STUDIES ON THE EFFECT OF TEMPERATURE ON GROWTH OF WHEAT CROP IN RELATION TO PHENOLOGY AND BIOMASS PRODUCTION

By

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A thesis submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

AGRICULTURAL PHYSICS

1988

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CERTIFICATE

This is to certify that the thesis entitled, "Studies on the effect of temperature on growth of wheat crop in relation to phenology and biomass production" submitted in partial fulfilment of the degree of DOCTOR OF PHILOSOPHY in Agricultural Physics of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, is a bona fide record of research carried out by Shri S.V.S.S. PRASAD under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma published in any other form.

The assistance and help received during the course of this investigation have been duly acknowledged.

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ACKNOWLEDGEMENTS

It is my proud privilege to work under the sagacious and inspiring guidance of Sh. P.S.N. Sastry, Senior Scientist, Division of Agricultural Physics and Chairman of my advisory committee. I express my deepest sense of gratitude for his valuable and constructive criticism at every stage of the study.

I take this opportunity to record my grateful thanks to Dr. C.V.S. Sastry, Dr. M. Bhavanarayana, Dr.A.K. Bagga, Dr. J.C. Bajaj, Dr. B.B. Turkhede (Retired), and Dr.R.K. Singh, members of my advisory committee for their constant help and valuable suggestions during the present investigation.

My sincere thanks are due to Dr. Y.N. Rao, Professor, Division of Agricultural Physics, for taking personal interest during the course of my study. My thanks are due to Dr. D.K. Das, Head, Division of Agricultural Physics, for providing the necessary facilities for the work.

I thank Dr. N.V.K. Chakravarthy and Dr. Y.V. Subba Rao for their constant help during the experimental study.

I thank S/Shri Bansi Rai, P.K. Sharma and Janardhan Poddar of Agricultural Physics Division for their assistance in conducting the experiment.

Heartfelt thanks are due to Ms. Potluri P.P., Ms. S.Vani, Ms. Jayasree, Mr. K.V. Ramana, Mr. M. Muralidhar, Mr. M.S. Rayan and

Mr. C.C.S.Rao for their kind cooperation and moral support at various stages of this investigation and preparation of manuscript. I am thankful to all my friends for making my stay at I.A.R.I. pleasant and profitable.

My thanks are due to Shri Shyam Lal Sharma for typing this manuscript.

My heart bends in gratitude before my parents, grand parents, uncle and aunty, sisters and also my well wishers, whose blessings and inspiration have silently worked in bringing me up nearer to my long cherished aspirations.

Finally, I sincerely express my thanks to the Indian Agricultural Research Institute, for the award of Senior Fellowship during the course of my study.

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INTRODUCTION

1. INTRODUCTION

Wheat is one of the major food crops of our country. Most of the wheat produced in India is grown in the northern parts. The agronomical, physiological, entomological, breeding and pathological aspects, critical stages for irrigation scheduling in relation to water management have received considerable attention by several researchers. A few attempts had been made in the past to study the effect of weather elements on wheat yield using long data series from the view point of climatological study.

During the rabi season in northern parts of our country, indices of climatic classification reveal temperature as a major factor determining yield of crops raised during the winter season. This is because only about 20 per cent of annual rainfall that too with low intensities is received in the wheat growing belt of the north during this season. Even if irrigation is assured it is mainly the temperature variations that influence the growth and development of wheat.

Rates of most biological processes are affected markedly by temperature. Growth and development show a response which results from the integrated effect of temperature on the many individual physiological processes involved. However, detailed studies on the short term effects of temperature variations on biomass production, crop growth rates and grain growth rates have been few.

Information on crop phenology (phenological events) forms an important aspect since the relation between grain yield and different yield components are known to greatly depend on the prevailing environmental conditions at various growth stages. Grain development stage in wheat received sufficient attention in relation to understanding the physiological processes leading to growth. However, not much attention appears to have been paid to study the effect of differing thermal environmental conditions on time of occurrance of phenological events. It is felt that a detailed study of crop phenological events would provide a base for understanding of the different growth and developmental processes as related to temperature.

The heat unit concept which is based on the idea that plants have a definite thermal requirement before they complete certain phenological stages, affords an opportunity to build up quantitative relationship between the heat unit system, biomass production and crop growth rates. Except for the extensive studies on wheat by Nuttonson in the 1950's in the U.S.A., heat unit concept does not seem to have been studied in detail in relation to crop growth and development in wheat. Thermal environment as stated above being an important ingradient infleuncing crop performance during <u>rabi</u> season (such as in wheat), it should be possible to apply this concept to study crop response in the differing phenological stages.

Crop canopy temperature is another parameter that has been receiving much attention in recent years after the development of infra red thermometry. It is gaining importance in crop stress and yield function studies in relation to spectral response. Ground based information on response of canopy temperatures in relation to short period weather induced variability in the different growth phases of crop thus forms an important aspect of research in relation to temperature.

Photosynthesis is known to depend on light energy and chlorophyll contents of crops in addition to temperature. Spectral response also is known to vary with changes in chlorophyll content of crops. In this context a study of chlorophyll content, photosynthetically active radiation and their distribution within the crop canopy in relation to temperature variations is considered important. It may be mentioned that such interactions have received little attention in our country and it is felt necessary to make a beginning in these aspects of research.

Most of the studies that have been reported in literature on the influence of temperature on crop growth and development were based on experiments carried out under controlled conditions in growth chambers. However, in view of the limited facilities for similar studies in our country and also keeping in view the fact that results from such experiments often render them difficult to interpret the response under field conditions, it is felt that a field trial with different planting dates within the normal crop growing season would provide a data base for studying crop response to thermal environment under natural conditions. One redeeming feature is that wheat growing belt in India is visited by one or two 'western disturbances' in each month during the wheat growing season. In association with these systems substantial temperature changes are known to occur over short periods which would provide contrasting situations of environmental warming and cooling lasting for a week or so providing possible field conditions for case study.

Keeping in view the above factors, field experiments on wheat crop were planned to study crop response to the thermal regime with the following objectives:

1) to study the short period effects of temperature on growth rate in wheat and the attendant plant parameters.

2) to establish a quantitative relationship between biomass production, phenology, yield and thermal environment in terms of accumulated heat unit system and

3) to study the relationship between spectral reflectance, chlorophyll content and phenology as influenced by temperature.

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REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The results reported by past researchers relating to different aspects of the physical environment of wheat (Triticum aestivum L.) pertinent to the present study were reviewed and are presented in this chapter. For convenience, the literature is given under the following heads:

1. Phenological development of crop in relation to temperature
2. Temperature, plant growth and development characteristics
3. Accumulated heat units during crop growth and development
4. Evaporation and biomass production
5. Canopy temperature characteristics
6. Effect of temperature on chlorophyll content
7. Phenology, chlorophyll content and spectral reflectance in crops.

2.1 Phenology - in relation to temperature

Phenological development of crop is known to closely follow the changes in weather conditions occurring during the crop growth season and since the earliest times, study of phenology of crops formed an important aspect in ecological research.

In general, under normal timely sown conditions in the Delhi region, cultivars Kalyansona and Sonalika were found to differ by 15-20 days to reach different phenological events. Boot leaf stage is reached in 65-70 days in variety Sonalika while variety Kalyanasona is known to take 80-85 days after sowing. Anthesis occurs around 92 and 107 days in Sonalika and Kalyanasona varieties respectively. Soft dough stage reaches by about 112 and 117 days in these two varieties respectively (I.A.R.I., 1976).

There have been several studies regarding the effect of temperature on growth and development of wheat plant. But many of these have concentrated on study of a single development stage such as grain growth (Wardlaw, 1970; Sofield et al., 1974). It was reported that unfavourable effects of temperature may come about by either too warm or too cool temperatures in the season in India leading respectively to (i) curtailment of the vegetative duration and (ii) lengthening of the vegetative phase (Venkataraman and Rahi, 1983).

Warrington et al. (1977) in Australia under controlled conditions observed that mean duration of three phenological stages viz. , vegetative , ear development and grain filling of wheat cv. Gamenya occur in 32, 62 and 96 days respectively at 15°C. The corresponding durations at 20 and 25°C were found to be 29, 37, 56 and 28, 29, 39 days respectively, showing a considerable decrease at higher temperatures. In a growth chamber experiment in USA by Frank and Bauer (1981), vegetative stage in wheat cv. Sinton took 24, 22 and 17 days at 10, 18 and 26°C respectively which also confirms the general observation regarding reduction in duration with increasing temperature.

Wheat cultivars are known to come to heading stage more rapidly at higher temperatures. They may also result in hastened anthesis. In a growth chamber study, Pirasteh and Welsh (1980) reported that it took 103 days at cool temperatures in comparison to 81 days under warm temperatures. Similar observations were also reported by Sayed and Gadallah (1983). Chakravarthy and Sastry (1983a) from their field experiments on wheat mentioned that the short duration changes in weather that prevail during the crop growth periods might result in considerable variation in phenological development depending on the planting date. Under Delhi conditions, during the warmer season, anthesis occurred 8-10 days earlier than in the cooler season. It was reported by Waldren and Flowerday (1979) from field experiments conducted in U.S.A. that temperature affected the length of time of each growth stage, with a relatively longer time at low mean air temperatures. Similar observations were made by O'Leary et al. (1985).

Occurrence of early, mid and late jointing dates differed significantly for two wheat cultivars in a field study in U.S.A. by Dunphy et al. (1984). Cultivar Coker 68-15 reached early jointing stage 14 to 59 days earlier. The greatest difference between cultivars occurred during the year when temperatures were quite cool and development was delayed. Bagga and Rawson (1977) observed from controlled chamber experiments on wheat in Australia that duration of sowing to anthesis stage in cv. Kalyansona was 105, 85 and 76 days at 15, 20 and 25°C temperatures respectively. Wardlaw et al. (1980) from Australia in growth chamber studies reported a similar reduction in duration of kernal filling period from 60 to 36 days when temperatures were increased from 15 to 21°C.

In an experiment under controlled conditions, Amores-Vergara and Cartwright (1984) transferred wheat cv. Sonara-64 to 27°C during 6 developmental stages and compared it with control plots grown at 17°C. The time from sowing to maturity was found to be reduced more by later exposures (after anthesis to maturity) to high temperatures. Halse and Weir (1970) reported that higher temperatures reduced the time from germination to initiation and anthesis of cultivars.

2.1.1 Date of sowing and phenology

Sowings over a 5 month period from October to February in Delhi by Saini *et al*. (1986) showed a two fold variation in the duration from sowing to first spikelet initiation and anthesis. When sown early or late the initiation of spikelets was found to be hastened with a consequent earlier occurrence of anthesis. Porter *et al*. (1987) in England under field conditions at different locations reported a difference of 90 days in duration from sowing to grain filling stage between first and third plantings in Avalon variety of winter wheat. They largely attributed this to the prevailing differences in mean air temperature. Russelle *et al*. (1984) under field conditions observed that late plantings reached different growth stages earlier than early plantings due to higher seasonal temperatures. Davidson and Campbell (1983) reported from studies under controlled conditions that the number of days to the various developmental stages was inversely and linearly related to the mean daily temperatures over the 15-25°C range. Balla (1983) studied winter wheat in Hungary under controlled conditions and reported delayed heading with decreased temperatures and a linear relationship between number of days to heading and temperature decrease. Shpiler and Blum (1986) also showed that the duration of all growth stages was reduced by high seasonal temperatures.

Phenological events are thus very much influenced by temperature, with the events occurring relatively in less number of days at warmer temperatures than at cooler temperatures. The change in duration between phenological events differs widely from place to place (location specific) and the effect of temperature needs to be worked out for a specific location with respect to seasonal conditions in different years.

2.2 TEMPERATURE, PLANT GROWTH AND DEVELOPMENT CHARACTERISTICS

2.2.1 Biomass accumulation

Periodic observations on plant dry weights usually show a sigmoidal increase with time. Biomass accumulation in wheat was found to be most intensive during the period from tillering to the heading stage when 70 to 90 per cent of the total biomass would be accumulated (Petrov and Dimitrov, 1976). However, Waldren and Flowerday (1979) reported a rapid increase in biomass from jointing to soft dough stages.

Davidson and Birch (1978) working in Australia observed that in the wheat cultivars Gabo (Australian Spring wheat) and Pitic 62 (Mexican semidwarf) maximum biomass production was obtained by anthesis stage. Under late sown conditions in wheat plants, biomass was found to decrease at anthesis and maturity (Doyle and Fischer, 1979). Under irrigated conditions in silt loam soils of Pantnagar India, where the sowing was done in first week of November wheat cv. Kalyansona was found to produce 75 per cent more biomass than cv. Sonalika (Reddy and Pyare Lal, 1976). Further, they inferred that in five wheat cultivars studied by them (Kalyansona, Sonalika, cv.306, K 68 and K 65) grain yield was highly correlated with biomass production 95 days after sowing and no correlation could be obtained with the biomass produced before 95 days. O'Leary et al. (1985) working in Australia on wheat cv. Olynysic observed that with a relatively cooler season, the cultivar achieved the same final biomass (13 t/ha), whereas in 1980 when the temperatures differed, the biomass produced by the late sowings (9 t/ha) was significantly lower than that for early sowing revealing the effect of higher temperature. Biomass at anthesis was also found to be lower in the late sown crop in both cases.

2.2.2 Rate of biomass accumulation

Several reports show lower rates of dry matter accumulation at higher temperatures when compared to lower temperatures (Wall and Cartwright, 1974; Ford and Thorne, 1975; Wardlaw et al., 1980). It was observed by Friend et al. (1962) that with increase in temperatures (10, 15 and 30°C) the maximum dry weight of the same wheat plant grown under controlled conditions tends to decrease (66, 46.8, 25.7 and 8.6 g). A reduction in the time of occurrence of maximum absolute growth rate with increase in temperature was also reported by them.

Waloszczyk and Focke (1980) obtained a lower rate of dry matter increase in the late sown crop. While day/night temperatures at 28/20°C accelerated dry matter accumulation rate (but with a shorter duration), the lower temperature regime studied by Nicolas et al. (1984) resulted in low dry matter accumulation.

Biomass production during the period from terminal spikelet to anthesis was used by Ritchie (1987) as an index to approximate the number of kernels that would fill an ear as temperature during this stage of development was considered to stronglyinfluence the yield. Thus the rate of biomass production in all the phases is influenced by temperature.

2.2.3 Leaf area index (LAI)

Leaf area index is an important parameter of plant growth. It is very much useful in knowing the interception of radiation and the amount of photosynthate manufactured. Dunphy et al. (1984) observed a higher LAI at the time of anthesis in wheat. In a field experiment with winter and spring wheats, Watson et al. (1962) observed that LAI increased to a maximum at ear emergence and then decreased. After ear emergence leaf dry weight and area decreased with age. Leaf area index reached maximum value between heading and anthesis but had a lower value in the late sown wheat than in the early sown crop (Walzoszczyk and Focke, 1980). Gales (1983) also observed a maximum value of LAI during anthesis stage.

At a LAI of 5, wheat crop was observed to intercept more than 80 per cent of the incident photosynthetically active radiation

(Gales, 1983). Laubscher (1982) observed average LAI in 12 Medeterranean wheat cultivars grown at eight sites in South African winter rainfall region. At the completion of leaf production, spikelet initiation and differentiation, appearance of beard tips and anthesis, LAI was noted to have attained the values of 0.4, 2.3, 6.5, 7.3 and 4.62 respectively. A study on Australian wheats by O'Leary et al. (1985) revealed that a maximum LAI of four was reached in all the sowings in 1979 (dry winter with rains in August and September) while in 1980 (after rain in June and July with a dry September), only the early sown crop approached this value. They also inferred that at anthesis, LAI varied significantly between sowings and this effect was due to different environmental conditions.

2.2.4 Crop growth rates in wheat

Crop growth rates are dependent, apart from cultivar parameters, on ambient temperature conditions. During winter season with meagre rainfall and fluctuating temperatures, under rainfed conditions the effect of temperature predominates over others.

2.2.5 Phenology and crop growth rates

The crop growth rates (CGR) of Mexican dwarf wheat cv. Sidimisri grown under field conditions in Egypt were determined by EL-Sharkawy (1975). It was observed that the maximum crop growth rate of 158 $g/m^2/week$ occurred after full ear emergence. In case of wheat cv. Timgalani, Doyle and Fischer (1979) reported crop growth rates ranging from 3 to 20 $g/m^2/day$ during the pre-anthesis to post-anthesis period. O'Leary et al.(1985) in growth chamber experiments in Australia observed higher crop growth rates from sowing to anthesis than from anthesis to maturity stage. In a controlled experiment Davidson and Cambell (1984) found the crop growth rates to increase rapidly to a peak between the last leaf visible and heading stage which later declined to zero just prior to soft dough stage. Negative values for crop growth rates were obtained after soft dough stage due to a decrease in dry weight, during the maturity stage.

2.2.6 Relative growth rates

Studying the physiological variability in ten wheat cultivars, Mehrotra and Mishra (1976) observed maximum relative growth rates in the cv. Kalyansona, further they observed that the difference in the relative growth rate before and after anthesis in Kalyansona was much less than in the cv. Sonalika which showed higher relative growth rates before anthesis than after anthesis. These are attributed to differential response of the genotypes to ambient temperature.

2.2.7 Temperature and growth rates

Temperature affects growth of the whole plant mainly through its effect on respiration and morphology. Sayed and Gadallah (1983) observed that crop growth rates accelerate with an increase in the mean air temperature during the growing season. At a mean temperature of 15°C or less, crop growth rates were very low. Similarly highest growth rates were observed by Davidson and Campbell (1984) at 22°C when compared to temperature regimes of 17°C under controlled conditions.

Crop growth rates of three wheat cultivars were found to be adversely affected because of excessive energy input in rabi season (Chakravarthy and Sastry, 1985) in a semi-arid environment. A reduction of about 10 to 14 $g/m^2/day$ in the crop growth rates was observed in the season during which the mean ambient air temperatures were higher by 5 to 6°C and the saturation deficit was higher by 3 to 4 mm of Hg. Friend et al. (1982) noted that the fall rate in relative growth rate with time increased with temperature from 10 to 30°C.

2.2.8 Temperature and duration of grain filling period

A significant variation in the duration of grain filling period was noted across years by Sayed and Gadallah (1983) owing to different response of each cultivar to temperature. Higher temperatures imposed maturity earlier on the plants by shortening the grain filling period. But they further noticed that yield was related to grain filling rate but not to duration. Wardlaw et al. (1980) reported that an increase of temperature from 21/16°C (day/night) to 30/25°C during the period of development from anthesis to maturity, substantially reduced grain dry weight in wheat. They also inferred that there was a faster rate of import of photosynthate by the grain at higher temperature but this was offset by greater respiratory losses. Peters et al. (1971) obtained markedly reduced grain yields at higher temperatures which was associated with earlier senescence and maturity, resulting in a reduction in grain filling period.

Saini and Dadhwal (1986a) in the Delhi region observed that between 13 and 27°C the grain-growth duration from anthesis to maturity declined by 2.6 days for every 1°C rise in temperature followed by a slow decline at higher temperatures upto 30°C.

2.2.9 Temperature and grain growth rates

Higher grain growth rates of wheat cv. SST 66 at higher temperature were obtained by Greenfield and Noble (1987). Growth rates were the highest with the latest sowing date implying the effect of temperature. Hot dry weather during grain filling causes early senescence and poor kernal development (Nicolas et al.,1984). Studies in Israel on wheat by Shpiler and Blum (1986) showed that high temperature reduced grain weight via reduced growth duration but not the grain growth rate.

High temperatures following anthesis adversely affected grain development in wheat (Sofield et al., 1974; Spiertz, 1974; Chowdhury and Wardlaw, 1978; Wiegand et al., 1981; Midmore et al., 1984). However, the optimum temperature required for crop growth seems to be 22°C .

Much literature was not available on crop growth rates between the different phenological stages from sowing to anthesis under field observations in relation to the influence of varying atmospheric conditions and as noticed above, most of the studies were confined to the grain filling period.

2.2.10 Dates of sowing and grain yield

During rabi season changes in dates of sowing implies a change of environmental conditions for the same crop species and variety and affords an opportunity for studying the infleunce of temperature on crop growth and development.

While studying the grain yields obtained from cv. Kalyansona sown on different dates from November 1st to November 30th, Chela and Brar (1975) observed that the yields ranged from 25.1 to 44.6 q/ha in the first season of their study and 14.1 to 38.8 q/ha during the second season (relatively warmer). The highest yields were obtained when the sowings were done on 10th November.

Singh and Dixit (1985) in their experiment with five wheat cultivars sown on 10th and 25th November and 10th and 25th December obtained average grain yields of 5.18, 5.64, 5.09 and 3.9 t/ha respectively. The number of grains per ear and 1000 grain weight decreased in late sowings. In an experiment conducted , Dhingra et al. (1986) observed that grain and straw yields were significantly influenced by planting dates in the two years of their study (rabi 1982-83 and 1983-84). Later sowings reduced yield in their experiments which were attributable to higher temperatures in later plantings.

Average grain yields of wheat with irrigation decreased with delay in sowing from 15th November to 6th and 26th December and especially 6th to 15th January because of 1000 grain weight (Joarder et al. (1981) and Thorne (1986).

On the whole temperature seems to have a definite influence on yield to a greater extent, as late sowings result in reduced grain yields even under irrigated conditions.

2.2.11 Harvest Index

Harvest index is an indicator of the partitioning of photosynthates between grain and straw yields. As photosynthetic rates decrease with increasing temperature, the harvest index is also influenced.

While studying the physiological variability in wheat cultivars, Mehrotra and Mishra (1976) and Reddy and Pyare Lal (1976) reported the harvest index of cv. Kalyansona (0.45) to be higher than for cv. Sonalika (0.37). In a study by Sayed and Gadallah (1983), reduced harvest index (0.21) was recorded in spring wheat when sown late.

The above review shows that to understand the interaction of crop growth and environmental factors, detailed knowledge about the rates of biomass production, crop growth rates at the different phenological stages and the influence of temperature on all these characters is essential.

2.3 ACCUMULATED HEAT UNITS AND CROP GROWTH

2.3.1 The heat unit system or growing degree days

The effect of temperature on plant growth and occurrence of phenological development can be inferred by way of accumulated heat units (AHU) which is based on the idea that plants have a definite temperature requirement before they attain certain phenological stages. In the past, accumulated heat units have been widely used to predict crop growth and development. Though plant growth and development are time related in a specific area, are also closely related to the occurrence of critical values in the rise or fall of seasonal temperature. Plants need a definite amount of accumulated heat to fulfil their requirement for phenological development. Unless this requirement is met, differentiation does not take place.

Reaumer (1735) was the first scientist to suggest that the sum of the mean daily shade temperature of the air between one stage of development and another was constant for a particular plant species. Bossingault (1834) calculated the "total quantity of heat" required to ripen grain by this method.

The degree day concept assumes that the relationship between growth and temperature is linear or a logarithmic one as predicted by the Van't Hoff law. The term degree days, growing degree days and heat units were used synonymously by various scientists. Thus day-degree is a measure of the departure of the mean daily temperature from a given base temperature expressed in °C or °F. Units of expression being same, day-degrees were also referred to as accumulated heat units (AHU) by several workers.

2.3.2 Heat units and crop growth

Extensive studies were made by Nuttonson (1956) to ascertain a satisfactory temperature base line which would permit the obtaining of reasonably consistant temperature summations for the various growth development phases of wheat over many wheat-growing countries for 14 crop years. Of the five base lines used by him (32,36, 40, 45 and 50°F), the lowest coefficient of variation was observed with 40°F (4.4°C) base line when the day-degree was taken from sowing to ripe period. Moreover, since physiological processes of wheat were found to be inactive below 40°F, this temperature was preferred by him.

Studies on peas by Katz (1952) in Wisconsin in U.S.A. - revealed that the heat accumulation (base temperature 40°F) necessary to bring the crop to maturity was not a constant, but varied in such a manner that it was lower when the season was cool and higher when the season was warmer. Between two varieties of peas, according to him, the relationship between the heat requirements and maturity period appeared to be nearly constant and did not vary significantly from year-to-year. Venkataraman (1972) in India found a near constancy of heat units required by wheat variety NP 4 from sowing to ear emergence though the length of growing season varied widely at different locations.

Bierhuizen (1973) observed that although a high degree of accuracy in predicting harvest dates was obtained within a certain area, heat units might vary consistently from one year to another and also during the season. In an experiment on maize, Tollenaar et al .(1979) used AHU from planting to silking, to predict flowering dates for breeding purposes. French and Schultz (1982) also used the day-degrees of maximum air temperature to determine the intervals of duration between stages. Steward and Dwyer (1987) expressed all growth stages as a function of growing degree days (GDD) with a base temperature of 5°C. The number of degree days required for a crop to progress from stage S_1 to stage S_2 is considered to be constant for a given crop variety and is defined by Davidson and Campbell (1983) as,

$$\text{Degree days} = \sum_{S_1}^{S_2} (T_m - b_0)$$

where,

T_m = daily mean temperature

b_0 = base temperature

The relation of accumlated thermal units to crop development has been variously tested, compared between crops (Neild, 1982), and compared with other energy summation indices (Sastry and Chakravarthy, 1982) with the conclusion that the precision of the system is superior or equal to others. Similar results were reported by Bauer and Frank (1981). According to Ritchie (1987) the thermal time concept has two important limitations: 1) the upper and lower threshold temperatures must be known and 2) the influence of genotype and photoperiod can alter the thermal time for phasic development in some stages of growth.

The heat unit requirement was estimated to be 393 degree days above 7.5°C by Saini and Dadhwal (1986) during the period of grain growth in three wheat cultivars (HD 4502, Kalyansona and Sonalika) sown on different dates in two years. Similar results were reported by Angus _et al_. (1981) for entire grain growth duration.

In a study on spring wheat growth in Australia Bauer _et al_. (1984) observed that, accumulated GDD from seeding to emergence ranged from 94 to 138. They also inferred that the GDD accumulated per plant growth unit from emergence to anthesis was the same as from emergence through full expansion of flag leaf. In a field experiment on irrigated wheat conducted by Chakravarthy and Sastry (1983a) they reported that for different varieties, plantings and the seasons together, growing degree days from sowing to maturity ranged between 1370 and 1691 units. They inferred that, GDD decreased with later sowings. Chakravarthy et al. (1984) observed differences in accumulated degree days upto soft dough stage suggesting the differential varietal response to the short period changes in ambient thermal environment.

2.3.3 Phenothermal index

The differences in relation to accumulated degree days between different growth stages was expressed in the form of phenothermal index, computed as degree days/growth day (Chakravarthy and Sastry, 1983). The index was found to be nearly constant irrespective of planting date and season, during sowing to boot leaf stage with a mean value of 9.5. While the indices in the different stages from boot leaf to hard dough gradually increased from a mean value of 12.2 between boot leaf and anthesis to 18.1 from milk to hard dough, for entire crop growth period taken as single unit, the coefficient of variability (CV) yielded a value of 3.1 (Chakravarthy and Sastry, 1983a). In barley crop, phenothermal index ranged from 11.5 to 14.5 during boot leaf to anthesis stage (Chakravarthy et al., 1984); from anthesis to soft dough, it ranged from 14.1 to 17.1 and for the entire growth season, the phenothermal index nearly remained constant around a value of 11.5 with a CV of 1.1%.

2.3.4 Heat use efficiency

Heat use efficiency (HUE) of three wheat varieties for different growth stages was evaluated using above-ground biomass and also the grain yield for different plantings (Sastry et al.,1985). HUE was found to be high during the boot leaf to milk stages of crop growth in both warmer and cooler seasons studied. During milk to maturity stage in 1978-79 (cooler) season, relatively high HUE, 17-22 x 10^2 q/ha/degree day was recorded in the second planting compared to 6 to 8 x 10^2 q/ha/degree day in 1979-80 (warmer) season. During this stage correspondingly higher crop growth rates were recorded during 1978-79 season compared to 1979-80. Because of higher maximum temperature (30°C) at grain filling period during 1979-80 season there was considerable reduction in HUE values (Sastry et al., 1985).

2.3.5 Heat units and biomass production

The relationship between biomass production in soybean and sum of the air temperatures (AHU) was found to be linear by Hanway and Weber (1971). A highly significant positive correlation (r=0.87 to 0.88) between biomass of soybean crop and the AHU was also reported by Uchijima (1975). Chakravarthy et al. (1984) also observed a linear relationship between accumulated temperature and biomass production in barley crop. Accumulated temperature (GDD) over weekly periods were also found to be significantly correlated for the treatments, irrespective of difference in environmental conditions (Chakravarthy and Sastry, 1983b). Biomass production in three varieties of wheat grown under irrigated field conditions at I.A.R.I. was found to be linearly related to accumulated heat units above certain threshold value; the correlation value was 0.95 at 0.01 probability level of significance (Chakravarthy and Sastry, 1983b). Similar relationships between biomass production and accumulated heat units in wheat crop do not appear to have been studied extensively and information presently available on these aspects is very meagre.

Thus, though considerable progress has been made in characterizing the biometeorological time scale in terms of degree days, it is obvious that detailed study at each station for different crops is necessary to predict the maturity date and other phenological events much in advance and help the plant breeders to characterize the varieties based on AHU rather than on the duration of the phase in terms of number of days. This type of information especially on wheat crop is lacking in our country.

2.4 EVAPOTRANSPIRATION (ET) AND BIOMASS PRODUCTION

When the actual evapotranspiration falls short of potential evapotranspiration, the actual yield would also be less than the maximum. However, the relationship between evapotranspiration and yield in the field may or may not be linear as it is between transpiration and biomass production. This is partly because the fraction of evaporation that does not contribute to plant growth varies throughout the crop life cycle (Chang, 1968).

It was observed by Viets (1962) that even when the biomass production increased linearly with evapotranspiration, the regression line seldom passed through the zero point. Working on the biomass accumulation and its relationship with the water use in wheat crop, Doyle and Fischer (1979) observed a linear relationship between cumulative evapotranspiration and biomass production.

Hanks et al. (1969) showed that biomass production of winter wheat was highly correlated with cumulative evapotranspiration and obtained a nearly linear relationship between evapotranspiration and biomass from the beginning until maturity. Jalota (1986) established a relationship between yield and evapotranspiration deficit at different growth periods of wheat variety WL 171, which explained 93 per cent variation in yield. Biomass production in three varieties of wheat grown under irrigated field conditions in the Delhi region was found to be linearly related to cumulative evaporation with a high correlation coefficient of 0.89 (Chakravarthy and Sastry, 1983b).

2.5 CROP CANOPY TEMPERATURE

The potential of infrared thermometer measurement of crop temperature for crop water deficit assessments was recognised by Tanner (1963). Ehrler et al. (1978) demonstrated that canopy temperature in wheat (Triticum aestivum L.) increased as plant water potential decreased . Differences in canopy temperatures between stressed and non-stressed wheat plants were shown to be a reliable indicator of plant moisture stress.

Quantitative data relating crop temperature to the phenological and physiological development of crops over a complete growing season are sparse. The only seasonal crop canopy temperature studies based on daily measurements reported thus far are those of Idso et al (1977) and Jackson et al. (1977) with Durum wheat. They showed that an accumulation of crop temperatures during the period between head emergence and cessation of head growth were related to final grain yield. Gardner et al. (1981a) suggested that crop temperature data obtained with infrared thermometers can be used to predict phenological stages in corn crop if the land is completely covered. They also inferred that decreases in grain yield should be reflected by increases in canopy temperatures since canopy temperatures increase as plant moisture stress develops.

Cloudy periods have been observed to lower leaf or crop temperatures (Stone et al.,1975) for, diminished radiant heat load requires less total energy dissipation. Studies by Walker and Hatfield (1983) revealed that net radiation and saturation deficit strongly influenced canopy air temperature differences (T_c - T_a) in well watered plots during the central portion of the growing season. Linear regressions with a correlation coefficient value of 0.80 were reported. Kirkham et al. (1983) also observed in their study similar results with regression analysis for the dry year and wet year. Maximum (T_c - T_a) values observed each year were not greatly different. In 1980, the maximum value was about -7°C and in 1981 (wet year) it was about -8.5°C . They also suggested that plants at high vapour pressure deficit (VPD) had cooler temperatures than plants at lower

VPD in the dry year. Similar results of negative correlation between VPD and (T_c - T_a) were reported by Reicosky (1985).

2.5.1 Canopy-air temperature differences (CATD)

The canopy-air temperature differences (CATD) represent an integrated response of a crop to prevailing weather and soil water conditions and therefore, this difference was considered to be an important variable for quantifying plant water use and grain yield (Jackson, 1982). In studies on canopy temperatures of wheat, Singh et al.(1985) observed the following results:

i) significant differences were found in the grain yield, T_c and (T_c -T_a) of cultivars, under both the stress, and non-stress treatments of irrigation and

ii) grain yield was negatively correlated significantly with average afternoon T_c (r= -0.92) and average afternoon CATD (r= 0.94).

Their results indicated that cultivars differ in their T_c and CATD. Plant temperatures were significantly correlated with grain yield especially in non-stressed environment. Steiner et al. (1985) monitored foliage temperatures at noon time and utilized them as indicators of plant stress. In their study, the mean differential between T_c and T_a from jointing to late grain filling showed a strong negative linear relationship to grain number per unit soil area (r^2=0.88 and to final yield (r^2 = 0.86).

Gates (1968) observed that most of the plants became cooler than the air temperature between air temperature range of 30 to 40°C and below these temperatures, the leaves were observed to be warmer than air. The mid-day temperature of sunlit leaves of non-stressed and moderately stressed plants was generally 1-2°C below air temperature and corn crop does not develop water stress unless leaf temperature exceeds air temperature (Gardner et al.,1981b).

2.5.2 Canopy temperature and evaporation

Canopy temperature indices have been shown to be related to evapotranspiration and grain yield for many crops at various locations. Idso et al. (1977) have developed the stress degree-day (SDD) concept to estimate evapotranspiration and yield relations for a variety of irrigated crops.

2.5.3 Stress degree days

The SDD concept is a promising method that involves the mid-day measurement of crop foliage/air temperature differences on a daily basis throughout the season.

Results reported by Idso et al. (1977), Jackson et al. (1977) and,Walker and Hatfield (1979) showed that ET is both linearly and inversely related to cumulative SDD (Σ SDD) values for Durum wheat. They also inferred that the relationship of ET with ΣSDD is influenced by date of planting. Similar results were reported by Diaz et al. (1983).

Grain yield was found to decrease with increasing Σ SDD (Idso et al.,1977; Walker and Hatfield, 1979; Diaz et al.,1983).

A low goodness of fit ($r^2 = 0.54$) of yield with ΣSDD for the combined data from the three planting dates was obtained by Diaz et al. (1983). The goodness of fit for individual planting dates was large ($r^2 = 0.80$ to 0.96). However, in their studies on red kidney beans Walker and Hatfield (1979) reported that field-stress degree day concept was stable over a wide range of planting dates.

In an experiment conducted on canopy temperatures of sugarcane, Khera and Sandhu (1986) observed a diurnal variation on cloudless day. They reported that canopy temperatures (T_c) of both the unstressed and stressed sugarcane on this day generally followed air temperature (T_a), but remained cooler than air. The ($T_c - T_a$) differences at 0950, 1455, 1550 and 1745 hrs were -6.1, -12.4, -11.8 and -7.5°C, respectively for unstressed crop and -5.4, -11.2, -8.1 and -6.8°C, respectively for the stressed sugarcane. The canopy and air temperature trends on the cloudy day were in general similar to those observed on non-cloudy day. However, differences were smaller on the former day than the latter which was relatively cooler. Environmental stress was lower on cloudy day than on clear day.

Thus, while the stress degree-day concept has been widely applied both for stressed and non-stressed crops and found useful for correlating with grain yields, information on SDD for different growth stages in different crops based on daily measurements of canopy temperature is limited in our country. The behaviour of canopy, ambient temperatures and CATD with respect to cloudy and clear sky condition needs further investigation, as reported investigations on these aspects are sparse.

2.6 EFFECT OF TEMPERATURE ON CHLOROPHYLL CONTENT

2.6.1 Leaf chlorophyll content

Marked differences in chlorophyll contents were recorded both between ecosystems and seasonally at each ecosystem. The concentration of chlorophyll in the various kinds of plant material differ greatly. Ovington and Lawrence (1967) showed that chlorophyll concentraction differences are related to environmental conditions and that the variations depend upon the month of sampling over the crop growth period. In studies made by Anderson (1967) it was reported that high chlorophyll content of plant communities is a concomitant of large leaf area index, increasing radiant energy absorption and total dry matter production. They also inferred that as the LAI of a plant community increases so will the crop chlorophyll content even if the average content per unit area of leaf decreases somewhat.

Yield was more closely correlated with chlorophyll contents in wheat crop (Tarchevskii and Andrianova, 1980). In their study of 12 wheat cultivars varying in maturity, Cupina *et al*. (1979) reported that chlorophyll content varied between year and between leaves in order of flag leaf > leaf below flag leaf > lower leaves. They also inferred that late cultivars contained more chlorophyll than early ones especially at heading; after heading the chlorophyll content decreased. In a study on soft red winter wheats Johnson and Ohki (1981) reported that total chlorophyll content varied from 4.5 to 5.3 mg/g fresh weight and differences between planting dates were found significant . In their experiments, the first harvest was significantly higher than the second harvest date for total chlorophyll. Friend (1960) observed maximum fresh weight coinciding with the time of maximal chlorophyll content.

2.6.2 Chlorophyll and temperature

The interaction between chlorophyll and temperature was studied under controlled conditions with wheat crop in cultivar Chris by Kuroyanagi and Paulsen (1985). They observed that increasing temperatures from 21/15°C to 35/25°C (day/night) after anthesis decreased chlorophyll content. Ray et al. (1978) reported that at low temperature, chlorophyll production was reduced and chlorophyll content increased during later growth whereas high temperatures reduced chlorophyll content.

The effect of temperature on chlorophyll accumulation was studied in etiolated wheat seedlings by Lubimenko and Hubbenet (1932) for periods of time upto 72 hours. The highest rate of formation and greatest chlorophyll content was found at 26°C. Very little chlorophyll was found below 4°C or above 44°C. According to them, this effect of temperature probably acts through the temperature control of protochlorophyll formation.

At the constant temperature of 25°C maintained in controlled experiments, Friend (1960) observed that chlorophyll content in the second leaf increased with increase in light intensity. The mean chlorophyll content in the first two leaves (mg per 10 g fresh weight) was 7.8 at 30°C, 4.9 at 34°C, 4.5 at 35°C and only 1.8 at 36°C. The rate of formation was also slow below 5°C. At temperatures below 20° C however, the greatest amount of chlorophyll was found at the intermediate light intensities (Friend, 1960). Bennett et al. (1982) inferred from their growth chamber studies in maize, that chlorophyll concentrations changed in response to both growth and acclimation temperatures. Those grown at 16°C had the lowest concentration and those grown at 35°C the highest chlorophyll concentration, changed over a 24 hour acclimation period in both expanding and fully expanded leaves, increasing when plants were transferred to higher temperatures and decreasing when the transfer was to lower temperature.

Total chlorophyll content at 25/20°C was observed to be higher at 11 hours photoperiod than at 14 hours photoperiod in several selections by Herath and Ormrod (1979) while the total chlorophyll content at 30/25°C varied with photoperiod and selection.

Friend et al. (1962) demonstrated the extremely critical temperature dependence of chlorophyll accumulation; a rise of about 0.5°C at a temperature of 34°C could change the pattern of normal chlorophyll accumulation and subsequent growth to failure of chlorophyll accumulation and early death in Marquis wheat.

It is evident that detailed investigations regarding the behaviour of chlorophyll content at different crop growth stages and the possible short term effects of temperature under field conditions had not been widely reported. There is insufficient literature particularly with respect to phenology and crop growth rates in relation to chlorophyll content as affected by the thermal regime in wheat crop grown under field conditions.

2.7 SPECTRAL REFLECTANCE-PHENOLOGY AND LEAF CHLOROPHYLL CONTENT

Studies of the optical properties of leaves have demonstrated that the reflectance of light in the chlorophyll absorption bands within the red region of the spectrum, is causally and negatively related to the concentration of chlorophyll within the leaf (Thomas and Gausman, 1977).

In studies of canopy reflectance where LAI is used to represent the state of canopy as seen by the sensor the concentration of chlorophyll (total chlorophyll per unit area of ground) within the canopy usually has a positive correlation with the LAI of the canopy. As a result Tucker et al. (1975) mentioned that the concentration of chlorophyll usually shows a negative correlation with the red and positive correlation with the near infrared canopy reflectance. Curran and Milton (1983) studied the relationship between the chlorophyll concentration, LAI and canopy reflectance. They reported that:

i) canopy reflectance is primarily related to the area of leaves covering the soil (LAI)

ii) there is a causal relationship between LAI and canopy reflectance, and

iii) there is a non-causal co-variate relationship between chlorophyll concentration and both LAI and canopy reflectance. In experiments conducted on winter wheat by Hinzman et al. (1986), nitrogen application reduced visible, increased near IR and decreased middle IR reflectance, and these changes were related to higher chlorophyll content and leaf area. Inada (1985) evaluated the ratios of spectral reflectance and chlorophyll content in wheat cv. Norin No.61. A chlorophyll-dependent visible band (500-600 nm) and a chlorophyll independent band (750 nm) were defined from hemispherical reflectance spectra. Highest correlations were observed between ratio (P800:P550) of reflectances and the chlorophyll content per unit leaf area.

Wheat, oats and barley reflected 5-20 per cent of the incident solar radiation in visible wave length (Glick et al.,1979). Visible light reflectance from wheat and barley was found to decrease from emergence to heading, and to increase from heading to maturity. These changes were inversely correlated with changes in chlorophyll concentration. They also observed that the reflectance from wheat was significantly greater in the chlorophyll absorption band during tillering and heading. Ahlrichs and Bauer (1983) found a high correlation between reflectance factor and percentage soil cover, LAI and biomass. In his report Tucker (1979) showed that red (620-720 nm) and photographic infrared (730-900 nm) spectral data and their various linear combinations had a strong correlation with photosynthetically active biomass. In a study of seasonal change, Wiegand et al. (1979) observed that reflectance from the plant canopy increases with LAI but at an exponentially decreasing rate as LAI increases. They also inferred from their experiments that in photosynthetically active radiation wavelengths, represented by 500 to 600 and 600 to 700 nm wave bands (MSS 4 and MSS 5), LAI, plant population and green biomass are negatively correlated with reflectance. Similar results were reported by Shashikumar et al. (1984).

Ajai et al. (1984) obtained different spectral reflectance curves showing the response of crop at various stages of growth. The decrease in reflectance at red region and increase in the near-IR with crop growth was observed by them and was attributed to chlorophyll concentration and green leaf biomass changes with plant growth. They also observed relationship between LAI, chlorophyll content and spectral reflectance at infrared wavelength to be linear.

It is evident that studies on spectral reflectance and chlorophyll relationship at different phenological stages in crops in our country have not been extensively reported and need further attention.

The foregoing review on the response between plant growth and developent in relation to temperature has shown that higher temperatures have an adverse effect on crop growth and development. Most of the studies reported were carried out under controlled conditions at fixed day/night temperatures with a very few reports on field experiments.

Of all the growth stages, research was confined mainly to the grain filling period of crop growth. Since the effect of environmental factors like temperature at earlier stages of growth is also known to influence further development and grain yield, it appears necessary to study such responses under field conditions.

The review also shows, that application of heat unit system in the wheat crop was limited to prediction of maturity dates. It should be worthwhile to utilise this technique for comparison of plant response at different growth stages. As far as wheat crop is concerned extensive information is not available with reference to accumulated heat unit system.

Similarly the review shows that effect of temperature on chlorophyll content and spectral response at different phenological stages of crop growth need to be further investigated.

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MATERIALS AND METHODS

3. MATERIALS AND METHODS

The field experiments described in the present investigation have been carried out in the experimental farm area of the Indian Agricultural Research Institute (I.A.R.I.), New Delhi during the period November, 1985 to April, 1987. The details of the materials used and techniques adopted in this investigation are given in this chapter.

3.1 CLIMATE AND SOILS

3.1.1 Climate

New Delhi is situated at Lat. 28° 35'N, long. 77°12' E and at an altitude of 228.16 m above mean sea level. It has a sub-tropical semi-arid climate, characterized by hot, dry summers and cool winters. Summer maximum temperatures reach as high as 46.8°C while winter minimum temperatures touch as low as 1°C. Average annual precipitation is 710 mm, of which nearly 600 mm is received during the south-west monsoon period i.e., July to mid-September. Climatic normals for Delhi are presented in Table 1.

3.1.2 Soils

The soils of I.A.R.I. belong to the major soil group of Indo-Gangetic Alluvium. The soils of the experimental field in particular belong to Halambi series which comprise moderately well drained to well drained, very deep, loamy soils of dark brown to dark yellowish brown colour. Some of the physical and physico-chemical properties are given in Table 2.

Table 1. Climatic normals for Delhi (I.A.R.I. observatory) based on 30 years average (1941 - 1970)

Month	Max. Temp °C	Min. Temp °C	Evapo-ration mm/day	Duration of bright sunshine hours	Wind speed km/hr	Rain-fall mm
Jan.	20.3	6.0	2.3	7.5	4.0	20.4
Feb.	23.6	7.7	3.9	8.3	4.8	16.7
Mar.	29.5	12.9	5.4	8.0	5.4	17.1
Apr.	36.0	18.9	9.5	8.9	6.5	5.5
May	40.0	24.1	12.2	9.3	8.2	13.3
June	40.0	27.6	12.8	7.3	10.5	45.8
July	35.2	26.7	8.4	6.0	8.8	214.2
Aug.	32.8	25.8	5.6	6.0	6.2	201.0
Sept.	33.3	23.6	5.5	7.3	5.6	137.1
Oct.	32.2	17.4	5.2	8.8	3.8	30.1
Nov.	28.0	6.8	3.8	9.0	2.7	2.4
Dec.	22.2	6.2	2.4	8.0	3.7	5.9

Table 2. Physical and physico-chemical properties of the soils of the experimental site

Depth (cm)	Bulk density (g/cc)	Particle size distribution			pH (1:2.5)	Electrical conductivity m mho/cm (1:2.5)	Organic carbon (%)
		Sand (%)	Silt (%)	Clay (%)			
0 - 15	1.59	48.5	35.9	13.9	7.2	0.45	0.47
15 - 30	1.62	49.1	37.7	14.2	7.5	0.25	0.24
30 - 60	1.59	39.2	37.1	25.2	7.6	0.25	0.18
60 - 90	1.62	42.3	32.5	24.0	7.5	0.25	0.13
90 - 120	1.62	44.8	32.5	22.4	7.7	0.30	0.12

3.2 CROP

Wheat crop was raised for the present investigation. Three cultivars of wheat (Triticum aestivum L.) viz., ISD 397, ISD 513 and HD 2281 (referred to as varieties V_1, V_2 and V_3 respectively) with different maturity periods and having different habitats of growth were used in this study. ISD 397 is of medium maturity, ISD 513 is a late maturing variety while HD 2281 is an early maturing variety. The crops were raised during rabi seasons of 1985-86 and 1986-87.

3.2.1 Treatments

Three varieties V_1, V_2 and V_3 mentioned above were sown on three different dates (P_1, P_2 and P_3) in the two seasons as shown below:

Rabi season	Date of sowing		
	P_1	P_2	P_3
1985-86	15-11-85	30-11-85	15-12-85
1986-87	18-11-86	01-12-86	15-12-86

3.2.2 Experimental layout

The layout (Fig. 1) consisted of 27 plots of size 6m x 6m laid out in a randomized block design with three replications.

Varieties 3

Replications 3

Treatments (planting dates) 3

Total number of plots 27

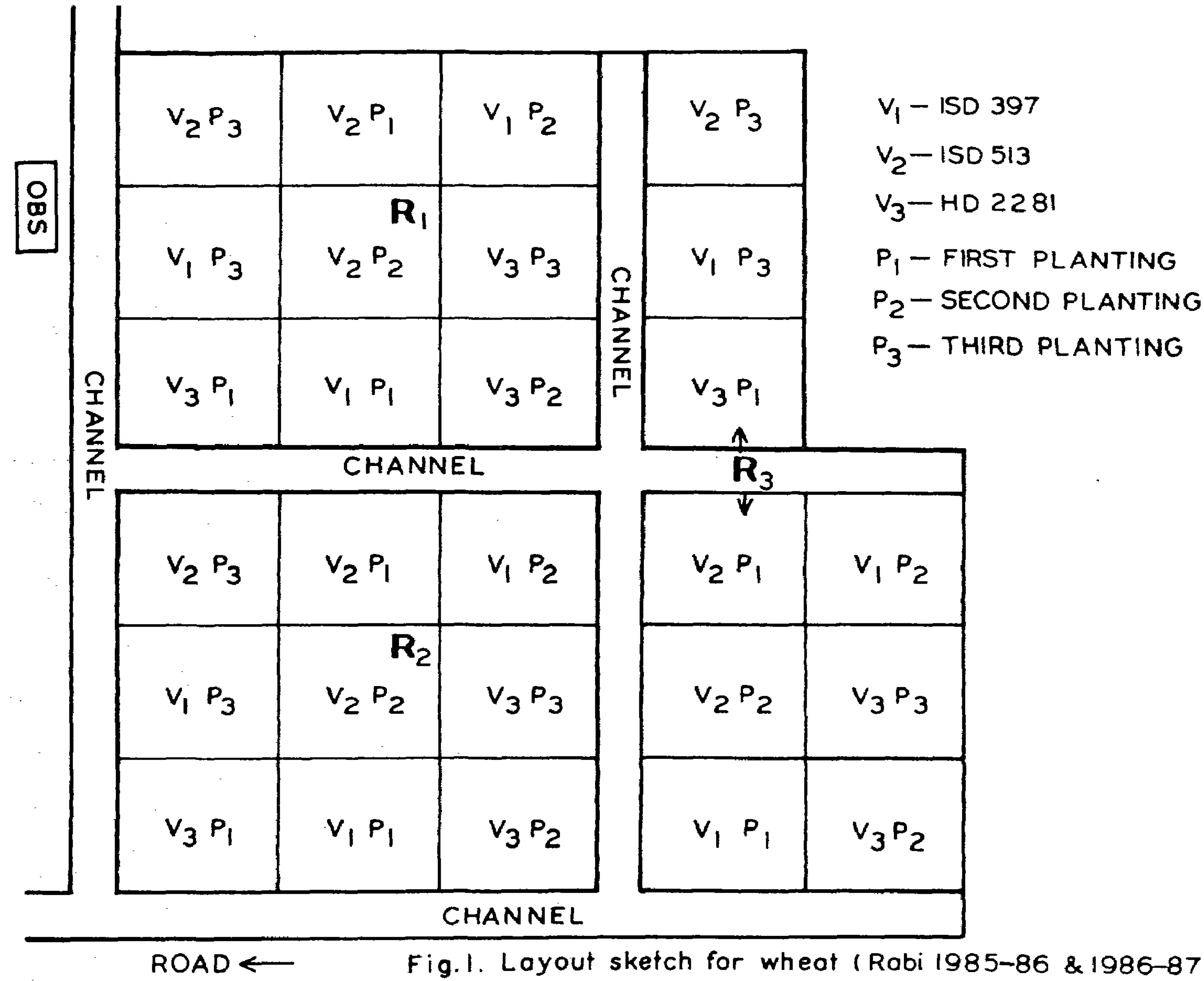

Fig.1. Layout sketch for wheat (Rabi 1985–86 & 1986–87)

3.2.3 Fertilizer application

Urea @ 120 kg N/ha, single superphosphate @ 40 kg P_2O_5/ha and muriate of potash @ 40 kg K_2O/ha as per recommended practice were added. Half the quantity of urea was mixed with other two fertilizers and applied to the soil before sowing while the other half was applied at the time of first irrigation.

3.2.4 Cultural practices

Cultural operations like thinning, weeding etc.were carried out at appropriate time after sowing.

3.2.5 Irrigation

Irrigations were given at three critical stages viz., crown root initiation, jointing and milk stages. To ensure maintenance of "not short of water" conditions and to retain the soil moisture in the root zone fairly within the "available" range, additional irrigations were also given whenever the gravimetric samples showed that the soil moisture got depleted to a value below 50 per cent 'available water' in the 15-60 cm depth.

3.2.6 Phenological observations

The plants were inspected frequently to closely follow the phenological events. From these observations boot leaf (BL), heading (H), anthesis (A), milk (M), soft dough (SD) and hard dough (HD) stages were identified and used in further analysis. The phenological stages for the present investigation are defined as follows:

a) boot leaf stage is defined as the stage when the ultimate leaf to come out was observed by closely examining the leaf for the absence of another folded leaf in it

b) heading stage is defined as the stage when the base of the rachis (or head) reached the same height as the ligule (or base of the shot blade)

c) anthesis stage is defined as that stage when anthers could be observed in the central portion of the earhead.

d) milk stage is defined as that stage when milk oozes out of the kernel on pressing it between the fingers

e) soft dough stage was determined by observing a kernel from the central portion of the earhead. At this stage the kernel is easily deformed when pressed between the fingers but no 'milk' or liquid exudes under such pressure

f) physiological maturity or hard dough stage was determined when the kernel becomes hard and it was no longer possible to deform it when pressed between the fingers.

Following the above definitions, boot leaf, heading and anthesis stages were noted in the following manner. In a meter length of a row, the shoots were counted and the percentage of shoots attaining the particular stage was noted. This was done at four places at random in each plot leaving the border rows. The day when 50 per cent of the samples in each treatment reached the stage as defined above, that date was taken to represent the particular event.

3.2.7 Biomass

Oven dried, above-ground plant material was used to determine biomass production at periodical intervals. For this purpose leaving two border rows in each plot, two rows were earmarked for sampling. At each sampling, plants from 50 cm length were cut at the ground level. Then samples were oven dried at 80°C for 48 hours and weighed. Oven drying was continued till constant weights were obtained.

3.2.8 Leaf area index

Leaves were separated from the fresh biomass samples to measure leaf area. Leaf area meter (LICOR Bench model LI 3100), was used to measure the leaf area at frequent intervals. Fresh green leaves and senescing leaves were separated and their respective leaf areas were measured for determining per cent contribution of senescing leaves to leaf area.

3.2.9 Earhead weight

Twenty earheads were collected at random from the plot from each replicate at 5 day intervals and their oven dry weights were noted at regular intervals.

3.2.10 Chlorophyll content of leaves

Chlorophyll content of the leaves was determined at different stages of crop growth regularly. To determine this, leaves were collected from top, middle and bottom levels of the plant, depending upon the growth stage and height of the plant. The samples were collected from four places at random from each of the plots. Chlorophyll content observations were started from 30 days after sowing and then continued periodically.

The method followed in total chlorophyll determination was as described by Hiscox and Israelistam (1979). Fifty mg of leaf pieces cut from the middle portion of the sample leaves were weighed. Then these weighed leaf parts were taken in a test tube and 20 ml of dimethyl sulphoxide ($DMSO_4$) was added. The test tubes were then kept in the oven at 65°C for 3 hours. Then transmission (TR) values at 652 nm for each leaf sample were noted using Spectronic 20. From TR values, optical density (OD) values were determined. Then the total chlorophyll content was determined by using the formula:

$$\text{Total chlorophyll} = \frac{OD_{652}}{34.5} \times \frac{V}{W} \text{ mg/g fresh wt.}$$

where, V = volume of $DMSO_4$

W = weight in mg of fresh leaf

3.2.11 Harvest

The crop was harvested manually with sickles. The sample size for yield estimation consisted of a randomly chosen area of 2m x 2m in each plot. Grain weight as well as straw weight were noted.

3.2.12 Harvest index

Harvest index was determined by dividing the grain yield with total biological yield expressed as percentage and is given by

$$\text{H.I.} = \frac{\text{Grain yield (q/ha)}}{\text{total biological yield (q/ha)}} \times 100$$

3.3 SOIL MOISTURE

In this crop soil moisture was determined by auger sampling method for the depths 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm in all the treatments. The samples were oven dried at 105 °C till constant weight was obtained. This sampling was done to maintain the crop at 'not-short of water' condition, through irrigation.

3.4 ACCUMULATED HEAT UNITS

Accumulated heat units were computed using the methods as follows:

3.4.1 Growing degree days (GDD)

The method employed to calculate the growing degree days following Nuttonson (1955) is

$$GDD = \sum_{i}^{N} \left[\frac{T_{max} + T_{min}}{2} - B.T \right]$$

where T_{max} = maximum temperature (°C) of the day

T_{min} = minimum temperature (°C) of the day

B.T. = base temperature (5°C)

N = period during which heat units are accumulated

3.4.2 Helio-thermal units

Helio-thermal units were computed following Sastry and Chakravarthy (1985). In this method the actual bright sunshine hours were used in place of the total day length to arrive at the heat summations. Thus the product of the day degrees (from base temperature 5°C) on any day and the corresponding actual bright sunshine hours had been termed as helio-thermal units and accumulated for the period of crop growth.

3.4.3 Phenothermal indices

With a view to express the complex relationships of the duration between phenological stages to the prevailing ambient temperature and their compensatory adjustment under field conditions in a single parameter, the heat units accumulated per growth day between two phenological stages were computed to obtain 'phenothermal index' which is expressed as degree day/growth day; this procedure was used earlier by Chakravarthy and Sastry (1983).

3.5 HEAT USE EFFICIENCY

To compare the relative performance of the different varieties and treatments with respect to utilization of heat in terms of growing degree days during the crop growth period, heat use efficiency was computed on the analogy of water use efficiency and is given by :

$$\text{H.U.E.} = \frac{\text{cumulative biomass (g/ha)}}{\text{accumulated heat units } (^{\circ}\text{C})}$$

The following observations were taken daily and some of them for diurnal variations on particular days, representing different growth stages of crop.

3.6 CROP GROWTH RATES

Crop growth rates were calculated from the smoothed curves for weekly biomass observations in each treatment.

$$C\ G\ R = \frac{\text{accumulated biomass}}{\text{number of days}} \qquad g/m^2/day$$

3.7 GLOBAL RADIATION

Global radiation was measured with Eppley Pyranometer model 8-48 (sensitivity 7.03 mv/Cal/cm²/min and of internal resistance 350 ohms at 25°C). Diffuse radiation was measured by shading the sun to avoid direct radiation.

3.8 NET RADIATION

Net radiation was measured with a portable Net Radiometer model CN-2 supplied by Middleton and Co., Australia (sensitivity 0.372 mv/mw/cm² at 20°C, and with internal resistance of 86 ohms). Measurements were taken 50 cm above the crop canopy. Net radiation was also calculated using the formula developed by Penman (1948).

Rn, the net radiation is estimated as follows:

$$Rn = Ra(1-r)\left(0.32+0.46\frac{n}{N}\right) - \sigma T_a^4\left(0.55-0.092\sqrt{e_d}\right) \times \left(0.10 + 0.90\frac{n}{N}\right)$$

where, Ra = Angot's value of solar radiation

r = albedo for crop surface (0.25)

n = actual duration of bright sunshine hours

N = maximum possible duration of sunshine hours

Ta = mean air temperature (°A)

e_d = saturated vapour pressure at dew point

3.9 PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

Line quantum sensor (Model LI 191 B, LI 1888-integrating quantum/radiometer/photometer) was used to measure the amount of photosynthetically active radiation (PAR) at different heights within the crop canopy. Observations were taken at the top of the canopy, at mid height and also keeping the sensor at 5 cm above ground level.

To obtain reflected PAR from the canopy and the ground, the line quantum sensor was exposed in an inverted position at the respective heights. Observations were also taken by exposing the instrument along the and across the rows of crop.

3.10 MESH COVERED PAN EVAPORATION

Values of evaporation in mm from class A mesh covered pan evaporimeter as per specification of I.M.D. (installed in the nearby meteorological observatory) were taken for the duration corresponding to the crop growth period.

3.10.1 Energy gain

Energy gain was computed from the differences of net radiation (calculated by Penman's method) and evaporation at weekly intervals.

3.11 SATURATION DEFICIT

Saturation deficit was calculated for morning 0721 IST and afternoon 1421 IST, and for the day from the differences of actual vapour pressure and saturated vapour pressure values from dry and wet bulb thermometers in the Stevenson's screen.

3.12 LEAF DIFFUSION RESISTANCE AND LEAF TEMPERATURE

A microprocessor controlled LICOR (Model LI-1600) steady state porometer which directly measures the leaf diffusion resistance (s/cm) and leaf temperature (°C) was used. For these measurements topmost two leaves were considered and observations were taken after the disappearance of dew from the leaves. Five or more intact leaves were used for each set of observations which were repeated at hourly or half hourly intervals.

3.13 CANOPY TEMPERATURE

Crop canopy temperatures were taken daily from February onwards in the respective cropping seasons. The canopy temperatures were measured using Telatemp Infrared Thermometer (model AG 42, with a 3° field of view, response time less than a second, accuracy ± 0.5°C and of spectral response 8 to 14 microns). Ambient temperature was also noted with the same instrument. Observations were taken at 1400 hrs daily till physiological maturity from four oblique angles from the different sides of the plot and averaged.

Canopy air temperature differences (CATD) values were noted along with canopy temperature readings from the same infrared thermometer.

3.13.1 Stress degree-days (SDD)

The summation of daily CATD values (Σ SDD) was made for each wheat planting from heading to physiological maturity. The procedure described by Jackson et al. (1977) was followed:

$$SDD = T_c - T_a$$

where, T_c = canopy temperature

T_a = ambient temperature

3.14 SPECTRAL REFLECTANCE

Spectral reflectance measurements were taken with a 12 band (multiband) ground truth Radiometer with range selector (W/cm^2). The measurements were taken with spectral Radiometer held at 2 m above the crop canopy. Spectral reflectance measurements were made between 1200 hrs and 1300 hrs I.S.T. Standard readings with barium plate were taken before and after the set of observations on crop canopy.

3.15 STATISTICAL ANALYSIS

The following statistical analysis was carried out in interpreting some of the results presented in the present investigation:

a) analysis of variance

b) coefficient of variation

c) correlation coefficients and regression equations

For this analysis the methods suggested by Fisher (1970) were followed.

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RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Results obtained in the field experiments conducted during *rabi* seasons 1985-86 and 1986-87 on wheat to study the effect of temperature are detailed and discussed below.

4.1 ENVIRONMENTAL CONDITIONS DURING *RABI* 1985-86 AND 1986-1987 SEASONS

Environmental conditions that prevailed during the *rabi* 1985-86 and 1986-87 seasons as recorded at the I.A.R.I. observatory are presented in Fig.2. From the daily data collected, mean daily values during the different standard meteorological weeks (Appendix-I) in both the seasons were computed. Weekly mean values for the different parameters are given in Appendix-II and III.

4.1.1 Maximum temperature

During the *rabi* 1985-86 season, the weekly mean maximum temperatures ranged between 18.1 to 37.1°C. Temperatures were the lowest during the early vegetative to late vegetative stages (18.1°C). During the grain filling and maturity stages they increased gradually from 20.5 to 37.1°C. Maximum temperatures were 2 to 5°C below normal from 7th to 9th weeks. Daily temperature data showed that during 10th and 11th weeks (grain filling to maturity stage) maximum temperatures were also above normal by 3-4°C followed by below normal temperatures (by 6-7°C) in subsequent weeks because of rainfall received during this period. During the *rabi* 1986-87 season maximum temperatures decreased gradually to 18.2°C in the last week of December, rising thereafter until 2nd week of January and again recording lowest temperature of 16.7°C in the 3rd week. Daily temperature data showed that during 3rd week of January the temperatures were below normal (of the order of 6 °C) in association with occurrence of rainfall. Then there was a continuous rise in temperatures reaching a value of 34.4°C at maturity period. In general, in the 1986-87 seasons, weekly mean maximum temperatures during the late vegetative stage (Ist week) till grain filling stage were 2-5°C higher than in the 1985-86 season.

4.1.2 Minimum temperature

Weekly mean minimum temperatures during 1985-86 crop growth season ranged between 3.1 to 19.6°C. Temperatures were the lowest during the vegetative stage compared to the other stages. An examination of daily temperature data showed that in this year on most of the days minimum tempteratures were below normal during 1st and 3rd week of January, 1st and 4th week of February, and first week of March (of the order of 3-4°c). Again from 15th to 30th March the temperatures were below normal deviating by 4-5°C.

During 1986-87 season the weekly mean minimum temperatures ranged from 2.0 to 19.3°C. Daily minimum temperatures were below normal for prolonged periods by 3-4°C from 17th January to 15th February and again from 25th February to 15th March. At other times the minimum temperature showed nearly normal conditions except for a spell of above-normal temperatures during the grain filling period intermittently which would usually result in an increase in crop respiration. The daily minimum temperatures during the reproductive stage

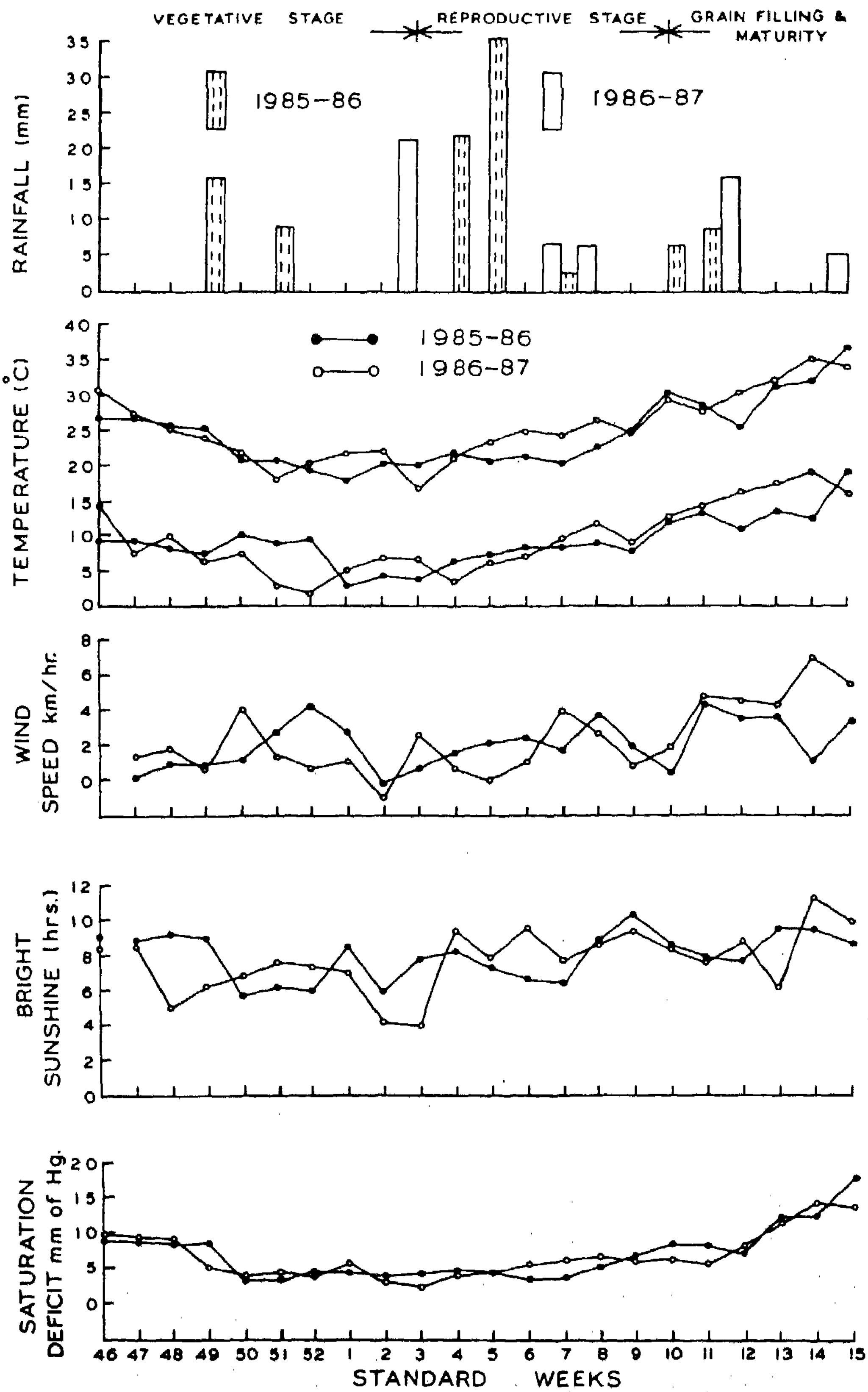

Fig. 2. Environmental conditions during 1985-86 & 1986-87 rabi seasons.

were 0.7 to 5.3°C higher than those in the 1985-86 season. On the whole, it can be said that 1985-86 season has cooler temperatures in respect of both maxima and minima than the 1986-87 season.

4.1.3 Duration of bright sunshine hours

The number of bright sunshine hours during 1985-86 season varied from 9.3 per day at the time of first sowing to a minimum of 5.9 per day during the second week of January and thereafter again increased to 9.5 hours per day at crop maturity period. During the 1986-87 season, they varied from 8.6 at the time of first sowing to a minimum of 3.9 hours per day during the 3rd week of January in association with rainfall due to a western disturbance and thereafter again increased to 11.2 hours per day at the crop maturity period. A salient feature is that while during rabi 1985-86 longer bright sunshine hours (7-8 hours per day compared to 4-6 hours per day in 1986-87) were observed during the vegetative stage, during 1986-87 season bright sunshine was of longer duration (8-9 hours per day compared to 6-7 hours per day in 1985-86) during the late vegetative to reproductive stages.

4.1.4 Wind speed

Mean daily wind speed ranged from 1.8 to 5.9 km/hr in the 1985-86 rabi season whereas during rabi 1986-87, it ranged from 1.1 to 9.0 km/hr. In general, the mean daily wind speeds in 1986-87 season were slightly higher than in 1985-86 season by 2 to 3 km/hr.

4.1.5 Rainfall

During the *rabi* 1985-86 season the total rainfall received from December to March was 80.2 mm on 11 rainy days. Highest rainfall of 39.6 mm was received in February (6th and 7th week) corresponding to anthesis and heading stages in variety ISD 397 (V_1), vegetative stage in ISD 513 (V_2) and post vegetative stage in HD 2281 (V_3).

Rainfall during the *rabi* 1986-87 season was only 61.8 mm which occurred on 12 rainy days from December to March. Rainfall of 21.7 mm was received on January 17th and again 16.4 mm in March with two more spells in between. In the 1985-86 *rabi* season all the first plantings were lodged due to a thunderstorm that occurred on 19th March, 1986. On the whole during the main vegetative stage of crop growth, 1986-87 *rabi* season did not receive any rainfall unlike that during the 1985-86 season.

4.1.6 Saturation deficit

Saturation deficit followed the pattern of maximum temperature in both the seasons viz., starting at a high value, decreasing to a minimum and thereafter showing an increasing trend. Starting from 8.9 mm at the time of sowing the saturation deficit decreased to a minimum of 2.3mm at the beginning of reproductive stage (week 3) and thereafter increased to a maximum of 18.2 mm at harvest. Saturation deficits during 1985-86 ranged from 3.2 to 18.2 mm of Hg and remained lower than those in 1986-87 by about 2 mm during early to mid reproductive stage (Fig.2).

The above observations show that the maximum and minimum temperatures, duration of bright sunshine hours and saturation deficits were higher from the late vegetative to early grain filling stage during rabi 1986-87 compared to the 1985-86 season. However, rainfall was higher in the first season (rabi 1985-86) than in the second (rabi 1986-87). The lowest minimum temperatures in both the seasons remained above the freezing point and generally, environmental conditions remained in the range favourable for crop growth, though relatively 1986-87 season can be termed as warmer than 1985-86 rabi season.

4.2 PHENOLOGY

The occurrence of the six phenological events as enumerated earlier in the two rabi seasons 1985-86 and 1986-87, for the three varieties ISD 397 (V_1), ISD 513 (V_2) and HD 2281 (V_3) planted at 15 day intervals were carefully noted following the definitions and procedures mentioned in section 3.2. and the number of days taken to reach the different stages are shown in Table 3.

4.2.1 Rabi 1985-86

ISD 397 (V_1): The variety ISD 397 (V_1) took 64, 66 and 72 days to reach boot leaf stage in first (P_1), second (P_2) and third (P_3) plantings respectively. There was not more than two days difference at heading and anthesis stages between the plantings. The duration between anthesis and maturity decreased with delay in planting. It took 128, 124 and 119 days to come to maturity in P_1, P_2 and P_3 respectively.

Table 3. Duration of phenological stages (days) in wheat during 1985-86 and 1986-87 *rabi* seasons

Phenological stages		IST 397				ISD 513				HD 2281			
		1st Pltg.	2nd Pltg.	3rd Pltg.	Diff. of 1st & 3rd	Ist Pltg.	2nd Pltg.	3rd Pltg.	Diff. of 1st & 3rd	1st Pltg.	2nd Pltg.	3rd Pltg.	Diff. of 1st & 3rd
Boot leaf	I	64	66	72	8	80	78	77	3	60	65	67	7
	II	68	71	70	2	84	83	74	10	64	68	68	4
Heading	I	80	78	80	0	99	95	85	14	82	83	83	1
	II	83	79	77	6	100	93	82	18	84	85	84	0
Anthesis	I	86	85	84	2	107	99	89	18	93	91	87	6
	II	99	86	82	6	108	98	86	19	96	92	86	6
Milk	I	109	103	96	13	121	109	102	19	106	104	100	6
	II	107	100	94	13	119	108	97	22	105	103	98	7
Soft dough	I	117	115	109	8	132	120	115	17	119	116	106	13
	II	114	109	101	13	132	120	112	20	116	115	104	12
Hard dough	I	128	124	119	9	140	127	123	17	132	126	118	14
	II	127	120	111	16	138	126	120	18	129	126	116	13

I = 1985-86; II = 1986-87; Pltg. = Planting.

ISD 513 (V_2): This variety took relatively more number of days in all the three plantings to reach the respective phenological stages when compared with ISD 397. For the boot leaf emergence it took 80, 78 and 77 days in P_1, P_2 and P_3 respectively. It took 8 days from heading to anthesis in P_1 while it was 4 days in case of P_2 and P_3 plantings. With reference to planting dates, difference in duration to maturity was seventeen days between P_1 and P_3 and the variety took 140, 127 and 123 days in P_1, P_2 and P_3 respectively for attaining hard dough stage.

HD 2281 (V_3): This variety took relatively lower number of days in all the three plantings to reach the boot leaf stage when compared with varieties ISD 397 and ISD 513. From anthesis to milk stage it took 13 days in all the three plantings P_1, P_2 and P_3 showing a constant value irrespective of temperature differences. The crop matured in 132, 126 and 118 days in the three plantings in this variety. Between P_1 and P_3 there is a difference of 14 days in the total duration of crop growth during this season.

4.2.2 Rabi 1986-87

ISD 397 (V_1): The variety ISD 397 took 68, 71 and 70 days to reach boot leaf stage in P_1, P_2 and P_3 plantings respectively. From boot leaf to heading it took 15 and 7 days in P_1 and P_3. There was a difference of 13 days in attaining milk stage between P_1 and P_3 respectively. This difference continued till the maturity stage. As the planting was delayed, the number of days taken for attaining the phenological stages decreased. For reaching maturity this variety took 127, 120 and 111 days in P_1, P_2 and P_3 respectively.

ISD 513 (V_3): This variety took relatively more number of days to reach the different phenological stages in all the three plantings. Like in the previous season , for all the phenological stages in P_3 the duration required was lower when compared to the year 1985-86 indicating the effect of warmer temperatures in 1986-87 season. For reaching maturity stage it took nearly the same time as the previous season's crop.

HD 2281 (V_3): The number of days taken from sowing to boot leaf stage did not practically show much differences when compared to the previous rabi season (1985-86). It took 64, 68 and 68 days for reaching boot leaf stage in P_1 , P_2 and P_3 respectively. For maturity it nearly took the same time as in the previous season.

The above results show that the number of days taken for different phenological stages to be reached were in the order of $V_2 > V_3 >$ and V_1 . The observed differences in duration between phenological events in the different plantings for the three varieties agree with those reported by Sofield et al.(1974), I.A.R.I. (1976) and Porter et al. (1987). The varieties V_1 and V_3 took almost the same number of days in the three planting dates whereas only V_2 differed from these two varieties in which case the duration from sowing to maturity increased by 10 days than the time taken by the other 2 varieties. With a view to obtain a comprehensive and comparative picture of the differences in phenological events under the different treatments, it has been summarized in the form of a chart and shown in Fig. 3.

In respect of corresponding planting dates and varieties viz. V_1 , V_2 and V_3 there was practically no difference in the total duration taken from sowing to maturity (hard dough) between rabi 1985-86 and 1986-87 except in $V_1 P_3$. Of all the varieties, V_1 showed effect of seasonal temperature from soft dough stage onwards. It exhibited 3-8 days difference between seasons at soft dough stage for P_2 and P_3 plantings, and at hard dough stage it exhibited maximum difference of 8 days in case of P_3. This is probably attributable to the higher temperatures in 1986-87 in the reproductive stage. Wardlaw et al (1980), Chakravarthy and Sastry (1983a) and O'Leary et al. (1985) also reported similar variations in phenological events with temperature .

4.2.3 Effect of planting date on the duration of phenological stages

The differences in number of days between the successive phenological events (between P_1 and P_3) are shown in Table 3. With the progress of crop development there is increase in duration between the phenological events. For e.g.: while at heading stage in 1985-1986 there is no difference between P_1 and P_3 in the number of days taken to attain this stage, at milk stage the difference increased in V_1 to 13 days. This effect is evident in all varieties in both the seasons.

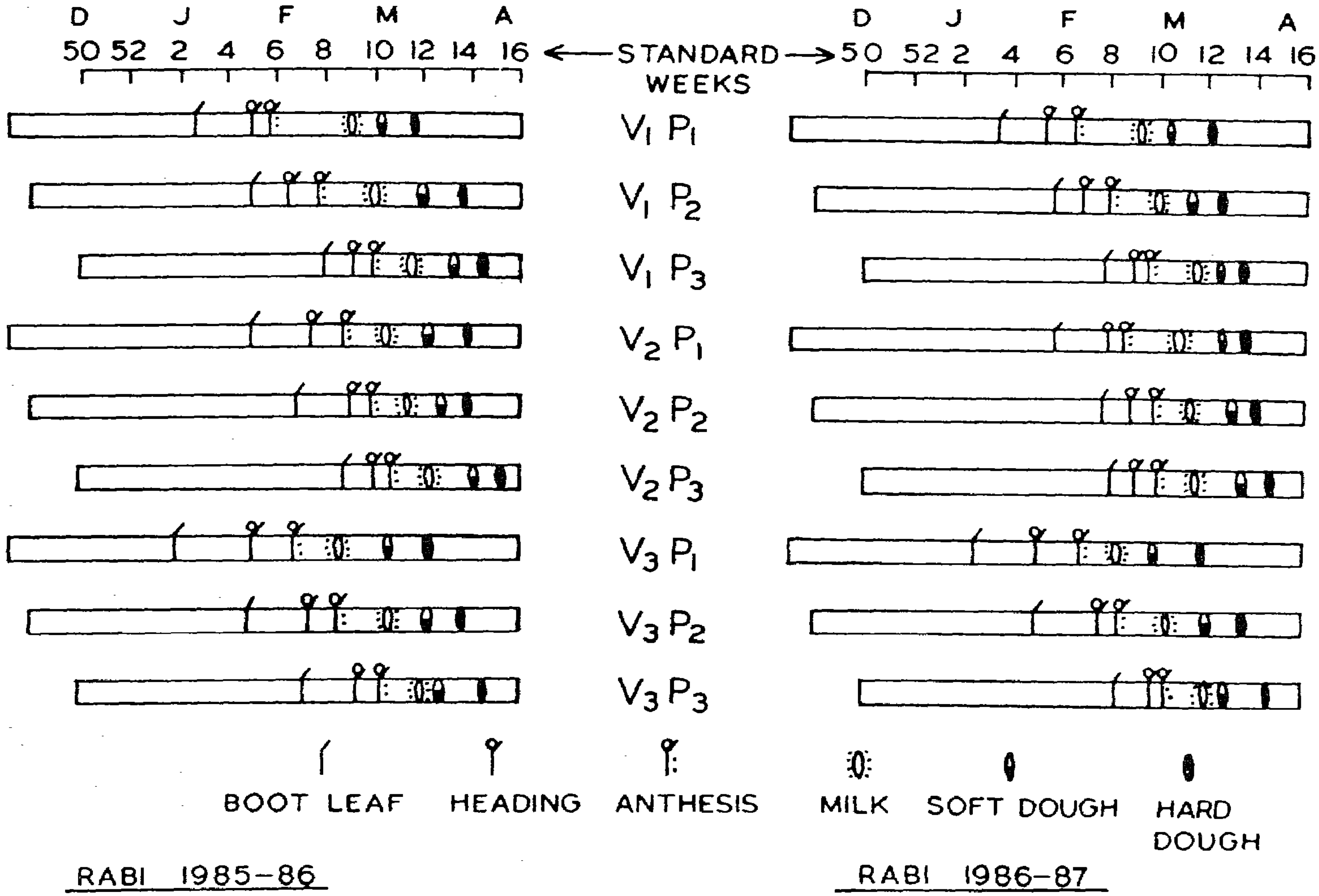

Fig.3. Phenology of wheat crop

Two salient features that are noticed are: (i) V_2 and V_3 reached the different stages nearly in the same number of days, both in the first (cooler) and second (warmer) seasons. In case of V_1 there was increase in number of days in the second season for attainment of heading, anthesis, soft dough and hard dough stages.
(ii) In V_2 both in the first (cooler) and second (warmer) seasons the difference in the duration of attainment of phenological stages between plantings P_1 and P_3 was relatively higher ranging from 17-21 days and the difference between the seasons was of not more than three days.

4.3 DURATION OF GRAIN FILLING PERIOD

Grain filling duration varied with the season and also with plantings in the same season in V_1 and V_3. V_1 took 42, 39 and 35 days in P_1 , P_2 and P_3 plantings. In V_1 the difference between seasons was 3, 5 and 6 days with less number of days during 1986-87 season. Similar trend was observed in V_3 also. P_2 and P_3 plantings were more influenced by high temperatures, thus showing a reduction in duration. Similarly in 1986-87 when the temperatures were high during the reproductive and maturity period the time taken from anthesis to maturity was less in the season clearly showing the effect of high temperatures as also observed earlier by Sayed and Gadallah (1983) and Saini and Dadhwal (1986) in their experiments.

Significantly, in spite of prevalence of high temperatures in <u>rabi</u> 1986-87 after anthesis and a consequent decrease in the number of days taken for the attainment of the different phenological events compared to 1985-86 season, in both the seasons the crop ultimately took the same number of days to mature. This could partly be explained by the fact that the duration from sowing to anthesis stages was little longer in 1986-87 season and as a result the total duration of crop growth period remained nearly the same.

4.4 TEMPERATURE, PLANT GROWTH AND DEVELOPMENTAL CHARACTERISTICS

4.4.1 Biomass production

Data on the above-ground weekly biomass production for the different plantings of the three wheat cultivars for the two rabi seasons 1985-86 and 1986-87 are shown in Table 4.

Rabi 1985-86

ISD 397 : Weekly biomass production upto the 12th week was the highest for the P_2 and the lowest for P_3 , the values being 1825, 1940 and 1620 g/m² for P_1, P_2 and P_3 respectively. This is perhaps because of presence of near normal temperatures for P_2 compared to P_1 and P_3.

ISD 513: In this variety the highest biomass production for the three plantings ranged between 2015 and 1380 g/m², P_3 giving the lowest, showing a reduction in biomass production at later plantings when compared to the earlier ones.

HD 2281 : Highest biomass production was observed in this variety in P_1 followed by P_2 and P_3. Maximum biomass produced in P_1, P_2 and P_3 was 2055, 1755 and 1660 g/m² respectively. In all the plant-

Table 4. Weekly biomass production (g/m²) in wheat cultivars during 1985-86 and 1986-87 *rabi* seasons

	Cv. ISD 397			Cv. ISD 513			Cv HD 2281		
Met. week	1st Pltg	2nd Pltg.	3rd Pltg.	1st Pltg.	2nd Pltg.	3rd Pltg.	1st Pltg.	2nd Pltg.	3rd Pltg.
				Rabi 1985-86					
1	180	85	35	245	60	5	215	50	5
2	240	135	50	300	120	20	285	95	25
3	330	185	75	360	180	40	355	145	60
4	405	270	105	420	240	75	450	210	85
5	510	360	150	525	320	120	540	300	125
6	630	500	195	630	415	165	655	390	185
7	855	640	300	810	580	270	855	510	255
8	1120	930	450	1110	860	450	1185	705	340
9	1490	1275	630	1500	1140	660	1550	1005	445
10	1815	1590	900	1800	1350	885	1855	1315	600
11	1875	1890	1250	1995	1515	1120	2025	1700	900
12	1825	1940	1620	2015	1530	1335	2055	1755	1335
13	1625	1615	1620	1740	1400	1380	1980	1710	1660
14	-	-	1455	1500	1245	1280	1880	1640	1660
				Rabi 1986-87					
1	75	50	15	85	70	15	100	30	20
2	100	80	30	105	105	20	140	45	40
3	150	140	50	150	150	30	210	100	65
4	245	230	70	270	220	45	360	300	100
5	475	300	90	420	300	60	500	430	130
6	555	360	120	480	350	90	575	500	150
7	610	405	210	540	380	120	645	560	210
8	660	485	435	630	420	180	700	630	310
9	795	605	630	730	600	360	810	790	435
10	1080	840	800	840	1150	675	1080	1215	600
11	1265	1110	1005	1140	1305	900	1245	1200	840
12	1350	1125	1205	1260	1365	930	1290	1095	950
13	1185	990	1215	1155	1310	850	910	960	825
14	750	-	1065	1020	1140	-	690	-	690

ings higher biomass was recorded at soft dough stage followed by a gradual reduction in the subsequent period.

Rabi 1986-87

ISD 397: The first planting recorded the highest biomass production throughout the growth season followed by second and third plantings upto 12th week. Later, P_3 showed higher biomass than P_2. The highest biomass production values achieved in this variety were 1350, 1125 and 1215 g/m² for P_1, P_2 and P_3 respectively.

ISD 513 : In this case also P_1 gave the highest biomass production than P_2 upto anthesis stage. From anthesis stage onwards P_2 had the highest biomass production.

HD 2281 : In this variety, the highest biomass production was achieved in the first planting (P_1) followed by P_2 and P_3 with the values of 1290, 1200 and 950 g/m² respectively.

During rabi 1985-86 compared to 1986-87 season, all the varieties and treatments (P_1, P_2 and P_3) showed relatively higher biomass throughout the growth period. The rabi season during 1986-87 being warmer than 1985-86 season, caused lower biomass. This is attributable to the effect of relatively higher tempertures in the second season which have the effect of reducing biomass production due to higher respiration as reported by Wall and Cartwright (1974), Wardlaw et al. (1980) and Ritchie (1987).

In all the varieties and plantings over both the seasons there was a rapid increase in biomass from jointing to soft dough stages as earlier observed by Waldren and Flowerday (1979).

The biomass produced in later plantings (P_3) decreased when compared to the earlier plantings. Reduction in biomass production in late sown wheat was also reported by Doyle and Fischer (1979) and O'Leary *et al.* (1985) and is attributed to prevalence of higher temperatures due to seasonal warming which affects the late sowings.

4.4.2 Leaf area index

Data on leaf area index (LAI for the different plantings of the three wheat cultivars for the two *rabi* seasons 1985-86 and 1986-87 are shown in Table 5.

Rabi 1985-86

ISD 397: Leaf area index during this season ranged from 1.6 to 4.4 from sowing to maturity in P_1. Highest LAI was 4.5 at heading stage. Maximum LAI for the individual plantings was in the order of $P_2 > P_3 > P_1$. The lowest LAI was recorded in P_1 at heading to anthesis stage. Rainfall on 29th January and in early February might have resulted in increased leaf area in P_2 and P_3 when compared to P_1.

ISD 513 Leaf area index values in all the three plantings ranged from 6.5 to 6.0 at the time of heading. The maximum values were reached at heading stage, which are in the order of $P_1 > P_2 = P_3$. This variety showed higher values than V_1.

HD 2281 : This variety had leaf area index values lower than those in V_2. All the three plantings reached their highest values

Table 5. Leaf area index of wheat cultivars

		Days after sowing							
		20	40	60	80	100	120	Peak value	
V_1P_1	I	-	1.6	3.2	4.4	3.4	1.6	4.5	(84)
	II	-	1.5	2.9	4.3	2.9	1.5	4.3	(80)
V_1P_2	I	-	1.1	2.8	4.8	4.6	1.8	5.3	(89)
	II	0.2	2.1	4.0	4.9	3.4	-	5.0	(76)
V_1P_3	I	-	1.0	3.2	5.2	3.5	-	5.2	(84)
	II	-	1.6	3.3	5.0	3.5	-	5.0	(80)
V_2P_1	I	0.2	1.2	3.4	5.6	6.4	3.2	6.5	(97)
	II	0.1	0.9	3.4	7.3	6.5	2.7	7.6	(86)
V_2P_2	I	0.2	0.8	2.3	4.8	5.5	1.8	6.0	(92)
	II	0.2	1.4	4.0	6.6	4.4	1.0	7.2	(72)
V_2P_3	I	0.1	0.9	3.2	5.7	3.5	-	6.0	(88)
	II	0.1	1.3	4.5	7.4	4.3	1.1	7.5	(82)
V_3P_1	I	0.5	1.5	3.6	4.6	2.3	1.2	4.6	(80)
	II	0.3	1.2	3.7	5.1	4.1	1.8	5.2	(86)
V_3P_2	I	0.3	1.3	3.3	4.4	2.3	1.0	4.6	(75)
	II	0.5	1.2	4.8	6.7	5.3	1.2	6.7	(84)
V_3P_3	I	0.2	1.1	2.9	4.5	2.8	-	4.6	(82)
	II	0.3	1.8	4.5	5.6	2.8	-	6.0	(72)

Figures in bracket indicate days after sowing.
I = 1985-86; II = 1986-87.

at the time of heading, and the values also remained the same. At 60 days after sowing P_1 had higher LAI than P_2 and P_3.

Rabi 1986-87

ISD 397 : The maximum values of LAI were attained at heading stage and were nearly equal when compared to the earlier season. They ranged from 4.3 to 5.0 and were higher in P_2 and P_3 compared to P_1 because of the favourable conditions for P_2 and P_3 in their vegetative stages.

ISD 513 : This variety showed a higher LAI for all the three palntings when compared to the *rabi* season 1985-86. The maximum values (7.6, 7.2 and 7.5 for P_1, P_2 and P_3 respectively) were reached at the time of heading. The highest values of LAI in this season may be due to cooler temperatures prevailing in the vegetative stage of crop growth when compared to 1985-86.

HD 2281: This variety also recorded higher LAI values for this season when compared to the previous *rabi* season, 1985-86; in all the three plantings P_2 recorded higher LAI of 6.7 followed by P_3 with a value of 6.0. P_1 recorded lower LAI value of 5.2 at heading stage. There was a reduction in the LAI after heading.

In 1986-87 senescing leaves in the lowest layers of the plant have contributed a LAI ranging from 0.5 to 1.0 from post boot leaf stage as shown in the Fig.4. Thus the effective LAI needs a correction while calculating LAI from post boot leaf stage. This is of significance since the leaves in the lowest layers are not functional due to senescence.

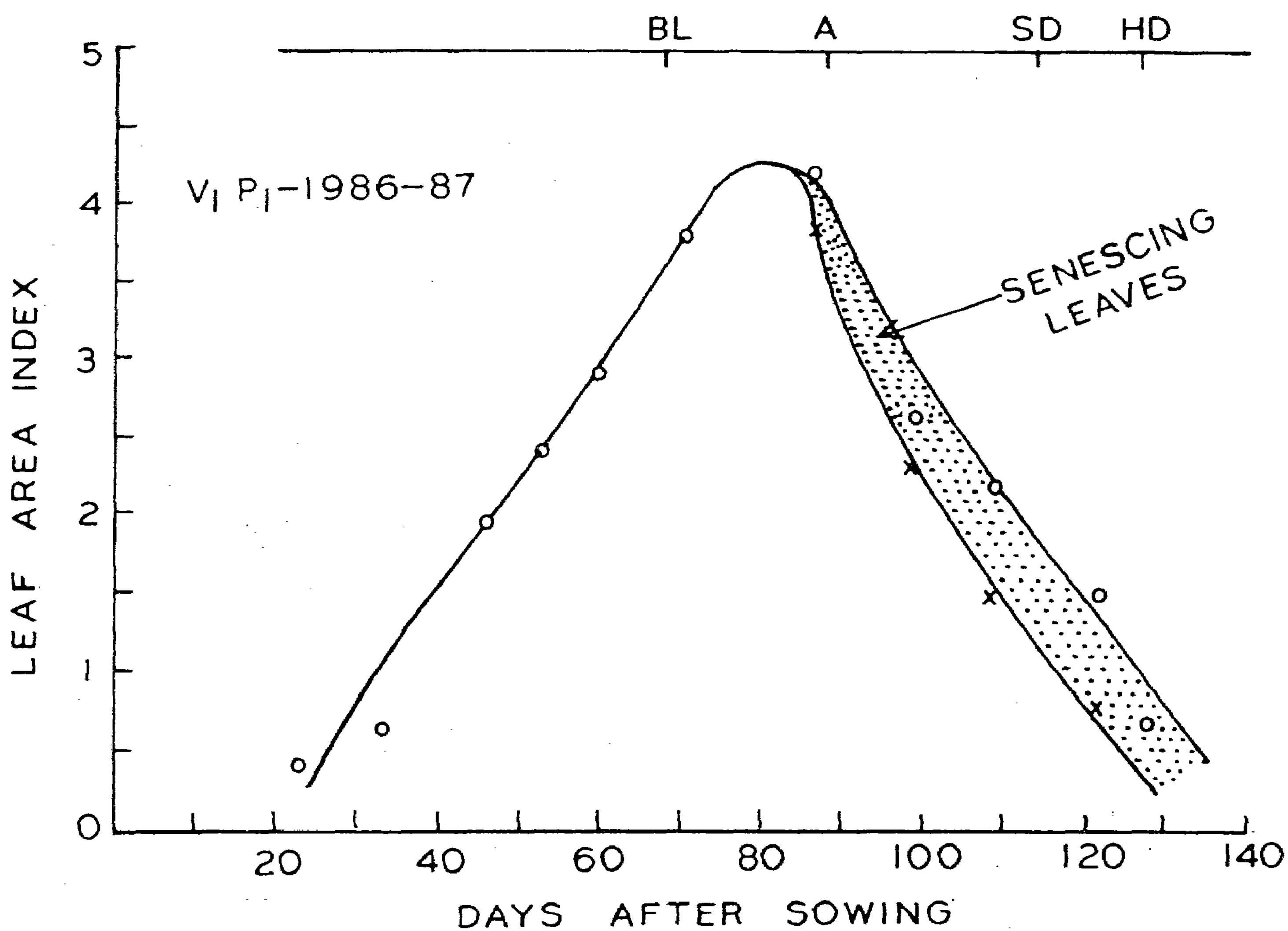

Fig.4. Leaf area index of green and senescing (shaded) leaves.

In all the varieties and planting dates for both the seasons higher LAI values were observed at heading stage in spite of temperature differences in the different treatments. Maximum LAI at heading stage was earlier reported by Waloszczyk and Focke (1980) but with respect to a single planting date. There was a gradual decrease from heading stage onwards. LAI varied with varieties at anthesis stage. Late sowings benefited from the rainfall received at their vegetative stages and thus recorded higher values of LAI than earlier sowings.

4.5 CROP GROWTH RATES

Weekly crop growth rates (CGR) were derived from growth curves for weekly biomass production for the different varieties and plantings in both the seasons and are presented in Table 6.

ISD 397: Crop growth rates during the *rabi* 1985-86 were the highest in the first planting followed by the second and third plantings. All the three sowings reached a maximum crop growth rate of about 50 g/m²/day. Both P_1 and P_2 reached peak growth rate in the same week (9th week) and did not exhibit the difference due to date of sowing. Irrespective of planting date, the highest CGR occurred at milk stage. In P_3 peak growth rate occurred in the 11th weak when temperatures were warmer than in the 9th week. A similar pattern was also observed during the second season (1986-87). However, the magnitude of highest CGR decreased (40.8, 38.6 and 29.3 g/m²/day) for P_1 , P_2 and P_3 respectively from those for the previous season. The

CGR in the individual weeks were also lower in rabi 1986-87 season compared to the earlier season in all the three plantings.

ISD 513: The CGR for this variety yielded maximum values of 55.7, 40.7 and 32.9 g/m²/day for P_1 , P_2 and P_3 respectively which were slightly lower than those observed in the variety ISD 397 in case of P_2 and P_3 plantings. The peak growth rates were attained at the time of heading in P_1 and P_2 while in P_3 it occurred at anthesis stage unlike in V_1 which occurred at milk stage in all plantings.

During rabi 1986-87 season, maximum growth rates were 42.9, 47.1 and 45 g/m²/day for the three plantings respectively. In this season P_2 and P_3 recorded higher crop growth rates than in P_1 and also higher than those in the previous season. As in the case of ISD 397, this variety also exhibited lower CGR in individual weeks, with delay in plantings. A significant feature in this season was that double peaks were observed in P_1 at 5th week and 11th week of crop growth; in P_2 and P_3 this effect was subdued.

HD 2281: During rabi 1985-86 this variety showed higher crop growth rates in P_1 and P_3 plantings compared to the other two varieties until 4th week (early vegetative stage). Maximum CGR for P_1 , P_2 and P_3 for any week were 52.9, 55.7 and 55.0 g/m²/day, which are higher compared to the other two varieties for the corresponding plantings.

During the rabi 1986-87 season the maximum CGR observed were 38.4, 50.0 and 34.3 g/m²/day; with the highest value in the second

Table 6. Weekly crop growth rates ($g/m^2/day$) in wheat cultivars ISD 397 (V_1), ISD 513 (V_2) and HD 2281(V_3) during *rabi* 1985-86 and *rabi* 1986-87

	ISD 397			ISD 513			HD 2281		
	1st Pltg.	2nd Pltg.	3rd Pltg.	1st Pltg.	2nd Pltg.	3rd Pltg.	1st Pltg.	2nd Pltg.	3rd Pltg.
1	7.1	5.0	2.1	10.0	5.7	1.4	8.6	5.8	2.9
2	9.3	7.9	2.9	7.1	8.6	2.9	10.0	6.4	5.7
3	12.9	7.9	2.9	8.6	8.6	3.6	9.3	6.4	4.3
4	10.7	11.4	4.3	8.6	10.0	4.3	13.6	8.6	7.1
5	15.0	12.9	5.7	15.7	10.7	6.4	13.6	12.9	7.3
6	17.1	19.3	8.6	14.3	12.1	7.1	15.0	12.9	11.4
7	32.1	20.7	12.9	25.7	24.3	15.7	29.3	17.1	11.4
8	37.9	41.4	21.4	42.9	39.3	25.7	47.9	27.9	15.7
9	52.9	49.3	25.7	55.7	40.7	28.6	52.9	42.9	20.0
10	47.1	45.0	38.6	44.3	30.0	31.4	45.7	42.9	42.1
11	17.8	42.1	50.0	26.4	23.6	32.9	24.3	55.7	55.0
12	-	7.8	52.9	4.3	4.3	31.4	7.2	8.6	46.4
					Rabi 1986-87				
1	2.9	2.9	1.4	4.3	4.3	1.4	5.7	1.4	0.7
2	4.3	3.6	3.1	4.3	5.0	1.4	5.7	2.1	2.9
3	7.1	8.6	2.9	5.8	6.5	1.4	12.9	7.9	3.6
4	12.9	13.6	4.3	17.1	10.7	2.1	21.4	28.6	5.0
5	34.3	10.0	2.9	21.4	10.7	2.1	21.4	18.6	4.3
6	10.7	8.6	4.3	8.6	6.4	4.3	8.6	10.0	2.9
7	7.1	6.4	12.9	8.6	4.3	4.3	10.8	8.6	8.6
8	8.6	12.1	32.1	12.9	25.7	8.6	8.6	10.0	14.3
9	19.3	17.1	27.9	14.3	47.1	25.7	15.0	23.6	19.2
10	40.8	34.3	24.3	15.7	25.7	45.0	38.4	50.0	23.6
11	25.8	38.6	29.3	42.9	7.9	32.1	23.6	28.5	34.3
12	12.9	2.1	27.7	17.1	-	4.3	6.4	6.8	15.7

plantings. In 1985-86 season the maximum CGR values were reached at milk and anthesis stages for P_1, P_2 and P_3 plantings respectively. In case of 1986-87 season P_1 reached the peak growth rate during soft dough stage while P_2 and P_3 reached the peak CGR at anthesis stage.

Unlike in 1985-86, in the 1986-87 peak growth rates occurred at soft dough stage in P_1. This delay in P_1 is attributable to the rainfall and cooler temperature prevailing in the early stages during 1986-87 season compared to 1985-86 season. In 1986-87 season the crop growth rates were very low in the individual weeks when compared to the previous season.

The weekly CGR in respect of differnt varieties during rabi 1986-87 as already mentioned were consistently lower when compared to the 1985-86 season. CGR showed a double peak in 1986-87 unlike in the previous season. The peak growth rates were attained earlier in 1985-86 than in 1986-87 in case of P_1 in all the varieties. Thus the time of attainment of peak growth rates in the three plantings are observed at different growth stages and at the first instance this is attributable to the differing temperatures and rainfall regimes under different plantings. The peak growth rates were attained at the time of heading (though individual calendar dates differed) in ISD 513, except in P_1 of 1986-87 and P_3 of 1985-86 when it occurred at milk and anthesis stages respectively. The delay in 1985-86 is attributable to the rainfall that occurred at time of heading and consequent cooling of environment.

Thus under the same environmental conditions, the different plantings exhibited differences both in the magnitude and time of occurrence of peak growth rates and the stage of occurrence. Results in the present experiment differ from the observations made by El-sharkawy (1975), Davidson and Campbell (1984) and O'Leary (1985) who obtained peak growth rates only at heading or anthesis stage. Short period variations in the maximum and minimum temperatures in addition to planting date, appear to determine the time of occurrence of peak growth rate in wheat at different growth stages such as those observed in the present experiment. Apparently, the response of crop to the environmental conditions, specially to the temperature regime is thus closely related to the growth stage. Another salient feature of these results is that the effects of relatively warm seasonal conditions in 1986-87 are reflected in CGR but not in the duration between phenological stages. These are attributable to the influence of short period weather conditions prevailing in the season, and are examined further and detailed below.

For this purpose, three specific periods were identified after examintion of the weather associated with the passage of western disturbances as mentioned in Indian daily weather reports of Indian Meteorological Department. As V_1 showed better response to temperature changes as evidenced from phenological observations, it was selected for detailed study for illustration.

Case (i) - Effect of higher maximum and lower minimum temperatures in 1986-87 season compared to 1985-86 season on crop growth rates (7th to 16th February).

This period is identifiable from the examination of data on daily temperature, dew point, sunshine hours, vapour presssure, evaporation and rainfall as showed in Table 7. During 1985-86 season, in 6th week, maximum temperatures decreased from 23 to 17°C. By the next week minimum temperatures increased from 5 to 12°C and continued to be above 8°C till the 16th of February, 1986. However, during the corresponding period of 1986-87, maximum temperatures remained around 23-25°C and the minimum temperatures around 7to 9°C. Corresponding differences in vapour pressure, dew point and sunshine hours and evaporation also could be clearly noticed from the daily data. Under these environmental conditions, both first and second plantings showed relatively higher CGR during 6th and 7th meteorological weeks in 1985-86 compared to 1986-87 season. However, except in the initial stages, P_3 does not seem to have been similarly affected.

A lowering of maximum temperature by 5 to 6°C and moderate minimum temperatures associated with rainfall in 1985-86 season appear to have resulted in better crop growth rates in that season compared to the second season. In both P_1 and P_2 the reduction in CGR in the warmer season could be considered significant, being of the order of 14 to 25 g/m²/day which could be expected to affect grain yields.

Case (ii) - Effect of higher maximum temperatures and higher minimum temperatures that prevailed in 1986-87 season compared to 1985-86 season (21st to 26th February).

The prevailing weather conditions are identified from the Table 8 which shows daily values of temperature, vapour pressure, sunshine hours and rainfall.

Table 7. Weather data and CGR for the period 7th - 16th February with high maximum and lower minimum temperatures

		Max.temp.(°C)		Mini.temp.(°C)		Vapour pressure(1400 hrs)		Dewpoint Temperature		Evaporation		Sunshine hours		Rainfall		CGR	
		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
	Feb.7	22.0	25.5	5.4	6.0	6.7	9.7	5.4	10.8	2.6	2.2	8.1	9.7	-	-		
6th	8	23.3	27.0	5.5	9.8	7.0	9.3	6.0	10.1	2.8	2.6	9.8	10.0	-	-	P_1=17.0	10.7
week	9	23.2	27.5	11.4	9.5	11.1	12.1	13.1	14.1	2.4	2.8	8.8	9.7	-	-	P_2=19.3	8.6
	10	17.7	25.0	12.8	8.0	11.6	11.1	13.5	12.8	0.6	3.2	0.4	9.2	1.8	-	P_3= 8.6	4.3
	11	18.8	23.8	12.4	7.5	11.3	10.0	13.1	11.3	1.0	3.4	1.8	8.9	27.8	-		
	12	19.8	24.0	8.2	7.0	11.8	10.9	13.7	12.5	1.0	3.0	1.9	9.8	7.4	-		
	13	17.0	24.5	9.0	6.5	11.4	11.8	13.2	13.7	0.6	2.8	0.0	8.7	-	-	P_1=32.1	7.1
	14	20.5	23.5	9.6	8.5	10.7	10.8	12.2	12.4	1.0	1.6	4.9	4.7	-	-	P_2=20.7	6.4
7th	15	22.0	27.5	10.0	11.0	9.4	12.8	10.3	15.0	1.4	2.6	8.3	7.5	-	-	P_3=12.9	12.9
week	16	21.0	25.5	8.5	12.2	7.4	14.3	6.8	16.8	1.6	4.4	10.4	7.6	-	2.4		
	17	20.5	22.0	6.2	10.5	8.4	12.6	8.6	14.8	2.6	2.6	10.2	6.2	-	4.6		
	18	23.0	24.5	8.9	11.6	9.7	12.4	10.8	14.5	3.2	3.0	9.8	7.8	-	-		

I = 1985-86; II = 1986-87.

Table 8. Weather data for the period 19th to 28th February with higher maximum and higher minimum temperatures

		Max.temp(°C)		Mini.temp.(°C)		Vapour pressure(1400 hrs.)		Dewpoint Temperature		Evaporation		Sunshine hours		Rainfall		CGR	
		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
8th Feb.	19	25.0	23.0	9.2	10.2	8.6	10.5	9.0	11.9	2.4	2.6	10.1	7.4	-	-	P_1=37.9	8.6
week	20	22.0	25.5	10.5	13.5	8.0	12.3	7.9	14.4	3.6	2.8	10.0	6.0	-	-	P_2=41.4	12.1
	21	23.0	26.5	12.4	10.0	13.5	12.2	15.8	14.3	3.2	3.0	6.6	8.3	-	Traces	P_3=21.4	32.1
	22	23.0	27.5	9.6	10.0	9.4	10.2	10.3	11.5	3.8	2.8	4.6	8.9	Traces	-		
	23	21.4	27.2	8.5	11.5	8.9	12.6	9.4	14.8	3.4	3.2	9.8	9.9	2.6	-		
	24	22.0	29.6	8.4	14.6	7.8	15.8	7.6	18.3	3.2	3.2	10.8	9.1	-	4.2		
	25	22.5	27.5	7.5	13.2	7.0	11.5	6.0	14.4	4.0	2.8	10.2	10.3	-	2.2		
9th	26	23.0	24.5	5.8	10.6	7.1	12.5	6.2	14.7	4.0	2.6	10.4	8.2	-	-	P_1=52.9	19.3
week	27	23.5	23.0	6.5	8.6	6.9	10.9	5.7	12.5	4.0	3.2	10.4	9.0	-	-	P_2=49.3	17.1
	28	24.5	23.2	10.0	7.4	7.4	10.7	6.8	12.2	4.2	5.0	10.7	10.2	-	-	P_3=25.7	27.9

I = 1985-86; II = 1986-87.

From examination of the weather parameters it is evident that vapour pressure was lower in 1985-86 season and higher in the 1986-87 season by 4-5 mm. The dew point temperature was also higher in 1986-87 season and rainfall of 6.4 mm was received in the 8th week with cloudy conditions earlier. In this case also the CGR in 1986-87 season were much lower in case of P_1 and P_2 compared to the previous one. Maximum temperatures were 4-7°C higher and minimum temperatures were also higher by 3-6°C in 1986-87 season. There was no appreciable difference in evaporation rates in this period between the seasons. The crop growth rates in P_1 and P_2 which were at anthesis to milk and anthesis stage respectively were very much depressed than those noticed in the previous case. These are probably attributable to higher respiration rates in 1986-87 season than in 1985-86 season which could be inferred from data on minimum temperatures as also reported by Wardlaw et al. (1980) in their study on wheat in U.S.A.

In P_3 the reduction is not evident probably due to the fact that it was in the boot leaf stage at this time. The warmer temperatures in 1986-87 appear to have helped in increasing crop growth rates in 1986-87 season in P_3 during this period. It may be reasonably concluded that environmental conditions remaining the same, such a situation as that observed in this case would prove beneficial to a crop in boot leaf stage while adversely affecting a crop in reproductive stage of growth.

Case (iii) - Effect of warming and variable weather on crop growth rates in rabi 1985-86 and rabi 1986-87 seasons (10th to 23rd March).

The different weather parameters and crop growth rates are presented in Table 9. There was a rainy spell between 10th and 23rd March during the 1985-86 season with 15.8 mm of rainfall (received on 3 rainy days). During 1985-86 season, maximum temperatures remained higher than those in 1986-87 by 3 to 7°C from 11th to 15th March and this position was reversed when maximum temperatures were higher ~~in~~ in 1986-87 season from 16th to 23rd, occassionally the difference between the two seasons reaching 6 to 7°C. Minimum temperatures were also higher from 20th to 25th March, 1987 compared to 1985-86 season, the difference occassionally reaching a value of 6 to 7°C.

An examination of the daily temperature data with the normals (Appendix IV) revealed that after initial warming till 14th March, in 1985-86 season cold wave conditions prevailed from 15th to 23rd March when maximum and minimum temperatures were below normal by 5-6°C and 3-4°C respectively. This situation prevailed in association with a western disturbance that moved over from Rajasthan, causing varying weather over the Delhi region.

During the corresponding period of 1986-87 season, a similar rain spell was noticed between 10th to 23rd March. However, warming prior to this remained only for 1 or 2 days when the maximum temperatures were above normal by 2-3°C and below normal from 11th to 15th and again from 22nd to 24th March by about 2-3°C. Minimum temperatures were below normal from 7th to 13th March (by 2-3°C) after which they remained above normal till 23rd March. However, compared to 1985-86 season as evident from the Table 9, 1986-87 season was characterised

Table 9. Weather data and CGR for the period 10th to 23rd March with above normal maximum temperatures

		Max.temp(°C)		Mini.temp(°C)		Vapour pressure(1400 hrs.)		Dewpoint temperature		Evaporation		Sunshine hours		Rainfall		CGR	
		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
	Mar. 10	31.0	29.0	13.0	11.4	13.0	12.0	15.2	14.0	3.8	4.4	8.9	9.3	-	-	-	-
	11	32.8	29.2	18.2	12.0	13.1	14.9	16.3	17.4	4.2	4.2	8.9	8.1	Tr.	-	-	-
	12	31.0	22.3	15.5	9.0	14.3	12.7	16.8	14.9	5.0	1.6	10.2	1.4	-	Tr.	P_1= 7.8	P_1=25.8
	13	32.5	26.5	14.6	13.0	9.3	15.2	10.2	17.7	4.6	2.8	10.0	10.3	-	-	P_2=42.1	P_2=38.6
11th	14	33.0	24.2	17.6	11.0	9.7	14.6	10.8	17.1	5.0	2.8	8.6	5.1	2.4	Tr	P_3=50.0	P_3=29.3
week	15	30.0	28.3	14.0	13.4	10.0	16.8	11.3	19.3	3.8	3.6	5.1	10.0	-	-	-	-
	16	25.5	31.9	10.0	19.4	8.6	17.2	9.0	19.7	4.6	4.0	10.6	8.6	-	-	-	-
	17	25.0	32.0	9.0	18.2	5.6	17.3	2.9	19.8	4.2	5.2	10.3	10.2	-	-	-	-
	18	24.5	30.0	14.5	15.0	13.8	15.7	16.2	18.2	4.2	5.6	0.5	8.8	4.2	-	-	-
	19	26.0	30.0	11.2	12.6	10.3	14.0	11.7	16.4	3.2	6.5	4.8	10.0	9.2	-	-	-
	20	25.0	32.5	9.6	18.6	8.1	16.3	8.1	18.8	3.6	7.2	10.6	9.2	-	Tr.	P_1=-6.4	P_1=12.9
12th	21	24.5	3.0	11.0	14.2	8.4	17.1	8.6	19.6	4.4	3.6	10.3	7.9	-	-	P_2= 7.8	P_2= 2.1
week	22	23.5	32.8	12.1	18.2	9.6	18.9	10.6	21.2	4.2	7.4	2.8	8.1	Tr.	14.0	P_3=52.9	P_3=27.9
	23	26.4	29.0	11.5	18.4	9.1	15.7	9.9	18.2	2.6	5.6	5.1	7.5	Tr.	2.4	-	-

I = 1985-96; II = 1986-87.

by prevalence of higher maximum and minimum temperatures by 4-6°C revealing considerable differnces in the temperature regime between the two seasons.

During the 11th week, the different plantings were in milk to soft dough stage which is an important phase in crop growth, determining the grain yield. This is the stage when the effect of temperature is very critical in spite of availability of moisture in the root zone. The first planting in 1985-86 recorded a growth rate of 7.8 $g/m^2/day$ where as in 1986-87 season it was 25.8 $g/m^2/day$.

The reasons for the lower crop growth rate in P_1 are:

(i) this planting has already reached a stage of decreasing phase of CGR in 1985-86 season, and

(ii) compared to 1986-87 season, higher maximum and minimum temperatures in 1985-86 at this time seemed to have suppressed growth rates further.

Of the P_2 and P_3 plantings which are at milk stage at this time, P_3 recorded a higher growth rate by 20 $g/m^2/day$ in 1985-86 compared to the second season.

During the 12th week when there was reversal of maximum and minimum temperatures (higher maximum and minimum temperatures in 1986-87 compared to 1985-86), P_3 was the most affected with a decrease of CGR by 25 $g/m^2/day$. P_2 which has reached the decreasing phase of CGR in soft dough stage also recorded decreasing growth rate in 1986-87 season by 5.7 $g/m^2/day$.

It can be said from the above results that higher maximum and minimum temperatures at milk stage in the late planting had a severe effect on CGR, reducing it by about 40 per cent.

4.5.1 Crop growth patterns

The weekly growth rates discussed above are shown in the form of a diagram (Fig. 5) for representative treatments. The crop growth rate curves for V_1 for the three plantings clearly show the effect of seasonal environmental conditions, namely;

1. decrease in growth rates in warmer season (1986-87) with a shift in the time of occurrence of peak growth rate in delayed plantings and

2. a double peak in the growth pattern with a progressive decrease in the distance between peaks with delayed planting as observed in 1986-87.

While the decrease in growth rate due to higher temperatures was reported earlier (Friend *et al.*, 1962) and a shift in time of occurrence of peak growth rate was reported by Chakravarthy and Sastry (1985), a double peak in the growth rate pattern which might have been possibly observed in experiments elsewhere does not seem to have been reported in literature. Occurrence of double peak is considered by us to be the effect of interruption of the normal growth pattern (such as that in 1985-86 season by a complex variation of maximum and minimum temperatures and can be considered as a short

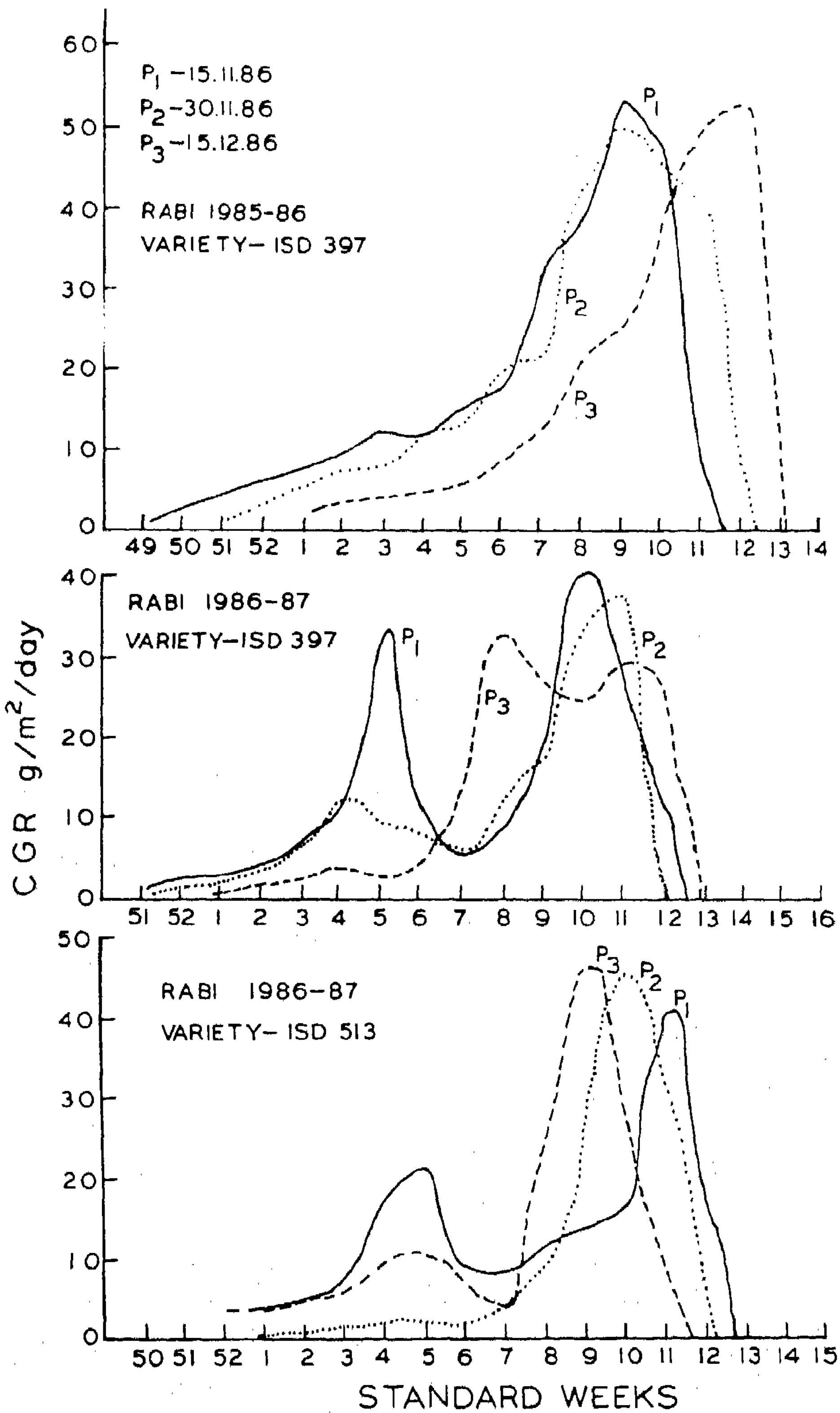

Fig.5. Crop growth rates (CGR) in wheat

term weather induced pattern of growth with consequent contribution to a reduction in grain yield.

4.5.2 Peak growth rates and varietal adaptability to warm seasonal conditions

Variety V_2 has shown different behaviour with respect to V_1 and V_3 in the peak growth rate values between cooler and warmer seasons. They ranged from 47.14 g/m²/day to 42.86 g/m²/day in the warm year 1986-87 while in 1985-86 they varied widely (33 to 55.7 g/m²/day). This suggests that in a relatively warmer year in this variety, while there may be difference in time of occurrence of peak growth rate, the rate itself would be more stable (Fig.5) indicating its adaptability to warmer thermal environment.

4.6 GRAIN FILLING STAGE

Immediately after attainment of anthesis stage, twenty ear heads were chosen at random from 3 replicates for each treatment at five days interval and its oven dry weight was noted to study the grain filling pattern (Fig. 5a).

It is seen that from the beginning of March there was a gradual increase in grain weight in P_1 having registered higher weights than P_2 . The growth rate was more or less the same in both the plantings and in both the seasons. While in case of P_1 the growth rate was consistently lower in 1986-87 season than that in 1985-86, in P_2 from around middle of March growth rates in the 1986-87 season were relatively higher (by about 1.5 g/day) though the crop growth

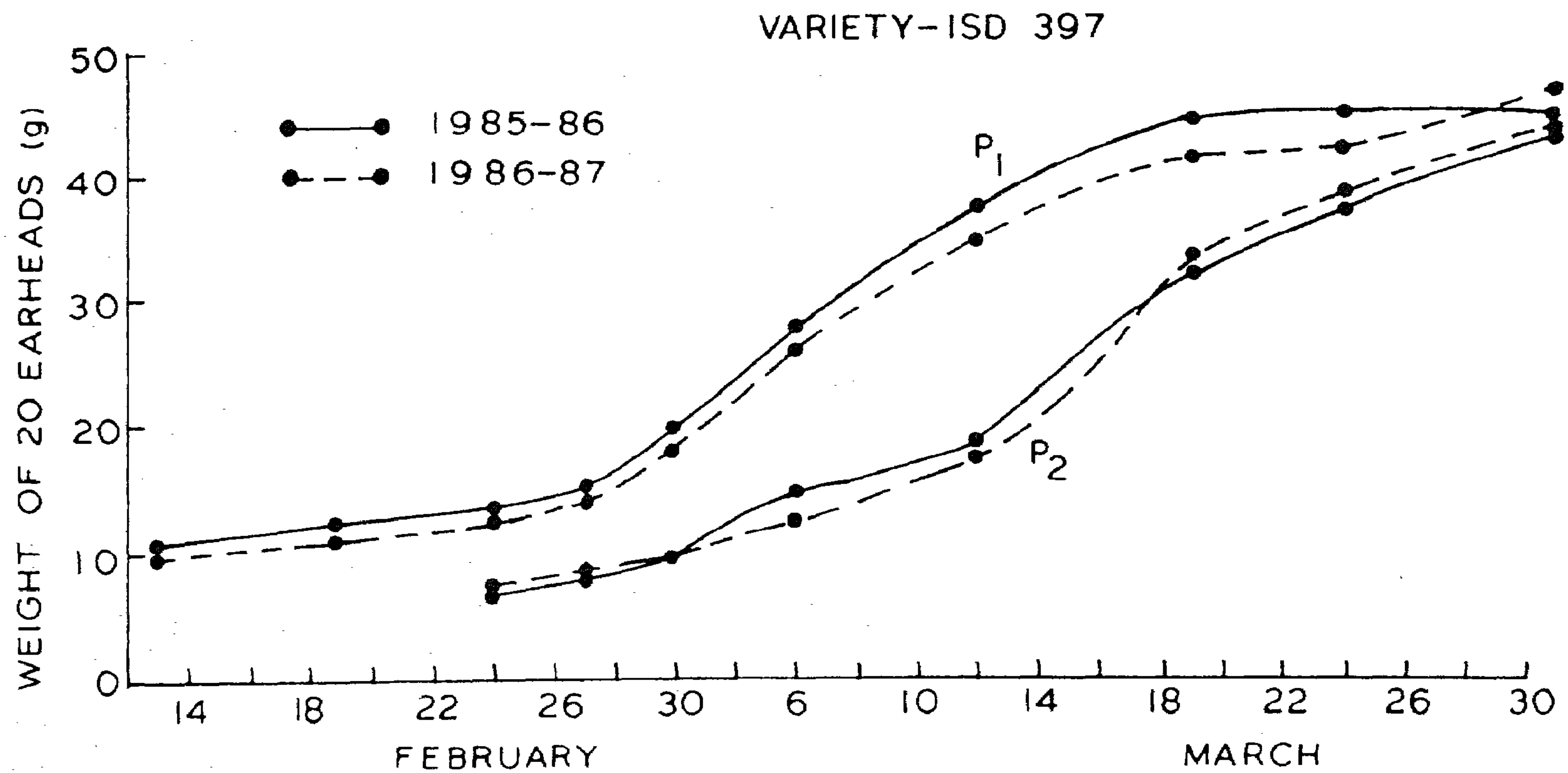

Fig. 5a. Earhead weight in wheat during grain filling period

rates were lower by 3.4 g/m²/day. However, $V_1 P_2$ had attained soft dough stage already by this time in 1986-87 season due to warmer temperatures whereas in the 1985-86 season it was still at milk stage. Thus the early attainment in phenological stage due to warmer temperatures in 1986-87 season would have contributed to the higher growth rate in grain filling.

In this context it is significant to take note of the observation made by Wardlaw *et al*. (1980) that faster rate of import of photosynthates prevail at higher temperatures but are offset by greater respiration rates. The accumulated heat units for 1986-87 were higher in case of both P_1 and P_2 by about 50 degree days and the yield reduced by 10 per cent and harvest index by 11 per cent (Tables 10 and 11). These are discussed in detail later. This is attributable to the higher temperatures that prevailed during the grain filling period in 1986-87 confirming the observation made by Wardlaw *et al*. (1980).

4.7 GRAIN YIELD

The grain yield (mean of 3 replicates) of the three cultivars in all the planting dates in the *rabi* seasons of 1985-86 and 1986-87 are presented in Table 10.

Analysis of variance showed that the differences in the grain yield between varieties and treatments were significant at 1% level.

Table 10. Grain yield (q/ha) of wheat cultivars as influenced by planting dates in the *rabi* 1985-86 and 1986-87 seasons

Cultivar	Rabi 1985-86			Rabi 1986-86		
	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)
ISD 397	36.47	42.72	43.66	41.42	38.32 (7.5)	39.66 (4.3)
ISD 513	38.76	42.17	42.88	43.55	39.96 (8.3)	34.55 (20.7)
HD 2281	37.38	49.38	46.63	48.67	44.03 (9.5)	45.81 (6.0)

Statistical analysis :

	Rabi 1985-86	Rabi 1986-86
F value	6.19**	4.44**
SEm±	1.99	2.01
CD (at 5% level)	6.01	6.07
CV (%)	8.28	8.35

Figures in brackets indicate decrease in yield over 1st planting(P_1).

Rabi 1985-86

The grain yield in this season ranged between 36.47 q/ha in V_1 P_1 to 49.38 q/ha in V_3 P_2. Of all the three varieties HD 2281 gave higher yields. There was reduction in yields in the first planting because the crop was lodged due to a thunderstorm on 19th March which affected the yields to a large extent. So the P_2 and P_3 plantings showed higher yields than P_1 .

Rabi 1986-87

During this season also HD 2281 gave higher yields than the other two varieties under the three plantings, the yields ranging from 44.03 to 48.67 q/ha. In 1986-87 season the yields decreased with delay in planting by 4.3 to 20.7 % in P_3 over P_1.

Unlike in the previous season, among the planting dates, P_1 showed higher yields in 1986-87. When compared between the two seasons, there was reduction of yield in P_2 and P_3 plantings. The percentage reduction of yields in 1986-87 when compared to 1985-86 for P_2 and P_3 plantings are given below:

P_1 is not included in this as yields in the season were affected by lodging.

	P_2	P_3
ISD 397	10.3	9.2
ISD 513	5.3	19.4
HD 2281	10.8	2.0

The magnitude of reduction varied from 2 to 19.4% with highest reduction in V_2 P_3 . It may be mentioned that this variety showed lower crop growth rates during 1986-87 season.

4.8 HARVEST INDEX

The harvest index (HI) of the three cultivars as influenced by different palnting dates in the two rabi seasons under investigation are presented in Table 11.

Table 11. Harvest Index as influenced by planting dates.

Cultivars	Harvest Year	P_1	P_2	P_3
ISD 397	1986	0.45	0.43	0.46
	1987	0.48	0.42	0.46
ISD 513	1986	0.49	0.46	0.44
	1987	0.48	0.45	0.42
HD 2281	1986	0.48	0.52	0.54
	1987	0.52	0.54	0.50

During the 1985-86 rabi season, the HI ranged from 0.43 to 0.54. In the cv. ISD 397 highest HI (0.46) was observed in the third planting followed by first and second plantings respectively. In cv. ISD 513 highest HI was observed in the first planting (0.49) followed by second and third plantings. In the cv. HD 2281 , third planting recorded higher HI (0.54) followed by second and first plantings.

During 1986-87 the HI varied from 0.42 to 0.54. In cv. HD 2281 higher HI values were obtained for P_1 and P_2 plantings in 1986-

1987 when compared to 1985-86 season. In cv. ISD 397 the first planting showed higher HI in 1986-87 season compared to 1985-86 season. In general, harvest index was higher in case of cv. HD 2281 in both the seasons and proved superior to the other two varieties.

4.8 ACCUMULATED HEAT UNITS

Two different accumulated heat unit systems viz., growing degree days, and helio-thermal units were computed following the methods presented in Section 3.4 and the results are as follows:

4.9.1 Growing degree days

Growing degree days (GDD) to reach different phenological stages from sowing date for the three cultivars and plantings during rabi 1985-86 and 1986-87 seasons are given in Table 12. Salient features are given below:

Rabi 1985-86

ISD 397 : From sowing to maturity this variety had accumulated 1407 GDD for the first planting followed by second planting with 1392 heat units accumulated. The third planting recorded 1428 accumulated heat units in the growth season. From sowing to anthesis this variety accumulated 863 units in P_1 followed by 815 units in P_3 with a difference of 48 heat units.

ISD 513: In this variety, first planting reached physiological maturity with accumulation of 1647 heat units. The third planting accumulated 1523 heat units followed by the second planting with 1441 heat units. A maximum difference of 124 units was observed between

Table 12. Accumulated growing degree days for different phenological stages in wheat

Phenological stages	ISD 397			ISD 513			HD 2281		
	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd pltg. (P_3)
				Rabi 1985-86					
Boot leaf	657	607	656	804	726	725	630	598	601
Heading	804	726	751	1000	919	832	825	782	799
Anthesis	863	804	815	1087	983	910	932	868	871
Milk	1112	1058	1006	1314	1149	1093	1074	1078	1062
Soft dough	1245	1229	1224	1467	1320	1332	1284	1244	1170
Hard dough	1407	1392	1428	1647	1441	1523	1467	1425	1403
				Rabi 1986-87					
Boot leaf	682	599	626	834	760	671	627	565	692
Heading	834	693	728	1042	892	743	795	775	840
Anthesis	888	807	809	1099	989	890	942	864	881
Milk	1142	1004	1003	1313	1152	1021	1066	1030	1078
Soft dough	1250	1132	1140	1561	1385	1324	1224	1245	1196
Hard dough	1480	1364	1347	1686	1519	1498	1444	1473	1458

first and third plantings with the units for the latter being lower. Anthesis was observed at 1087 heat units for first planting followed by second and third plantings with 983 and 910 units accumulated respectively. The range between the plantings P_1 and P_3 at anthesis stage was 177 heat units compared to 48 units in case of variety ISD 397.

HD 2281 : From sowing to maturity this variety had accumulated 1467 GDD for the first planting followed by second and third plantings with 1425 and 1403 GDD respectively. A maximum difference of 64 units was observed between 1st and 3rd plantings with the units for the latter being lower. A similar trend was noticed from sowing to anthesis also with a difference of 61 units between the plantings.

Rabi 1986-87

ISD 397 : The heat units accumulated from sowing to maturity for different plantings P_1, P_2 and P_3 were 1480, 1364 and 1347 respectively. Only P_1 showed higher values than the previous season by 73 units. Both in P_2 and P_3 the heat units were lower than the previous season by 28 and 81 day degrees. The range between the plantings P_1 and P_3 was 133 day degrees.

ISD 513 : The heat units from sowing to maturity in this variety for the three plantings ranged from 1686 in the first, to 1498 in the third planting. The GDD in this variety showed higher accumulation than in ISD 397 and HD 2281 reflecting the longer duration of the variety in the different plantings. Even at anthesis P_1 had higher GDD followed by P_2 and P_3. The difference between the first and third plantings at maturity was 188 degree days. The difference at the time of anthesis was 209 degree days, thus showing a reduction at maturity, due to shorter ripening period at higher temperatures.

HD 2281 : The accumulated heat units from sowing to maturity in this case for the three plantings ranged from 1473 in the first to 1444 in the second plantings. The third planting recorded 1458 degree days. An accumulation of 942 heat units brought the first planting to anthesis, whereas 881 units were found accumulated for the third planting to reach this stage with a difference of 61 units between the plantings. At anthesis stage the accumulated heat units in this year were higher than in the previous season.

In all the three varieties, the three plantings accumulated 1392 to 1647 degree days from sowing to maturity in 1985-86, while in the rabi 1986-87, it took 1347 to 1686 units, thus showing the differential varietal response to the short period changes in the ambient thermal environment. There was in general, a decrease in GDD with later sowings. Chakravarthy and Sastry (1983a) also reported that for different varieties , plantings and the seasons together, GDD from sowing to maturity ranged between 1370 and 1691 heat units, which are nearly the same as obtained in the present investigation.

The results show that irrespective of plantings and variety, the total requirement for the crop to mature is more or less constant in the different seasons.

4.9.2 Helio-thermal units

The helio-thermal units (HTU) for different growth stages, for the three varieties and three plantings in both 1985-86 and 1986-87 *rabi* seasons are shown in Table 13. The salient features are as follows:

Rabi 1985-86

ISD 397: The first plantings reached maturity after accumulating a sum of 11047 HTU, whereas second and third plantings reached maturity after accumulating 10988 and 11460 HTU. From sowing to anthesis, first planting accumulated the highest HTU (6683 units) than P_2 (5762 units) and P_3 (6171 units). The range for the P_1 and P_3 plantings was 512 HTU. In general, P_1 recorded higher values of HTU uptill soft dough stage than the second and third plantings.

ISD 513 : From sowing to maturity, accumulated units reached a value of 13371 HTU in case of first planting, whereas second and third plantings accumulated 11495 and 12453 HTU respectively. The range between the first and third plantings was 918 HTU. Upto anthesis, first planting accumulated more number of HTU (8439) than second planting (7486 units) and third planting (7060 units). Significantly there were larger differences (of about 1379 units) compared to 512 units for V_1 at anthesis stage between first and third plantings.

HD 2281 : The first plantings reached maturity after accumulating a sum of 11645 HTU whereas, second and third plantings reached maturity after accumulating comparatively more or less lower number

Table 13. Accumulated helio thermal units for different phenological stages in wheat.

Phenological stages	ISD 397			ISD 513			HD 2281		
	1st Pltg.	2nd Pltg.	3rd pltg.	1st Pltg,	2nd Pltg.	3rd Pltg.	1st Pltg.	2nd Pltg.	3rd Pltg.
				Rabi 1985-86					
Boot leaf	5057	4359	4662	6195	5094	5248	4811	4319	4210
Heading	6195	5094	5578	7540	6893	6322	6343	5611	6040
Anthesis	6683	5762	6171	8439	7486	7060	6970	6439	6694
Milk	8707	8199	7749	10476	8797	8454	8315	8375	8151
Soft dough	9885	9466	9673	11645	10345	10752	10251	9594	9167
Hard dough	11047	10988	11460	13371	11495	12453	11645	1317	1257
				Rabi 1986-87					
Boot leaf	4547	4229	4636	5878	5479	5058	4159	3852	5259
Heading	5878	4965	5606	7587	6731	5939	5501	5623	6577
Anthesis	6328	5938	6279	8137	7564	6577	6719	6488	6873
Milk	8527	7690	7980	9904	8967	8114	7793	7860	8581
Soft dough	9354	8967	9153	12012	10628	10532	9213	9757	9427
Hard dough	11406	10494	10776	12926	12016	12248	11055	11519	11787

of units (P_2 - 11317 and P_3 - 11257 HTU), with a difference of about 388 units between the highest and lowest value.

Rabi 1986-87

ISD 397 : Upto maturity the first planting accumulated the highest number of HTU (11406 units) followed by third and second plantings with 10776 and 10494 units respectively. The same trend was also observed in case of accumulation upto anthesis.

ISD 513 : In this variety, first planting recorded the highest number of HTU (12926) followed by third and second plantings with 12248 and 12016 HTU, respectively. The difference between the first and the third plantings was 678 HTU, which was nearly same (630 HTU) as in V_1 . From sowing to anthesis first planting accumulated more number of HTU (8137) than second planting (7564) followed by third planting (6577 units). The difference between first and third plantings at this stage was 1560 HTU which was reduced at maturity.

HD 2281 : Contrary to the observations on the other two varieties considered above, this variety behaved differently in thermal accumulation till maturity. The highest number of HTU recorded were for the third plantings (11787 units) followed by P_2 (11519 units) and P_1 (11055 units). In all the growth stages P_3 showed higher accumulated units which are attributed to higher temperatures in this season.

In both the seasons the differences between plantings from sowing to maturity were lower when compared to the differences from sowing to anthesis. Both the seasons did not show any significant differences. In general, irrespective of the duration of the phenological stages the number of heat units required to reach a particular stage were more or less constant in both the seasons. The above results confirms the observations made by Chakravarthy (1980) in case of wheat crop.

The helio-thermal units showed the same trend as those of GDD in all the treatments and inclusion of actual bright sunshine hours did not show any deviation in the results, thus indicating that compared to temperature, bright sunshine is not a significant factor in wheat crop.

4.9.3 Phenothermal Index

Phenothermal index (ratio of accumulated GDD to the number of days during a particular stage) during the different stages of crop growth were worked out for both the seasons and shown in Table -14.

Phenothermal index values ranged from 8.9 to 23.9 in the different treatments. Two salient features are (i) in most cases, within a growth stage, the index did not show much variation and (ii) between each growth stage, however, variation was high with the highest value having been recorded during the grain filling period of crop growth.

Between plantings, which are indirectly influenced by the temperature regime, much variation was noticed in the heading to anthesis

Table 14. Phonothermal Index

Phenological stages	ISD 397 1st pltg.	ISD 397 2nd pltg.	ISD 397 3rd pltg.	ISD 513 1st pltg.	ISD 513 2nd pltg.	ISD 513 3rd pltg.	HD 2281 1st pltg.	HD 2281 2nd pltg.	HD 2281 3rd pltg.	CV(%)
					Rabi 1985-86					
Sowing to B.l.	10.3	9.2	9.1	10.0	9.3	9.3	10.5	9.2	9.0	5.2
B.l. to Heading	9.2	9.8	11.9	10.3	11.4	14.9	8.9	10.2	12.4	16.6
Heading to Anth.	9.8	11.1	16.0	10.9	16.0	19.5	9.5	10.7	18.0	26.8
Anth. to Milk	10.8	14.1	15.8	16.2	16.6	14.0	10.9	16.2	14.7	13.9
Milk to S.d.	14.8	14.3	16.8	13.9	15.5	18.4	16.2	13.8	18.0	9.6
S.d. to H.d.	16.2	18.0	20.4	22.5	17.3	23.9	14.0	18.1	19.4	15.8
Sowing to H.d.	11.0	11.4	13.0	11.8	11.3	12.3	11.1	11.3	11.9	5.1
					Rabi 1986-87					
Sowing to B.l	9.4	8.4	8.9	9.3	9.1	9.1	8.9	8.2	9.0	3.9
B.l. to Heading	10.1	11.7	14.6	13.0	13.2	13.0	8.4	12.6	14.3	15.9
Heading to Anth.	10.8	16.2	16.2	11.4	19.4	16.3	12.3	12.7	13.7	16.7
Anth. to Milk	13.4	14.0	16.3	15.3	16.4	16.5	13.8	15.1	17.9	9.9
Milk to S.d.	15.3	16.5	19.4	19.0	19.3	20.2	14.4	17.9	19.7	10.8
S.d. to H.d.	17.7	19.1	20.7	20.8	22.3	21.8	16.9	20.7	21.8	9.8
Sowing to H.d.	11.2	11.4	12.1	11.8	12.0	12.5	10.8	11.6	12.6	4.9

B.l = Boot leaf; Anth = Anthesis; S.d. = Soft dough; H.d. = Hard dough.

stage. The index values for the entire crop season showed very little variation between the different treatments or between the two seasons since similar results were observed in _rabi_ 1985-86 and 1986-87 also. For the entire crop growth period taken as a single unit, the mean value is 11.7 in both the seasons showing a constant rate.

Coefficient of Variation : The Coefficient of variation (CV) for the three varieties and three plantings pooled together for each stage (Table 14) show the lowest CV when the entire growing season (sowing to maturity) is considered as a single unit, with a value of 5.1 and 5.0 per cent respectively for the two seasons 1985-86 and 1986-87. Highest CV values are observed at heading to anthesis stages in both the seasons. The high CV at this stage indicates that much variation in the environmental thermal regime occurs during this period of crop growth in the Delhi region. Similar CV values were obtained by Chakravarthy and Sastry (1983a) with respect to wheat and barley crops in the Delhi region for the entire growing season taken as a unit.

4.10 HEAT USE EFFICIENCY DURING THE DIFFERENT PHENOLOGICAL STAGES OF WHEAT

Stage-wise heat use efficiency (HUE) which expresses biomass production in g/m^2 per unit degree day was computed for the three varieties and plantings and is given in Table 15. In general, heading to anthesis and anthesis to milk stages showed relatively higher HUE in comparison to the other stages. Between the two seasons, it was observed that HUE was comparatively lower during the _rabi_ 1986-87

Table 15. Heat use efficiency in different wheat cultivars ($g/m^2/GDD$)

Phenological stages	ISD 397 1st pltg. (P_1)	ISD 397 2nd Pltg. (P_2)	ISD 397 3rd Pltg. (P_3)	ISD 513 1st Pltg. (P_1)	ISD 513 2nd Pltg. (P_2)	ISD 513 3rd Pltg. (P_3)	HD 2281 1st Pltg. (P_1)	HD 2281 2nd Pltg. (P_2)	HD 2281 3rd Pltg. (P_3)
Rabi 1985-86									
1. Sowing to boot leaf	0.5	0.7	0.8	0.7	0.8	0.9	0.5	0.5	0.5
2. Boot leaf to heading	1.5	3.0	2.8	2.8	3.3	2.3	1.5	1.9	1.4
3. Heading to anthesis	1.6	3.5	2.3	3.2	1.9	1.9	2.7	4.0	2.1
4. Boot leaf to anthesis	1.6	2.8	2.6	3.6	2.9	2.0	1.9	2.6	1.6
5. Anthesis to milk	4.0	3.3	3.5	2.0	1.0	1.6	4.7	3.1	4.2
6. Sowing to hard dough	1.3	1.0	0.8	0.9	0.9	0.8	1.4	1.2	1.1
7*.HUE with grain yield	2.6	3.0	2.8	2.4	2.9	2.8	2.6	3.5	3.3
Rabi 1986-87									
1. Sowing to boot leaf	0.5	0.6	0.7	0.6	0.5	0.4	0.5	0.9	0.5
2. Boot leaf to heading	1.8	0.7	2.0	1.0	2.2	3.3	1.8	0.8	1.4
3. Heading to anthesis	0.7	0.7	1.7	1.1	4.7	2.6	0.8	1.9	2.6
4. Boot leaf to anthesis	1.5	0.7	1.8	1.0	3.2	3.0	1.3	1.1	1.6
5. Anthesis to milk	1.5	2.1	1.8	2.2	1.4	0.7	1.9	2.5	1.0
6. Sowing to hard dough	0.9	0.7	0.8	0.6	0.7	0.5	0.7	0.6	0.4
7*.HUE with grain yield	2.9	2.8	2.9	2.6	2.6	2.3	3.5	3.0	3.1

* g/ha/degree day.

season when ambient temperatures were higher. Considering the HUE with respect to grain yield, during the rabi season 1985-86 (P_2) and 1986-87 (P_1) cv. HD 2281 showed the highest HUE (3.5) among all treatments for both the seasons which is similar to the observations reported by Sastry et al. (1985).

4.11 GROWING DEGREE DAYS vs ACCUMULATED BIOMASS PRODUCTION

Correlation coefficients between the growing day degrees and accumulated biomass production in respect of the different varieties and the two seasons were worked out and are given in Table 16a.

These characters were found to be significantly correlated with each other at 1 per cent level, the correlations ranging from 0.87 to 0.97 for the individual seasons as well as for the pooled data. In view of the high correlation, regression equations were computed for individual seasons as well as for the pooled data and are given in Table 16a.

Using the regression, biomass production at different accumulation levels of degree days were estimated and are given in Table 16b. As already observed in respect of the relationship between the two characters, cv. ISD 397 showed higher biomass production followed by HD 2281 and ISD 513 at different levels of accumulated heat units. As an illustration, at an accumulation of 1000 degree days the biomass produced in ISD 397, ISD 513 and HD 2281 were 1151, 1058 and 1130 g/m^2 respectively. Similar linear relationship was earlier reported for other wheat varieties by Chakravarthy (1980) and Chakravarthy et al (1984) in wheat and barley crops.

Table 16a. Correlation and regression between biomass (g/m2) and accumulated heat units

Variety	Regression equation	Correlation coefficient (r)	S.E.
	Rabi 1985-86		
V_1	BM = 1.60 GDD - 481.0	0.867	306.5
V_2	BM = 1.97 GDD - 775.3	0.927	223.6
V_3	BM = 2.14 GDD - 887.2	0.966	164.9
	Rabi 1986-87		
V_1	BM = 1.37 GDD - 444.2	0.963	105.6
V_2	BM = 1.27 GDD - 423.5	0.937	128.1
V_3	BM = 1.31 GDD - 392.2	0.966	95.4
	Pooled data over two seasons		
V_1	BM = 1.81 GDD - 658.6	0.920	204.5
V_2	BM = 1.69 GDD - 626.8	0.907	214.9
V_3	BM = 1.80 GDD - 668.9	0.941	180.0

BM = Biomass

GDD= growing degree days.

Table 16b. Biomass production at different levels of Growing degree days (GDD)

GDD	ISD 397	ISD 513 Biomass (g/m²)	HD 2281
400	65	47.2	51
500	246	215.7	231
600	427	384	411
700	608	553	591
800	789	721	770
900	970	890	950
1000	1151	1058	1130
1100	1332	1227	1310
1200	1513	1395	1490
1300	1694	1564	1670
1400	1875	1732	1850

4.12 EVAPOTRANSPIRATION AND BIOMASS PRODUCTION

4.12.1 Pan evaporation

Mean daily rates of evaporation during different weeks of the wheat crop growing season using measured pan evaporation for the two rabi seasons (1985-86 and 1986-87) are shown in Fig.6. Upto anthesis stage pan evaporation rate increased at about 2 to 2.5 mm/day after which it rapidly increased due to spring warming and summer seasons. It ranged from 3 mm/day in 8th week to greater than 6 mm/day by soft dough stage. Between seasons, evaporation rates were higher in 1986-87 season 2 weeks before and after boot leaf stage compared to 1985-86 season by about 1 mm/day. Around soft dough stage also for 2 weeks evaporation was higher by 2 mm/day in 1986-87 season than in 1985-86 season.

4.12.2 Energy gain by pan

The energy gain by the evaporating surface (pan) represented by the deviation of the pan evaporation from estimated net radiation for the 2 seasons 1985-86 and 1986-87 is shown in Fig.6. In general, energy gain by the pan ranged between 0.5 to 1 mm/day till about soft dough stage and later it showed an increase due to seasonal conditions. Even pan evaporation increased from anthesis stage as mentioned above. Between boot leaf and anthesis the 1986-87 season showed a higher energy gain by about 1 mm/day for about 2 weeks. At the soft dough stage and beyond also energy gain was higher in 1986-87 season compared to 1985-86 season.

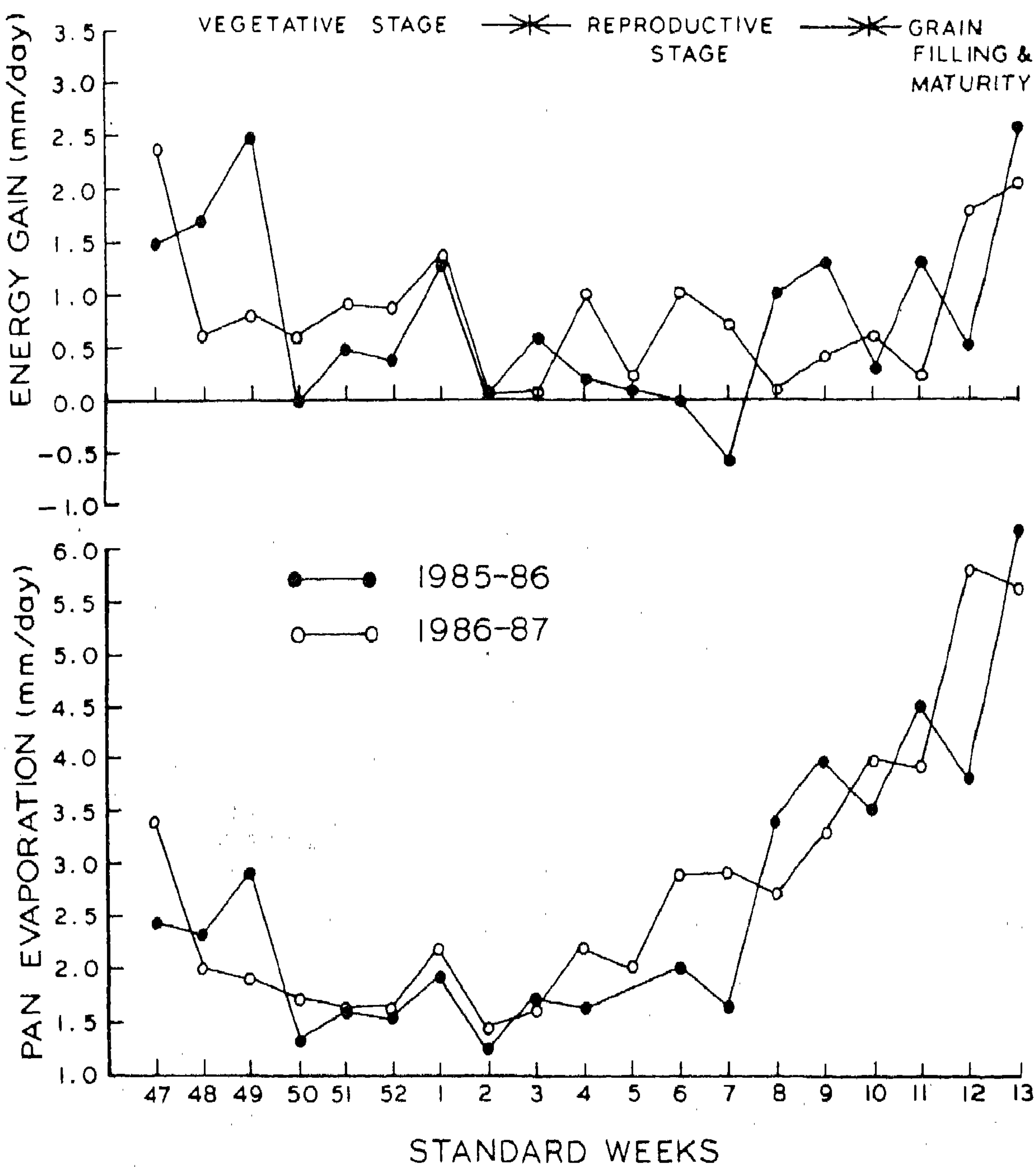

Fig. 6. Pan evaporation and energy gain by pan during 1985-86 and 1986-87 rabi seasons.

4.12.3 Cumulative pan evaporation vs. biomass production in wheat

Correlation coefficients between cumulative pan evaporation (mm) and biomass production (g/m^2) were worked out and are shown in Table 17a. The correlation values were found to be highly significant at 1 per cent level. Similar significant correlations were earlier reported by Hanks *et al.* (1969), and Chakravarthy and Sastry (1983b) in case of barley and wheat crops. In view of the high correlation, regression equations were fitted to the data for the three varieties by pooling together the observations from the three plantings for each variety. The regression equations for both the seasons are given in the Table 17a. These would enable estimation of biomass production at any chosen level of cumulative pan evaporation in Delhi region.

Using the regression, biomass production in wheat at different levels of cumulative pan evaporation for each of the three wheat varieties used in this investigation were computed and shown in Table 17b.

Of the three varieties studied it is seen that the biomass production at 200 mm of evaporation corresponding to the variety ISD 397 was higher followed by HD 2281 and ISD 513. This is similar to the observation earlier made in respect of the relationship between cumulative GDD and biomass. The varieties ISD 397 and HD 2281 nearly produced the same amount of biomass at different levels of cumulative evaporation. The linear relationship between cumulative evaporation and biomass production observed by Viets (1962), Doyle and Fischer (1979) and Chakravarthy and Sastry (1983b) is further confirmed by the above results.

Table 17a. Correlation and regression between biomass (g/m²) and cumulative pan evaporation (mm)

Variety	Regression equation	Correlation coefficient (r)	S.E.
	Rabi 1985-86		
V_1	BM = 10.10 CPE - 710.9	0.975	136.1
V_2	BM = 8.76 CPE - 598.4	0.935	212.3
V_3	BM = 9.38 CPE - 680.7	0.975	141.6
	Rabi 1986-87		
V_1	BM = 6.03 CPE - 421.1	0.978	81.0
V_2	BM = 5.60 CPE - 401.5	0.944	121.0
V_3	BM = 5.65 CPE - 358.6	0.966	94.2
	Pooled data over two years		
V_1	BM = 7.82 CPE - 534.7	0.907	220.2
V_2	BM = 7.32 CPE - 513.6	0.887	235.5
V_3	BM = 7.80 CPE - 548.9	0.928	197.4

BM = Biomass

CPE= Cumulative pan evaporation

Table 17b. Biomass production at different levels of cumulative pan evaporation

Cumulative evaporation	Biomass (g/m²)		
	ISD 397	ISD 513	HD 2281
100	247	218	231
120	403	365	387
140	560	511	543
160	716	657	699
180	872	804	856
200	1029	950	1011
220	1185	1097	1168
240	1341	1243	1324
260	1498	1389	1480
280	1654	1536	1636
300	1810	1682	1792
320	1967	1828	1948
340	2123	1975	2104

The regressions showed that for establishment of the crop in the initial stages, an accumulation of 370 GDD and 70 mm of cumulative evaporation are needed in the Delhi region.

4.13 CANOPY TEMPERATURES, CANOPY AIR TEMPERATURE DIFFERENCE AND AMBIENT TEMPERATURE IN WHEAT CROP

Crop canopy temperature (Tc), canopy air temperature difference (CATD) and ambient temperature (Ta) represent the effect of the balance between radiation received by the crop and energy utilized in transpirational cooling for decreasing the heat load, depending on the evaporative power of air.

With a view to study these characteristics, daily observations at 1400 hours on crop, ambient temperatures and CATD were correlated with maximum temperature and saturation deficit. Canopy temperatures were observed daily from heading to maturity in all of three cultivars and three plantings. For illustration the canopy temperatures (Tc) of cv. ISD 397 for both the rabi seasons (1985-86 and 1986-87) are as shown in the Fig. 7. The salient features are as follows:

4.13.1 Canopy temperature

Tc increased gradually from 17°C at heading to 29°C at the time of milk stage and further increased to 35°C at the maturity stage.

During the 1986-87 season the Tc ranged from 20 to 27°C from February till the maturity of crop. At the time of heading stage, it was 21.8°C which increased to 29.5°C at milk stage and further increased to 37°C at maturity. Between the two seasons, it is evident

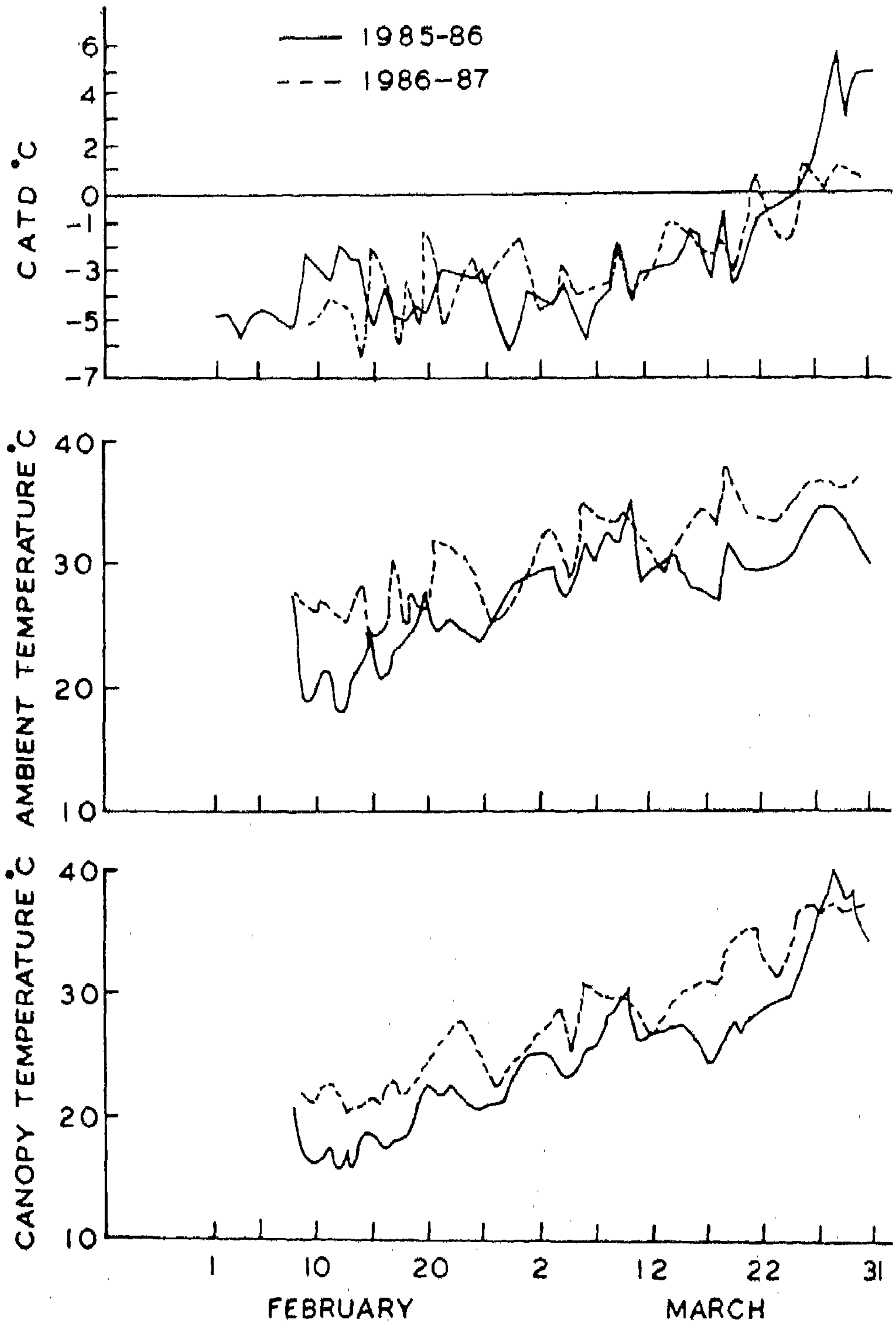

Fig. 7. Canopy, ambient temperature and crop-air temperature differences (CATD) in wheat crop

from the figure that 1986-87 showed higher Tc throughout when compared to the *rabi* 1985-86 season. The difference in Tc between the two seasons was of the magnitude of 1 to 6°C. With such a difference in Tc between the two seasons, a reduction in yield in the warmer season could be expeted as earlier reported by Stone *et al*. (1975).

4.13.1.1 Canopy temperature vs. Saturation deficit

Correlation coefficients between canopy temperature (°C) and saturation deficit (mm) worked out for cv. ISD 397 for both the seasons, for the first and third plantings are given in Table 18. Highly significant positive correlations at 1 per cent level ranging from 0.71 to 0.88 were obtained in both the plantings.

In view of the high correlation obtained regression equations were fitted to the data for P_1 and P_3. A regression equation was also fitted to the pooled data for the 3 planting dates and both the seasons and is shown in the Fig.8. A linear relationship was observed between Tc and saturation deficit, confirming the results observed by several workers.

4.13.1.2 Canopy temperature (Tc) vs. maximum temperature (Tmax)

Correlaton coefficents between Tc and Tmax were worked out for cv. ISD 397 for the first and third plantings in both the seasons and are given in Table 18. The values were found to be highly significant at 1 per cent level. In view of the high correlation obtained, regression equations were fitted to the data. A regression equation

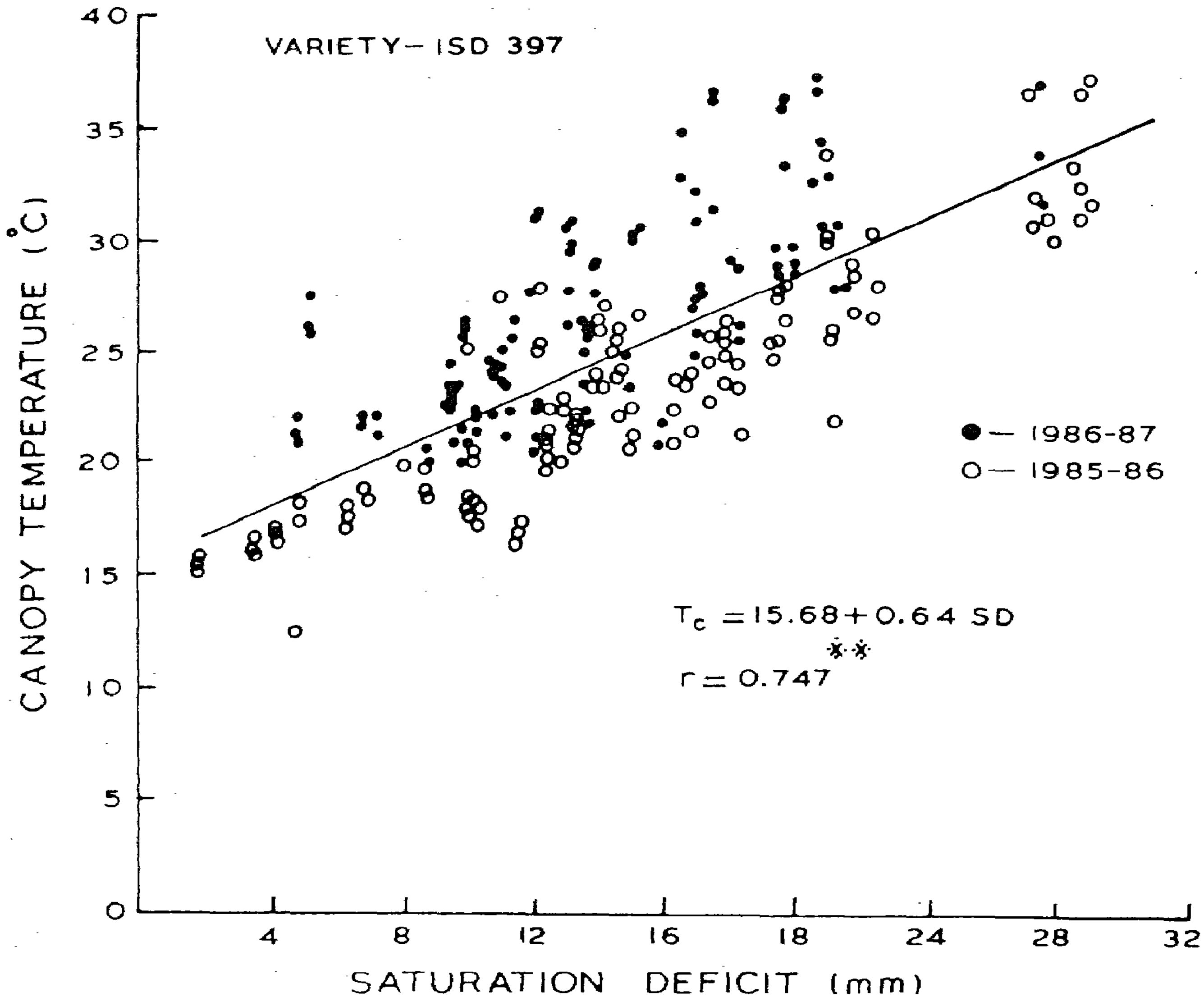

Fig. 8. Canopy temperature vs saturation deficit

was fitted for the pooled data also (over three plantings and two seasons) for cv. ISD 397 and is shown in Fig. 9. A linear relationship was observed. Such a correlation with maximum temperature does not appear to have been reported so far and the result is significant. This regression would enable estimation of Tc from the Tmax which is a routine measurement in agrometeorological observations.

4.13.1.3 Canopy temperature (Tc) vs. Ambient temperature (Ta)

Correlaion coefficients between Tc and Ta were worked out for cv. ISD 397 in the same manner as above and are given in Table 18. The values were found to be highly significant at 1 per cent level. Regression equations were fitted to the pooled data for the cv. ISD 397 and are shown in Table 18.

In all cases, a positive linear correlation is noticed. However in magnitude, among the three parameters, correlation with ambient temperature in both the cooler and warmer seasons is the highest. Another feature noticed is that the magnitude of correlation coefficients were relatively lower in the warmer season.

4.13.2 Canopy air temperature differences (CATD)

Canopy air temperature differences have been used to identify moisture stress in crops for irrigation scheduling. As these arise due to transpirational cooling. It is felt that saturation deficit is one of the parameters that could be associated with this.

Canopy air temperature differences (CATD) at 1400 hrs IST were observed daily from heading to maturity in all the varieties

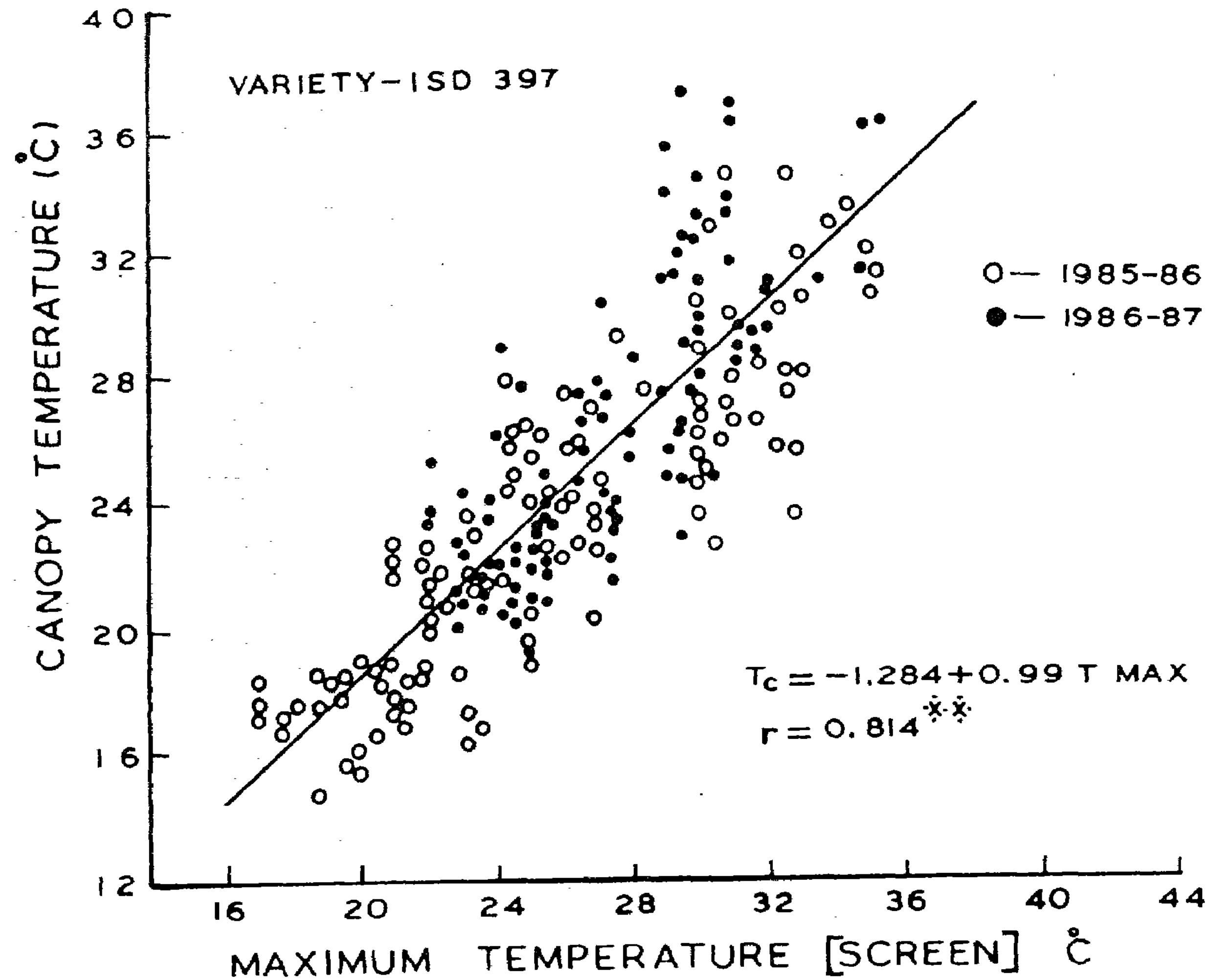

Fig. 9. Daily maximum temperature vs canopy temperature

Table 18. Correlation and regression between canopy temperature (Tc) Vs (i) Saturation deficit (SD) (ii) Maximum temperature (Tmax) and (iii) Ambient temperatures (Ta)

	Rabi 1985-86		Rabi 1986-87	
	Correlation coefficient	Regression	Correlation coefficient	Regression
Tc vs SD				
First planting	0.88	12.9+0.79 SD	0.76	16.5+0.75 SD
Second planting	0.88	13.2+0.62 SD	0.71	19.2+0.48 SD
Tc vs Tmax				
First planting	0.84	-2.9+1.07 Tmax	0.78	-8.3+1.30 Tmax
Second planting	0.83	1.7+0.81 Tmax	0.81	2.3+0.87 Tmax
Tc vs Ta				
First planting	0.90	-9.6+1.25 Ta	0.94	-10.5+1.25 Ta
Second planting	0.93	-2.6+0.93 Ta	0.90	1.2+0.83 Ta

Temperature in °C Saturation deficit in mm of Hg and three plantings. For illustration the CATD of cv. ISD 397 for both the *rabi* seasons (1985-86 and 1986-87) in the first planting are shown in the Fig. 7. The CATD (Tc-Ta) ranged from -6°C at heading stage (on 3rd February) to -1°C (on March 21st) at hard dough stage, after which it became positive in both the years.

Early in the season from 13th to 20th February, 1987 CATD showed great variation. At time of reproductive stage i.e. from 12th to 25th March, the canopy air temperature differnces in 1986-87 were slightly higher when compared to 1985-86 season.

4.13.2.1 Canopy air temperature difference vs. saturation deficit

Correlation coefficients between CATD and saturation deficit were worked out for cv. ISD 397 for both 1985-86 and 1986-87 for the three plantings. The correlation value was negative (-0.50) and was significant at 1 per cent level. In view of the high correlation obtained, regression equation was fitted to the pooled data and regression line drawn as shown in the Fig.10. The results confirm the observations of Walker and Hatfield (1983), Kirkham *et al*. (1983) in kidney bean and alfalfa crops. Similar results were also reported by Choudhury (1985) in wheat.

4.13.2.2 Canopy air temperature differnces and crop-maturity date

In each treatment, canopy air temperature differences at 1400 hrs which were negative for most part of crop growth period showed a reversal at the end of the season. The dates of reversal

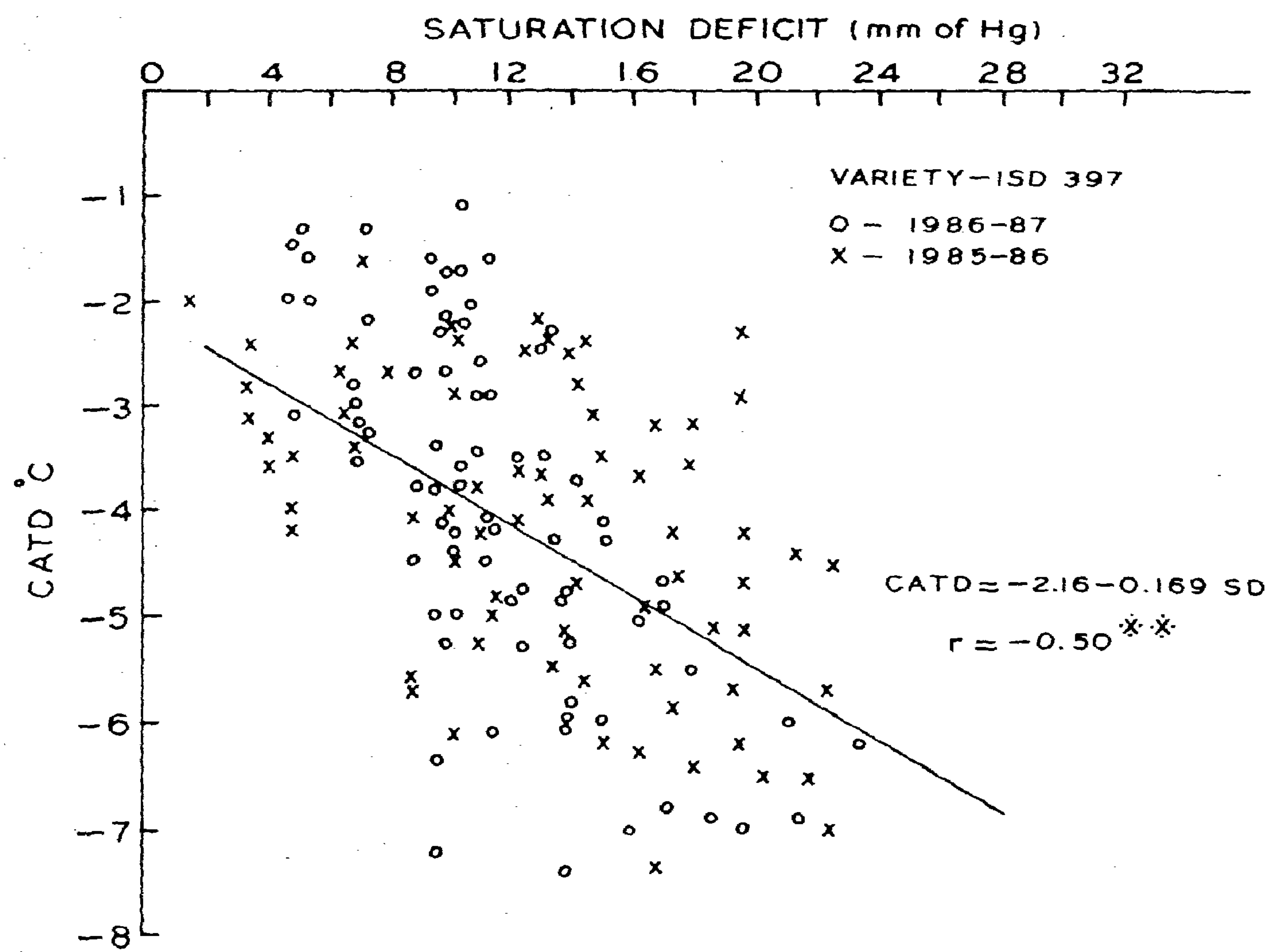

Fig. 10. Daily saturation deficit (2pm) vs canopy air temperature difference (CATD)

were noted and they mostly coincided with the date of attainment of 50 per cent hard dough stage of the crop as shown below in the Table--19.

Table 19. Dates of reversal of CATD and hard dough stage in three wheat cultivars.

Treatment	Rabi 1985-86 Date of temperature reversal	Rabi 1985-86 Date of attainment of HD stage	Rabi 1986-87 Date of temperature reversal	Rabi 1986-87 Date of attainment of HD stage
V_1P_1	27-3-86	24-3-86	25-3-87	25-3-87
V_1P_2	05-4-86	03-4-86	03-4-87	31-3-87
V_1P_3	09-4-86	12-4-86	04-4-87	06-4-87
V_2P_1	04-4-86	06-4-86	27-3-87	04-4-87
V_2P_2	09-4-86	06-4-86	03-4-87	07-4-87
V_2P_3	15-4-86	17-4-86	08-4-87	13-4-87
V_3P_1	28-3-86	27-3-86	25-3-87	23-3-87
V_3P_2	28-3-86	02-4-86	28-3-87	05-4-87
V_3P_3	09-4-86	12-4-86	09-4-87	11-4-87

HD - Hard dough.

Continuous positive values of canopy air temperature differences thus seem to indicate the time of attainment of physiological maturity in crops and could be used as an indicator.

4.13.3 CROP CANOPY AND EARHEAD TEMPERATURES

As the crop reaches physiological maturity leaf and earhead material may exhibit different temperatures. With a view to study the magnitude of the differences, if any, observations were made on the leaf and earhead using the infra-red thermometer by keeping them as separate targets.

Crop canopy and earhead temperatures were noted during the rabi 1986-87 for two varieties ISD 397 and HD 2281 for the first planting and are shown in Table 20.

The observations were recorded daily at 1400 hrs from milk to soft dough stages in both the varieties. Earhead temperatures were slightly warmer than canopy temperatures by 0.5 to 0.7°C. CATD was lower by similar magnitude over the earheads than the crop canopy indicating warmer atmosphere near earheads. Such differences arise due to earhead turning gradually less green to brown colour than the leaves as the crop grows to physiological maturity.

4.13.4 CUMULATIVE PAN EVAPORATION vs STRESS DEGREE DAYS (Σ SDD)

Stress degrees day (SDD) concept is a promising method for irrigation scheduling that involves the mid-day measurement of crop foliage/air temperature differences and their summation on a daily basis from heading to maturity stage of crop growth. Since atmospheric and crop stress are dependent on evaporation potential of the air, the relationship between evaporation and SDD was studied.

The correlation coefficient between cumulative pan evaporation (CPE) and Σ SDD from boot leaf to soft dough stages was worked out for cv. ISD 397 for the rabi 1986-87 using pooled data for the three

Table 20. Earhead and canopy temperatures in wheat crop

Date	V_1P_1 Canopy temperature		Earhead Temp.		V_3P_1 Canopy Temp.		Earhead Temp.	
	Tc	CATD	T_E	EATD	Tc	CATD	T_E	EATD
2.3.87	26.3	-4.6	27.8	-3.6	26.2	-5.0	26.5	-4.9
4.3.87	27.8	-3.8	27.8	-3.8	27.6	-4.7	28.0	-3.9
5.3.87	24.9	-4.4	25.7	-3.6	24.9	-4.3	25.4	-3.7
6.3.87	31.4	-2.5	31.7	-2.7	30.8	-4.0	31.0	-3.8
9.3.87	29.7	-2.4	30.0	-2.6	29.3	-3.7	29.6	-3.6
12.3.87	26.3	-2.4	26.9	-2.4	26.6	-3.1	27.1	-2.4
13.3.87	28.2	-0.7	28.5	-0.4	27.7	-1.3	28.3	-0.8
14.3.87	29.5	-1.5	30.5	-0.7	29.4	-1.5	30.0	-1.2
18.3.87	31.2	-2.1	32.1	-1.1	31.0	-2.4	31.4	-2.0

Tc : Canopy temperature
CATD : Canopy air temperature difference
T_E : Earhead temperature
EATD : Earhead air temperature difference

plantings. Cumulative pan evaporation was highly and significantly correlated with Σ SDD (r= -0.95). Cumulative pan evaporation and ΣSDD during the individual plantings show a large goodness of fit (r = -0.98 to -0.99) thus further confirming the results of Walker and Hatfield (1979) and Diaz et al. (1983). Similar correlations under Indian conditions do not seem to have been worked out, and since pan evaporation was significantly correlated with biomass, the result is of significance for use in remote sensing research for estimation of biomass and its correlation with ground truth.

In view of the high correlation obtained, regression equation was fitted to the data and is shown in the Fig.11. Regressions worked out for each individual planting dates are given below:

Regression of cumulative pan evaporation vs ΣSDD for individual and pooled data for planting dates.

Index	Planting date	n	a	b	r
Σ SDD	18th November	6	-26.8	- 1.2	-0.98**
	1st December	6	-13.2	- 1.3	-0.98**
	15th December	6	-5.38	- 0.9	-0.99**
	Pooled data	18	-7.5	- 1.1	-0.95**

** - Significant at 1% level.

The results show that in the individual planting dates the two characters are more closely correlated than in the pooled data as also observed earlier by Diaz et al. (1983).

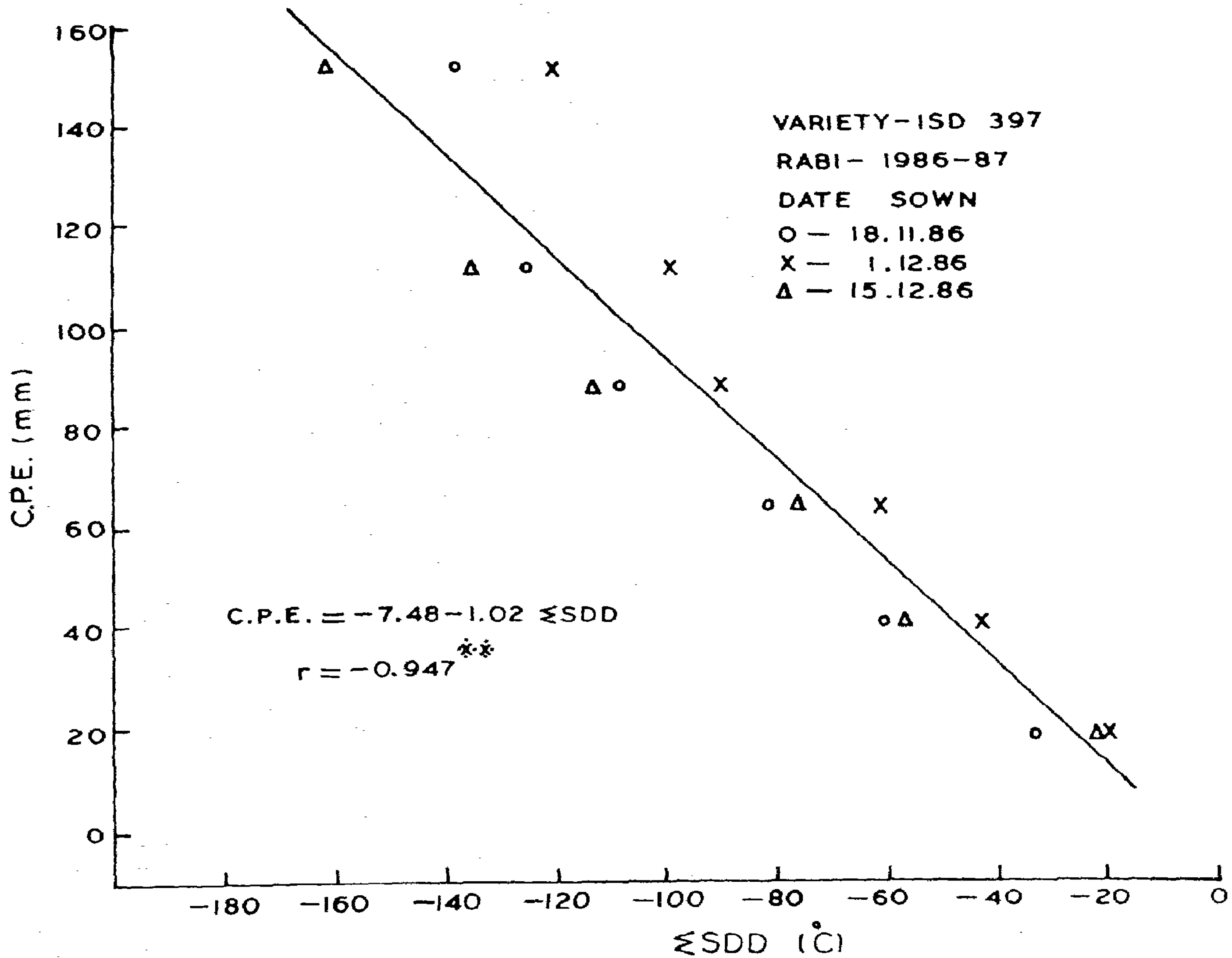

Fig.11. Cumulative pan evaporation [C.P.E.] vs stress degree days [SDD]

From the Fig.11 it is obvious that cumulative pan evaporation is both linearly and inversely related to cumulative SDD (Σ SDD) as reported by Idso et al. (1977), Jackson et al. (1977) and Walker and Hatfield (1979).

4.13.5 STRESS DEGREE DAYS vs GRAIN YIELD

Degree of moisture stress in a crop with different stages is an indication of the grain yield in crops. However, since the stress degree day concept could be used both for rainfed and irrigated crop conditions to estimate relative stress under different treatments, stress degree days were worked out for different plantings and the three varieties, were correlated with grain yield.

A correlation coefficient of -0.60 was observed between these parameters with significance at 5 per cent level.

Regression equation was fitted to the data and shown in Fig.12. As could be observed, grain yield has shown a decrease with increasing ΣSDD. Similar results were reported by Walker and Hatfield (1979), Diaz et al. (1983) and Singh et al. (1985).

Stress degree days is an important parameter which showed good relation with both cumulative pan evaporation and grain yield thus providing an important index to assess wheat yields.

4.13.6 AMIBIENT TEMPERATURES

Ambient temperatures during the rabi season 1985-86 and 1986-1987 season are shown in the Fig.7. Ambient temperature in 1985-86

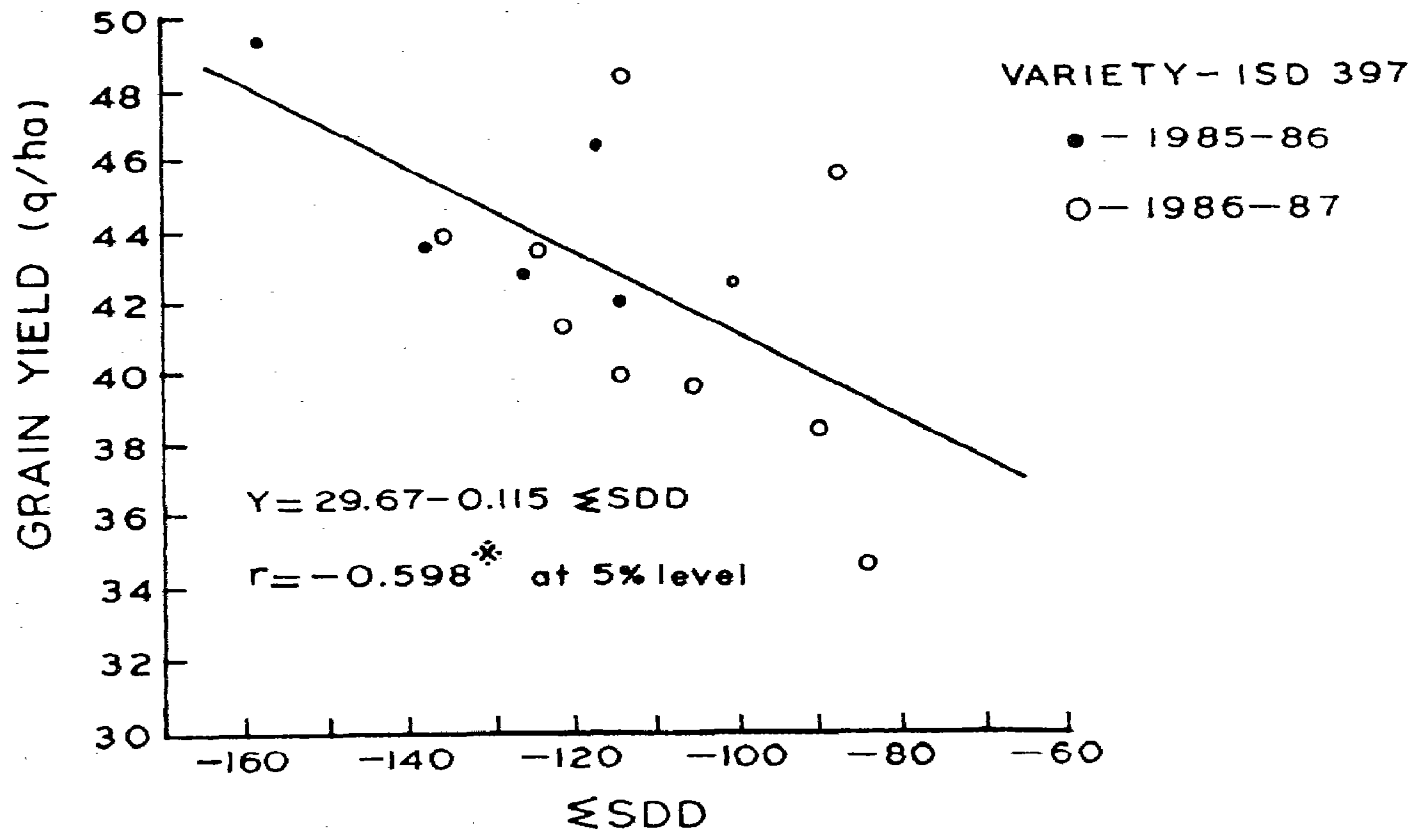

Fig. 12. Grain yield vs stress degree days in wheat

was lower almost throughout the season than in 1986-87 from 9th to 15th February by 7°C, from 19th February to 28th May by 5-6°C and after 13th March by 3-6°C.

Thus both canopy temperature and ambient temperatures were higher during rabi 1986-87 compared to the 1985-86 season, showing the relatively warmer conditions in the season even with an irrigated crop.

4.13.7 VARIATIONS IN CANOPY TEMPERATURE IN RELATION TO CLEAR AND CLOUDY SPELLS

Cloudiness alters the amount of radiation received at the crop surface and consequently the canopy temperature. Review shows that there are very few reports on this aspect.

To study the variation in canopy temperature, in relation to clear and cloudy spells caused by short period changes in weather, daily canopy and ambient temperatures noted at 1400 hrs in different treatments were analysed and the following cases are presented.

Case (i). Overcast sky followed by clear days.

In association with the passage of western disturbance over Punjab and Himachal Pradesh, the sky became overcast on 3rd February, 1986, and cleared on the following day. However, during this period the maximum temperatures were nearly normal and minimum temperatures were 2°C below normal and there was no rainfall; except for overcast sky on the third, local weather was not much affected. The Tc, CATD and Ta are shown in the Table 21 on the respective days. The canopy temperature in all the treatments ranged from 16.4 to 18.1°C on the

Table 21. Variation in canopy temperature, CATD and ambient temperatures during short period changes in weather

Date	ISD 397 1st Pltg.	ISD 397 2nd pltg.	ISD 397 3rd pltg.	ISD 513 1st pltg.	ISD 513 2nd pltg.	ISD 513 3rd pltg.	HD 2281 1st pltg.	HD 2281 2nd pltg.	HD 2281 3rd pltg.
					CANOPY TEMPERATURE (Tc)				
	Case (a)								
3.2.86	16.4	16.8	17.9	17.3	16.8	18.1	16.7	16.6	17.2
4.2.86	21.4	22.4	22.2	21.5	22.8	22.6	22.5	21.2	21.9
5.2.86	20.0	20.1	19.3	19.8	19.4	20.5	20.5	19.1	19.2
				CANOPY-AIR TEMPERATURE DIFFERENCES (CATD)					
3.2.86	-5.9	-4.8	-5.0	-4.4	-5.3	-3.8	-5.5	-5.9	-5.0
4.2.86	-4.9	-2.4	-4.3	-3.1	-3.8	-1.9	-4.2	-5.3	-4.0
5.2.86	-4.5	-2.7	-4.4	-2.7	-4.5	-1.7	-3.9	-5.5	-4.3
					AMBIENT TEMPERATURE(Ta)				
3.2.86	22.3	21.3	22.3	21.7	22.1	21.9	22.2	22.5	22.2
4.2.86	26.6	24.8	26.5	24.6	26.6	24.5	26.7	26.7	25.9
5.2.86	24.5	22.8	23.7	22.5	23.9	22.2	24.7	27.1	26.7
	Case (b)				CANOPY TEMPERATURE (Tc)				
8.2.86	21.8	21.1	20.8	20.6	20.6	21.1	22.6	20.3	20.8
9.2.86	16.5	16.1	16.2	15.8	16.1	16.0	16.5	16.1	16.0
10.2.86	16.4	16.9	16.9	17.0	16.8	17.5	16.9	16.3	16.8
				CANOPY-AIR TEMPERATURE DIFFERENCES (CATD)					
8.2.86	-5.5	-3.9	-6.2	-3.7	-5.8	-2.5	-4.1	-6.8	-5.9
9.2.86	-2.4	-3.1	-2.8	-3.5	-3.0	-3.7	-2.3	-2.6	-2.1
10.2.86	-3.3	-3.6	-3.3	-4.0	-3.3	-4.1	-3.1	-3.2	-3.2

Table 21 Contd...

Table 21.. Contd..

Date	ISD 397			ISD 513			HD 2281		
	1st Pltg.	2nd pltg.	3rd pltg.	1st pltg.	2nd pltg.	3rd pltg.	1st pltg.	2nd pltg.	3rd pltg.
				AMBIENT TEMPERATURE (Ta)					
8.2.86	27.3	25.0	27.0	24.3	26.4	23.6	26.7	27.1	26.7
9.2.86	18.9	19.2	19.0	19.3	19.1	19.7	18.8	18.8	19.1
10.2.86	19.7	20.5	19.0	21.1	20.1	21.6	20.0	19.8	20.1
	Case (c)			CANOPY TEMPERATURE (Tc)					
3.3.86	24.7	25.8	22.8	24.7	22.9	23.0	25.5	23.8	21.5
4.3.86	23.0	22.4	20.1	21.0	20.5	20.0	22.7	21.6	20.2
5.3.86	23.3	24.5	21.4	24.1	21.3	23.0	23.4	23.5	20.5
6.3.86	25.4	24.7	24.7	23.5	23.5	23.2	26.8	23.7	23.6
			CANOPY-AIR TEMPERATURE DIFFERENCES(CATD)						
3.3.86	-4.6	-1.9	-5.9	-2.4	-5.9	-2.6	-3.9	-5.1	-6.7
4.3.86	-3.7	-1.9	-5.0	-3.0	-4.8	-3.6	-3.1	-4.6	-4.9
5.3.86	-5.1	-2.1	-6.9	-2.0	-6.3	-2.0	-5.4	-5.2	-7.0
6.3.86	-6.2	-5.7	-7.0	-6.8	-7.6	-7.0	-5.1	-8.5	-6.8
				AMBIENT TEMPERATURE (Ta)					
3.3.86	29.3	27.7	28.7	27.1	28.8	26.6	29.4	28.9	28.2
4.3.86	26.7	24.3	25.1	24.0	25.3	23.9	25.8	26.2	25.1
5.3.86	28.4	26.6	28.3	26.1	27.6	25.0	28.8	28.7	27.5
6.3.86	31.6	30.4	31.7	30.2	31.1	30.2	31.9	32.2	30.4

3rd (overcast day). The temperatures ranged from 21.2 to 22.8°C on the following day showing increase of 4-6°C. However, the canopy air temperature differnce did not show a similar variation in any of the treatments except for a slight decrease.

The ambient temperature indicated a corresponding increase on the clear day. It was about 3-4°C higher. Thus the response to overcast condition in Tc and Ta is more conspicuous than in CATD during the rising phase of temperature.

Case (ii). Clear sky followed by overcast rainy days.

In association with a western disturbance which moved from Rajasthan, rainfall of 1.8, 27.8 and 7.4 mm was received at the station on 10th, 11th and 12th February, 1986, respectively. On analysis of daily weather data it was found that after clear day from 4th to 7th during the cloudy period that followed from 9th to 16th February the maximum temperatures were 3-5°C below normal whereas minimum temperatures were 3°C above normal from 8th to 12th February. The data on Tc, CATD and Ta are given in Table 21. The sky cleared only on 16th February.

Tc ranged from 20.3 to 22.6°C on 8th (clear day) February. In association with overcast skies and cold wind Tc fell by 4-6°C on 9th February and continued at the same level till 16th February. However, Ta which ranged from 23.6 to 27.3°C on 8th decreased by 5 to 8°C in most of the treatments on the 9th and continued to remain so, till 16th February. CATD which ranged from -2.5 to -6.8°C on 8th decreased to -2.3°C to -3.7°C on 9th and continued so till 16th February showing a relatively large change in ambient temperatures.

Case (iii). <u>Warm day with diffuse radiation and calm winds</u>

The sky was clear on 3rd March, 1986 and became mostly overcast on 4th and cleared on 5th. However, on 6th March, the sky was covered by 5 octa of Cirrocumulus and Cirrostratus clouds with calm wind and the day was stuffy with typically diffuse radiation due to extensive cloud cover. The Tc, Ta and CATD are shown in Table 21.. In this sequence of events when there was no perceptible change in Tc in the different treatments, the Ta on 6th March was warmer by 2-3°C compared to the previous 3 days. However, CATD on 6th was relatively higher ranging from -5.5 to -8.5°C in the different treatments. By this time the different plantings were in the heading to milk stage. This pattern of very little increase in Tc and increase of 2-3°C in Ta and a considerably high CATD seems to be the characteristic of typically stuffy day with predominantly diffuse radiation conditions in the sky.

The three cases mentioned above showed different effects of cloudy and clear sky weather on Tc, Ta and CATD. When overcast skies cleared (case i), increase in Tc was the highest followed by Ta with no perceptible change in CATD.

When overcast sky is preceded by clear skies, the order of magnitude of decrease in the three parameters are Ta > Tc > CATD with a decrease of 5-8°C, 4-6°C and 2-3°C, respectively. On a sultry, calm day with predominantly diffuse radiation, it was CATD which showed large variation (-5.5°C to -8.5°C) from that of a clear day, whereas Ta became warmer by 2-3°C with no perceptible change in Tc unlike the case (i).

Thus with two seasons' data, while it is not possible to precisely conclude regarding the magnitude of the variation in the above three parameters, the results bring out a significant feature, hitherto not come across that specific environmental conditions, produce specific but widely different variations in canopy, ambient temperatures and their difference, in spite of their known interdependence. The results point out to the necessity of further detailed investigation on these aspects in relation to day to day weather conditions.

The cloudy periods have been observed to lower Tc, since diminished radiant heat load requires less total energy dissipation. Stone *et al*. (1975) and Khera and Sandhu (1986) observed similar results of lowered canopy temperatures, during cloudy periods, but did not mention regarding the variations in ambient and CATD values.

4.13.8 DIURNAL VARIATIONS IN DIFFUSION RESISTANCE, CANOPY AND LEAF TEMPERATURES

Leaf temperature (Tl) on which diffusion resistance in crops is dependent, does not necessarily represent the Tc. With a view to understand the extent of differences between the two at different times of the day, leaf and canopy temperature data were collected on three days with clear and overcast sky conditions during the crop growth season.

Day time diffuse radiation during these three days are shown below:

(as per cent of total raditation)

Date	Time hrs. 0940	1045	1120	1220	1300	1430	1530	1630
25-1-86	38	38	32	35	37	41	43	60
13-3-86	26	27	26	31	36	28	48	65
21-3-86	54	69	90	70	94	100	90	80

On 25th January diffuse radiation ranged between 30 to 40 per cent (except late in the evening) reflecting clear sky conditions in early winter season. On 13th March the diffuse radiation ranged from 26 to 36 per cent till 1530 hrs which increased later due to partly cloudy conditions with six octa Cirrus clouds. On the third day, (21st March) the skies were overcast with diffuse radiation accounting for about 90 per cent of the total radiation. These three days represent typical weather situations that prevail on idividual days during wheat crop growing season in Delhi region. The days were characterised by low, high and medium saturation deficits and mean air temperatures as follows:

Day	Saturation deficit (mm)	Mean air-temperature (°C)
25th January,1986	4.7 (low)	11.6
13th March, 1986	12.6 (high)	23.6
21st March, 1986	6.7 (medium)	17.8

Diurnal variations in diffusion resistance (with porometer), canopy temperature(Infrared thermometer) and leaf temperature (with porometer) were noted during the day light hours. Cultivar ISD 397 was chosen for illutration and the results are shown in Fig. 13.

25th January : This is clear sky day early in the cropping season. Leaf temperature was higher than the canopy temperature by 2°C early in the morning. This difference gradually increased to 5°C, in the later hours. Saturation deficit was the lowest (4.7 mm) with a nearly normal maximum temperature, the minimum temperature being 4.6°C below normal. Diffusion resistance under these conditions was higher (Fig. 13).

13th March : It was a clear sky day, late in the cropping season. Till 12.30 hrs., the leaf temperture was 2°C higher than the canopy temperature. Later the difference between Tl and Tc increased vastly, which by 1500 hrs. became 7°C, Tl being warmer. This is perhaps attributable to the seasonal warming at this part of the year with a high saturation deficit. However, it represents the pattern of Tl, CATD on a normal day as both maximum and minimum temperatures were within 1-2°C of their normal values. Diffusion resistance was the lowest though the saturation deficit was higher as the crop was in active stage of growth under irrigated conditions.

21st March : This is a cold windy day with a mean air temperature of 17.8°C and both maximum and minimum temperatures were below normal by about 7.1 and 5.2°C respectively with overcast skies and cold waves conditions. On this day leaf temperature was higher by 3-5°C than the canopy temperature. Diffusion resistance was the highest among the three days ranging from 2.3 to 3.5 s/cm. The

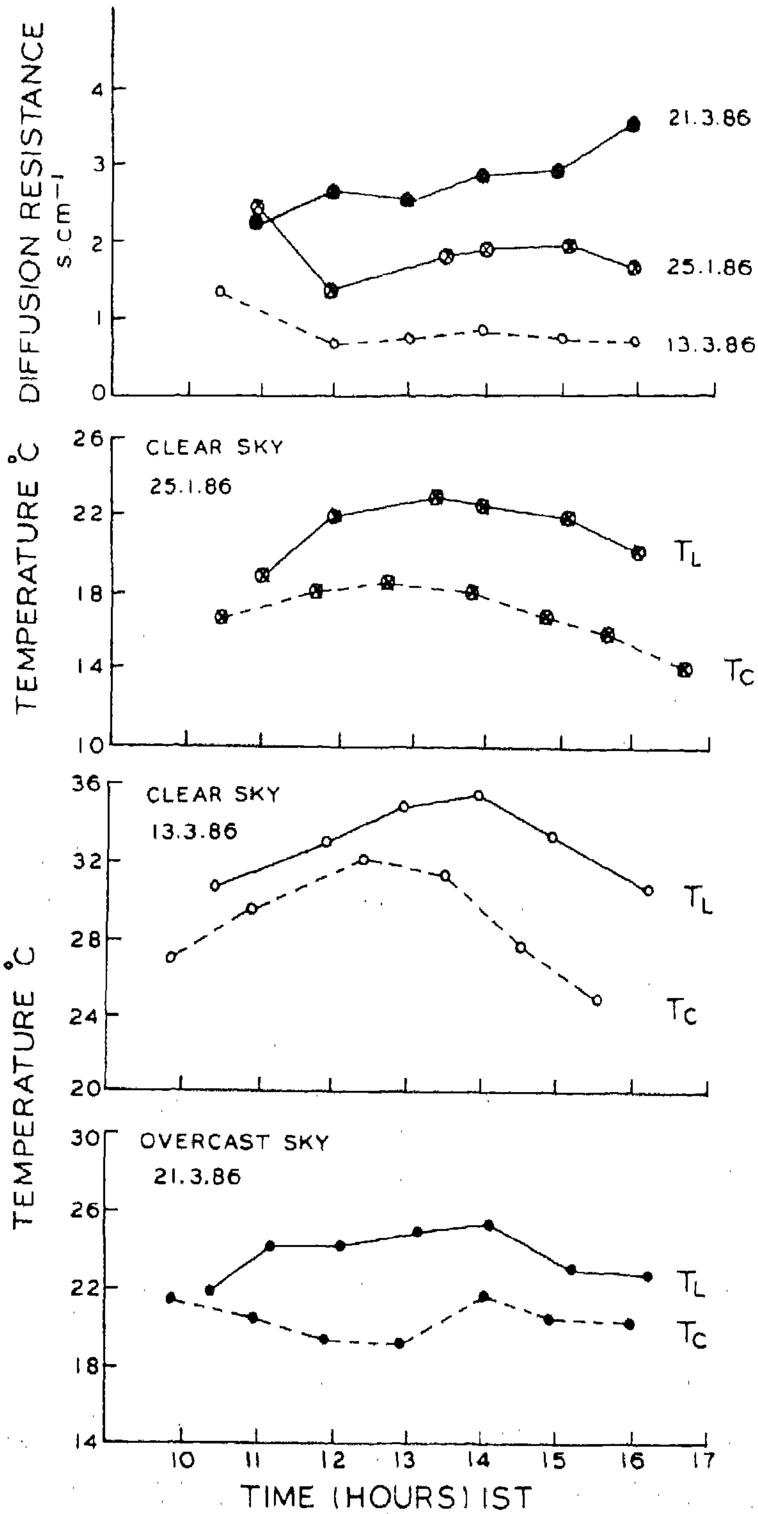

Fig. 13. Diffusion resistance, leaf (T_L) and canopy (T_C) temperatures in wheat crop with clear and overcast skies

individual leaf temperatures were found always to be higher than canopy temperatures throughout the day time. The above results show that under irrigated crop conditions,

i) warmer temperatures after 1200 hrs. increase the difference between Tl and Tc, the difference further becomes larger during the later periods of cropping season due to seasonal warming

ii) during cold wave conditions, Tl is greater than Tc throughout the day time hours by 3-5°C, with a high diffusion resistance, and

iii) the leaf temperature being a spot measurement apparently gives an over estimated value of canopy temperature irrespective of weather conditions that might prevail.

Similarly diffusion resistance observed on single leaf with porometer is also known to be an over estimate. Earlier studies by Pannalal (1983) showed that canopy resistance in wheat is one third of diffusive resistance measured with porometer. Thus the extent of over estimation in these parameters should be taken into account when interpreting single leaf measurement in relation to crop canopy characteristics.

4.14 LEAF CHLOROPHYLL CONTENT AND PHOTOSYNTHETICALLY ACTIVE RADIATION IN WHEAT CROP CANOPY

Leaf chlorophyll content, among other factors is dependent on light interception and temperature. With a view to study the variation of radiation interception (photosynthetically active radiation) and chlorophyll content in leaf at differnt growth stages of crop and the influence of temperature, chlorophyll content and photosynthetically active radiation (PAR) were monitored at periodic intervals during 1985-86 and 1986-87 rabi seasons in all treatments.

4.14.1 Chlorophyll patterns

The pattern of variation in chlorophyll content with the advancement of the crop is given in Fig. 14 for V_2P_1 and V_2P_3 in 1985-86 season. Both in the first and third plantings and at different canopy levels, the pattern was observed to be similar with intermittent peak values. The leaf chlorophyll content showed an intermittent increase and decrease with the progress of growth season. Similar observations were made by Cupina *et al*. (1979) in wheat crop.

4.14.2 Leaf chlorophyll content

With a view to explain the salient features, data regarding V_1 (ISD 397) and V_3 (HD 2281) for first and third plantings are presented in Table 22a and 22b. Highest chlorophyll content was reached at anthesis stage in both first and third plantings in rabi 1985-86 season. The top leaf showed higher chlorophyll content than the middle and the bottom leaves.

Chlorophyll content during 1985-86 season in P_1 ranged from 0.04 to 3.7 mg/g (fresh weight) in the top leaf with lower changes in the middle and bottom leaves. In the 1986-87 season they ranged from 1.1 to 4.2 mg/g in top leaf, while in the bottom leaf they ranged from

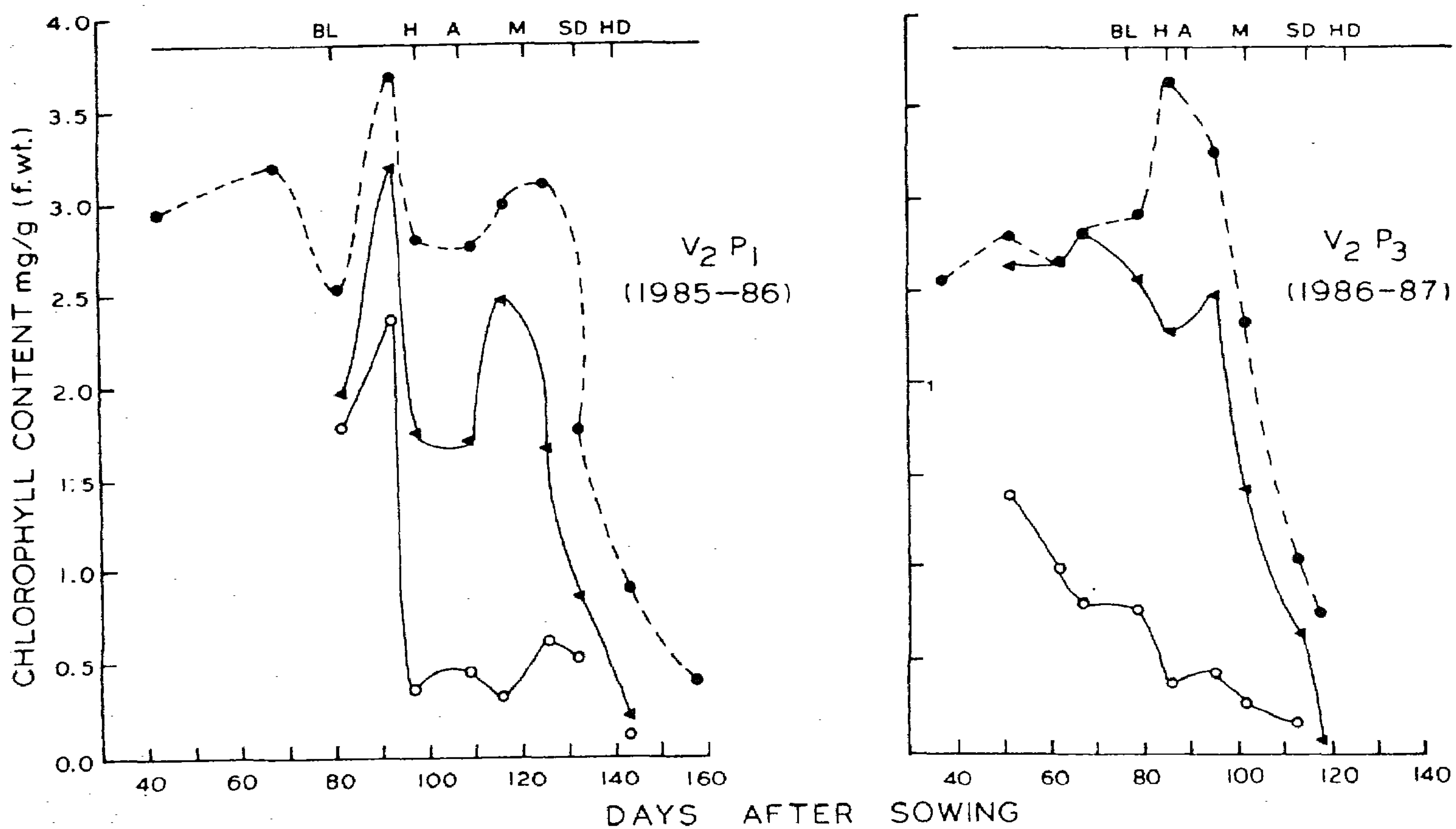

Fig. 14. Chlorophyll content of top (●) middle (▲) and bottom (o) leaves in wheat crop

Table 22a. Seasonal variation of leaf chlorophyll content (mg/g fresh wt.) in wheat at different levels in the canopy of cv. ISD 397

Date	First planting			Third planting		
	Top	Middle	Bottom	Top	Middle	Bottom
			Rabi 1985-86			
27/12	3.1	-	-	-	-	-
21/1	3.6	2.7	2.0	2.2	-	-
4/2	2.4	2.4	1.8	2.7	-	-
15/2	3.7	2.9	1.9	3.1	2.0	0.7
4/3	1.6	1.4	0.6	2.9	1.5	0.6
11/3	1.4	1.4	0.3	3.7	2.7	0.9
20/3	0.7	0.6	0.2	3.2	1.9	0.6
27/3	0.4	0.2	0.09	2.5	1.3	0.3
7/4	0.04	-	-	1.5	1.0	0.4
12/4	-	-	-	0.6	0.1	-
			Rabi 1986-87			
12/12	2.4	-	-	-	-	-
8/1	2.8	-	-	2.2	-	-
15/1	2.8	-	-	2.3	-	-
3/2	3.0	2.8	1.2	2.8	1.0	0.7
10/2	4.2	3.4	1.6	3.2	1.9	0.9
19/2	4.0	3.8	1.2	4.2	2.6	1.1
27/2	2.6	2.0	1.4	3.1	2.1	0.8
6/3	3.2	2.8	1.0	3.5	3.2	1.2
24/3	1.1	0.9	0.4	1.5	1.0	0.5

Table 22b. Seasonal variation of leaf chlorophyll content in wheat at different levels in the canopy of cv. HD 2281

(in mg/g fresh wt.)

Date	First planting			Third planting		
	Top	Middle	Bottom	Top	Middle	Bottom
			1985-86			
27/12	3.1	-	-	-	-	-
21/1	3.7	3.2	2.6	3.2	-	-
4/2	2.4	2.3	1.4	2.4	-	-
15/2	3.6	3.4	2.5	2.9	1.6	1.0
20/2	3.0	1.7	1.0	2.3	1.3	0.9
4/3	2.3	1.0	1.0	2.3	1.3	0.6
20/3	0.91	0.4	0.2	3.3	1.3	0.20
27/3	0.41	0.1	-	2.7	1.0	0.10
7/4	-	-	-	1.3	0.6	-
			1986-87			
22/12	2.2	-	-	-	-	-
8/1	2.8	-	-	2.0	-	-
15/1	3.4	-	-	2.2	-	-
19/1	3.0	-	-	2.2	-	-
3/2	3.2	3.0	1.5	2.2	-	-
10/2	4.2	2.9	1.8	2.7	1.2	0.8
19/2	4.8	4.4	1.8	3.6	1.6	1.2
27/2	3.2	2.9	0.7	3.0	1.8	1.3
6/3	3.3	3.1	1.8	3.1	2.4	1.3
24/3	1.8	1.0	0.8	3.4	3.2	1.9
29/3	0.6	0.2	-	1.2	0.8	0.4

0.4 to 1.6 mg/g showing lower chlorophyll content in the bottom leaves. Cupina et al. (1979) reported that the chlorophyll content varied between years and also between leaves in the order of flag leaf > below flag leaf > lower leaves. Similar pattern was observed in the third planting also.

Compared to 1985-86 season chlorophyll values in 1986-87 season were higher in both the plantings. From second to fourth week of February and 15th to 27th March, the 1986-87 season recorded higher temperatures by 5-6°C than 1985-86 season. The leaf area index was of same magnitude in both the seasons in ISD 397 for both the plantings under consideration. Though crop growth rates were much reduced due to higher temperatures in 1986-87 season both top and bottom leaves showed higher chlorophyll content.

Higher chlorophyll content at higher temperature of 30°C and 35°C when compared to 20 and 25°C were reported by Friend (1960), Ray et al. (1978), Roy and Biswas (1980) and Bennet et al. (1982) in wheat, rice and maize crops, and temperatures upto 35°C are considered optimum for chlorophyll accumulation. Since temperatures upto 35°C are considered optimum for chlorophyll content, the higher values in 1986-87 are attributable to the higher but optimum temperature regime in 1986-87 season.

4.14.3 Chlorophyll content and leaf area index

Maximum value of chlorophyll content was observed at anthesis stage in V_1. In the *rabi* season 1986-87 also in the first planting peak value was attained at heading to anthesis stage while in the third planting it was attained at boot leaf stage. The observations on leaf area index cited earlier (Table 5) show that the peak chlorophyll values are obtained when the LAI also reached its highest value. In the cv. HD 2281 also the highest chlorophyll content values were recorded at anthesis stage in both the first and third plantings in 1985-86, while in 1986-87 highest values of chlorophyll were noted at anthesis stage in case of first planting and at boot leaf stage in third planting. In case of V_1 higher chlorophyll content was attained when the LAI values reached 4.0, 5.2 in 1985-86 and 4.2, 4.3 in 1986-87 in P_1 and P_3 respectively. Similar pattern was observed in V_2 in both the seasons The attainment of highest values of chlorophyll content at boot leaf stage in $V_3 P_3$ is attributable to the peak leaf area index (5.4) attained at this stage. Examination of data on peak values of chlorophyll in Table 22b confirmed the relationship of maximum chlorophyll content with leaf area index substantiating the result obtained by Anderson (1967).

Percent reduction in chlorophyll content with crop canopy

The percentage reduction in chlorophyll content of middle and bottom leaves with reference to top leaf in different treatments are shown in Table 23 for the two seasons under study.

In $V_1 P_1$ the reduction at the middle canopy level showed wide variation ranging from 0.0 to 6.7 per cent by the end of the season. This irregular variation is attributable to the wide variation in chlorophyll content as also evident from Fig.14 which showed a minimum of three peaks with intermittent decrease in values. However , the reduction

Table 23. Percentage reduction in chlorophyll content in wheat canopy.

Date	Leaf	ISD 397			ISD 513			HD 2281		
		1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)	1st Pltg. (P_1)	2nd Pltg. (P_2)	3rd Pltg. (P_3)
					1985-86					
21/1	M	25.83	-	-	-	-	-	13.51	-	-
	B	40.83	-	-	-	-	-	30.54	-	-
4/2	M	0.0	8.3	-	23.32	-	5.04	5.34	-	-
	B	25.6	13.0	-	30.04	-	49.0	44.4	-	-
15/2	M	21.0	-10.6	37.5	13.0	25.0	-	6.6	-	46
	B	48.7	23.6	76.2	36.0	45.0	63.00	31.0	37.0	65
20/2	M	3.0	18.0	52.3	38.0	32.0	2.0	44.0	49.0	42
	B	72.1	78.5	77.3	87.0	85.0	71.7	68.0	60.0	60
4/3	M	15.5	42.6	50.2	39.0	52.0	11.0	55.0	4.0	47
	B	64.0	67.8	78.2	84.0	83.0	74.0	56.0	46.0	74
11/3	M	-4.2	30.0	27.9	18.0	-1.6	38.0	26.0	14.0	47
	B	76.1	67.0	76.42	90.0	69.0	90.0	47.0	55.0	79
20/3	M	21.92	52.0	38.99	48.0	41.0	24.0	56.0	31.0	61
	B	72.6	65.0	92.14	81.0	85.0	87.0	73.0	71.0	94
27/3	M	67.4	54.0	47.76	51.7	48.0	39.0	76.0	22.0	64
	B	80.0	74.0	72.24	70.0	90.0	89.0	90.0	91.0	98
7/4	M	-	69.0	30.41	77.0	63.0	38.0	-	52.0	79
	B	-	95.0	70.27	90.0	90.0	85.0	-	96.0	-
					1986-87					
3/2	M	7.4	-	-	-	-	-	6.23	-	-
	B	-	-	-	-	-	-	-	-	-
10/2	M	19.0	8.4	42.0	5.7	-	-	32.0	13.2	-
	B	62.0	63.0	73.0	63.0	-	-	57.0	-	-
19/2	M	5.0	35.0	40.0	14.0	21.1	19.2	10.0	15.0	21
	B	71.0	80.0	73.0	77.0	78.0	76.3	63.0	69.0	48
27/2	M	26.0	27.0	32.0	1.2	52.0	34.0	8.0	13.0	39
	B	47.0	75.0	73.0	59.0	84.0	84.0	79.0	56.0	53
6/3	M	13.0	41.0	8.2	10.7	31.0	25.0	9.0	26.0	23
	B	67.0	68.0	58.0	48.0	65.0	75.0	46.0	67.0	57
24/3	M	-	34.0	23.0	2.8	46.0	39.0	-	30.0	5
	B	-	69.0	50.0	-	57.0	72.0	-	72.0	44

M - Middle; B - Bottom

at the bottom level was about 40 per cent of the top leaf in the earlier stages; in the post anthesis stage the depletion in chlorophyll content was higher than 70 per cent.

In P_3 while the reduction in chlorophyll content at the middle level of the canopy ranged between 28 and 52 per cent when the LAI was greater than 3.5, the bottom leaf showed a depletion of more than 70 per cent. Thus while in P_1 the 70 per cent depletion at the bottom level was reached by anthesis stage, in P_3 it got depleted to this level in the late vegetative stage (15th February, 1986). Similar pattern was observed in 1986-87 season as well as for other varieties.

Interception of photosynthetically active radiation (PAR) at the top, middle and bottom canopy levels was also measured to examine if there was any corresponding variation between intercepted radiation and chlorophyll content. It may be mentioned that Friend (1960) showed an increase in chlorophyll content with intercepted light at constant temperature. PAR showed an increased depletion upto anthesis stage, thereafter showing an increase in the intercepted light. This is attributable to leaf shedding and setting in of senescence in the crop which is also evidenced by a decrease in LAI.

In the initial stages of crop growth due to good leaf cover, reduction in PAR was of the order of 95 per cent whereas in the later stages of growth, the depletion of PAR at the bottom level decreased to about 50 per cent. In the earlier stages, the depletion at the middle canopy level was 60-70 per cent which decreased at the end of crop growth

Table 24. Percentage reduction in photosynthetic active radiation in wheat canopy

Date	Place	ISD 397 1st pltg.	ISD 397 2nd pltg.	ISD 397 3rd pltg.	ISD 513 1st pltg.	ISD 513 2nd pltg.	ISD 513 3rd pltg.	HD 2281 1st pltg.	HD 2281 2nd pltg.	HD 2281 3rd pltg
Rabi - 1985-86										
27.1.86	50 cm ht									
	Bottom	98	79	36	97	70	11	93	46	36
17.2.86	50 cm ht	72	77	88	70	70	45	79	82	78
	Bottom	97	93	96	98	95	70	96	93	92
1.3.86	50 cm ht	28	67	86	63	88	64	44	49	84
	Bottom	65	95	98	98	97	95	71	88	92
20.3.86	50 cm ht	50	50	67	66	29	60	46	59	63
	Ground	68	87	88	92	69	92	73	89	90
4.4.86	50 cm ht	25	28	32	44	22	34	22	21	41
	Ground	53	38	62	48	57	39	51	35	71
Rabi - 1986-87										
23.1.87	Ground	88	82		77	66	72	80	80	
11.2.87	50 cm ht	67	93	63	85	88	86	63	85	70
	Ground	91	97	93	96	93	92	91	92	93
21.2.87	50 cm ht	68	95	59	88	94	71	80	72	89
	Ground	89	98	80	98	99	84	93	97	98
7.3.87	50 cm ht	40	86	47	88	73	70	43	74	88
	Ground	73	96	83	96	97	93	77	94	96
18.3.87	50 cm ht	47	35	33	47	56	55	35	30	67
	Ground	65	74	61	88	89	86	66	59	94
4.4.87	50 cm ht	29	41	30	47	42	52	43	41	39
	Ground	47	60	46	65	58	75	53	58	61

season to about 20-40 per cent. The results show that maximum interception of PAR coincided with attainment of maximum LAI and leaf chlorophyll contents in all the treatments. Similar observation was reported by Singh and Gill (1987) on wheat crop, at 90 days after sowing. However, in the present experiment it did not occur at fixed number of days after sowing as reported by them. It occured at different times depending on the phenology- temperature interactions. Their conclusion was drawn on a single date of sowing experiment and the 3 planting dates of the present experiment yielded a different result.

The results also show corresponding relationship in the depletion pattern of light interception and chlorophyll contents. The difference between the two was that in the initial stages percentage depletion of PAR is higher than that of chlorophyll content; at the later stages of crop growth, percentage depletion of chlorophyll content was higher than that in intercepted PAR. This is naturally attributable to setting in of senescence, as also noted by Friend (1960).

4.15 CROP GROWTH STAGE AND SPECTRAL REFLECTANCE

Spectral reflectance is an important parameter in remote sensing for understanding the plant spectral signature and its response to environment. The variation of wheat canopy reflectance at different growth stages with wave length is shown in the Fig.15.

It is apparent from the figure that reflectance in the red region decreases while, with crop growth it increases in the near Infrared region. This is because both the chlorophyll concentration and green leaf biomass change with plant growth and it absorbs the radiation in red region and reflects more in near infrared region of the spectrum.

Table 25. Leaf area index, chlorophyll content and spectral reflectance in wheat crop (Rabi 1986-87).

		V_1P_1 Days after sowing				V_3P_1 Days after sowing			
	Parameter	35	58	84	110	35	58	84	110
	LAI	0.65	2.9	4.2	1.47	0.8	3.6	5.2	2.0
	Chlorophyll content (mg/g)	1.92	2.8	4.0	3.3	2.2	3.4	4.2	3.4
Blue	450	9	4	6	6	10	6	9	8
Green	540	16	8	12	10	18	9	15	10
Red	650	13	9	11	11	14	10	13	11
IR	800	23	28	34	29	28	32	38	34
Far IR	950	35	36	43	35	37	40	47	42

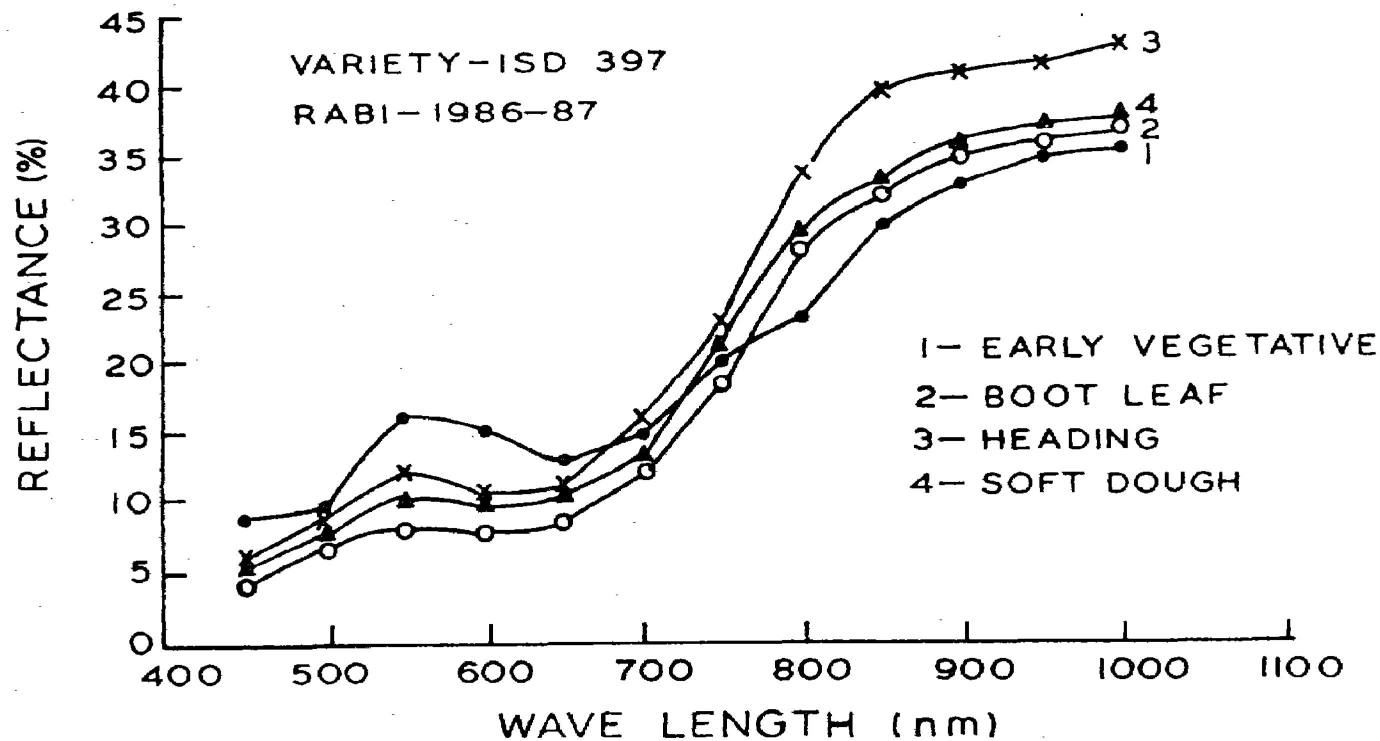

Fig. 15. Spectral reflectance from wheat canopy at various growth stages

In the far infra-red region also there was a decrease in reflectance after heading. Ajai et al. (1984) reported a similar decrease in reflectance in red region and increase in infra-red region with progress of crop.

Another feature observed was that in the early vegetative stage between 450 and 750 nm reflectance was higher than that at other stages. Beyond these wavelengths the reflectance was lower than that at other growth stages. Heading stage had shown highest reflectance of 40-45 per cent in wavelengths beyond 850 nm compared to 30-35 per cent reflectance at heading stage was observed by Glick et al. (1979) in wheat crop.

Spectral reflectance, chlorophyll content and LAI values in respect of cv. ISD 397 and HD 2281 are shown in Table 25. As already mentioned earlier, chlorophyll content had a positive relationship with LAI which is also evident from Table 25. Two regions of lower reflectance at 450 nm and another at 650 nm which are known for absorption by chlorophyll material were observed. These also correlated with leaf area index at different growth stages. The present results reflect the conclusion drawn by Tucker et al. (1975) that the concentration of chlorophyll is negatively correlated with red and positively correlated with the near infrared reflectance. Highest reflectance in the infrared region was observed at the time of maximum leaf area index in the crop which also recorded a higher chlorophyll content at this time in both the cultivars. This substantiates the results reported by Curran and Milton (1983) and Hinzman et al. (1986).

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SUMMARY

5. SUMMARY

The present investigations were carried out at the Indian Agricultural Research Institute to study the effect of short period variations in temperature on growth and development of wheat (*Triticum aestivum* L.) crop.

Three varieties of wheat, ISD 397 (V_1), ISD 513 (V_2) and HD 2281 (V_3) were sown during *rabi* 1985-86 and 1986-87 seasons at fifteen day intervals. Irrigation was provided to maintain "not-short-of-water" conditions.

Daily weather data were collected from the meteorological observatory located in the farm area. Phenological events, weekly biomass and leaf area index were recorded in the different treatments. Weekly crop growth rates were derived from the growth curves.

Daily canopy temperatures and canopy air temperature differences were recorded from heading to maturity stages at 1400 hrs. IST. Chlorophyll cotent and photosynthetically active radiation at different levels within the crop canopy and spectral reflectance from crop canopy were recorded periodically during crop growth.

During the wheat growth seasons 1985-86 and 1986-87, temperatures, duration of bright sunshine hours and saturation deficits re-mained higher from the late vegetative to early grain filling stage during *rabi* 1986-87 as compared to 1985-86 season.

Two salient features observed from phenological events were:

1) unlike cv. ISD 397, V_2 and V_3 reached the different growth

stages nearly in the same number of days both in the warmer (1986-87) and cooler season (1985-86), and

2) In V_2 the duration of phenological events were influenced by temperature in respect of planting date treatments (differences to reach physiological maturity ranged from 17-21 days) but not between the seasons (not more than 3 days).

During rabi 1985-86, compared to 1986-87 season all the varieties and treatments (P_1 , P_2 and P_3) showed higher biomass accumulation and leaf area index (LAI) throughout the growth period. V_2 recorded higher LAI (7.6) than V_3 (6.7) followed by V_1 (5.3). In spite of temperature differences between the plantings and the two seasons, the peak LAI was recorded at heading stage, and did not occur after a fixed number of days from sowing as hitherto reported.

Senescing leaves in the lowest layers of the plants contributed to an increase in LAI ranging from 0.5 to 1.0 from post boot leaf stage. Since these leaves are not fully functional, the result shows that it is necessary to make a correction to that extent to arrive at effective LAI from this stage onwards.

Weekly crop growth rates (CGR) in respect of different varieties during rabi 1986-87 were consistently lower when compared to 1985-86 season. CGR showed a double peak in 1986-87 unlike in the previous rabi season. Such a double peak in CGR had not been reported so far in respect of wheat crop.

Another salient feature was that the time of occurrence of peak growth rate differed from planting to planting and season to season. It ranged from anthesis to soft dough stages in the present experiment and thus differs from those reported in literature which showed peak growth rate at heading or anthesis stages only. To examine this feature further, three case studies were chosen to understand the influence of short period temperature variations on crop growth in the different treatments.

In the first case for the period 7th to 16th February the effect of higher maximum and lower minimum temperatures showed that: a lowering of maximum temperature from 23°C by 5-6°C and moderate minimum temperatures (about 12°C) associated with rainfall during vegetative stage results in better crop growth rates, which may increase by 14 -25 g/m²/day than in a warmer season.

In the second case, study on the effect of higher maximum and higher minimum temperatures in rabi 1986-87 from 21st to 26th February showed that higher maximum temperatures and minimum temperatures (4-7°C and 3-6°C above normal) would prove beneficial to a crop in the boot leaf stage while the same conditions may adversely affect a crop in reproductive stage.

In the third case, the effect of warming for a few days followed by variable weather on CGR was studied. Results showed that higher minimum and maximum temperatures in late plantings would result in reduced growth rate of the order of 25 g/m²/day which is partly attributable to higher respiratory losses.

From the results of this experiment occurrence of double peak is considered to be the effect of interruption of normal growth pattern by a complex variation of maximum and minimum temperatures associated with the passage of western disturbances during rabi season. Another salient feature of the results is that the adverse effects of relatively warm seasonal condition are reflected in CGR but not in the duration between phenological stages while the effect of temperature differences between planting dates is reflected both in the duration of phenological stages and also in the crop growth rates.

In V_2 the range of peak growth rates in warmer year (1986-87) between the plantings ranged from 37.14 to 42.86 g/m²/day unlike in the cooler year (1985-86) when it was high (33 to 55.7 g/m²/day). This indicated that V_2 is relatively better adapted to the warmer thermal environment.

Grain filling growth rates recorded in rabi 1986-87 were higher in P_2 than in P_1 in the 1986-87 season by 1.5 g/day, though relatively higher yields were obtained in P_1. This effect is attributable to the fact that benecial effects of higher but below upper threshold temperatures on growth rates or offset by higher respiration losses leading to lower yields.

The grain yield in the different varieties and treatments for both the seasons ranged between 36.47 q/ha and 49.38 q/ha. Differences in the grain yield between varieties and treatments were found significant at 1 per cent level. In the 1986-87 rabi season, the yields decreased with delay in planting by 4.32 to 20.7% in P_3 over P_1. In general, harvest index was higher (0.48 to 0.54) in case of cv. HD 2281 in both the seasons and proved superior to the other two varieties which recorded values ranging from 0.42 to 0.49.

Two different accumulated heat unit systems namely growing degree days and heliothermal units were computed for studying crop response to the thermal environment. While in the different individual growth stages and between the plantings, the accumulated degree days showed differences (ranging from 1347 to 1647 units), for the entire cropping season both in the cooler and warmer seasons, the total degree day requirement remained more or less constant in the individual plantings. Heliothermal units also indicated a similar result but inclusion of bright sunshine hours in this system did not show any deviation from the nature of results obtained in case of GDD.

Phenothermal index (ratio of accumulated GDD to the number of days during a particular stage) values for the entire crop season showed very little variation between the two seasons and remained at about 11.5 day degrees per growth day. In the individual growth stages, highest coefficient of variability in this index was observed at heading and anthesis stages in both the seasons indicating that much variation in the environmental thermal regime occurs during this period of crop growth in the Delhi region. This period generally coincides with the transition from winter to pre-summer conditions which show large temperature variation.

Heat use efficiency based on mean air temperature accumulation was derived. Heading to anthesis and anthesis to milk stages showed relatively higher HUE in comparison to other stages in all the plantings.

Highly significant relationships were obtained between biomass, cumulative evaporation and accumulated heat units. From these, biomass production at differnt levels of mean temperature accumulation and cumulative evaporation were derived. The derived data are of practical utility in crop-weather simulation studies and for evaluation of crop performance in relation to mean air temperature in the different wheat growing regions.

The regression showed that for establishment of wheat crop in the initial stages, an accumulation of 370 GDD and 70 mm of cumulative pan evaporation are needed in the Delhi region.

Measurements of canopy temperature at 2 pm showed 1 to 6°C difference between the two seasons. Canopy temperatures showed highly significant correlation with (a) saturation deficit (range 0.7 to 0.94 at 1% level), (b) maximum temperature ($r = 0.814$ at 1% level). Such a correlation with maximum temperature had not been reported so far and the results are of practical use for estimation of canopy temperature using maximum temperature which is a routine measurement in meteorological observatories.

At the end of the season, CATD values became positive showing a reversal in sign from the earlier period. Examination of phenological data in the different treatments showed that the date of reversal coincided with physiological maturity of the crop. Thus results show that continuous positive CATD values could be used as an indication of physiological maturity in wheat crop.

Stress degree days were computed and found to be significant but negatively correlated with:

1) cumulative pan evaporation in the different treatments, and

2) with grain yield

The effect of clear and cloudy conditions on canopy temperature was studied for three types of weather conditions.

Results showed different effects on Tc, CATD and Ta and the salient features are as follows:

i) when overcast skies cleared, increase in Tc was the highest followed by Ta with no perceptible change in CATD

ii) when ovecast skies are preceded by clear skies, the order of magnitude of decrease in the three parameters were Ta > Tc > CATD with a decrease of 5-8°C, 4-6°C and 2-3°C respectively, and

iii) on a sultry, calm day with predominantly diffuse radiation, it was CATD which showed large variation (-5.5 to -8.5°C) from that of a clear day, whereas Ta became warmer by 2-3°C with no perceptible change in Tc.

Thus it is evident that day to day weather conditions determine the nature of variation in Ta, Tc and CATD. The results point out the importance of taking weather conditions into account while interpreting the three parameters.

Studies on the relationship between leaf temperature Tl (measured with porometer) and canopy temperature Tc (measured with infrared thermometer) showed that:

i) warmer temperatures after 12.00 hrs. increase the differences between Tl and Tc, the difference further becoming larger during later periods of crop growth due to seasonal warming.

ii) during cold wave conditions, Tl is higher than Tc throughout the day time hours by 3-5°C in irrigated wheat crop, and

iii) leaf temperature being a spot measurement, apparently gives overestimated value of canopy temperature irrespective of the weather conditions that prevail.

Measurement of leaf chlorophyll content in all the treatments showed an intermittent increase and decrease with the progress of growth season. Chlorophyll content during 1985-86 season in the first planting ranged from 0.04 to 3.7 mg/g fresh weight in the top leaf with lower ranges in the middle and bottom leaves. In the warmer season, they were relatively higher ranging from 1.1 to 4.2 mg/g in the top leaf. This increase is attributable to higher temperatures in 1986-87 season which were within the permissibe temperature threshold of 35°C for chlorophyll accumulation.

Examination of chlorphyll depletion in relation to that of PAR at the middle and bottom levels of crop canopy showed percentage depletion of PAR to be higher than that of chrolophyll content in the initial stages of crop growth. At the later stages, percentage depletion of chlorophyll content was higher than that in intercepted PAR. This is attributable to setting in of senescence.

Spectral reflectance in the red region decreased while with progress in crop grwoth, it showed an increase in the near infrared region. The highest reflectance in the infrared region was observed at the time of maximum leaf area index in the crop when a higher chlorophyll content was also recorded. Thus spectral reflectance is highly dependent on both chlorophyll content and leaf area index, which in turn are governed partly by the thermal regime.

The results brought out quantitatively the extent to which biomass accumulation, crop gowth rates, canopy, ambient and canopy air temperature differences at different growth stages are influenced by short period changes that occur in maximum, minimum temperatures, over cast and clear sky conditions in association with western disturbances passing over the Delhi region. The results also showed significant correlations between accumulated temperatures, evaporation and biomass, canopy temperature and maximum temperatures and dependence of spectral response on leaf chlorophyll content and leaf area index which are highly influenced by the temperature regime prevailing during the different growth stages of wheat crop.

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BIBLIOGRAPHY

BIBLIOGRAPHY

Ahlrichs, J.S. and Bauer, M.E. 1983. Relation of agronomic and multispectral reflectance characteristics of spring wheat canopies. Agron. J. 75: 987-993.

Ajai, Sashikumar, M.N., Kamat, D.S., Chaturvedi, G.S., Singh, A.K. and Sinha, S.K. 1984. Signatures, effect of water stress and crop identification/descrimination. Proc. Seminar on 'Crop growth condition and remote sensing', June 22-23, 1984,I.A.R.I. New Delhi, p. 1-1-1 to 1-1-9.

Amores-Vergara, E. and Cart Wright, P.M. 1984. Effects of short periods of exposure to high temperature on the phenology and shoot apex development of wheat cv. Sonara 64. Aug. J. Agric.Res. 35 : 139-148.

Anderson, C.M. 1967. Photon flux, chlorophyll content and photosynthesis under natural conditions. Ecology, 48: 1050-1053.

Angus, J.E., Mackenzie, D.H., Morton, R. and Schaffer, C.A. 1981. Phasic development in field crops. II Thermal and photoperiodic responses of spring wheat. Field Crops Res. 4: 269-283.

Bagga, A.K. and Rawson, H.M. 1977. Contrasting responses of morphologically similar wheat cultivars to temperatures appropriate to warm temperate climates with hot summers. Aust. J. Plant Physiol. 4 : 877-887.

Balla, L. 1983. Regulation of the development of winter wheat varieties using low temperatures. Acta. Agron. Acad. Scientiarum Hungaricae. 31: 235-240.

Bauer,A. and Frank, A.B. 1981. Seedling development of hard red spring and durum wheats as a function of days, growing degree units and photothermal units. Agron. abstracts, 73rd annual meeting, Amer. Soc. Agron.

Bauer, A., Frank, A.B. and Black, A.L. 1984. Estimation of spring wheat leaf growth rates and anthesis from air temperature. Agron. J. 76 : 829-835,

Bennett,K.J., Mcpherson, H.G. and Wrrington, I.J. 1982. Effect of pretreatment temperature on response of photosynthetic rate in maize to current temperature. Aust. J. Plant Physiol. 9:773-781.

Berhuizen, J.F. 1973. The effect of temperature on plant growth, development and yield. Proc. Uppsala symp. (Paris) on 'Plant response to climatic factor'.p.89-98.

*Bossingault, J.J.B.D. 1834. Economic rurale consideree dansres rapports avee la climie la physigue et la Meteonologic 1st Ed.80 Paris.

Chakravarthy, N.V.K. 1980. Crop-weather interactions in wheat (Triticum aestivum L.) and mung bean (Vigna radiata L. Wilczek) with reference to crop phenology. Ph.D. thesis, I.A.R.I., New Delhi.

Chakravarthy, N.V.K., Murthy, B.N. and Sastry, P.S.N. 1984. Degree days and biomass accumulation in different genotypes of barley. Indian J. Plant Physiol. 27: 290-294.

Chakravarthy, N.V.K. and Sastry, P.S.N. 1983a. Phenology and accumulated heat unit relationships in wheat under different planting dates in the Delhi region. Agril. Sci. Progress 1:32-42.

Chakravarthy, N.V.K. and Sastry, P.S.N. 1983b. Biomass production in wheat in relation to evaporative demand and ambient temperature. Mausam 34: 323-326.

Chakravarthy, N.V.K. and Sastry, P.S.N. 1983c. Biomass production in mung (Vigna radiata L. Wilczek) in relation to pan evaporation and ambient temperature. Agric. Meteorol. 29: 57-62.

Chakravarthy, N.V.K. and Sastry, P.S.N. 1985. Some aspects of crop-weather interactions in wheat cultivars. Int. J. Ecol.and Environ.Sci. 11; 139-144.

Chang, Jen - Hu. 1968. 'Climate and Agriculture' Aldine Publ.Co.,Chicago. p.149-193.

Chela, K.S. and Brar, H.S. 1975. Studies on the effect of sowing date and seed rate on the growth and yield of wheat (Kalyansona). Indian J. Agron. 20 : 87-90.

Chowdhury, B. 1985. A note on canopy and air temperature equality. Agric. and Forest Meteorol.34 : 333-336.

Chowdhury, S.I. and Wardlaw, I.F. 1978. The effect of temperature on kernel development in cereals. Aust. J. Agric. Res.29:205-223.

*Cupina, T.,Borojevic, S. and Janjatovic, V. 1979. Chlorophyll content and mesophyll thickness in the green parts of differnt cultivars of wheat. Savremena Poljoprivreda.27: 389-399.

Curran, P.J. and Milton, E.J. 1983. The relationships between the chlorophyll concentration, LAI and reflectance of a simple vegetation canopy. Int. J. Remote Sens. 4: 247-255.

Davidson, H.R. and Campbell, C.A. 1983. The effect of temperature, moisture and nitrogen on the rate of development of spring wheat as measured by degree days. Can. J. Plant Sci. 63: 833-846.

Davidson, H.R. and Campbell, C.A. 1984. Growth rates, harvest index and moisture use of monitor spring wheat as influenced by nitrogen, temperature and moisture. Can. J. Plant Sci.64: 825-939.

Davidson,J.L. and Birch, J.W. 1978. Growth cabinet until anthesis at 20°C and hence in glass house var: a) Gabo-Australian spring wheat; b) Pitic 62-M semi-dwarf. Australian J. Agric. Res. 29: 1091-1106.

Dhingra, K.K., Dhillon, M.S., Grewal, D.S. and Sharma, K. 1986. Effect of row orientation on growth, yield and yield attributes of wheat sown on three dates. J. agric. Sci. 107:343-346.

Diaz, R.A., Mathias, A.D. and Hanks, R.J. 1983. Evapotranspiration and yield estimation of spring wheat from canopy temperature. Agron. J. 75: 805-810.

Doyle, A.D. and Fischer, R.A. 1979. Dry matter accumulation and water relationships in wheat crops. Aust. J. Agric. Res. 30: 815-829.

Dunphy, D.J., Holt, E.C. and McDaniel, H.E. 1984. Leaf area and dry matter accumulation of wheat following forage removal. Agron. J. 76: 871-874.

Ehrler, W.L., Idso, S.B., Jackson, R.D. and Reginato, R.J. 1978. Wheat canopy temperature: relation to plant water potential. Agron. J. 70: 251-256.

*EL-Sharkawy, M.A. 1975. Analysis of crop growth and yield of dwarf wheat grown in Libyan desert as affected by phosphorous fertilizer. In "Crop research in Kufra oasis" , Lybyan Arab Republic. Tripoli, Libyan Arab Repub. Agric. Develop. Council. p.3-30.

Fisher, R.A. 1970. Statistical methods for research workers. Oliver and Boyd, Edinburough. p. 339.

Ford, M.A. and Thorne, G.N. 1975. Effects of variation in temperature and light intensity at different times on growth and yield of spring wheat. Ann. appl.Biol. 80: 283-299.

Frank, A.B. and Bauer, A. 1981. Effect of temperature and fertilizer nitrogen on apex development in spring wheat. Agron. abstracts, 73rd Annual meeting, Amer. Soc. Agron.

French, R.J. and Schultz, J.E. 1982. The phenology of eight cereal, grain legume and oilseed crops in South Australia. Aust. J. Expt. agric. & Animal Husbandary. 22: 67-75.

Friend, D.J.C. 1960. The control of chlorophyll accumulation in leaves of Marquis wheat by temperature and light intensity. 1. Rate of chlorophyll accumulation and maximal absolute chlorophyll contents. Physiol. Planta. 13: 776-785.

Friend, D.J.C., Helson, V.A. and Fisher, J.E. 1962. The rate of dry weight accumulation in Marquis wheat as affected by temperature and light intensity. Can. J. Bot. 40: 939-954.

Gales, K. 1983. Yield variations of wheat and barley in Britain in relation to crop growth and soil conditions - A review. J. Sci. Food agric. 34:1085-1104.

Gardner, B.R., Blad, B.L., Maurer, R.E. and Watts, D.G. 1981a. Relationship between crop temperature and the physiological and phenological developlopment of differentially irrigated corn. Agron. J. 73:743-747.

Gardner, B.R., Blad, B.L. and Watts, D.G. 1981b. Plant and air temperatures in differentially irrigated corn. Agric. Meteorol. 25 : 207-217.

Gates, D.M. 1968. Transpiration and leaf temperature. Ann. Rev. Plant Physiol. 19: 211-238.

Glick, H., Shaykewich, C.F., Lacroix, L.J. and Clark, K.W. 1979. Species and cultivar discrimination of cereals by field spectroscopy. Technical and scientific papers presented at 1979. Manitoba agronomists' annual Conference, Winnipeg, Canada. p.119-123.

Greenfield, P.L. and Noble, A.D. 1987. Yield and phenological development of wheat grown in winter under full irrigation at Ukulinga as influenced by planting date, N2 fertilizaton and previous crop. Proc. 15th ann. Cong. South Africa. 604-618. Field crops abstract. 40: p.292.

Halse, N.J. and Weir, R.N. 1969. Effects of vernalization, photoperiod, and temperature on phenological development and spikelet number of Australian wheat. Aust. J. Agric. Res. 21: 383-393.

Hanks, R.J., Klute, A. and Bresler, E. 1969. A numeric method for estimating infiltration, redistribution, drainage and evaporation of water from soil. Water Resources Res. 5: 1064-1069.

Hanway, J.J. and Weber, C.R. 1971. Dry matter accumulation in eight soybean (Glycine max L. Merrill) varieties. Agron. J. 63: 227- 230.

Herath, H.M.W. and Ormrod, D.P. 1979. Effects of temperature and photoperiod on winged beans (Prophocarpus tetragonolobus.). Ann. Bot. 43: 729-736.

Hinzman, L.D., Baurer, H.E. and Daughtry, C.S.T.1986. Effects of nitrogen fertilization on growth and reflectance characteristics of winter wheat. Remote Sens. Environ.19: 47-61.

Hiscox, J.D. and Israelistam, G.F. 1979. A method for the extraction of chlorophyll from leaf tissue without masceration. Can. J. Bot. 57: 1332-1334.

I.A.R.I., 1976. "Soil Survey and Land Use Planning of I.A.R.I.Farm", I.C.A.R., Report No. 375.

Idso, S.B., Jackson, R.D. and Reginato, R.J. 1977. Remote sensing of crop yields. Science 196: 19-25.

Inada,K. 1985. Spectral ratio of reflectance for estimating chlorophyll content of leaf. Japan. J. Crop Sci. 54: 261-265.

Jackson,R.D. 1982. Canopy temperature and crop water stress. In: Advances in irrigation Vol.1, D. Hillel (Ed.), p. 43-85.

Jackson, R.D., Reginato, R.J. and Idso, S.B. 1977. Wheat canopy temperature: A practical tool for evaluating water requirements. Water Resour. Res. 13: 651-656.

Jalota, S.K. 1986. Evapotranspiration sequence for increasing the yield of wheat with a given water supply. Indian J. agric. Sci. 56: 392-394.

Joarder, O.I., Islam, R., Rahman, S. and Eunus, A.M. 1981. Effect of seeding date on yield and other agronomic traits of some wheat varieties grown on irrigated lands in Bangladesh. Indian J. agric. Sci. 51: 489-493.

Johnson, J.W. and Ohki, K. 1981. Variation among wheat cultivars for chlorophyll content. Cereal Research Communications. 9: 311-315.

Kamat, D.S., Ajai, Sashikumar, H.N., Sinha, S.K., Chaturvedi, G.S. and Singh, A.K. 1983. Relationship of spectral parameters of wheat crop with yield. Indian J. agric. Sci. 53 :89-93.

Katz, Y.H. 1952. The relationship between heat unit accumulation and the planting and harvesting in canning peas. Agron. J. 44: 74-78.

Khera, K.L. and Sandhu, B.S. 1986. Canopy temperature of sugarcane as influenced by irrigation regime. Agric.For Meteorol. 37: 245-258.

Kirkham, M.B., Johnson, D.E., JR., Kanemasu, E.T. and Stone, L.R. 1983. Canopy temperature and growth of differentially irrigated alfalfa. Agric. Meteorol. 29:235-246.

Kuroyanagi, T. and Paulsen, G.M. 1985. Mode of high temperature injury wheat. II. Comparisons of wheat and rice with and without inflorescences. Physiol. Planta. 65: 203-208.

Laubscher, E.W. 1982. An evaluation of the influence of wheat leaf area index upon yield potential. Crop production. 11: 194-197.

Lubimeuko, V.N. and Hubbenet, E.R. 1932. The influence of temperature on the rate of accumulation of chlorophyll in etiolated seedlings. New Phytologist. 31: 26-31.

Mehrotra, O.N. and Mishra, P.H. 1976. Physiological Variability in wheat genotypes. Indian J. Plant Physiol. 19: 20-27.

Midmore, D.J., Cart Wright, P.M. and Fischer, R.A. 1984. Wheat in tropical environments II. Crop growth and grain yield. Field Crops Res. 8: 207-227.

Neild, R.E. 1982. Temperature and rainfall influences on the phenology and yield of grain sorghum and maize: a comparison. Agric. Meteorol. 27: 79-88.

Nicolas, M.E., Gleadow, R.M. and Dalling, M.J. 1984. Effects of drought and high temperature on grain growth in wheat. Aust. J. Plant Physiol. 11: 553-566.

Nuttonson,M.Y. 1955. 'Wheat-climate relationships and use of phenology in ascertaining the thermal and photo-thermal requirements of wheat'. An. Instt. Crop. Ecol. Washington, D.C. p.150.

O'Leary, G.J., Connor, D.J. and White, D.H. 1985. Effect of sowing time on growth, yield and water-use of rainfed wheat in the Wimmera, Vic. Aust. J. Agric. Res. 36: 187-196.

Ovington, J.D. and Lawrence, D.B. 1967. Comparative chlorophyll and energy studies in priarie, savanna, oak wood and maize field ecosystems. Ecology, 48: 515-524.

Pannalal, 1983. Evaluation of energy balance over crop canopies by humidity profile technique. Ph.D. thesis, IARI, New Delhi.

Penman,H.L. 1948. 'Natural evaporation from open water, bare soil and grass'. Proc. Roy Soc. Land. Ser. A-193: 120-146.

Peters, D.B., Pendleton, J.W., Hangeman, R.H., and Brown, C.H. 1971. Effect of night air temperature on grain yield of corn, wheat and soybeans. Agron. J. 63: 809.

*Petrov, M. and Dimitrov, S. 1976. Rates and proportions of nitrogen, phosphorus and potassium for wheat on dark-grey forest soil in the Ludogr'e region I. Effect of fertilizers on growth and development of plants. Rasteniev dri Nauki. 13:91-101.

Pirasteh, B. and Welsh, J.R. 1980. Effect of temperature on the heading date of wheat cultivars under a lengthening photoperiod. Crop Sci. 20: 435-456.

Porter, J.R., Kirby, E.J.M., Day, W., Adam, J.S., Margaret, A., Ayling,S., Baker,C.K., Beale, P., Belford, R.K., Biscoe, P.V., Chapman, A., Fuller, M.P., Hampson, J., Hay,R.K.M, Hough, M.N., Mathews, S., Thompson, W.J., Weir, A.H.,Willington, V.B.A. and Wood, D.W. 1987. An analysis of morphological development stages in avalon winter wheat crops with different sowing dates and at ten sites in England and Scotland. J. agric. Sci., Camb.109: 107-121.

Randhawa, A.S., Dhillon, S.S. and Singh, D. 1981. Productivity of wheat Varieties as influenced by time of sowing. J. Res., PAU. 18: 227-233.

Ray, P., Gupta, K. and Chatterjee, S.K. 1978. A comparative study of temperature effect on two wheat cultivars (Janak and Sonalika). Indian Agriculturist. 22: 55-60.

*Reaumer, R.A.F. de 1735. 'Observations du thermometers, faites a paris pendant 1 annee 1735, comparees ovee celles Q'uiont et e faites sons la ligne, a lisle de france, a recent studies on Bioclimatology 2 :1-3. Amer. Meteorol Soc. (1954).

Reddy, G.G. and Pyare Lal 1976. Physiological analysis of yield variation in triticale and wheat varieties under irrigated condition. Indian J. Plant Physiol. 19: 154-163.

Reicosky, D.C. 1985. Foliage temperature as a means of detecting stress of cotton subjected to a short-term water-table gradient. Agric.For. Meteorol. 35: 193-203.

Ritchie, J.T. 1987. Using thermal time to describe plant development. Agron. abstracts, Annual meeting, Nov. 29-Dec.04, Amer. Soc. Agron.

Russelle, M.P., Wilhelm, W.W., Olson, R.A. and Power, J.F. 1984. Growth analysis based on degree days. Crop Sci. 24: 28-32.

Saini, A.D. and Dadhwal, V.K. 1986a. Influence of sowing date on grain-growth duration and kernel size in wheat. Indian J. agric. Sci. 56: 439-447.

Saini, A.D. and Dadhwal, V.K. 1986b. Heat unit requirement during the period of grain growth in wheat and its application for adjusting sowing dates in different regions. Indian J. agric. Sci. 56: 444-452.

Saini, A.D., Dadhwal, V.K., Phadnawis, B.N. and Nanda, R. 1986. Influence of sowing dates on pre-anthesis phenology in wheat. Indian J. agric. Sci. 56: 503-511.

Sashikumar, M.N., Ajai, Kamat, D.S., Chaturvedi, G.S., Singh, A.K. and Sinha, S.K. 1984. Relationship of spectral and crop growth variables. Proc. Seminar on 'Crop Growth Condition and Remote Sensing', June 22-23, 1984. IARI, New Delhi p.2-1-1 to 2-1-10.

Sastry, P.S.N. and Chakravarty, N.V.K. 1982. Energy summation indices for wheat crop in India. Agric. Meteorol. 27: 45-48.

Sastry, P.S.N., Chakravarthy, N.V.K. and Rajput, R.P. 1985. A suggested index for characterization of crop response to thermal environment. Int. J. Ecol. Environ. Sci. 11: 25-30.

Sayed, H.I. and Gadallah, M .A. 1983. Variation in dry matter and grain filling characteristics in wheat cultivars. Field Crops Res. 7: 61-71.

Shpiler, L. and Blum, A. 1986. Differential action of wheat cultivars to hot environments. Euphytica (Neth.). 35:483-492.

Singh, H. and Gill, H.S. 1987. Interacting effects of magnesium with nitrogen on growth and yield of wheat. J. agric. Sci.(U.K.) 109: 399-403.

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

Singh, V.P., Singh, M., Singh, R. and Kairon, M.S. 1985. Canopy temperature of wheat under different soil moisture conditions. Indian J. Ecol. 12: 261-266.

Sofield, I., Evans, L.T. and Wardlaw, I.F. 1974. The effects of temperature and light on grain filling in wheat. In 'Mechanisms of regulation of plant growth'. Roy. Soc. Newzealand, Wellington.

Spiertz, J.H.J. 1974. Grain growth and distribution of dry matter in the wheat plant as influenced by temperature, light energy and ear size. Neth. J. agric. Sci. 22: 207-220.

Steiner, J.L., Smith, R.C.G., Meyer, W.S. and Adency, J.A. 1985. Water use, foliage temperature and yield of irrigated wheat. Aust. J. agric. Res., 36: 1-11.

Stewart, D.W. and Dwyer, L.M. 1987. Analysis of phenological observations on barley using the feekers scale. Agric. For. Meteorol. 39: 37-48.

Stone, L.R., Kanemasu, E.T. and Horton, M .L. 1975. Grain sorghum canopy temperature as influenced by clouds. Remote Sens.Environ. 4: 177-181.

Tanner, C.B. 1963. Plant temperatures. Agron. J. 55: 210-211.

Tarchevskii, I.A. and Andrianova, Yu.E. 1980. Pigment content as an index of development of the photosynthetic apparatus in wheat. Fiziologiya Rastenii. 27: 341-347. From Soviet Plant Physiol. 27: 266-272.

Thomas, J.R. and Gausman, H.W. 1977. Leaf reflectance vs. leaf chlorophyll and caroteroid concentrations of eight crops. Agron. J. 69: 799-802.

Thorne, G.N. 1986. Multifactorial studies of causes of variation in growth and yield of winter wheat over six years. J. Sci. Food Agric.37: 674.

Tollenaar, M., Daynard, T.B. and Hunter, R.B. 1979. Effect of temperature on rate of leaf appearance and flowering date in maize. Crop Sci. 19: 363-366.

Tucker, C.J. 1979. Red and photographic infrared linear combinations for monitoring vegetations. Remote sens. Environ. 8:127-150.

Tucker,C.J., Miller, L.D. and Pearson, R.L., 1975. Short grass pria spectral measurements. Photogramm. Emgng. remote sensing. 41: 1157.

Uchijima, Z. 1975. Dry matter production of crops in relation to climatic conditions. Collected papers of Agric. Meteorol. No.16. Nat. Inst.Agric. Sci. Japan: 2-5.

Venkataraman, S. 1972. Climatic consideration in cropping patterns in India. I.C.A.R., New Delhi, 1968. P. 251-260.

Venkataraman, S. and Rahi, A.K. 1983. Influence of temperature climatology on productivity of wheat crop in India. Mausam 34: 81-84.

Viets, F.G. 1962. Fertilizers and efficient use of water. Adv. Agron. 14: 224-264.

Waldren, R.P. and Flowerday, A.D. 1979. Growth stages and distribution of dry matter, N,P and K in winter wheat. Agron. J. 71:391-397.

Walker, G.K. and Hatfield, J.L. 1979. Test of the stress-degree-day concept using multiple planting dates of red kidney beans. Agron. J. 71: 967-971.

Walker, G.K. and Hatfield, J.L. 1983. Stress measurement using foliage temperatures. Agron. J. 75: 623-629.

Wall, P.C. and Cart Wright P.M. 1974. Effects of photoperiod, temperature and vernalization on the phenology and spikelet numbers of spring wheats. Ann. appl. Biol.76: 299-309.

Waloszczyk,K. and Focke, R. 1980. Data on the yield and DM production process in spring wheat in relation to temperature and radiation. Archiv für Zückt. 10: 237-246.

Wardlaw, I.F 1970. The early stages of grain development in wheat: response to light and temperature in a single variety. Aust. J. Biol. Sci. 23: 765-774.

Wardlaw, I.F., Sofield, I. and Cart Wright, P.M. 1980. Factors limiting the rate of DM accumulation in the grain of wheat grown at high temperature. Aust. J. Plant Physiol. 7: 387-400.

Warrington, I.J., Dunstone, R.L. and Green,L.M. 1977. Temperature effects at three development stages on the yield of the wheat ear. Aust. J. Agric. Res. 28: 11-27.

Watson, D.J., Thorne, N.G. and French, S.A.W. 1962. Analysis of growth and yield of winter and spring wheats. Can. J. Bot. 40: 1-21.

Wiegand, C.L., Gerbermann, A.H. and Cuellar, J.A. 1981. Development and yield of hard red winter wheats under semi-tropical conditions. Agron. J. 73: 29-37.

Wiegand, C.L., Richardson, A.J. and Kanemasu, E.T. 1979. Leaf area index estimates for wheat from LANDSAT and their implications for evapotranspiration and crop modelling. Agron. J. 71: 336-341.

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* Original not seen.

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APPENDICES

Appendix I : Standard Meteorological weeks

Week No.	Month	Date
47	November	19 - 25
48	November	26 - 02 December
49	December	03 - 09
50	December	10 - 16
51	December	17 - 23
52	December	24 - 31
1	January	01 - 07 January
2	January	08 - 14
3	January	15 - 21
4	January	22 - 28
5	January	29 - 04 February
6	February	06 - 11
7	February	12 - 18
8	February	19 - 25
9	February	26 - 04 March
10	March	05 - 11
11	March	12 - 18
12	March	19 - 25
13	March	26 - 01 April
14	April	02 - 08
15	April	09 - 15
16	April	16 - 22
17	April	23 - 29
18	April	30 - 06 May
19	May	07 - 13

Appendix II: Environmental conditions during rabi 1985-86 season (weekly means).

Met week	Temperature °C Max.	Min.	Mean	Pan Evp. mm	S.S. hrs/ day	S.D. mm	W.spd km/hr	Weekly rain-fall mm
47	27.0	9.2	2.4	2.4	8.9	8.7	2.1	
48	25.9	8.2	17.1	2.3	9.3	8.4	3.0	
49	25.3	7.6	16.5	2.9	9.0	8.4	2.8	
50	21.1	10.2	15.7	1.3	5.7	3.2	3.3	15.8
51	21.0	9.0	15.0	1.6	6.2	3.2	4.8	
52	19.4	9.6	14.5	1.5	6.0	4.1	6.3	9.0
1	18.1	3.1	10.6	1.9	8.6	4.2	4.8	
2	20.4	4.6	12.5	1.2	5.9	3.6	1.8	
3	20.1	3.9	12.0	1.7	7.8	4.1	2.7	
4	22.0	6.7	14.4	1.6	8.3	4.9	3.7	
5	20.8	7.6	14.2	1.8	7.3	4,4	3.8	22.4
6	21.4	8.7	15.1	2.0	6.7	3.8	4.4	29.6
7	20.5	8.6	14.6	1.6	6.5	3.8	3.7	7.4
8	22.6	9.4	16.0	3.4	8.9	5.1	5.9	2.6
9	25.2	8.1	16.7	4.0	10.4	7.0	4.0	
10	30.5	12.0	21.3	3.5	8.6	8.6	2.4	
11	28.8	13.6	21.2	4.5	7.9	8.4	6.6	6.6
12	25.7	11.1	18.4	3.8	7.7	7.2	5.6	9.2
13	31.6	13.8	22.7	6.2	9.5	12.6	5.8	
14	32.3	12.7	22.5	5.5	9.5	12.5	3.2	

Max. = Maximum; Min. = Minimum; Pan Evp. = Pan evaporation

S.S. = Actual bright sunshine; S.D. = Saturation Deficit;

W.spd. = Wind speed.

Appendix III : Environmental conditions during *rabi* 1986-87 season (Weekly means)

Met week	Temperature °C Max.	Min.	Mean	Pan Evp. mm	S.S. hrs/day	S.D. mm	W.spd km/hr	Weekly rain-fall mm
47	27.3	7.8	17.6	3.4	8.6	8.9	3.4	
48	25.4	9.9	17.7	2.0	5.0	8.6	3.7	
49	24.1	6.5	13.8	1.9	6.2	5.1	2.6	
50	21.8	7.8	14.8	1.7	6.8	3.7	6.1	5.4
51	18.2	2.8	10.5	1.6	7.6	4.2	3.4	
52	20.4	2.0	11.2	1.6	7.4	4.0	2.7	
1	21.8	5.2	13.5	2.2	7.0	5.7	3.2	
2	22.1	7.0	14.6	1.4	4.2	3.2	1.1	
3	16.7	6.6	11.7	1.6	3.9	2.3	4.7	21.4
4	21.3	3.7	12.5	2.2	9.4	4.8	3.1	
5	23.6	6.3	15.0	2.0	7.8	4.4	2.3	
6	25.2	7.7	16.5	2.9	9.5	5.5	3.0	
7	24.5	9.6	17.1	2.9	7.6	3.7	6.0	7.0
8	26.7	11.9	19.3	2.7	8.6	6.5	4.8	6.4
9	24.8	9.0	16.9	3.3	9.4	6.5	3.2	
10	29.6	12.7	21.2	4.0	8.5	6.6	4.0	
11	28.0	14.1	21.1	3.9	7.7	5.8	6.7	
12	30.7	16.4	23.6	5.8	8.8	8.1	6.5	16.4
13	32.5	17.3	24.9	5.6	6.1	11.9	6.3	
14	35.6	19.3	27.5	8.5	11.2	14.7	9.0	

Max. = Maximum; Min. = Minimum; Pan Evp. = Pan evaporation;
S.S. = Actual bright sunshine; S.D. = Saturation Deficit;
W.spd. = Wind speed.

Appendix IV : Daily maximum and minimum normal temperatures.

Day of month	November		December		January		February		March		April	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1			24.1	10.0	22.0	7.1	21.5	9.1	25.8	12.3	32.4	17.2
2			25.2	9.5	21.6	6.1	22.4	8.6	25.0	11.7	33.6	18.4
3			24.8	8.9	21.8	7.4	22.1	9.2	27.4	13.1	34.4	18.0
4			24.9	9.1	22.4	7.5	21.8	9.1	26.6	13.3	34.1	18.0
5			25.1	9.0	21.8	6.6	23.0	8.7	27.0	13.0	33.9	18.2
6			25.3	8.8	21.8	7.1	23.3	8.7	27.5	12.8	34.8	17.9
7			23.6	9.0	21.1	6.9	23.4	9.0	26.9	13.5	34.7	18.9
8			23.7	9.1	21.3	7.3	23.4	9.0	27.8	14.2	35.0	18.6
9			24.3	9.0	20.8	7.4	23.3	9.3	28.2	14.0	34.9	19.0
10			23.6	8.6	21.3	7.4	22.7	9.8	28.3	13.6	35.0	19.0
11			24.2	9.3	21.3	6.6	22.5	9.8	27.9	13.8	34.5	19.0
12			24.4	9.0	20.8	6.4	23.0	9.8	28.2	15.0	35.6	19.9
13			24.5	8.0	21.0	6.6	23.0	10.1	30.0	15.4		
14			23.8	8.0	21.1	6.9	23.1	9.7	29.5	15.3		
15			24.0	7.8	20.7	6.0	23.7	10.1	30.1	14.6		
16			24.1	8.4	21.0	7.3	24.0	9.9	29.5	14.5		
17			22.6	7.3	21.0	7.1	21.6	9.8	28.9	14.5		
18	27.7	11.5	22.6	7.8	20.9	6.7	24.3	9.3	31.2	15.1		
19	27.6	11.5	22.9	8.2	21.2	6.5	24.4	10.0	30.9	15.8		
20	26.8	10.8	23.3	8.1	21.4	7.0	24.8	9.6	30.6	14.8		
21	27.8	11.0	22.7	8.5	21.0	6.6	25.0	10.9	31.1	15.0		
22	26.0	11.3	22.8	8.1	20.6	7.7	24.7	11.0	32.3	14.9		
23	27.0	9.6	22.8	7.6	20.7	7.6	25.0	11.0	31.6	16.2		
24	27.4	9.6	22.0	7.4	21.3	7.8	24.0	11.5	32.0	16.5		
25	27.0	9.7	22.6	8.0	20.7	8.2	26.0	11.0	32.5	16.3		
26	27.0	10.3	22.6	8.6	21.4	7.8	26.0	12.3	32.3	16.2		
27	26.3	10.4	22.5	8.4	21.5	8.4	26.0	12.0	33.1	16.2		
28	25.7	10.4	22.4	6.9	21.7	7.7	26.0	10.1	32.8	16.5		
29	25.2	10.0	22.1	7.3	21.7	6.4			33.5	17.3		
30	26.4	10.0	22,0	7.4	22.1	6.7			32.9	17.1		
31			21.6	7.4	22.3	6.6			32.6	16.7		