

RESPONSE OF WHEAT TO IRRIGATION, AMENDMENTS AND MICRONUTRIENTS UNDER NORTH-BENGAL CONDITION

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Amulya Kumar Mitra

DEPARTMENT OF AGRONOMY
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Bidhan Chandra Krishi Viswavidyalaya

FACULTY OF AGRICULTURE

DEPARTMENT OF AGRONOMY

Dr. P. K. Jana, Ph.D. (I.A.R.I.)
Professor of Agronomy

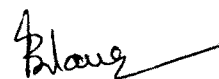


P. O. KALYANI, Dist. NADIA
Pin-741235
WEST BENGAL, INDIA.

Dated 18.8.1986.

CERTIFICATE

This is to certify that the investigation recorded in the thesis entitled "Response of wheat to irrigation, amendments and micronutrients under North Bengal condition" submitted by Shri Amulya Kumar Mitra, to the Bidhan Chandra Krishi Viswavidyalaya, Mohanpur for award of the Degree of Doctor of Philosophy in Agronomy, is the faithful and bonafide research work carried out by him under my supervision and guidance. The thesis is, in my opinion, is worthy of consideration for the award of the Degree of Philosophy in accordance with the regulations of the Viswavidyalaya. The results embodied in this thesis have not been submitted to any other University or Institution for the award of any degree or diploma. The assistance and help received during the course of investigation and sources of literature have been duly acknowledged.


(P. K. JANA)

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(AMULYA KR. MITRA)

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ABSTRACT

Response of wheat to irrigation, amendments and micronutrients under North Bengal condition

The field experiments were conducted at Teaching and Instructional Farm of Cooch-Bihar Campus, Bidhan Chandra Krishi Viswavidyalaya during winter season of 1979-80 to 1983-84 to study the influence of (i) irrigation at different physiological growth stages (crown-root-initiation (C), tillering (T), Flowering (F) and dough (D) stages and their different combinations), (ii) the application of soil amendments (lime @ 1.5 tonnes/ha and dolomite @ 1.5 tonnes/ha) and micronutrients (Zinc-15 kg $ZnSO_4$ /ha, boron-20 kg borax/ha and molybdenum-800 gm Sod-molybdate/ha), (iii) the doses of boron (0, 10, 20 and 30 kg borax/ha) and methods of its application (full soil, half soil + half foliar and full foliar) on the yield attributes and yield of wheat.

Irrigation significantly increased the plant height, total and effective tillers, ear length, grain number per ear, thousand grain weight, grain and straw yields of wheat. Two irrigations applied one each at tillering and flowering stages (TF) recorded maximum grain yield and gave additional grain yield of 5.02 q/ha over unirrigated control. Application of three or four irrigations to wheat crop did not give any extra advantage over two irrigations.

In all irrigation treatments, rate of evapotranspiration (E_T) increased with age of the wheat crop and then decreased due to crop senescence. The equations were fitted to express the relationship between E_T and days of crop growth. E_T was influenced very much with change in the soil moisture status due to either irrigation or rainfall and it decreased considerably due to soil moisture deficit as a result of withholding irrigation. Four irrigations (CTFD) recorded maximum E_T (3.25 mm/day) on 72 days of crop growth. Corresponding E_T under rainfed treatment was only 2 mm/day. Two irrigations at TF stages recorded maximum E_T (3.1 mm/day) between flowering and dough stage of crop growth.

Application of soil amendments (lime and dolomite) and micronutrients (boron, molybdenum and zinc) significantly increased dry matter, number of total and effective tillers, ear length, grain number per ear, 1000 grain weight, grain and straw yields of wheat. Increase in grain yield over control was 2.65 and 1.77 q/ha with dolomite and lime applications respectively. Application of boron, molybdenum and zinc increased grain yield over control by 238.5, 62.8 and 33.8 per cent respectively. Dolomite (1.5 tonnes/ha) in combination with boron (20 kg borax/ha) gave maximum grain yield of 29.3 q/ha.

Yield and yield attributing characters of wheat were significantly influenced by the levels of boron upto 20 kg borax/ha which gave additional grain yield of 18.90 q/ha over control.

Half soil and half foliar method of boron application produced maximum dry matter, total and effective tillers, ear length, 1000 grain weight, straw and grain yields. This method was significantly superior to other two methods and gave 6.6 and 8.8 per cent more grain yield over full soil and full foliar method of application respectively. 20 kg borax/ha applied half in soil and other half as foliar spray gave maximum grain yield (28.7 q/ha) of wheat.

The response due to boron application was found quadratic. The optimum dose of boron as borax was 23.4, 19.4 and 15.6 kg/ha for full soil, half soil + half foliar and full foliar method of application respectively. Response to boron application was maximum (155 kg grain/kg boron) at 10 kg/ha boron and decreased to 94 kg grain/kg boron at 20 kg/ha boron. Benefit-cost ratio of 20 kg/ha boron was Rs. 9.45 per rupee invested on fertilizer.

CHAPTER-I

INTRODUCTION

INTRODUCTION

Wheat farming in India has been almost revolutionised with introduction of the high yielding dwarf wheat varieties in 1963-64. Thereafter, a number of dwarf varieties have been evolved in the country which are very responsive to irrigation and fertilizer application. The short stiff and strong stem of dwarf wheat allows the plant to utilize irrigation water without lodging and results in higher yields. Considerable research information on the water management of wheat using various criterion of scheduling based on soil, plant and climatic factors has been obtained. The optimum depletion of available soil water for wheat has been observed to be about 40-50 per cent in the surface 60 cm depth of soil layer (Bathkal and Dastane, 1968; Gautam et al., 1968). The optimum soil moisture tension is 0.5 bar as measured at a soil depth of 22 cm (Singh and Dastane, 1971; Bhardwaj, 1972). The most practical criterion commonly adopted by the farmers for scheduling of irrigation to wheat is the one based on the physiological growth stages critical in demand for water. In wheat, different growth stages such as crown root initiation, tillering, jointing, flowering, milk and dough could be well delineated. Experiments conducted to study the important stages critical in their demand for water have clearly indicated that some stages can tolerate moisture stress to a certain extent. Most of the workers have observed that in case of dwarf varieties of wheat irrigation at crown

root initiation stage has resulted in the maximum production per unit of water applied and, therefore, this stage has been considered as the most critical stage for irrigation (Bhardwaj and Wright, 1968). The second important stage is that of flowering. Among the other stages, jointing and milk rank third, followed by tillering and then dough stage. The information on the critical stages is useful in areas with limited water resources where maximum production per unit water is aimed at. Such information on wheat is not available for North Bengal condition. So this factor has been included in the present investigation.

Irrigation water, being a limited but essential input for crop production, is to be efficiently and judiciously applied in such a manner that maximum yield is obtained per unit water supplied. Attempts have, therefore, been made to study the water use efficiency of wheat crop.

The micronutrient problem in India has recently drawn the attention of the agricultural Scientists. Micronutrient deficiency, although sporadic, has been observed more in light-textured and calcareous soils. Soils of northern part of this are light textured and acidic in nature. Such soils with high rainfall has favoured high rate of leaching of plant nutrients and this creates the problem of micronutrient deficiency. Due to micronutrient deficiency, grain setting in wheat is affected and the yield is decreased. In order to overcome this problem,

soil may be corrected by the amendments and enriched with the application of micronutrients. Keeping this point in view, effect of the application of amendments and micronutrients is to be studied.

The objectives of the present investigation are :

- i) to examine the influence of irrigation at different physiological growth stages on the yield attributes, yield and water use efficiency of wheat
- ii) to examine the relationship between evapotranspiration rate and days of growth under varying levels of irrigation
- iii) to study the effect of soil amendments and micronutrients on the yield attributing characters and yield of wheat
- iv) to determine the optimum dose of micronutrient boron.

CHAPTER-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Wheat, of late has received special importance to farmers, as a cereal crop all throughout India. Superiority of high yielding dwarf wheat is no longer debatable, but the high yielding character can only be manifested if the right course of agro-technique is followed. Irrigation is one such factor which influences yield of dwarf wheat.

Investigation on water-management of wheat has started long back. But there is a marked difference between early investigations and studies after introduction of dwarf wheat. The early tall varieties of wheat have weak stature and have only limited capacity to endure irrigation. Irrigation after flowering is most important, but this will often result in lodging. The present high yielding varieties are free from such defects. Thus, it offers scope for wide and more comprehensive investigations to identify irrigation needs of wheat crop during critical periods.

There has been a change in approach of the problem of irrigation in wheat. Earlier investigations were centered mainly around depth, delta and frequency (Bartel and Charles, 1935; Mitra and Sabins, 1945; Bhattacharya, 1954). It was considered later on, to be inadequate and emphasis was given on identifying the critical stages of growth regarding water requirement and on the effect of soil moisture stress at such physiological or critical stages of growth (Bhardwaj and Wright, 1967; Haise and Hagan,

1967; Day and Intelap, 1970; Singh et al., 1970). So an attempt has been made to review the literature on the effect of irrigation and soil moisture status in influencing the yield attributes and yield of wheat.

To have a clear understanding regarding the past work on water management in wheat, the whole review has been classified with the following approaches in view

1. Influence of irrigation or soil moisture stress on the yield attributing characters of wheat.
2. Influence of irrigation or soil moisture stress on yield of wheat. This approach has again been subdivided as follows :
 - a) Effect of irrigation based on depth, interval or critical stages of growth.
 - b) Effect of irrigation based on energetics of soil moisture.
 - c) Effect of irrigation based on climatological approach.
3. Studies on the consumptive use of water by wheat.

Acidic areas with light textured soil and high rainfall accompanied by high rate of leaching for long period may also develop the deficiency of micronutrient. Such acidic soil may be corrected by the application of soil amendments. Literature on the influence of micronutrient and soil amendments on the growth and yield of wheat, therefore, have been reviewed in the subsequent paragraphs.

2.1 Influence of irrigation and soil moisture

2.1.1 Influence of irrigation or soil moisture stress on yield attributing characters of wheat

Effect of irrigation on yield is determined to a great extent by its effect on the yield attributing characters. The following review aims at determining the extent of influence on the yield attributing characters from previous investigations.

During early investigations, reduction in grain weight as a result of decreased translocation of assimilates to the grain due to moisture stress has been observed by many workers (Preul, 1908; Harris, 1916 and Zablude, 1958).

Asana et al. (1958) found that drought occurring 4 weeks after ear emergence, reduced the grain yield through reduction in grain number per ear. From another study Asana and Saini (1958) reported that it was the ear number which was the most dominating factor affecting yield, whereas under restricted soil moisture, grain number per ear and sometimes 1000 grain weight were the major yield contributing factors. From yet another study, Asana (1960, 62) stated that under conditions of moisture deficiencies especially during the grain swelling stage grain number per ear and sometimes the 1000 grain weight had as much effect as ear number which had the most potent effect on yield under adequate moisture condition.

Gautam (1961) stated that higher level of irrigation resulted in significantly larger number of tillers per plant, but there was no significant difference in the number of ear bearing tillers per plant.

Robins and Domingo (1962) concluded from an experiment on spring wheat at Kansas (U.S.A.) that moisture stress during and following heading resulted in reduction in grain yield through reduction in grain number per panicle.

Prashar and Singh (1963) reported that plant height, mean internodal length, the total effective shoot number and total dry matter were increased with the increase in number of irrigation and straw to grain ratio was also increased by frequent irrigations.

Storrier (1965) studied the effect of number of irrigations at 5 stages of growth and found that irrigation before anthesis increased grain number per ear and straw yield, but significantly reduced the loss of dry matter when irrigation was applied after anthesis.

Dimitrijevi and Saric (1965) noted reduction in the number of spikelets per ear, 1000 grain weight and ultimately the grain yield by soil drought treatment.

Tiwari and Singh (1969) pointed out that various irrigation intensities and frequencies had no significant effect on any plant character except a significant positive response on 1000 grain weight with increased irrigation frequencies.

Misra et al. (1969) observed that tillering, 1000 grain weight and grain yield of dwarf variety "Lerma Rojo" had been adversely affected by withholding irrigation (in the absence of rains) at crown root initiation and flowering stages.

Strotriya et al. (1970) stated that withholding of irrigation at the crown root initiation and milk ripe stages significantly decreased the 1000 grain weight and had little effect on ear length and number of grains per panicle.

Day and Intelap (1970) studied the effect of soil moisture stress on growth stages of wheat at Tukson (Arozona) U.S.A. and found that moisture stress at jointing, flowering and dough stages of growth significantly reduced grain yield as compared to optimum irrigation. The greatest reduction in yield occurred due to few ear heads per hill and fewer seeds per head when irrigation was withheld at flowering and dough stages.

* Sharma and Singh (1971) observed that amongst the yield attributing characters, 1000 grain weight and grain per panicle were adversely affected by late irrigation and it ultimately reduced yield.

Patel et al. (1971) conducted an experiment at Kanpur for two years with the dwarf variety "Kalyan Sona" and observed that moisture stress at crown root initiation stage and late tillering stage significantly reduced the tiller number per plant, plant height, length of ear head and thereby grain number per ear.

Bhardwaj et al. (1971) noted that timing of first irrigation at about the crown root initiation stage for dwarf variety "Kalyan Sona" had a pronounced effect on production of effective tillers. Early irrigations encouraged effective tillers and delayed irrigation inhibited tiller formation.

Narang and Sachan (1971) noticed that the adverse effects of delayed first irrigation (withholding irrigation at CRI stage) to Mexican wheat variety may be because of the following five reasons

- i) delayed crown root initiation
- ii) imbalanced root-tiller development
- iii) consequently, poorer plant growth
- iv) less number of total and effective tiller and
- v) their reduced ability to compete with the weed and withstand adverse conditions due to poor growth and anchorage

Petrunin and Okolovich (1972) reported that 3 irrigations gave best yield than 2, 1 or no irrigation by increasing tillers, number of grains per ear and 1000 grain weight.

Jana and Sen (1973) reported from an experiment with dwarf variety 'Sonalika' at Kalyani that the height of the plant, length of panicle and number of grains per panicle were affected by levels of irrigation, but number of effective tillers per meter length and 1000 grain weight remained unaffected by irrigation frequencies.

Fischer (1973) conducted experiments to study the effect of water stress for 3-4 days during 3 weeks before and after ear emergence and observed that water stress at all stages consistently reduced the photosynthetic areas and that was again evident in grain filling. Water stress also affected grain number/ear and also number of grains/spikelet over the period 15 to 5 days before ear emergence.

Srivastava and Bansal (1975) after conducting trials with dwarf wheat cv. Kalyan Sona, reported that delaying the first irrigation from 21 to 28 or 35 days after sowing had no adverse effect on tiller production and grain yield; further delay in the first irrigation to 45 days after sowing decreased those attributes.

Hellman (1975) at Makatini Research Station, Gozini, South Africa, conducted field experiments to note the effect of water stress on different yield attributing characters and reported that water stress during tillering resulted in marked secondary growth, while stress either before or after anthesis decreased length of ears and weight of individual grains. Stress after anthesis decreased the weight of individual grains only, but this reduction being significantly greater than that resulted from irrigation applied before anthesis. Wheat showed signs of moisture stress when 65 % of available soil moisture in the top 60 cms of soil had been depleted.

Patil and Ansari (1975) reported that in trials with wheat given 8 irrigations in the Tungabhadra Project Area in Karkataka,

a delay of one week in the last irrigation from 19 to 12 days before maturity increased number of grains/ear from 19.04 to 32.6 grains, yields from 50.4 to 112.59/m row and 1000 grain weight from 29.6 to 36.3 gm; further delay in the last irrigation decreased them.

Ghosh et al. (1975) conducted trial with wheat cv. Kalyan Sona in brick lysimeters at Kalyani with 0, 60, 120 or 180 kg N/ha in 1970-71 and 0, 100 or 200 kg N/ha in 1971-73 at 5 soil moisture tensions ranging between 0 and 1.3 atm. and observed that highest LAI was observed at 0.25 atm. tension and value of LAI increased with increase in applied nitrogen.

Misra et al. (1976) reported that the yield increased in dwarf wheat cvs. by giving 4 irrigations at CRI, late tillering, earing and milk ripe stages, was due to increased tiller number, increased grain weight/ear and increased 1000 grain weight.

Hussein et al. (1978) conducted field trials, at Giza, Cairo with wheat cv. (a) Giza-155 and (b) Mexipak-69 and was given 1 to 6 irrigations applied at different stages and was given 0, 30, 45, 60 or 75 kg N/feddan. It was observed that plant height and tillering were increased with irrigation upto 4 (upto milk stages) for both cvs. Ear emergence was delayed by increased irrigation. Yield of grain was increased upto application of 4 irrigations and after this there was no further increase in yield.

Ibrahim et al. (1980) in field trials at Zagazig in Egypt with wheat cv. (a) Giza-155 and (b) Mexipak-69 given irrigation 4, 5 or 6 times observed that effect of irrigation was significant on weight of grain/ear and 1000 grain weight with increased number of irrigation.

Choudhury and Kumar (1980) conducted trials with dwarf wheat to note the effect of water stress at 3 growth stages (sowing to maximum tillering, maximum tillering to flowering and flowering to maturity) and observed that moderate to severe water stress decreased plant height, leaf area, ear number, 1000 grain weight, grain yield and water use efficiency. In stage-3 the effect of water stress on yield was not marked. Wheat was most sensitive to water stress during stage-1 when the reduction in grain yield was caused by a reduction in number of ears and grains per ear. In stage-2 grain yield reduction was due to fewer grains/ear and a lower 1000 grain weight.

Misra (1981) conducted trials to note the effectiveness of different methods of scheduling and effects of irrigation on yield attributes. Different methods of scheduling irrigation were on the basis of physiological stages of growth, soil moisture condition, pan evaporation and leaf water potential. Grain and straw yields, ears/m, fertile spikelets/ear and number and weight of grains/ear were significantly influenced by treatments. Irrigation based on leaf water potential was as good as when based on physiological stages, or soil moisture, and the use of pan evaporation was in no way better than other methods of scheduling.

Singh (1981) conducted an experiment on cv. Kalyan Sona with 10 (no irrigation after sowing) 29, 56, 83 or 102 cm of water and 0, 61, 150, 239 or 300 kg N/ha. It was observed that the effect of evapotranspiration deficit (ETD) was reflected in all yield components. The main yield limiting component was number of grains/ear. LAI at boot stage ranged from 2.3 at the lowest irrigation rate to 4.6 at the highest and grain yields from 1.2 to 5.43 t/ha. The yield decrease was due mainly to floret abortion. ETD at different growth stages decreased in the order of booting/heading flowering to grain development vegetative phase.

Gales and Wilson (1981) investigated the effects of shortage of water on the grain yield of winter wheat cv. Maris Huntsman. Plants were subjected to water stress at different stages of growth, but it was observed that none of the treatments significantly decreased yield. Some treatments decreased the ears/unit area and number of grains/ear, but these effects were offset by increase in individual grain weight. It was also estimated that the soil water deficit (151 mm) in the treatment which had the largest effect on yield would be expected in nature about 15 yrs. in 100 yrs. or even less.

Gajri and Prihar (1983) in field experiments studied the effects of pre-sowing, post-sowing and split application of limited amounts of water on root growth, water use, D.M. accumulation and grain yield of wheat. Early season water stress decreased D.M. accumulation rate. Grain yield was increased as compared

to unirrigated control. The increase in yield was associated with an increase in tiller number/m row length, number of grains/ears and 1000 grain weight.

From the earlier investigations reviewed, it is clear that the effect of irrigation on yield attributing characters of wheat is variable. Many investigators reported significant increase in yield by applying irrigation water while, many other workers did not get any response. Reason for such conflicting results may be attributed to the degree of moisture deficit before irrigation which again depends on soil types and climatic conditions prevailing in areas of investigation. In general the yield attributing characters like tiller number was influenced most by timely application of irrigation. Other attributes like grain number per panicle and 1000 grain weight were adversely affected by soil moisture stress which ultimately caused a reduction in grain yield.

2.1.2 Influence of Irrigation or Soil Moisture Stress on Yield of wheat

2.1.2.1 Effect based on depth, interval or critical stages of growth

In the entire biological cycle of growth of wheat a few critical stages have been identified. Water stress at any such critical stage may affect the yield attributing character and finally the yield. Again each critical stage for irrigation influences specific yield contributing character of wheat. Actual

requirement of irrigation may vary depending on the soil climatic condition. In some areas irrigation at all the critical stages may not be necessary. In other areas, number of irrigations needed may be more than the total number needed to cover all critical stages. The following review would provide a clear idea regarding the effect of irrigation at different critical stages of growth and also the number and depth of irrigation needed for wheat crop.

Bhardwaj and Wright (1967) reported from Indian Agricultural Research Institute, New Delhi, that dwarf wheat (2 gene dwarf) got four critical growth stages for soil moisture viz. (i) crown root initiation (ii) tillering (iii) earing and (iv) dough stages.

Gautam et al. (1968) observed that intake of water by wheat was maximum at the later stage of development and moisture stress during these stages may result in considerable reduction in yield.

Misra et al. (1969) suggested that irrigation to dwarf wheat at crown root initiation, late tillering, flowering and dough stages is essential for good yield. When the early irrigations were not given, the straw yield was reduced.

Sharma (1969) found that 4 irrigations to dwarf wheat at crown root initiation, late jointing, flowering, milk stages gave higher yield than at late tillering, flowering, milk and dough stages.

Chauhan et al. (1970) from a trial conducted at Delhi reported that 1-6 irrigations applied to wheat cv. Sonora 64 at

various growth stages increased the yields by 13-450% compared to yields of 9.3 kg grain/ha on unirrigated plots. The yield increases resulting from 1-irrigation applied at 25 days (crown root initiation stage), 65 days (jointing stage) or 105 days (milk ripe stage) after sowing were 227, 122 and 13% respectively over control (no irrigation) and those resulting from 2 irrigations applied at 25 and 65 days, 65 and 105 days, or 25 and 105 days after sowing were 268, 180 and 240% respectively.

Shrotriya et al. (1970) in a trial at Durgapura stated that dwarf wheat was given 4, 5, 6 irrigations at the crown root initiation, late tillering, late jointing, flowering, milk, ripe and dough stages. Withholding of 2 irrigating at the crown root initiation and late tillering stages delayed maturation and decreased grain yield, the yield reduction was greater when irrigation was withheld at the crown root initiation stage than at late tillering stage indicating that the former is the critical stage for irrigation. They also found that withholding irrigation at the milk ripe stage induced pre-mature drying of grains.

Mihalyfulvi (1970) reported from a small plot experiments that 1, 2 or 3 irrigations at ear emergence, flowering and grain formation stages respectively increased yields by 13-84%; the response was increased with the number of irrigations. The most effective result was obtained when 2 irrigations were given at ear emergence and at flowering.

Mandloi and Kushesaha (1970) reported that yields of wheat (var. HY-65) were increased by 59, 37, 27 and 23% over no irrigation when 3 irrigations at tillering, earing and milk ripe stages, 2 irrigations at tillering and earing stages and 1-irrigation at tillering or at earing stage, were given respectively.

Bhardwaj et al. (1971) showed the importance of first irrigation at crown root initiation stage in dwarf wheat variety "Kalyan Sona" and they also concluded that the yield was decreased when the first irrigation was delayed.

Patel et al. (1971) studied the effect of scheduling irrigation on physiological growth stages on dwarf wheat variety Kalyan Sona at Kanpur. They observed that the crown root initiation (21 days) and dough (115 days) stages were the most critical periods for irrigation. Irrigation at late tillering (42 days), flowering (61 days) and milk (98 days) stages should be given adequately for highest grain yields in such similar conditions. While irrigation at late jointing stage (61 days) could be skipped off and time could be adjusted with 5 irrigations.

Sharma and Singh (1971) found that in dwarf wheat varieties e.g. Kalyan Sona, Sonalika, Chhotilerma (S-331), U.P.-301, EA-221-1 and HD-1941, the crown root initiation stage was the most appropriate time for application of first irrigation. Early and late irrigations resulted in reduction in yield.

Narang and Sachan (1971) found that when the application of first irrigation was delayed beyond 20 days (C.R.I. stage) after sowing, the yield was progressively reduced.

Singh and Narang (1971) found that different Mexican strains behaved differently to the delay in first irrigation. This variable behaviour might be on account of the differential tillering time span. On the basis of tiller number, the ideal time for application of first irrigation would be about 21 days after sowing, the period coinciding closely with the C.R.I. and tiller development in Mexican wheats.

Gill et al. (1971) from Ludhiana reported that higher levels of irrigation (5 to 6 irrigations) increased the yield of dwarf varieties "Lerma Rojo" and "Sonora-64". "Lerma Rojo" was benefitted significantly when the frequency of irrigation was increased upto 9.

Bhardwaj (1970-71), in his report on the Co-ordinated Agronomic Experiments of all India Wheat Improvement Project mentioned the following findings of irrigation experiments on critical stages of growth of dwarf wheat.

Trials were conducted at 8 centres namely, Bichpuri, Delhi, Kanpur, Kalyani, Pant Nagar, Varanasi, Durgapur and Ludhiana. At Delhi, Kanpur, Varanasi, Durgapur and Ludhiana, the yields were increased with increasing number of irrigation from 0-6. With one irrigation, crown root initiation stage was

found to be the best at Bichpuri, Delhi and Pant Nagar. At Kanpur, irrigation at C.R.I. and at late tillering were at par but superior to late jointing and flowering stages.

With two irrigations, one at C.R.I. plus one more at late jointing, flowering or milk stages appeared to be superior to those treatments where the irrigation at C.R.I. stage was missing.

With three irrigations, C.R.I. + late jointing + milk stages proved superior to late jointing + flowering + dough stages.

Four irrigations given at C.R.I., late tillering, flowering and milk stages in general superior to 3-irrigating irrespective of their time of application.

For highest yields of the 3-gene dwarf wheat, 6 irrigations at C.R.I., late tillering, late jointing, flowering, milk and dough stages were found desirable.

Yadav (1972) reported that in the new Mexican wheats, crown root initiation, jointing, flowering and grain formation stages were the critical stages.

Jana et al. (1972) reported that irrigation at tillering and flowering with a common irrigation at crown root initiation stage increased significantly the yield of wheat over no irrigation and one irrigation at tillering.

Sharma and Bhattacharya (1972) conducted experiment at Karnal on wheat variety Kalyan Sona and showed that the grain yield was reduced significantly by missing irrigation at C.R.I. + Flowering stage at Karnal. This experiment also showed that irrigation at tillering, late jointing and late flowering stages gave the highest grain yield. The same author quoted other review on water requirement of crops that at Roorkee, the maximum yield of 42.46 q per ha for Lerma Rojo and 34.75 q/ha for Sonora-64 was obtained with three waterings of 5 cm depth at 3 weeks interval, total water use inclusive of rainfall of 15.88 cm being 30.88 cm. For C-306, the best yield of 32.68 q/ha was obtained with three irrigation applications of 5 cms. depth at 4 weeks interval, total water use being the same. With the same irrigation practice and water use Lerma Rojo gave 22% and 30% higher yield than those for Sonora-64 and C-306.

Reddi Sankar (1972) at Chittor (A.P.) conducted an experiment with dwarf varieties "R.R.-21, Sharbati-Sonora" and Kalyan Sona and suggested that irrigations at crown root initiation, late tillering, primordial initiation, flowering milky and dough stages were essential for good yield.

Garg and Saraswat (1972) studied the response of dwarf wheat varieties "R.R.-21" and "Kalyan Sona" to different irrigation frequencies at Bhind, Baroda and Jora of the Chambal Command Area and found that grain yield was increased with the number of irrigations upto five at Bhind and Jora and upto six at Baroda.

Lerma Rojo and Sonora-64 thus need lighter but more frequent irrigation applications, ranging from 3 to 5 or even 6 depending upon the pattern and distribution of rainfall.

Department of Agriculture at Powerkheda M. P. concluded that three or four irrigations of 7.5 to 10 cm depth were necessary for dwarf wheat; their observation was :

1. Irrigation of 5 cm depth was found to be optimum for soil of medium texture. Depth of irrigation might be higher for heavier soils + lower for lighter soils.
2. Earlier irrigations might be light, while the depth of irrigation might be increased gradually for subsequent irrigations.
3. Irrigation depths from 40 to 50 mm and number of irrigation varying from 2-5 showed no differential response on wheat yield, provided that total water use was kept same.

Jana and Sen (1973) reported that 3 irrigations at crown root initiation, tillering and dough stages with rainfall at flowering stage, were found sufficient for dwarf wheat variety Sonalika in alluvial soil under the conditions prevailing in West Bengal. They have also found that if 2 irrigations are to be given in case of shortage of irrigation water, irrigation should be given at crown root initiation and tillering stages for maximum yield and if only one irrigation is to be applied, irrigation should be given at crown root initiation for higher production.

Cheema ~~et al.~~ (1973) conducted trials with wheat cv. Kalyan Sona on sandy loam soils and noted the effect of withholding

1 or 2 irrigations at consecutive stages of plant growth viz. crown root initiation (CRI), late tillering (LT), late jointing, flowering (F) milk and dough stages. The grain yield was decreased by 27, 23 and 20%, when irrigation was missed at CRI, LT and F stages respectively, but missing 2 consecutive irrigations at CRI and LT reduced yield by 60%. Soil moisture stress increased grain protein content.

Kulkarni et al. (1974) conducted trial with wheat cv. Safed Lerma. Irrigation was given (a) 5 times (sowing, CRI, late tillering, flowering and dough stage) (b) 4 times as in (a) omitting the last, or 3 times (sowing, CRI and flowering) and fertilizer doses given were 150 kg N + 100 kg P_2O_5 + 75 kg K_2O /ha or 75% and 50% of the dose. The average yield obtained with all fertilizer doses were 2.18, 2.02 and 1.3 t/ha for (a), (b) and (c) irrigation treatments respectively. The average yield over irrigation treatments declined from 1.85 to 1.84 to 1.81 t/ha respectively with decline of fertilizer dose from full to 75% to 50%. It was concluded that a minimum of 4 irrigations and 50% of the recommended fertilizer dose was essential for high yield.

Rajput and Jadav (1974) after conducting field trials with wheat cv. Kalyan Sona and irrigating at 1 or more of the growth stages - late tillering, booting, flowering and early dough ripe stages observed that grain yields were significantly lower in plots without irrigation than in those with irrigation at flowering. It was also observed that omitting irrigation at the boot

stage reduced grain yield significantly when no significant rainfall had occurred since sowing. It was concluded that with 1 irrigation before sowing and 2 after sowing one at crown root formation and the other at flowering or booting, grain yields of 5 t/ha could be obtained.

Sharma et al. (1974) reported that when three gene dwarf wheat cv. UP-301 was given 60-180 kg N + 75 kg P_2O_5 /ha and treatments of one common irrigation was given in all plots 5 days after sowing and 0-6 irrigation at different growth stages, the treatment of 3 irrigations at the CRI stage, at the jointing stage and at the milk ripe stage produced the highest grain yields of 4.35 - 4.51 t/ha compared with 2.6 - 3.12 t/ha without irrigation. It was also observed that yield with irrigations at the depletion of 50% of available soil moisture in the top 30 cm soil layer were similar to those with 3 irrigations at the above stages. It was further reported that single irrigation at the CRI stage gave higher yields than did 1 irrigation at any other stage. Yields were highest with 180 kg N/ha among the 3 nitrogen doses. The nitrogen x irrigation interaction was not significant, indicating that the normal N rate can be applied under conditions of limited water supply.

Singh et al. (1975) after conducting trials with dwarf wheat cv. Kalyan Sona in the terai tract of U.P. reported that irrigation at the CRI stage was the most effective in increasing grain yields while irrigation at the late tillering flowering and

milk ripe stages were also important. It was also observed that irrigation at the late jointing and dough ripe stages were not effective. One irrigation at the CRI stage with 60 kg N + 30 kg P_2O_5 + 15 kg K_2O /ha, two irrigations at the CRI and milk ripe stages with 120 kg N + 60 kg P_2O_5 + 30 kg K_2O /ha and four irrigations at the CRI, late tillering, flowering and milk ripe stages with 180 kg N + 90 kg P_2O_5 + 45 kg K_2O /ha gave economic yield.

Patel and Patel (1975) noted that highest reduction in the grain yields of wheat occurred by withholding irrigation at the milk ripe stage, followed in order by withholding irrigation at the boot, late jointing, CRI and flower stages.

Bhan (1978₀) observed that in dwarf wheat irrigation at the (a) CRI; at (a) and flowering; at (a) and jointing; at (a) jointing and milk ripe stages and at (a), jointing, flowering and milk ripe stages increased the grain yields of 3 locations by 1.63, 2.04, 2.41 and 2.97 t/ha respectively from 1.85 t without irrigation.

Kulkarni et al. (1978) conducted field trials with durum wheat cvs. HD-4500, HD-4501, HD-4502 and HD-4503 and breed wheat cv. Kalyan Sona and gave upto 5 irrigations and noted that Kalyan Sona gave average grain yield of 2.39 t/ha and consistently outyielded the durum which yielded on an average 1.42 - 1.70 t/ha. Average yield was increased from 925 kgs to 2.64 t/ha with increasing number of irrigations from 0 to 5 mainly due to an increase in plant population and number of grains per ear. Water supply was most critical

at sowing, crown root and flowering stages. Kalyan Sona was very susceptible to moisture stress at the crown root stage.

Malik (1978) reported that increasing the number of irrigation from 1 to 4 applied at crown root initiation, tillering, flowering and dough ripening stages increased 3 year average grain yields from 2.68 to 4.42 t/ha in dwarf wheat cv. Kalyan Sona and from 2.32 to 3.66 t/ha in tall cv. C-306; the tall cv. yielded 3.42 t/ha with 3 irrigations. The dwarf cv. was superior to the tall cv. in water use efficiency at all irrigation frequencies.

Sharma et al. (1978) noted that when wheat cv. Kalyan Sona received from 0 to 6 irrigations, grain and straw yield were increased from 1.60 + 2.08 t/ha respectively with no irrigation to 4.22 and 6.25 t/ha with 6 irrigations. Uptake of K in grain and straw increased with increasing frequency of irrigation. N, P, Ca + Mg uptake was highest with 5 irrigations.

Jana et al. (1978) conducted field trials with dwarf wheat cv. Sonalika and observed that of the different stages of irrigations, irrigation at CRI and T stages were the most important for irrigation. The 2 year average grain yields with 2 irrigations at CRI and tillering stages were 3.01 t/ha compared with 3.97 t/ha with 4 irrigations and 2.29 - 2.58 t/ha with 2 irrigations of which one was either at the CRI or T stage and the other at any other stage.

Saxena and Singh (1979) observed that grain yields of two wheat cvs. were higher with one irrigation applied at the (a)

tillering stage than when applied at (b) flowering or (c) milk ripe stage. Yield was however, higher with 3 irrigations applied at (a), (b) and (c) but were not significantly different from those obtained with 2 irrigations applied at (a), and (b).

Gill and Singh (1980) concluded from field trials that the average grain yields of 1.64 t/ha in dwarf wheat cv. Kalyan Sona given 0-120 kg N + 60 kg P_2O_5 /ha and 4 irrigations upto the flowering stage were increased to 2.98 t/ha with two more irrigations applied at milk ripe and soft dough stages; yields were not further increased with additional applied at the hard dough and/or at full ripe stages.

Rahman et al. (1980) conducted field studies to note the response of irrigation provided at various critical stages of growth with high yielding dwarf wheat cv. Sonalika on a calcareous brown flood plain soil in Mymansingh (Bangladesh) with 8 irrigation treatments applied at critical growth stages. It was observed that the grain yield was highest and the irrigation efficiency was maximum when 2 irrigation totalling 9.5 cms were given at the tillering and booting stages. The quantity of irrigation water applied was calculated on the basis of soil moisture deficit. The lowest grain yields were obtained in treatment receiving either no irrigation or only 1 irrigation at the grain filling stage. The yield increase over the control (no irrigation) due to various irrigation treatments ranged from 21 to 92%. It was concluded that the present yield levels of wheat in Bangladesh could easily be increased by 50-100% by irrigating with only 33-50% of the water

currently used provided it was scheduled and managed efficiently.

Nayek and Sengupta (1981) after conducting field experiments with 12 irrigation treatments conducted at 3 locations in new alluvial tracts of West Bengal noted that dwarf wheat cv. Sonalika required only 3 irrigations each of 50-60 mm depth besides a pre-sowing irrigation of 70-75 mm for successful growth and yield when judiciously applied at the sensitive stages of growth, viz. crown root initiation, late tillering + peak flowering. Flowering stages found to be most critical stage followed by crown root initiation, while the grain filling stage was less critical for moisture.

Rao and Bhardwaj (1981) reported that increasing the number of irrigations from 1 to 2 or 5 increased the average grain yields and (a) consumptive use of water by 3 wheat cvs. and decreased (b) water use efficiency.

Sarmadnia (1981) noted that with 150 mm pre-sowing irrigation, grain yields of wheat ranged from 2.4 to 3.4 t/ha in 1979 and from 2.4 to 3.7 t/ha in 1980 with different wheat cvs., at Mesa, Arizona, on a clay loam soil and from 1.1 to 3.0 t/ha in 1980 at Tucson, Arizona on a sandy loam soil. At Tucson with irrigation 2-3 weeks before flowering yields ranged from 2.3 to 3.4 t/ha, with irrigation 1 week prior to anthesis from 1.6 to 3.61 t/ha and well watered from 2.7 to 4.6 t/ha when grown under dryland conditions.

Majumder and Roychoudhury (1981) after conducting trials in 1975-78 with 2 wheat cvs. grown on lateritic soil with water table depth of 76-135 cms arrived at the inference that grain yields remained unaffected by giving 2-5 irrigations compared to 1 irrigation at the crown root initiation stage.

Dhima and Gjergji (1982) conducted irrigation trials with wheat in Albania and observed that grain yields were increased by 31-58% by 3 irrigations in April-May between 2 weeks before ear formation and grain maturity, in dry year and by 23-35% with 20 irrigations when rainfall was low in April + May. In year of abundant rainfall in April, 1 irrigation in May increased yields by 10-12%. Yields were increased through increases in 1000 grain weight, ear weight, grain yield/plant and grain yield/ha.

Souza et al. (1982) conducted field trials in Sao Paulo and observed that wheat cv. B.H.-1146 had 2 critical periods for water supply - irrigation was beneficial until early flowering, but increased water supply at late flowering to the milk stage reduced grain yield.

Sharma and Bhardwaj (1983) concluded from field trials that an irrigation at the crown root initiation stage (CRI) produced more tillers, fertile spikelets and number of grains/ear and higher grain and straw yield than an irrigation at later stage. They further reported that two irrigations at CRI and boot stages yielded more than two irrigation at late tillering and flowering stages.

Overall assessment of the above findings of different investigators reveal that of the different vegetative and reproductive stages, crown root initiation stage is the most sensitive to soil moisture stress compared with other stages of growth. Other critical stages of growth identified are tillering, flowering and grain filling stages. In areas of more water requirement other critical stages in reproductive phase have been identified. These are floral initiation, anthesis and grain filling stages. Thus, identification of critical stages of growth depending on the area is of paramount importance for efficient and economic use of available water resources by providing the water at most sensitive stage/(S) only and allowing maximum admissible level of stress during the less critical stages of growth.

Regarding depth and interval of irrigations the review leads to the following conclusion.

1. Irrigation of 50 mm is optimum for soil. With medium texture. Depth of irrigation may be higher for heavier soils.
2. Earlier irrigation may be light, while the depth of irrigation may be increased gradually for subsequent irrigations.
3. Number of irrigations may vary from 2-5 depending on soil and climatic conditions.

2.1.2.2 Effect of irrigation based on energetics of soil moisture

Scheduling of irrigation based on energetics of soil moisture (per cent of available soil moisture, soil moisture stress etc.) is better than other methods (number of irrigations, stage of crop) because such an approach can guard against possible changes caused by vagaries of nature - by a chance shower or high temperature or prolonged drought conditions etc. Good number of investigations have been carried out, a few important of which are enumerated below.

Singh (1945) reported that for wheat varieties soil moisture regime maintained at 60 to 70 per cent of field capacity appeared to be satisfactory, while for dwarf varieties 100 to 60 per cent was necessary. About 49 and 75 per cent of moisture was extracted by wheat from the surface 0 to 30 cm and 0 to 60 cm of soil depth respectively.

Dubetz (1961), Lehane and Staple (1962) found that the best soil moisture regime for wheat crop ranged from 100 to 75 per cent available soil moisture throughout the season. Prashar and Singh (1963a) found that 48 per cent moisture was extracted by wheat from the surface 30 cms depth of soil layer and about 75 per cent from 0 to 60 cm depth of soil layers on a sandy loam soil at IARI, New Delhi.

Modgal and Das (1963) found that irrigation at 25 per cent available soil moisture was best among the three treatments when

irrigations were applied at 10, 25 and 50 per cent available soil moisture. Negomireanu (1965) concluded from investigations on moisture utilization by wheat that uninterrupted moisture supply of greater than 65 per cent of field capacity during the period from sowing to milk stage was best for maximum yield.

Dastane and Singh (1963) under Delhi conditions found that 3 irrigations at an atmospheric tension of 0.5 atm would be adequate. Optimum soil moisture tension to irrigate wheat crop was about 0.5 atm. measured at 22.5 cm soil depth for Indian wheat (Anon, 1964).

Haise and Hagan (1967) reported that irrigation at 0.5 bar to 1.5 bar, measured at maximum root activity zone was the optimum.

Hallings (1967) obtained economically best result by irrigation wheat at 75 to 80 per cent available soil moisture. Bathkal and Dastane (1968) at New Delhi, found that the optimum soil moisture was from 100 to 50 per cent availability in the surface 60 cm depth of soil layer.

The optimum soil moisture regime for Sonora 64 variety of wheat was 100 to 60 per cent of moisture availability in the surface 30 cm depth of soil layer (Goutam et al., 1968). Chambell (1968) reported that wheat grown in soil containing 10 to 25 per cent of moisture by weight gave greater yield of straw and root but grain yield varied with temperature.

Modgal et al. (1968) found at Pantnagar that irrigating wheat crop at 0.8 atm. moisture tension significantly increased 26.4 per cent grain yield of N P 824 variety of wheat over the plots where irrigation was applied at 5 atm. There was, however, no difference in yield amongst treatments where irrigation was applied at 0.4, 0.5 or 0.8 atm. soil moisture tensions measured at 23 cms soil depth.

Singh and Dastane (1970) at I.A.R.I., New Delhi, found that irrigating Mexican dwarf wheat at 0.25 atm. soil moisture tension, measured at 22 cm soil depth, gave maximum yield. They, however, recommended that for optimum economic yield the crop should be irrigated at 0.2 atm. soil moisture tension.

Bhattacharya (1972) reported that 60 per cent available soil moisture regime was optimum for wheat. Sharma and Bhattacharya (1972) mentioned in their review on water requirement of crops that highest yield was obtained from Lerma rojo and Sonora with irrigation application at 70 per cent available soil moisture at Dhumuri, U.P. Srivastava (1972) obtained highest grain yield of wheat with irrigation at 60 per cent available soil moisture.

Shukla et al. (1972) on the basis of a trial conducted with wheat grown on sandy loam soil, reported that irrigation at 60 per cent available soil moisture (ASM) in the 15 to 45 cm layer gave higher grain yields than the yields obtained by giving irrigation at 20 to 50 per cent ASM. It was also observed

that yield response to the application of N @ 45 to 135 kg/ha was quadratic and the optimum rate was 80.4 kg N/ha. Crops showed little response to the application of 45 to 135 kg P_2O_5 /ha. Applied N increased protein content in grain and straw, but irrigation and P had little effect. None of the interactions was significant.

Lebedev and Singh (1973) conducted a trial in Kiev, Ukrainian, U.S.S.R., with the treatments of no irrigation, pre-sowing irrigation and pre-sowing irrigation + irrigations during vegetative growth. Irrigations were given whenever soil moisture contents fell below 55 or 75 per cent of field capacity. All treatments were given 90 kg N + 60 kg P_2O_5 /ha. The irrigation treatments markedly increased tillering, leaf area, leaf chlorophyll and carotenoid contents and co-efficient of absorption of photosynthetically active radiation and resulted in average grain yields of 3.72 to 5.19 t/ha in cv. Bezotstaya I, and 3.21 to 5.54 t/ha in cv. Kavkaz, compared to 1.16 and 1.34 t/ha respectively in unirrigated plots. Irrigations given during vegetative growth, when soil moisture contents reached to 75 per cent of field capacity, gave maximum increase in yield. Irrigation decreased grain protein contents, but increased protein yield and grain yield.

Pyarelal and Sharma (1973), from a trial with dwarf wheat cvs. Kalyan Sona and Sonalika in a silt loam soil maintaining 3 soil moisture regimes of 25, 50 and 75 per cent depletion of

available soil moisture maintained after a general irrigation given at crown root initiation stage, reported that the irrigation treatments produced almost similar yields of 4.43 to 4.61 t/ha.

Singh et al. (1973) observed that 3 wheat varieties given 0 to 120 kg N/ha in addition to a basal dressing of 40 kg P_2O_5 /ha and irrigating at 90, 70, 50 or 30 per cent depletion of available soil moisture in the top 75 cm soil layer produced yields of 2.69, 2.76, 3.01, 3.06 t/ha, respectively, in 1968-69 and 2.98, 3.41, 3.76 and 3.55 t/ha in 1969-70. Application of 120 kg N/ha to dwarf cvs. Kalyan Sona and Sonalika and 80 kg N to tall cv. C 306 gave the highest yields. There was no interaction between irrigation regimes and N application. N uptake by plants was increased with increasing rates of applied N. P uptake was not affected by irrigation or N application.

Rathore and Singh (1973), conducted field trials with dwarf wheat cv. Sonora 64 and was given 4 irrigation treatments at 20, 40, 60 or 80 per cent of available soil moisture, along with 0, 30, 60, 90 and 120 kg N/ha, and 0 or 30 kg P/ha observed that growth, grain and straw yields were increased significantly with irrigation at 60 and 80 per cent available soil moisture (from 3.45 t grains/ha at 20 per cent to 4.51 t/ha at 80 per cent available moisture). Dry matter, yield attributes and grain yield were increased with increasing levels of N. Application of 30 kg P/ha increased growth, grain and straw yields.

Reddy and Dakshinamurti (1975) observed that two dwarf wheat cvs. gave highest grain yields when each of the 4 irrigations was given at 0.75 to 1 x field capacity; yields were decreased with irrigations given at 0.5, 1.5, 2 or 3 x field capacity.

Singh and Aggarwal (1976) observed that when wheat variety Kalyan Sona was given 40 to 120 kg N/ha, in addition to 0 to 80 kg P_2O_5 /ha and irrigations given as and when available soil moisture contents in the top 30 cm soil layer was depleted to (a) 30, (b) 50 and (c) 70 per cent, grain yield was increased from 2 to 3.6 t/ha during 1969-70 with increasing N rates from 40 to 120 kg N/ha. N content in the grain was decreased and N content/ha was increased with increasing moisture supply and/or N rates. N use efficiency was increased with increasing N rates. The treatment combining (b) with 80 kg N/ha was considered to be the best in terms of yields and N-use efficiency under conditions of limited water and N supplies.

Rathi et al. (1976) reported that wheat cv. Sonalika during a period of 2 years, irrigated at the depletion of 70 per cent available soil moisture (ASM) throughout the growth period, gave the highest grain yields of 4.25 and 5.82 t/ha followed by 3.66 and 5.33 t/ha with irrigation at 50 per cent ASM upto flowering and at 70 per cent ASM upto maturation, compared with 3.27 and 5.62 t/ha with 6 irrigations given at the critical growth stages (recommended practice). Yields with 120 kg N + 80 kg P_2O_5 + 40 kg K_2O or 80 kg N + 60 kg P_2O_5 + 20 kg K_2O /ha were 3.51 to 5.32 and 3.2 to 4.97 t/ha respectively.

Reddy (1976) reported highest grain yield with irrigation levels of 0.75 F.C. followed by 1.0 F.C., this trial was conducted with 2 wheat cvs. sown with a pre-sowing irrigation and thereafter given, either no irrigation or 4 irrigations each with different amounts of water to give 0.5, 0.75, 1, 1.5, 2 or 3 times field capacity, the amount of water applied at each irrigation was based on the amount of moisture depleted from the top 40 cm of soil layer.

Reddy (1978) noted that wheat cv. RR 21 when sown with two seed rates 120 and 160 kg/ha, irrigated at the depletion of 25 or 50 per cent available soil moisture (ASM) and given two N doses - 50 and 100 kg/ha in 2 or 3 split applications, the highest grain yield was recorded at a seed rate of 160 kg/ha with irrigation applied at 25 per cent depletion of ASM under 100 kg N/ha supplied in 3 splits at sowing, crown root initiation and ear initiation stages.

Marinato and Palacios (1979) conducted an experiment with wheat cv. Potam 70 under four moisture regimes when soil moisture content fell to 20, 40, 60 and 80 per cent of field capacity (F.C.) between (a) germination and gametogenesis, between (b) gametogenesis and milky ripeness and (c) milky ripeness and maturity and obtained grain yields ranging between 4.6 t/ha with irrigation applied at 20 per cent F.C. at all the 3 stages to 6.77 t/ha with irrigation applied at 20 per cent F.C. at (a), 60 per cent at (b) and 60 per cent at (c).

Rao and Bhardwaj (1982) conducted field trials with dwarf wheat varieties and irrigations applied at (a) crown root initiation (CRI), (b) CRI plus boot stage and (c) whenever soil moisture tension at 25 cm depth reached 0.5 atm. They obtained highest grain yield with (c) (total 5 irrigations) and the yield was decreased with further increase in irrigation frequency.

Investigations on the effect of irrigation on the basis of energetics of soil moisture suggest that maintaining available soil moisture level at 60 to 100 per cent was most effective in giving high yield. Irrigation should be given whenever level of available soil moisture falls below 60 per cent, a level of 50 per cent being critical.

Regarding scheduling irrigations depending on soil moisture tension, 0.5 atmosphere tension appears to be indicative of irrigation requirement for wheat.

2.1.2.3 Irrigation based on climatological approach

Recently, climatological approach is being used to correlate consumptive use of water with Open Pan Evaporation and computed values obtained on the basis of climatological informations using Penman's formula or Blanney Criddle's formula or Thornthwaite's formula. The ratios of values obtained from Open Pan Evaporation and computed values are used as a guideline for irrigating crops.

Prashar and Singh (1963b) in their irrigation studies on wheat correlated consumptive use with evaporation from U.S. Open Pan Evaporimeter. The value ranged from 0.52 to 0.56 in 1958-59 and from 0.41 to 0.50 in 1959-60. The corresponding ratios with Penman formula varied from 0.63 to 0.08 in 1958-59 and between 0.58 to 0.81 in 1959-60. The consumptive use increased with the advance of season from 0.8 mm per day during the growth of crop.

• Singh (1966) studied at Udaipur the relation of actual evapotranspiration with computed values with the help of Blaney and Criddle's formula and U.S. Pan Evaporimeter. He found that type of vegetation and stage of growth did not play any part in water use by crops. Both the evaporimeter as well as Blany Criddle formula were found to be useful for estimating consumptive use of water by wheat.

Sharma and Dastane (1968) correlated values of evaporation from screened evaporimeters of different sizes with consumptive use of water by wheat crop. They found that the values from all the screened evaporimeters gave a very high degree of correlation (more than +0.97). From the proximity point of view, however, screens of 6 x 2 = size gave a ratio nearer to unity. They recommended the use of these evaporimeters for direct estimation of consumptive use of water and also for precise scheduling of irrigation.

Singh and Dastane (1970) correlated consumptive use of wheat with values of evaporation from the U.S. Open Pan Evaporimeter for different periods. The total consumptive use of water was about 470 mm while the corresponding value of evaporation from the U.S. open pan being 660. They found a high degree of correlation between these two entities, the value of correlation co-efficients being above 0.9 in the optimum moisture regime.

Work regarding the approach on irrigation based on water use/cumulative pan evaporation ratio was conducted at a number of stations during 1970-71 and 71-72. The overall findings were as follows :

1. The efficiency per unit of water applied declined with the increase in $1W/CPE$ ratio from 0.60 to 1.05.
2. The Depth of irrigation had little effect on the water use efficiency.
3. Adoption of 0.75 or 0.90 ratio of $1W/CPE$ for scheduling irrigation ensured optimum yield.

Gowda (1972) while reporting the results of a field trial conducted with dwarf wheat cv. Lerma Rojo given @ 60 kg N + 30 kg P_2O_5 + 20 kg K_2O (b) 120 kg N + 60 kg P_2O_5 + 40 kg K_2O or (c) 180 kg N + 90 kg P_2O_5 + 60 kg K_2O and irrigated at 50, 75 and 100 mm evaporation on an evaporimeter concluded that the highest grain yield (4.35 t/ha) was obtained with the application of

360.77 mm of irrigation water at 50 mm evaporation and fertilizer rate (c), while the lowest grain yield (3.39 t) was obtained with the application of 227.47 mm of irrigation water at 100 mm evaporation and fertilizer rate of (a).

Gowda and Patil (1973) conducted an experiment on wheat cv. Lerma Rojo which was irrigated when evaporation from evaporimeters amounted to (a) 50, (b) 75, and (c) 100 mm. The grain yield was highest (4.35 t/ha) with irrigation treatment at (a) plus fertilizer at 180 kg N/ha + 90 kg P_2O_5 /ha + 60 kg K_2O /ha and was lowest (3.39 t/ha) with treatments (c) plus 60 kg N + 30 kg P_2O_5 + 20 kg K_2O /ha. Amounts of irrigation water applied were 360.77 and 227.47 mm respectively. Water consumption was 352.26, 277.99 and 244.61 mm with irrigation treatments (a), (b) and (c) respectively. It was concluded that the tin evaporimeter can be conveniently used for scheduling irrigation in wheat.

Cheema and Kaul (1974) after an investigation with dwarf wheat cv. Kalyan Sona observed that irrigation based on the values of evaporation from the U.S. open pan evaporimeter in the range of 300 to 1000 mm (4-12 irrigations) gave similar grain yields of 3.36 to 3.77 t/ha in 1968-69 and 3.6 to 3.76 t/ha in 1969-70, indicating that 4 to 5 irrigations based on 75 to 100 mm evaporation from the open pan evaporimeter were adequate for cv. Kalyan Sona and the efficiency of moisture use was highest in that treatment. Crops showed significant yield response to the application of N upto 80 kg/ha.

Ram and Singh (1976) reported that irrigation of 32 mm depth should be applied after 60 mm cumulative pan evaporation (CPE) during 23 to 45 days after sowing, after 40 mm CPE during 48 to 105 days and after 60 mm CPE during 106 to 133 days after sowing.

Lal and Sharma (1976) conducted field trials on silt loam soils with a depth of water table ranging between 125 to 171 cm; and reported that when 2 dwarf wheat cvs. were given 0 to 200 kg N/ha and were irrigated at the depletion of 75, 50 or 25 per cent available soil moisture (ASM), the consumptive use of water (CUW) was 350.9, 473.7 and 536.8 mm with irrigations at the depletion of 75, 50 and 25 per cent ASM respectively. It increased from 390 to 485.7 mm with increased nitrogen rate from 0 to 150 kg/ha and was 473.2 mm with 200 kg N/ha.

Ehlig and Le Mert (1976) reported that in field trials with wheat cv. Blue bird 2 grown on silty clay loam soil, irrigated at 5 different rates ranging from 11 per cent more to 23 per cent less than evapo-transpiration from a weighing lysimeter. Grain yield decreased as irrigation rates decreased except between treatments equal to ET and 10 per cent less than E.T. At the three driest treatments yield decreased proportionately with water use, indicating that water use efficiency was not increased by restricting water use below ET from adequately watered crops.

Bhan (1977) in trials on scheduling of irrigation for triple-dwarf variety on light textured alluvial soil with treatments

consisted of all combinations of 3 irrigation depths of 6, 8 or 10 cm and 4 irrigation water depth cumulative pan evaporation (ID : CPE) ratios of 0.6, 0.75, 0.9 or 1.05 observed that the first irrigation of 6 cm depth at the CRI stage followed by 3 irrigations each of 8 cm depth after a cumulative pan evaporation of 89 mm (IW : CPE ratio of 0.9) gave the highest grain yields and net profit.

Agarwal (1977) recorded grain yields in wheat to the tune of 3.24, 3.50 and 4.28 t/ha with 4, 5 and 6 irrigations respectively. When irrigation was given at water use factors of 0.7 (6 irrigations) and 0.9 (7 irrigations) corresponding to 100 and 78 mm pan evaporation, the yields were 4.38 and 4.30 t/ha respectively. The consumptive use of water was increased with increasing number of irrigations, but water use efficiency was highest with 6 irrigations.

Singh et al. (1979) conducted field trials to study response of wheat to different levels of irrigations and nitrogen fertilization. The treatments were number of irrigations at 0, 1, 2, or 3 scheduled according to an irrigation water applied : pan evaporation ratio of 0.90 and the nitrogen levels used were 60, 80, 100 and 120 kg N/ha. In the normal rainfall year 1974-75 and 1976-77 wheat yield was increased with the number of irrigations. In the unusually wet year of 1975-76 the response to irrigation was not significant. No response was observed beyond an application of 80 kg N/ha without irrigation whereas the response

was linear upto 120 kg N/ha in the treatment with three irrigations. Uptake of nitrogen showed a linear relationship with yield. The apparent water use increased in the high rainfall year and with the increasing number of irrigations.

Choudhury and Kumar (1980) conducted field trials with dwarf wheat varieties subjected to a ratio of irrigation water to cumulative pan evaporation (IW : CPE) of 0.45, 0.60 or 0.75 at each of the 3 growth stages (sowing to maximum tillering, maximum tillering to flowering, flowering to maturity) and during the remaining stages, the crop was irrigated with an IW : CPE ratio of 0.9. Results indicated that wheat should be irrigated at an IW : CPE ratio of 0.75 when water resources are limited. With an unlimited water supply, the ratio may be increased to 1.2 in stage 2 to maximize the yield.

Singh (1981) reported that at Jodhpur, wheat cv. Kalyan Sona was sown with 5 different seed rates of 75, 95, 125, 155 or 175 kg/ha and received 10, 29, 56, 83 or 102 cm of water and 0, 61, 150, 239 or 300 kg N/ha. It was observed that with N and seed rates at intermediate levels there was least limitation in yield, the effects of evapo-transpiration deficit (ETD) were reflected in all yield components. The main component limiting to yield was number of grains per earhead. LAI at the boot stage ranged from 2.3 at the lowest irrigation rate to 4.6 at the highest and grain yields ranged from 1.20 to 5.43 t/ha. The yield decreased was considered due mainly to floret abortion. When

ETD timing was optimum the relation between yield reduction and ETD was linear. Sensitivity to ETD at different growth stages decreased in the order booting/heading flowering to grain development vegetative. Yields were relatively insensitive to water stress at the booting/heading stages when there was prior ETD.

Singh et al., (1981) reported that wheat was irrigated at $IW \text{ [Irrigation water Depth]} / CPE \text{ [Cumulative Pan Evaporation]}$ ratios of 0.6 - 1.05 with irrigation depths of 6-10 cm. The IW/CPE ratio of 1.05 with irrigation depth of 6 cm gave the highest grain yield. *

Miller and Hang (1982) conducted field trials in sandy and loam soils with irrigation in wheat at the pre- to early boot stage and observed that the effect of daily deficit from sprinkler irrigation depended on the water holding characteristics of the soil. In sand, the yield and quality of wheat were increased with increase in water application upto 100 per cent of estimated evapo-transpiration but on loam soil daily irrigation which equalled or exceeded 40 per cent of estimated evapo-transpiration produced similar yield.

Mazumder and Mondal (1984) observed that irrigation applied at an IW : CPE ratio of 1.0 produced the maximum grain and straw yields and the treatment was significantly the best. The yields at IW : CPE ratio of 0.8 were also significantly

higher than that the yields at the ratio of 0.6. The response curve on grain yield indicated that the optimum IW : CPE ratio for irrigation in wheat was 0.923.

Overall findings of different investigations on the approach of irrigation based on the irrigation water use/cumulative pan evaporation ratio are as follows -

1. The efficiency of water use declines with the increase in IW/CPE ratio from 0.60 to 1.05.
2. Adoption of 0.75 or 0.90 ratio of IW/CPE for scheduling irrigation will ensure optimum yield.

2.1.3 Consumptive use (C.U.) of water by wheat crop

Consumptive use of water comprised the water lost in evaporation, transpiration and that used by a plant in metabolic activities. It is generally expressed as depth of water in inches or millimeters. It is the best index of water need by a crop.

Venkatraman (1956) reported that the consumptive use of water by wheat crop was increased with the advancement in age of the crop in the following order :-

<u>Period</u>	<u>Consumptive use</u>
2nd week - 4th week	42.5 mm
5th week - 7th week	70.0 mm
8th week - 10th week	88.5 mm
11th week - 17th week	170.0 mm
	<u>371.0 mm</u>

Crop was sown in the second week of November and was harvested in the third week of March. He observed that this trend of increasing consumptive use with time might be the combined effect of plant growth and climate and not a simple crop phenomenon.

At IARI, Chandani et al., (1960) found that evapo-transpiration under field condition was very much influenced by climate and varied from 300 to 500 mm.

Prashar and Singh (1963 a) carried out a study on the relationship between consumptive use and actual evaporation calculated from weather data. They found that ratio U/E_p between consumptive use and Penman evaporation rose from about 0.36 to 0.44 during early stages to unity during the period of maximum growth and fell to about 0.30 to 0.42 in maturation phase. Again Prashar and Singh (1963b) found that the rate of water use by the wheat crop was 0.8 mm per day upto 50 to 55 days after sowing and was increased to 4 to 5 mm per day during heading and grain development stage.

Ferguson (1965) observed an increase in evapo-transpiration by wheat crop from 17.5 mm/week at three leaf stage to 36.25 mm per week at flowering and then declined to 15 mm per week at maturity.

According to Gautam et al., (1966) consumptive use of dwarf wheat was about 260 mm under Delhi condition.

Pandey and Singh (1966) from IARI observed that the consumptive use by wheat was increased with increasing delta of irrigation. They found 386.3, 460.5 and 526.3 mm respectively besides rainfall.

Quisenberry and Reitz (1967) reported that the daily consumptive use rate by wheat crop at Garden city (Kansas) U.S.A. was increased steadily with the advancement in crop growth and then declined with the onset of senescence.

Gautam et al., (1968) observed at I.A.R.I., New Delhi, that water use rate during early stages (November-December) of growth was only 0.7 to 0.88 mm per day which increased steadily to 3.25 mm per day at flowering (February).

Singh et al., (1970) from same experimental station found that C.U. by wheat crop decreased with increasing water deficit in soil. They found 469.47, 412.66 and 373 mm C.U. values for 0 to 0.25, 0 to 0.50 and 0 to 0.70 atmosphere soil moisture tensions, respectively.

Pandey (1972) determined the consumptive use of water for wheat crop by soil moisture study method and by applying Blaney and Criddle's formula. Three moisture treatments viz. M_1 (over 80 per cent of available moisture content), M_2 (over 60 per cent of available moisture content) and M_3 (over 40 per cent of available moisture content) were taken. Consumptive use of water by moisture studies was found to be 39.383, 64.188 and 64.808 cm

at M_1 , M_2 and M_3 , respectively. According to Blaney and Criddle formula C.U. was 26.771 cm at M_1 , 43.363 cm at M_2 and 43.335 cm at M_3 treatment. The values of co-efficient 'K' were found to be 0.259, 0.459, 0.531 and 0.623 at M_1 treatment, 0.358, 0.685, 0.995 and 1.004 at M_2 treatment and 0.401, 0.755, 1.066 and 0.849 at M_3 treatment for the period of 0 to 31 days, 31 to 61 days, 62 to 90 days, and 90 to 109 days. These values were used in calculating the C.U. by Blaney and Criddle's formula. The yield of wheat crop was found to be 482.67, 570.50, 555.53 kg/ha at moisture treatments M_1 , M_2 and M_3 respectively.

Shukla and Sarkar (1974) reported that potential consumptive use of water by wheat in Allahabad region reached the peak during the 12th week after sowing and average water use throughout the growth period was observed to be 1.15 cm/day.

Talha (1975) conducted field trials at Baptim in Egypt with Mexican wheat variety Super x and local variety Giza 155 and applied 0, 30, 60 or 90 kg N/ha and the crop was subjected to soil moisture deficit of 30, 55, or 80 per cent of available soil moisture. Consumptive water use was increased as soil moisture deficit decreased and N rate increased and was higher in Super X than Giza 155. The highest water use efficiency for grain and dry matter production was recorded from plots which experienced 80 per cent soil moisture deficit and 90 kg N/ha with Super X.

Lifanenkova (1975) from trials in Kabardino-Balkar, U.S.S.R., reported that optimum conditions for high yields in 4 winter wheat varieties were created with one pre-sowing irrigation (1040 to 1200 m³ water/ha) and by 1 to 3 irrigations (500 to 600 m³/irrigation) during the growth period depending on weather condition. It was also observed that irrigation not only increased consumptive use of water but also increased water use efficiency by decreasing water consumption/100 kg grain produced. The water consumption depended on weather condition and it was more under irrigated condition than under rainfed condition.

Jain and Jain (1975), on the basis of results of studies on consumptive use of water by dwarf wheat variety Kalyan Sona on light textured soils of Rajasthan, reported that 60 per cent of water consumed by the crop was obtained from the top 30 cm layer of soil and 40 per cent from 30 to 60 cm depth. Application of 40 to 50 mm water/irrigation after a cumulative pan evaporation of 45 to 55 mm from the standard U.S. pan was optimum and 8 to 10 irrigations with a total water depth of 360 to 450 mm were required.

Singh and Ramakrishna (1975) reported that in trials with wheat variety Kalyan Sona and Barley variety EB 3/Ratna which were given 20 to 80 kg N/ha by three methods, moisture use efficiency (grain yield/mm moisture/ha) was the highest with 40 kg N/ha. The moisture use efficiency in wheat was higher with N

applied in (a)-2 split dressings (50 per cent drilled before sowing and the remainder as foliar spray) than when the full N rate was either (b) drilled or (c) broadcasted, whereas in barley it was higher with (a) and (b) than with (c).

Tomar et al., (1976) reported from a trial with wheat that when irrigation was given at the crown root initiation stage (control) and thereafter irrigations were given when the soil contained 30, 45, 60 and 75 per cent available soil moisture (ASM), the consumptive use of water ranged between 151 to 194 mm in control and from 387 to 441 mm with (a) irrigation at 60 per cent ASM. The highest average grain yield of 5.3 t/ha was obtained with (a) compared to 3.12 t/ha in control.

Shahi (1976) carried out an experiment with wheat variety Kalyan Sona in which first irrigation was given at 3 weeks after sowing and reirrigated at 50 per cent depletion of available soil moisture. He observed that daily water use was (about 2 mm/day) during early growth stage and gradually increased upto ear emergence and grain development stage and then again declined.

Rathore and Singh (1976) observed that average consumptive use of water by wheat variety Sonora 64 grown at 80, 60, 40 and 20 per cent available soil moisture content was 396, 342, 303 and 263 mm, respectively; daily rates of consumptive use averaged over entire crop seasons were 3.1, 2.7, 2.4 and 2.1 mm, respectively. The seasonal water requirements of wheat under the 4 soil moisture

regimes were 417, 386, 377 and 372 mm, respectively. Water use efficiency was decreased and grain yield was increased with irrigation at increasing available soil moisture percentage. Comparison of data on consumptive use of water with evapo-transpiration calculated by Thorthwaite, Penman or Blaney and Criddle equations and with evaporation from the USWB open pan evaporimeter was the most convenient for scheduling irrigation.

Patil (1976) observed that the daily consumptive use of water in wheat was low upto the boot stage, increased upto the grain formation stage, being highest from flowering to grain formation stage and decreased thereafter. A similar trend was observed in evapo-transpiration rate.

Saicu (1978) reported from field trials conducted in Romania that the consumption of water by winter wheat was assessed between sowing and harvest and the mean total obtained was $5420 \text{ m}^3/\text{ha}$, - 66 per cent of which was used between May and harvest in August.

Bapna and Khuspe (1980) in trials with dwarf wheat HD (M) 1593 irrigated at 20, 40, 60 and 80 per cent available soil moisture (2, 3, 6 and 10 irrigations, respectively) observed that the increasing soil moisture regimes increased average grain yields from 2.48 to 4.71 t/ha and increased water use efficiency from 8.35 to 12.03 kg grain/ha. The consumptive use of water increased from 296.93 to 391.19 mm with increasing soil moisture regimes.

Singh and Bhardwaj (1981) observed that the consumptive use was lowest in rainfed wheat and increased with increasing number of irrigations from 1 to 6; water use with the small number of irrigations (2 or 3) varied when applied at different growth stages. Water extraction was higher by irrigated crop than by rainfed crops from 0 to 30 cm of soil layer and higher by the rainfed crops from the 60 to 90 cm layer; results for the 30 to 60 cm layer was found to be inconsistent.

Mazumdar and Mondal (1984) reported that the seasonal consumptive use of water by wheat was found to be 230.8, 291.0 and 243.4 mm for IW : CPE ratios of 0.6, 0.8 and 1.0, respectively indicating that consumptive use was increased appreciably with the rise in soil moisture. The average daily consumptive use was recorded to be the lowest (1.65 mm/day) during the first 20 days of crop growth and increased gradually reaching the peak of 5.17 mm/day at 87 to 98 days after sowing (grain filling stage), it again declined sharply when compared with the daily open pan evaporation, the daily consumptive use was lower during the early stage and maturity stage of the crop, but higher during the period of intense vegetative growth, flowering and grain filling. They also reported that maximum water use efficiency (WUE) was achieved when irrigations were applied at an IW : CPE ratio of 0.6. The response function revealed that the optimum WUE could be achieved by irrigating the crop at an IW : CPE ratio of 0.874.

From the findings of the above investigations it may be concluded that C.U. values which is low (less than 1 mm per day) during the early stages of crop growth increases gradually to attain a peak of 4 mm per day at flowering and then again decreases with the onset of senescence. Such a curve may be beneficial for scheduling of irrigation based on C.U. at different growth stages. So, the plant growth stages and prevailing climatic conditions determine the rate of C.U. by wheat crop. It also indicate that with the increase in moisture stress, C.U. by wheat crop decreases.

2.2 Effect of micronutrients

Attention of agricultural scientists has recently been genuinely focussed on the micronutrient problem in India. Micronutrient deficiency, although sporadic, has generally been observed more in light textured and calcareous soils. Acidic areas with light textured soil and high rainfall accompanied by high rate of leaching for long period may also develop micronutrient deficit tract.

Changing agro-technique for high rate of production oriented plan may also help to develop new problem areas of micro-nutrients. Adopting intensive cropping programme with high yielding varieties aids in removing more plant food from soil including micronutrients. Thus, new areas with micro-nutrient problem may appear in future.

Any approach towards solving the micronutrient problem is confronted with many problems. Critical levels of micronutrients

for several crops have not been well defined. Indian soil, which may be proved to be more erratic in micronutrient status than major elements, has not been fully probed to determine the available level of micronutrients in soil. Any field trial on this problem again has to be carefully laid out as the deficiency and toxicity level is very narrow. Lastly, research on effect of various micro-nutrients on various crops at many soil groups has not yet been undertaken which would otherwise have been a guideline. In any case, the problem has gained importance during recent years and with passage of time, sufficient information is expected to be available to provide with a definite guideline for specific crop for a specific area regarding micronutrient problem.

2.2.1 Effect of micronutrients on the yield and yield attributes of wheat

Joshi (1956a) reported that response to application of boron and zinc increased when these elements were added with organic matter. Joshi and Joshi (1956) failed to get significant response to the application of Mn, but recorded at the same time, beneficial effect of zinc and copper in Maharashtra and Kankar regions.

Kanwar (1964) reported that zinc sulphate application to acid soils of Majhenu and Bhadiarkar (Kangra) increased the wheat yield significantly over NPK only where no zinc was applied.

Kanwar and Joshi (1964a) found that foliar as well as soil application of zinc sulphate to local wheat resulted in significant yield increase of 91 and 50 kg/acre in Kangra and Kulu districts, respectively. Koraddi and Seth (1964) obtained maximum increase in yield of wheat by foliar application of manganese, but highest net profit of Rs.203 per ha was obtained by spraying with zinc sulphate.

Grewal et al., (1965) reported that application of zinc sulphate increased the yield by 72 and 146 kg/acre at Kulu and Palampur respectively. The results of the experiments on wheat in Bombay compiled by Rajani (1965) showed Zn, B, Zn + B + Mo and Zinc + Mn + B treatments gave yield increases varying from 21.6 to 79.2 per cent. The increases, however, were not consistent

Grewal et al., (1967) reported a significant increase in yield of wheat with spray application of molybdenum when soil contained 0.1 ppm of acid oxalate extractable molybdenum. Gupta and Manglik (1967) reported that under high water stress conditions application of molybdenum or any other micronutrient assisted in better utilization of NPK by wheat.

Samboornaraman et al., (1968) reported that soil or spray application of zinc was found to be effective in increasing the height of plant, number of tillers, and dry weight of wheat plants grown on Delhi soil containing 0.62 ppm of ammonium acetate and 3.95 ppm EDTA extractable zinc. Zinc application also increased the yield of grain and its protein, phosphorus and zinc contents.

Mehta et al. (1969) reported that soil application of zinc sulphate increased the wheat yield significantly over NPK treatment in field experiment conducted at village Torna of Kaira district in Gujrat. The soil contained 0.54 ppm of available zinc (dithizone extractable). Soil application of zinc sulphate was superior source of zinc application than zincated superphosphate or zinc dust.

Kurchania et al., (1969) observed a slight improvement in the yield of wheat the application of molybdenum in the first year, but the trend was not maintained in the second year. Dubey et al., (1969) studied the effect of Mn, Zn, Cu, B and Mo alone or in combination with basal doses of NPK, on the yield of wheat. Highest yield of wheat grain was obtained with the application of molybdenum alone in both seasons.

Randhawa et al. (1970) conducted a number of field experiments on wheat which showed zinc deficiency in Jullandar and Ludhiana districts. Zinc was applied in soil, one to two and half months after sowing and it gave yield increases upto 70 per cent over NPK alone.

Sharma and Kurar (1971) reported that foliar application of zinc to wheat showing Zn deficiency symptoms, could remove the deficiency signs and increased grain yield by increasing number of grains/ear and 1000 grain weight.

Chavan et al., (1972) conducted trials for several years with wheat, grown on soil of low Mo content (0.066 to 0.086 ppm) and observed the foliar application of solutions containing 210 gm sodium molybdate in 1110 lit water/ha increased average grain yields from 672 kg/ha without Mo to 976 kg/ha with spray treatment in research farm and from 670 kg to 970 kg/ha on farmer's field.

Gupta and Singh (1972) noted that wheat cv. given 0, 4.48, 8.96, or 13.44 kg/ha each of ZnSO_4 and CuSO_4 , produced highest yield of 1.81 and 1.65 t/ha with application of 4.48 kg ZnSO_4 or 4.48 kg CuSO_4 /ha, respectively, compared with 1.66 t/ha on plots given no Zn and 1.62 t/ha on those given no Cu.

Yafaev et al., (1973) reported that given NPK on Chernozem soil low in Mo and Mn, foliar application of solution containing 0.05 per cent Mo or Mn at earing markedly increased grain yields and quality and showed a positive residual effect on wheat yields in the following year.

Mazumdar (1973) reported that wheat variety Kalyan Sona given besides NPK, soil application of 6.25 kg zinc sulphate, 25 kg manganese sulphate or 12.5 kg manganese sulphate + 12.5 kg borax + 6.25 kg zinc sulphate + 6.25 kg copper sulphate/ha, increased grain yield by 295, 394, and 511 kg/ha, respectively over 3.93 t/ha on plots which received NPK alone.

Takkar et al., (1974) in pot experiments, observed that higher increases in grain yield of wheat and dry matter yield of

maize resulted from soil application of 5 ppm Zn and foliar application 0.5 per cent ZnSO_4 solution at 30 and 45 days after sowing than from seed treatment of Zn. Higher increase in yields of wheat was obtained with Zn applied broadcast than when placed below or to the side of the seed or top-dressed. Zn applied at any time upto 105 days after sowing significantly increased yields, the highest yield increase being with Zn applied at sowing or upto 45 days after sowing.

Singh and Tripathi (1974) on the basis of pot experiments reported that dry matter yields at the tillering, jointing, and flowering stages were not influenced due to the application of 50 to 100 ppm P_2O_5 or 10 ppm Zn; but yield was significantly increased from P x Zn interaction. Applied Zn markedly increased Zn contents in the plant; applied P reduced the uptake of soil and applied Zn.

Sakal and Singh (1974) reported that when Kalyan Sona was given 0, 12.5, 25, 50, 100 or 200 m eq. Mg CO_3 /100 gm soil and 0, 5, or 10 ppm Zn in pot experiment with silty clay loam soil, shoot weight was increased by Zn application along with low levels of Mg application, but shoot weight was decreased at high levels of Mg application. Mg application markedly increased plant Fe and Mg content and decreased Zn and Ca content. Zn application increased Zn and reduced Fe content in the plant.

Lodha et al., (1975) conducted field trial with wheat variety Lal Bahadur besides giving NPK, the effect of application of 5 kg Fe, 5 kg Zn, 5 kg Mn, and 15 kg Cu/ha alone and in different combinations by (a) soil application, (b) foliar application or (a) + (b) and observed that application of Cu and Fe + Zn in 2 split dressings as (a) + (b) gave the highest yields of grain (2.33 t/ha) and dry matter (6.3 t/ha), respectively; the corresponding yield with NPK alone were 1.75 and 4.58 t/ha.

Shukla et al., (1976) after a prolonged trials during 1967-71 with wheat and rice on alluvial soil at 2 locations in U.P. concluded that 2 foliar applications of Mn, Cu, B, Mo, Fe, or all trace elements in addition to the basal dressing of 120 kg N + 60 kg P_2O_5 + 60 kg K_2O /ha had no effect on grain yields of wheat; 0.5 per cent $ZnSO_4$ increased yields of rice at both locations and Mo increased only at one location.

Singh et al., (1976) reported that poor grain setting in wheat in North Bihar was due to B deficiency in soil. Application of 22.4 kg borax/ha in addition to 33.6 kg N/ha significantly increased the yield.

Singh and Singh (1976) conducted pot experiment by applying B @ 0, 1, 2, or 4 ppm, 10 days after sowing in B deficient alluvial and red soils with a basal NPK dressing and observed that B increased grain carbohydrate content in alluvial but not in red soils, the later gave decreased

carbohydrate content with 2 ppm boron. It was also observed that fat and protein content was not significantly affected in either soil. B treatment increased grain B content in both soils, but to a greater extent in alluvial soil where the greatest effect was given by 1 ppm B. Grain and dry matter production were also increased by B in both soils, with the greatest effect at 4 ppm again alluvial soil gave the greatest response.

Ryakhovskaya et al., (1976) in trials with spring wheat on leached chernozem soil in Ural region observed that application of Mn, B and Zn increased grain yields by 220, 140, 210 kg/ha, respectively by increasing leaf area and dry matter accumulation by plants and increased grain protein and P content.

Shinde et al., (1977) conducted field trials on a clay loam soil and was given 0, 10, 20 or 30 kg Zn/ha as ZnSO_4 or ZnO to wheat variety Sonalika. Average grain yield increased from 2.27 t/ha in the untreated control to 3.53 and 3.13 t/ha with application of 20 kg Zn/ha as ZnSO_4 and ZnO, respectively. Yield decreased at higher levels of Zn application.

Agarwala et al., (1977) from the findings of pot trials conducted with Kalyan Sona grown in soil, collected from Gomti upland alluvium of U.P., with available Zinc content ranging from 0.17 to 1.14 ppm reported that when zinc was applied as pre-sowing @ 0 or 10 ppm as zinc sulphate, application of zinc significantly increased dry matter production in most of the soils of low available zinc content and in some of those with marginal available zinc content. The critical level of available zinc appeared to be 0.53 ppm and that of middle leaves at tillering appeared to be 36 ppm. In soils with low content of available Zn, applied Zinc, increased the uptake of soil P.

Rai and Singh (1978) conducted a field trial with all combinations of 0, 12.5, or 25 kg ZnSO_4 and 0, 40, 80 or 120 kg K_2O /ha. Grain yield was increased by Zn from 2.38 t/ha to 2.73 t/ha and was increased by K from 2.22 t/ha with no K to 2.85 and 2.94 t/ha with 40 and 80 kg K_2O /ha, respectively. Further increase in applied potash to 120 kg K_2O /ha decreased yield to 2.48 t/ha. The interaction of K x Zn was significant.

Ganguly (1979) observed that when wheat varieties Sonalika and Hira were given NPK and a foliar spray of trace element mixture in Block Seed Farm, Pundibari, in the district of Cooch-Bihar, (North Bengal), grain yields of both the varieties were significantly increased by application of trace elements in the year 1973-74. In a second trial in 1974-75 with specific treatment of 15 kg Borax/ha + NPK, yield of Hira increased from

1.25 t/ha with NPK alone to 3.40 t/ha with NPK + Borax. In 1975-76 when Janak and Sonalika were given NPK + 15 kg Borax/ha grain yield and number of grains/ear significantly increased in Janak with B application.

Samui et al., (1979) from findings of field trials with wheat recorded that when wheat was sown late on 7th December, application through foliar sprays of 4 kg NCP 75 (a mixture of all trace elements), 4 kg of Agromin (a chelated mixture of trace elements), 5 kg of ZnSO_4 or 0.5 kg of Sodium molybdate/ha at the late tillering stage increased the average grain yields from 1.48 t/ha in water sprayed crops to 2.02 to 2.1 t/ha and decreased straw yields from 6.41 to 4.59-5.11 t/ha + dry matter yields from 9.97 to 7.13 - 8.37 t/ha. It was also observed that Janak and Sonalika gave yields of 2.01 and 1.89 t grain, 6.18 and 4.33 t straw and 9.13 and 7.26 t dry matter/ha, respectively.

Singh and Singh (1979), on the basis of field trials, arrived at the inference that when wheat cv. R.R. 21, was given 30, 60 or 90 kg P_2O_5 /ha and 0, 4, 8, 16 or 32 kg Zn/ha grain and straw yields increased with increasing Zn application upto 16 kg/ha and with increasing P application upto 90 kg/ha. The optimum Zn rate varied with P application. Zinc content in grain and straw increased with increased Zn application, but decreased with increased P_2O_5 application.

Patil (1979) conducted field trials with dwarf wheat varieties with treatments of 0 or 25 kg ZnSO_4 /ha, 10 kg FeSO_4 /ha or 12.5 kg ZnSO_4 + 5 kg FeSO_4 /ha, and observed that Zn application increased plant height, dry matter accumulation, seed yields and yield components. Maximum increase in 1000 grain weight, number of effective tillers/unit area, fertile spikelet/ear and length of ears were obtained with Zinc alone and yield also increased with zinc application. Grain yields and yield components were positively correlated with Zn uptake; the relationship of yield and yield components with Fe uptake was negative.

Ahmed et al., (1979) reported that wheat cv. Ternab 70 showed increase in average grain yields from 3.53 t/ha to 4.12, 4.45 and 4.15 t/ha with soil application of B as 0, 1, 2, or 3 kg borax/ha, respectively. Average 1000 grain weight was 40.01 g with no B and 41.40 to 42.93 g with B.

Bhardwaj and Prosad (1979) from pot trial experiments arrived at the conclusion that with dwarf wheat grown in a heavy silty loam soil containing 54.3 ppm total Zn and 2.34 ppm available Zn (dithizone extract) and was given NPK + 0 to 40 kg ZnSO_4 /ha, application of 20 kg ZnSO_4 /ha was most effective in increasing 1000 grain weight and Zn uptake and resulted in the highest grain yield of 4.03 t/ha compared to 3.28 t/ha without Zn.

Shinde et al., (1980) observed that soil application of 3.75 kg sodium molybdate/ha to the soil at sowing or 100 to 2000 gm sodium molybdate/ha as a foliar spray 1 month after sowing increased grain yields. There was no significant difference between soil and foliar application of Mo.

Chatterjee et al., (1980) conducted a trial at Block Seed Farm of Pundibari, in the district of Cooch Behar, West Bengal, with wheat varieties Sonalika, UP 262 and Janak, to note the effect B and Zn on yield. B was applied at the rate of 21.4 kg/ha as soil application, 1.25 kg as single foliar spray 20 days after sowing and 1.25 kg as two foliar sprays at 20 and 35 days after sowing. Zn was applied at the rate of 50 kg/ha as ZnSO_4 as soil application, 2.5 kg/ha as foliar application in single spray 20 days after sowing and 2.5 kg/ha as two foliar sprays at 20 and 35 days after sowing. It was observed that Janak responded well to boron. The response of UP 262 was also highly significant, but slightly less pronounced than Janak. Although yield increase in case of Sonalika was least, still it was significant. The crop responded to soil application better than foliar application.

Singh et al., (1980) conducted pot experiments with 30 old alluvial soils to evaluate the critical Zn concentration in soils and wheat plants for predicting the response to Zn application. The DTPA extractable Zn (available Zn) in those soils ranged from 0.37 to 4.50 mg/kg of soil and the total Zn in the

wheat plants of the control pots ranged from 17 to 65 mg/kg wheat shoots. The DTPA extractable zinc was positively correlated with organic carbon ($r = 0.72$), negatively with pH ($r = -0.48$) and again positively with wheat tissue Zn concentration ($r = 0.85$). The critical concentration of zinc in soil and plant below which responses to applied Zn might be expected was 0.65 mg Zn/kg soil and 24.5 mg Zn/kg wheat shoot, respectively. All the soils below 0.65 mg Zn/kg of soil responded to Zn application. The percentage of response at 5 mg added Zn/kg soil ranged from 22.65 to 100.00 with a mean value of 58.24, whereas at 10 mg added Zn/kg it ranged from 13.08 to 97.14 with a mean value of 40.08. Soils above the critical level responded negatively to Zn application.

Sakal et al., (1981) conducted trials with wheat grown on sandy loam soils and observed that grain yield was increased by 34 and 22 per cent with application of 5 kg Zn and 5 kg Mn/ha respectively. The yield was slightly suppressed by further increase in their rates to 10 kg/ha and was not affected by application of 5 to 10 kg Cu/ha. Application of Zn, Mn + Cu increased their respective contents and uptake in grain and straw. Reduction in Mn uptake by application of Zn was greater than that in Zn uptake by applied Mn.

Prasad et al., (1981) noted that increasing application of Zn from 0 to 5 kg/ha to 4 wheat varieties in soils with

0.49 to 0.56 ppm available Zn increased the average grain yield from 2.38 to 3 t/ha and increased content and uptake of Zn in grain; the response varied in different varieties.

Sharma and Das (1982) observed that the dwarf wheat Kalyansona, grown on a sandy loam soil, showed the highest grain yield response to the application of Zn followed by B and Mo.

2.3 Liming of acid soils and crop growth

Liming of acid soils enhances the availability and plant uptake of some of the nutrients such as Ca, Mg, phosphorus and molybdenum; at the same time it reduces the concentration and toxic effect of iron, aluminium and manganese. Lime also stimulates the growth of soil microorganisms. Liming is thus considered as a beneficial practice for increasing the crop production in the acid soils. Kipps (1947) has shown that the pH of the soil, yield and calcium content of the crop were increased by the application of calcium hydroxide. But when Ca-sulphate was used, it increased the Ca content of the soil, whereas pH and yield of the crop decreased.

Mandal et al. (1955) reported that appreciable and economical returns from maize, wheat and groundnut were obtained by applying lime in acidic soils. From the agronomic trials (1956, 1957) with T.C.M. fertilizers, it was reported that in several cases application of lime more than one tonne per acre

significantly increased the yield of rice. Several other workers also observed that sorghum and alfalfa responded significantly to lime (Hourigan et al., 1961 and Ross et al., 1964). Halkilathi (1964) found that infection of clover by the fungus Sclerotinia trifoliorum was decreased and numbers of other organisms were increased by liming acid soils. Mandal and Co-workers (1966) studied the effect of liming acidic red loam soils on crop growth and found that production of many upland crops increased considerably due to liming. Tamboli and Tulsi (1967) obtained increased yield of paddy over control by using basic slag as the liming material.

Fisher (1969) noted that when pH of the soil was modified by liming the yields of different crops increased only when the pH of the acid soil was less than pH 5.5. Tanaka et al. (1970) reported that the yield of onions was increased by the application of lime @ 3.9 tonnes/ha instead of 6 tonnes.

Beneficial effects of liming on lucerne and barley were reported by Mc Lean and co-workers (1972). This observation was later supported by Amarasiri and Olsen (1973) who reported that the yield of millet increased with increasing pH upto 5 to 6 by liming, but further addition of lime decreased the yield. Hera et al. (1973) conducted experiments at several locations where the pH was lower than 6. They found that with the higher soil pH resulted from liming, yield of wheat increased to the tune of 0.46 to 1.53 t/ha. Bugreev (1974) conducted an experiment

to study the comparative response by wheat, barley and oat to lime on acid soils and observed that grain yield response to the application of lime was highest in barley, intermediate in wheat and lowest in oats.

However, Souza et al. (1976) observed that when dolomitic lime stone was applied @ 0, 1, 2, 3, 4 and 5 tonnes/ha, grain yield, plant height and panicle length were not increased at any rates of lime application. Winkler (1976) in an experiment on wheat applied 0 to 75 kg N/ha, and lime to increase the soil pH to 6.5 and found that lime increased grain yield by 227 to 709 kg/ha on three soils but decreased yield by 176 kg/ha on one soil. Rajas (1977) reported that the yield of cotton decreased on liming the acid soils in excess than the amount required to produce the maximum yield. Gonzales et al. (1979) observed that liming decreased the aluminium concentration and increased the yield of corn.

Vostal and Vanek (1979) carried out a pot trial in acid soil having pH 4.5 on spring wheat observed that application of CaCO_3 @ 10 g/pot increased plant growth, root dry matter and grain yield especially with N as ammonium sulphate; the grain yield was increased to the extent of 82.1 per cent. At tillering, CaCO_3 improved the plant content of Ca in the dry matter and decreased contents of Mn and Cu. While Mg and Cu contents increased, the content of P, K, Mn and Zn decreased in the grains of wheat by the application of CaCO_3 ; in straw; the contents of Ca and Mg increased and those of N, P, Mn and Zn decreased.

CaCO_3 also influenced the uptake of N, K, Ca, Cu and especially Zn and decreased uptake of Mn. Belokin (1979) recorded highest grain yields of wheat and tuber yields of potatoes with the application of a single dose of CaCO_3 to plots given F.Y.M. and NPK on podzolic acid soils in Moscow region. Gorlova and Koroleva (1972) reported that application of NPK + lime to wheat and barley grown on derno-podzolic acid soil increased grain yield by 710 and 520 kg/ha respectively, compared with plots given NPK alone and increased grain content of protein, N, P and other minerals.

Boerin et al. (1981) conducted a field trial from 1961-76 on two types of podzol at Libada (Romania). They applied CaCO_3 @ 2.5, 5 and 10 t/ha at 5 or 10 years interval to wheat/maize rotations for first 10 years and grass ley/soybean or maize rotations for the subsequent years. Liming significantly increased soil pH as well as grain yields of wheat and maize. Liming with little or moderate rates at every 5 year had more beneficial effect on soil and crop yields as compared to high rates applied at every 10 year. Siqueira (1981) carried out an experiment in field on acid soils with the application of limestone and found that maximum wheat yields (2.47 t/ha) were recorded at pH 5.6 and reduction in yield took place at soil Al content 20 per cent of the soil CEC and at pH 6.0. Laboratory and micro-plot trials revealed that lime application higher than usual rates ($1.5 \times$ hydrolytic acidity) enhanced winter wheat yields.

Glazunova (1983) reported from laboratory and micro-plot experiments that application of lime at higher than usual rates ($1.5 \times$ hydrolytic acidity) increased yield of winter wheat but the effect of applied phosphorus decreased.

CHAPTER-III

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 Experimental Site

With the objective of making an inroad into the two major problems associated with wheat cultivation under North Bengal conditions - namely, ascertaining correct irrigation schedule and also evolve agronomic solution to the problem of grain sterility in case of some varieties, three sets of investigations were carried out at Teaching and Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, N. B. Campus, Cooch-Behar, during the winter season of 1979-80, 1980-81, 1981-82, 1982-83 and 1983-84.

3.2 Soil characteristics of the experimental field

The land, where the investigations were carried out, was in a medium high situation, having good drainage and irrigation facilities.

The Physico-chemical properties of soil related to the study on irrigation and grain sterility problem are presented in tables 3.1a and 3.1b. All the experiments were conducted at close proximity to one another and analysis of composite soil sample was made.

Soil of the experimental field was sandy loam in texture (Table 3.1a). Clay and silt content decreased with increasing depth and sand content gradually increased with increasing depth and was highest at 30-45 cm depth.

Field capacity was found to be the highest at 15-30 cm soil layer and gradually decreased with increasing depth (Table 3.1a). There was very little difference in the values of bulk density and it was found to increase with increase in depth with highest value at 30-45 cm depth.

The soil was moderate in nitrogen status and was acidic in reaction (Table 3.1b).

Table 3.1a Physico-chemical status of the soil (Mechanical composition and physical constants of soil)

	Soil depth (cm)				
	0-15	15-30	30-45	45-60	60-75
A. Mechanical composition					
i) Clay (P.C.)	15.25	14.24	12.62	13.92	13.58
ii) Silt (P.C.)	39.34	39.62	38.71	38.43	39.12
iii) Sand (P.C.)	45.41	46.14	48.67	46.65	47.30
B. Field capacity (P.C.)	32.12	32.65	32.43	31.36	31.34
C. Bulk-density (gm/cc)	1.40	1.41	1.42	1.41	1.41

Table 3.1b Physico-chemical status of the soil
Chemical composition (composite sample of 0-30 cm depth)

Particulars		Method followed
a) Total nitrogen (%)	0.152	Modified Kjeldahl method (Jackson, 1967)
b) pH	5.7	
c) Micronutrients	Total	Beckman's pH meter; in
i) Zinc (ppm)	15	1 : 2.5 soil water suspension
ii) Boron (ppm)	.34	(Jackson, 1967)
iii) Molybdenum (ppm)	.12	

3.3 Climate and Weather condition

The experimental site was situated in a terai zone at sub-tropical region having $89^{\circ}23'53''$ E longitude and $26^{\circ}19'86''$ N latitude and 43 m altitude. There were two dominant seasons very extended winter season and a long rainy season. The winter season started after middle of October with a fall in night temperature and continued upto March with the same range of low night temperature. Severe winter was experienced in December and January when maximum temperature ranged between $21-27^{\circ}\text{C}$ and minimum temperature ranged between $8-11^{\circ}\text{C}$. In January, every year, the minimum temperature went down to 7°C or even a little below for a couple of days.

Normally, pre-monsoon rain started from the middle of March on a sporadic note and became a regular feature from April. During April there would be 12-15 rainy days. The total average rainfall was little above 3000 mm and may often cross 4000 mm mark. During the year 1984 the area experienced a record of 4660 mm rainfall.

Table 3.2 Daily rainfall (mm) during the period of experimentation

Year			
1979-80		1980-81	
November		November	
26	0.2	Nil	
29	2.6	Nil	
December		December Nil	
1	13.6		
2	1.8		
31	6.6		
January Nil		January	
		25	11.4
February		February	
18	22.0	2	3.2
March		10	
1	0.4	11	25.0
2	16.0	March	
April		13	3.0
6	5.4	14	2.4
19	8.6	25	6.2
22	19.6	26	0.3
23	17.2		
26	5.6		
30	7.2		
		April	
		1	8.8
		13	17.6
		14	10.2
		15	22.6
		16	4.6

1980-81			1981-82		
April			April		
	1	24.8		17	11.6
	2	19.6		18	41.4
	5	21.2		19	6.0
	10	6.6		23	41.6
	17	110.0		24	36.0
				25	13.0
				26	26.0
				27	7.8
1982-83					
November	1	3.2			
December	29	7.8			
January	3	15.8			
	29	1.2			
	30	2.2			
February	26	2.2			
	27	1.2			
March	21	48.0			
	22	2.4			
April	11	trace			
	16	3.4			
	17	0.8			
	19	0.8			
	24	11.6			
	28	4.4			
	29	48.0			
	30	6.0			

Table 3.3 Meteorological data during the period of experimentation (1979-80)

Meteorological parameters	November	December	January	February	March	April
Rainfall (mm)	2.20	22.00	-	22.00	24.20	63.90
Maximum temperature (°C)	28.70	24.50	23.40	25.30	29.10	33.10
Minimum temperature (°C)	17.6	12.1	9.60	11.80	15.60	21.50
Relative humidity (%)						
Maximum	96	94	95	93	82	81
Minimum	61	57	51	49	47	54
Sunshine (hr/day)	8.55	8.11	8.69	8.91	8.17	8.31
Evaporation from U.S.A. standard open pan evaporimeter (mm/day)	2.05	1.64	1.53	2.14	3.51	4.73

Table 3.4 Meteorological data for 1980-81

Meteorological parameters	November	December	January	February	March	April
Rainfall (mm)	-	-	11.40	31.2	14.2	265.2
Maximum temperature (°C)	29.01	26.54	23.43	25.55	29.49	29.61
Minimum temperature (°C)	14.50	11.04	8.78	11.36	14.49	17.39
Relative humidity (%)						
Maximum	89.56	95.00	93.12	91.03	85.09	83.43
Minimum	50.66	52.45	57.74	55.32	46.58	57.13
Sunshine (hr/day)	9.94	8.69	7.25	8.70	7.25	8.34
Evaporation from U.S.A. standard open pan evaporimeter (mm/day)	2.61	1.77	1.73	2.33	3.66	4.10

Table 3.5 Meteorological data for 1981-82

Meteorological parameters	November	December	January	February	March	April
Rainfall (mm)	-	31.00	-	-	36.6	247.6
Maximum temperature (°C)	28.68	24.66	24.71	25.44	28.83	29.83
Minimum temperature (°C)	13.86	9.54	9.47	10.05	14.21	18.68
Relative humidity (%)						
Maximum	89.30	90.29	95.0	89.21	81.51	82.82
Minimum	50.00	52.80	54.74	44.14	49.45	65.85
Sunshine (hr/day)	9.31	7.98	8.26	8.57	7.74	7.81
Evaporation from U.S.A. standard open pan evaporimeter (mm/day)	2.63	1.83	1.44	2.53	3.40	3.89

Table 3.6 Meteorological data for 1982-83

Meteorological parameter	November	December	January	February	March	April
Rainfall (mm)	3.2	7.8	19.2	3.4	50.40	75.00
Maximum temperature (°C)	27.87	24.11	22.97	24.87	28.78	30.50
Minimum temperature (°C)	16.05	12.03	9.23	11.08	15.57	18.66
Relative humidity (%)						
Maximum	88.36	94.70	94.35	90.03	82.25	80.83
Minimum	55.43	56.61	49.16	42.64	39.61	50.23
Sunshine (hr/day)	9.56	8.42	8.18	8.46	8.14	8.26
Evaporation from U.S.A. standard open pan evaporimeter (mm/day)	1.9	1.3	1.4	2.3	3.8	4.0

Table 3.7 Meteorological data for 1983-84

Meteorological parameter	November	December	January	February	March	April
Rainfall (mm)		32.2	32.0	14.8	15.0	214.2
Maximum temperature (°C)	28.9	23.8	22.4	25.2	30.7	32.0
Minimum temperature (°C)	15.7	10.6	9.7	11.7	16.5	20.1
Relative humidity (%)						
Maximum	78	94	98	93	83	84
Minimum	48	54	53	46	41	55
Sunshine (hr/day)	9.75	7.72	7.81	8.12	8.23	8.22
Evaporation from U.S.A. standard open pan evaporimeter (mm/day)	2.4	1.5	1.5	2.0	3.3	4.3

3.4 Title of the experiments

To complete the the investigation three sets of experiments were conducted with following title

Experi- ment No.	Title	Duration
1	Effect of irrigation at physiological stages of growth on yield attributes, yield and evapotranspiration by wheat	1979-83
2	Effect of micronutrients (B, Mo and Zn) with or without soil amendment on yield and yield attributes of wheat	1979-82
3	Effect of Boron at different doses and with different methods of application on wheat	1981-84

3.5 Previous cropping history of experimental plots

Experiment No.	Year	Kharif	Rabi
1	1978-79	Transplanted rice	Wheat
	1979-80	Aus paddy	wheat
2	1978-79	Transplanted rice	Mustard
	1979-80	Aus paddy	Wheat
3	1980-81	Transplanted rice	Mustard
	1981-82	Transplanted rice	Wheat

3.6 Experimental details

3.6.1 Design and layout

3.6.1.1 Experiment 1

Experiment 1 was conducted in a randomised Block Design with four replications. Sixteen treatments were allotted in each replication randomly. Each plot was bounded by ridges on all four sides with the provisions of irrigation each plot independently with P.V.C. hose pipe. The gross plot size was 5 m x 4 m and a passage of 1 m on all sides was left so as to avoid possible side seepage from irrigated plot to unirrigated plot (Fig. 3.1). Variety sown was Sonalika. Treatments are as follows :

<u>Treat- ment</u>	<u>Symbol</u>	
1	C	- One irrigation at crown root initiation (C) stage only
2	T	- One irrigation at tillering (T) stage only
3	F	- One irrigation at flowering (F) stage only
4	D	- One irrigation at dough (D) stage only
5	CT	- One at C stage + one at T stage
6	CF	- One at C stage + One at F stage
7	CD	- One at C stage + One at D stage
8	TF	- One at T stage + One at F stage
9	TD	- One at T stage + One at D stage
10	FD	- One at flowering stage + One at D stage
11	CTF	- One at C stage + One at T stage + One at F stage
12	CFD	- One at C stage + One at F stage + One at D stage

REPLICATION - I REPLICATION - II REPLICATION - III REPLICATION - IV

11	14	2	7
15	9	13	3
4	16	6	1
5	12	10	8
6	4	14	5
8	11	10	7
9	15	1	2
12	3	16	13
13	11	6	8
5	15	1	4
14	9	10	12
3	16	7	2
8	4	11	1
6	7	5	2
13	15	12	16
1	14	9	10



PLOT SIZE: 3 m X 4 m

TREATMENTS :

1. IRRIGATION AT CROWN ROOT INITIATION (C)
2. IRRIGATION AT TILLERING (T)
3. IRRIGATION AT FLOWERING (F)
4. IRRIGATION AT DOUGH (D)
5. IRRIGATION AT C + T
6. IRRIGATION AT C + F
7. IRRIGATION AT C + D
8. IRRIGATION AT T + F
9. IRRIGATION AT T + D
10. IRRIGATION AT F + D
11. IRRIGATION AT C + T + F
12. IRRIGATION AT C + F + D
13. IRRIGATION AT C + T + D
14. IRRIGATION AT T + F + D
15. IRRIGATION AT C + T + F + D
16. RAINFED CONTROL

FIG. 3.1 LAYOUT PLAN OF EXPERIMENT - I

<u>Treat-</u> <u>ment</u>	<u>Symbol</u>	
13	CTD	- One at C stage + One at T stage + One at D stage
14	TFD	- One at T stage + One at F stage + One at D stage
15	CTFD	- One at C stage + One at T stage + One at F stage + One at D stage
16	R	- Control (Unirrigated)

3.6.1.2 Experiment 2

Experiment 2 was conducted in a split plot design with four replications (Fig. 3). The Sub-plot size was 5 m x 3 m. Treatments in the main plots were soil amendments - Lime and Dolomite and treatments in the Sub-plots were micronutrients - Zinc, Boron and Molybdenum. Thus each of the three main plots (Lime, Dolomite and control) were divided into four sub-plots for four micronutrient treatments (Zinc, Boron, Molybdenum and control). Lime and dolomite was applied 15 days before sowing at the early stage of land preparation. Micronutrients were applied after final layout in soil in individual sub-plot and was mixed by ranking. Detailed treatments are given below

I Treatments in the main plot

A₀ - control - No soil amendment

A₁ - Lime @ 1.5 Tonnes/ha

A₂ - Dolomite @ 1.5 Tonnes/ha

II Treatments in the Sub-plot

M₀ - Control - No micronutrient

M₁ - Zinc @ 15 kg/ha as ZnSO₄

M₂ - Boron @ 20 kg/ha as borax

M₃ - Molybdenum @ 800 gm/ha as Sod-molybdate.

Variety of wheat - UP 262

3.6.1.3 Experiment 3

Experiment 3 was designed only after the effect of boron revealed a significant positive response. The objective of this experiment was to investigate on the optimum dose and correct method of application of boron as a micronutrient.

The design and sub-plot size of experiment 3 was similar to that of experiment 2. Treatments on method of application were allotted on main plots and different doses of borax were allotted in the sub-plots (Fig. 3). Details of treatment are given below

I Doses of Borax

- B₀ Control
- B₁ 10 kg/ha
- B₂ 20 kg/ha
- B₃ 30 kg/ha

II Methods of application

- M₁ Full soil along with basal application of fertilizers
- M₂ Half soil and half foliar - Soil - applied as basal
Foliar - at 60 and 80 DAS
- M₃ Full foliar in 4 split applications at 20, 40 60 and 80 DAS

Variety of wheat - UP 262

REPLICATION - I	A ₂ M ₁	A ₀ M ₀	A ₁ M ₂	A ₀ M ₁	A ₁ M ₂	A ₂ M ₃
	A ₂ M ₃	A ₀ M ₂	A ₁ M ₃	A ₀ M ₀	A ₁ M ₃	A ₂ M ₀
	A ₂ M ₂	A ₀ M ₃	A ₁ M ₀	A ₀ M ₃	A ₁ M ₁	A ₂ M ₂
	A ₂ M ₀	A ₀ M ₁	A ₁ M ₁	A ₀ M ₂	A ₁ M ₀	A ₂ M ₁
	A ₂ M ₁	A ₁ M ₃	A ₀ M ₁	A ₁ M ₁	A ₂ M ₃	A ₀ M ₂
	A ₂ M ₂	A ₁ M ₀	A ₀ M ₃	A ₁ M ₃	A ₂ M ₀	A ₀ M ₁
	A ₂ M ₃	A ₁ M ₁	A ₀ M ₂	A ₁ M ₀	A ₂ M ₂	A ₀ M ₃
	A ₂ M ₀	A ₁ M ₂	A ₀ M ₀	A ₁ M ₂	A ₂ M ₁	A ₀ M ₀

EXPERIMENT - II

REPLICATION - IV



SUB - PLOT SIZE : 5 m X 3 m

TREATMENTS :

MAIN PLOT : AMENDMENTS

A₀ : NO AMENDMENT

A₁ : LIME @ 1.5 tonnes / ha

A₂ : DOLOMITE @ 1.5 tonnes / ha

SUB PLOT : MICRONUTRIENTS

M₀ : NO MICRONUTRIENT

M₁ : ZINC AS ZINC SULPHATE
@ 15 Kg / ha

M₂ : BORON AS BORAX
@ 20 Kg / ha

M₃ : MOLYBDENUM AS SODIUM
MOLYBDATE @ 800 gm / ha

REPLICATION - II			REPLICATION - I		
B ₁ M ₂	B ₁ M ₃	B ₁ M ₁	B ₀ M ₁	B ₀ M ₂	B ₀ M ₃
B ₃ M ₂	B ₃ M ₁	B ₃ M ₃	B ₃ M ₂	B ₃ M ₃	B ₃ M ₁
B ₀ M ₃	B ₀ M ₂	B ₀ M ₁	B ₁ M ₃	B ₁ M ₁	B ₁ M ₂
B ₂ M ₃	B ₂ M ₁	B ₂ M ₂	B ₂ M ₁	B ₂ M ₃	B ₂ M ₂
B ₂ M ₁	B ₂ M ₂	B ₂ M ₃	B ₀ M ₂	B ₀ M ₃	B ₀ M ₁
B ₀ M ₂	B ₀ M ₃	B ₀ M ₁	B ₂ M ₂	B ₂ M ₁	B ₂ M ₃
B ₁ M ₃	B ₁ M ₁	B ₁ M ₂	B ₁ M ₁	B ₁ M ₃	B ₁ M ₂
B ₃ M ₂	B ₃ M ₃	B ₃ M ₁	B ₃ M ₃	B ₃ M ₂	B ₃ M ₁

REPLICATION - III

EXPERIMENT - III

SUB - PLOT SIZE : 5 m X 3 m

TREATMENTS :

MAIN PLOT : BORON

B₀ : CONTROL

B₁ : BORAX @ 10 Kg / ha

B₂ : BORAX @ 20 Kg / ha

B₃ : BORAX @ 30 Kg / ha

SUB PLOT : METHOD OF
APPLICATION

M₁ : FULL SOIL

M₂ : HALF SOIL + HALF FOLIAR

M₃ : FULL FOLIAR

FIG. 3.2 LAYOUT PLAN OF EXPERIMENT II AND III

3.6.2 Records of important cultural operations

3.6.2.1 Experiment 1

<u>Operations</u>	<u>Dates of operation</u>	<u>Details of operation</u>
a. Land preparation	1979-80	Started on 12/11/79
	1980-81	Started on 15/11/80
	1981-82	Started on 14/11/81
	1982-83	Started on 12/11/82
Generally power tiller was used at initial stage of land preparation and 2 ploughings were given. It was followed by necessary laddering and final and preparation was done by 2 more ploughings with country plough followed by necessary laddering. During the years of non-availability of power tillers altogether 6 ploughings were given by country plough followed by necessary laddering.		
b. Basal application of inorganic fertilizers	1979-80	Applied on 6/12/79
	1980-81	Applied on 29/11/80
	1981-82	Applied on 1/12/84
	1982-83	Applied on 23/11/82
A basal application of 50 kg N, 60 kg P₂O₅ and 60 kg K₂O was made during the final stage of land preparation and method of application employed was broadcasting. Urea, single super phosphate and muriate of potash were used as source of N, P₂O₅, K₂O respectively. This dosage was common for all the experiments during all the years.		

c. Sowing 1979-80 Sown on 4/12/79 Sowing was done at a distance of 20 cm by opening furrow
 1980-81 Sown on 30/11/80 with duck foot tynes and dropping the seeds by hand. Sepa-
 1981-82 Sown on 5/12/81 rate packet containing 240 gm seed was used for each plot.
 1982-83 Sown on 25/11/82

d. Top-dressing
 1979-80 Applied on 3/1/80 Top dressing was normally done at 40-42 days after sowing
 1980-81 Applied on 10/1/81 during different years of experimentation.
 1981-82 Applied on 15/1/82
 1982-83 Applied on 4/1/83

e. Dates of
 irrigation 1979-80 - 26/12/79 T - 16/1/80 F - 17/2/80 D - 12/3/80
 1980-81 - 22/12/80 T - 13/1/81 F - 13/2/81 D - 6/3/81
 1981-82 - 26/12/81 T - 17/1/82 F - 16/2/82 D - 9/3/82
 1982-83 - 15/12/82 T - 6/1/83 F - 8/2/83 D - 3/3/83

f. Harvesting 1979-80 Harvested on 18/4/80 Net plot area discarding a border area of 50 cm
 Harvested on 12/4/81 at ends and a single row at both sides of rows.
 Harvested on 22/4/82
 Harvested on 15/4/84

C - Crown root initiation stage; T = Tillering stage; F = Flowering stage; D = Dough stage

3.6.2.2 Experiment 2

<u>Operations</u>	<u>Dates of operation</u>	<u>Details of operation</u>
a. Land preparation		
1979-80 started on	3.11.79	
1980-81 started on	2.11.80	Similar to experiment 1
1981-82 started on	5.11.81	
b. Basal application of inorganic fertilizers, micronutrients and soil amendments		
Application of soil amendments -		Basal dressing of 50 kg N, 60 kg P_2O_5 and 60 kg K_2O in the form of urea, single superphosphate and muriate of potash was made during final stage of land preparation. Application of soil amendments was made 3 weeks before actual sowing. Application of micronutrients was made in soil by mixing it with soil for even distribution in each plot.
1979-80	15.11.79	
1980-81	10.11.80	
1981-82	12.11.81	
Application of fertilizers and micronutrients		
1979-80	3.12.79	
1980-81	24.11.80	
1981-82	2.12.81	
c. Sowing		
1979-80 sown on	6/12/79	Sowing was done maintaining a spacing of 20 cm between rows by opening furrows with duck foot tynes and sowing with hand by dropping 180 gm of seeds by hand uniformly in each sub-plot.
1980-81 sown on	28/11/80	
1981-82 sown on	5/12/80	

- d. Top-dressing
- | | | |
|---------|----------|--|
| 1979-80 | 15/1/80 | Top dressing was done 30-35 days after sowing before first irrigation during different years of experimentation. |
| 1980-81 | 30/12/80 | |
| 1981-82 | 10/1/82 | |
- e. Irrigation
- | | | |
|---------|----------------------|--|
| 1979-80 | 7/1/80 and 28/2/80 | Two irrigations one before tillering stage (30-35 DAS) and the other just after flowering (80-85 DAS) were found to be enough. |
| 1980-81 | 31/12/80 and 27/2/81 | |
| 1981-82 | 12/1/82 and 26/2/82 | |
- f. Harvesting
- | | | |
|---------|---------|---|
| 1979-80 | 18/4/80 | Net plot area was harvested for yield estimation discarding border area of 50 cm on ends and single row on both sides |
| 1980-81 | 12/4/81 | |
| 1981-82 | 22/4/82 | |

3.6.2.3 Experiment 3

- a. Land preparation
- | | | |
|---------|----------|--------------------------------|
| 1981-82 | 8/11/81 | Similar to earlier experiments |
| 1982-83 | 15/11/82 | |
| 1983-84 | 5/11/83 | |
- b. Basal application of inorganic fertilizers and borax
- | | | |
|---------|----------|--|
| 1981-82 | 22/11/81 | Basal dressing of 50 kg N, 60 kg P_2O_5 and 60 kg K_2O per ha in the form of urea, single super phosphate and muriate of potash respectively was made at the final stage of land preparation. Different amounts of borax were mixed with soil for even distribution. |
| 1982-83 | 30/11/82 | |
| 1983-84 | 25/11/83 | |

c. Sowing

1981-82 Sown on 25/11/81
 1982-83 Sown on 2/12/82 Similar to experiment 2
 1983-84 Sown on 28/11/83

d. Top dressing

1981-82 29/12/81
 1982-83 4/1/83 Similar to experiment 2
 1983-84 2/1/84

e. Irrigation

1981-82 31/12/81 and 26.2.82
 1982-83 5/1/83 and 3/3/83 Similar to experiment 2
 1983-84 4/1/84 and 28/2/84

f. Harvesting

1981-82 8/4/82
 1982-83 14/4/83 Similar to experiment 2
 1983-84 12/4/84

3.7 Details of observation

3.7.1 Pre-harvest

- a) Height of plant Height of plant was recorded by randomly selecting ten plants in each plot and average was recorded. Measurement was done five times just before each irrigation and at harvest.
- b) Dry matter Plants from one meter linear length were uprooted just before harvest and the roots were thoroughly washed. After drying root and shoot ratio was determined. With the help of this

ratio root yield was determined from the straw and grain yield per plot. Total dry weight of root, straw and grain was noted and converted to quintal per hectare.

c) Number of total and effective tillers

Count of total and effective tillers was taken from the plants to one linear meter length from each treatment. This count was made just before each irrigation for total tillers and at harvest for effective tillers.

3.7.2 Post harvest

a) Length of ear

Observation was taken by randomly selecting ten ears and measuring the length from base of the ear to the end of last spikelet excluding awn. Average value was recorded.

b) Number of grains per ear

Average number of grains was recorded by randomly selecting ten ears.

c) Grain and straw yield

Of the gross plot of 5 m x 4 m a net area of 4 m x 3 m was harvested leaving 50 cm of border on all sides. Per plot yield was converted to quintal/ha.

3.8 Soil moisture study

Daily evapotranspiration rate was determined from amount of moisture depleted from the soil during the period between sowing and first irrigation at CRI stage and then between two successive irrigations at T, F and D stages and finally between D and time of harvest and then dividing the amount of depleted moisture by the number of days elapsed between any two stages. The moisture depletion was also studied at 15 cm depth interval upto 90 cm depth and was calculated by the formula given by Singh et al. (1960).

3.9 Statistical analysis

For interpreting the effect of different treatments on yield and yield attributing and other characters, the recorded data were analysed statistically by following Fisher's method of analysis of variance. For comparison of 'F' values and for determination of critical difference at 5 per cent level of significance, Fisher's and Yate's tables were consulted.

3.10 Response curve

Production function or response is the relationship between levels of input and corresponding output. When the output is related to variations in the levels of single factor a response curve is obtained. For studying the relationship between the levels of boron application and grain yield of wheat a response curve was fitted. The following generalised

response equation expressing yield and level of input relationship was used.

$$Y = a + bx - cx^2$$

where, Y denotes the yield, x is the dose or level of boron, and a, b, c are constants.

3.11 Economics of boron application

The economics of the application of boron in the form of borax was calculated. The price of borax and wheat grain were as follows .

1. Price of borax - Rs. 1500=00/quintal
2. Price of wheat grain - Rs. 180=00/quintal.

CHAPTER-IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 Influence of irrigation

4.1.1 Yield and yield attributes

4.1.1.1 Height of the plant

In all the irrigation treatments the height of the plant was found to increase with advancement of age during three years (Tables 4.1, 4.2 and 4.3). Irrigation significantly increased the height of the plant at all stages of growth of wheat. As no irrigation was applied to the plants before crown root initiation stage (C), the effect of irrigation treatments was not observed on the height of the plant recorded just before irrigation at crown root initiation stage.

Plants received irrigation at crown root initiation stage recorded significantly more plant height at tillering over control. Similarly, at flowering stage plants received irrigation at crown root initiation or tillering (T) or at both stages were generally taller as compared to those received no irrigation before the date of observation. At dough stage all treatments received irrigation earlier showed significantly higher plant height over irrigation at dough stage (D) and unirrigated control with a few exceptions during 1980-81 and 1981-82 when the difference did not reach the level of significance (Tables 4.2, and 4.3).

At harvest almost all irrigation treatments significantly increased the height of the plant over unirrigated

Table 4.1 Effect of irrigation on the height of the plant during 1979-80

Irrigation at stage	Height of the plant (cm)				
	Observation before irrigation at stage				
	C(21 DAS)	T(42 DAS)	F(76 DAS)	D(96 DAS)	Harvest
C	19.5	46.1	80.3	103.0	102.8
T	19.4	45.1	75.7	101.9	102.4
F	19.3	44.9	73.4	102.1	102.7
D	19.1	44.2	74.5	97.9	99.2
CT	19.4	46.1	81.7	103.3	103.7
CF	19.2	47.5	77.9	103.4	103.6
CD	19.5	48.4	82.9	102.4	102.6
TF	19.1	44.3	76.6	103.5	103.1
TD	19.5	44.1	75.4	103.1	102.5
FD	19.6	43.4	74.3	102.5	102.0
CTF	19.5	46.2	80.4	105.6	106.0
CFD	19.7	46.9	78.9	104.1	104.7
CTD	19.3	47.6	82.6	104.2	104.6
TFD	19.2	43.6	76.9	102.5	103.4
CTFD	19.6	46.2	78.9	102.4	103.4
R	19.5	44.0	73.3	98.4	99.1
SEm $\pm$	0.32	0.72	1.37	0.98	0.95
C.D. 5%	N.S.	2.06	3.92	2.79	2.71

C = Crown root initiation; T = Tillering; F = Flowering; D=Dough

Table 4.2 Effect of irrigation on the height of the plant during 1980-81

Irrigation at stage	Height of the plant (cm)				
	Observation before irrigation at stage				
	C(21 DAS)	T(42 DAS)	F(76 DAS)	D(96 DAS)	Harvest
C	19.2	49.0	76.9	103.7	104.8
T	19.6	47.9	76.1	102.3	104.1
F	20.1	47.4	75.6	101.5	102.1
D	20.1	47.6	74.2	99.6	101.1
CT	19.7	49.3	78.6	104.3	105.0
CF	20.8	49.7	76.0	104.8	105.6
CD	20.6	49.7	76.7	103.0	103.8
TF	19.9	47.8	76.0	104.8	104.8
TD	19.9	48.1	75.9	102.8	103.9
FD	20.2	49.2	74.9	102.0	102.6
CTF	20.7	50.6	77.5	105.7	106.3
CFD	20.7	50.2	76.9	105.2	106.0
CTD	20.8	50.7	76.2	105.0	106.0
TFD	21.0	48.3	76.5	104.0	104.8
CTFD	20.3	50.3	77.1	106.1	106.1
R	20.0	47.4	73.4	97.7	99.8
SEm $\pm$	0.60	0.76	0.78	1.12	0.88
C.D. 5 %	N.S.	2.17	2.23	3.36	2.51

Table 4.3 Effect of irrigation on the height of the plant during 1981-82

Irrigation at stage	Height of the plant (cm)				
	Observation just before irrigation at stage				
	C(21 DAS)	T (42 DAS)	F(76 DAS)	D(96 DAS)	Harvest
C	20.1	52.5	76.3	104.0	104.4
T	20.2	49.1	75.4	103.0	103.7
F	20.1	49.4	75.6	102.1	103.4
D	20.4	50.5	74.5	101.5	102.9
CT	20.4	51.6	77.9	103.9	104.3
CF	20.2	52.6	76.4	104.1	105.0
CD	20.6	51.3	76.7	103.5	103.8
TF	20.5	50.1	76.7	103.1	104.1
TD	20.6	50.3	72.2	102.6	103.5
FD	20.5	50.2	75.1	102.1	103.1
CTF	20.1	52.4	76.8	104.9	104.7
CFD	20.5	52.6	76.6	104.3	104.7
CTD	20.6	52.9	77.9	104.0	104.3
TFD	20.6	50.5	76.9	103.5	103.9
CTFD	20.7	51.8	77.2	104.3	104.7
R	20.6	49.8	74.1	101.6	101.9
SEm $\pm$	0.44	0.92	0.99	0.72	0.45
C.D. 5 %	N.S.	2.62	2.81	2.05	1.29

control during three seasons except one irrigation at dough stage. This indicates that only one irrigation at dough stage had no beneficial effect on the height of the plant, but soil moisture stress upto flowering stage had profound influence on the height of the plant. This supports the earlier findings reported by Patel et al. (1971) who observed that moisture stress at early stages of growth reduced the height of the plant.

4.1.1.2 Dry matter production

Irrigation significantly influenced dry matter accumulation during three seasons (Table 4.4). Effect of single irrigation applied at any physiological growth stage was not significant in all three years. Plants received more than one irrigation significantly increased dry matter over control. Dry matter accumulation was maximum when the plants were given four irrigations (CTFD) one each at crown root initiation, tillering, flowering and dough stages, but this treatment was at par with irrigation treatments received two or three irrigations. Prashar and Singh (1963) also reported increased dry matter accumulation with increase in the number of irrigation.

4.1.1.3 Tillering pattern

4.1.1.3.1 Number of total tillers

Number of total tillers was significantly influenced by irrigation treatments during tillering, flowering and dough

Table 4.4 Effect of irrigation on dry matter accumulation

Irrigation at stage	Dry matter accumulation (g / ha)		
	1979-80	1980-81	1981-82
C	73.2	67.1	69.5
T	74.5	69.6	72.8
F	73.6	68.6	70.6
D	72.6	67.3	68.0
CT	76.6	74.9	79.8
CF	77.9	79.3	83.9
CD	75.7	76.0	79.7
TF	79.2	79.5	85.4
TD	77.6	75.3	80.2
FD	78.1	75.3	81.6
CTF	84.1	80.1	88.4
CFD	83.0	79.4	87.4
CTD	82.3	80.3	87.3
TFD	80.0	79.2	88.0
CTFD	83.0	81.1	91.2
R	68.5	66.5	70.1
S.E.m $\pm$	1.92	1.54	2.13
C.D. 5%	5.48	4.40	6.07

stages in three years (Tables 4,5, 4.6 and 4.7). First observation on tiller number was recorded before crown root initiation stage when the plants did not receive differential irrigation treatments. So it is quite logical that the irrigation treatments did not influence the total tiller counted before that stage of crop growth.

All treatments received irrigation at crown root initiation stage recorded increased tiller number at tillering stage over treatments receiving no irrigation before tillering stage, but the differences were not always statistically significant.

Number of total tillers recorded before irrigation at flowering stage was more in treatments receiving irrigation at crown root initiation or tillering or both stages as compared to treatments received no irrigation before the date of observation. At this stage tiller number was maximum in all irrigation treatments in comparison to that recorded in either crown root initiation or tillering stage.

Tiller number at dough stage was found to decrease from that recorded at flowering stage. This trend was observed in all treatments during three seasons. Tiller number with rainfed treatment and irrigation at dough stage which did not receive irrigation so far was lower than that recorded under treatments received irrigation. This was due to the favourable influence of soil moisture in the rootzone of the crop due to irrigation.

Table 4.5 Effect of irrigation on the number of total tillers during 1979-80

Irrigation at stage	Number of total tillers			
	Observation before irrigation at stage			
	C(21 DAS)	T(42 DAS)	F(76 DAS)	D(96 DAS)
C	51.5	71.5	99.2	85.0
T	52.5	67.5	97.7	82.0
F	52.2	68.7	91.7	78.2
D	52.5	68.7	90.0	77.2
CT	53.0	73.7	107.2	92.0
CF	53.2	75.5	106.2	90.0
CD	53.2	72.7	103.7	89.2
TF	52.2	68.7	101.7	86.2
TD	53.2	68.0	100.5	84.2
FD	52.2	66.7	91.6	78.5
CTF	52.5	71.0	109.5	90.0
CFD	53.2	72.2	102.7	90.2
CTD	53.6	72.7	108.0	90.6
TFD	52.6	66.2	100.5	83.5
CTFD	53.2	74.0	108.7	91.5
R	53.5	68.0	92.0	79.5
S.E.m $\pm$	1.52	1.45	2.03	1.88
C.D. 5%	N.S.	4.14	5.79	5.37

Table 4.6 Effect of irrigation on the number of total tillers during 1980-81

Irrigation at stage	Number of total tillers			
	Observation before irrigation at stage			
	C (21 DAS)	T(42 DAS)	F(76 DAS)	D(96 DAS)
C	50.7	70.0	95.0	86.7
T	51.0	65.5	90.7	82.2
F	50.5	66.0	90.0	81.7
D	50.5	65.5	90.2	80.0
CT	51.2	72.2	98.5	87.2
CF	51.0	70.5	94.2	83.2
CD	52.0	70.0	97.5	83.5
TF	51.5	66.0	94.5	84.7
TD	52.0	68.5	97.0	82.5
FD	51.5	66.5	90.7	80.5
CTF	51.5	72.7	97.0	87.0
CFD	51.5	70.0	95.2	85.2
CTD	52.0	71.0	99.0	86.2
TFD	52.0	67.0	96.2	85.2
CTFD	51.2	70.2	99.0	86.2
R	52.0	67.2	90.0	77.0
S.Em $\pm$	1.31	1.16	1.58	1.59
C.D. 5%	N.S.	3.31	4.52	4.55

Table 4.7 Effect of irrigation on the number of total tillers during 1981-82

Irrigation at stage	Number of total tillers			
	Observation before irrigation at stage			
	C (21 DAS)	T(42 DAS)	F(76 DAS)	D(96 DAS)
C	54.0	77.5	100.0	86.5
T	54.0	74.0	98.5	87.0
F	53.7	74.0	95.2	86.0
D	54.2	73.5	96.0	85.2
CT	53.5	78.2	100.5	89.5
CF	53.8	78.0	99.2	88.6
CD	54.0	74.2	98.5	87.4
TF	54.0	73.7	98.0	90.2
TD	54.5	72.5	97.0	86.5
FD	54.2	74.2	94.0	85.0
CTF	54.0	78.8	99.5	89.5
CFD	53.5	76.7	99.0	88.0
CTD	54.15	78.2	100.0	82.2
TFD	54.0	74.5	97.5	86.5
CTFD	54.0	77.8	100.0	90.0
R	53.5	73.5	93.2	83.0
S.E.m $\pm$	1.07	1.04	1.51	1.80
C.D. 5%	N.S.	2.95	4.32	5.15

This is in conformity with the findings reported by Gautam (1961) and Misra et al. (1976) who observed increased number of tillers due to higher level of irrigation.

4.1.1.3.2 Number of effective tillers

The effect of irrigation treatments on the number of effective tillers was statistically significant during two (1979-80 and 1980-81) out of three years (Table 4.8). One irrigation applied at any of the four growth stages failed to increase the effective tiller over unirrigated control. Two, three or four irrigations being at par significantly increased the number of effective tillers over control except two irrigations applied at flowering (F) and dough (D) stages which was at par with control. Bhardwaj et al. (1971) also reported that early irrigations encouraged effective tillers. Frequent and higher level of irrigation was found to increase the number of effective tillers (Prashar and Singh, 1963) in wheat.

4.1.1.4 Length of ear

Length of ear was significantly affected by the level of irrigation during three seasons (Table 4.9). Among one irrigation treatments, single irrigation at tillering (T) stage maintained higher level of moisture in soil during panicle initiation stage which might be conducive for longer ear. As a result irrigation at T stage significantly increased length

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Table 4.8 Effect of irrigation on the number of effective tillers

Irrigation at stage	Number of effective tillers		
	1979-80	1980-81	1981-82
C	78.5	80.0	84.0
T	77.7	80.0	85.0
F	76.0	79.2	83.7
D	75.5	78.5	83.5
CT	82.7	83.2	88.0
CF	83.5	83.7	87.2
CD	84.6	82.5	86.0
TF	83.2	84.0	88.5
TD	80.5	81.0	86.5
FD	78.7	78.5	84.7
CTF	84.0	84.5	88.7
CFD	83.0	83.2	87.0
CTD	84.7	83.7	88.5
TFD	82.0	82.0	85.7
CTFD	84.7	81.7	89.2
R	76.6	76.8	80.2
SEm $\pm$	1.24	1.47	1.97
C.D. 5%	3.54	4.19	N.S.

of ear over control. But one irrigation at other stages failed to exhibit such beneficial effect over control.

Increase in the number of irrigation to two significantly increased the ear length over that recorded under one irrigation as well as in control. Among two irrigations, irrigation at tillering and flowering (TF) stages was found to record bigger ear in all years. Further increase in the level of irrigation to three or four had no additional benefit over two irrigations, however, three and four irrigations were significantly superior to one irrigation or control. Similar increase in the length of ear due to increase in the number of irrigation was also reported by Mehrotra and Singh (1969) and Jana and Sen (1973) in wheat.

4.1.1.5 Number of grains per ear

One irrigation at any of the four growth stages did not increase the number of grains per ear in almost all the years of experimentation (Table 4.10) over control. Favourable influence of irrigation on grain number was observed when the level of irrigation was increased to two or more. However, two, three or four irrigations were at par. Mehrotra and Singh (1969) and Gill (1980) observed similar findings who reported that increase in the number of irrigations augmented grain number per ear.

Table 4.9 Effect of irrigation on the length of ear

Irrigation at stage	Length of ear (cm)		
	1979-80	1980-81	1981-82
C	9.2	9.4	9.5
T	9.7	10.0	9.8
F	9.4	9.6	9.7
D	9.4	9.6	9.6
CT	10.8	10.9	10.9
CF	11.0	10.7	10.9
CD	10.5	10.7	10.6
TF	11.0	10.9	11.0
TD	10.5	10.5	10.5
FD	10.5	10.6	10.6
CTF	11.0	10.9	11.0
CFD	10.7	10.7	11.0
CTD	10.8	10.7	11.0
TFD	10.8	10.6	11.1
CTFD	11.0	10.9	11.1
R	9.1	9.2	9.2
SEm $\pm$	0.15	0.20	0.22
C.D. 5%	0.43	0.57	0.62

Table 4.10 Effect of irrigation on the number of grains per ear

Irrigation at stage	Number of grains per ear		
	1979-80	1980-81	1981-82
C	30.8	32.6	32.4
T	32.5	33.4	32.4
F	32.0	32.4	32.6
D	31.3	31.5	30.5
CT	34.1	35.8	36.4
CF	36.2	36.1	36.5
CD	34.6	34.6	34.7
TF	36.6	36.6	36.6
TD	35.5	35.4	34.8
FD	35.1	35.5	35.4
CTF	36.5	36.3	37.5
CFD	36.3	36.2	37.4
CTD	36.7	36.5	37.4
TFD	36.5	35.6	37.9
CTFD	36.9	36.3	37.2
R	30.5	30.4	30.3
SEm $\pm$	0.91	1.04	1.04
C.D. 5%	2.60	2.97	2.97

4.1.1.6 Thousand grain weight

Irrigation had no significant influence on the weight of thousand grains in any of the year of investigation (Table 4.11). Although the application of two or more number of irrigations tended to increase the weight of 1000 grains, the increase over control was not significant in three seasons.

4.1.1.7 Grain yield

Grain yield was significantly influenced by the level of irrigation during all the years of experimentation as well as in pooled data (Table 4.12). One irrigation applied at any one of the four growth stages did not increase the number of effective tillers (Table 4.8), the number of grains per ear (Table 4.10) and weight of thousand grains (Table 4.11) over unirrigated control. Hence, single irrigation did not influence the grain yield over control except in 1980-81 and pooled data when one irrigation was found superior to control. However, there was no significant difference in grain yield among one irrigation treatments during all the years as well as in pooled data.

Two irrigations significantly increased the grain yield over control. This was mainly due to an increase in the yield attributing characters (Tables 4.8, 4.9 and 4.10) with two irrigations over control. This is in conformity with the findings reported earlier by several workers (Mehrotra and Singh, 1969; Petrunin and Okolovich, 1972; Misra et al., 1976; Gill, 1980 and

Table 4.11 Effect of irrigation on thousand grain weight

Irrigation at stage	Thousand grain weight (gm)		
	1979-80	1980-81	1981-82
C	39.9	40.8	41.9
T	39.9	41.4	42.1
F	40.2	41.3	42.6
D	40.4	41.7	43.2
CT	40.2	41.3	42.7
CF	39.9	41.6	43.1
CD	40.5	42.1	43.6
TF	40.2	41.8	43.2
TD	40.3	41.9	43.4
FD	40.3	41.7	43.4
CTF	40.2	41.6	43.3
CFD	40.7	42.1	43.5
CTD	40.6	41.8	43.4
TFD	40.6	42.1	43.5
CTFD	40.5	41.8	43.4
R	39.6	40.2	41.8
SEm $\pm$	0.55	0.43	0.51
C.D. 5%	N.S.	N.S.	N.S.

Prihar, 1983) who also observed that the increase in the number of irrigation augmented effective tiller, ear length and grain number per ear and ultimately grain yield of wheat.

Among two irrigation treatments maximum grain yield was observed with TF irrigation treatment which was at par with CF and CT irrigation treatments (Table 4.12). Further increase in the level of irrigation to three or four did not significantly increase the yield over two irrigations. There was also no significant difference in yield among two, three or four irrigations. This is quite logical, because there was no significant difference in the effective tiller (Table 4.8), grain number (Table 4.10) and thousand grain weight (Table 4.11) among two, three and four irrigation levels. The results thus indicate that two irrigations at CF or CT or TF stages were considered necessary for wheat in this locality.

4.1.1.8 Straw yield

Irrigation had significant influence in increasing the straw yield of wheat during three years (Table 4.13). While one irrigation significantly increased the straw yield over rainfed treatment in one (1980-81) out of three years, two, three and four irrigations increased it over unirrigated control in all years. Maximum straw yield was recorded with four irrigations which was at par with three irrigation treatments except three irrigations applied at CTD stages during 1979-80. Increase in

Table 4.12 Effect of irrigation on the grain yield of wheat

Irrigation at stage(S)	Grain yield (g/ha)				
	1979-80	1980-81	1981-82	1982-83	Pooled
C	25.5	27.9	26.7	27.4	26.86
T	26.6	28.7	27.6	28.1	27.74
F	25.9	28.2	27.0	28.4	27.35
D	25.5	27.4	26.4	27.6	26.72
CT	27.9	29.2	30.3	30.0	29.34
CF	28.8	29.4	31.3	30.3	29.94
CD	28.1	28.0	29.9	29.8	28.96
TF	28.8	29.3	31.9	31.1	30.29
TD	27.6	28.7	29.4	30.1	28.98
FD	27.0	28.4	29.9	29.3	28.68
CTF	28.5	29.4	31.7	30.3	29.94
CFD	28.8	29.5	31.6	30.9	30.18
CTD	28.4	29.0	31.5	30.1	29.76
TFD	28.5	28.5	31.5	30.8	29.85
CTFD	28.4	29.0	31.2	30.6	29.78
R	24.4	25.0	25.3	26.3	25.27
SEm $\pm$	0.86	0.75	0.97	0.89	0.45
C.D. 5%	2.47	2.13	2.76	2.52	1.25

the number of irrigation to two or more influenced straw yield by increasing the height of the plant (Tables 4.1, 4.2 and 4.3), dry matter (Table 4.4) and total tillers (Tables 4.5, 4.6 and 4.7). Prashar and Singh (1963) reported that increase in the number of irrigation increased plant height and total dry matter and also raised straw to grain ratio.

4.1.2 Evapotranspiration

4.1.2.1 Rate of evapotranspiration

The results indicate that rate of evapotranspiration (E_T) was influenced very much by maintenance of soil moisture with irrigation given at each of four stages (CTFD) in wheat crop.

During 1979-80 crop season it is observed (Fig. 4) that, E_T gradually increased after emergence to 2.7 mm per day at 40th day and further increased slowly to reach its peak (3 mm/day) at 94th day and thereafter it decreased due to ageing of the crop. The E_T of wheat crop under rainfed condition clearly indicated very low rate of 1.5 mm/day upto 72 days then attained a peak 2.7 mm/day only at 94 days because of influence of rainfall and thereafter it decreased (Fig. 4.1).

During 1980-81 while the E_T from irrigated wheat crop gradually increased to its peak at 3.25 mm/day on 72 days and then decreased slightly, E_T for rainfed crop was much lower (2 mm/day) and remained almost same throughout the growth period (Fig. 4.1).

Table 4.13 Effect of irrigation on the straw yield of wheat

Irrigation at stage	Straw yield (q/ha)		
	1979-80	1980-81	1981-82
C	39.2	40.0	36.7
T	38.4	41.1	38.3
F	38.1	40.0	37.8
D	36.9	40.2	36.3
CT	43.6	43.2	41.3
CF	46.5	42.2	43.9
CD	42.6	41.0	42.0
TF	47.9	42.4	42.7
TD	49.2	42.5	41.5
FD	44.2	44.0	40.8
CTF	50.2	46.0	45.7
CFD	49.5	45.9	45.2
CTD	48.7	43.8	45.0
TFD	49.2	44.8	44.7
CTFD	52.0	46.3	46.3
R	36.6	36.8	36.2
SEm $\pm$	1.91	0.93	1.14
C.D. 5%	2.38	2.67	3.25

During the next crop season of 1981-82 because of rainfall in between dough and harvesting (D to H) stage E_T for both irrigated and rainfed crop continued to increase upto the harvesting stage and the rates were higher compared to that of previous seasons (Fig. 4.1).

When three seasons' data (1979-82) are considered together the marked difference in E_T between irrigation given at each of four stages of crop growth and rainfed wheat was observed. But the trend of the curve had testimony of similarity with individual season (Fig. 4.1). The relationship between E_T and days of growth is expressed by the following equation :

1979-1982

Irrigated wheat (CTD) ;

$$E_T = .0935021D - .0009579D^2 + .0000033D^3 - 0.0089822$$

Rainfed wheat (R)

$$E_T = .0469336D - .000412D^2 + .0000013D^3 + 0.2842467$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth after emergence.

The E_T for 1979-80 crop season under three irrigation treatments (CTD) continued to rise steadily reaching its peak (2.7 mm/day) at 48 days after emergence and due to no irrigation at next stage of flowering (F), E_T decreased slightly afterwards, but started increasing again after flowering, due to rain and higher physiological need maintaining the trend beyond dough stage (D) and dropped a little during harvest (Fig. 4.2).

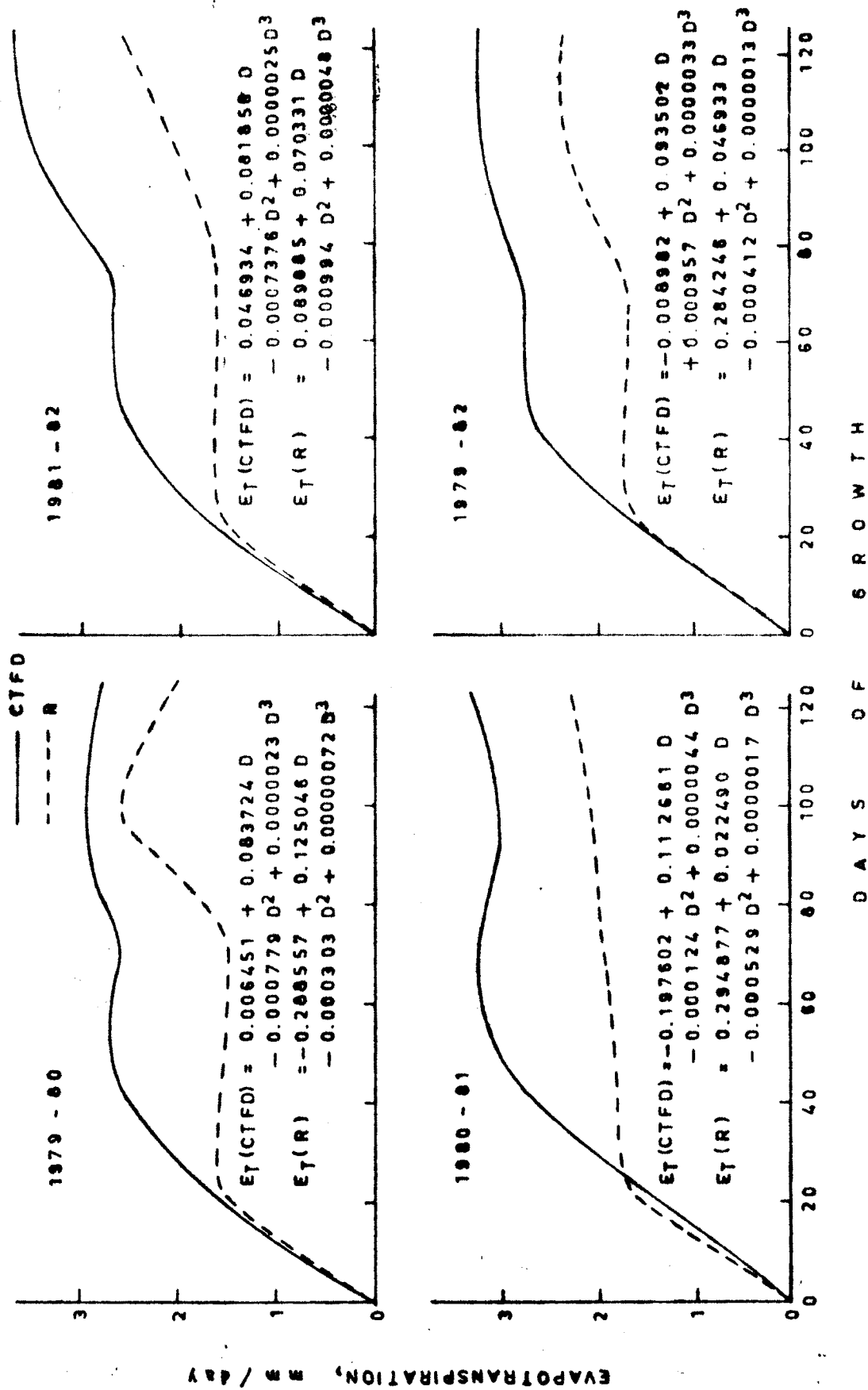


FIG. 4.1 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

During the next crop season (1980-81) the initial trend of E_T was similar to that of previous crop season but the rate of increase was more after crown root initiation (C) and upto the stage of flowering (F) reaching its peak (3.1 mm/day) at 72 days after emergence and then dropped remarkably due to no irrigation at F stage. The rate increased only after irrigation given at the next dough (D) stage. The trend of the curve for 1981-82 followed almost the same pattern with only slightly different E_T (Fig. 4.2).

For treatment (TFD) when first irrigation was given at tillering stage, the E_T for 1979-80 crop season after a steady increase upto 21st day, dropped a little upto the next T stage and maintained a steady rise due to the effect of irrigation at the next two successive stages registering a peak of 3.00 mm/day at 96th day ending with only a slight fall (Fig. 4.2).

During the next two seasons of 1980- 81 and 1981-82, the E_T followed the same trend with only slight variation in rate (Fig. 4.2).

The mean value of E_T for three seasons indicates that it increased upto C stage for both treatments of CTD and TFD, but thereafter in case of treatment CTD effect of irrigation at first two stages was manifested by a uniform rise in E_T upto F stage (70th day after emergence), decreased slightly upto D stage and then rose again. But in case of treatment TFD, the trend was different and more or less similar to individual seasons (Fig. 4.2).

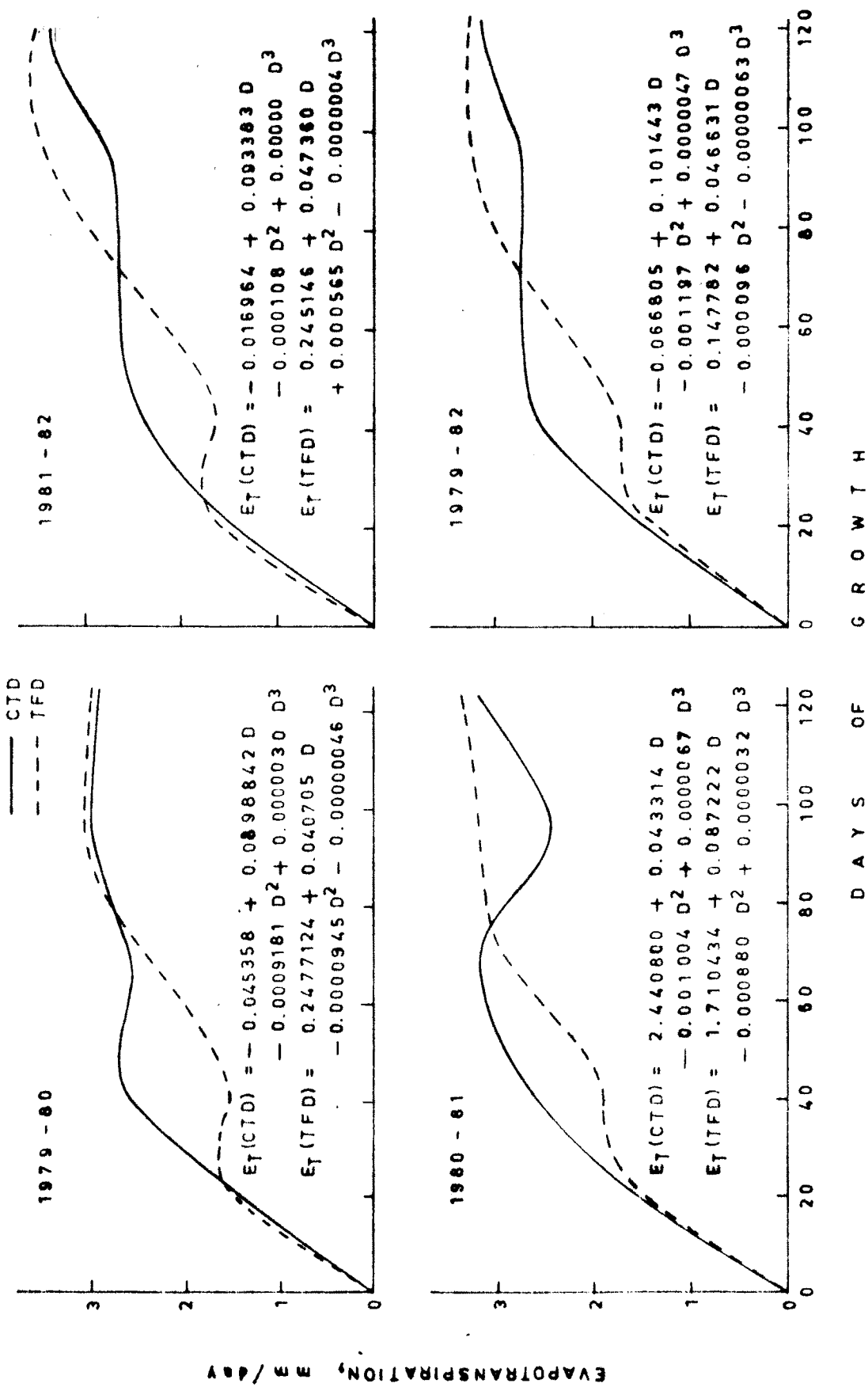


FIG. 4.2 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

The relationship between E_T and days of growth is given by the following equation :

1979-1982

Irrigation at CTD :

$$E_T = 0.1014435D - 0.0011976D^2 + 0.00000472D^3 - 0.0668054$$

Irrigation at TFD

$$E_T = 0.0626526D - 0.0003425D^2 + 0.00000063D^3 - 0.199343$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth after emergence

During all the three crop seasons the E_T from treatments CTF and CFD increased steadily upto tillering stage to the tune of 2.5 to 2.7 mm/day due to the effect of irrigation at C in both the treatments and thereafter the E_T varied depending on irrigation treatments (Fig. 4.3). In treatment CTF, due to the effect of irrigation at both tillering and flowering stages the E_T continued to maintain a high rate. Because of additional effect of rainfall between T and F stages during 1980-81 season the E_T was maintained at the highest level of above 3.00 mm/day from T stage to beyond D stage.

The influence of irrigation at CFD on E_T had different effect after tillering stage. Having no irrigation at this stage E_T value dropped after T stage and rose again after being influenced by two successive irrigations at next two stages of F and D. This was true for all the three crop seasons with slight

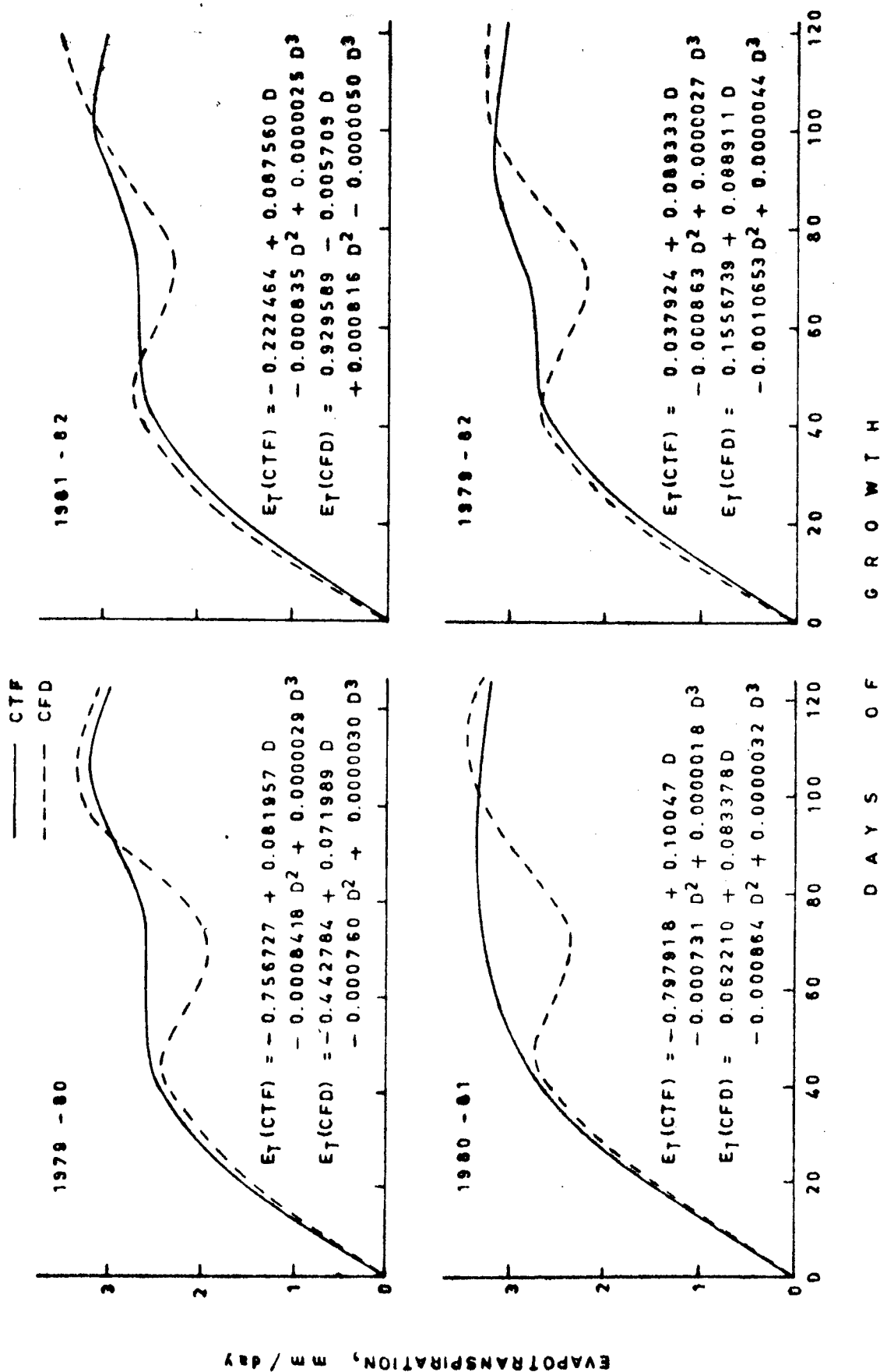


FIG. 4.3 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

variation due to different influence of rainfall during different crop seasons (Fig. 4.3).

The mean values of E_T under both treatments of CTF and CFD during 1979-82 indicated the similar trends of individual seasons.

The following equations express the relationship between E_T and days of growth after emergence :

1979-1982

Irrigation at CTF :

$$E_T = 0.0893333D - 0.0008636D^2 + 0.0000027D^3 + 0.0379243$$

Irrigation at CFD :

$$E_T = 0.0889117D - 0.0010653D^2 + 0.0000044D^3 + 0.1556739$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth

The E_T for treatments TD and FD indicated a striking similarity at early stages and difference during later stages of growth due to the effect of irrigation treatment during all the three seasons (Fig. 4.4).

For treatment TD, the E_T varied between 2.6 and 3.1 mm/day from tillering to dough stage during all three seasons. In FD treatment, E_T increased only after irrigation at flowering stage. Because of no irrigation at C and T stages, E_T instead of rising steadily remained almost static between 1.5 to 1.7 mm/day during different crop seasons.

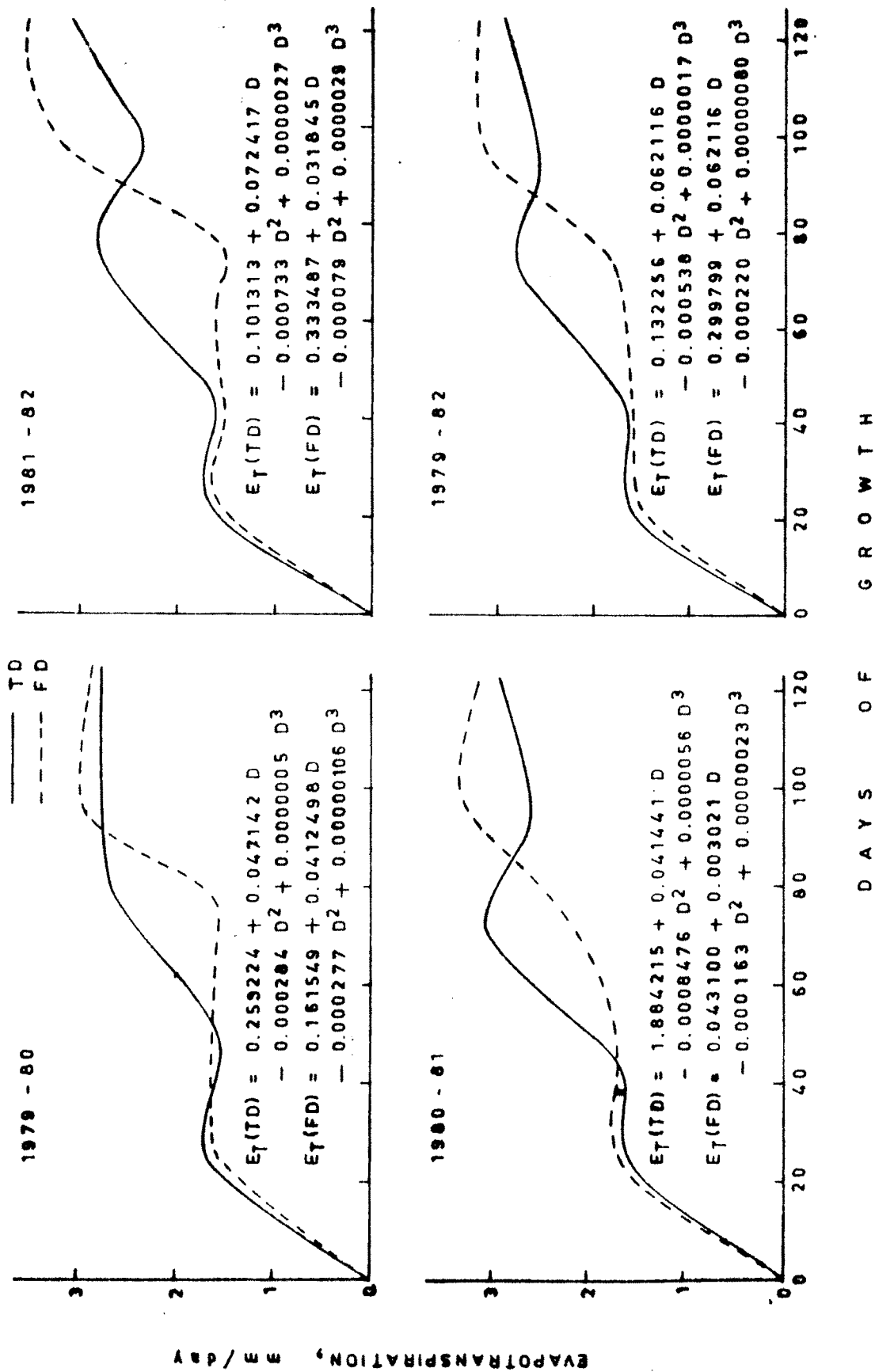


FIG. 4.4 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

The E_T for the average of three seasons for both treatments of TD and FD was found to be similar to individual seasons with only slight variation.

The relationship between E_T and days of growth is expressed by the following equations :

1979-82

Irrigation at TD :

$$E_T = 0.062116D - 0.0005381D^2 + 0.0000017D^3 + 0.1322556$$

Irrigation at FD :

$$E_T = 0.0392845D - 0.0002208D^2 + 0.00000080D^3 + 0.2997998$$

Where, E_T = Evapotranspiration rate, mm/day

D = Days of growth

The E_T for treatments CD and TF treatments was found to have been differentially influenced by different irrigation treatments (Fig. 4.5).

For treatment CD the E_T increased from sowing to C stage at 22nd day to a level 1.5 mm/day during all the crop seasons. Due to the effect of irrigation at C stage the rise in E_T was maintained till the next stage of tillering attaining a level of 2.5 to 2.7 mm/day during different crop seasons. The E_T decreased to a level of 1.8 to 2.4 mm/day at flowering stage (72-72 days) during different crop seasons, the crop being very sharp during 1979-80 because of no influence of rain during T-F stages, but not so sharp during 1980-81 because of available

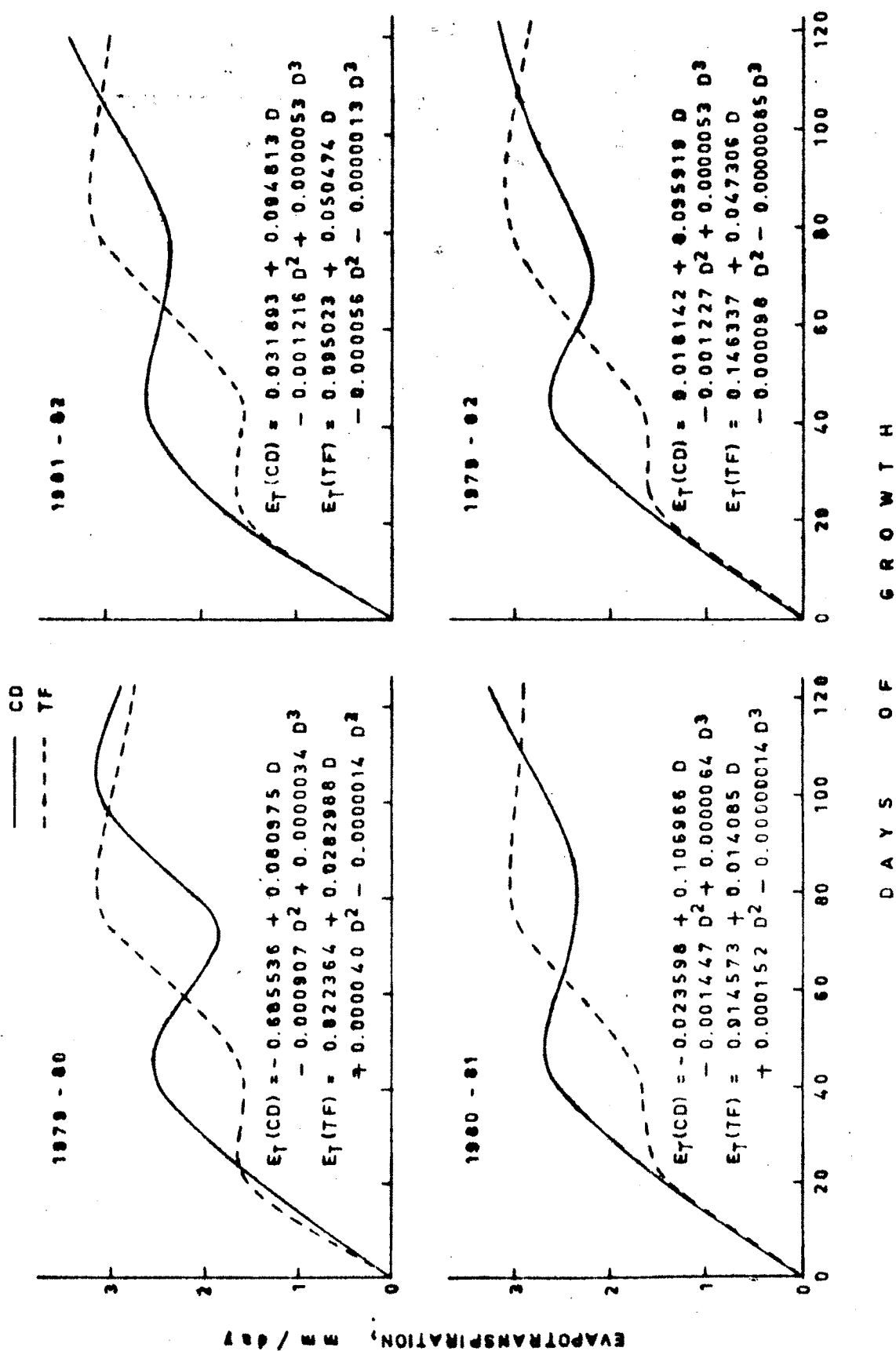


FIG. 4.5 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

soil moisture at this stage. After this stage E_T rose again due to influence of rain during 1979-80 crop season reaching a peak of 3.0 mm/day during D stage. During other crop seasons of 1980-81 and 1981-82 the E_T curves in between F and D stages are more or less flat due to non-availability of irrigation or substantial quantity of rains to influence the E_T . The E_T increased only after a irrigation was given at D stage to a level of 3.4 mm/day during both the crop seasons.

The effect of treatment TF on E_T was different. The rate was increased to an optimum level of 1.5 mm/day at C stage (22nd day after emergence), but because of non-availability of irrigation at C stage E_T remained more or less static in between C and T stages. But after getting irrigation at successive stages of T and F, the E_T increased steadily to a peak of 3.0 to 3.1 mm/day during the period between F and D stages for different crop seasons.

The mean values of E_T for three crop seasons showed similar trend of individual crop seasons and the relationship between E_T and days to growth is expressed by the following equations :

1979-82

Irrigation at CD :

$$E_T = .0959196D - .001227D^2 + .0000053D^3 + .0181423$$

Irrigation at TF :

$$E_T = .0473065D - .0000983D^2 - .00000085D^3 + .1463373$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth

The effect of irrigation given at each of CT and CF on E_T was found to be different and remarkable (Fig. 4.6).

With treatment CT, the rate of increase of E_T was at faster pace from the stage of sowing till the stage of a first irrigation at C and next irrigation at T and thereafter the increase was very slow upto the stage prior to harvest except during 1980-81 when E_T rose to 3.3 mm/day due to 12.6 mm of rainfall after tillering.

With treatment CF the E_T maintained a close similarity with treatment CT upto T stage. Thereafter, because of no irrigation at T stage the E_T rate was reduced, but again increased because of irrigation at F stage and attained a peak of 3.0 mm/day or a little above at 100 day stage during different seasons and again decreased at harvest time.

Due to irrigation at CT stage E_T differed (Fig. 4.6) with that from irrigation at CF stages indicating clearly the influence of irrigation on E_T (Three seasons data). However, E_T under CF increased over that on CT due to supplementary effect of rainfall.

The relationship between days to growth and E_T is expressed the following equations :

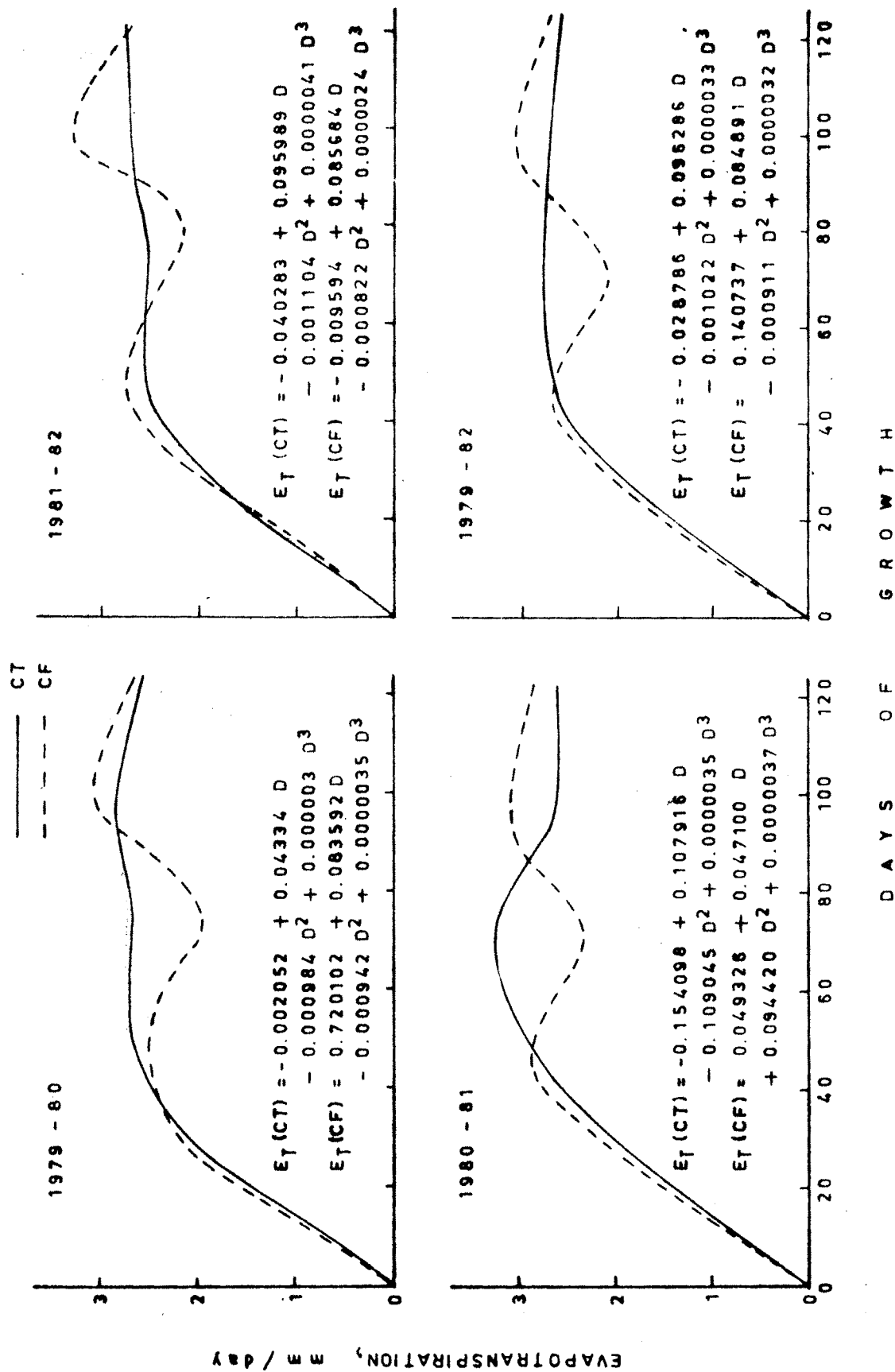


FIG. 4.6 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

1979-82

Irrigation at CT :

$$E_T = .0962866D - .0010228D^2 + .000003356D^3 - .0287869$$

Irrigation at CF :

$$E_T = .0848918D - .0009111D^2 + .0000032D^3 + .140737$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth.

The result (Fig. 4.7) revealed influence of irrigation treatment at F and D stages of crop growth on E_T during all three crop seasons. The E_T under both F and D gradually increased from the date of emergence to C stage due to available soil moisture and was about 1.6 mm/day for all three seasons. The value of E_T was comparable upto the next stage of T (42 days) also, for F and D treatments.

While during 1979-80 crop season E_T under treatment F remained practically same (1.6 mm/day) upto the next stage of F, this value during 1980-81 crop season rose a little more because of influence of rain after tillering and before flowering stage. There was a general rise in the value of E_T after F stage reaching a peak at about 90 days after emergence during all crop seasons and then slowly decreased.

E_T under treatment D increased slowly due to influence of rain after flowering stage during 1979-80 and after irrigation at D stage reached a peak of 2.9 mm/day at 110 day after emergence.

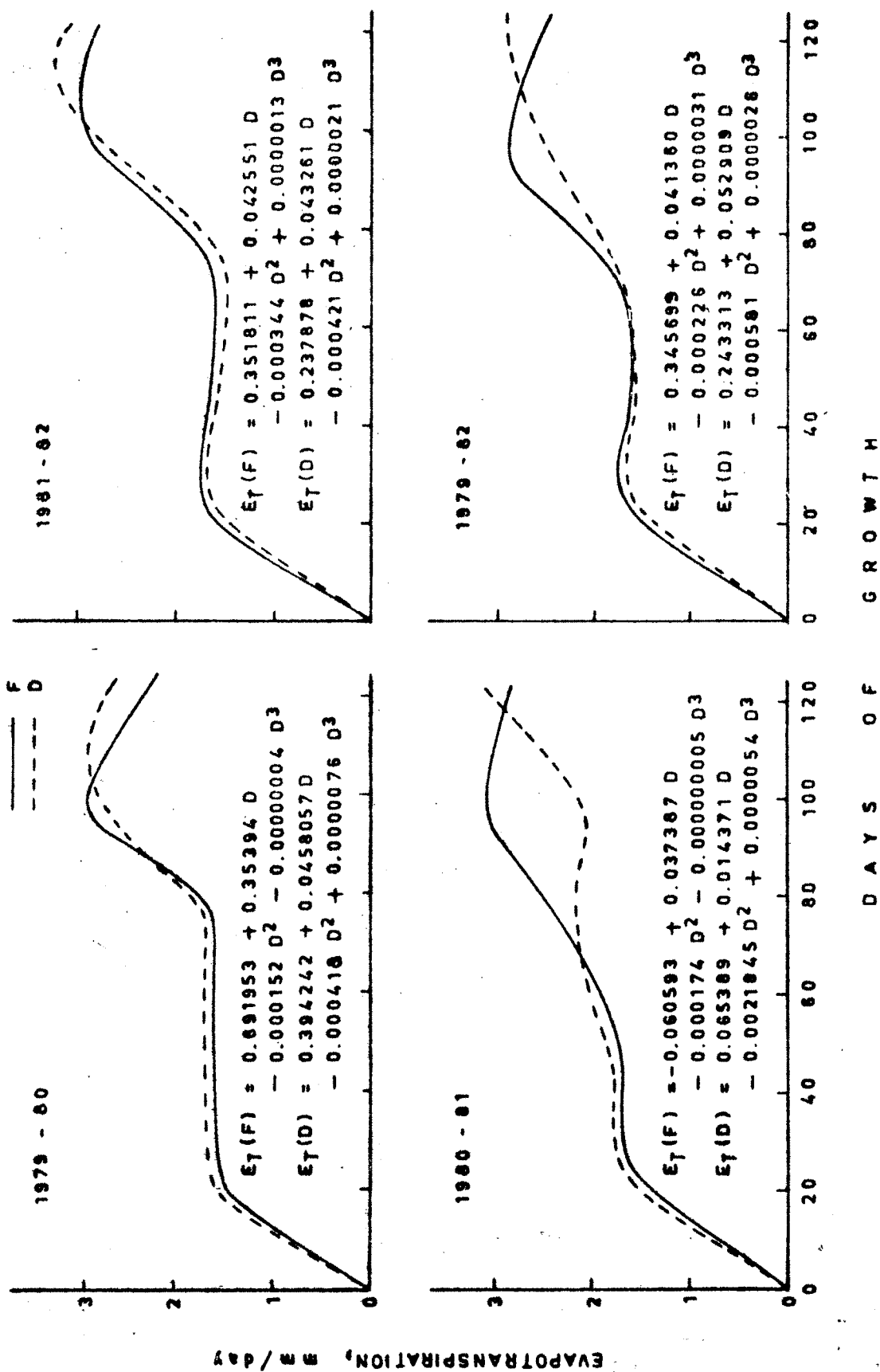


FIG. 4.7 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

During the next crop season of 1980-81 (Fig. 4.7) due to influence of rainfall after tillering stage the E_T was more (7.2 mm/day) even without any irrigation treatment at flowering and reached 3.0 mm/day after irrigation at D stage and then decreased.

The trend in value of E_T during crop season of 1981-82 was observed to be similar to that of 1979-80, with only difference in the fact that the rise of E_T in the last stage was much more prominent due to irrigation treatment at D stage and supplementary effect of rains.

The mean rate of E_T of three crop seasons indicated more or less the same trend.

The following equations have been deduced to establish relationship between E_T and days of growth :

1979-82

Irrigation at F

$$E_T = .0413601D - .0002263D^2 + .00000031D^3 + .3456995$$

Irrigation at D

$$E_T = .0529093D - .0005816D^2 + .0000026D^3 + .2433133$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth

Irrigation treatments of C and T showed differential effects on the value of E_T (Fig. 4.8).

Effect of irrigation at C on E_T showed similar influence on E_T at the initial stage. The E_T increased steadily upto the stage of C and continued to rise further after irrigation at this stage to a peak of 2.6 mm/day at T stage and dropped thereafter due to obvious reason to a least value of 1.9 mm/day at F stage. Although there was no irrigation at F stage, due to the effect of rainfall in between F and D stages during 1979-80 crop season, E_T increased to a highest level of 2.7 mm/day and then decreased again to 2.1 at harvest.

During the 1980-81 crop season the E_T rate was similar to the previous season at early stage, but because of influence of rainfall between T-F stages the drop in the value of E_T was not as low as in case of 1979-80 and again because of absence of any influence of rain during next stages the increase in E_T was not as high as earlier season during the later part of growth.

The trend of E_T curve (Fig. 4.8) of 1981-82 was similar to earlier seasons at first phase but had only slight variation at the last phase of growth.

Treatment T showed influence on E_T . E_T rose upto C stage and then remained more or less static upto the next stage of T during all the three seasons.

After T stage the E_T rose during 1979-80 by the influence of irrigation treatment to a peak of 2.7 mm/day at D stage followed by a decrease at harvest.

During 1980-81 season the increase of E_T after T stage was more pronounced (3 mm/day at F stage) due to combined influence of irrigation and rainfall and thereafter decreased to 2.3 mm/day at 90 days and remained almost unchanged till harvest. During 1981-82 the trend was similar at early stage, but after attaining a peak of 2.9 mm/day at F stage, there was a drop in E_T followed by slight increase.

To express relationship between E_T and days of growth the following equations have been derived :

Irrigation at C :

$$E_T = .0950519D - .00011342D^2 + .0000041D^3 + .0131519$$

Irrigation at T :

$$E_T = .0620887D - .0004139D^2 + .00000043D^3 + .0554413$$

where, E_T = Evapotranspiration rate, mm/day

D = Days of growth.

4.1.2.2 Total evapotranspiration

Total evapotranspiration was studied during three years (Table 4.14). It was minimum under rainfed treatment (R) in all years. This is due to increase in resistance to the flow of water vapour through dry soil (Ritchie, 1971) under rainfed condition. When irrigation was applied, soil moisture content was increased after each irrigation. Evaporation as well as transpiration was increased because of higher availability of moisture in soil which received irrigation. The maximum evapotranspiration under four (CTFD) irrigations is, therefore, logical (Table 4.14).

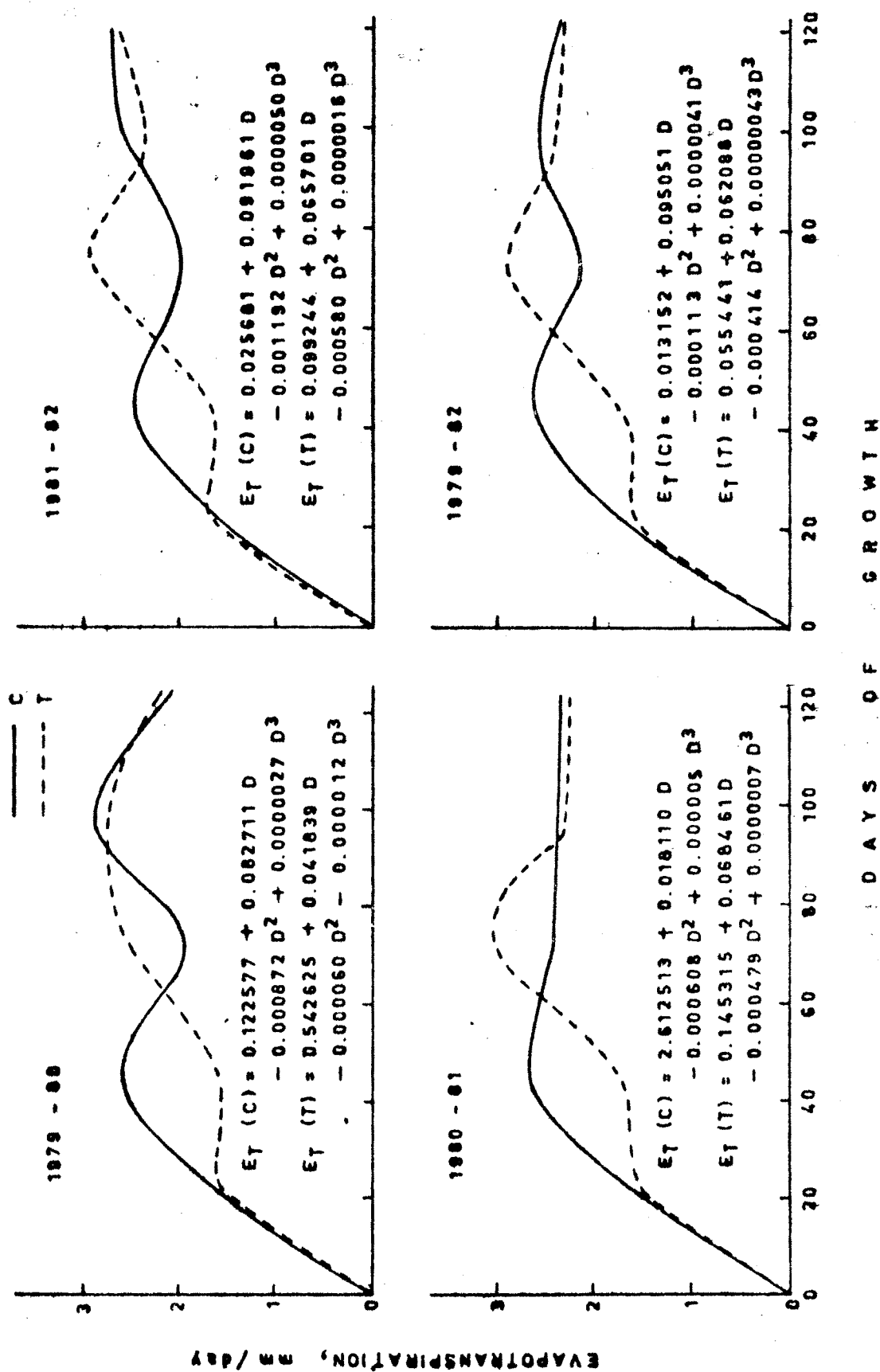


FIG. 4.8 MEAN EVAPOTRANSPIRATION RATE AS FUNCTION OF DAYS OF GROWTH UNDER DIFFERENT IRRIGATION TREATMENTS

Table 4.14 Effect of irrigation treatment on total evapotranspiration (mm) of wheat

Irrigation at stage	Total evapotranspiration (mm)			
	1979-80	1980-81	1981-82	Average
C	269.5	274.5	264.2	269.4
T	266..4	271.3	274.7	270.8
F	243.6	285.4	249.0	259.3
D	250.8	262.2	249.4	254.1
CT	309.1	310.2	292.4	303.9
CF	289.1	303.4	299.7	297.4
CD	288.5	302.8	301.0	297.4
TF	289.2	306.6	293.5	296.4
TD	287.1	309.6	284.3	293.6
FD	264.3	289.1	271.2	274.8
CTF	322.0	347.7	310.0	326.5
CFD	302.4	326.5	313.2	314.0
CTD	315.8	322.7	309.5	316.0
TFD	297.8	321.4	312.3	310.5
CTFD	322.4	340.8	329.9	331.0
R	228.4	237.7	209.7	225.2
SEm $\pm$	4.53	7.74	4.92	-
C.D. 5%	12.91	22.06	14.03	-

Total evapotranspiration with four irrigations did not differ significantly from that recorded under CTF and CTD during 1979-80 and under all three irrigation treatments during 1980-81. Total evapotranspiration was found to decrease with decrease in the number of irrigation. Similar observation was also made by Singh et al. (1970) on wheat. In the present investigation, two and one irrigation treatments had significantly lower evapotranspiration as compared to four irrigations in all years. Treatments CT, CF and TF recorded 9, 10 and 10.5 per cent decrease in evapotranspiration as compared to that obtained under four (CTFD) irrigation treatment on an average basis (Table 4.14).

4.1.2.3 Water use efficiency

Water use efficiency (WUE) is the yield (Y) of marketable crop produced per unit of water used in evapotranspiration (E_T). Therefore, $WUE = Y/E_T$. If yield were completely independent of E_T , any factor which caused an increase of yield, or a decrease of E_T , would have a favourable effect on WUE. If yield were proportional to E_T , water use efficiency would be constant. Actually, Y and E_T are not independent of each other. Both Y and E_T can be influenced, either independently or differentially, by crop management and environment. Crop yield is also greatly dependent on moisture regime, the more water available to the crop, the higher the yields will generally be. The greater water supply

will, however, increase E_T . In the present investigation, greater water supply through four irrigations (CTFD) recorded maximum evapotranspiration (331 mm) but the yield was less (29.78 q/ha) than the maximum yield (30.29 q/ha) recorded under TF irrigation treatment (Table 4.12). So WUE (8.92 kg/ha/mm) of CTFD treatment was not maximum (Table 4.15). WUE was maximum (11.05 kg/ha/mm) under rainfed treatment. This was mainly because of lowest evapotranspiration (225.2 mm) under rainfed treatment. TF irrigation treatment which recorded maximum grain yield gave 10.12 kg/ha/mm WUE on an average basis which was higher than WUE of CT and CF treatments in all years and on average basis (Table 4.15). Considering yield and water use efficiency, irrigation at tillering and flowering stages was found beneficial for wheat grown under North Bengal condition.

Table 4.15 Water use efficiency (kg/mm) of wheat as influenced by different irrigation treatments

Irrigation at stage		1979-80	1980-81	1981-82	Average
C	Y (kg/ha)	2550	2790	2670	2670
	E_T (mm/day)	269.5	274.5	264.2	269.4
	E (kg/mm)	9.46	10.16	10.10	9.91
T	Y (kg/ha)	2660	2870	2760	2763
	E_T (mm/day)	266.4	271.3	274.7	270.8
	E (kg/mm)	9.98	10.58	10.04	10.20

Table contd.....

Irrigation at stage		1979-80	1980-81	1981-82	Average
F	Y (kg/ha)	2590	2820	2700	2703
	E _T (mm/day)	243.6	285.4	249.0	259.3
	E (kg/mm)	10.63	9.88	10.84	10.42
D	Y (kg/ha)	2550	2740	2640	2643
	E _T (mm/day)	250.8	262.2	249.4	254.1
	E (kg/mm)	10.17	10.45	10.58	10.40
CT	Y (kg/ha)	2790	2920	3030	2913
	E _T (mm/day)	309.1	310.2	292.4	303.9
	E (kg/mm)	9.03	9.41	10.36	9.58
CF	Y (kg/ha)	2880	2940	3130	2983.0
	E _T (mm/day)	289.1	303.4	299.7	297.4
	E (kg/mm)	9.96	9.69	10.44	10.03
CD	Y (kg/ha)	2810	2800	2990	2867
	E _T (mm/day)	288.5	302.8	301.0	297.4
	E (kg/mm)	9.74	9.25	9.93	9.64
TF	Y (kg/ha)	2880	2930	3190	3000
	E _T (mm/day)	289.2	306.6	293.5	296.4
	E (kg/mm)	9.96	9.55	10.87	10.12

Table contd.....

Irrigation at stage		1979-80	1980-81	1981-82	Average
TD	Y (kg/ha)	2760	2870	2940	2856
	E _T (mm/day)	287.1	309.6	284.3	293.6
	E (kg/mm)	9.61	9.27	10.34	9.73
FD	Y (kg/ha)	2700	2840	2990	2843
	E _T (mm/day)	264.3	289.1	271.2	274.8
	E (kg/mm)	10.22	9.82	11.02	10.34
CTF	Y (kg/ha)	2850	2940	3170	2987
	E _T (mm/day)	322.0	347.7	310.0	326.5
	E (kg/mm)	8.85	8.45	10.22	9.15
CFD	Y (kg/ha)	2880	2950	3160	2997
	E _T (mm/day)	302.4	326.5	313.2	314.0
	E (kg/mm)	9.52	9.03	10.09	9.54
CTD	Y (kg/ha)	2840	2900	3150	2963
	E _T (mm/day)	315.8	322.7	309.5	316.0
	E (kg/mm)	8.99	8.99	10.17	9.38
TFD	Y (kg/ha)	2850	2850	3150	2950
	E _T (mm/day)	297.8	321.4	312.3	310.5
	E (kg/mm)	9.57	8.87	10.09	9.50

Table contd.....

Irrigation at stage		1979-80	1980-81	1981-82	Average
CTFD	Y (kg/ha)	2840	2900	3120	2953
	E _T (mm/day)	322.4	340.8	329.9	331.0
	E (kg/mm)	8.81	8.51	9.46	8.92
R	Y (kg/ha)	2440	2500	2530	2490
	E _T (mm/day)	228.4	237.7	209.7	225.2
	E (kg/mm)	10.68	10.51	12.06	11.05

Y = Yield; E_T = Evapotranspiration; E = WUE

4.2 Effect of micronutrients and soil amendments

4.2.1 Yield and yield attributes

4.2.1.1 Height of the plant

Application of micronutrients had no significant effect on height of the plant in different years as well as in pooled data (Table 4.16).

Table 4.16 Effect of micronutrients on height of the plant

Treatments	Height of the plant (cm)		
	1979-80	1980-81	Pooled
Control	101.1	101.3	101.2
Zinc	101.4	102.1	101.7
Boron	101.6	103.2	102.0
Molybdenum	101.3	102.4	101.8
SEm ±	0.42	0.47	0.37
C.D. 5%	N.S.	N.S.	N.S.

While there was a trend of increase in height of plant with the application of dolomite in all years and pooled data, the effect of soil amendment was not significant (Table 4.17).

Table 4.17 Effect of soil amendments on height of the plant

Treatment	Height of the plant (cm)		
	1979-80	1980-81	Pooled
Control	101.3	102.3	101.8
Lime	101.2	102.0	101.6
Dolomite	101.6	102.5	102.0
S Em $\pm$	0.36	0.41	0.24
C.D. at 5%	N.S.	N.S.	N.S.

4.2.1.2 Dry matter accumulation

Dry matter accumulation was maximum with the application of boron which was significantly superior to zinc, molybdenum and control during three seasons and in pooled data (Table 4.18). Boron, zinc and molybdenum recorded significantly higher dry matter over control. This is in conformity with the findings reported by Ryakhovskaya et al. (1976) who observed increased dry matter accumulation in wheat due to the application of boron and zinc.

Table 4.18 Effect of micronutrients on dry matter accumulation

Treatment	Dry matter accumulation (q/ha)			
	1979-80	1980-81	1981-82	Pooled
Control	43.18	43.85	44.27	43.77
Lime	48.42	49.65	49.44	49.17
Boron	70.06	73.26	73.67	72.3
Molybdenum	51.36	53.23	53.40	52.66
S Em $\pm$	0.80	0.67	0.62	0.50
C.D. at 5%	2.29	1.92	1.77	1.42

Soil amendment significantly increased dry matter accumulation during three seasons as well as in pooled data (Table 4.19). Dolomite recorded maximum dry matter which was at par with lime during 1979-80 and in pooled data. However, lime application failed and increase dry matter significantly over control in 1979-80 and pooled data.

Table 4.19 Effect of soil amendments on dry matter accumulation

Treatment	Dry matter accumulation (q/ha)			
	1979-80	1980-81	1981-82	Pooled
Control	52.04	52.20	52.25	52.16
Lime	53.09	55.25	55.57	54.63
Dolomite	54.63	57.54	57.76	56.64
S Em $\pm$	.69	0.58	0.54	1.06
C.D. at 5%	1.97	1.66	1.54	3.17

Interaction between micronutrients and soil amendments was significant during 1979-80 (Appendix-II). Applications of micronutrients with or without soil amendments significantly increased dry matter accumulation over control (Table 4.20). Maximum dry matter accumulation was observed with boron followed by molybdenum in presence and absence of soil amendments. Dolomite in combination with boron produced highest dry matter of wheat.

Table 4.20 Interaction between micronutrients and soil amendments on dry matter accumulation during 1979-80

Micronutrients	Soil amendments		
	Control	Lime	Dolomite
Control	42.13	43.05	43.38
Zinc	47.19	48.56	49.50
Boron	68.90	70.02	71.27
Molybdenum	49.97	50.72	53.39
S.E.m ±	1.38	C.D. at 5%	3.95

Interaction effect of micronutrients with soil amendments on dry matter accumulation was found significant during 1981-82 (Appendix-II). Application of dolomite in combination with either zinc or boron recorded significantly higher dry matter over control and lime treated plots (Table 4.21). Dolomite and lime in presence of molybdenum had no effect on dry matter accumulation. Zinc or boron in combination with lime increased dry matter over control.

Table 4.21 Interaction between micronutrients and soil amendments on dry matter accumulation during 1981-82

Micronutrients	Soil amendments		
	Control	Lime	Dolomite
Control	43.20	44.56	45.04
Zinc	45.60	49.62	53.11
Boron	67.75	75.02	78.24
Molybdenum	52.47	53.08	54.64
S. Em $\pm$	1.07	C.D. at 5%	3.06

4.2.1.3 Tillering pattern

4.2.1.3.1 Number of total tillers

Micronutrients significantly increased the number of total tillers over control during two seasons and in pooled data (Appendix-II and III). Among the micronutrients, boron was found to exert its profound influence on the production of total tillers followed by molybdenum and zinc (Table 4.22). Boron produced significantly higher number of total tillers over control, zinc and molybdenum. However, zinc and molybdenum being at par was significantly superior to control. Beneficial effect of micronutrient zinc to increase total tillers of wheat was reported by Samboor-naraman et al. (1968) and Patil (1979).

Table 4.22 Effect of micronutrients on number of total tillers

Treatments	Number of total tillers		
	1979-80	1980-81	Pooled
Control	71.83	73.16	72.50
Zinc	73.08	75.25	74.16
Boron	76.08	80.83	78.45
Molybdenum	73.75	75.83	74.79
S.E.m $\pm$	0.33	0.40	0.29
C.D. at 5%	0.94	1.14	0.84

Soil amendments were found to have significant effect on total tillers of wheat during 1979-80 and 1980-81 (Appendix II). Lime and dolomite being at per significantly increased total tillers over control (Table 4.23).

Table 4.23 Effect of soil amendments on number of total tillers

Treatment	Number of total tillers		
	1979-80	1980-81	Pooled
Control	73.00	75.43	74.21
Lime	74.31	76.81	75.56
Dolomite	73.75	76.56	75.15
S.E.m $\pm$	0.29	0.35	1.16
C.D. at 5%	0.83	1.00	N.S.

4.2.1.3.2 Number of effective tillers

Micronutrients significantly increased the number of effective tillers during both the years and in pooled data (Appendix II and III). The number of effective tillers was maximum with the application of boron which was superior to zinc and molybdenum (Table 4.24). However, zinc and molybdenum were at par and were significantly superior to control. This confirms the findings reported by Patil (1979) who observed the favourable influence of zinc on the yield attributes of wheat.

Table 4.24 Effect of micronutrients on number of effective tillers

Treatment	Number of effective tillers		
	1979-80	1980-81	Pooled
Control	63.42	64.33	63.87
Zinc	67.66	69.08	68.37
Boron	75.16	79.00	77.08
Molybdenum	68.67	70.25	69.45
S.Em $\pm$	0.92	0.72	0.63
C.D. at 5%	2.63	2.06	1.79

Effect of soil amendments on the production of effective tiller was found significant in two years and pooled data (Appendix-II and III). Lime significantly increased effective tiller

over control except during 1979-80 (Table 4.25). Maximum number of effective tiller was observed with dolomite which was significantly superior to control and lime except during 1979-80 when lime and dolomite were at par.

Table 4.25 Effect of soil amendments on number of effective tillers

Treatment	Number of effective tillers		
	1979-80	1980-81	Pooled
Control	67.12	68.25	67.68
Lime	68.44	70.87	69.65
Dolomite	70.62	72.87	71.75
S.Em $\pm$	0.80	0.62	0.48
C.D. at 5%	2.29	1.77	1.49

4.2.1.4 Length of ear

Micronutrients significantly increased the length of ear of wheat in both the years and in pooled data (Appendix-II and III). Boron produced longest ear which was significantly superior to that obtained with either zinc or molybdenum (Table 4.26) or control. However, there was no significant difference in ear length between zinc and boron during 1980-81 only. Increase in yield components of wheat due to an application of zinc was also reported by Patil (1979).

Table 4.26 Effect of micronutrients on length of ear

Treatment	Length of ear		
	1979-80	1980-81	Pooled
Control	9.81	10.10	9.87
Zinc	9.97	10.19	10.04
Boron	10.39	10.35	10.42
Molybdenum	10.24	10.10	10.24
S.Em $\pm$	0.05	0.06	0.03
C.D. at 5%	0.14	0.17	0.08

Soil amendments significantly increased the length of ear of wheat during both the years and in pooled data (Appendix-II and III). Lime and dolomite were at par, but these amendments were superior to control (Table 4.27).

Table 4.27 Effect of soil amendments on length of ear

Treatment	Length of ear		
	1979-80	1980-81	Pooled
Control	9.96	10.07	10.01
Lime	10.14	10.29	10.21
Dolomite	10.20	10.19	10.19
S.Em $\pm$	0.04	0.05	0.05
C.D. at 5%	0.11	0.14	0.16

4.2.1.5 Number of grains per ear

Micronutrients played a significant role in increasing setting of grains in the ear during both the years as well as in pooled data (Appendix-II and III). Zinc, boron and molybdenum significantly increased the number of grains per ear over control (Table 4.28). The effect was well pronounced with the application of boron which increased the number of grains per ear to 37.9 from 10.0 in control on an average basis, the increase was in the order of 380 per cent with boron over control. Poor grain setting in wheat due to boron deficiency in soil was observed by Singh et al. (1976) who observed increased grain setting with application of 22.4 kg borax/ha in North Bihar soil. Sharma and Kumar (1971) reported an increase in the number of grains per ear due to the foliar application of zinc to wheat.

Table 4.28 Effect of micronutrients on number of grains per ear

Treatment	Number of grains per ear		
	1979-80	1980-81	Pooled
Control	9.75	10.33	10.04
Zinc	13.08	13.75	13.41
Boron	36.91	39.00	37.95
Molybdenum	15.66	16.75	16.20
S.Em $\pm$	0.45	0.42	0.93
C.D. at 5%	1.29	1.20	2.66

Application of soil amendments significantly increased the number of grains per ear (Appendix-II) over control. The number of grains was maximum with dolomite which recorded higher grain number over lime and lime in turn recorded more grain number over control during two seasons and in pooled data (Table 4.29).

Table 4.29 Effect of soil amendments on number of grains per ear

Treatment	1979-80	1980-81	Pooled
Control	17.31	18.00	17.65
Lime	18.93	20.25	19.59
Dolomite	20.31	21.62	20.96
S.Em $\pm$	0.39	0.37	0.38
C.D. at 5%	1.12	1.06	1.16

4.2.1.6 Thousand grain weight

Application of zinc, boron and molybdenum significantly increased the weight of 1000 grains over control (Table 4.30). Maximum 1000 grain weight was observed with boron which was significantly more than that recorded under zinc and molybdenum. The increase in the thousand grain weight on an average basis over control was in the order of 1.55, 7.62 and 2.58 gm with zinc, boron and molybdenum respectively. Increase in 1000 grain

weight due to the application of zinc was also reported by Sharma and Kumar (1971) and Bhardwaj et al. (1979) and due to the application of boron by Ahmed et al. (1979).

Table 4.30 Effect of micronutrients on weight of 1000 grains

Treatments	Weight of 1000 grains (gm)		
	1979-80	1980-81	Pooled
Control	33.87	33.92	33.89
Zinc	35.32	35.56	35.44
Boron	41.32	41.70	41.51
Molybdenum	36.47	36.48	36.47
S.E.m $\pm$	0.37	0.30	0.30
C.D. at 5%	1.06	0.86	0.86

Effect of soil amendments on 1000 grain weight was significant in both the years and in pooled data (Table 4.31). Dolomite and lime being at par significantly increased 1000 grain weight over control except during 1980-81 when lime did not increase the 1000 grain weight significantly over control.

Table 4.31 Effect of soil amendments on weight of 1000 grains

Treatment	Weight of 1000 grains (gm)		
	1979-80	1980-81	Pooled
Control	36.01	36.32	36.16
Lime	37.05	37.05	37.05
Dolomite	37.16	37.38	37.27
S.Em $\pm$	0.32	0.26	0.22
C.D. at 5%	0.91	0.74	0.67

Interaction between micronutrients and soil amendments on the weight of 1000 grains was significant in pooled data (Appendix-III). Boron with or without soil amendments significantly increased 1000 grain weight over control, zinc and molybdenum (Table 4.32). In presence of soil amendments, zinc and molybdenum being at par were superior to control. Effect of soil amendments was not significant in case of boron and molybdenum, whereas it was significant in case of zinc.

Table 4.32 Effect of interaction between micronutrients and soil amendments on weight of 1000 grains in pooled data

Micronutrients	Weight of 1000 grains (gm)		
	Control	Soil amendment Lime	Dolomite
Control	32.67	34.71	34.30
Zinc	33.73	36.50	36.08
Boron	41.30	41.50	41.75
Molybdenum	36.95	35.51	36.96
S.Em $\pm$	0.53	C.D. at 5%	1.50

4.2.1.7 Grain yield

The experimental field, light-textured acidic soil (Table 3.1a) and is situated in a high rainfall (above 3000 mm) area. This condition favours high rate of leaching of soluble micronutrients like zinc, boron and molybdenum from soil and so the content of these micronutrients is low (Table 3.1 b) in the soil under investigation. Hence the application of zinc, boron and molybdenum to the soil was found to exert a favourable influence on the yield attributing characters of wheat. The number of effective tillers (Table 4.24), length of ear (Table 4.26), number of grains per ear (Table 4.28) and 1000 grain weight (Table 4.30) were significantly increased with the application of zinc, boron and molybdenum. The favourable influence of micronutrients on the yield attributes was reflected on the grain yield of wheat. Micronutrients increased significantly grain yield of wheat over control during three seasons and in pooled data (Table 4.33). Boron produced significantly more grain yield over zinc and molybdenum and molybdenum recorded higher grain yield over zinc. The increase in yield over control on an average basis was 19.70, 5.19 and 2.79 q/ha with boron, molybdenum and zinc respectively. Increase in grain yield of wheat was also observed by Singh et al. (1976), Singh and Singh (1976) and Ahmed et al. (1979) due to the application of boron, by Grewal et al. (1967), Kurchania et al. (1969), Chavan et al. (1972), Shinde et al. (1980) and Sharma and Das (1982) due to an application of molybdenum, by Kanwar (1964),

Randhawa et al. (1970), Bhardwaj et al. (1979), Prasad et al. (1981) and Sharma and Das (1982) due to the application of zinc.

Table 4.33 Effect of micronutrients on grain yield

Treatment	Grain yield (q/ha)			
	1979-80	1980-81	1981-82	Pooled
Control	7.41	8.34	9.03	8.26
Zinc	10.50	11.45	11.21	11.05
Boron	26.96	28.29	28.63	27.96
Molybdenum	12.65	13.62	14.08	13.45
S.Em $\pm$	0.31	0.28	0.26	0.22
C.D. at 5%	0.89	0.80	0.74	0.62

Application of amendments to acid soil enhances the availability and plant uptake of some of the nutrients such as Ca, Mg, phosphorus and molybdenum; at the same time reduces the concentration and toxic effect of iron, aluminium and manganese and stimulates the growth of soil microorganisms. It is thus considered as a beneficial practice for increasing crop production in acid soils. Soil of the experimental field is acidic in nature (Table 3.1b). Application of lime and dolomite to such soil was found beneficial for the growth and yield of wheat.

Application of amendments significantly increased the grain yield over control during three seasons and in pooled

data (Table 4.34). This was mainly because of the increase in the yield attributes like number of effective tillers (Table 4.25), length of ear (Table 4.27), number of grains per ear (Table 4.29) and 1000 grain weight (Table 4.31) due to the application of soil amendments. Dolomite produced higher grain yield over lime, but the difference in yield between lime and dolomite did not reach the level of significance during 1979-80 and 1981-82.

Beneficial effect of the application of amendments to acid soil was also observed by Mandal *et al.* (1955), Winkler (1979), Yostal and Vonek (1979), Boerin *et al.* (1981) and Siqueira (1981) on wheat by Hourigsu *et al.* (1961) and Ross *et al.* (1964) on sorghum and alfalfa, by MacLean and co-workers (1972) on lucerne and barley, by Amarasiri and Olsen (1973) on millet, by Tamboli and Tulsi (1967) on rice and Tanaka *et al.* (1970) on onion.

Table 4.34 Effect of soil amendments on grain yield

Treatments	Grain yield (q/ha)			
	1979-80	1980-81	1981-82	Pooled
Control	13.18	13.81	14.15	13.71
Lime	14.58	15.81	16.06	15.48
Dolomite	15.40	16.66	17.02	16.36
S.E.m $\pm$	0.36	0.32	0.30	0.22
C.D. at 5%	1.03	0.92	0.86	0.64

Interaction between micronutrients and amendments was significant on grain yield of wheat during 1981-82 (Table 4.35). Micronutrients with or without soil amendments significantly increased the grain yield over control. Among the micronutrients, maximum grain yield was observed with application of boron, next in order being molybdenum and zinc. Application of amendments to acid soil enhances the availability of nutrients like calcium, magnesium, phosphorus and molybdenum. This may be the possible reason of no response of application of molybdenum in presence of amendments over control (without amendments). Application of soil amendments in combination with zinc and boron significantly increased grain yield over no application of soil amendments.

Table 4.35 Interaction between micronutrients and soil amendments on grain yield during 1981-82

Micronutrients	Grain yield (q/ha) Soil amendments		
	Control	Lime	Dolomite
Control	7.17	9.38	10.54
Zinc	9.11	11.99	12.54
Boron	26.40	28.99	30.52
Molybdenum	13.90	13.87	14.49
S.E.m $\pm$	0.56	C. D. at 5%	1.14

Interaction effect of micronutrients and soil amendments was significant in pooled data (Table 4.36). Soil amendments significantly increased the grain yield over no application of amendment in presence of zinc and boron and in absence of micronutrients. Soil amendments did not increase grain yield in presence of molybdenum. This might be due to increased availability of molybdenum in presence of amendments. Application of micronutrients increased grain yield of wheat over control in both presence and absence of amendments.

Table 4.36 Interaction between micro-nutrients and soil amendments on grain yield in pooled data

Micronutrients	Grain yield (q/ha) Soil amendments		
	Control	Lime	Dolomite
Control	6.38	8.62	9.77
Zinc	9.08	11.66	12.42
Boron	26.27	28.34	29.27
Molybdenum	13.10	13.29	13.96
S.Em $\pm$	0.38	C.D. at 5%	1.08

4.2.1.8 Straw yield

Straw yield was significantly increased with the application of micronutrients in three seasons and in pooled data (Table 4.37). Micronutrients significantly increased the height of plant (Table 4.16) and number of total tillers (Table 4.22). Hence it

is quite logical that micronutrients would increase straw yield over control. Among micronutrients, boron recorded significantly higher straw yield over zinc and molybdenum and molybdenum in turn produced significantly higher straw yield over zinc.

Table 4.37 Effect of micronutrients on straw yield

Treatment	Straw yield (g/ha)			
	1979-80	1980-81	1981-82	Pooled
Control	33.19	33.17	33.79	33.38
Zinc	35.39	35.74	35.59	35.57
Boron	40.13	41.66	42.10	41.29
Molybdenum	36.17	36.96	37.15	36.75
S. Em $\pm$	0.48	0.35	0.34	0.29
C.D. at 5%	1.37	1.00	0.97	0.81

Soil amendments significantly increased straw yield over control in two out of three years and in pooled data (Table 4.38). This was mainly because of the increased plant height (Table 4.17) and number of total tillers (Table 4.23) due to the application of soil amendments. However, there was no significant difference in straw yield between lime and control in pooled data. Dolomite recorded higher straw yield over lime in three years as well as in pooled data.

Table 4.38 Effect of soil amendments on straw yield

Treatment	Straw yield (q/ha)			
	1979-80	1980-81	1981-82	Pooled
Control	36.02	35.70	35.50	35.74
Lime	35.89	36.78	37.03	36.57
Dolomite	36.76	38.17	38.93	37.95
S.Em $\pm$	0.42	0.31	0.30	0.28
C.D. at 5%	N.S.	0.89	0.86	0.82

4.3 Influence of boron and method of application

4.3.1 Yield and yield attributes

4.3.1.1 Height of the plant

Application of boron was found to influence the height of the wheat plant on an average basis (Table 4.39). Plant height was increased due to the application of boron upto 10 kg/ha. But higher level (30 kg/ha) decreased the plant height compared to 10 and 20 kg/ha.

Method of application of boron did not increase the height of the plant (Table 4.40).

Table 4.39 Effect of boron on height of the plant

Level of Boron (kg/ha)	Height of the plant (cm)		
	1981-82	1982-83	Pooled
0	100.91	101.00	100.95
10	102.16	101.83	102.00
20	102.33	102.50	102.41
30	101.00	100.91	100.95
S.Em $\pm$	0.44	0.45	0.31
C.D. at 5%	N.S.	N.S.	0.89

Table 4.40 Effect of method of application on height of the plant

Method of application	Height of the plant (cm)		
	1981-82	1982-83	Pooled
Full soil	101.62	101.81	101.71
Half soil + half foliar	101.87	101.50	101.68
Full foliar	101.31	101.37	101.34
S.Em $\pm$	0.38	0.39	0.30
C.D. at 5%	N.S.	N.S.	N.S.

4.3.1.2 Dry matter accumulation

Application of boron significantly increased the production of dry matter upto 20 kg/ha in all years as well as in pooled data (Table 4.41). Increasing the dose to 30 kg/ha increased dry matter production over control, but decreased it over 10 and 20 kg/ha levels. Beneficial effect of boron on dry matter production was thus observed upto 20 kg/ha level. Increase in dry matter accumulation in wheat due to the application of boron was also reported by Ryakhovskaya *et al.* (1976).

Table 4.41 Effect of boron on production of dry matter

Level of Boron (kg/ha)	Dry matter accumulation (g/ha)			
	1981-82	1982-83	1983-84	Pooled
0	47.04	47.62	45.69	46.85
10	62.84	69.62	69.01	67.16
20	68.04	69.89	69.61	69.17
30	65.01	65.34	60.50	63.61
S.Em $\pm$	0.84	0.66	0.78	0.52
C.D. at 5%	2.42	1.90	2.25	1.46

Boron application either full through soil or half through soil and half as foliar spray significantly increased the dry matter production over full foliar application of boron (Table 4.42). Full soil application was found as good as half soil and half foliar application.

Table 4.42 Effect of method of application of boron on production of dry matter

Method of application	Dry matter accumulation (g/ha)			
	1981-82	1982-83	1983-84	Pooled
Full soil	60.02	63.30	62.21	62.51
Half soil + half foliar	63.45	64.73	62.91	63.69
Full foliar	57.72	61.46	57.50	58.89
S.E.m $\pm$	0.73	0.57	0.67	0.46
C.D. at 5%	2.09	1.65	1.93	1.37

Interaction effect of level of boron and method of application on dry matter accumulation was found significant during 1981-82 (Table 4.43). Full soil application was found at par with half soil and half foliar method of application at almost all levels of boron. But half soil and half foliar method was at par with full foliar method only at lower level (10 kg borax/ha).

Interaction between level and method of application of boron was significant during 1982-83 also (Table 4.44). At almost all levels of boron, both the methods of application (half soil + half foliar and full foliar) were almost equal in respect to their dry matter production. Dry matter production was increased upto 20 kg/ha level when boron was applied full through soil or half through soil and half as foliar spray.

When boron was applied full through foliar dry matter production was increased at 10 kg/ha only and thereafter it was decreased significantly with increase in the level of boron.

Table 4.43 Effect of interaction between level of boron and method of application on dry matter (1981-82)

Level of Boron(kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Dry matter (q/ha)		
0	44.74	47.42	48.72
10	57.60	63.51	61.41
20	68.89	72.20	63.03
30	72.86	70.69	51.47
S.Em $\pm$	1.46	C.D. at 5%	4.20

Table 4.44 Effect of interaction between level of boron and method of application on dry matter (1982-83)

Level of Boron(kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Dry matter (q/ha)		
0	46.43	49.83	47.17
10	64.72	71.68	72.47
20	73.14	73.86	62.64
30	68.91	63.54	63.57
S.Em $\pm$	1.15	C.D. at 5%	3.31

Interaction between method of application and level of boron was significant during 1983-84 (Table 4.45). Application of boron increased the dry matter upto 20 kg/ha when it was applied full in soil or half in soil and other half through foliar spray (Table 4.45). Full foliar application increased the dry matter at 10 kg/ha and thereafter decreased it.

Table 4.45 Effect of interaction between level of boron and method of application on dry matter (1983-84)

Level of Boron(kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Dry matter (g/ha)		
0	46.10	45.60	45.36
10	64.54	71.07	71.43
20	73.14	74.49	61.20
30	69.04	60.46	52.00
S.Em $\pm$	1.35	C.D. at 5%	3.88

Interaction between level and method of application of boron was significant in pooled data (Table 4.46). With increase in the level of boron dry matter was found to increase up to 20 kg/ha applied full in soil or half in soil and half as foliar. When boron was applied full as foliar, the dry matter production was maximum at 10 kg/ha level, further increase in boron level decreased it.

Table 4.46 Effect of interaction between level of boron and method of application on dry matter (Pooled data)

Level of Boron(kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Dry matter (q/ha)		
0	45.76	47.62	47.16
10	62.28	68.75	70.43
20	71.72	73.51	62.29
30	70.27	64.89	55.68
S.Em $\pm$	0.90	C.D. at 5%	2.53

Interaction between level of boron and year was significant (Table 4.47). Irrespective of year, application of boron increased dry matter production over control. During 1981-82 significant increase in dry matter production was observed upto 20 kg/ha boron application, further increase in the dose of boron to 30 kg/ha, significantly decreased it. During 1982-83 and 1983-84, 10 kg and 20 kg being at par increased dry matter production over 30 kg/ha boron level.

Interaction among level of boron, method of application and year was significant (Table 4.48). Irrespective of method of application, boron significantly increased the dry matter over control in all years. When boron was applied full in soil significant increase in dry matter production was recorded upto

Table 4.47 Effect of interaction between level of boron and year on dry matter

Level of Boron (kg/ha)	Dry matter (q/ha)		
	1981-82	1982-83	1983-84
0	47.04	47.81	45.69
10	62.84	69.62	69.01
20	68.04	69.88	69.61
30	65.00	65.34	60.50
S.Em $\pm$	0.90	C.D. at 5%	2.53

20 kg/ha boron level, and increase of dose to 30 kg/ha boron had no effect over 20 kg/ha boron in the first two years, but decreased it during 1983-84. When boron was applied half in soil and half through foliar 20 kg/ha boron recorded maximum dry matter production, but this dose was at par with 30 kg/ha during 1981-82 and with 10 kg/ha during last two years. Application of 30 kg/ha boron half through soil + half as foliar decreased dry matter over 20 kg/ha boron during 1982-83 and 1983-84. Foliar application of boron increased dry matter upto 10 kg/ha and then decreased it significantly.

Table 4.48 Effect of interaction among level of boron, method of application and year on dry matter

Method of application	Level of Boron (kg/ha)	Dry matter (g/ha)		
		1981-82	1982-83	1983-84
Full soil	0	44.74	46.43	46.10
	10	57.59	64.72	64.54
	20	68.88	73.13	73.14
	30	72.85	68.91	67.04
Half soil + half foliar	0	47.42	49.83	45.60
	10	63.51	71.67	71.07
	20	72.20	73.86	74.49
	30	70.69	63.54	60.46
Full foliar	0	48.97	47.16	45.36
	10	69.41	72.46	71.43
	20	63.03	62.64	61.20
	30	51.47	53.57	52.00
S.E.m $\pm$		1.55	C.D. at 5%	4.35

4.3.1.3 Tillering pattern

4.3.1.3.1 Number of total tillers

Number of total tillers was significantly increased with boron application. Maximum tiller was observed at 20 kg/ha which was at par with 10 kg/ha in all years (Table 4.49). 30 kg/ha boron level decreased total tillers compared to 20 kg/ha boron.

Table 4.49 Effect of boron on number of total tillers

Level of boron(kg/ha)	Number of total tillers		
	1981-82	1982-83	Pooled
0	76.75	76.42	76.58
10	79.00	79.75	79.37
20	80.33	80.25	80.29
30	78.25	78.00	78.12
S.Em $\pm$	0.51	0.44	0.77
C.D. at 5%	1.47	1.26	2.19

Method of boron application did not influence the number of total tillers (Table 4.50).

Table 4.50 Effect of method of application of boron on number of total tillers

Method of application	Number of total tillers		
	1981-82	1982-83	Pooled
Full soil	78.62	79.00	78.81
Half soil + half foliar	79.06	78.69	78.87
Full foliar	78.06	78.12	78.09
S.Em $\pm$	0.44	0.38	0.39
C.D. at 5%	N.S.	N.S.	N.S.

Interaction between level of boron and its method of application was significant during 1981-82 (Table 4.51). Full soil application of boron increased total tillers upto 10 kg/ha level. However, there was no significant difference in total tillers among 10, 20 and 30 kg/ha boron levels. 30 kg/ha boron produced maximum tillers but it was at par with 10 and 20 kg/ha when boron was applied half in soil and half through foliar. Highest level of boron (30 kg/ha) when applied through foliage was found detrimental for production of total tillers, This dose of boron decreased total tillers over other levels of boron including control.

Table 4.51 Effect of interaction between levels of boron and method of application on total tillers (1981-82)

Level of boron kg/ha	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number total tillers		
0	75.50	77.00	77.75
10	78.50	78.75	79.75
20	80.50	80.00	80.50
30	80.00	80.50	74.25
S.Em $\pm$	0.88	C. D. at 5%	2.53

Interaction between level of boron and the method of application was significant during 1982-83 (Table 4.52). While

full soil or full foliar application increased the total tillers upto 10 kg/ha boron, half soil and half foliar application increased it upto 20 kg/ha boron. Highest level (30 kg/ha) of boron had no extra advantage over 20 kg/ha boron applied full in soil or half in soil and half as foliar, but it had deleterious effect of reducing total tillers over all other levels of boron including control when it was applied full as spray. Maximum total tillers were observed with 20 kg/ha boron applied half in soil and half through foliage.

Table 4.52 Effect of interaction between levels of boron and method of application on total tillers (1982-83)

Level of boron kg/ha	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of total tillers		
0	76.25	75.00	78.00
10	79.00	78.50	81.75
20	80.25	81.50	79.00
30	80.50	79.75	73.75
S.Em $\pm$	0.76	C.D. at 5%	2.18

Interaction between level of boron and method of its application was significant in pooled data (Table 4.53). 20 kg/ha boron applied either full in soil or half in soil and half as spray, produced maximum number of total tillers, but it was

at par with 10 and 30 kg/ha levels. When boron was applied as foliar spray, 30 kg/ha boron decreased total tillers over other levels of boron, but there was no significant difference among 0, 10 and 20 kg levels.

Table 4.53 Effect of interaction between levels of boron and method of application on total tiller (1981-83)

Level of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of total tillers		
0	75.87	76.00	77.87
10	78.75	78.62	80.75
20	80.37	80.75	79.75
30	80.25	80.12	74.00
S.E.m $\pm$	1.33	C.D. at 5%	3.78

4.3.1.3.2 Number of effective tillers

Boron application significantly increased the number of effective tillers in both years as well as in pooled data (Table 4.54). Maximum number of effective tillers was observed at 20 kg/ha boron which was at par with 10 kg/ha boron, but it produced significantly more effective tillers over control and 30 kg/ha boron.

Table 4.54 Effect of level of boron on number of effective tillers

Level of boron(kg/ha)	Number of effective tillers		
	1981-82	1982-83	Pooled
0	61.25	62.83	62.04
10	71.08	72.66	71.87
20	72.33	72.75	72.54
30	66.58	65.33	65.95
S.Em $\pm$	0.78	0.47	0.47
C.D. at 5%	2.25	1.35	1.33

Number of effective tillers was significantly influenced by the method of boron application (Table 4.55). Half soil and half foliar method of boron application recorded maximum number of effective tillers which was significantly more than that recorded by full soil or full foliar method of application.

Table 4.55 Effect of method of application of boron on number of effective tillers

Method of application	Number of effective tillers		
	1981-82	1982-83	Pooled
Full soil	69.06	69.62	69.34
Half soil + half foliar	70.87	71.81	71.34
Full foliar	63.50	63.75	63.62
S.Em $\pm$	0.67	0.41	0.58
C.D. at 5%	1.93	1.18	1.79

Interaction between level of boron and its method of application was significant during 1981-82 (Table 4.56). When boron was applied full in soil, 30 kg level gave maximum number of effective tillers which was at par with that obtained at 20 kg level. When it was applied full as spray, 10 kg produced maximum tillers but it was at par with 20 kg/ha level. 30 kg/ha as foliar spray was detrimental for production of effective tiller. It was observed that this dose (30 kg) decreased number of effective tillers over control. This trend was also observed in case of total tillers (Table 4.51). However, 10 kg/ha boron applied half in soil and half as foliar spray recorded maximum number of effective tillers but it was at par with 20 and 30 kg/ha.

Table 4.56 Effect of interaction between levels of boron and method of application on number of effective tillers (1981-82)

Levels of boron (kg/ha)	Methods of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of effective tillers		
0	62.75	60.75	60.25
10	65.75	75.50	72.00
20	73.50	74.50	69.00
30	74.25	72.75	52.75
S.Em $\pm$	1.35	C.D. at 5%	3.89

Interaction between level of boron and method of its application was significant during 1982-83 (Table 4.57). Full soil application of boron increased effective tiller upto 20 kg/ha level, thereafter effective tiller was decreased. Significant increase in the number of effective tillers was observed upto 10 kg/ha level when boron was applied either full as spray or half in soil and half as spray.

Table 4.57 Effect of interaction between levels of boron and method of application on number of effective tillers (1982-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of effective tillers		
0	62.25	63.75	62.50
10	67.75	75.75	74.50
20	76.25	76.25	65.75
30	72.25	71.50	52.25
S.Em $\pm$	0.82	C.D. at 5%	2.36

Interaction between level of boron and method of its application was significant in pooled data (Table 4.58). Number of effective tillers was increased significantly at 10 kg/ha level when boron was applied full as spray or as half soil + half spray and upto 20 kg/ha level when it was applied full in

soil. However, maximum number of effective tillers was observed at 10 kg/ha boron level applied half in soil and half as spray.

Table 4.58 Effect of interaction between levels of boron and method of application on number of effective tillers (1981-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of effective tillers		
0	62.50	62.25	61.37
10	66.75	75.62	73.25
20	74.87	75.37	67.37
30	73.25	72.12	52.50
S.E.m $\pm$	0.81	C.D. at 5%	2.30

4.3.1.4 Length of ear

With each increment in the level of boron, length of ear was significantly increased upto 20 kg/ha level, thereafter it was decreased significantly in all years as well as in pooled data (Table 4.59).

Method of boron application significantly increased the ear length in both the years and in pooled data (Table 4.60). Half soil and half foliar method of application of boron recorded significantly more length of ear over other methods of application.

Table 4.59 Effect of different level of boron on length of ear

Level of boron (kg/ha)	Length of ear (cms)		
	1981-82	1982-83	Pooled
0	9.52	9.73	9.62
10	10.16	10.36	10.26
20	10.46	10.53	10.49
30	10.23	10.22	10.22
S.Em $\pm$	0.05	0.06	0.04
C.D. at 5%	0.14	0.17	0.11

Table 4.60 Effect of method of application on length of ear

Method of application	Length of ear (cms)		
	1981-82	1982-83	Pooled
Full soil	10.07	10.10	10.08
Half soil + half foliar	10.19	10.35	10.27
Full foliar	10.02	10.19	10.10
S.Em $\pm$	0.04	0.05	0.05
C.D. at 5%	0.12	0.14	0.15

Interaction between level of boron and its method of application was significant during 1981-82 (Table 4.61). Significant increase in the length of ear was observed upto 20 kg/ha level when boron was applied full in soil or half in soil and half as spray. Full foliar application of boron increased the ear length upto 10 kg/ha, thereafter significant decrease in the length of ear was observed with the increase in boron level.

Table 4.61 Effect of interaction between levels of boron and method of application on length of ear (1981-82)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Length of ear (cms)		
0	9.47	9.52	9.57
10	9.95	9.97	10.57
20	10.37	10.72	10.27
30	10.47	10.55	9.67
S.E.m $\pm$	0.09	C.D. at 5%	0.26

Interaction between level of boron and method of its application was significant during 1982-83 (Table 4.62). While full soil application increased the length of ear upto 20 kg/ha

boron level, half soil and half spray and full spray application of boron increased it upto 10 kg/ha boron only. Full spray at higher level of boron (30 kg/ha) was found harmful and this dose significantly reduced ear length over control.

Table 4.62 Effect of interaction between levels of boron and method of application on length of ear (1982-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Length of ear (cms)		
0	9.60	9.80	9.77
10	9.90	10.57	10.62
20	10.52	10.60	10.45
30	10.37	10.37	9.92
S.Em $\pm$	0.10	C. D. at 5%	0.29

Interaction between level of boron and its method of application was significant in pooled data (Table 4.63). Significant increase in ear length was recorded upto 20 kg/ha level in full soil or in half soil + half foliar method of application of boron. When boron was applied full as spray ear length was increased upto 10 kg/ha level, thereafter it was decreased significantly.

Table 4.63 Effect of interaction between levels of boron and method of application on length of ear (1981-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Length of ear (cms)		
0	9.53	9.67	9.67
10	9.92	10.27	10.60
20	10.45	10.67	10.36
30	10.42	10.46	9.80
S.E.m $\pm$	0.07	C.D. at 5%	0.20

Interaction among level of boron, method of application and year was significant in pooled data (Table 4.64). Irrespective of level and method of boron application, there was practically no difference in ear length in two years. In both years, full soil application of boron increased the length of ear upto 20 kg/ha. Half soil and half foliar method of application recorded maximum length of ear at 20 kg/ha level which was at par with 30 kg/ha level during 1981-82 and 10 and 20 kg/ha level during 1982-83. Full foliar application of boron produced larger ear head at 10 kg/ha level in both years, but highest level (30 kg/ha) decreased the ear length.

Table 4.64 Effect of interaction amongst level of, boron, method of application and different year on length of ear

Method of application	Level of boron (kg/ha)	Length of ear (cms)	
		1981-82	1982-83
Full soil	0	9.47	9.60
	10	9.95	9.90
	20	10.37	10.52
	30	10.47	10.37
Half soil + Half foliar	0	9.52	9.82
	10	9.97	10.57
	20	10.72	10.62
	30	10.55	10.37
Full foliar	0	9.57	9.77
	10	10.57	10.62
	20	10.27	10.45
	30	9.67	9.92
S.E.m $\pm$		0.10	C.D. at 5% 0.20

4.3.1.5 Number of grains per ear

Effect of boron application on grain number followed the trend of ear length (Table 4.63). Significant increase in the number of grains per ear was observed upto 20 kg/ha boron

and thereafter a decline was noted in both years as well as in pooled data (Table 4.65). Poor grain setting due to boron deficiency in soil was reported by Singh et al. (1976). In the present experiment the soil is highly deficient in available boron (0.34 ppm boron), so grain number/ear was only 9.54 on an average basis in control. Boron application increased grain setting by 173, 243 and 207 percent at 10, 20 and 30 kg/ha level respectively over control in pooled data. Increase in the number of grains/ear with boron application was also observed by Oliver et al. (1974) and Ganguly (1979) in wheat.

Table 4.65 Effect of boron on number of grains per ear

Level of boron (kg/ha)	Number of grains per ear		
	1981-82	1982-83	Pooled
0	9.50	9.58	9.54
10	25.58	26.50	26.04
20	33.00	32.50	32.75
30	30.33	28.25	29.29
S.E.m $\pm$	0.31	0.96	0.52
C.D. at 5%	0.89	2.76	1.48

Method of application of boron did not influence the grain number per ear in any of the year or in pooled data (Table 4.66).

Table 4.66 Effect of method of application of boron on number of grains per ear

Method of application	Number of grains per ear		
	1981-82	1982-83	Pooled
Full soil	24.18	24.37	24.28
Half soil + half foliar	24.06	23.12	23.59
Full foliar	25.56	25.12	25.34
S.E.m $\pm$	0.27	0.83	0.57
C.D. at 5%	N.S.	N.S.	N.S.

Interaction between level of boron and method of its application was significant during 1981-82 (Table 4.67). Significant increase in grain setting was observed at 20 kg/ha boron applied full in soil or half in soil and half as spray and at 10 kg/ha boron applied full as foliar spray. 30 kg/ha boron decreased the grain number compared to 20 kg/ha boron applied full as spray or half in soil and half as spray.

Interaction between level of boron and its method of application was significant during 1982-83 (Table 4.68). With each increase in level of boron grain number was increased upto 20 kg/ha boron applied full in soil or half in soil and half as spray and upto 10 kg/ha boron applied full as spray.

Table 4.67 Effect of interaction between level of boron and method of application on number of grains per ear (1981-82)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of grains		
0	9.25	9.75	9.50
10	18.75	23.25	34.75
20	34.00	34.75	30.25
30	34.75	28.50	27.75
S.E.m $\pm$	0.54	C.D. at 5%	1.55

Table 4.68 Effect of interaction between level of boron and method of application on number of grains per ear (1982-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of grains		
0	10.00	9.25	9.30
10	21.00	24.00	34.50
20	33.25	34.50	29.75
30	33.25	24.75	26.75
S.E.m $\pm$	1.66	C.D. at 5%	4.78

Interaction between level of boron and method of application was significant in pooled data (Table 4.69). The effect of level and method of boron application on grain number followed the same trend as was observed in the interaction effect during 1981-82 (Table 4.67).

Table 4.69 Effect of interaction between level of boron and method of application on number of grains per ear (1981-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Number of grains		
0	9.62	9.50	9.50
10	18.87	23.62	34.62
20	33.62	34.62	30.00
30	34.00	26.62	27.25
S.E.m $\pm$	0.90	C.D. at 5%	2.56

4.3.1.6 Thousand grain weight

Boron increase the weight of thousand grain in both the years as well as in pooled data (Table 4.70). 20 kg/ha boron gave maximum weight of 1000 grains, but it was at par with 30 kg/ha in 1981-82 and in pooled data and with 10 and 30 kg/ha in 1982-83. The increase in 1000 grain weight at 20 kg/ha boron over control was 34, 34.6 and 35 per cent in 1981-82, 1982-83

and in pooled data respectively. This supports the findings reported by Ahmed et al. (1979) who observed average 1000 grain weight of 40.01 gm with no boron and 41.40 - 42.93 gm with 1 to 3 kg borax/ha.

Table 4.70 Effect of level of boron on weight of 1000 grains

Level of boron (kg/ha)	Weight of 1000 grains (gm)		
	1981-82	1982-83	Pooled
0	30.49	31.09	30.79
10	40.43	40.66	40.54
20	41.34	41.84	41.59
30	40.86	41.44	41.15
S.Em $\pm$	0.29	0.30	0.19
C.D. at 5%	0.84	0.86	0.54

Weight of 1000 grains was significantly influenced by method of boron application in 1981-82 only (Table 4.71). Half soil and half foliar method of application was found to increase the test weight of grain over full soil application. Though this trend was observed in 1982-83 and in pooled data the effect was nonsignificant.

Table 4.71 Effect of method of application of boron on weight of 1000 grains

Method of application	Weight of 1000 grains (gm)		
	1981-82	1982-83	Pooled
Full soil	37.83	38.37	38.1
Half soil + half foliar	38.85	39.15	39.00
Full foliar	38.15	38.76	38.45
S.E.m $\pm$	0.25	0.26	0.29
C.D. at 5%	0.73	N.S.	N.S.

Interaction between level of boron and its method of application was found significant in 1981-82 (Table 4.72). Irrespective of method of application, 20 and 30 kg/ha boron levels were at par. There was also no difference in test weights observed between 10 and 20 kg/ha boron applied either half soil and half foliar or full foliar. Test weight was significantly increased upto 20 kg/ha boron applied full in soil and upto 10 kg/ha boron applied either full as foliar or half as foliar and half in soil.

Interaction between level of boron and its method of application was significant during 1982-83 (Table 4.73). Significant increase in test weight was observed upto 20 kg/ha boron applied full in soil and upto 10 kg/ha boron applied either half soil and half foliar or full foliar.

Table 4.72 Effect of interaction between levels of boron and method of application on weight of 1000 grains (1981-82)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
Weight of 1000 grains (gms)			
0	30.85	31.05	29.57
10	37.20	42.32	41.77
20	41.80	41.30	40.92
30	41.47	40.75	40.35
S.E.m $\pm$	0.50	C.D. at 5%	1.45

Table 4.73 Effect of interaction between levels of boron and method of application on weight of 1000 grains (1982-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
Weight of 1000 grains (gms)			
0	30.95	31.32	31.00
10	38.45	42.10	41.42
20	42.17	41.85	41.50
30	41.90	41.32	41.10
S.E.m $\pm$	0.51	C.D. at 5%	1.47

Interaction between level of boron and method of its application was significant in pooled data (Table 4.74). Interaction effect on test weight in pooled data followed the trend observed in 1981-82 (Table 4.72).

Table 4.74 Effect of interaction between levels of boron and method of application on weight of 1000 grains (1981-83)

Levels of boron kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Weight of 1000 grains(gms)		
0	30.90	31.18	30.28
10	37.82	42.21	41.60
20	41.98	41.57	41.21
30	41.68	41.03	40.72
S.E.m $\pm$	0.34	C.D. at 5%	0.96

4.3.1.7 Grain yield

Grain yield was significantly influenced by boron application during all years and in pooled data (Table 4.75). With each increase in the dose of boron grain yield was significantly increase upto 20 kg/ha boron, thereafter a decline in grain yield was observed. 20 kg/ha boron produced maximum grain yield by increasing dry matter production (Table 4.41),

effective tillers (Table 4.54), length of ear (Table 4.59), grains per ear (Table 4.65) and 1000 grain weight (Table 4.70). The increase in yield at 20 kg/ha boron over control was 248, 225.6, 281, and 249 per cent. in 1981-82, 1982-83, 1983-84 and pooled data respectively. This is in conformity with the findings reported by earlier workers (Singh and Singh, 1976; Singh et al., 1976; Ryakhovskaya et al., 1976; Ganguly, 1979 and Ahmed et al., 1979) on wheat.

Table 4.75 Effect of level of boron on grain yield

Level of boron (kg/ha)	Grain yield (g/ha)			
	1981-82	1982-83	1983-84	Pooled
0	7.42	8.27	7.04	7.58
10	21.11	23.34	24.80	23.08
20	25.84	26.93	26.84	26.48
30	24.16	23.04	22.65	23.28
S.Em $\pm$	0.32	0.36	0.62	0.20
C.D. at 5%	0.92	1.04	1.78	0.56

Method of boron application significantly increased the grain yield of wheat in all years and pooled data (Table 4.76). Half soil and half foliar method of application of boron significantly increased the grain yield over other methods of its application, mainly due to higher number of

effective tillers (Table 4.55), and more weight of 1000 grains (Table 4.71) under this treatment.

Table 4.76 Effect of methods of application of boron on grain yield

Method of application	Grain yield (q/ha)			
	1981-82	1982-83	1983-84	Pooled
Full soil	19.32	19.95	20.20	19.82
Half soil + half foliar	20.42	21.58	21.38	21.12
Full foliar	19.16	19.66	19.42	19.41
S.Em $\pm$	0.28	0.31	0.53	0.19
C.D. at 5%	0.79	0.91	1.53	0.56

Interaction between level of boron and its method of application was significant during 1981-82 (Table 4.77). With each increment of the dose of boron, the grain yield was increased significantly upto 30 kg/ha boron applied full in soil. Half soil and half foliar application increased grain yield upto 20 kg/ha. When boron was applied full as foliar spray grain yield was increased upto 10 kg/ha boron, thereafter a decline was observed.

Table 4.77 Effect of interaction between level of boron and method of application on grain yield (1981-82)

Level of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Grain yield (q/ha)		
0	7.02	7.51	7.74
10	17.03	20.79	25.51
20	25.14	27.49	24.88
30	28.07	25.90	18.52
S.E.m $\pm$	0.55	C.D. at 5%	1.59

Interaction between level of boron and method of its application was found significant during 1982-83 (Table 4.78). Significant increase in grain yield was observed upto 20 kg/ha boron applied either full in soil or half in soil and half as spray and upto only 10 kg/ha boron applied full as spray.

Interaction between level of boron and its method of application was significant during 1983-84 (Table 4.79). Interaction effect on grain yield during 1983-84 followed the same trend as was observed during 1982-83 (Table 4.78).

Table 4.78 Interaction between level of boron and method of application on grain yield (1982-83)

Level of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Grain yield (q/ha)		
0	7.84	8.79	8.20
10	19.85	23.09	27.10
20	26.83	29.56	24.40
30	25.29	24.89	18.94
S.E.m $\pm$	0.63	C.D. at 5%	1.81

Table 4.79 Interaction between level of boron and method of application on grain yield (1983-84)

Level of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Grain yield (q/ha)		
0	6.74	7.00	7.39
10	22.10	25.08	27.22
20	27.54	29.03	23.94
30	24.40	24.40	19.15
S.E.m $\pm$	1.07	C.D. at 5%	3.08

Interaction between level of boron and its method of application was significant in pooled data (Table 4.80). At 10 kg/ha boron, grain yield was at its highest when applied full as spray. At 20 kg/ha boron, half soil and half foliar application recorded maximum grain yield. 30 kg/ha boron decreased the grain yield over 20 kg/boron when applied full as spray or half in soil and half as spray.

Table 4.80 Interaction between level of boron and method of application on grain yield (1981-84)

Level of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Grain yield (q/ha)		
0	7.20	7.76	7.77
10	19.65	22.98	26.61
20	26.50	28.69	24.40
30	25.92	25.06	18.87
S.Em $\pm$	0.35	C.D. at 5%	0.98

Interaction between level of boron and year was significant in pooled data (Table 4.81). Grain yield at 10 and 20 kg/ha boron was significantly more during second and third year over first year. This might be due to favourable residual effect of boron application in first year. At 30 kg/ha boron,

grain yield of second and third year was significantly reduced over first year. Higher level of boron application in first year left the residual effect of boron for next year. Application of 30 kg/ha boron coupled with its residual effect of previous years might have unfavourable effect on grain yield in subsequent years.

Table 4.81 Effect of interaction between levels of boron and year on grain yield

Level of boron (kg/ha)	Grain yield (g/ha)		
	1981-82	1982-83	1983-84
0	7.42	8.27	7.04
10	21.11	23.34	24.80
20	25.83	26.93	26.83
30	24.16	23.04	22.65
S.Em $\pm$	0.35	C.D. at 5%	0.98

Interaction among level of boron, method of its application and year was significant in pooled data (Table 4.82). When boron was applied full in soil, grain yield was at its maximum at 30 kg/ha level in first year and at 20 kg/ha level in second and third years. Half soil and half foliar method of application recorded maximum grain yield at 20 kg/ha level

in all years. At 10 kg/ha level grain yield was maximum when boron was applied full as spray irrespective of years.

Table 4.82 Interaction amongst level of boron, method of application and year on grain yield

Method of application	Level of boron (kg/ha)	Grain yield (q/ha)		
		1981-82	1982-83	1983-84
Full soil	0	7.02	7.84	6.74
	10	17.03	19.84	22.10
	20	25.13	26.83	27.53
	30	28.07	25.29	24.40
Half soil + half foliar	0	7.51	8.79	7.00
	10	20.79	23.09	25.07
	20	27.49	29.56	29.63
	30	25.90	24.88	24.40
Full foliar	0	7.73	8.19	7.39
	10	26.51	27.09	27.22
	20	24.88	24.44	23.94
	30	18.52	18.94	19.15
S.E.m $\pm$		0.60	C.D. at 5%	1.69

4.3.1.8 Response

Production function between level of boron and grain yield of wheat was studied. The relationship was quadratic in nature during all years and in pooled data. The functional relationship is described by the equations given in table 4.83 and depicted in Fig. 4.9. The optimum dose of boron in kilogram per hectare ranged from 21.1 to 22.5 for full soil application (M_1), 18.5 to 20.7 for half soil and half foliar application (M_2) and 15.4 to 15.5 for full foliar application (M_3) during different years with average values of 23.4, 19.4 and 19.6 kg boron per hectare for M_1 , M_2 and M_3 methods of boron application respectively.

Response to boron application over control was maximum (55 kg grain/kg boron) at 10 kg boron and decreased with increase in the level of boron (Table 4.84).

Economics of fertilizer application

Application of 10 kg/ha boron gave maximum benefit-cost ratio (Rs.15.50 per rupee invested on fertilizer) and it was minimum at 30 kg/ha boron (Table 4.85).

Table 4.83 Functional relationship between level of boron and grain yield of wheat during different years

Year	Regression equation	Optimum dose (kg/ha boron)
M_1 - Full soil application		
1981-82	$Y = 4.10 + 20.71x - 4.53x^2$	21.9
1982-83	$Y = 7.65 + 16.11x - 3.39x^2$	22.5
1983-84	$Y = 7.31 + 18.20x - 4.21x^2$	21.1
Pooled	$Y = 7.11 + 16.08x - 3.26x^2$	23.4
M_2 - Half soil and half foliar application		
1981-82	$Y = 7.88 + 17.04x - 3.72x^2$	20.7
1982-83	$Y = 8.62 + 19.70x - 4.74x^2$	19.0
1983-84	$Y = 7.27 + 22.66x - 5.68x^2$	18.5
Pooled	$Y = 7.77 + 19.89x - 4.41x^2$	19.4
M_3 - Full foliar application		
1981-82	$Y = 3.48 + 20.98x - 5.94x^2$	15.5
1982-83	$Y = 9.16 + 21.14x - 6.06x^2$	15.4
1983-84	$Y = 7.45 + 24.65x - 7.15x^2$	15.5
Pooled	$Y = 12.24 + 17.65x - 4.85x^2$	15.6

Where Y is the expected grain yield in quintal per hectare due to an application of 'x' unit of boron per hectare, where one unit is 10 kg boron per hectare

Price of wheat grain Rs. 180=00 per quintal

Price of (borax) Rs. 1500=00 per quintal

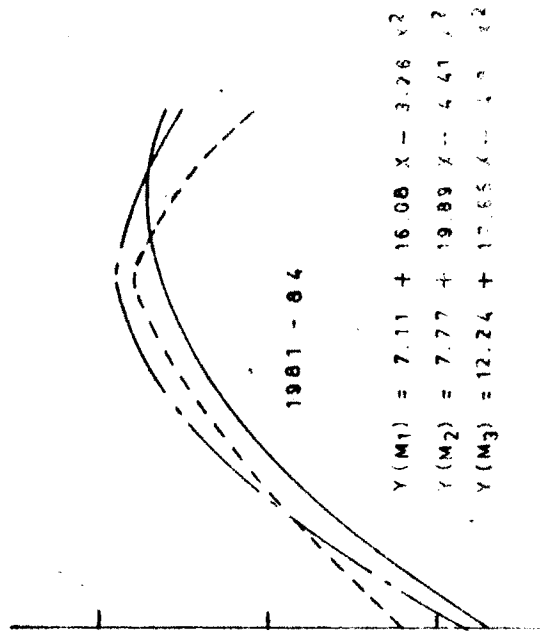
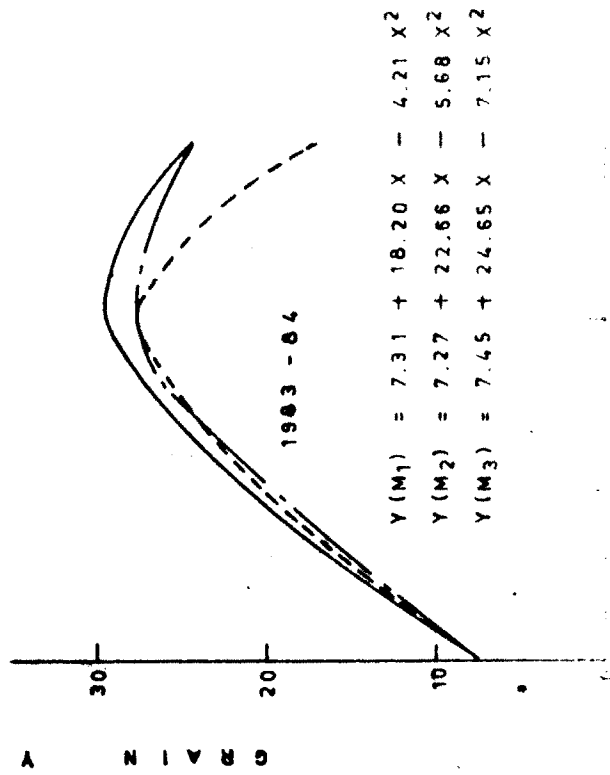
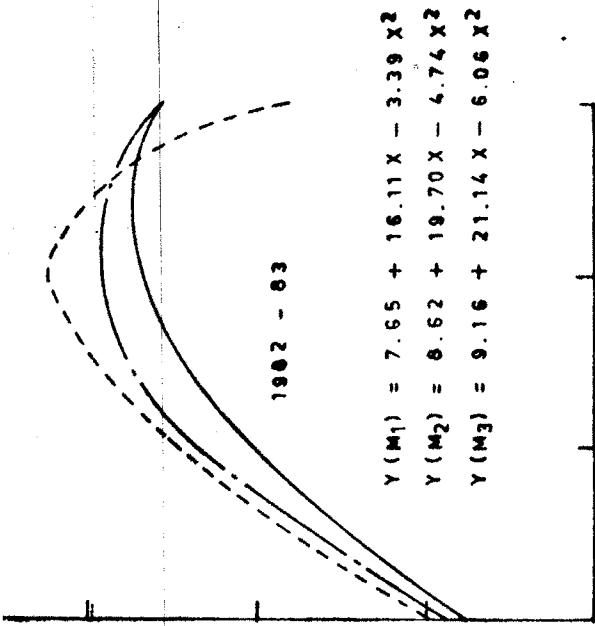
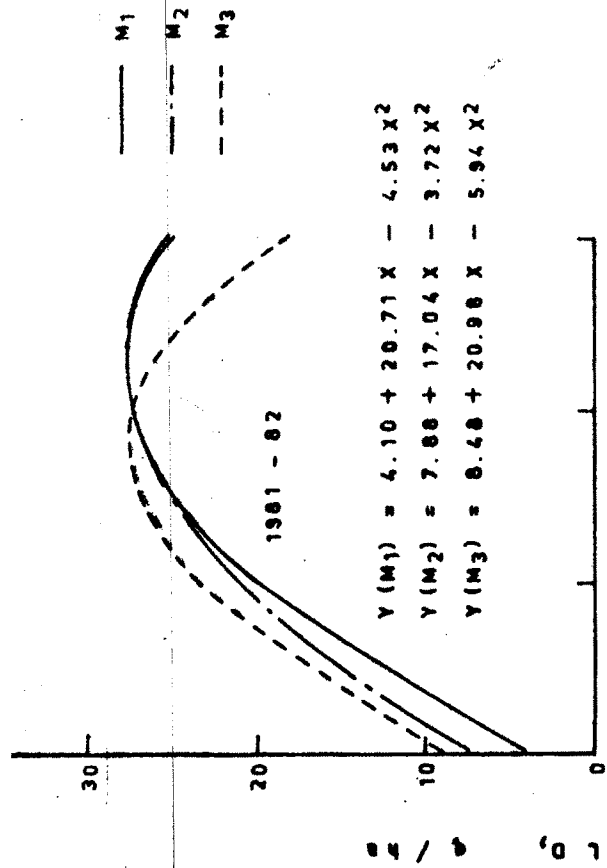


Table 4.84 Response of wheat to boron application in kg grain per kg of applied nutrient (based on pooled data)

Dose of boron	kg grain/kg boron 1981-84
10 kg/ha (First dose over control)	155
20 kg/ha (Second dose over control)	94
30 kg/ha (Third dose over control)	52

Table 4.85 Economics of fertilizer application (average for three seasons) in wheat

Ferti- lizer app- lied	Yield (g/ha)	Return from ferti- lizer* (Rs.)	Cost of ferti- lizer (Rs.)	Marginal benefit cost
1	2	3	4	3 ÷ 4
Boron (kg/ha)				
0	7.58			
10	23.02	2325	150	15.50
20	26.48	2835	300	9.45
30	23.28	2353	450	5.23

*Include deduction $\frac{1}{6}$ th for cost of harvesting etc. for increased production due to boron application.

4.3.1.9 Straw yield

Straw yield was significantly affected by level of boron (Appendix-IV). Application of 10 kg/ha boron significantly increased straw yield over control in all years, thereafter a decline was observed during 1982-83, 1983-84 and in pooled data (Table 4.86). This was mainly due to the increase in height of plant (Table 4.39) and total tillers (Table 4.49) with application of 10 kg/ha boron over control.

Table 4.86 Effect of different levels of boron on straw yield

Level of boron (kg/ha)	Straw yield (g/ha)			
	1981-82	1982-83	1983-84	Pooled
0	36.53	38.27	36.24	36.68
10	38.61	42.31	41.20	40.70
20	38.64	39.21	39.61	39.15
30	37.45	35.77	35.17	37.13
S.E.m ±	0.50	0.43	0.46	0.32
C.D. at 5%	1.43	1.24	1.32	0.90

Method of boron application significantly influenced straw yield (Appendix-IV). Full foliar application of boron significantly decreased straw yield over full soil and half

soil + half foliar methods of application (Table 4.87). However, full soil and half soil + half foliar methods of boron application were at par in respect of their straw yield.

Table 4.87 Effect of method of application of boron on straw yield

Method of application	Straw yield (g/ha)			
	1981-82	1982-83	1983-84	Pooled
Full soil	38.60	39.67	39.60	39.29
Half soil + half foliar	39.28	40.32	38.70	39.43
Full foliar	35.55	35.94	35.86	36.78
S.E.m $\pm$	0.43	0.37	0.40	0.34
C.D. at 5%	1.24	1.06	1.15	1.01

Interaction between level of boron and method of its application was significant during 1981-82 (Appendix-IV). Maximum straw yield was obtained at 30 kg/ha boron applied full in soil which was at par with 20 kg/ha boron applied half in soil and half as spray (Table 4.88).

Interaction between level of boron and method of application was significant during 1982-83 (Appendix-IV). Straw yield was at its maximum at 10 kg/ha boron applied half in soil and other half as spray and this treatment combination produced ^{*}more straw yield over all other treatment combinations (Table 4.89).

Table 4.88 Effect of interaction between levels of boron and method of application on straw yield (1981-82)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Straw yield (q/ha)		
0	35.53	36.52	37.54
10	37.86	39.16	38.81
20	38.45	42.30	35.17
30	42.56	39.12	30.69
S.E.m $\pm$	0.86	C.D. at 5%	2.48

Table 4.89 Effect of interaction between levels of boron and method of application on straw yield (1982-83)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Straw yield (q/ha)		
0	37.51	37.96	36.37
10	39.21	45.32	41.81
20	40.60	41.23	35.81
30	40.77	36.78	29.78
S.E.m $\pm$	0.74	C.D. at 5%	2.13

Interaction between level of boron and method of application was significant during 1983-84 (Appendix-IV). Straw yield was maximum at 20 kg/ha boron applied full in soil and at 10 kg/ha boron applied either full as spray or half in soil and other half as spray (Table 4.90).

Table 4.90 Effect of interaction between levels of boron and method of application on straw yield (1983-84)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Straw yield (q/ha)		
0	36.61	35.73	36.38
10	38.51	43.68	41.40
20	41.73	41.94	35.15
30	41.53	33.45	30.52
S.E.m $\pm$	0.79	C.D. at 5%	2.27

Interaction between level of boron and method of its application was significant in pooled data (Appendix-V). 10 kg/ha boron applied half in soil and other half as spray produced maximum straw yield, but this treatment combination was at par with 20 kg/ha boron applied half in soil and half as spray and with 30 kg/ha boron applied full in soil (Table 4.91).

Table 4.91 Effect of interaction between levels of boron and methods of application on straw yield (1981-84)

Levels of boron (kg/ha)	Method of application		
	Full soil	Half soil + half foliar	Full foliar
	Straw yield (q/ha)		
0	36.55	36.73	36.76
10	38.72	42.72	40.67
20	40.26	41.82	35.37
30	41.62	36.45	34.32
S.E.m $\pm$	0.56	C.D. at 5%	1.57

SUMMARY AND CONCLUSION

The field experiments were conducted at Teaching and Instructional Farm of Cooch-Bihar Campus, Bidhan Chandra Krishi Viswavidyalaya during winter season of 1979-80 to 1983-84 to study the effect of (i) irrigation at different physiological growth stages (crown-root-initiation (C), tillering (T), flowering (F) and dough (D) stages and their different combinations), (ii) soil amendments (lime @ 1.5 tonnes/ha and dolomite @ 1.5 tonnes/ha) and micronutrients (Zinc-15 kg ZnSO_4 /ha, boron-20 kg borax/ha and molybdenum-800 gm sod-molybdate/ha), (iii) the doses of boron (0, 10, 20 and 30 kg borax/ha) and methods of its application (full soil, half soil + half foliar and full foliar) on the yield attributes and yield of wheat.

Irrigation significantly increased the plant height, total and effective tillers, ear length, grain number per ear, thousand grain weight, grain and straw yields of wheat. Two irrigations applied one each at tillering and flowering stages (TF) recorded maximum grain yield. Increase the grain yield with irrigation at TF stages over unirrigated control was 9.02 q/ha. Application of three or four irrigations did not increase the yield over two irrigations.

Rate of evapotranspiration (E_T) was found to influence with change in the soil moisture status due to either rainfall or irrigation. It increased with increase in the number of

irrigation and decreased as a result of withholding irrigation. In all irrigation treatments E_T increased with age of the crop and then decreased due to crop senescence. The equations were fitted to express the relationship between E_T and days of crop growth. Maximum E_T was observed with four irrigations and minimum E_T was recorded under rainfed treatment. Water use efficiency was maximum (11.05 kg/ha/mm) under rainfed treatment and was 10.12 kg/ha/mm with TF irrigation treatment.

Application of soil amendments (lime and dolomite) and micronutrients (zinc, boron and molybdenum) significantly increased dry matter, number of total and effective tillers, length of ear, number of grains per ear, 1000 grain weight, grain and straw yields. Increase in grain yield over control was 2.65 and 1.77 q/ha with dolomite and lime applications respectively. Application of boron, molybdenum and zinc increased grain yield over control by 238.5, 62.8 and 33.8 per cent respectively. Dolomite (1.5 tonnes/ha) in combination with boron (20 kg borax/ha) gave maximum grain yield of 29.3 q/ha.

Yield and yield attributing characters of wheat were significantly influenced by the levels of boron upto 20 kg borax/ha which gave additional grain yield of 18.90 q/ha over control.

Half soil and half foliar method of application of boron produced maximum dry matter, total and effective tillers, ear

length, 1000 grain weight, straw and grain yields. This method was superior to other two methods and gave 6.6 and 8.8 per cent increased grain yield over full soil and full foliar method of application of Boron respectively. 20 kg borax/ha applied half in soil and other half as foliar spray gave maximum grain yield (28.7 g/ha) of wheat.

The response due to boron application was found quadratic. The optimum dose of boron as borax was 23.4, 19.4 and 15.6 kg/ha for full soil, half soil + half foliar and full foliar method of application respectively. Response to boron application was maximum (155 kg grain/kg boron) at 10 kg/ha boron and decreased to 94 kg grain/kg boron at 20 kg/ha boron. Benefit-cost ratio at 20 kg/ha boron was Rs. 9.45 per rupee invested on fertilizer.

CONCLUSION

Two irrigations applied one each at tillering and flowering (TF) stages produced maximum grain yield and were significantly superior to unirrigated control. Application of three or four irrigations did not increase grain yield over two irrigations (TF).

Total evapotranspiration and water use efficiency of wheat with two irrigations at T and F stages were 296.4 mm and 10.12 kg grain/ha/mm water respectively.

Application of soil amendments @ 1.5 tonnes/ha was found beneficial for wheat and gave extra grain yield of 2.65 and 1.77 q/ha over control with dolomite and lime respectively.

Micronutrients-boron, molybdenum and zinc influenced favourably the yield attributes and increased the grain yield of wheat over control by 238.5, 62.8 and 33.8 per cent respectively. Dolomite in combination with boron recorded maximum grain yield (29.3 q/ha) of wheat.

The response due to graded doses of borax was found quadratic and the optimum dose of boron as borax was 23.4, 19.4 and 15.6 kg/ha for full soil, half soil + half foliar and full foliar method of application respectively. Response to 20 kg/ha boron was 94 kg grain/kg boron and the benefit-cost ratio at this level was Rs. 9.45 per rupee invested on fertilizer borax.

Among the methods of boron application, half soil + half foliar method of application was found superior to other two methods and gave 6.6 and 8.8 per cent more grain yield over full soil and full foliar method of application respectively. 20 kg/ha boron as borax applied half in soil and other half as foliar spray gave maximum grain yield (28.7 q/ha) of wheat.

CHAPTER-VI

FUTURE SCOPE OF RESEARCH

FUTURE SCOPE OF RESEARCH

The present investigation has revealed that the application of micronutrients to the terai soils of North Bengal which are acidic and light in texture, is very much beneficial for increased production of wheat. Regarding the relative efficiency of these micronutrients studied, boron gave maximum response. Hence the graded doses of boron with its method of application were tried in this investigation and the optimum dose with method of application was worked out. No such information is now available for terai soils of North Bengal in respect to zinc, molybdenum and other micronutrients. So field investigation should be carried out with the graded doses of zinc, molybdenum and other micronutrients to find out the optimum dose of these nutrients for wheat crop. Determination of their correct method of application is also essential. The response of these micronutrients to other crops may also be studied.

It is also necessary to study the concentration and uptake of the micronutrients in wheat due to the application of micronutrients.

The study on the direct and residual effect of the application of micronutrients also deserves special attention.

Emphasis should also be given on the study of the change of physical and chemical parameters in the soil subjected to the application of soil amendments. The residual effect is also to be studied.

CHAPTER-VII

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APPENDIX TABLES

APPENDIX-I

Analysis of Variance

Yield and yield attributes : Number of total tillers/Effective tillers
Just before irrigation at

Sources of variation	D.F.	Mean sum of squares									
		CRI					T				
		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1981-82
Replication	3	13.12	2.27	1.55	14.22	4.91	5.58	18.30	14.38	7.79	7.79
Treatment	15	1.58(N.S)	0.86(N.S)	0.21(N.S)	33.32**	17.95**	23.58**	206.89**	48.28**	20.18*	20.18*
Error	45	9.30	5.26	4.64	8.47	5.41	4.29	16.50	10.05	9.19	9.19
Total	63										

Sources of variation	D.F.	Mean Sum of Squares					
		D		At Harvesting (Effective tillers)			
		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
Replication	3	38.46	14.46	19.79	0.27	27.76	16.27
Treatment	15	117.43**	34.35*	18.13	24.61	22.65	26.25
Error	45	14.20	10.18	13.03	6.12	8.64	15.52
Total	63						

APPENDIX-I (contd.)

Analysis of Variance
Yield and yield attributes : Height of the plant

Sources of variation	D.F.	Mean Sum of Squares									F	1981-82
		C.R.I			T			F				
		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82		
Replication	3	2.29	2.09	0.45	1.07	6.51	5.68	13.77	4.05			3.80
Treatment	15	0.12	0.74	0.16	9.52**	5.66*	2.85	46.00**	3.48			3.45
Error	45	0.40	1.43	0.77	2.09	2.31	3.41	7.57	2.46			3.89
Total	63											

Sources of variation	D.F.	Just before Irrigation at			At harvesting		
		1979-80	D 1980-81	1981-82	1979-80	1980-81	1981-82
Replication	3	5.17	4.58	0.86	2.10	2.42	1.06
Treatment	15	16.76**	20.66**	4.30*	12.70**	15.84**	2.62**
Error	45	3.84	5.57	2.08	3.61	3.09	0.82
Total	63						

APPENDIX-I (contd.)

Analysis of Variance Yield and yield attributes :

Sources of variation	D.F.	Minimum Sum of Squares			Mean Sum of Squares		
		Length of ear			Number of grains per ear		
		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
Replication	3	0.06	.53	.04	.27	2.54	1.35
Treatment	15	2.10**	1.19**	1.41**	20.24**	14.26**	22.20**
Error	45	.09	.16	.19	3.34	4.36	4.35
Total	63						

Sources of variation	D.F.	Mean Sum of Squares			Mean Sum of Squares			
		Weight of 1000 grains			Grain yield			
		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1982-83
Replication	3	0.46	2.03	3.02	1.83	11.59	9.40	1.73
Treatment	15	0.38	0.68	1.31	9.95**	4.73*	20.25**	8.31**
Error	45	1.21	0.75	1.03	3.00	2.33	3.75	3.14
Total	63							

APPENDIX-I(contd.)
Analysis of Variance
Yield and yield attributes

Sources of variation	D.F.	Mean sum of squares					
		Straw yield			Total dry matter		
		1979- 80	1980- 81	1981 82	1979- 80	1980- 81	1981- 82
Replication	3	5.02	9.06	19.44	10.50	26.46	34.69
Treatment	15	48.47**	27.75**	106.31**	112.08**	74.58**	241.55**
Error	45	4.11	3.51	5.17	14.80	9.52	18.19
Total	63						

Analysis of Variance
Grain yield - pooled

Source of variation	D.F.	Mean sum of squares
Replication	3	2.33
Year (Y)	3	63.16**
Treatment (T)	15	36.02**
Interaction Y x T	45	1.81
Error	189	3.24

APPENDIX-II

Analysis of Variance (Yield and Yield attributes)

Source of variation	D.F.	Mean sum of squares	
		Height of the plant 1979-80	1980-81
Replication	3	7.85	2.14
Amendment (A)	2	0.64	1.27
Micronutrients(M)	3	0.52	7.47
Interaction (A x M)	6	0.39	0.58
Error	33	2.08	2.70
Total	47		

Source of variation	D.F.	Mean sum of squares		
		Total dry matter		
		1979- 80	1980- 81	1981- 82
Replication	3	27.32	19.60	5.44
Amendment (A)	2	27.14*	114.99**	122.78**
Micronutrients (M)	3	1643.06**	1957.68**	1987.79**
Interaction (A X M)	6	00.64	5.83	19.31**
Error	33	7.65	5.45	4.62
Total	47			

APPENDIX-II (contd.)

Source of variation	D.F.	Mean sum of squares	
		Number of total tillers	
		1979-80	1980-81
Replication	3	12.58	8.24
Amendment	2	6.93*	8.58*
Micronutrient	3	38.18**	126.74**
Interaction (A X M)	6	1.60	1.97
Error	33	1.35	1.92
Total	47		

Analysis of Variance

Source of variation	D.F.	Mean sum of squares	
		Number of effective tillers	
		1979-80	1980-81
Replication	3	9.91	6.17
Amendment	2	50.02*	86.08**
Micronutrient	3	283.19**	448.94**
Interaction (A X M)	6	1.94	11.52
Error	33	10.20	6.24
Total	47		

APPENDIX-II (contd.)
Analysis of Variance

Source of variation	D.F.	Mean sum of squares Length of ear	
		1979-80	1980-81
Replication	3	0.10	0.18
Amendment	2	0.25**	0.20
Micronutrient	3	0.83**	0.16
Interaction (A X M)	6	0.03	0.09
Error	33	0.03	0.04

Source of variation	D.F.	Mean sum of squares Number of grains per ear	
		1979-80	1980-81
Replication	3	6.35	6.14
Amendment	2	36.08**	53.58**
Micronutrient	3	1810.41**	2016.25**
Interaction (A X M)	6	2.14	4.08
Error	33	2.44	2.15

APPENDIX-II (contd.)

Sources of variation	D.F.	Weight of 1000 grains	
		1979-80	1980-81
Replication	3	8.08	1.47
Amendment	2	6.50*	4.74*
Micronutrient	3	115.42**	135.77**
Interaction(A X M)6		7.59**	6.87**
Error	33	1.63	1.11

Analysis of Variance

Sources of variation	D.F.	Mean sum of squares Grain yield		
		1979-80	1980-81	1981-82
Replication	3	3.32	1.96	.81
Amendment	2	20.12**	34.08**	39.72**
Micronutrient	3	899.21**	939.68**	926.78**
Interaction(AXM)	6	1.01	2.74	3.33*
Error	33	1.55	1.26	1.10

APPENDIX-II (contd.)

Sources of variation	D.F.	Mean sum of squares		
		1979-80	Straw yield 1980-81	1981-82
Replication	3	7.72	5.76	3.76
Amendment	2	3.49	24.59**	47.23**
Micronutrient	3	100.52**	151.75**	152.67**
Interaction (A X M)	6	2.36	1.76	3.35
Error	33	2.78	1.52	1.43

APPENDIX-III
Analysis of Variance (Yield and Yield attributes)

Source of variation	D.F.	Mean Sum of Squares			
		Height of plant	Number of total tillers	Number of effective tillers	Length of panicle
Replication	3	2.32	13.10	11.34	0.25
Harvest year(Y)	1	19.26	160.17**	90.09*	0.17
Error (a)	3	7.67	2.55	4.73	0.03
Amendment (A)	2	1.78	15.20	132.07**	0.37*
Interaction(YxA)	2	0.13	0.32	4.03	0.05
Error (b)	12	2.48	43.02	7.52	0.09
Micronutrients (M)	3	5.87	151.60**	722.06**	1.35**
Interactions					
Y X M	3	2.12	13.36**	10.06	0.03
A X M	6	0.43	2.85	6.47	0.03
Y X A X M	6	0.54	0.72	6.99	0.01
Error (c)	54	3.30	2.08	9.51	0.02

APPENDIX-III (contd.)

Analysis of Variance (Yield and yield attributes)

Source of variation	D.F.	Mean Sum of Squares	
		Number of grains per ear	Weight of 1000 grains
Replication	3	7.70	6.12
Harvest year (Y)	1	29.26	0.72
Error (a)	3	4.79	3.44
Amendment (A)	2	88.62**	11.05**
Interaction - Y X A	2	1.04	0.19
Error (b)	12	4.54	1.54
Micronutrient (M)	3	3823.82**	261.02**
Interactions			
Y X M	3	2.84	0.04
A X M	6	5.59	7.23**
Y X A X M	6	0.62	2.28
Error (c)	54	20.98	2.21

APPENDIX-III (contd.)

Analysis of Variance (Yield and yield attributes)

Source of Variation	D.F.	Mean sum of squares		
		Total dry matter	Grain yield	Straw yield
Replication	3	33.76	4.24	9.89
Harvest year	2	60.39*	24.23**	11.31
Error (a)	6	7.13	1.07	3.34
Amendment (A)	2	241.72*	87.16**	60.21
Interaction Y X A	4	8.84	0.66	7.55
Error (b)	18	54.59	2.26	3.67
Micronutrients (M)	3	5577.79**	2775.36**	400.59**
Interactions				
Y X M	6	3.53	0.77	2.17
A X M	6	14.16	5.34**	5.80
Y X A X M	12	6.71	0.49	0.73
Error (c)	81	9.15	1.76	2.97

APPENDIX-IV

Analysis of Variance (Yield and yield attributes)

Sources of variation	D.F.	Mean Sum of Squares	
		Weight of the plant 1981-82	1982-83
Replication	3	0.24	2.07
Method of application	2	1.27	0.81
Boron	3	6.74*	6.74*
Interaction	6	2.16	1.03
Error	33	2.33	2.44
Total	47		

Sources of variation	D.F.	Mean Sum of squares Total dry matter		
		1981-82	1982-83	1983-84
Replication	3	22.68	2.73	2.84
Method	2	132.37**	42.39**	165.17**
Boron	3	1020.36**	1309.19**	1491.61**
Interaction	6	207.94**	74.53**	133.30**
Error	33	8.55	5.30	7.31
Total	47			

APPENDIX-IV (contd.)

Sources of variation	D.F.	Mean Sum of Squares Number of total tillers	
		1981-82	1982-83
Replication	3	3.06	3.24
Method	2	4.02	3.15
Boron	3	26.83**	36.69**
Interaction	6	17.19**	26.39**
Error	33	3.11	2.33
Total	47		

Sources of variation	D.F.	Mean Sum of Squares Number of effective tillers	
		1981-82	1982-83
Replication	3	19.96	8.35
Method	2	236.31**	278.15**
Boron	3	302.85**	310.08**
Interaction	6	159.65**	153.20**
Error	33	7.28	2.69

APPENDIX-IV (contd.)

Sources of variation	D.F.	Mean Sum of Squares	
		Length of ear	
		1981-82	1982-83
Replication	3	0.10	0.19
Method	2	0.12*	0.25**
Boron	3	1.92**	1.42**
Interaction M X B	6	0.52**	0.25**
Error	33	0.03	0.04

Sources of variation	D.F.	Mean Sum of Squares	
		Number of grains per ear	
		1981-82	1982-83
Replication	3	2.18	19.92
Method	2	11.08**	16.67
Boron	3	1329.63**	1216.92**
Interaction M X B	6	114.61**	96.17**
Error	33	1.16	11.08
Total	47		

APPENDIX-IV (contd.)

Sources of variation	D.F.	Mean Sum of Squares	
		Weight of 1000 grains 1981-82	1982-83
Replication	3	1.92	1.33
Method	2	4.39*	2.44
Boron	3	325.26**	316.38**
Interaction(A X M)	6	10.63**	4.65**
Error	33	1.02	1.06
Total	47		

Sources of variation	D.F.	Mean Sum of Squares		
		1981-82	Grain yield 1982-83	1983-84
Replication	3	1.84	1.26	1.73
Method	2	7.59**	17.19**	15.44**
Boron	3	841.21**	821.22**	976.81**
Interaction(A X M)	6	57.95**	37.89**	25.15**
Error	33	1.22	1.59	4.58
Total	47			

APPENDIX-IV (contd.)
Analysis of Variance

Sources of variation	D.F.	Mean Sum of Squares		
		1981-82	1982-83	1983-84
Replication	3	12.80	2.04	1.93
Method	2	63.07**	89.38**	60.84**
Boron	3	12.38**	95.56**	95.56**
Interaction(A&M)	6	47.35**	38.96**	52.19**
Error	33	2.98	2.21	2.51
Total	47			

APPENDIX-V

Analysis of Variance (Yield and yield attributes)

Sources of variation	D.F.	Mean Sum of Squares		
		Height of plant	Number of total tillers	Number of effective tillers
Replication	3	0.91	3.96	24.57
Harvest year (Y)	2	0.04	0.10	8.17
Error (a)	6	1.40	2.34	3.75
Method (M)	2	1.38	6.03	513.51**
Interaction Y X M	4	0.70	1.03	0.95
Error (b)	18	2.88	4.92	10.65
Boron (B)	3	13.1**	62.04**	602.15**
Interactions				
Y X B	6	0.29	1.48	10.77
M X B	6	2.57	39.85*	302.70**
Y X M X B	12	0.63	3.73	10.09
Error (c)	81	2.38	14.14	5.30

APPENDIX-V (contd.)

Analysis of Variance (Yield and yield attributes)

Sources of variation	D.F.	Mean Sum of Squares		
		Length of ear	Number of grain per ear	Weight of 1000 grains
Replication	3	0.15	16.76	2.22
Harvest year (Y)	2	0.34	3.76	5.46
Error (a)	6	0.14	5.34	1.03
Method (M)	2	0.33*	24.87	6.62
Interactions				
Y X M	4	0.04	2.54	0.21
Error (b)	18	0.10	10.27	2.27
Boron (B)	3	3.29**	2533.59**	641.46**
Interactions				
Y X B	6	0.06	9.62	0.28
M X B	6	0.64**	204.42**	14.45**
Y X M X B	12	0.12*	1.51	0.83
Error (c)	81	0.04	6.42	0.95

APPENDIX-V (contd.)

Sources of Variation	D.F.	Mean Sum of Squares		
		Total dry matter	Grain yield	Straw yield
Replication	3	16.09	3.54	4.99
Harvest year (Y)	2	88.66**	8.36**	8.50
Error (a)	6	6.09	0.74	5.74
Method (M)	2	299.45**	38.47**	205.37**
Interactions				
Y X M	4	20.57	1.02	4.19
Error (b)	18	10.02	1.70	5.43
Boron (B)	3	3718.87**	2606.34**	165.27**
Interactions				
Y X B	6	67.86**	16.54**	19.21**
M X B	6	381.43**	113.53**	120.67**
Y X M X B	12	39.63**	3.69**	6.81
Error (c)	81	9.67	1.44	3.76