the yield through effective manipulation of these management options at the Agriculture College and Research Institute (Tamil Nadu Agricultural University), Madurai.

The experiments were laid out in split-split design and replicated thrice. The treatments included combinations of two irrigation levels, viz., I_1-Irrigation to the entire area and I_2 -Irrigation to the effective root zone width (ERW), four plant populations, viz., 55,000, 83,000, 1,11,000 and 1,66,000 plants ha^{-1} and three nitrogen levels at 100,135 and 170 kg N ha^{-1}.

Water use studies revealed that irrigation to the effective root zone width resulted in nine per cent saving in irrigation water without affecting grain yield. The soil moisture content and soil moisture depletion pattern did not vary among the irrigation levels, but varied with plant population and nitrogen levels. The soil moisture content was less under higher plant population and N levels indicating greater absorption of water as revealed by the increased moisture depletion.

The leaf proline content, RLWC, leaf temperature, transpiration rate and leaf diffusive resistance did not differ considerably between irrigation levels. However, the leaf proline content, leaf temperature and leaf diffusive resistance increased and RLWC and transpiration rate decreased under higher population and lower N levels to keep the maize plant physiologically withstand the short term moisture stress. These factors favoured the plants for proper functioning under adverse physiological conditions.

The higher LAI of higher plant population increased the interception of PAR and offset the effect of low chlorophyll content and lower photosynthetic efficiency to such an extent that the higher population had a higher CGR. But the RGR was more for low plant population.

All the crop physiological parameters studied, viz., chloropphyll content, photosynthetic rate, percentage of PAR interception, CGR and RGR were positively influenced by N application and a linear response was noticed.

Irrigation levels did not have any influence on the growth components studied. The higher plant height and increased LAI under higher plant population led to higher DMP too. Increased rates of N application increased the plant height, LAI and DMP.

Increased root length and root dry weight were recorded under irrigation to the effective root zone width during summer. Both these parameters were reduced under higher plant population, but increased with increased rates of N application.

The relative competitive ability of maize to weeds was increased under higher plant population and increased N levels and hence the weed interference was less under these situations.

Tassel and silk emergence were delayed under higher plant population and lower N application.

The N, P and K uptakes were not affected by irrigation levels. The increased nutrient uptake at higher plant population and N levels can be attributed to the increased DMP under such situations.

Irrigation levels did not influence the yield components. All the yield components studied were adversely affected by increased plant population, whereas increased N application favourably influenced all the studied parameters.

Under both irrigation levels, desirable plant water relations were maintained and the yield did not vary significantly. Maximum grain yield was recorded under the population of 1,11,000 plants ha^{-1} and the yield was minimum at 55,000 plants ha^{-1}. Increased rate of N application increased the grain yield. Significant interaction effects of plant population and N levels were noticed. The optimum plant population of 1,11,000 plants ha^{-1} combined with the application of 170 kg N ha^{-1} increased the grain yield significantly.

The residual N status was low under high plant population and low N levels. Irrigation did not influence the post harvest soil available N status.

A quantitative dilution effect was noticed in the protein content at higher population, whereas increased N application increased the protein content.

Irrigation to the effective root zone width resulted in an increased WUE during summer. Higher WUEs were associated with a population of 1,11,000 plants ha^{-1} and 170 kg N ha^{-1}.

Gross and net returns and benefit - cost ratio were highest with a population of 1,11,000 plants ha^{-1} and at a N application rate of 170 kg ha^{-1}.

The plant population (x) and grain yield of maize (y) were related using the modelling function,

$$y^{-1} = a + bx^{2.5} + cx^{3}$$

where, a, b and c are parametric constants.

The results of the present investigation and subsequent discussions supported by pertinent literatures provided information to arrive at the following conclusions:

1. Irrigation to the effective root zone width is sufficient to maintain the required plant water relations and to produce comparable yields as that of irrigation to the entire area.

2. Eventhough, all the yield attributes were adversely affected by increasing the plant population, the plant population can be increased up to an optimum level (1,11,000 plants ha^{-1}) at which the yield is maximum due to increased number for cobs present per unit area and beyond this level the yield is declined.

3. The present study confirmed the critical importance of N supply on the growth and development of maize, influencing the above-ground biomass and grain yield.

4. The higher LAI under higher plant population resulted in an increased interception of PAR, which offset its lower photosynthetic efficiency leading to higher CGR and DMP.

5. The weed interference is minimized under higher population and N levels.

6. The grain yield of maize can be increased substantially by adopting a plant population of 1,11,000 plants ha^{-1} (60 x 30 cm double side sowing) combined with the application of 170 kg N ha^{-1} and irrigating to the effective root zone width (2/3 of the furrow depth).

Future line of work

Since modern hybrids respond more favourably to plant population, still higher population can be tried with modern hybrids to maximise the yield.

Since a linear response is noticed to the application of N, a sensitivity analysis which highlights the quantity of biomass accumulated per unit of N, efficacy of increasing the N supply rate for leaf growth and optimum leaf N for maximum biomass accumulation may be done.

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APPENDICES

Appendix A

Plant height (cm)

(i)

60 DAS - Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	168.3	176.4	180.0	174.9
P_2	175.2	184.2	191.3	183.6
P_3	164.2	177.7	182.4	174.8
P_4	171.7	181.5	188.8	180.6
	169.9	179.9	185.6	
		SE_D	CD (P= 0.05)	
D at N		1.37	2.78	
N at D		1.26	2.50	

Appendix A

Plant height (cm)

(ii)

60 DAS - *Kharif*

	N- levels			
Plant population	N_1	N_2	N_3	Mean
P_1	176.5	188.7	201	188.7
P_2	185.1	202.2	209	198.8
P_3	167.5	177.1	188.8	177.8
P_4	181.1	195.8	205.3	194.1
	177.6	190.9	201.0	
		SE_D	CD (P= 0.05)	
D at N		1.60	3.21	
N at D		1.55	3.08	

Appendix B

Dry matter production (kg ha^{-1})

(i)

30 DAS - Summer

	N- levels			
Plant population	N_1	N_2	N_3	Mean
P_1	465	527	579	523
P_2	567	652	729	649
P_3	376	426	477	427
P_4	517	608	667	598
	482	553	613	
		SE_D	CD (P= 0.05)	
D at N.		16	33	
N at D		5	10	

Appendix B

Dry matter production (kg ha^{-1})

(ii)

60 DAS - Summer

	N- levels			
Plant population	N_1	N_2	N_3	Mean
P_1	5867	6712	7520	6700
P_2	7018	8183	9210	8137
P_3	4794	5601	6486	5627
P_4	6513	7792	8668	7658
	6048	7072	7971	
		SE_D	CD (P= 0.05)	
D at N		189	386	
N at D		33	66	

Appendix B

Dry matter production (kg ha^{-1})

(iii)

30 DAS - *Kharif*

	N- levels			
Plant population	N_1	N_2	N_3	Mean
P_1	502	528	594	541
P_2	604	678	751	678
P_3	411	460	518	463
P_4	538	632	684	618
	514	574	637	
		SE_D	CD (P= 0.05)	
D at N		22	45	
N at D		10	20	

Appendix B

Dry matter production (kg ha^{-1})

(iv)

60 DAS - *Kharif*

	N- levels			
Plant population	N_1	N_2	N_3	Mean
P_1	6374	6997	7744	7038
P_2	7516	8607	9707	8610
P_3	5257	6206	7199	6221
P_4	6891	8318	9157	8122
	6509	7532	8452	
		SE_D	CD (P= 0.05)	
D at N		200	407	
N at D		58	115	

Appendix C

Leaf area index

(i)

60 DAS - Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	3.72	4.16	4.61	4.17
P_2	6.28	7.13	7.72	7.04
P_3	2.67	3.12	3.39	3.06
P_4	4.99	5.54	6.03	5.52
	4.42	4.98	5.44	
		SE_D	CD (P= 0.05)	
D at N		0.08	0.16	
N at D		0.08	0.15	

Appendix C

Leaf area index

(ii)

Harvest - Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	1.98	2.26	2.62	2.29
P_2	2.99	3.51	3.93	3.48
P_3	1.09	1.41	1.80	1.44
P_4	2.41	2.79	3.20	2.80
	2.12	2.49	2.89	
		SE_D	CD (P= 0.05)	
D at N		0.06	0.12	
N at D		0.05	0.10	

Appendix C

Leaf area index

(iii)

Harvest - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	2.54	2.80	3.33	2.89
P_2	3.95	4.26	4.73	4.31
P_3	1.41	1.64	1.98	1.68
P_4	3.14	3.58	3.91	3.54
		SE_D	CD (P= 0.05)	
D at N		0.07	0.14	
N at D		0.06	0.12	

Appendix D

Days to mid tasseling - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	53.8	51.3	49.8	51.7
P_2	56.8	54.2	51.8	54.3
P_3	50.5	49.2	48.7	49.4
P_4	55.0	51.8	51.3	52.7
	54.0	51.6	50.4	
		SE_D	CD (P= 0.05)	
D at N		0.6	1.2	
N at D		0.7	1.3	

Appendix E

Weed dry matter production (kg ha^{-1})

45 DAS - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	740	681	628	683
P_2	602	547	525	558
P_3	789	717	668	725
P_4	665	623	584	624
	699	624	601	
		SE_D	CD (P= 0.05)	
D at N		10	21	
N at D		10	21	

Appendix F

N uptake (kg ha^{-1})

(i)

30 DAS - Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	4.9	6.2	7.2	6.1
P_2	6.4	8.2	10.1	8.2
P_3	4.4	5.1	6.0	5.2
P_4	6.3	7.7	9.1	7.7
	5.5	6.8	8.1	
		SE_D	CD (P= 0.05)	
D at N		0.3	0.6	
N at D		0.3	0.6	

Appendix F

N uptake (kg ha^{-1})

(ii)

30 DAS - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	5.3	6.3	7.4	6.3
P_2	6.8	8.6	10.4	8.5
P_3	4.6	5.4	6.4	5.5
P_4	6.5	7.9	9.2	7.9
	5.8	7.1	8.3	
		SE_D	CD (P= 0.05)	
D at N		0.03	0.6	
N at D		0.03	0.7	

Appendix F

N uptake (kg ha^{-1})

(iii)

Harvest - Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	120.2	133.8	147.7	133.8
P_2	145.5	163.0	182.3	163.5
P_3	85.3	98.6	114.7	99.5
P_4	135.9	162.5	179.7	159.4
	121.7	139.4	156.1	
		SE_D	CD (P= 0.05)	
D at N		3.9	7.9	
N at D		2.25	4.48	

Appendix F

N uptake (kg ha^{-1})

(iv)

Harvest - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	138.5	154.6	168.5	153.8
P_2	152.1	170.1	194.3	172.1
P_3	107.1	122.9	139.2	123.1
P_4	145.4	161.4	176.9	161.3
	135.8	152.3	169.8	
		SE_D	CD (P= 0.05)	
D at N		0.25	0.50	
N at D		0.23	0.46	

Appendix G

Cob length (cm) - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	15.7	16.9	18.4	17
P_2	13.8	14.8	15.9	14.8
P_3	16.3	18.9	21.1	18.7
P_4	14.8	16.5	17.8	16.4
	15.1	16.7	18.3	
		SE_D	CD (P= 0.05)	
D at N		0.45	0.92	
N at D1		0.23	0.47	

Appendix H

Grain rows cob^{-1} Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	12.4	13.9	14.2	13.5
P_2	10.9	11.7	12.2	11.6
P_3	12.0	14.2	14.7	13.6
P_4	11.3	12.7	13.4	12.5
	11.7	13.1	13.6	
		SE_D	CD (P= 0.05)	
D at N		0.24	0.50	
N at D		0.24	0.49	

Appendix I

Grain number cob^{-1} - Summer

(i)

Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	355	419	464	413
P_2	225	287	337	283
P_3	366	479	548	465
P_4	288	363	410	354
		387	440	
		SE_D	CD (P= 0.05)	
D at N		7	15	
N at D		7	14	

Appendix I

Grain number cob^{-1}

(ii)

Kharif

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	379	456	521	452
P_2	248	312	364	308
P_3	413	518	597	509
P_4	307	413	449	390
	337	424	489	
		SE_D	CD (P= 0.05)	
D at N		9	18	
N at D		10	20	

Appendix J

Grain number row^{-1} *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	30.8	32.9	35.1	32.9
P_2	24.3	29.1	30.8	28.0
P_3	33.1	35.7	40.2	36.3
P_4	27.3	30.8	32.8	30.3
	28.9	32.1	34.7	
		SE_D	CD (P= 0.05)	
D at N		0.84	1.77	
N at D		0.71	1.44	

Appendix K

Hundred grain weight (g) - Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	21.8	24.0	25.5	23.8
P_2	18.7	19.7	21.3	19.9
P_3	23.0	25.8	28.0	25.6
P_4	18.8	22.3	23.8	21.7
	20.6	23.0	24.7	
		SE_D	CD (P= 0.05)	
D at N		0.27	0.54	
N at D		0.29	0.58	

Appendix L

Shelling percentage (%)

(i)

Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	66.8	71.1	74.1	70.7
P_2	63.1	69.3	71.8	68.1
P_3	68.5	72.8	74.1	71.8
P_4	64.2	69.5	72.8	68.8
	65.7	70.7	73.2	
		SE_D	CD (P= 0.05)	
D at N		0.73	1.46	
N at D		0.71	1.41	

Appendix L

Shelling percentage (%)

(ii)

Kharif

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	67.3	71.9	74.7	71.3
P_2	63.7	70.0	72.8	68.8
P_3	69.0	74.0	74.8	72.6
P_4	64.5	70.0	74.1	69.6
	66.1	71.5	74.1	
		SE_D	CD (P= 0.05)	
D at N		0.68	1.36	
N at D		0.66	1.31	

Appendix M

Grain yield (kg ha^{-1})

(i)

Summer

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	4406	5086	5484	4992
P_2	4196	4943	5353	4831
P_3	3959	4693	4933	4528
P_4	4731	5712	6075	5506
	4323	5108	5461	
		SE_D	CD (P= 0.05)	
D at N		59	118	
N at D		53	106	

Appendix M

Grain yield (kg ha^{-1})

(ii)

Kharif

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	5417	6365	6745	6176
P_2	5280	6155	6521	5985
P_3	5003	5879	6311	5731
P_4	5765	6816	7407	6663
	5366	6304	6746	
		SE_D	CD (P= 0.05)	
D at N		77	155	
N at D		78	154	

Appendix N

WUE (kg ha^{-1}) - *Kharif*

	N levels			
Plant population	N_1	N_2	N_3	Mean
P_1	9.7	11.4	12.0	11.0
P_2	9.4	11.0	11.6	10.7
P_3	8.9	10.5	11.3	10.2
P_4	10.3	12.1	13.2	11.9
	9.6	11.2	12.0	
		SE_D	CD (P= 0.05)	
D at N		0.13	0.26	
N at D		0.13	0.27	