RESPONSE OF BRASSICA SPECIES TO THE THERMAL ENVIRONMENT UNDER DELHI CONDITIONS

BY

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CERTIFICATE

This is to certify that the thesis entitled "Response of Brassica species to the thermal environment under Delhi conditions" submitted to the Faculty of 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 by Mr Rajendra Prasad, is a genuine record of bona fide research work carried out by him under my guidance and supervision. No part of this study reported here, has so far been submitted anywhere for publication or for any other degree or diploma in any other form.

It is to certify that such help and sources of information as have been availed of during the course of the investigation have been duly acknowledged by him.

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INTRODUCTION

1. INTRODUCTION

India's varied soil and climatic conditions permit cultivation of wide range of oil yielding plants such as groundnut, rapeseed-mustard, sesame, safflower, sunflower, linseed, soybean, niger and castor. The area under these crops which was only 10.1 m ha in 1949-50 rose to 18.7 m ha in 1986-87 and production increased from 5.23 to 11.15 mT. It reached a peak of 12.95 mT in 1984-85.

Rapeseed and mustard are the major rabi oilseed crops next in importance to groundnut, both in area and production. India is one of the largest producers of rapeseed and mustard in the world. Their production is around 2.63 mT which accounts for 22.9% of the total oilseed production of the country. In India, the cultivation is mainly confined to Uttar Pradesh, Rajasthan, Madhya Pradesh, Haryana, Delhi, Punjab, Orissa, Assam, Bihar, Gujarat and West Bengal. Among different states, Uttar Pradesh alone accounts for about 60% of total rapeseed and mustard production in India. In order to increase the domestic availability of edible oils, emphasis has been laid on accelerating the production of oilseeds through oilseed development programmes.

The complex phenomenon of plant growth involves the interaction of an array of many physical, chemical and physiological phenomena. All these are influenced by temperature to a varying degree. In presence of adequate soil moisture and nutrient supply, temperature is considered as the most important climatic factor affecting the periodic development of plants.

The economic yield of a field crop is determined by the pattern of biomass production, crop growth rates and radiation interception by the canopy. These factors are however, influenced by the prevailing day to day weather conditions. A major source of these variations is temporary warming and cooling of the atmosphere caused by the weather associated with passage of western disturbances over north India during this season. Under irrigated conditions meagre rainfall of 2 to 3 cm received during the rabi months does not have much significance. Hence, in the Delhi region, it is the changes in temperature that would induce short-term weather effects on crop growth. This is one of the aspects that has received very little attention in the past in our country and in the absence of controlled environmental facilities, this aspect has been studied through field experiments with dates of sowing as a treatment.

Only within a certain range of temperatures the plants can grow and in parts of this range the crops will grow most rapidly and grow best. Heat unit concept is based on idea that plants have a definite thermal requirement before they complete certain phenological stages. This provides an opportunity to build up quantitative relationships between heat unit system, biomass production and crop growth rates. Except for the extensive studies on Brassica spp. by Hodgson(1978) in Australia, accumulated heat unit system does not seem to have been applied in detail in India to study crop growth and development in Brassica spp. The thermal environment as stated above being an important ingradient influencing crop performance during rabi season, it should be possible to apply this concept to study crop response to different phenological stages.

Although knowledge of phenology-environment interactions comes handy in planning operations for maximizing yield, study of phenology of crops, an important aspects, still for some reason or the other has not received due attention in our country.

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

Photosynthesis is known to depend on light energy and chlorophyll content of crops in addition to temperature. Chlorophyll content is known to vary with changes in photosynthetically active radiation and its distribution within the crop canopy in relation to temperature variation 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 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 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 normal crop growing season would provide a data base for studying crop response to thermal environment under natural conditions. One redeeming feature is that rapeseed and mustard growing belt is visited by one or two western disturbances in each month during its active growth season from December to March. 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 for a week or so providing different field conditions for a case study.

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

1. to study the effects of short period variation in temperature on growth and yield in relation to phenology
2. to study crop response to thermal environment using accumulated heat unit system and,
3. to study radiation interception by the crop and leaf chlorophyll content in relation to leaf area development as affected by changes in thermal environment.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

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

1. Phenology in relation to temperature
2. Temperature, plant growth and development characteristics
3. Accumulated heat units, crop growth and development
4. Evapotranspiration and biomass production
5. Crop canopy temperature characteristics
6. Effect of temperature on chlorophyll content

1.0 PHENOLOGY IN RELATION TO TEMPERATURE

1.1 PHENOLOGY

Phenological development of crop is known to closely follow the changes in weather conditions occurring during crop growth season and since the earliest times, study of phenology of crops formed an important aspect in ecological research. Phenology, is a study of timing of recurring natural phenomenon, especially in relation to climatic conditions (Murray, 1909). The effects of environmental factors like photoperiod, solar radiation and soil moisture on development (i.e., progress of crop towards maturity) were different from those on general growth pattern.

Consequently, a different set of methods were designed for relating environmental conditions to duration of specific developmental phases.

Since temperature has an overriding influence on plant development, it was the first variable to be studied when phenological studies were started some two centuries ago. The temperature based methods were modified later to take into account photoperiod, solar radiation and soil moisture also. The earlier history of these studies was described by Abbe(1905), Shelford(1930) and Wang(1960).

Katiyar and Singh (1974) while working in Indian mustard reported that date of planting had pronounced effect on days taken to reach a particular growth stage and emphasized that days to flower were negatively associated with days taken from flowering to maturity.

Under the Delhi conditions, Pusa Bold took 39,52,63,77 and 130 days to attain first flower, 50% flowering, 100% flowering, 100% pod formation and maturity, respectively(Ravindra,1985). In Uttar Pradesh region under normal sown conditions, Shastry and Kumar (1981) reported that cultivar Pusa Bold took 52,71,95 and 126 days, respectively to attain 50% flowering, 50% pod formation, complete pod formation and maturity of the crop.

Through a controlled study in winter rape, Gvozdikova(1984) observed that younger the plants, higher was the response to light and temperature treatment for flowering and differentiation.

✓2.0 TEMPERATURE, PLANT GROWTH AND DEVELOPMENT CHARACTERISTICS

✓2.1 DRY MATTER ACCUMULATION

Dry matter accumulation in crop plants is of importance not only because it is the one which ultimately gets transformed into economically usable product but in case of Brassica spp. it assumes still greater importance because a major portion of dry matter gets accumulated after anthesis when leaf area is on the decline. The levels of accumulation before and after anthesis however are known to vary with species and varietal groups. In Brassica campestris, 85% of total dry matter was found to be accumulated after anthesis whereas in Brassica napus, it was only 50% (Thurling, 1974a). The work of Campbell and Kondra(1977,1978) revealed that the duration of vegetative phase and higher dry matter production during vegetative phase were positively correlated with seed yield.

Periodic observations on plant dry weights usually show a sigmoidal increase with time. Dry matter accumulation of irrigated Polish rape(Brassica campestris L. cv. span) and Argentina rape(Brassica napus L. cv. zephyr) in Canada were determined by Major (1977) and he found that maximum dry matter accumulation occurred 89 and 84 days after sowing (DAS) in case of cv. span and 96 and 91 DAS in cv. zephyr, respectively during different growing seasons. Maximum dry matter production ranged from 312 to 1174 g/m^2.

In Canada, under non-irrigated and higher seed rate conditions dry matter production was found to be higher in B.napus cv. Tower before flowering in contrast to higher dry matter accumulation after flowering under irrigation and low seed rate conditions as observed by Clarke and Simpson(1978b).

The pattern of dry matter accumulation was reported to be the major distinguishing feature between species contributing the most of differences in yield (Richards and Thurling, 1978) and pre-anthesis dry matter accumulation in Brassica napus L. resulted in greater contribution of reserves for grain filling.

The relative importance of key growth parameters like net assimilation rate (NAR), relative growth rate(RGR) crop growth rate(CGR), leaf area ratio(LAR) and specific leaf area (SLA) in relation to growth behaviour of Brassica spp. were employed by Allen and Morgan(1972, 1975), Thurling (1974a), Clarke and Simpson(1978a), Chauhan(1980) and Khadar (1983).

2.2 CROP GROWTH RATES

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

The growth of two cultivars of Brassica napus was characterized into four different phases by Allen *et al.* (1971) on dry matter distribution pattern. The first phase lasted 6 to 7 weeks from date of sowing while a second phase lasted for a period of two weeks when a marked reduction of crop growth rate(CGR) was observed. The third phase extended to another two weeks during which the CGR rose to the highest level, and was characterized by marked increase in size and weight of pods.

The crop growth rates of irrigated polish rape (*Brassica campestris* L. cv. span) and Argentina rape (*B.napus* L. cv. zephyer) were determined by Major(1977) in Canada. It was observed that maximum crop growth rates of 9.88 to 22.07 g/m^2/d occur in 46 to 49 DAS in two seasons in case of cv. span and 17.44 g/m^2/d in 77 DAS in first season and 24.05 g/m^2/d in 49 DAS in second season in case of cv. zephyr showing wide range of CGR.

In the Delhi region, Ravindra(1985) reported two patterns in crop growth rates(CGR) for Pusa Bold sown on four dates starting from Ist October, the first pattern being parabolic in nature with higher initial crop growth rate(CGR) in first two sowings and linear in later two sowings with lower initial CGR. Peak CGRs were found to be 20 to 35 g/d in first two sowings and 5 to 12 g/d in two later sowings, revealing the effect of delayed planting and consequent differences in the thermal environment. In Italy, Frenquelli *et al.*(1985) while working with *B.napus* reported two peaks of CGR, first at the anthesis stage and second at the pod growth and seed maturity stages.

An experiment was conducted by Clarke and Simpson (1978a) for two years at Saskatoon(Canada) who found that CGR was influenced by seeding rates and irrigation. Thurling (1974a), in his study in Australia observed no significant variation in relative growth rates(RGR) in *B.napus* L. and attributed this to the marked negative association between net assimilation rate (NAR) and leaf area ratio (LAR).

2.3 LEAF AREA INDEX

Leaf area index(LAI) is an important parameter of plant growth. It is very useful in knowing the interception of radiation and amount of photosynthates synthesized. Major(1977) observed maximum leaf area index(LAI) in irrigated Polish rape(Brassica campestris L. cv. span) and Argentina rape(B.napus L. cv. zephyr) with values 1.35 and 3.48 for cv. span (42 and 50 DAS) and 1.91 and 5.51 for cv. zyphyr (54 and 57 DAS) in two growing seasons, respectively. Maximum LAI was observed at anthesis stage in Brassica napus by Frenquelli et al.(1985).

In an experiment conducted to compare the growth, development and yield of four varieties of oilseed rape, Cressus, Gulle, Rigo and Nilla, Allen and Morgan(1975) observed that more number of pods per plant and more seeds per pod were positively related with LAI on the onset of flowering which resulted in higher seed yield in cv. Cressus. In a study in Canada, LAI reached a maximum near start of flowering and then declined rapidly in B.napus cv. Tower (Clarke and Simpson,1978a). LAI was shown to be positively correlated with seed yield in Brassica napus L.(Mendham and Scott,1975; Norton and Harris,1975 ; Clarke and Simpson, 1978a).

Mendham and Scott(1975) in their study on limited effect of plant size at inflorescence initiation on subsequent growth and yield of B.napus concluded that leaf area reaches a peak at about full flowering time and declines rapidly with the onset of pod growth. Through their experiments, Holland (1971) and Thorne(1966) concluded that by the time crop is in flowering stage, the leaves have already fulfilled their role in plant development as photosynthetic surfaces. This study leads to the conclusion that photosynthetic activity of pods and stems appear to contribute at least half of the material for seed development in Brassica. Thurling(1974a) reported that leaf area ratio(LAR) of plant at anthesis contributed significantly to total dry weight at final harvest in rapeseed; he further emphasized that _Brassica campestris_ is photosynthetically more efficient than _B.napus_ L.

2.4 DATES OF SOWING AND SEED YIELD

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

Delayed sowing is known to cause reduction in seed yield as suggested by Gross(1963); Singh, _et al._(1972); Scott _et al._(1973a), Thurling(1974b); Dagenhardt and Kondra (1981) and Singh and Singh(1985). The yield per unit area in _Brassica_ spp. is determined by three major yield components viz., number of pods per plant, number of seeds per pod and 1000-seed weight. Any reduction in seed yield is likely to be reflected through these components. In _Brassica napus_ this reduction in yield was attributed to reduction in total dry weight of the plant which in turn was most closely related with duration of vegetative phase of growth. The total dry weight of the plant and seed yield were observed to be the greatest in the first sowing where flowering was substantially later than in later sowings(Thurling,1974a).

Experiments on delayed sowing of *Brassica* spp. in India and abroad have shown a reduction in plant height causing a proportional decrease in seed yield(Dagenhardt and Kondra, 1981; Shastry and Kumar,1981 and Vasi *et al*.,1986).

Thurling(1974a) observed that variation in sowing date had a marked effect on seed yields and different morphological and growth characteristics of spring cultivars of rapeseed. The species differed appreciably in their response to successive delay in planting date. The seed yields of *Brassica campestris* were noted to be substantially greater in second sowing than in the first and third sowings. Elf and Ohlsson(1987) in field experiments exposed *Brassica juncea* cv. Varuna to low temperature conditions(-3 to 0°C) at flowering and pod filling stages and observed 50% reduction in seed yield when crop got exposed to -1°C at flowering and -2°C at pod filling stages.

Many researchers have reported differential response of varieties to planting dates, early maturity and decrease in seed yield with delay in sowing of rapeseed and mustard (Gross,1963; Scott *et al*.,1973a; Kondra,1977; Saini *et al*., 1977; Hodgson,1979; Richards and Thurling,1978b; Bishoni and Singh,1979; Bowerman and Lewis,1980 and Dagenhardt and Kondra,1981).

2.5 OIL CONTENT

A reduction in oil content was noted in Brassica napus due to delayed sowing by Scott *et al.*(1973a), Bishnoi and Singh(1979) and Hodgson (1979). Hodgson(1979) in his study in New South Wales concluded that oil content was inversely related to mean daily temperature during seed filling period. Maximum temperature at vegetative phase was found to be positively correlated with per cent oil content by Shastry and Kumar (1981) and Vasi *et al.*(1986).

Gambhir *et al.*(1979,1983) conducted experiments to find out the effect of maturity on oil yield of Indian mustard. They suggested that harvesting of the crop should be done at yellow stage as the oil yields are observed to be optimum at this stage. Serial harvests at the time of ripening indicated that the maximum seed and oil yields could be obtained by cutting plants before they are fully ripe thus avoiding the seed loss through pod shatter. Oil content of bulk samples reached a peak about a week before maximum seed yield(Scott *et al.*,1973b; Gambhir *et al.*,1979, 1983).

Hodgson(1979) reported that oil production was favoured in B.napus when seed developed during the coolest part of the year(temperature not below zero and mean temperature between 13.1 to 15.4°C) under field conditions. Canvin(1965) supported these results from data obtained from controlled environmental conditions. However, Elf and Ohlsson (1987) reported a reduction in oil content when flowering and pod filling stages experienced a low temperature in the range of -3 to 0°C under field conditions in B. juncea cv. Varuna.

2.6 HARVEST INDEX

An alternative to yield component approach is to view yield as a product of total dry matter(i.e.,biological yield) and harvest index (the proportion of total dry matter found in economic parts). The biological yield is the product of growth rate and duration while harvest index integrates photosynthesis, translocation and storage processes. Studies on Brassica spp. indicate that harvest index(HI) is strongly influenced by environment(Thurling,1974a). He also reported that HI was more closely related to yield in Brassica campestris than in Brassica napus. However, total dry matter and HI were found to contribute significantly to yield in both the species. The value of HI ranged between 10 to 23%. Delayed sowing causes reduction in HI(Dagenhardt and Kondra,1981). Mehrotra et al.(1976) recorded considerable variation of HI in their experiments which varied between 25 and 35% in early varieties, 25 to 32% in medium maturing varieties and 26 to 40% in late maturing varieties. However, Chauhan (1980) and Bhargava and Tomar(1982) reported lower values of HI for Brassica ecotypes. But Khader(1983) reported that HI of Brassica campestris and Brassica juncea species ranged between 26 and 31%. A value of 11.6 to 31.6% was given by Hodgson(1979). Bhargava et al.(1984) reported that HI of 4 Brassica ecotypes ranged from 27 to 42%.

In terms of energy, 600 g of mustard is equivalent to 1 kg of wheat. If harvest index is compared on the basis of energy, the oilseed crops were shown to be as efficient as many cereals (Sinha et al.,1982).

To understand the interaction of crop growth and environmental factors, detailed knowledge about the rates of biomass production, crop growth rates at different phenological stages and the influence of temperature on all these characters is essential. Review shows that biomass production and crop growth rates have not been studied at different phenological stages and related to temperature conditions.

3.0 ACCUMULATED HEAT UNITS AND CROP GROWTH AND DEVELOPMENT

3.1 THE HEAT UNIT SYSTEM AND GROWING DEGREE DAYS

The effect of temperature on plant growth and occurrence and phenological development can be inferred by way of accumulated heat unit(AHU) which is based on the idea that plants have a definite temperature requirement before they attain certain phenological stage. 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 specific area, they 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 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 Van't Hoff Law. The terms degree days, growing degree days and heat units are used synonymously by various scientists. Thus degree day is a measure of departure of mean daily temperature from a given base temperature expressed in °C or °F. Day-degrees were also referred to as accumulated heat units(AHU) by several workers.

Arnold(1959) suggested methods for determining the base temperatures (a) least variability method and (b) X-intercept method in which a regression equation is fitted between mean temperature(independent variable) and growth rate(inverse of duration). The value of X-intercept is taken as base temperature.

Hodgson(1978b) following Arnold's(1959) method, determined the base temperature for Brassica spp. Iwata and Okubo(1969) extended the least variability method of Arnold to jointly consider the base and optimum temperatures. Baskerville and Emin(1969) developed equations to determine degree days for conditions when base temperature is above daily minimum and optimum temperature is less than daily maximum temperature.

Lindsey and Newman(1956) estimated degree hours as

$$\frac{12(T_{max} - B.T.)^2}{T_{max} - T_{min}}$$

where, T_{max} is temperature maximum, T_{min} is temperature minimum and B.T. is the base temperature.

Gilmore and Rogers(1958) suggested that crop development is also inhibited at temperatures higher than optimum.

3.2 HEAT UNITS AND DRY MATTER PRODUCTION

A high positive correlation between dry matter of soybean and sum of air temperatures was obtained by Uchijima (1975) and Rajput(1980), in wheat by Chakravarty and Sastry (1983 a,b,c). Uchijima (1975) concluded that the sum of air temperatures is highly responsible for accumulation of dry matter of the crop stand.

When the day degree accumulation is above 1000°C the rate of dry matter accumulation in soyabean was found to be 49.9 $g/m^2/100°C$ day. Similar dependence of accumulation of dry matter by soyabean on sum of air temperatures is in good accordance with results reported on soyabean by Hanway and Weber(1971), who found a linear dependence of dry matter accumulation on number of days after emergence.

Robinson(1971) in a study on sunflower reported that GDD summation to either head visible or first anther stage did not vary greatly under different environments. Both day and GDD summations varied among years for all growth periods but the magnitude of variation in some periods was not great. In New South Wales, Hodgson (1978b) calculated the growing degree day (°C) requirements for Brassica napus L. and Brassica campestris L. from phenological and thermal data and found that duration of all phenophases are significantly correlated with the phase mean temperatures.

Similar relationships between biomass production, phenology and accumulated heat units in Brassica spp. do not appear to have been studied and information on these aspects is lacking at present.

Thus, though considerable progress had been made in characterizing the biometeorological time scale in terms of degree days, it is obvious that detailed study on 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 in Brassica crops is lacking in our country.

3.3 PHENOTHERMAL INDEX

The differences in relation to accumulated degree days between different growth stages in case of wheat was expressed in the form of phenothermal index, by Chakravarty and Sastry(1983 a,b) computed as degree days/growth day. The index was found to be nearly constant, irrespective of planting date and season, during sowing to boot leaf stage. While the indices in different stages from boot leaf to hard dough in wheat 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 a single unit, the coefficient of variability(C.V.) yielded a value of 3.1(Chakravarty and Sastry,1983a). In barley crop, phenothermal index ranged from 11.5 to 14.5 during boot leaf to anthesis stage(Chakravarty 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 C.V. of 1.1%.

Phenothermal indices in case of Brassica spp. have not been attempted so far.

3.4 HEAT USE EFFICIENCY

Based on accumulated heat unit system, a heat use efficiency index was proposed for characterization of biomass production at different stages of crop growth and grain yield of soyabean, summer mung and wheat in relation to ambient temperature (Sastry et al.,1985). Heat use efficiency (HUE) of three soyabean varieties for different growth stages was evaluated using above-ground biomass and also the grain yield. HUE was found to be high during the flowering to pod formation stage and ranged from 32.7 to 60.6 q/ha/degree day x 10^3. In summer mung, at all stages of crop growth HUE was higher during the cooler season(1979), ranging from 14.4 to 73.8 q/ha/degree day x 10^2 than in the warmer (1978) season(8.8 to 46.6 q/ha/degree day x 10^2) because of lower summer mean temperatures in 1979 as compared to 1978 (cooler season); relatively high HUE, 17 to 22 x 10^2 q/ha/degree day, was found in second planting compared to 6 to 8 x 10^2 q/ha/degree day in 1979-80(warmer season). During this stage, correspondingly higher CGRs were recorded during 1978-79 compared to 1979-80. Because of higher maximum temperatures(30°C) at grain filling period during 1979-80 there was considerable reduction in HUE values(Sastry *et al.*, 1985).

Such heat use efficiency indices are yet to be evaluated in *Brassica* spp. to facilitate relative assessment of varietal response to prevailing thermal environment at different growth stages of the crop which can be considered as a measure of crop growth character in response to ambient temperature.

4.0 EVAPOTRANSPIRATION(ET) AND BIOMASS PRODUCTION

When the actual evapotranspiration falls short of potential evapotranspiration, the actual yield could 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 the 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 water use in the 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 them from sowing until maturity. Jalota(1986) established a relationship between evapotranspiration deficit at different growth periods of wheat variety WL-171 which explained 93% variation in yield. Biomass production in three varieties of wheat grown under irrigated field conditions in Delhi region was found to be linearly related to cumulative evaporation with a high correlation coefficient of 0.89(Chakravarty and Sastry,1983b). In case of Brassica, evapotranspiration and biomass relationships are yet to be established.

5.0 CROP CANOPY TEMPERATURE CHARACTERISTICS

5.1 CROP CANOPY TEMPERATURE

Canopy temperature is an integrated result of energy absorption and dissipation mechanisms acting within the canopy (Ferguson *et al.*,1973). The use of canopy temperature to detect water stress in plants is based upon the assumption that transpired water evaporates and cools the leaves below the temperature of the surrounding air. As water becomes limiting, transpiration is reduced and the leaf temperature increases(Jackson, 1982).

The potential of infrared thermometer in measurement of crop temperature for assessment of crop water deficit was recognised by Monteith and Szeicz(1962) and Tanner (1963). Ehrler _et al._(1978) also 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 reliable indicators of plant moisture stress.

Quantitative data relating crop temperature to phenological and physiological development of the crop over a complete growing season are sparse. The only seasonal crop canopy temperatures 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 observed with infrared thermometer could be used to predict phenological stages in corn crop if land is completely covered. They also inferred that decrease in grain yield can be reflected by increase in canopy temperature since canopy temperature increases as plant moisture stress starts developing.

Cloudy periods have been observed to lower leaf or crop temperature(Stone _et al._, 1975) for, diminished radiant heat load requires less total energy dissipation. Studies by Walker and Hatfield(1983) revealed the influence of net radiation and saturation deficit on canopy(T_c) air temperature(T_a) difference(T_c - T_a) in well watered plants during central portion of the growing season. 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 found to be not greatly different. In dry year, the maximum value was about -7°C and in the wet year it was -8.5°C. They also suggested that plants at high vapour pressure deficit(VPD) had cooler temperatures than plants at lower VPD in dry year. Similar results of negative correlation between VPD and (T_c-T_a) were reported by Reicosky(1985). Information on Brassica crops on this account seems to be lacking.

5.2 CANOPY-AIR TEMPERATURE DIFFERENCES

The canopy-air temperature differences(CATD) represent an integrated response of a crop to the 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 temperature(T_c) of wheat, Singh et al.(1985) observed the following results:

i) Significant differences were found in grain yield T_c and (T_c-T_a) of cultivars, under both moisture stressed and non-stressed treatments.

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

Plant parameters are 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-T_a) from jointing to late grain filling period showed a strong negative linear relationship to grain number per unit soil area(r^2=0.88) and final yield (r^2=0.86).

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

In a study carried out by Kalra *et al*.(1985) it was observed that during early growth phase, 85 days after sowing(DAS), the CATD was higher in *Brassica campestris* and *Brassica juncea* than in *B.napus* and *B.carinata* and a reverse trend was found in later growth phase(85 to 125 days). CATD was found to be highly and linearly correlated with LAI and dry matter production during the vegetative phase of the crop.

Cumulated stress degree days(Σ SDD) were found to be highly and linearly correlated with leaf area index (LAI) and dry matter production (DM) during the vegetative phase, in four Brassica species viz., campestris' juncea, napus and carinata(Kalra et al.,1985). Grain yield was found to decrease with increasing ΣSDD(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 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.

Jackson et al.(1977) evaluated the SDD parameter as a possible irrigation scheduling tool. It was concluded that irrigation should be given for wheat when or before the positive SDD's reached a value of 10. 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, particularly on Brassica spp, based on daily measurement of canopy temperature is limited in our country.

6.0 EFFECT OF TEMPERATURE ON CHLOROPHYLL CONTENT

Photosynthesis depends upon many factors but even chlorophyll content gives an indication about the productivity status of a crop. Chlorophyll estimation gives an idea about rate of production, since the rate of production is proportional to chlorophyll content.

6.1 CHLOROPHYLL CONTENT

Marked differences in leaf chlorophyll content were recorded both between ecosystems and seasonally in each ecosystem. The chlorophyll concentration in various kinds of plant materials differ greatly. Ovington and Lawrence(1967) showed that concentration differences are related to environmental conditions and that the variation depends 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. He 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 content 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 in wheat crop stand varied between years and between leaves in the 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 these experiments, the first harvest was significantly higher than the second harvest date for total chlorophyll. Friend(1960) observed that maximum fresh weight coincided with the time of maximal chlorophyll content.

A study was carried out in winter rape by Vincenc <u>et al</u>.(1984) in Czechoslovakia to find out the chlorophyll content of siliqua and seeds in winter rape during ripening and he found that total chlorophyll content increased during green ripening and then markedly decreased by full ripening time.

6.2 <u>Chlorophyll and Temperature</u>

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 temperature from 21/15°C to 35/25°C(day/night) after anthesis decreased chlorophyll content. Ray <u>et al</u>. (1978) reported that at low temperature, chlorophyll content increased during later growth whereas high temperatrures reduced the same.

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 a 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 concentration 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 hours acclimation period in both expanding and fully expanded leaves, increasing when plants were transferred to higher temperatures and decreasing when the transfer was to low temperatures.

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

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 investigation regarding the behaviour of chlorophyll content at different crop growth stages and 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 *Brassica* spp. grown under field conditions.

The foregoing review on the response between plant growth and development in relation to temperature had 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. The reported literature on these aspects in *Brassica* spp. is insufficient and sparse.

In *Brassica* spp. generally the research reports had been confined mainly to the entire crop growth period without any mention to phenological stages. Since the effect of environmental factors like temperature has a overriding influence in *rabi* season in the Delhi region on almost all the phenological stages of crop growth, it is necessary to study such responses under field conditions.

The review also shows that accumulated heat unit system has not been applied to study the influence of thermal environment on growth and yield in rapeseed and mustard, particularly under Indian conditions.

Similarly, the review shows that effect of temperature on chlorophyll content at different phenological stages of the crop growth which is indirectly affected by temperature through development of leaf area and biomass need to be investigated.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The details of materials used and techniques adopted in carrying out the present investigation are mentioned in the chapter under different titles.

3.1 SITE OF THE EXPERIMENT

Two field experiments were conducted during Rabi seasons of 1987-88 and 1988-89 from October to April in the research farm of Indian Agricultural Research Institute(I.A.R.I.) New Delhi (latitude 28°37'N, longitude 77°10'E). The field had a fairly levelled topography and experimental site was located adjoining the agrometeorological observatory. The soils in the experimental area were sandy loam in nature.

3.2 CLIMATE

New Delhi has a subtropical semi-arid climate, characterized by hot, dry summers and cold 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 are received during the southwest monsoon period i.e., July to mid September. Climatic normals for Delhi are presented in Table 1.

3.3 CROP

Brassica crop was raised for carrying out the experiment. Three cultivars viz., *Brassica napus* var. B.O.54, *Brassica juncea* var. Pusa Bold and *Brassica campestris* var. Toria-T9(referred to hereafter as variety V_1, V_2 and V_3, respectively).

with different maturity periods were used for this study. B.O.54 is a late maturing variety, Pusa Bold has medium maturity and Toria-T9 is the one which matures early.

Table 1. Climatic normals for Delhi, I.A.R.I. Agrometeorological Observatory

Month	1941-1970					
	Max. temp. (°C)	Min. temp. (°C)	Evaporation (mm day^{-1})	Duration of bright sunshine, hours	Wind speed (km hr^{-1})	Rainfall (mm)
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
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

3.3.1 Treatment

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

Rabi season	Date of sowing		
	P_1	P_2	P_3
1987-88	7.10.87	21.10.87	4.11.87
1988-89	5.10.88	22.10.88	5.11.88

3.3.2 Experimental layout

The layout(Fig.1) consisted of 27 plots of size 8m x 5m laid out in a randomized block design with three replications.

Varieties	3	Treatments(sowing dates)	3
Replications	3	Total number of plots	27

3.3.3 Fertilizer application

Urea @ 60 kg N/ha, single superphosphate @ 92 kg P_2O_5/ha and muriate of potash @ 48 kg k_2O/ha were applied. Half the quantity of urea was mixed with the other two fertilizers and applied to the soil during discing before sowing while the other half was applied at pod formation stage.

3.3.4 Cultural operation

Cultural operations like weeding and thinning were done. Weeding was carried out manually and thinning was done to keep the plant to plant distance at 8 to 10 cm while the row to row distance was maintained at 22.5 cm at the time of sowing as per the recommended practices for this crop.

3.3.5 Irrigation

Irrigations were given at two critical stages viz., flowering and pod formation. 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

V_1 – BRASSICA NAPUS VAR. B.O.54
V_2 – B.JUNCEA VAR. PUSA BOLD
V_3 – B.COMPESTRIS VAR. TORIA-T9

P_1 – FIRST SOWING
P_2 – SECOND SOWING
P_3 – THIRD SOWING

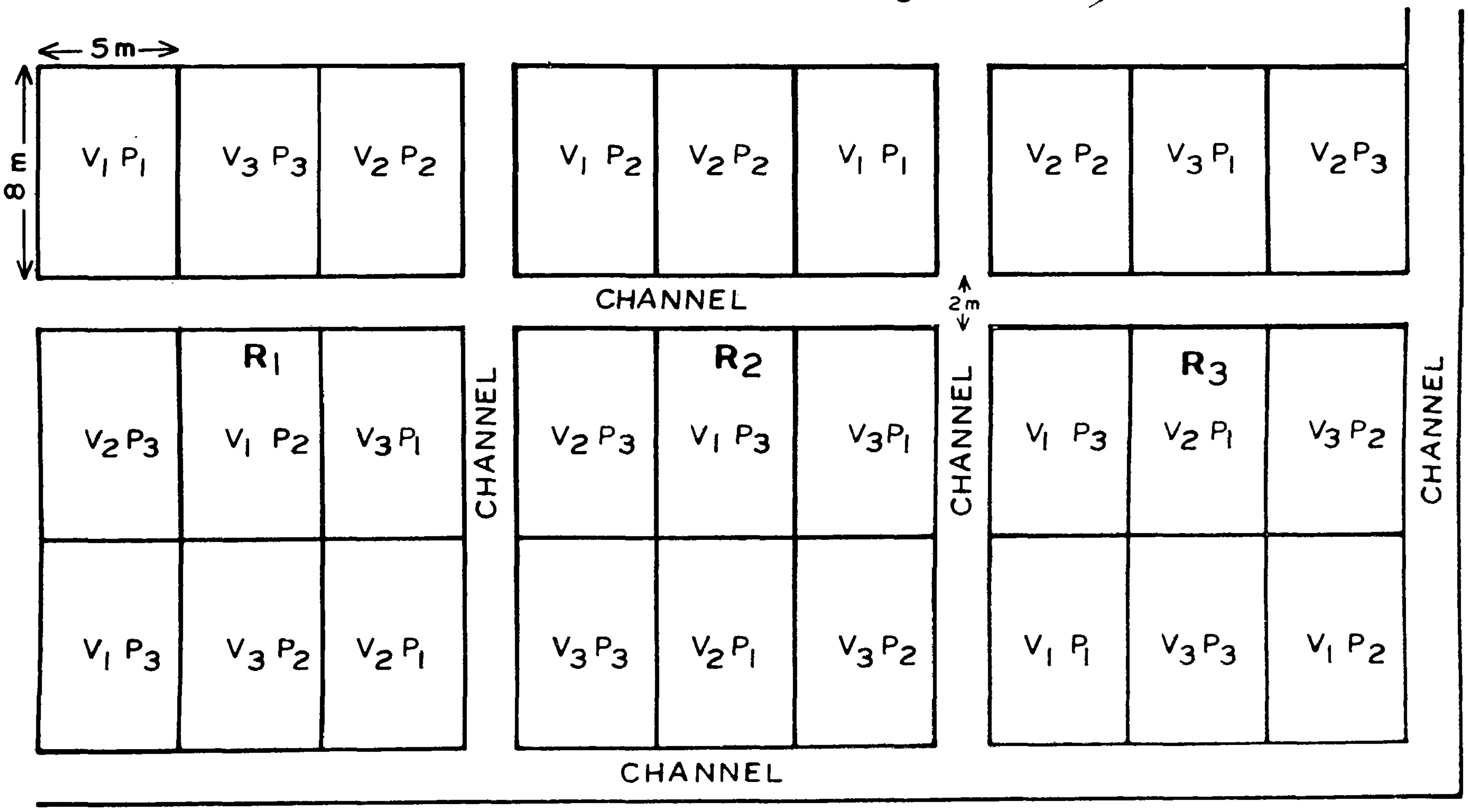


FIG.1. FIELD LAYOUT FOR BRASSICA SPP. (RABI 1987-88 AND 1988-89)

50% 'available water' in the 15 to 60 cm depth.

3.3.6 Plant observations

3.3.6.1 Phenological observations

The plants were inspected at frequent intervals (2 to 3 days) to closely follow the phenological events. From these observations first flower appearance(FF), 50% flowering (FF50), 90% podding (P90), end of seed filling(ESF) and maturity(MAT) were identified in each treatment and used in further analysis. (a) First flower appearance is defined as the time when the apical bud opens into the first flower; (b) 50% flowering is defined as the time when 50% of the plants have flowered; (c) 90% podding is defined as the stage when pods have already set in 90% of plants which coincides with the beginning of seed filling (when growing seed starts accumulating green mass in them), identified by opening the pod and pressing the seed; (d) end of seed filling is taken as the stage when no further pod growth takes place and the pods start turning yellow and (e) maturity is defined as the stage when 90% of pods get dried while the seeds get hardened and crop is nearly ready for harvest.

Based on these, phenological stages were further classified as follows:

1. Vegetative stage : Emergence to first flower appearance(FF)
2. Flowering : First flower appearance(FF) to 50% flowering(FF50)
3. Pod formation : 50% flowering(FF50) to 90% podding(P90)

4. Pod filling : 90% podding to end of seed filling(ESF)

5. Maturity phase : End of seed filling (ESF) to maturity(MAT).

3.3.6.2 Biomass

Oven dried, above-ground plant material was used to determine biomass production at periodic intervals. For this purpose leaving two border rows in each plot, two rows were earmarked for sampling. At each sampling, 6 plants at earlier stages, and 3 plants at later stages were randomly selected. These samples were oven dried at 80°C for 48 hours. Oven drying was continued till samples attained constant weight.

3.3.6.3 Crop growth rates

Crop growth rates(CGR) were evaluated over 5-day period from the smoothed biomass observations in each treatment.

$$\text{CGR} = \frac{\text{Accumulated biomass}}{\text{Number of days}} \quad \text{g/plant/day}$$

3.3.6.4 Leaf area index

Leaves were separated from the fresh biomass samples to measure the leaf area. LI-COR Model 3100 Area meter was used for this purpose.

3.3.6.5 Chlorophyll content of leaves

Chlorophyll content of leaves was determined at different crop growth stages. Leaves were sampled from top, middle and bottom levels of plant depending upon the growth stage and height of the plant. Three samples were collected at random from each treatment for this purpose.

Chlorophyll amount was determined following Hiscox and Israelstam(1979). 100 mg leaf discs were cut from the middle portion of the sample leaf and transferred to 20 ml test tubes and 7 ml of dimethylsulphoxide was added. The test tubes were kept in oven at 65°C for 4 hours and the volume was made up to 10 ml by adding another 3.0 ml of dimethylsulphoxide. Transmittance values at 645 nm and 663 nm were recorded by using Bausch and Lomb Spectronic-20. From the transmittance values, optical density(O.D.) values were determined. If O.D. value was higher than 0.7 the solution was diluted to 50% of its original concentration by adding another 10 ml of dimethylsulphoxide. The total chlorophyll content was determined using the expression:

$$\text{Total chlorophyll content (mg/g of fresh leaf wt.)} = 22.2(\text{O.D.}645) + 8.02(\text{O.D.}663) \times \frac{10}{\text{wt.(mg)}}$$

3.3.6.6 Oil content

The procedure suggested by Kartha *et al.*(1954) was adopted for determining the oil content in seeds. Brassica seeds weighing 0.5g were taken and ground with 2.0 g of pyrex glass powder and 2.5 g of anhydrous sodium sulphate (Na_2SO_4). The mixture was put in tapering glass tubes and extracted with 20 to 22 ml of petroleum benzene(boiling range 40-60°C) into the conical flasks. The aliquot was heated on water bath till it completely evaporated off leaving behind oil in the conical flasks. The per cent oil content was calculated as:

$$\text{Oil content}(\%) = \frac{\text{Wt. of oil in the seeds}}{\text{Wt. of seeds}} \times 100$$

The sampling for oil content was started after seed formation and was continued at periodic intervals till the maturity of the crop. Oil content was also determined at harvest by using NMR technique.

3.3.6.7 Harvest

The crop was harvested manually with sickles. The yield samples were obtained randomly from 1m x 1m area from each plot at two places. The number of plants per square metre were counted. Seed yield as well as straw yield were recorded.

3.3.6.8 Harvest index

Harvest index(HI) was determined by dividing the seed yield by total biological yield expressed as percentage and is given by

$$\text{HI} = \frac{\text{Seed yield(g/plant)}}{\text{Total biological yield(g/plant)}} \times 100$$

3.4 SOIL MOISTURE

Soil moisture was determined by auger sampling method for the depths 0-5, 5-15, 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.

3.5 ACCUMULATED HEAT UNITS

Accumulated heat units were computed using three different methods as follows:

3.5.1 Growing degree days

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

$$GDD = \sum_{1}^{n} \left(\frac{T_{max} + T_{min}}{2} - B.T. \right)$$

where,

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

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

B.T. = base temperature(4.5°C)

n = number of days during which the heat units were accumulated.

3.5.2 Photo-thermal units

The product of the growing degree days and the length of the day in hours accumulated over a given period gives photo-thermal units(PTU). Values of day length hours were obtained from Smithsoninian Tables.

3.5.3 Helio-thermal units

Helio-thermal units(HTU) were computed following Sastry and Chakravarty(1985). In this method the actual bright sunshine hours were used in place of total day length in PTU to arrive at the heat summations. Thus the product of the day degrees(from the base temperature 4.5°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.

3.5.4 Pheno-thermal indices

The heat units accumulated per growth day between two phenological stages were computed to obtain 'pheno-thermal index' which is expressed as degree days per growth day; this procedure was used earlier by Chakravarty and Sastry(1983).

3.5.5 Heat use efficiency

With a view 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(HUE) was computed by the method suggested by Sastry *et al.*(1985). It is given by the expression:

$$\text{HUE} = \frac{\text{Accumulated biomass(g/plant or q/ha}}{\text{Accumulated heat units(°C)}}$$

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

3.6 PHOTOSYNTHETICALLY ACTIVE RADIATION

Line quantum sensor(Model LI 191B, LI 1888 - integrating quantum/radiometer/photometer) was used to measure the amount of photosynthetically active radiation (PAR) received at different heights within the crop canopy--below inflorescence, at 50% height of crop canopy and at the ground surface, keeping the sensor at 5 cm above ground level.

3.7 LEAF TEMPERATURE

A microprocessor controlled LICOR(Model LI-1600) steady state porometer which measures leaf temperature(°C) was used. For this measurement top second or third leaf was taken for observations after the disappearance of dew from the leaves. Three to four intact leaves were used for each set of observations which were repeated at hourly intervals during the day.

3.8 MESH COVERED PAN EVAPORATION

Values of evaporation in mm from class A mesh covered pan evaporimeter as per specifications of IMD installed in the nearby agrometeorological observatory were taken for the duration corresponding to the crop growth period.

3.9 CANOPY TEMPERATURE

Canopy temperatures(T_c) were taken daily from December onwards in the respective cropping seasons 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. Observations were made between 1300 to 1400 hours IST daily, from corners/sides of the plots and averaged, till crop got matured. Canopy air temperature differences(CATD) were noted along with canopy temperature readings from the same infrared thermometer.

3.10 STRESS DEGREE DAYS(SDD)

The summation of daily CATD values ($\sum$ SDD) was made for each crop sowing from flowering to maturity. The procedure described by Jackson et al.(1977) was followed:

$$SDD = \sum T_c - T_a$$

where,

T_c = canopy temperature

T_a = ambient temperature

SDD = stress degree days

3.11 STATISTICAL ANALYSIS

The following statistical analysis was carried out for interpreting the results presented in the present investigations:

a) analysis of variance

b) coefficient of variation

c) correlation coefficients and regression analysis

For this analysis the methods suggested by Gomez and Gomez(1984) were followed.

RESULTS AND DISCUSSION

4 RESULTS AND DISCUSSION

Results obtained in the field experiments conducted during *rabi* seasons 1987-88 and 1988-89 on *Brassica* spp. to study the effect of temperature are detailed and discussed below:

4.1 ENVIRONMENTAL CONDITIONS DURING RABI 1987-88 AND 1988-89 SEASONS

Environmental conditions that prevailed during the *rabi* 1987-88 and 1988-89 seasons as recorded at the IARI agrometeorological 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 different parameters are given in Appendix-II and III.

4.1.1 Maximum temperature

During the *rabi* 1987-88 season, weekly mean maximum temperatures ranged between 21.8 to 36.9°C. Temperatures were the lowest during the flowering to pod development stages (21.8°C). During maturity, temperatures gradually increased from 25.1 to 35.3°C. An examination of daily temperature data showed that during vegetative phase, temperatures were 1 to 4°C above normal during the weeks 44 to 48. During pod development stage, maximum temperature was 3 to 6°C higher than the normal. In the maturity phase (weeks 8 to 14) the temperatures were 2 to 6°C below normal which could be associated with cooling due to 64.6 mm of rainfall received in weeks 9 to 13.

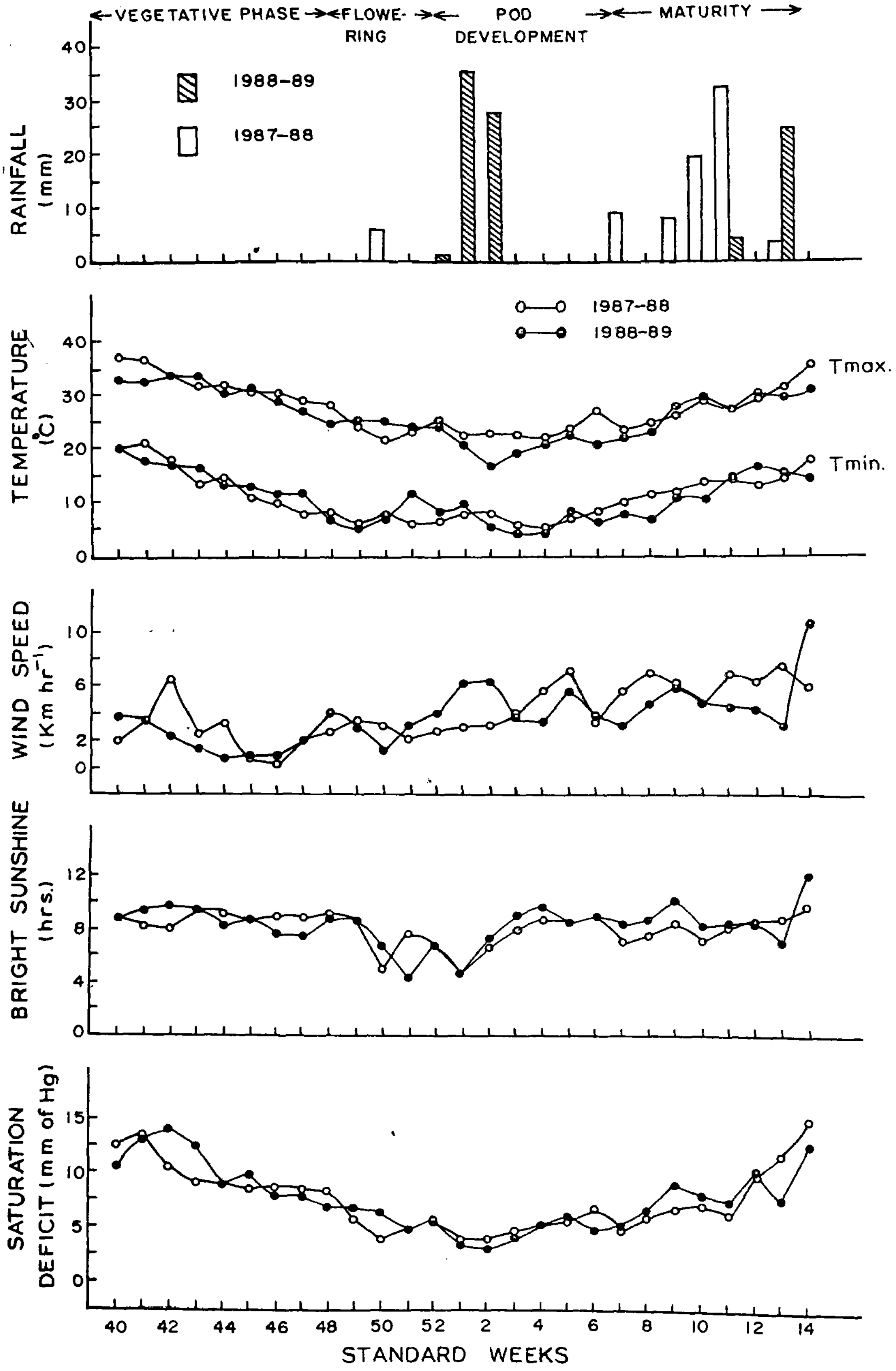


FIG. 2. ENVIRONMENTAL CONDITIONS DURING 1987-88 AND 1988-89 RABI SEASONS

During the *rabi* 1988-89, maximum temperatures decreased gradually to a lowest of 16.7°C in the second week of January rising to a highest of 30.9°C by the end of the growth season. An examination of daily temperature data showed that during early pod development stage(weeks 52 to 4) maximum temperatures were 2 to 6°C below normal in association with 64.6 mm of rainfall received during the period. During the late pod development and early maturity phases (weeks 5 to 8) temperatures were 2-4°C below normal. In the late maturity phase(weeks 11 to 14) temperatures were 1 to 7°C below normal which could be attributed to 29.0 mm of rainfall received during this period.

In general, maximum temperatures recorded in 1987-88 season were warmer than those in the 1988-89 season.

4.1.2 Minimum temperature

Weekly mean minimum temperatures during 1987-88 crop growth season ranged between 4.9 to 21.1°C. Temperatures were the lowest (4.9 to 8.2°C) during the flowering and pod development periods(weeks 48 to 4). An examination of daily data showed that during this year, on most of the days minimum temperatures remained 1-3°C below normal during weeks 44 to 49(Late vegetative to early flowering), weeks 49 to 52(late flowering to pod development period) and weeks 12 to 14 (maturity phase).

During *rabi* 1988-89 season, weekly mean minimum temperatures ranged between 4.4 to 20.1°C. Daily minimum temperatures were below normal by 2 to 4°C in weeks 48 to 50 in the late vegetative and early flowering period and for a prolonged period from weeks 2 to 11 in the pod development and early maturity periods (by 4 to 6°C) suggesting mild cold wave conditions. Daily minimum temperatures during the late vegetative to early pod development periods(weeks 44 to 2) were 2 to 8°C higher than those in 1987-88 season for the corresponding period but during the early maturity period (weeks 6 to 11) they were lower by 4 to 7°C.

On the whole, it can be said that 1988-89 was relatively a cooler season compared to 1987-88 rabi season, when near normal temperatures were observed.

4.1.3 Duration of bright sunshine hours

The number of bright sunshine hours during 1987-88 season varied from 8.7 per day at the time of first sowing to 4.9 hours during the 2nd week of December and thereafter again decreased to a minimum of 4.7 hours in first week of January, increasing to 9.6 hours per day during the crop maturity period.

During 1988-89 season, they varied from 9.4 to 7.5 hours per day in the vegetative period, decreased to a minimum of 4.3 hours in the 3rd week of December, thereafter for a second time, decreased to 4.6 hours per day in the first week of January. And later during the maturity period, they ranged between 6.8 to 10.9 hours per day.

A salient feature was that during rabi 1988-89, longer bright sunshine hours(7.5 to 10.0 hours per day compared to 8.1 to 9.5 hours per day in 1987-88) were observed during the vegetative phase. In 1988-89, sunshine hours were of longer duration (4.6 to 11.0 hours per day compared to 4.7 to 9.6 hours in 1987-88) during the pod development and maturity phase.

4.1.4 Rainfall

During the *rabi* 1987-88 season, the total rainfall received from November to March was 79.8 mm on 6 rainy days. The highest rainfall spell was 50.0 mm received on 11th, 12th and 14th March during the early maturity period which led to lodging in the first and second sowings of variety B.O.54 and caused heavy pod shattering due to the accompanying hail storm.

Rainfall during the *rabi* 1988-89 season was higher i.e., 93.6 mm which occurred on 5 days from December to January. The highest rainfall(a total of 63.2 mm) was received on 3 rainy days during the early pod development period and another spell of 29.0 mm during the maturity period.

Among the two seasons, 1988-89 received rainfall during the pod development stage whereas no rainfall was received during the corresponding period in 1987-88, which contributed to a relatively cooler season during 1988-89 at this stage.

4.1.5 Saturation deficit

Saturation deficit followed the pattern of maximum temperature in both the seasons viz., starting with a higher value, decreasing to a minimum and thereafter showing an increasing trend. Starting with 10.0 to 13.7 mm of Hg at the time of sowing, saturation deficit decreased to 5 to 7 mm at flowering time and to 3 to 7 mm at pod development stage and thereafter increased to 4.7 to 15.1 mm at maturity with the approaching summer conditions.

4.2 PHENOLOGY

The occurrence of five phenological stages as enumerated earlier in the two <u>rabi</u> seasons 1987-88 and 1988-89 for three varieties B.O.54, (V_1), Pusa Bold (V_2) and Toria-T9 (V_3) sown at 15 day intervals and the number of days taken to complete different growth stages are shown in the Table 2.

4.2.1 Rabi 1987-88

B.O.54: The variety B.O. 54 took 45,33 and 41 days to reach first flower in first (P_1), second (P_2) and third (P_3) sowings, respectively. Flowering stage and maturity phase showed longer duration in P_2(15, 25 and 18 days), (37,48 and 30 days), respectively. For pod formation, P_1 and P_2 took almost same number of days (24 and 23 days) and in P_3 the event was delayed by a week(30 days). There was progressive decrease in pod filling period with sowing date: 34,20 and 16 days. The variety took 155, 149 and 135 days to attain maturity in P_1, P_2 and P_3, respectively.

Pusa Bold: The variety took relatively lesser number of days in all the three sowings for completion of the vegetative period when compared with B.O.54. It took 22,26 and 31 days in P_1, P_2 and P_3, respectively. Pod formation period in P_1 and P_2

Table 2. Duration of phenological stages(days) in *Brassica* spp.during 1987-88 and 1988-89 *rabi* seasons

Phenological stage		Var. B.O. 54			Pusa Bold			Toria-T9		
		P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
Vegetative	I	45	33	41	22	26	31	21	20	18
	II	26	30	40	26	26	38	21	17	29
Flowering	I	15	25	18	10	8	7	11	7	10
	II	17	20	17	8	12	7	10	7	6
Pod formation	I	24	23	30	34	38	27	36	40	37
	II	41	33	40	35	24	46	33	43	30
Pod filling	I	34	20	16	24	22	20	24	23	20
	II	35	24	19	24	32	30	24	25	18
Maturity phase	I	37	48	30	47	35	42	25	23	20
	II	33	39	25	59	51	17	35	29	31
Entire crop period	I	155	149	135	137	129	127	117	113	105
	II	152	146	141	152	145	138	123	121	114

P_1, P_2 and P_3 are sowing dates 1,2 and 3,respectively. I = 1987-88, II = 1988-89.

and maturity phase in P_1 and P_3 took relatively more number of days, that is, 34, 38 days and 47, 42 days, respectively. The variety matured in 137,129 and 127 days in the different sowings.

Toria-T9: The variety took relatively lesser number of days in all the three sowings to reach the first flower appearance when compared with B.O.54 and Pusa Bold. Toria-T9 took 21,20 and 18 days for completion of its vegetative phase. The maturity period was of short duration (25, 23 and 20 days) than in the other two varieties. This variety matured in 117,113 and 105 days in P_1,P_2 and P_3 sowings, respectively.

4.2.2 Rabi 1988-89

B.O.54: This variety took 26, 30 and 40 days to complete its vegetative phase in P_1,P_2 and P_3 sowings, respectively. The flowering period was of 17, 20 and 17 days duration. Duration of pod formation was nearly the same (41 and 40 days) for P_1 and P_3 sowings whereas in P_2 it had shortened to 33 days. On the whole this variety took 152, 146 and 141 days to mature for P_1, P_2 and P_3 sowings respectively.

Pusa Bold: The vegetative phase of this variety took 26, 26 and 38 days for its completion in the three sowings. When compared among the sowings, P_3 took 12 days more to reach first flower stage.

The pod formation and pod filling stages in P_3 got prolonged over P_1 by 11 and 6 days respectively. The maturity phase had been hastened by as high as 42 days. This variety completed its life cycle in 152,145 and 138 days for the three sowings, P_1, P_2 and P_3, respectively.

Toria-T9: This variety took 21,17 and 29 days for first flower appearance. When P_3 was compared with P_1, it was observed that the pod filling and maturity phases had been hastened by 6 and 4 days and flowering had been delayed by 8 days. This variety took a total of 123, 121 and 114 days to complete the entire crop growth period in sowings P_1,P_2 and P_3.

4.2.3 Maximum temperature and duration of vegetative phase

The review had shown that duration of vegetative phase is an important factor in determination of yield in Brassica spp. Correlations were worked out between average maximum temperature and the duration of vegetative phase (number of days) for each treatment for the two seasons separately. These parameters were found to be negatively correlated with a significantly higher correlation(-0.806) during the relatively cooler season 1988-89. During 1987-88, which was a warmer season with near normal temperatures for the Delhi region, the correlation was lower (-0.332). The result shows that significant differences could occur in the duration of vegetative phase due to the occurrence of cold and warm spells associated with passage of western disturbances. This was reflected in treatments, V_1P_1, V_2P_3 and V_3P_3(Table 2).

The results show that in all the sowings, B.O.54 took one to two weeks longer for flowering in both the seasons compared to the other two varieties. Irrespective of the seasonal differences between 1987-88 and 1988-89, P_1 treatment in B.O.54 took longer duration for pod filling than the other treatments.

Between the seasons, in all the stages except in vegetative and flowering, Pusa Bold showed higher variation in P_2 and P_3 sowings. Pusa Bold thus appears to be relatively more subject to seasonal effects in the post flowering stage, in addition to the effects of date of sowing.

Except during the maturity phase, sowings P_1 and P_2 in Toria-T9 did not exhibit large differences in the duration of different growth stages in spite of temperature differences that prevailed between the two seasons. This indicates its insensitivity to the seasonal differences in temperature though it exhibited differences due to date of sowing within the season.

The maturity periods in Pusa Bold and Toria-T9 were of longer duration in 1988-89 compared to the 1987-88 season reflecting the effect of cooler temperatures on the duration of this phase in these varieties.

One feature observed was that during the relatively cooler season 1988-89, vegetative period in P_3 in all the treatments was of longer duration when compared with the other two sowings indicating the influence of temperature on phenological events. Compared to the time taken for pod formation, pod filling was of shorter duration in P_3; this is a character exhibited by all the varieties in the two seasons, which is attributed to seasonal increase in temperature with the approaching summer.

The days to occurrence of different phenological events in Pusa Bold during 1987-88(warmer season) obtained here were within the range earlier reported by Ravindra(1985). However, in the present experiment, during the year with below normal temperatures i.e., in the 1988-89 season, the duration to maturity was longer than that observed by him.

When the duration of total growth season in the different treatments is considered, apparently it is seen that variety B.O.54 is very little affected because of cooler temperatures during 1988-89. This is more due to adjustments in duration between pod formation and pod filling stages which were highly variable that ultimately resulted in very little differences in the total duration of crop growth in spite of 4-5°C below-normal temperatures during the 1988-89 season. Thus, for this variety interactions with weather conditions during the pod formation and pod filling stages which are yield determining factors can be considered important.

Compared to variety B.O.54, in Pusa Bold and Toria-T9, the crop growth duration was extended by about two weeks and one week respectively during the cooler season 1988-89.

In these varieties as mentioned earlier, post flowering stages were seen to be more subjected to the influence of low temperature spells which resulted in prolonging the duration of crop growth periods in these two varieties.

With a view to obtain a comprehensive and comparative picture in phenological events under different treatments, it had been summarized in the form of a chart and presented in Fig.3.

4.3 TEMPERATURE, PLANT GROWTH AND DEVELOPMENTAL CHARACTERISTICS

4.3.1 Biomass production

Data on above-ground biomass production for different sowings of three Brassica spp. for the two rabi seasons 1987-88 and 1988-89 are shown in Tables 3a and 3b, respectively.

Rabi 1987-88

B.O.54: Biomass production ranged from a maximum value of 83.0 g/plant in P_1 at pod filling stage and 28.8 g/plant for P_3 at pod formation stage, with a value of 65.0 g/plant for P_2, which showed a peak at early maturity stage. The reduction in the magnitude of biomass by 22% and 66% in P_2 and P_3 in comparison with P_1, is attributable to the differences in thermal environment as a result of different dates of sowing. It may be mentioned that the later sowings were subjected to higher temperature and evaporative environments than those of P_1, during the post flowering period till maturity.

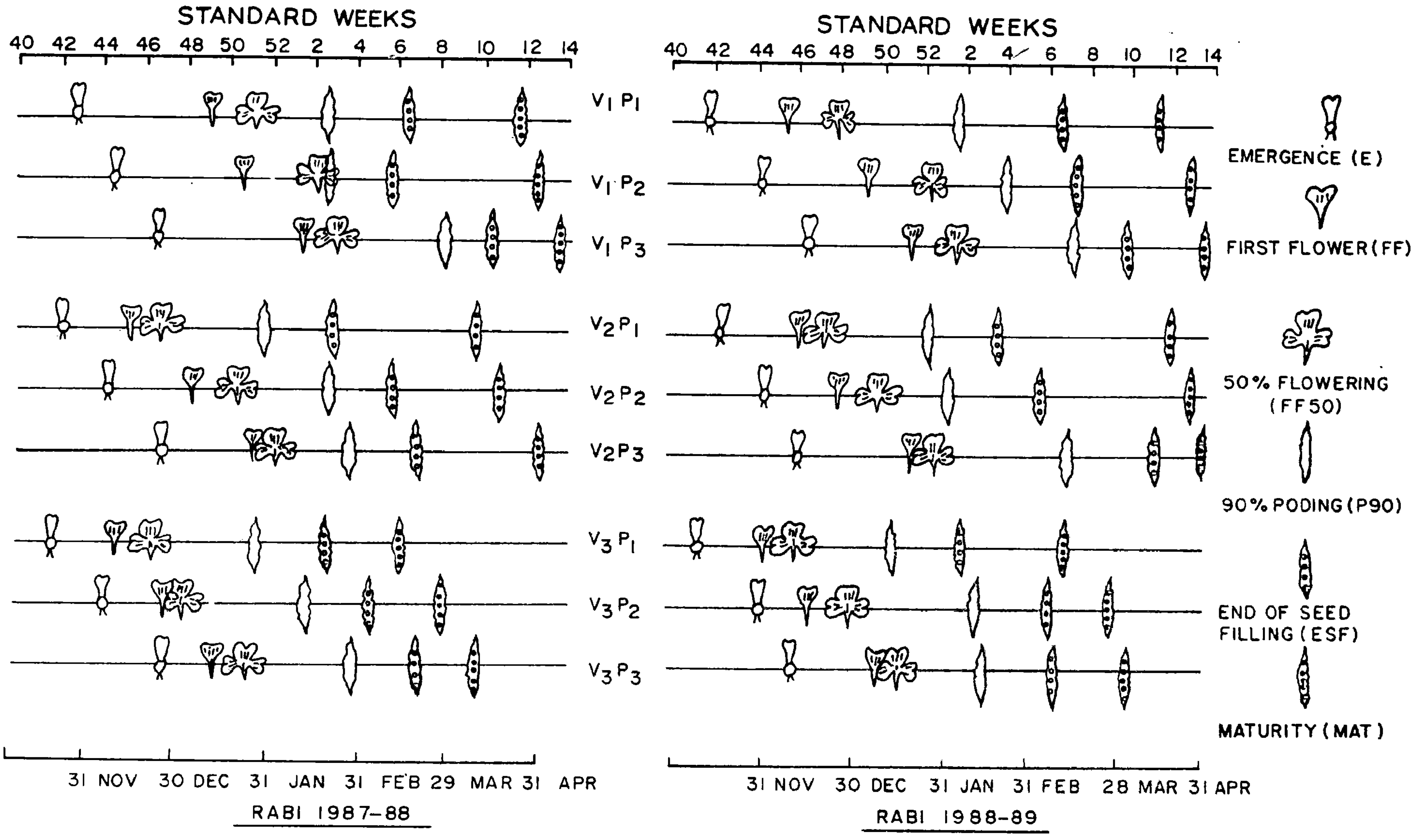


FIG. **3.** PHENOLOGY OF BRASSICA SPP.

Table 3a. Pentad biomass production(g $plant^{-1}$) in <u>Brassica</u> spp.

Rabi 1987-88

Pentad	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
1	2	3	4	5	6	7	8	9	10
					Rabi 1987-88				
14-19/11	2.7						2.0		
19-24/11	4.0						4.0		
24-29/11	5.5	1.2		2.5	2.3		7.5	2.2	
29-4/12	7.0	1.5		5.0	4.0		15.0	4.0	
4-9/12	8.8	5.0		8.0	6.2		22.0	7.0	
9-14/12	12.0	8.5		23.0	9.7		28.0	11.0	2.0
14-19/12	16.0	12.5		40.0	14.8		34.0	16.0	3.5
19-24/12	23.0	18.0	2.2	56.0	20.0	8.5	41.5	22.0	6.0
24-29/12	31.0	26.0	3.7	71.0	28.0	11.8	49.0	28.5	9.5
29-3/1	39.5	31.5	5.7	79.5	37.0	14.5	55.0	33.5	13.0
3-8/1	47.5	37.8	8.5	85.5	45.5	18.0	61.0	37.5	17.5
8-13/1	53.0	44.0	11.0	90.0	54.5	21.5	66.0	40.5	22.5
13-18/1	60.0	48.5	14.0	93.0	65.0	24.8	70.5	41.8	29.0

Table continued.....

Table 3a continued.......

1	2	3	4	5	6	7	8	9	10
18-23/1	67.0	53.3	17.0	95.0	75.0	29.0	72.5	41.0	35.0
23-28/1	74.0	58.0	20.0	95.5	82.5	33.0	70.5	38.5	42.2
28-2/2	78.0	62.2	24.0	95.2	90.0	36.7		33.0	48.5
2-7/2	82.0	64.5	26.5	94.5	95.0	40.0			52.0
7-12/2	83.0	65.0	28.0		96.0	42.0			54.0
12-17/2	81.5	64.0	28.8		94.5	48.0			53.0
17-22/2	77.5	62.0	28.5		92.5	52.0			
23-28/2			28.0			55.0			
28-4/3			26.8			58.0			
4-9/3						60.0			
9-14/3						61.0			
14-19/3						60.0			

P_1, P_2 and P_3 are sowing dates 1,2 and 3, respectively.

Table 3b. Pentad biomass production (g $plant^{-1}$) in *Brassica* spp.

Rabi 1988-89

Pentad	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
1	2	3	4	5	6	7	8	9	10
				Rabi 1988-89					
18-23/11				5.5					
23-28/11				7.8			5.7		
28-3/12				10.0			8.3		
3-8/12	11.3			13.5			11.0	3.5	
8-13/12	15.7			16.0			15.0	6.0	
13-18/12	22.0	6.5		21.0			19.5	9.0	
18-23/12	27.0	9.5		25.0	10.5		24.5	12.0	
23-28/12	34.0	13.0		30.0	14.5		30.0	16.0	
28-2/1	43.0	18.0		35.0	18.5		36.0	20.0	
2-7/1	52.0	25.0		41.0	23.5	2.5	42.5	24.5	4.5
7-12/1	61.5	32.5		48.0	28.5	3.7	49.5	29.0	6.0

Table continued..........

Table 3b continued.......

1	2	3	4	5	6	7	8	9	10
12-17/1	70.5	38.5		54.0	33.5	6.0	56.0	34.0	8.0
17-22/1	76.5	44.0		60.0	38.5	9.0	59.8	39.0	10.5
22-27/1	78.5	48.5	5.0	69.0	44.0	12.7	59.3	44.0	15.0
27-1/2	78.0	52.5	8.0	78.0	50.0	17.6	55.0	48.5	20.5
1-6/2	75.8	56.0	12.0	85.3	56.5	23.0	47.0	50.0	26.5
6-11/2	72.0	56.4	17.0	93.0	63.0	28.5		47.5	37.0
12-17/2	63.0	55.5	22.5	97.5	69.5	34.2		41.0	46.0
17-22/2		51.5	27.0	99.0	71.5	37.0			52.0
22-27/2		43.0	30.0	99.0	70.5	38.0			51.7
27-4/3			33.0	97.0	68.0	37.5			48.5
4-9/3			34.5	93.0	64.0	35.5			38.0
9-14/3			33.3		54.0	32.0			
14-19/3			30.5			27.0			
19-24/3			26.0						
24-29/3			18.5						

P_1, P_2 and P_3 are sowing dates 1,2 and 3, respectively.

Pusa Bold: Above-ground biomass in this variety yielded 95.5, 96.0 and 61.0 g/plant respectively in the three sowings. Peak biomass periods corresponded to end of pod filling stage for P_1 and P_2 and to early maturity time in P_3. Both P_1 and P_2 maintained nearly the same level of biomass production whereas in P_3 there was a 35% reduction.

Toria-T9: In this variety, unlike the other two varieties, peak biomass production was lower (41.8 g/plant) in P_2 than in P_1 (72.5 g/plant) or P_3(54.0 g/plant). Peak biomass occurrence corresponded to early maturity phase P_1 and P_3, whereas it coincided with pod filling stage in P_2.

An examination of daily maximum temperatures in the second fortnight of January 1988 revealed that maximum temperatures were 2 to 4°C above normal, and thus, lower biomass recorded by P_2 is attributable to occurrence of adverse temperature conditions during the pod filling period.

Rabi 1988-89

B.O.54: Maximum biomass production ranged from 78.5 g/plant in P_1 to 34.5 g/plant in P_3(Table 3b), reduction amounting to 30% in P_2 and 56% in P_3 with respect to P_1. Similar reduction was observed in 1987-88 also but in this season it was lower in case of P_3. This appears to be due to relatively cooler post flowering temperatures (thermal conditions) in 1988-89 experienced by the crop.

Pusa Bold: Biomass production was the highest in P_1(99.0 g/plant) and the lowest in P_3(38.0 g/plant). While in 1987-88, P_1 and P_2 recorded the same level of peak biomass i.e., 95 g/plant, during this season, P_2 recorded lower biomass by about 28% compared to P_1. Thus this variety is subjected to the effect of temperature regime on biomass production.

Toria-T9: This short duration variety unlike the other two varieties exhibited small differences in peak biomass production. In P_1, P_2 and P_3 it was 59.8, 50.0 and 52.0 g/plant, respectively. The pattern of biomass production was thus different than that exhibited in 1987-88, a relatively warmer season, when considerable differences were noticed in the magnitude of biomass production between P_1, P_2 and P_3.

For the same sowing date, the early maturing variety could be expected to produce relatively higher biomass upto pod formation stage. This trend got reversed after this stage in the long duration varieties which went through longer pod filling periods.

Thus, the results show that the nature of biomass production pattern is highly influenced by the thermal environment irrespective of variety or the date of sowing. While in many cases biomass decreased with delayed sowings, in a few cases due fluctuating thermal environment, such differences were not evident. This aspect is being examined further, in the study of crop growth rates and biomass-accumulated heat relations.

4.3.2 Leaf area index

Data on leaf area index(LAI) for different sowings of three Brassica spp. for the rabi season 1987-88 are shown in Table 4.

B.O.54: Leaf area index in this season ranged from 0.3 to 9.0 during the growing season, with a maximum of 9.0 at pod formation stage in P_1. Maximum leaf area indices for individual sowings were in the order $P_1 > P_2 > P_3$.

Pusa Bold: LAI values in all the sowings ranged from 0.7 to 7.9 from emergence to maturity. The maximum LAI 7.9 was attained during pod filling period in P_1. The peak LAI values for individual sowing were in the order $P_2 > P_1 > P_3$.

Toria-T9: LAI values ranged from 0.2 to 7.4 from emergence to maturity. The maximum LAI value, 7.4 was attained during pod formation period in P_1. The peak LAI values for individual sowings were in the order $P_1 > P_2 > P_3$ in accordance with date of sowing. Thus LAI is seen to be affected by date of sowing, in general delayed sowing resulting in lower LAI. The time of occurrence of peak LAI also slightly differed with both variety and date of sowing; however, it occurred either at pod formation or pod filling stage in different treatments.

Table 4. Leaf area index of *Brassica* spp. *rabi* 1987-88

Treatment	Days after sowing(DAS)						
	40	60	80	100	120	140	Peak value(DAS)
V_1P_1	1.8	3.2	8.1	8.7	5.5	1.8	9.0(90)
V_1P_2	0.5	3.5	7.0	7.2	4.0	-	7.5(93)
V_1P_3	0.3	1.7	2.8	2.6	-	-	3.0(88)
V_2P_1	3.0	5.0	6.4	6.9	4.5	-	6.9(100)
V_2P_2	0.7	3.5	7.3	7.5	4.7	-	7.9(93)
V_2P_3	0.7	4.5	6.4	1.3	-	-	6.4(80)
V_3P_1	0.2	4.5	7.2	5.5	-	-	7.4(84)
V_3P_2	0.6	4.9	5.0	-	-	-	6.1(70)
V_3P_3	0.8	3.7	3.1	0.6	-	-	3.7(64)

V_1, V_2 and V_3 are varieties B.O.54, Pusa Bold and Toria-T9, respectively.

P_1, P_2 and P_3 are sowings 1, 2 and 3, respectively.

4.4 CROP GROWTH RATES

Crop growth rates(CGRs) over 5-day periods were evaluated from biomass curves for the different sowings in both the seasons and presented in Tables 5a and 5b respectively.

4.4.1 Rabi 1987-88

B.O.54: Crop growth rates in different 5-day periods(pentads) ranged from 0.18 to 1.70 g/plant/day in P_1, 0.06 to 1.60 in P_2 and 0.14 to 0.80 g/plant/day in P_3 showing a decrease in growth rate in later sowings.

Pusa Bold: In this variety, maximum CGRs of 3.40, 2.10 and 1.20 g/plant/day was attained in P_1, P_2 and P_3 respectively. These are relatively higher than those in variety B.O.54.

Toria-T9: This variety attained CGR values of 1.50, 1.30 and 1.30 g/plant/day under the different sowings. Though this is a short duration variety, crop growth rates (CGRs) were comparable to those attained in case of B.O.54, a long duration variety.

4.4.2 Rabi 1988-89

B.O.54: The CGR values ranged from 0.4 to 2.0 in P_1, 0.4 to 1.5 in P_2 and 0.3 to 1.1 g/plant/day in P_3 respectively. These rates are comparable to those obtained in the warmer season, 1987-88 except in respect of P_3 which gave relatively higher growth rates in this season.

Table 5a. Pentad crop growth rates (g plant^{-1}day^{-1}) in *Brassica* spp.

Rabi 1987-88

Pentad	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
1	2	3	4	5	6	7	8	9	10
14-19/11	0.18						0.16		
19-24/11	0.27						0.40		
24-29/11	0.30	0.10		0.20	0.26		0.70	0.18	
29-4/12	0.30	0.06		0.50	0.34		1.50	0.36	
4-9/12	0.36	0.70		0.60	0.44		1.40	0.60	
9-14/12	0.65	0.70		3.00	0.70		1.20	0.80	0.20
14-19/12	0.80	0.80		3.40	1.02		1.20	1.00	0.30
19-24/12	1.40	1.10	0.14	3.20	1.04	0.80	1.50	1.20	0.50
24-29/12	1.60	1.60	0.30	1.00	1.60	0.66	1.50	1.30	0.70
29-3/1	1.70	1.10	0.40	1.70	1.80	0.54	1.20	1.00	0.70
3-8/1	1.50	1.26	0.56	1.20	1.70	0.90	1.20	0.80	0.90
8-13/1	1.20	1.44	0.50	0.90	1.80	0.70	1.00	0.60	1.00

Table continued......

Table 5a continued.....

1	2	3	4	5	6	7	8	9	10
13-18/1	1.40	0.95	0.60	0.60	2.10	0.66	0.90	0.27	1.30
18-23/1	1.40	0.93	0.60	0.40	2.00	0.84	0.20		1.20
23-28/1	1.40	0.94	0.60	0.10	1.50	0.80			1.44
28-2/2	0.90	0.84	0.80		1.50	0.74			1.26
2-7/2	0.70	0.46	0.60		1.00	0.66			0.90
7-12/2	0.20		0.30		0.20	0.40			0.40
12-17/2			0.16			1.20			
17-22/2						0.80			
23-28/2						0.60			
28-4/3						0.60			
4-9/3						0.40			
9-14/3						0.20			

P_1, P_2 and P_3 are sowing data 1,2 and 3, respectively.

Table 5b. Pentad crop growth rates(g plant^{-1}day^{-1}) in *Brassica* spp.

Rabi 1988-89

Pentad	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
1	2	3	4	5	6	7	8	9	10
18-23/11				0.40					
23-28/11				0.46			0.44		
28-3/12				0.44			0.46		
3-8/12	0.80			0.70			0.54	0.40	
8-13/12	0.88			0.50			0.80	0.50	
13-18/12	1.26	0.40		1.00			0.84	0.60	
18-23/12	1.00	0.60		1.00	0.50		1.06	0.80	
23-28/12	1.40	0.70		1.10	0.80		1.10	0.80	
28-2/1	1.80	1.00		1.00	0.80		1.20	0.80	
2-7/1	2.00	1.40		1.20	1.40	0.20	1.30	0.90	0.20
7-12/1	2.00	1.50		1.40	1.00	0.24	1.40	0.90	0.30

Table continued......

Table 5b continued......

1	2	3	4	5	6	7	8	9	10
12-17/1	1.80	1.40		1.40	1.00	0.46	1.30	1.00	0.40
17-22/1	1.20	1.10		1.20	1.00	0.60	0.76	1.00	0.50
22-27/1	0.40	0.90	0.40	2.00	1.10	0.74		1.00	0.90
27-1/2		0.80	0.60	1.80	1.20	0.82		0.90	1.10
1-6/2		0.70	0.80	1.66	1.30	1.10		0.30	1.00
6-11/2			1.00	1.54	1.30	1.10			2.10
12-17/2			1.10	1.10	1.30	1.14			1.80
17-22/2			0.90	0.30	0.40	0.60			1.20
22-27/2			0.60			0.20			
27-4/3			0.60						
4-9/3			0.30						

P_1, P_2 and P_3 are sowing dates 1, 2 and 3, respectively.

Pusa Bold: This variety showed similar growth rates as those of B.O.54 but the higher growth rates prevailed uniformly over a longer period than those observed in case of B.O.54.

Toria-T9: In this short duration variety the CGR values ranged from 0.44 to 1.4 g/plant/day in P_1, 0.3 to 1.0 in P_2 and 0.2 to 2.1 g/plant/day in P_3. In this season, they were relatively lower than those observed in 1987-88 in respect of sowings P_1 and P_2 and during earlier stages in P_3.

The occurrence of peak growth rates corresponded to either pod formation or pod filling stages in most of the 18 sowings in this investigation. However, in V_2P_2, V_3P_1 and V_3P_3 peak growth rates were noticed in the early maturity stage while in V_1P_2 peak growth rates were noticed even as early as late flowering period. Similar results were also reported by Frenquelli *et al.*(1985) in *Brassica napus*.

During 1987-88, in the mid season there was a decrease in CGR values in respect of V_1P_1, V_1P_2, V_2P_1, V_2P_2 and V_3P_3. In 1988-89, similar was the case with respect to V_2P_1 and V_2P_2. This differing pattern in CGR values appears to have been influenced by the passage of cold and warm spells associated with passage of western disturbances over Delhi region.

This is examined further in the form of case studies in which the crop growth rates of two varieties Pusa Bold(long duration) and Toria-T9(short duration) varieties were examined for any possible differences in their response to the prevailing thermal environment. It may be mentioned that, different sowings encountered the same weather conditions but due to differences in sowing dates, they recorded different growth rates.

For this purpose, three specific periods were identified after examination of weather associated with the passage of western disturbances as mentioned in India Daily Weather Reports of the India Meteorological Department.

Case(i) - Effect of higher minimum temperatures and nearly same maximum temperatures in 1988-89 season compared to 1987-88 season on crop growth (11th to 28th December).

This period is identifiable from the examination of data on daily temperatures, sunshine hours, saturation deficit, evaporation, vapour pressure, dew point and rainfall as shown in the Table 6.

Maximum temperatures were nearly the same in both the seasons from 11th to 26th December. Minimum temperatures were lower in 1988-89 during the first three days and later (18th to 25th December) were higher by 7 to 10°C. These conditions were associated with lower sunshine hours, saturation deficit and evaporation rates during the 1988-89 season.

Table 6. Weather data for the period 11th to 28th December

Date	Max.temp. (°C)		Min.temp. (°C)		Sunshine hours		Saturation deficit (mm)		Evaporation (mm)		Vapour pressure (mm Hg)		Dew point temp. (°C)		Rainfall (mm)	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
11	24.0	24.2	12.5	6.8	4.6	8.2	8.0	10.1	1.2	1.2	10.1	8.6	11.4	9.0	0.0	0.0
12	21.6	22.0	11.0	8.0	0.0	0.0	0.3	16.9	0.6	0.6	11.4	5.8	13.2	3.3	4.6	0.0
13	18.2	25.5	8.8	5.8	0.9	8.2	7.7	17.5	0.8	2.0	9.0	6.6	9.7	5.2	1.4	0.0
14	19.5	26.7	6.5	6.4	5.3	8.8	10.0	16.5	1.2	1.8	9.0	5.9	9.6	3.6	0.0	0.0
15	22.2	25.8	5.1	8.2	8.9	8.3	13.0	16.1	1.6	1.8	7.6	6.6	7.2	5.2	0.0	0.0
16	24.0	26.7	4.6	8.0	8.7	8.3	11.3	17.8	1.2	2.0	9.1	6.5	9.8	4.9	0.0	0.0
17	23.0	25.8	5.5	9.0	7.4	7.7	13.5	11.4	1.4	2.6	8.2	8.9	8.3	9.5	0.0	0.0
18	24.0	23.0	5.5	12.0	8.5	3.9	11.7	13.2	1.2	1.4	8.4	8.9	8.7	9.5	0.0	0.0
19	23.0	24.8	5.2	11.5	8.1	5.3	14.0	8.1	1.4	1.6	7.3	10.6	6.5	12.1	0.0	0.0
20	23.5	22.4	4.8	14.5	8.1	0.0	13.8	10.4	1.6	1.2	2.8	11.2	5.5	13.0	0.0	Tr.

Table continued....

Table 6 continued....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
21	23.0	24.2	5.5	11.0	6.1	5.4	12.9	6.7	1.8	1.4	9.2	12.5	10.0	14.6	0.0	0.0
22	24.5	22.5	6.0	11.0	7.5	5.2	11.8	8.7	1.4	1.4	8.8	10.2	9.3	11.5	0.0	0.0
23	23.0	22.8	6.5	15.0	7.4	2.9	10.6	6.6	1.4	1.4	9.0	12.3	9.6	14.4	0.0	Tr.
24	22.2	23.0	4.8	9.0	7.8	3.7	11.3	13.6	1.8	2.0	7.6	7.2	7.2	6.4	0.0	0.0
25	22.0	24.2	4.6	12.0	8.1	5.2	10.8	1.2	1.0	1.4	8.5	11.8	8.8	13.8	0.0	0.0
26	22.2	21.8	5.6	6.8	6.8	1.0	10.5	5.8	1.0	0.8	8.8	10.0	9.3	11.2	0.0	1.0
27	22.2	17.5	5.0	6.8	5.7	4.4	10.2	5.8	1.0	1.0	8.7	9.1	9.2	9.9	0.0	0.0
28	22.2	18.5	5.2	5.5	6.4	6.5	11.3	10.8	0.8	1.4	8.5	7.1	8.9	6.1	0.0	0.0

I = 1987-88; II = 1988-89.

In V_1P_1, during 1987-88, CGR during this period gradually increased from 0.65 to 1.6 g/plant/day while in 1988-89 CGRs were relatively higher till 18th December (0.88 and 1.26 g/plant/day) then decreased to 1.0 g/plant/day. V_2P_1 and V_2P_2 both recorded higher growth rates during this period in 1987-88 while in rabi 1988-89, they were lower. The same was true in case of V_3P_1 and V_3P_2. Thus the weather situation during this period in 1988-89 resulted in lowering the growth rates and had a depressing effect on CGR values in all the three varieties. In Pusa Bold, CGR decreased by 50% whereas in Toria-T9 the decrease was about 30%. Warmer minimum temperatures appear to have contributed in lowering the CGR in 1988-89 during the late flowering stages in the different crops.

Case(ii) - Effect of lower maximum temperatures and lower minimum temperatures that prevailed in 1988-89 compared to 1987-88 season(Ist to 23rd January), on CGR at pod development stage.

The prevailing weather conditions are identified from Table 7, which shows daily values of temperature, sunshine hours, saturation deficit, evaporation, vapour pressure, dew point and rainfall. During the first week of January 1988-89, the season was characterized by maximum temperatures which were around 22.0 to 23.0°C. They dropped to about 16.0°C during the second week and reached about 19.0°C in the third week. In 1987-88 during the corresponding period, maximum

Table 7. Weather data for the period Ist to 23rd January

Date	Max.temp. (°C)		Min.temp. (°C)		Sunshine hours		Saturation deficit (mm)		Evaporation (mm)		Vapour pressure (mm Hg)		Dew point temp(°C)		Rainfall (mm)	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	21.5	23.0	5.0	8.0	4.2	8.3	10.1	9.7	1.0	1.4	9.0	7.8	9.6	7.6	0.0	0.0
2	23.0	22.5	6.2	8.8	7.0	7.0	8.2	6.0	1.2	1.4	8.7	9.7	9.2	10.8	0.0	Tr.
3	19.6	18.8	7.0	8.5	0.2	1.7	12.1	9.5	1.6	0.8	7.7	8.2	7.4	8.3	0.0	0.0
4	22.5	21.4	8.2	9.0	5.3	8.1	10.1	3.1	1.8	1.2	10.1	10.5	11.4	11.9	0.0	0.0
5	24.0	18.2	10.0	10.0	7.2	1.1	4.4	6.2	1.4	1.0	11.9	10.5	13.9	12.0	0.0	0.0
6	23.0	21.4	8.0	12.5	7.3	4.1	11.4	5.3	0.8	1.6	9.7	11.2	10.8	13.0	0.0	0.0
7	24.0	20.8	8.2	13.0	1.6	2.0	8.0	0.0	1.8	0.8	10.1	12.0	11.4	14.0	0.0	32.0
8	21.5	16.0	6.4	10.8	7.1	0.0	9.2	3.2	1.8	1.0	9.8	11.3	11.0	13.1	0.0	28.0
9	22.0	16.6	7.0	5.5	7.5	8.4	12.8	3.4	1.6	2.0	8.3	8.4	8.5	8.7	0.0	0.0
10	23.5	15.0	6.0	6.0	7.6	5.1	13.1	8.0	1.4	1.8	7.0	5.6	6.0	2.8	0.0	0.0
11	22.5	16.5	7.4	5.0	7.4	9.4	10.4	9.1	1.6	2.6	10.2	5.4	11.6	2.2	0.0	0.0

Table continued.....

Table 7 continued......

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12	24.0	16.5	11.8	3.5	5.5	9.4	9.9	9.5	1.0	2.8	11.2	5.0	12.9	1.2	Tr.	0.0
13	23.6	17.5	8.0	2.0	6.4	9.8	6.9	8.9	1.8	2.8	11.2	6.8	12.9	5.5	0.0	0.0
14	21.2	18.5	7.4	3.0	4.2	9.1	7.8	4.7	1.4	2.4	9.4	10.0	10.3	11.3	0.0	0.0
15.	21.0	18.0	5.8	4.3	3.3	8.6	8.7	3.6	1.0	2.0	9.4	11.5	10.3	13.4	0.0	0.0
16.	21.5	18.0	7.0	2.5	7.4	9.5	9.2	10.9	1.4	1.6	8.9	5.3	9.4	2.0	0.0	0.0
17.	20.8	19.8	6.0	4.5	9.0	8.7	10.4	9.4	2.8	2.6	8.9	6.1	9.4	4.1	0.0	0.0
18.	22.0	18.8	5.0	3.0	9.4	9.1	11.3	10.6	2.6	2.8	7.6	4.9	7.2	0.9	0.0	0.0
19.	23.0	18.8	5.1	4.0	9.5	9.0	12.1	9.2	2.8	2.4	8.3	6.7	8.4	5.3	0.0	0.0
20.	23.0	19.8	4.8	6.5	9.0	8.4	18.8	9.2	2.6	1.6	5.3	6.7	1.8	5.3	0.0	0.0
21.	26.0	19.2	6.8	6.0	8.0	9.4	11.9	10.2	2.6	2.4	8.7	6.5	9.2	4.8	0.0	0.0
22	24.0	20.0	8.6	2.5	7.8	9.8	16.0	8.8	2.8	3.2	7.1	7.3	6.1	6.6	0.0	0.0
23	25.0	19.5	6.1	3.0	6.8	9.6	11.5	12.5	3.0	2.6	6.0	5.6	3.7	2.8	0.0	0.0

I = 1987-88; II = 1988-89.

temperatures remained nearly constant at 22.0 to 23.0°C and minimum temperatures remained 3 to 5°C higher during the second week.

During the first week of January, the 1988-89 season was characterized by lower sunshine hours and saturation deficit. On 7th and 8th January, 32.0 and 28.0 mm of rainfall were received in 1988-89 season. Temperature range was low by 7°C from 5th to 11th January in association with this weather, which coincided with the pod development stage of the crops.

CGR values during 1988-89 season remained higher for longer period in 6 out of 9 treatments except in V_2P_2, V_2P_3 and V_3P_3 which recorded lower CGRs than those of 1987-88. The reduction in CGR in V_3P_3 is attributable to earliness of its maturity. While variety B.O.54 responded favourably with higher CGR, P_2 and P_3 treatments in Pusa Bold showed a depressing trend during 1988-89. This is attributable to delayed occurrence of phenological events due to cooler weather conditions in 1988-89 in this variety.

The CGRs in V_2P_2, V_2P_3 decreased by 50 and 30% respectively in 1988-89.

Case (iii) - Effect of cooler maximum and minimum temperatures in 1988-89 season on crop growth rates during pod filling stage in different treatments (Ist to 23rd February).

During the 1988-89 season, temperatures were lower by 4 to 6°C during the second week of February than those recorded in 1987-88. The different weather parameters are presented in Table 8. The crops were at pod filling and early maturity stages at this time. Higher CGR values were recorded during 1988-89 season which were generally 30% higher than those observed during the 1987-88 season.

It may be mentioned that both the maximum and minimum temperatures were 4-6°C below normal during this period in 1988-89. Thus, this magnitude of lowering of temperatures had affected the CGR by 30% irrespective of the sowing date or variety. This period during 1987-88 was characterized by a series of upper air circulations one of which resulted in occurrence of 9.2 mm of rainfall on two days whereas mild cold wave conditions were noticed during the 1988-89 season.

4.4.3 Crop growth patterns

Allen *et al.*(1971) reported that there are 4 different phases of dry matter distribution pattern during the crop growth cycle. In the first phase there is an increase in CGR for about 6 to 7 weeks which then markedly decreases in the next phase. In the third phase, it increases to the maximum and finally it shows a decrease in the last phase. The third phase is characterized by marked increase in size and weight of pods in *Brassica napus*. In the present investigation similar

Table 8. Weather data for the period Ist to 23rd February

Date	Max.temp. (°C)		Min.temp. (°C)		Sunshine hours		Saturation deficit (mm)		Evaporation (mm)		Vapour pressure (mm Hg)		Dew point temperature (°C)		Rainfall (mm)	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	24.0	24.5	7.5	9.0	9.7	2.2	13.3	13.2	4.2	3.2	6.5	8.5	4.9	8.8	0.0	0.0
2	23.0	24.5	6.8	8.5	6.5	7.3	13.7	11.5	4.0	3.8	7.6	7.2	7.1	6.4	0.0	0.0
3	24.0	22.2	8.2	8.4	10.0	8.3	14.2	12.4	4.4	3.8	8.2	7.7	8.3	7.4	0.0	0.0
4	25.2	23.2	5.0	8.5	9.6	9.8	16.5	13.7	3.8	3.6	7.3	9.0	6.6	9.6	0.0	0.0
5	25.5	25.0	5.5	13.0	9.7	8.9	15.6	11.6	4.2	3.6	9.0	10.0	9.7	11.3	0.0	Tr.
6	26.8	24.0	8.0	7.5	9.6	4.8	21.5	10.1	3.6	3.8	7.8	7.6	7.5	7.1	0.0	0.0
7	29.0	21.5	8.2	5.5	8.0	9.5	21.7	10.8	3.6	3.8	8.7	7.1	8.0	6.1	0.0	0.0
8	29.8	21.5	9.0	5.2	3.3	9.7	18.7	10.2	3.0	3.8	9.7	6.3	10.8	4.5	0.0	0.0
9	25.9	19.8	11.6	2.5	8.9	9.9	13.0	10.9	3.2	3.4	10.2	5.4	11.6	2.3	0.0	0.0
10	25.0	19.2	8.5	3.0	8.5	9.9	15.1	10.1	3.4	3.4	7.7	6.0	7.4	3.8	0.0	0.0
11	24.8	19.9	8.2	5.5	9.3	9.7	15.5	8.6	3.6	4.0	10.6	8.1	12.1	8.0	0.0	0.0

Table continued........

Table 8 continued......

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12	27.2	20.0	13.5	5.0	7.8	10.1	9.8	10.9	4.0	4.0	9.5	7.8	10.5	7.5	0.0	0.0
13	22.2	22.0	9.2	8.5	6.7	8.0	12.4	10.5	4.0	4.2	11.9	7.0	13.9	6.0	0.0	0.0
14	26.2	20.8	10.4	9.0	5.6	4.4	2.9	11.2	1.0	2.6	11.6	9.1	13.5	9.9	4.0	0.0
15	20.0	24.0	8.2	7.2	4.0	9.7	8.9	10.9	1.2	3.8	10.3	7.8	11.7	7.5	5.2	0.0
16	22.4	21.8	12.4	8.0	6.3	7.0	8.7	11.0	2.2	3.4	10.0	9.1	11.3	9.9	0.0	0.0
17	22.5	23.6	9.0	9.0	8.7	9.5	12.0	14.4	2.4	3.6	9.5	6.2	10.5	4.3	0.0	0.0
18	24.0	23.8	10.0	8.8	9.7	9.5	13.5	10.5	3.0	3.4	8.5	7.0	8.7	6.0	0.0	0.0
19	24.5	21.2	12.4	7.0	7.0	9.2	15.4	9.7	3.6	3.8	8.7	7.0	9.1	5.9	0.0	0.0
20	25.5	19.8	12.4	5.5	5.6	10.0	15.3	13.2	3.8	4.4	10.2	5.9	11.5	3.5	0.0	0.0
21	26.5	22.6	14.5	7.5	2.9	9.2	12.5	13.4	3.8	4.0	10.7	6.9	12.3	5.8	0.0	0.0
22	25.0	23.5	14.2	6.0	7.7	10.4	10.0	12.4	4.2	4.0	13.5	6.9	16.2	5.7	0.0	0.0
23	26.0	22.6	11.8	5.4	8.0	10.3	12.9	13.7	4.4	4.0	8.0	7.4	9.3	6.7	0.0	0.0

I = 1987-88; II = 1988-89.

pattern of dry matter accumulation in terms of CGR was observed in V_1P_1, V_1P_2 and V_3P_1, V_3P_3 during 1987-88 season with normal temperatures for the Delhi region and in respect of V_1P_1, V_2P_2 and V_3P_2 during the relatively cooler season of 1988-89.

The other sowings mainly showed a single peak during the entire growth season which is one of the characteristic features of third sowing with the exception of V_3P_3 during 1988-89.

Typical growth patterns for the long duration variety Pusa Bold and short duration variety Toria-T9 for this period in 1988-89 are shown in the Figs.4a and 4b, respectively. It is noticed that Pusa Bold sowing P_1 exhibited a longer growth period with a typical growth pattern reported by Allen <u>et al.</u> (1971). P_2 also followed a similar trend but with lesser magnitude. The relative differences in growth rates due to interval in planting dates under the same weather conditions are clearly evident from the Fig.4a which could be expected to result in decrease in yield as planting date is delayed.

In case of Toria-T9(Fig.4b), similar differences were maintained but increase in CGR in P_3 occurred at a very late stage in the growth cycle and prevailed for only a short duration of one to two weeks. P_2, however, maintained higher growth rates for a longer duration. Of the three growth patterns that of P_2 seems to be more conducive to relatively better yields because of prolonged period of pod growth and seed filling stages.

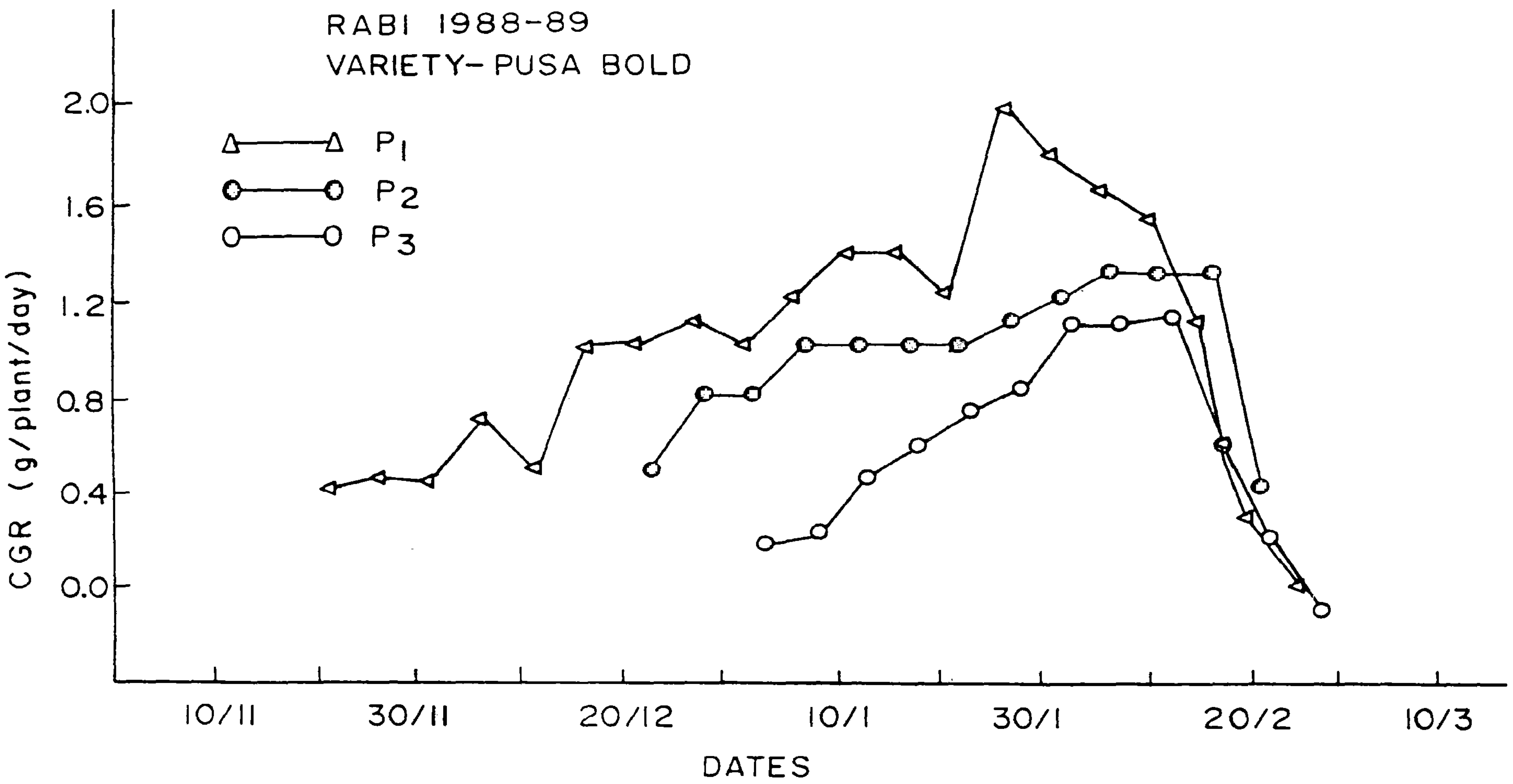


FIG.4(a). EFFECT OF SOWING DATES ON CROP GROWTH RATES IN PUSA BOLD

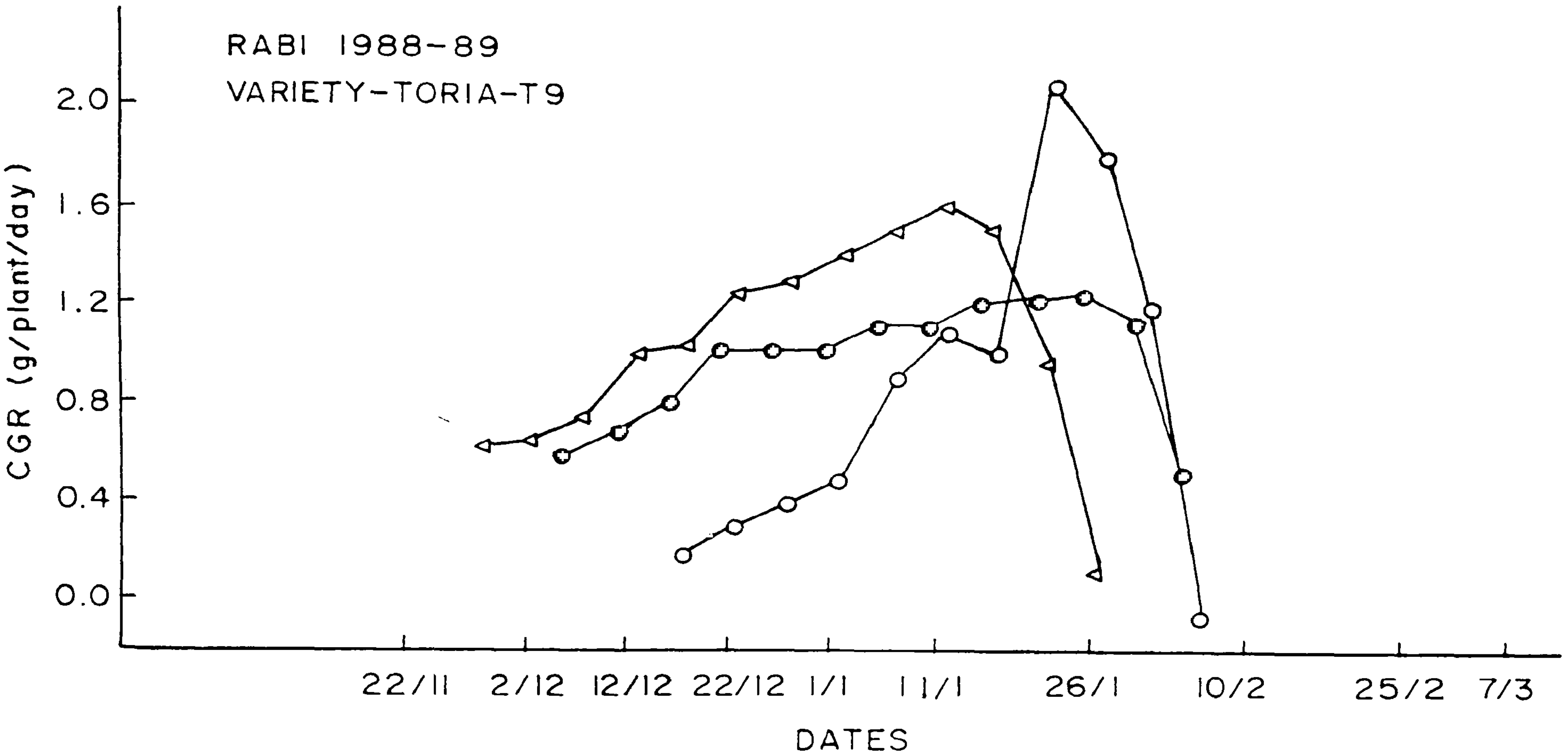


FIG.4(b). EFFECT OF SOWING DATES ON CROP GROWTH RATES IN TORIA-T9

4.4.4 Seasonal influence on crop growth patterns

For studying the influence of seasonal differences in temperature on CGR values, the variety Toria-T9 is taken for illustration (Fig.5). The CGR pattern for 1987-88 shows two peaks whereas that for 1988-89 a single peak. The maximum temperatures during mid November to mid December were warmer in 1987-88 by 3 to 5°C but represented near normal temperature conditions for the period in the Delhi region. While in 1987-88 peak growth rates corresponded to pod formation stage and the growth pattern was in accordance with that proposed by Allen et al.(1971), the CGR got reduced by nearly 50% during 1988-89 season. Also, time of occurrence of peak growth rate got shifted during the latter season by about 3 weeks and occurred at the pod filling stage.

Thus, the effect of cooler temperatures was not only to prolong the growth period and decrease the CGR, but also resulted in shifting the time of occurrence of peak growth period.

4.5 SEED YIELD

The seed yield(mean of 3 replicates) of the varieties for all the sowing dates in rabi 1987-88 and 1988-89 seasons are presented in Table 9.

4.5.1 Rabi 1987-88

The seed yield in this season ranged from 5.85 in V_1P_1 to 13.64 g/plant in V_2P_1. Of all the varieties Pusa Bold gave the highest yields. There was reduction in yield in the first sowing of B.O.54 because the crop was lodged due to

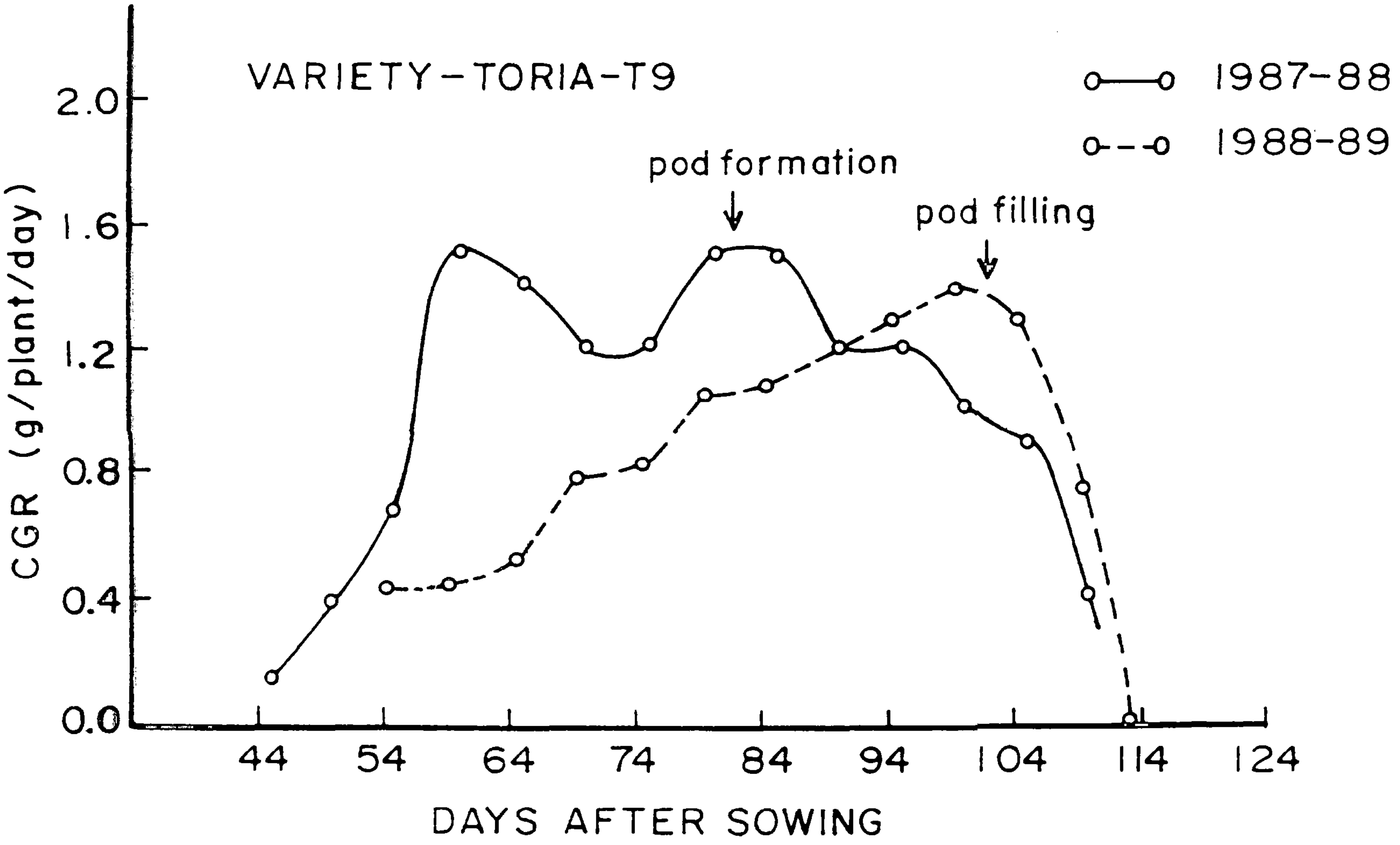


FIG. 5. SEASONAL EFFECTS ON CROP GROWTH RATES IN TORIA-T9

rainfall that occurred from 11 to 14th March for 3 days, and there was pod shattering due to accompanying hailstorm. This affected the yield to a large extent.

During 1987-88, the maximum LAI was found to be positively related with seed yield in P_2 and P_3 of Brassica napus var. B.O.54. These results are in confirmation with those of Clarke and Simpson, 1978b; Mendham and Scott, 1975; Norton and Harris, 1975 for Brassica napus.

The yield decreases in Pusa Bold and Toria in P_3 were 41 and 58% respectively with reference to P_1 showing the extent to which higher temperatures at pod filling stage due to delayed sowing would affect the seed yield.

4.5.2 Rabi 1988-89

During this season, Toria-T9 gave higher yield than the other two varieties among the P_1 sowings. The seed yield ranged from 5.34 to 15.80 q/plant. In this season, in general, in respect of the three varieties, yield decrease with delayed sowings ranged from 47 to 66% in P_3 over P_1.

The analysis of variance (Table 9) showed that during 1987-88, rabi season, both varieties and sowing dates gave significant differences in yield per plant whereas during 1988-89 which was relatively a cooler season, only the different sowing dates gave significantly different yields, while varieties did not reveal significant difference in seed yield per plant.

Table 9. Seed yield (g $plant^{-1}$) of _Brassica_ spp. as influenced by varieties and sowing dates in _rabi_ 1987-88 and 1988-89 seasons

Variety	Rabi 1987-88			Rabi 1988-89		
	P_1	P_2	P_3	P_1	P_2	P_3
B.O.54	5.85	6.62	4.33	12.13	8.29	6.45
Pusa Bold	13.64	14.14	8.08	13.63	7.79	6.29
Toria-T9	13.62	9.10	5.69	15.80	7.22	5.34

Statistical analysis

	Rabi 1987-88	Rabi 1988-89
F value		
(i) Variety	6.74*	0.09
(ii) Sowing date	4.56*	24.61*
SE m ±	2.136	1.434
CD(5% level)	6.40	4.304
C.V.(%)	41.1	27.0

P_1, P_2 and P_3 are sowing dates 1,2 and 3, respectively.

*Significant at 5% level.

It may be recalled that peak growth rates in V_2P_1 and V_2P_2 were higher in 1987-88 compared to 1988-89. While the yield reduction in P_1 is not evident, it decreased by 45% in P_2. However, in Toria-T9, the yield differences in

P_1 and P_2 between the two seasons were within 15% and in P_3 it was only 6%. This indicates that Toria-T9 is not much influenced by seasonal differences in temperatures.

In general, the lower seed yield in third sowing is attributable to limited period available for pod filling in the late sowings due to increasing seasonal temperatures with a consequent decrease in total dry weight. Similar reduction in seed yield in the late sowings was attributed to reduction in total dry weight in the plant by Gross(1963); Singh *et al.*(1972); Thurling(1974b) and Singh and Singh(1985). The variation observed in yield in different sowing dates in Pusa Bold are supported by the observations made by Thurling(1974a) who obtained higher yields in second sowing than in the first or the third.

4.6 HARVEST INDEX

The harvest index(HI) of 3 varieties as influenced by different sowing dates in the two *rabi* seasons under investigation are presented in Table 10.

During *rabi* 1987-88, HI ranged from 0.18 to 0.38. In variety B.O.54, second sowing gave higher HI(0.21) followed by first and third sowings. In variety Pusa Bold, HI was 0.32 in first sowing followed by second and third sowings. In Toria-T9, highest HI(0.38) was observed in first sowing followed by second and third sowings.

Table 10. Harvest Index in <u>Brassica</u> spp. as influenced by sowing dates

Variety	Harvest year	P_1	P_2	P_3
B.O.54	1988	0.19	0.21	0.18
	1989	0.26	0.28	0.24
Pusa Bold	1988	0.32	0.29	0.24
	1989	0.33	0.32	0.30
Toria-T9	1988	0.38	0.33	0.30
	1989	0.33	0.39	0.36

P_1, P_2 and P_3 are sowing dates 1, 2 and 3 respectively.

Like in <u>rabi</u> 1987-88, during <u>rabi</u> 1988-89 variety B.O.54 gave high HI(0.28) for second sowing followed by first and third sowings. In variety Pusa Bold, high HI(0.33) was obtained in first sowing followed by second and third sowings. In variety Toria-T9, highest HI(0.39) was obtained for P_2 sowings followed by 0.36 for P_3 and 0.33 for P_1.

Among the varieties studied, Toria-T9 recorded higher HI ranging from 0.30 to 0.39, followed by Pusa Bold (0.24 to 0.33) and B.O.54, (0.18 to 0.28). The values of HI were higher in case of variety Toria-T9 in both the seasons and proved superior to the other two varieties. The values of HI obtained in the present investigation are in the same range as those reported by Mehrotra *et al.*(1976) and Khader(1983).

In general, in all the sowings except in V_3P_1, HI was higher in the relatively cooler season 1988-89. Variety B.O.54 gave higher HI in the second sowing in both the seasons. This date of sowing around 20th October appears to be the most suitable in the Delhi region for this variety whether the season is cooler or warmer. The lower HI in the first season is obviously attributable to warmer maximum and minimum temperatures recorded on most of the days in the season, 1987-88.

In variety B.O.54 and Pusa Bold, compared to 1987-88, HI improved in the range 3 to 33% in the cooler season. The increase was relatively higher (27 to 33%) in B.O.54. In variety Toria-T9, while P_1 showed a decrease in HI during the cooler season, it increased by 18 to 20% in P_2 and P_3 during *rabi* 1988-89 season. Response in B.O.54 was in accordance with the increase in seed yield in P_2 and P_3 sowings.

4.7 OIL CONTENT

The per cent oil content values measured at frequent intervals by the method suggested by Kartha *et al.*(1954) are shown in Table 11. Relatively higher values of oil content were attained by the early maturity stage which continued to show slight fluctuations during the maturity period till harvest.

Table 11. Oil content(%) in *Brassica* spp. in post pod formation stage during *rabi* 1988-89

Treatment	Sample	Jan.24	Feb.2	Feb.15	Feb.28	Mar.11	Mar.19	Mar.31
V_1P_1	1	30.95	29.5	36.9	38.2	34.2	38.4	-
	2	-	27.4	42.4	38.1	36.6	42.5	-
V_1P_2	1	-	8.7	16.1	40.6	30.3	34.7	-
	2	-	8.4	17.6	40.2	36.0	37.9	-
V_1P_3	1			11.3	19.2	39.5	36.7	31.7
	2			14.7	23.5	38.1	38.6	33.0
V_2P_1	1	35.75	35.4	33.7	31.9	37.9	-	-
	2	34.86	35.9	32.6	30.9	36.7	-	-
V_2P_2	1	-	24.2	34.7	33.3	36.7	36.5	-
	2	-	25.9	36.8	32.4	35.5	32.3	-
V_2P_3	1	-	4.9	18.1	30.9	39.9	32.5	30.3
	2	-	4.2	18.3	31.0	39.2	29.3	32.5
V_3P_1	1	36.61	31.5	33.0	-	-	-	-
	2	38.62	33.7	37.3	---------Crop harvested----------			
V_3P_2	1	40.36	41.8	42.8	38.9	-	-	-
	2	42.15	42.3	41.4	38.3	-	-	-
V_3P_3	1	-	22.5	39.2	42.7	35.6	-	-
	2	-	21.6	31.1	42.1	40.1	-	-

V_1, V_2 and V_3 are varieties, B.O.54, Pusa Bold and Toria-T9, respectively. P_1, P_2 and P_3 are sowing dates 1,2 and 3, respectively. Underlined values indicate accumulation of maximum oil content.

At the time of early maturity the pods had yellowish tinge, when oil accumulation was the highest. The highest values of per cent oil content in the different treatments ranged from 39.5 to 42.4 in variety B.O.54, 34.7 to 39.9 in Pusa Bold and 36.61 to 42.7% in Toria-T9. It may be mentioned that Gambhir et al.(1983), using NMR technique reported the highest per cent of oil content at yellow pod stage in Pusa Bold, in the Delhi region.

4.8 ACCUMULATED HEAT UNITS AND CROP GROWTH

Three different accumulated heat unit systems viz., growing degree days(GDD), photo-thermal units(PTU) and helio-thermal units(HTU) were evaluated following the method described in the section 3.5 and the results are as follows:

4.8.1 Growing degree days

The growing degree days(GDD) to attain different phenological stages for three varieties and three sowings during *rabi* 1987-88 and 1988-89 seasons are given in the Table 12. The salient features are given below:

Rabi 1987-88

B.O.54: Till maturity stage, this variety had accumulated 2056 GDD for first sowing followed by second sowing with 1939 heat units. The third sowing recorded 1762 accumulated heat units in the growing season. From emergence to pod filling this variety accumulated 1504 units

Table 12. Accumulated growing degree days (GDD) for different phenological stages in *Brassica* spp.

Phenological stage	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
Rabi 1987-88									
Vegetative	743	605	455	420	399	362	407	322	234
Flowering	893	852	643	566	480	427	581	418	332
Pod formation	1131	985	989	941	858	696	999	828	696
Pod filling	1504	1203	1221	1183	1095	937	1240	1056	937
Maturity	2056	1939	1762	1773	1598	1597	1510	1353	1221
Rabi 1988-89									
Vegetative	505	453	528	505	428	502	460	301	385
Flowering	743	697	693	627	561	576	632	406	462
Pod formation	1188	970	1053	1048	834	988	1052	888	743
Pod filling	1498	1217	1314	1247	1112	1397	1309	1089	918
Maturity	1973	1836	1750	1973	1824	1702	1614	1418	1281

P_1, P_2 and P_3 are sowings 1, 2 and 3, respectively.

in P_1 followed by 1221 units in P_3 with a difference of 283 GDD.

Pusa Bold: In this variety, first sowing reached maturity with accumulation of 1773 heat units. The second and third sowings accumulated same amount of heat units(1598 for P_2 and 1597 for P_3). The difference between the P_1 and P_2 or P_3 is 176 GDD. From emergence to pod filling P_1 accumulated 1183 heat units and P_3,937 units with a difference of 246 GDD.

Toria-T9: From emergence to maturity this variety had accumulated 1510 GDD for first sowing followed by second and third sowings with 1353 and 1221 GDD,respectively. Upto pod filling stage, P_1 accumulated 1240 heat units and P_3 937 units with a difference of 303 GDD.

Rabi 1988-89

B.O.54: The heat units accumulated upto maturity for different sowings were 1973, 1836 and 1750 GDD for P_1, P_2 and P_3,respectively. Upto pod filling stage P_3 accumulated 184 GDD lesser than P_1(P_1 = 1498, P_3 = 1314 GDD).

Pusa Bold: The heat units upto maturity in this variety for three sowings ranged from 1973 in the first,to 1824 in the second and 1702 GDD in the third sowing. Till pod filling stage this variety accumulated 1247, 1112 and 1397 units,respectively in P_1, P_2 and P_3. In P_2,GDD were 150 units more than those in P_1 for completion of pod filling stage, which was not exhibited by the other treatments.

Toria-T9: The accumulated heat units from emergence to maturity in this case were 1614 in the first and 1418 in the second sowing, and 1218 GDD in the third sowing.

4.8.2 Photo-thermal units

The photo-thermal units (PTU) accumulated for completion of different phenological stages in different sowings and varieties are shown in Table 13. The following salient features were observed during the two growing seasons, rabi 1987-88 and 1988-89.

Rabi 1987-88

B.O.54: From emergence to maturity, this variety had accumulated 22474 PTU for first sowing followed by 21314 for second sowing and 19698 units for the third sowing. Till pod filling stage this variety accumulated 16040 units in P_1 and 13093 units in P_3 with a difference of 2947 PTU.

Pusa Bold: In this variety, first sowing reached maturity by accumulating 19110 PTU. The second and third sowings reached maturity by taking 17280 and 17632 PTU, respectively. Till pod filling stage P_3 accumulated 2697 units less than those in P_1.

Toria-T9: From emergence to maturity this variety had accumulated 16117 PTU for first sowing followed by 14360 for second sowing and 13093 for third sowing. Till pod filling stage P_3 had accumulated 3375 PTU lower than those for P_1.

Table 13. Accumulated photo-thermal units(PTU) for different phenological stages in *Brassica* spp.

Phenological stage	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
Rabi 1987-88									
Vegetative	8047	6408	4683	4618	4222	3730	4531	3450	2426
Flowering	9583	8936	6640	6165	5058	4399	6400	4446	3422
Pod formation	12030	10322	10422	10026	8946	7202	10719	8660	7202
Pod filling	16040	12678	13093	12531	11493	9834	13209	11056	9834
Maturity	22474	21314	19698	19110	17280	17632	16117	14360	13093
Rabi 1988-89									
Vegetative	5564	4802	5477	5564	4573	5213	5167	3246	4022
Flowering	8066	7302	7172	6855	5945	5968	7023	4349	4811
Pod formation	12631	10128	11061	11189	8742	10332	11391	9299	7693
Pod filling	15965	12840	14087	13251	11668	15063	14025	11427	9569
Maturity	21509	20214	19407	21509	19991	18795	17301	15121	13695

P_1, P_2 and P_3 are sowing dates 1,2 and 3, respectively.

Rabi 1988-89

B.O.54: For different sowings. PTU accumulated till maturity, were 21509, 20214 and 19407, respectively for P_1, P_2 and P_3 sowings. Uptill the pod filling stage P_3 accumulated 1878 units lower than those of for P_1 and 1247 units more than those for P_2.

Pusa Bold: Photo-thermal units accumulated in this variety in the three sowings were 21509, 19991 and 18795 units, respectively. Upto pod filling stage P_3 accumulated 1812 units more than those in P_1 and 3395 units more than those for P_2.

Toria-T9: The accumulated PTU till maturity were 17301, 15121 and 13695, respectively in respect of P_1, P_2 and P_3 sowings. Till pod filling stage P_1 accumulated 14025 units whereas in P_3 they were 9569 units, i.e., 4456 units less than those in P_1.

4.8.3 Helio-thermal units

The helio-thermal units (HTU) for attaining different phenological stages for three varieties and sowings in both 1987-88 and 1988-89 rabi seasons are shown in Table 14. The salient features are as follows:

Rabi 1987-88

B.O.54: The first sowing reached maturity after accumulating a sum of 16380 HTU whereas second and third sowings reached maturity after accumulating 15254 and 13824 HTU, respectively. From emergence to pod filling, first sowing

Table 14. Accumulated helio-thermal units (HTU) for different phenological stages in *Brassica* spp.

Phenological stage	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
				Rabi 1987-88					
Vegetative	6679	5115	3299	3870	3565	2816	3679	2875	1992
Flowering	7671	6684	4569	5175	4177	3190	5222	3747	2588
Pod formation	9144	7639	7370	8050	6483	5013	8533	6436	5013
Pod filling	12150	9533	9250	9521	8543	6971	9931	8195	6971
Maturity	16380	15254	13824	14297	12265	12184	12291	10505	9250
				Rabi 1988-89					
Vegetative	4486	3726	3760	4486	3470	3676	4242	2491	3001
Flowering	6349	5172	4617	5379	4610	4002	5723	3276	3541
Pod formation	9022	7081	7738	8221	6149	7199	9001	6322	5075
Pod filling	11698	9161	10248	9556	8256	10881	10200	8055	6594
Maturity	15870	14353	13714	15870	14323	13201	12827	11098	10039

P_1, P_2 and P_3 are sowings 1,2 and 3, respectively.

took the highest HTU (12150 units), followed by P_2(9533 units) and P_3(9250 units). Sowing P_3 took 2900 units less than P_1 for completing pod filling stage.

Pusa Bold: From emergence to maturity, the accumulated helio-thermal units reached a value of 14297 in case of first sowing whereas second and third sowings accumulated 12265 and 12184 HTU, respectively. Upto pod filling stage first sowing accumulated 9521 units, second sowing 8543 units and third sowing 6971 units. In the third sowing, the HTU were 2550 units less than those for P_1 for completing the pod filling stage.

Toria-T9: First sowing reached maturity after accumulating a sum of 12291 HTU whereas second and third sowings reached maturity after accumulating 10505 and 9250 HTU, respectively. Upto pod filling stage first sowing accumulated 9931 units, second sowing 8195 and third sowing 6971 units. Third sowing took 2960 HTU less than first sowing to complete pod filling stage.

Rabi 1988-89

B.O.54: Upto maturity, first sowing accumulated 15870 HTU, followed by second and third sowings with 14353 and 13714 units, respectively. For completing the pod filling stage P_3 took 1450 HTU lesser than P_1 by accumulating 11698 units for P_1 and 10248 HTU for P_3.

Pusa Bold: In this variety, the first sowing accumulated 15870, second sowing 14323 and third sowing 13201 HTU. For completion of pod filling stage P_3 took 1325 and 2625 HTU more than those accumulated by P_1 and P_2, respectively.

Toria-T9: The variety matured after accumulating 12827, 11098 and 10039 HTU for P_1, P_2 and P_3 sowings, respectively. Upto pod filling stage, P_1 accumulated 10200 units, P_2 8055 and P_3 6594 HTU. P_3 accumulated 3606 HTU less than P_1. Since the trend of accumulated heat units in the three systems were similar, the discussion below is confined to only one unit namely, the growing degree days.

A comparison between P_2 and P_3 sowings in respect of long duration varieties B.O.54 and Pusa Bold shows that during the relatively cooler season, P_3 accumulated higher GDD during the different stages before maturity while in 1987-88 there was accumulation of lower heat units in respect of P_3. However, this phenomenon is not apparent in case of Toria-T9 during the cooler season except for periods upto flowering.

Upto week 48, maximum temperatures were relatively higher during 1987-88 and minimum temperatures lower, resulting in a high temperature range during this period. The thermal regime during the vegetative stage seems to have influenced the heat units accumulated.

Among the long duration varieties B.O.54 and Pusa Bold, during the cooler season, corresponding sowings namely V_1P_1, V_2P_1, V_1P_2, V_2P_2 and V_1P_3, V_2P_3 recorded nearly same amount of accumulated heat units whereas in the relatively warmer season 1987-88, all the sowings in B.O.54 accumulated higher heat units compared to that of Pusa Bold, the differences between the two seasons being higher in Pusa Bold.

It was already noted under phenology that cooler temperatures(below normal temperatures) prolonged the phenological events in Pusa Bold to a greater extent than in variety B.O.54 and the above observation is attributable to this.

When the entire season is considered, the results in Table 12 show that there was higher accumulation of heat units during rabi 1988-89 than in 1987-88 season in respect of Pusa Bold and Toria-T9 varieties. In case of B.O.54, the 1987-88 season recorded higher units than the 1988-89 season.

Thus, the results of heat unit system indicate that heat unit requirement is different for different varieties and sowings, showing a differential response to short period temperature changes in ambient thermal environment.

4.8.4 Pheno-thermal index

Pheno-thermal index(ratio of accumulated GDD to the number of days during a particular stage) during different stages of crop growth were worked out for both the seasons and are shown in the Table 15.

Pheno-thermal index(PTI) values ranged from 5.78 to 25.48 in the different treatments in the two seasons. Two salient features were (i) in most stages within a growth season the index showed much variation and (ii) between each growth stage, variation was high with the highest value having been recorded during the vegetative period of crop growth.

Between sowings, which are indirectly influenced by the temperature regimes, much variation was also noticed in the vegetative phase, the values ranging from 10.75 to 25.48. The lowest value of pheno-thermal index was obtained during pod formation stage in both the seasons, with the lowest values of 5.78 during the relatively warmer season, 1987-88. This reflects the conducive nature of thermal environment during the pod formation and pod filling period, in this year.

Taking the total crop growth period (emergence to maturity) into consideration, the pheno-thermal index was found to be nearly constant around a value of 14.3 degree days per growth day which is similar to that reported for other <u>rabi</u> crops, wheat and barley(Chakravarty and Sastry, 1983a). This index is not affected by cooler or warmer seasons indicating the stability of the index under different thermal environments.

Table 15. Pheno-thermal index in *Brassica* spp. during 1987-88 and 1988-89 *rabi* seasons

Phenological stage	B.O.54			Pusa Bold			Toria-T9			C.V.(%)
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	
					Rabi 1987-88					
Vegetative	16.07	25.48	10.75	18.32	14.73	16.57	18.24	15.35	12.22	25.8
Flowering	10.00	9.88	10.44	14.60	10.13	9.29	15.82	13.71	9.80	21.4
Pod formation	9.92	5.78	11.53	11.03	9.95	9.96	11.61	10.25	9.84	17.4
Pod filling	10.97	10.90	14.50	10.08	10.77	12.05	10.04	9.91	12.05	12.9
Maturity	14.92	15.33	18.03	12.55	14.37	15.70	10.80	12.91	14.20	14.5
Entire crop growth period	15.14	14.31	15.10	15.34	14.63	14.76	14.98	13.98	14.27	3.1
					Rabi 1988-89					
Vegetative	18.60	14.53	12.80	18.62	15.81	12.79	19.91	16.71	12.72	17.7
Flowering	14.00	12.20	9.71	15.25	11.08	10.57	17.20	15.00	12.83	18.8
Pod formation	10.85	8.27	9.00	12.03	11.38	8.96	12.73	11.21	9.07	15.0
Pod filling	8.86	10.29	13.74	8.29	8.69	13.63	10.71	8.04	9.72	21.1
Maturity	14.39	15.87	17.44	12.31	13.96	17.94	8.71	11.34	11.71	22.1
Entire crop growth period	14.91	14.28	13.40	14.91	13.94	13.34	14.47	13.35	12.46	5.9

P_1, P_2 and P_3 are sowings 1, 2 and 3, respectively; C.V. = Coefficient of variation.

4.8.4.1 Coefficient of variation of pheno-thermal index

The coefficient of variation(C.V.) values for 3 varieties and 3 sowings pooled together for each growth stage(Table 15) showed the lowest C.V. when entire growing season was considered as a single unit with a value of 3.1 and 5.9%, respectively for the two seasons 1987-88 and 1988-89. This indicates the relatively more uniform thermal environment during the 1987-88 season when compared to 1988-89 season which revealed more fluctuations in maximum and minimum temperatures due to influence of cold wave periods passing over the Delhi region. The highest C.V. values were observed at emergence to first flower appearance stage i.e., in the vegetative period in both the seasons. The C.V. at this stage indicates that much variation in the environmental thermal regimes occurs during this period of crop growth in the Delhi region.

Similar observations were made by Chakravarty and Sastry (1983a) in respect of wheat crop in the Delhi region.

4.8.5 Heat use efficiency during different phenological stages of Brassica spp.

Stage-wise heat use efficiency(HUE) values which express biomass production in g/plant per unit degree day computed for 3 varieties and sowings are given in Table 16.

In general, pod formation and pod filling stages showed higher HUE in comparison to the other three stages.

Table 16. Heat use efficiency(HUE) in different *Brassica* spp.(g $plant^{-1}$ GDD^{-1} x 10^3)

Phenological stage	B.O.54			Pusa Bold			Toria-T9		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
				Rabi 1987-88					
Vegetative	7.0	6.0	3.0	0.4	3.0	7.0	0.5	1.0	1.0
Flowering	13.0	26.0	10.0	1.0	5.0	9.0	42.0	2.0	4.0
Pod formation	34.0	30.0	15.0	50.0	43.0	19.0	35.0	26.0	27.0
Pod filling	46.0	40.0	13.0	60.0	55.0	25.0	47.0	23.0	29.0
Maturity	10.0	13.0	9.0	30.0	30.0	20.0	35.0	15.0	8.0
HUE with seed yield	2.9	3.4	2.5	7.7	8.9	5.1	9.0	6.7	4.7
				Rabi 1988-89					
Vegetative	3.0	2.0	0.3	3.0	1.4	0.5	1.0	0.3	0.6
Flowering	5.0	8.0	0.7	6.0	4.0	0.9	1.8	1.0	0.9
Pod formation	43.0	31.0	13.0	20.0	13.0	19.0	14.0	17.0	5.0
Pod filling	35.0	28.0	16.0	40.0	31.0	14.0	31.0	29.0	15.0
Maturity	3.0	2.0	2.0	3.0	2.0	2.0	4.0	1.0	1.0
HUE with seed yield	6.2	4.5	3.7	6.9	4.3	3.7	9.8	5.1	4.2

P_1, P_2 and P_3 are sowings 1,2 and 3, respectively.

Between the two seasons, it was observed that except in case of B.O.54, HUE values during rabi 1987-88 were higher when the ambient temperatures were also higher than those during rabi 1988-89. Sastry et al.(1985) reported similar results in case of wheat crop. Considering the heat use efficiency with respect to grain yield during both the rabi seasons 1987-88 and 1988-89, first sowing of Toria-T9 showed the highest HUE(9.0 and 9.8 g/plant per degree day x 10^3), respectively. Also during 1987-88 season, second sowing of Pusa Bold recorded high HUE(8.9 g per plant per degree day x 10^3).

4.9 GROWING DEGREE DAYS VS CUMULATIVE BIOMASS PRODUCTION

Correlation coefficients between the accumulated growing degree days and accumulated biomass production in respect of different varieties and the two seasons were worked out and are given in the Table 17.

These parameters were found to be significantly correlated with each other at 1% level, the correlations ranging from 0.867 to 0.922 for 1987-88 season and from 0.850 to 0.951 for 1988-89 season. For pooled data over two years for the three sowings, the correlation varied from 0.823 to 0.895. In view of the high correlation, regression equations were computed for individual seasons as well as for the pooled data and are given in the Table 17.

Table 17. Correlation and regression between cumulative biomass(g plant^{-1}) and accumulated heat units

Variety	Regression equation	Correlation coefficient	S.E.
	Rabi 1987-88		
V_1	BM = 0.081 GDD - 60.5	0.922	7.61
V_2	BM = 0.099 GDD - 67.9	0.867	12.51
V_3	BM = 0.076 GDD - 47.0	0.903	7.60
	Rabi 1988-89		
V_1	BM = 0.097 GDD - 84.7	0.867	13.54
V_2	BM = 0.095 GDD - 81.5	0.951	7.37
V_3	BM = 0.068 GDD - 51.4	0.850	9.54
	Pooled data over two seasons		
V_1	BM = 0.083 GDD - 64.5	0.895	7.61
V_2	BM = 0.090 GDD - 66.9	0.849	10.51
V_3	BM = 0.065 GDD - 41.8	0.823	7.94

Data pooled for three sowings

V_1, V_2 and V_3 are varieties B.O.54, Pusa Bold and Toria-T9, respectively. All values are significant at 1% level.

BM = Biomass; GDD = Growing degree days(°C); S.E. = Standard error of estimate.

From the regressions, it was estimated that for the establishment of the crop, B.O.54 needs more GDD(800 units) followed by Pusa Bold (750 units) and Toria-T9(650 units), respectively. For illustration, regression lines were drawn between accumulated degree days and biomass production for varieties Pusa Bold and Toria-T9 and shown in Fig.6.

Using the regression, biomass production at different accumulated levels of degree days was estimated and given in Table 18. Upto 1000 degree days the order of biomass production was Toria-T9 > Pusa Bold > B.O.54 when the crops were at pod formation stage. Later, Pusa Bold showed higher biomass production followed by B.O.54 and Toria-T9 at different levels of

Table 18. Biomass production at different levels of growing degree days(GDD)

GDD	Biomass (g $plant^{-1}$)		
	B.O.54	Pusa Bold	Toria-T9
800	1.9	5.1	10.2
900	10.2	14.1	16.7
1000	18.5	23.1	23.2
1100	26.8	32.1	29.7
1200	35.1	41.1	36.2
1300	43.4	50.1	42.7
1400	51.7	59.1	49.2
1500	60.0	68.1	55.7
1600	68.3	77.1	62.2
1700	76.6	86.1	68.7
1800	84.9	95.1	75.2
1900	93.2	104.1	81.7

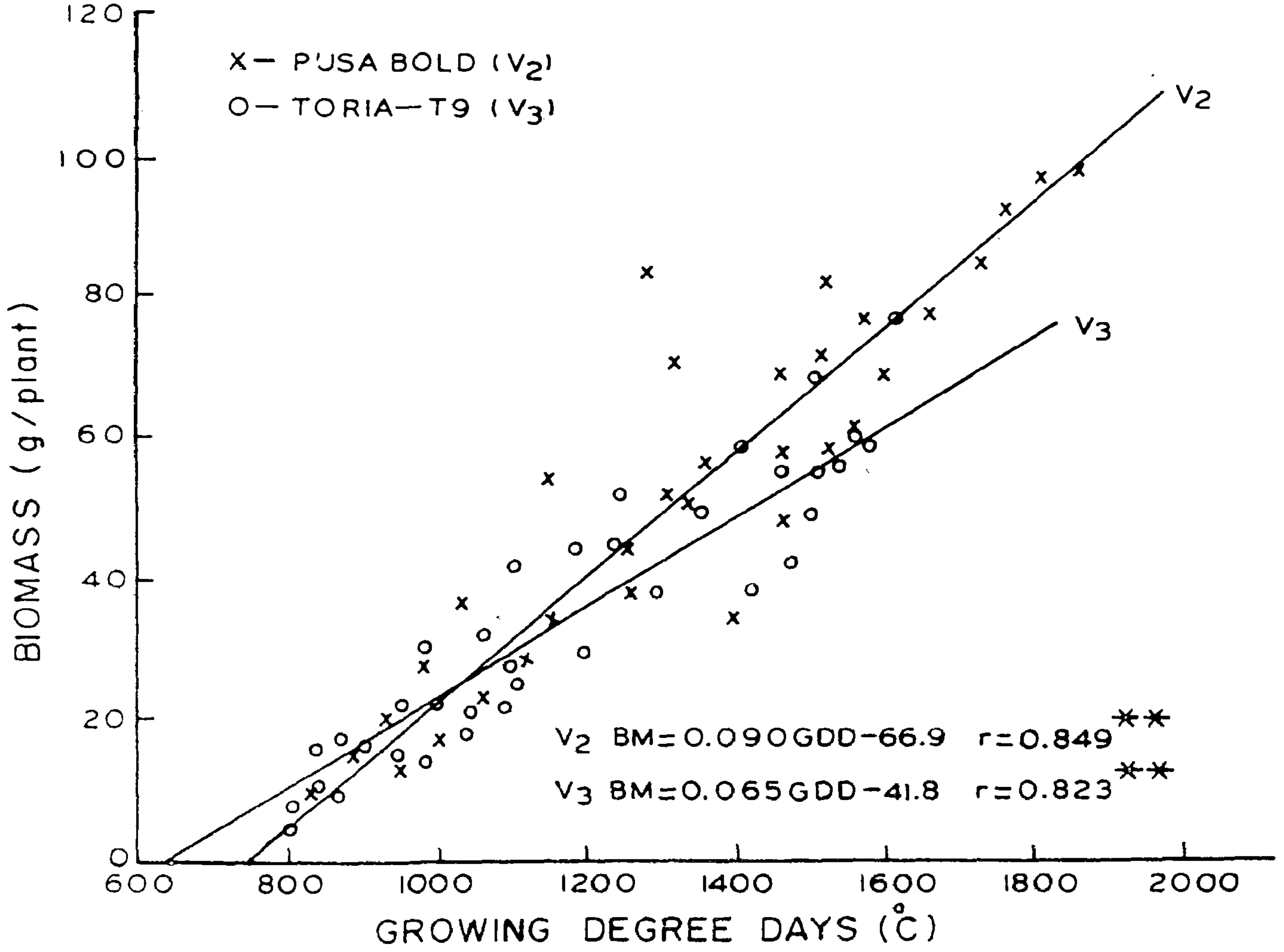


FIG. 6. GROWING DEGREE DAYS (°C) vs BIOMASS PRODUCTION

accumulated heat units above 1200 degree days. As an illustration, at an accumulation of 1500 degree days when crop was in pod filling stage for B.O.54 and Pusa Bold, and end of seed filling stage for Toria-T9, the biomass produced in Pusa Bold, B.O.54 and Toria-T9 was 68.1, 60.0 and 55.7 g/plant, respectively. Similar linear relationships were earlier reported for wheat varieties by Chakravarty(1980) and Chakravarty et al.(1984) in wheat and barley crops.

4.10 GROWING DEGREE DAYS VS OIL CONTENT

Oil content values at harvest obtained with the help of NMR and the accumulated growing degree days(GDD) during the oil accumulation period are given in the Table 19. The oil content in Brassica spp. under study ranged from 39.3 to 47.45% in the different sowings. During 1988-89 rabi season, it took more GDD for oil accumulation which resulted in higher oil content. This is more attributable to the prolonged growing season, relatively but with cooler temperatures, in 1988-89 season during the oil accumulation period.

Oil content at harvest in variety B.O.54 ranged between 39.7 to 45.0%. In Pusa Bold it ranged from 39.3 to 43.9%. First sowing in both the varieties B.O.54 and Pusa Bold gave higher percentage of oil content. In Toria-T9 oil content ranged from 44.9 to 47.45%. The higher percentage of oil content(46.8 and 47.45%) was found in the third sowing, respectively in both the seasons. The optimum temperature conditions

Table 19. Oil content(%) and accumulated growing degree days (GDD) during oil accumulation period in *Brassica* spp.

Variety	Season	Oil content			GDD		
		P_1	P_2	P_3	P_1	P_2	P_3
B.O.54	I	42.50	42.26	39.70	1300	1324	1296
	II	45.00	43.75	43.75	1452	1371	1209
Pusa Bold	I	41.66	39.30	40.80	1337	1186	1226
	II	43.90	42.70	43.20	1452	1385	1186
Toria-T9	I	45.80	45.15	46.80	1087	1017	975
	II	45.40	44.90	47.45	1137	1102	884

P_1, P_2 and P_3 are sowing dates 1, 2 and 3, respectively.

I = 1987-88; II = 1988-89.

for oil accumulation appear to correspond to the thermal environment that prevailed during pod filling stage of variety Toria-T9 with accumulation of 1033 GDD.

The relationship between per cent oil content at harvest and accumulated heat unit system in Brassica spp. is shown in Fig.7. These lines were drawn using eye estimation which shows a linear trend in the relationship. In case of variety B.O.54 and Pusa Bold, the per cent oil content showed an increase with increasing GDD. The short duration variety Toria-T9 on the other hand gave an inverse relationship showing a decrease in oil content with increase in GDD.

Hodgson(1979) reported that oil content was inversely related to mean daily temperature during seed filling period. Shastry and Kumar(1981); Vasi et al.(1986) observed that maximum temperature at vegetative stage was positively correlated with per cent oil content in Brassica. Results in the present investigation showed a direct relationship in long duration varieties(B.O.54 and Pusa Bold) and an inverse relationship with temperature in Toria-T9. This type of behaviour is probably attributable to the differing thermal regimes encountered by the short and long duration varieties and needs further study.

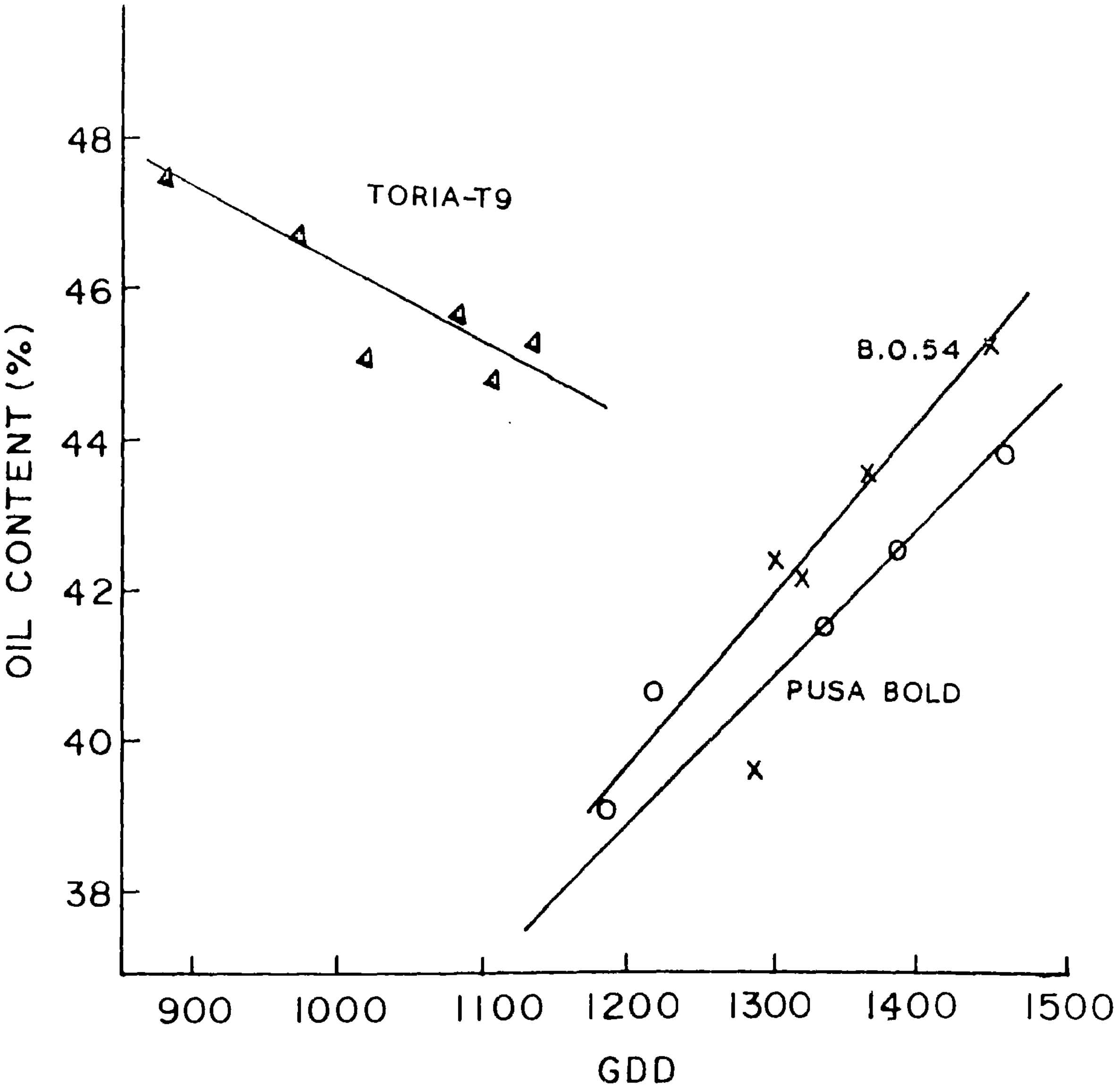


FIG. 7. RELATIONSHIP BETWEEN OIL CONTENT (%) AND ACCUMULATED GROWING DEGREE DAYS (GDD)

4.11 CUMULATIVE PAN EVAPORATION VS BIOMASS PRODUCTION

Correlation coefficients between cumulative pan evaporation(mm) and biomass production (g/plant) were worked out and are shown in Table 20. The values were found to be highly significant at 1% level. Similar significant correlations were earlier reported by Hanks _et al_.(1969) in case of wheat and for barley and wheat by Chakravarthy and Sastry(1983b). In view of the high correlation obtained, regression equations were fitted to the data for the three varieties by pooling together the observations from the three sowings for each variety and shown in Table 20. Correlation coefficients ranged between 0.776 to 0.865 for _rabi_ 1987-88 and 0.619 to 0.945 for _rabi_ 1988-89. They ranged from 0.786 to 0.844, pooled over two seasons. These would enable estimation of biomass production at any chosen level of cumulative pan evaporation in the Delhi region. Regression lines between cumulative pan evaporation and biomass production were drawn for Pusa Bold and Toria-T9 and shown in Fig.8. From the regression, it was estimated that variety B.O.54 would get established after cumulation of 121 mm of pan evaporation followed by Pusa Bold(118 mm) and Toria-T9(106 mm) in the Delhi region.

Using the regression, biomass production at different levels of cumulative pan evaporation for each of the three Brassica varieties used in this investigation were computed and shown in Table 21.

Table 20. Correlation and regression between cumulative biomass(g plant^{-1}) and cumulative pan evaporation (mm)

Variety	Regression equation	Correlation coefficient	S.E.
	Rabi 1987-88		
V_1	BM = 0.341 CPE - 45.2	0.865	9.20
V_2	BM = 0.381 CPE - 41.3	0.776	14.44
V_3	BM = 0.314 CPE - 32.4	0.806	9.85
	Rabi 1988-89		
V_1	BM = 0.261 CPE - 24.0	0.619	15.78
V_2	BM = 0.383 CPE - 49.5	0.945	6.49
V_3	BM = 0.298 CPE - 32.6	0.844	8.00
	Pooled data over two seasons		
V_1	BM = 0.317 CPE - 38.4	0.786	9.66
V_2	BM = 0.381 CPE - 45.0	0.844	9.83
V_3	BM = 0.307 CPE - 32.6	0.816	7.55

Data pooled for three sowings

V_1, V_2 and V_3 are varieties B.O.54, Pusa Bold and Toria-T9, respectively.

BM = Biomass; CPE = cumulative pan evaporation; SE = Standard error of estimation.

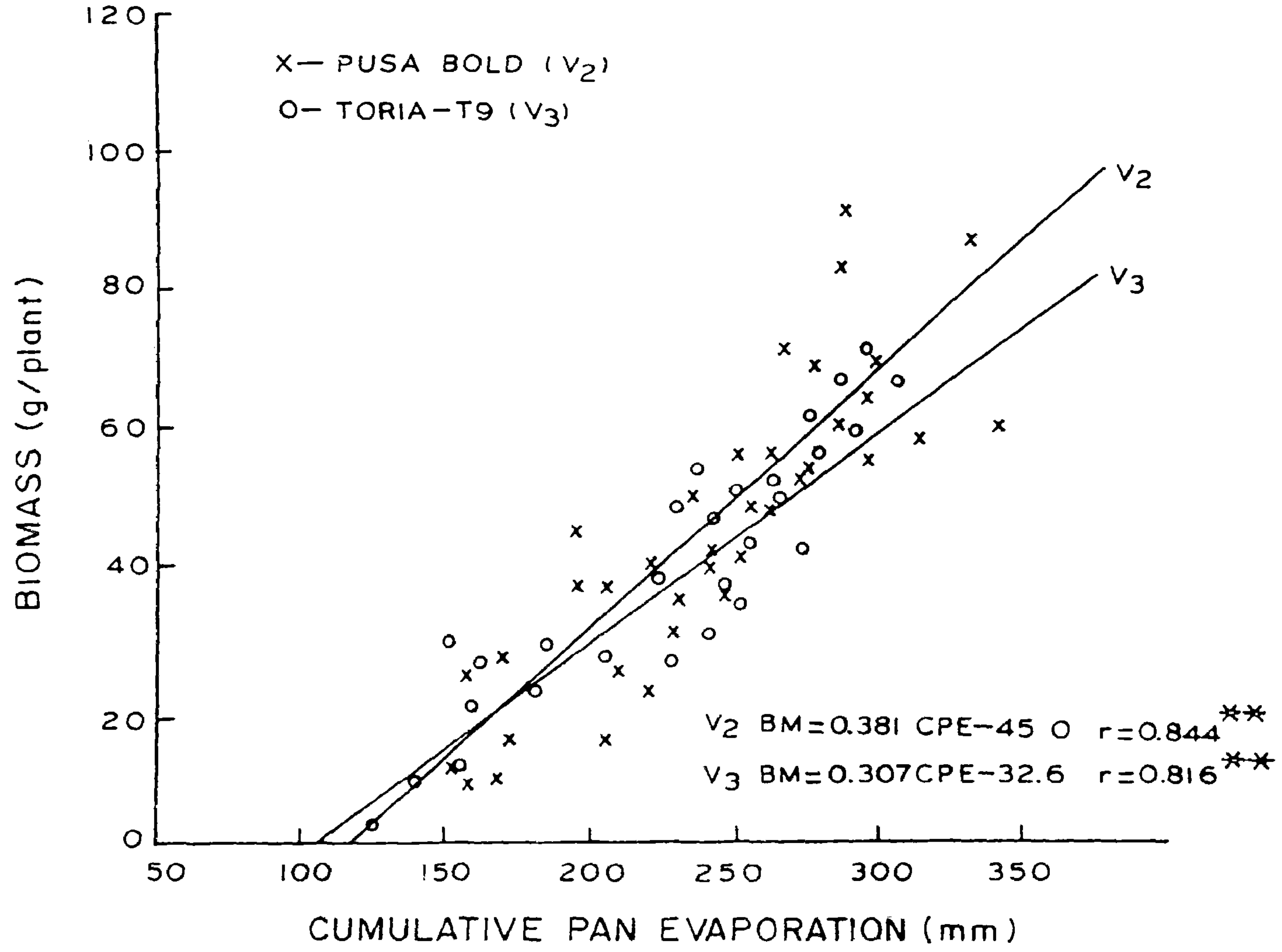


FIG. 8. CUMULATIVE EVAPORATION vs BIOMASS PRODUCTION

Upto cumulative pan evaporation of 150 mm, the order of biomass production was Toria-T9 > Pusa Bold followed by B.O.54. As an illustration, after accumulation of 155 mm of evaporation, the biomass production was 13.4, 12.1 and 9.1 g/plant, respectively for Toria-T9, Pusa Bold and B.O.54 and after accumulation of 300 mm, the biomass production was 69.3 for Pusa Bold, 59.5 for Toria-T9 and 56.7 g/plant for B.O.54.

Table 21. Biomass production at different levels of cumulative pan evaporation

Cumulative evaporation (mm)	Biomass (g $plant^{-1}$)		
	B.O.54	Pusa Bold	Toria-T9
125	1.2	2.6	5.7
150	9.1	12.1	13.4
175	17.1	21.7	21.1
200	25.0	31.2	28.8
225	32.9	40.7	36.5
250	40.8	50.2	44.1
275	48.7	59.8	51.8
300	56.7	69.3	59.5
325	64.6	78.8	67.2
350	72.5	88.3	74.8

4.12 CANOPY TEMPERATURE, CANOPY AIR TEMPERATURE DIFFERENCE AND AMBIENT TEMPERATURE RELATION IN BRASSICA SPP.

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

With a view to study these characters, daily observations at 1300 hours I.S.T. on crop temperatures were correlated with saturation deficit, maximum temperature, and mean air temperature observed in the Stevenson screen, and ambient temperature of crop.

4.12.1 Canopy temperature(T_c) vs saturation deficit(SD)

Correlation coefficients between canopy temperature(°C) and saturation deficit(mm) worked out for all the three varieties and three sowing dates for both seasons are given in Table 22a. Considering both the seasons, highly significant (at 1% level) and positive correlations ranging from 0.676 to 0.888 for variety B.O.54, 0.556 to 0.884 for Pusa Bold and 0.530 to 0.901 for Toria-T9 were obtained in all the three sowings.

In view of the high correlation obtained, regression lines were fitted to pooled data for three sowings

Table 22(a) Correlation and regression between canopy temperature(T_c) vs. saturation deficit (SD) in *Brassica* spp.

Variety	Rabi 1987-88		Rabi 1988-89	
	Correlation coefficient	Regression	Correlation coefficient	Regression
B.O.54				
P_1	0.676	16.176 + 0.429 SD	0.888	10.978 + 0.781 SD
P_2	0.843	11.395 + 0.766 SD	0.861	10.876 + 0.758 SD
P_3	0.793	15.054 + 0.541 SD	0.847	12.283 + 0.676 SD
Pusa Bold				
P_1	0.556	14.400 + 0.531 SD	0.884	11.284 + 0.785 SD
P_2	0.789	10.316 + 0.855 SD	0.879	10.850 + 0.775 SD
P_3	0.858	10.509 + 0.816 SD	0.855	11.158 + 0.729 SD
Toria-T9				
P_1	0.530	15.358 + 0.404 SD	0.787	12.737 + 0.663 SD
P_2	0.559	13.460 + 0.666 SD	0.899	11.810 + 0.766 SD
P_3	0.699	11.606 + 0.781 SD	0.901	12.972 + 0.706 SD

Temperature(°C); Saturation deficit(mm of Hg). All values are significant at 1% level.

P_1,P_2 and P_3 are sowing dates 1,2,and 3,respectively.

of varieties Pusa Bold and Toria-T9 and are shown in Figs.9a and 9b, respectively. A linear relationship was observed between T_c and saturation deficit. Walker and Hatfield(1980) reported that saturation deficit has an influence on canopy temperature during the central portion of the growing season. The results presented here support this view.

4.12.2 Canopy temperature(T_c) vs maximum temperature(T_{max})

Correlation coefficients between T_c and T_{max} were worked out for the three varieties, viz., B.O.54, Pusa Bold, Toria-T9 in both the seasons and are given in Table 22b. The values were found to be highly significant at 1% level. In view of the high correlation obtained, regression equations were worked out. For illustration, regression lines were fitted to pooled data(for the three sowings and two seasons) for varieties Pusa Bold and Toria-T9 and are shown in Figs.10a and 10b, respectively. A linear relationship was observed in both the cases. Such a correlation with maximum temperature was reported by Prasad(1988) in wheat variety ISD 397. This regression would enable estimation of T_c from T_{max} which is a routine measurement in agrometeorological observatories.

4.12.3 Canopy temperature(T_c) vs mean air temperature(T_{mean})

Correlation coefficients between T_c and T_{mean} were worked out for the three varieties and for all of the

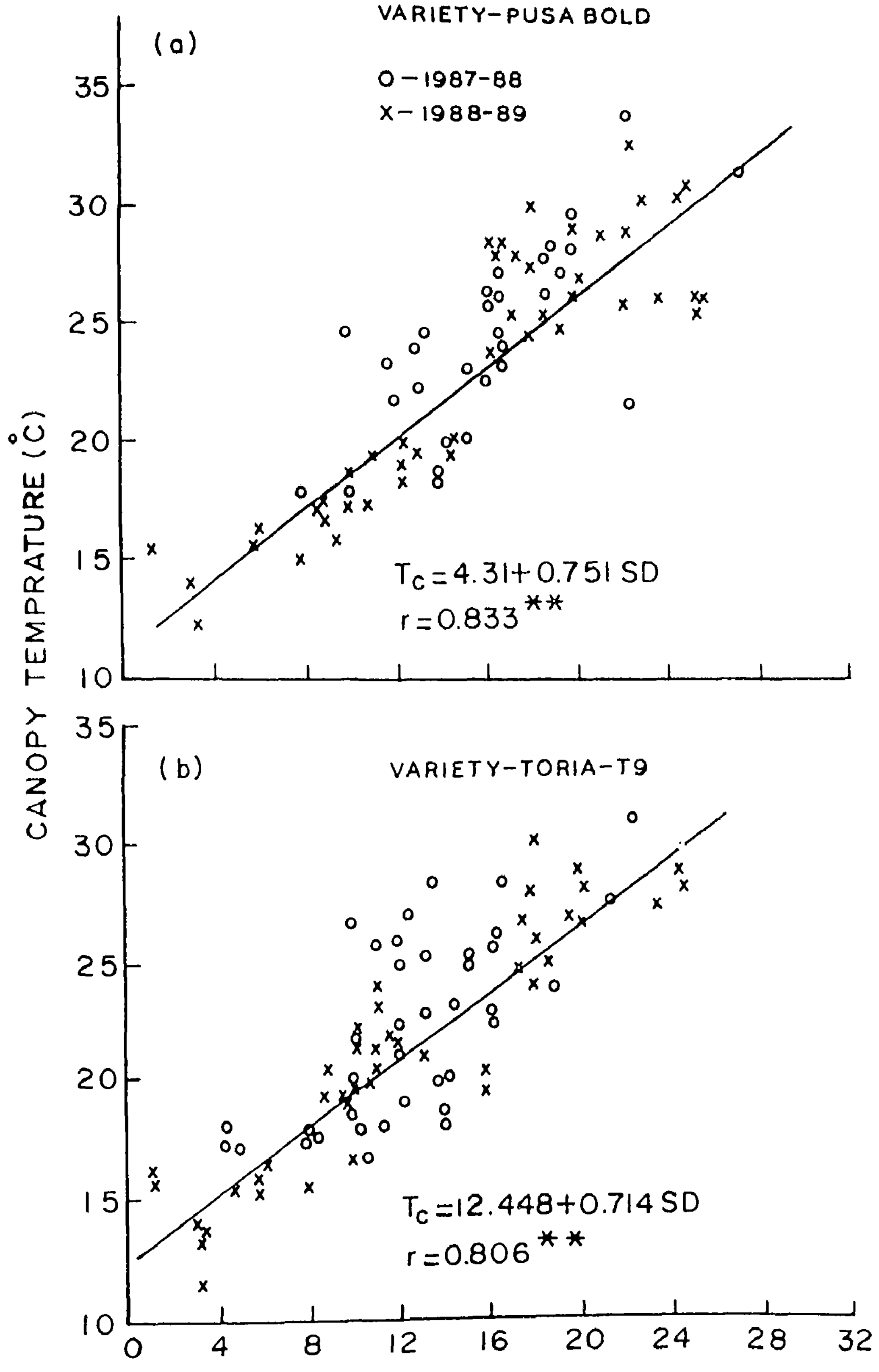
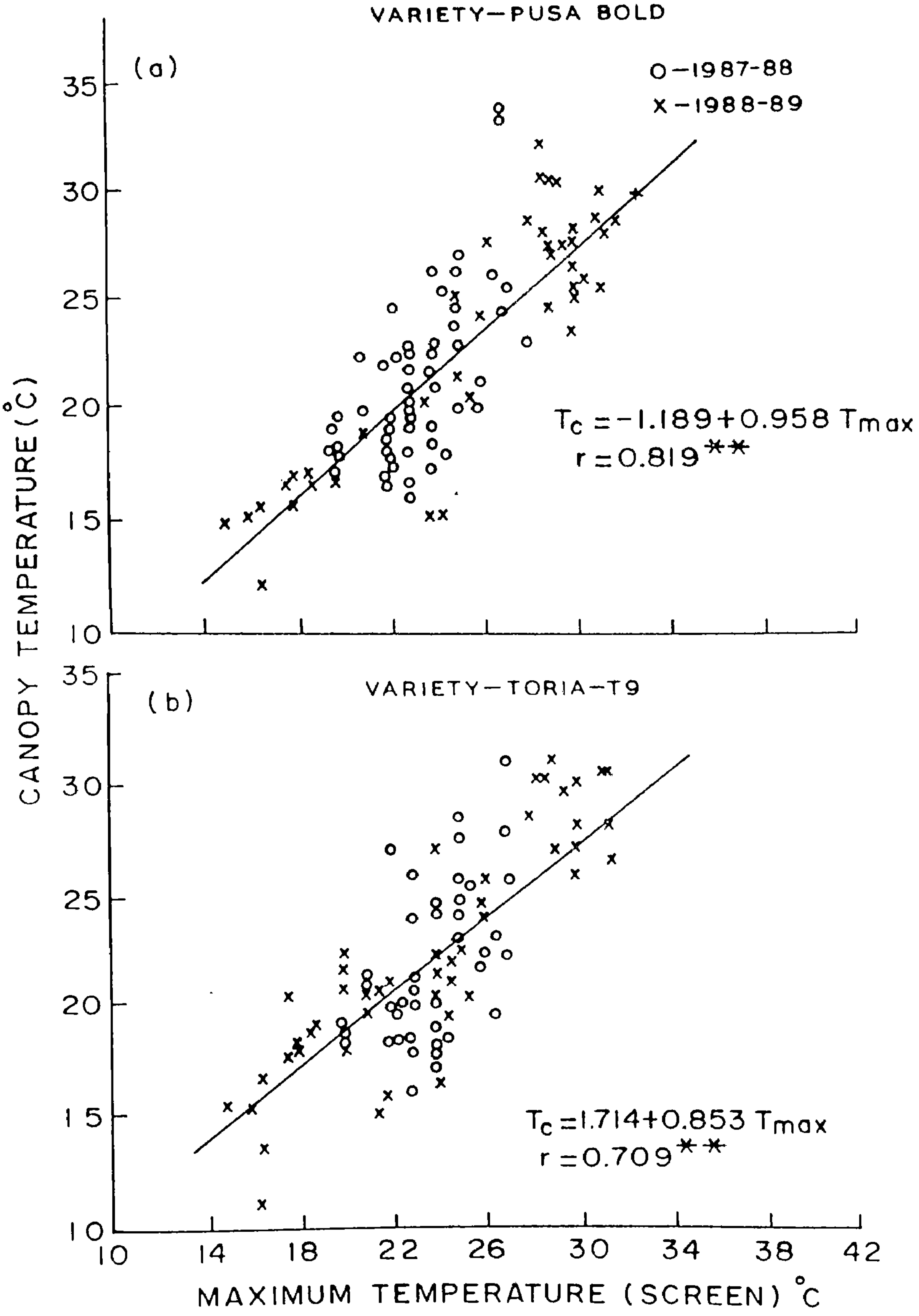


FIG. 9. CANOPY TEMPERATURE (T_c) vs SATURATION DEFICIT (SD)

Table 22(b). Correlation and regression between canopy temperature(T_c) vs. maximum temperature(T_{max}) in <u>Brassica</u> spp.

Variety	Rabi 1987-88		Rabi 1988-89	
	Correlation coefficient	Regression	Correlation coefficient	Regression
<u>B.O.54</u>				
P_1	0.681	$-3.690 + 1.051\ T_{max}$	0.892	$-1.134 + 0.965\ T_{max}$
P_2	0.806	$-8.824 + 1.284\ T_{max}$	0.887	$-1.790 + 0.974\ T_{max}$
P_3	0.715	$-6.642 + 1.185\ T_{max}$	0.867	$1.406 + 0.850\ T_{max}$
<u>Pusa Bold</u>				
P_1	0.487	$3.771 + 0.741\ T_{max}$	0.873	$-1.316 + 0.993\ T_{max}$
P_2	0.633	$-4.940 + 1.116\ T_{max}$	0.892	$-0.918 + 0.945\ T_{max}$
P_3	0.724	$-7.109 + 1.199\ T_{max}$	0.881	$-0.732 + 0.923\ T_{max}$
<u>Toria-T9</u>				
P_1	0.187	$14.497 + 0.248\ T_{max}$	0.566	$7.017 + 0.605\ T_{max}$
P_2	0.207	$17.655 + 0.150\ T_{max}$	0.828	$0.297 + 0.934\ T_{max}$
P_3	0.538	$-1.960 + 1.008\ T_{max}$	0.820	$0.377 + 0.926\ T_{max}$

Temperature(°C); All values are significant at 5%.
P_1, P_2 and P_3 are sowing dates 1,2, and 3,respectively.


VARIETY—PUSA BOLD

VARIETY—TORIA—T9

FIG. 10. MAXIMUM TEMPERATURE (T_{max}) vs CANOPY TEMPERATURE (T_c)

three sowings separately, and are presented in the Table 22c. The correlations were significant at 1% level except in case of V_3P_1 which was significant at 5% level. In view of the high correlation obtained, regression equations were worked out and included in the table.

4.12.4 Canopy temperature(T_c) vs ambient temperature(T_a)

Correlation coefficients between T_c and T_a were worked out for B.O.54, Pusa Bold and Toria-T9 in the same manner as above and are given in Table 22d. The values were highly significant at 1% level. Regression equations were fitted to pooled data and are shown in the table. Such correlations were not reported in literature for Brassica crop.

Magnitudes of the correlation coefficients were higher in the relatively cooler season 1988-89 in all the varieties. This was true not only in respect of saturation deficit but in the case of correlation of canopy temperature with maximum, mean and ambient temperatures also. However, it may be mentioned that in case of variety Toria-T9, the magnitude of correlation though significant at 5% level was low during 1987-88 in respect of maximum and mean temperatures in first sowing. These results are in confirmation with Prasad(1988) in respect of wheat crop in the Delhi region.

4.12.5 Stress degree days vs grain yield

Degree of moisture stress in a crop at different growth stages is an indication of grain yield in crops. Since

Table 22(c). Correlation and regression between canopy temperature(T_c) vs. mean air temperature(T_{mean}) in *Brassica* spp.

Variety	Rabi 1987-88		Rabi 1988-89	
	Correlation coefficient	Regression	Correlation coefficient	Regression
B.O.54				
P_1	0.726	$5.527 + 0.999\ T_{mean}$	0.874	$5.295 + 1.016\ T_{mean}$
P_2	0.645	$7.378 + 0.899\ T_{mean}$	0.890	$4.424 + 1.041\ T_{mean}$
P_3	0.632	$6.881 + 0.920\ T_{mean}$	0.872	$6.875 + 0.901\ T_{mean}$
Pusa Bold				
P_1	0.599	$8.879 + 0.798\ T_{mean}$	0.841	$5.023 + 1.068\ T_{mean}$
P_2	0.591	$7.652 + 0.878\ T_{mean}$	0.886	$5.230 + 1.003\ T_{mean}$
P_3	0.579	$8.175 + 0.820\ T_{mean}$	0.893	$5.190 + 0.982\ T_{mean}$
Toria-T9				
P_1	0.156	$16.819 + 0.229\ T_{mean}$	0.340	$14.114 + 0.407\ T_{mean}$
P_2	0.488	$10.293 + 0.725\ T_{mean}$	0.744	$6.722 + 0.981\ T_{mean}$
P_3	0.500	$9.238 + 0.796\ T_{mean}$	0.804	$5.156 + 1.064\ T_{mean}$

Temperature(°C); All values are significant at 5% level.

P_1 P_2 and P_3 are sowing dates 1,2 and 3, respectively.

Table 22(d). Correlation and regression between canopy temperature(T_c) vs. Ambient temperature(T_a) in *Brassica* spp.

Variety	Rabi 1987-88		Rabi 1988-89	
	Correlation coefficient	Regression	Correlation coefficient	Regression
B.O.54				
P_1	0.809	$-0.205 + 0.840\ T_a$	0.903	$-7.167 + 1.185\ T_a$
P_2	0.742	$3.594 + 0.714\ T_a$	0.914	$-8.084 + 1.225\ T_a$
P_3	0.806	$-3.247 + 0.946\ T_a$	0.915	$-6.354 + 1.133\ T_a$
Pusa Bold				
P_1	0.729	$-0.354 + 0.828\ T_a$	0.933	$-10.329 + 1.291\ T_a$
P_2	0.804	$-0.085 + 0.849\ T_a$	0.905	$-8.825 + 1.268\ T_a$
P_3	0.835	$-4.958 + 0.835\ T_a$	0.897	$-7.245 + 1.163\ T_a$
Toria-T9				
P_1	0.725	$3.656 + 0.665\ T_a$	0.858	$-2.632 + 0.995\ T_a$
P_2	0.753	$0.181 + 0.810\ T_a$	0.900	$-7.010 + 1.177\ T_a$
P_3	0.797	$-4.483 + 1.003\ T_a$	0.919	$-9.261 + 1.248\ T_a$

Temperature (°C); All values are significant at 1% level.

P_1, P_2 and P_3 are sowing dates 1,2 and 3, respectively.

the stress degree day concept could be used both for rainfed and irrigated crops to estimate the relative stress under different treatments, stress degree days were worked out for different sowings and three varieties and compared with seed yield data.

Table 23. Stress degree days(ΣSDD) from pod filling stage to maturity and seed yield(g plant^{-1}) during 1988-89 rabi season

Treatment	ΣSDD	Seed yield (g plant^{-1})
V_1P_1	-158.1	12.13
V_1P_2	-178.2	8.29
V_1P_3	-218.5	6.45
V_2P_1	-173.7	13.63
V_2P_2	-150.3	7.79
V_2P_3	-231.5	6.29
V_3P_1	- 64.7	15.80
V_3P_2	-116.9	7.22
V_3P_3	-182.1	5.34

Stress degree days(SDD) were accumulated for the pod filling stage to maturity for different treatments during rabi 1988-89 season, and are given in Table 23.

In general, as ΣSDD became more negative, yield also showed a correspondingly increasing trend. Increasing seed yield with increasing negative SDD was also observed by Idso et al. (1977), Walker and Hatfield (1977) and Diaz et al. (1983) in case of wheat. In Pusa Bold, however, this trend did not hold good with respect to first and second sowings, where higher yields were associated with relatively positive values of SDD. To examine this further, for long duration varieties B.O.54 and Pusa Bold SDD accumulation was carried out only for pod filling stage and the values are shown in Table 24.

Table 24. Accumulated stress degree days (ΣSDD) during pod filling stage and seed yield (g plant^{-1})

Treatment	ΣSDD	Seed yield (g plant^{-1})
V_1P_1	-113.1	12.13
V_1P_2	-134.8	8.29
V_1P_3	-192.0	6.45
V_2P_1	- 23.9	13.63
V_2P_2	- 79.1	7.79
V_2P_3	-217.5	6.29

More negative values in ΣSDD were associated with decreasing yields in both the varieties. The anamoly observed earlier in Pusa Bold for P_1 and P_2 in Table 23 is not seen here.

This indicates that ΣSDD accumulation over pod filling stage might be a better indicator of seed yield rather than SDD accumulation from pod filling to maturity stage.

4.13 LEAF-CANOPY TEMPERATURE DIFFERENCES

With a view to examine leaf and canopy temperature differences during the day, leaf temperatures were measured with thermocouple and compared with canopy temperature measured by infrared thermometer. It may be mentioned that leaf temperature is a spot measurement and canopy temperature is an area measurement giving an integrated value. For this purpose, data for a day was taken when P_1, P_2 and P_3 were at pod filling stage, flowering and vegetative stages with leaf area indices 5.0, 1.5 and 0.5, respectively.

The day was marked with a mean temperature of 15.7°C and saturation deficit of 15.7 mm at 1400 hours. The leaf-canopy temperature differences during the day time hours are presented in Fig.11. The difference between leaf temperature (T_L) and canopy temperatures(T_C) was high (3.9 to 6.6°C) in early hours of the day, reduced to 2.6 to 3.9°C during mid-day and showed a slight increase in the afternoon hours of the day(2.7 to 4.4°C).

In the first sowing of variety B.O.54, the lowest difference(2.9°C) in T_L and T_C was found at 1445 noon; in case of second sowing, it occurred at 1345 hours(Fig.11a).

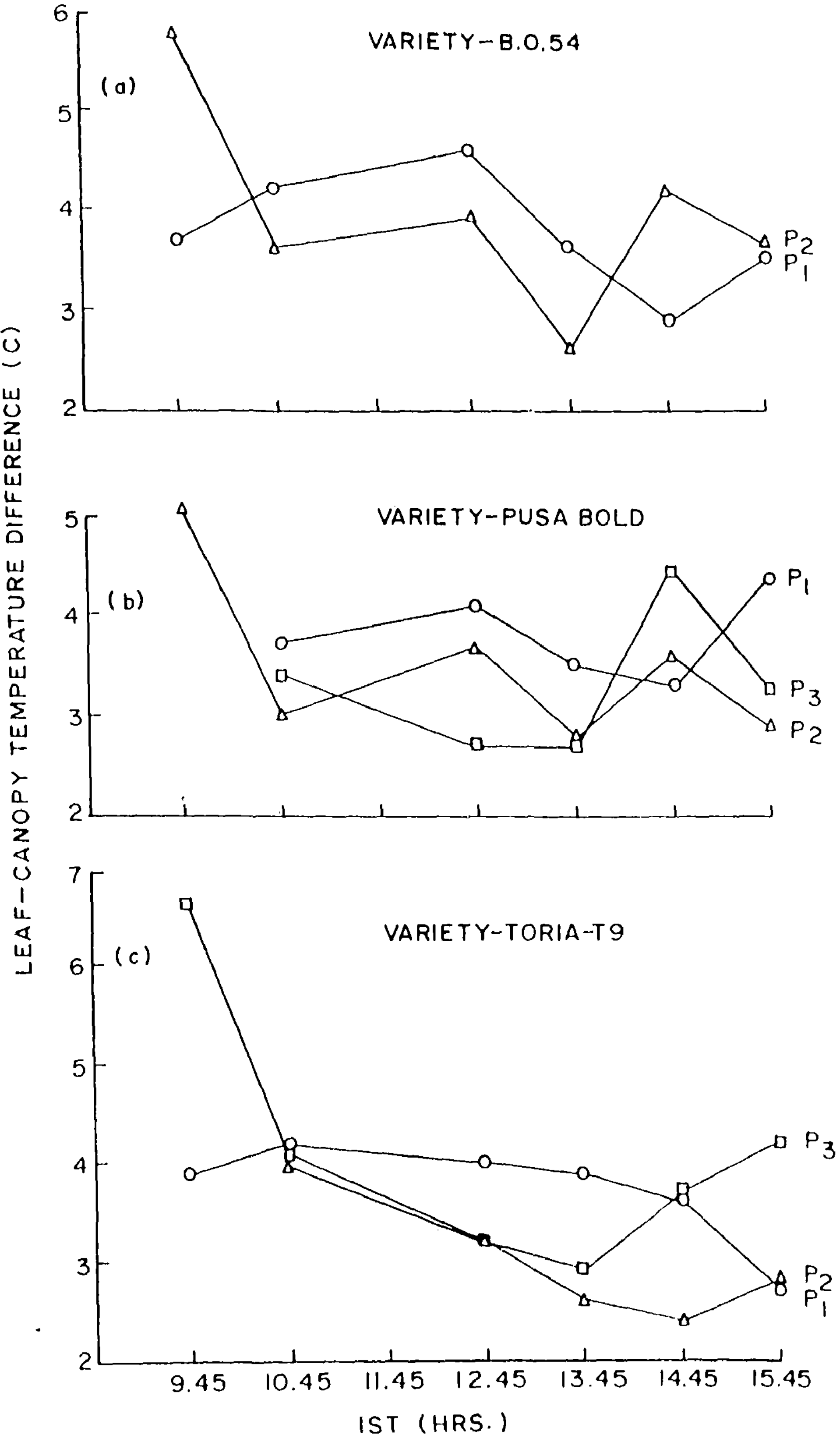


FIG. 11. LEAF-CANOPY TEMPERATURE DIFFERENCES IN BRASSICA SPP.

In Pusa Bold, the temperature differences were the lowest at 1445 hours in P_1, at 1345 hours in P_2 and P_3(Fig.11b). In variety Toria-T9, it was at 1545 hours for P_1, at 1445 hours for P_2 and 1345 hours for P_3(Fig.11c).

Depending on the growth stage the leaf-canopy temperature differences were the highest in P_1 and the lowest in P_3 (Fig.11b). This is attributable to the differences created by canopy structures at this time in the different sowings under the same prevailing weather conditions.

In general, the differences in leaf temperatures and canopy temperatures are the lowest (3.6 to 4.2°C) around 1345 hours to 1445 hours when the transpirational cooling is maximum. Since the magnitude of difference between leaf and canopy temperatures was not reported in literature for Brassica crop, this could not be compared with data elsewhere.

4.14 LEAF CHLOROPHYLL CONTENT AND PHOTOSYNTHETICALLY ACTIVE RADIATION INTERCEPTION IN BRASSICA CROP CANOPY

Photosynthesis depends upon many factors but chlorophyll content gives a good indication about the productivity status of a crop. Chlorophyll estimation gives an idea about the rate of production since the rate of production is known to be proportional to chlorophyll content.

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 leaves at different growth stages of crop and the influence of the temperature regime, chlorophyll content and photosynthetically active radiation(PAR) were monitored at periodic intervals during 1987-88 and 1988-89 *rabi* seasons in all the treatments.

4.14.1 Average chlorophyll content

In all the sowings and varieties, at the bottom level the average chlorophyll content varied from 0.085 to 0.495(mg/g) of fresh leaf weight. The content at middle and top levels, respectively varied from 0.870 to 1.385(mg/g) and 1.3 to 1.569 (mg/g) of fresh leaf weight (Fig.12).

4.14.2 Seasonal variation of chlorophyll content

The seasonal variation of chlorophyll content(mg/g fresh leaf wt.) in variety Pusa Bold and Toria-T9 are presented in Tables 25a and 25b. In Pusa Bold, the chlorophyll content values ranged between 0.872 to 1.878 for top, 0.527 to 1.545 in middle and 0.071 to 0.678 mg/g at the bottom levels of crop canopy(Table 25a) in the first sowing in both 1987-88 and 1988-1989 *rabi* seasons. But in case of the third sowing, they ranged from 0.669 to 1.662 for top, 0.721 to 1.701 for middle and 0.05 to 0.445 mg/g of fresh leaf weight at the bottom levels of the canopy during both the seasons(Table 25a).

In Toria-T9, for the first sowing, it ranged between 0.404 to 1.8 at the top, 0.413 to 1.214 at the middle and 0.120 to 1.125 mg/g of fresh leaf weight at the bottom levels of crop canopy in both the seasons. In the case of third sowing, values ranged from 0.545 to 1.586 for top level 0.545 to 1.467 for middle and 0.061 to 0.154 mg/g of fresh leaf weight at the bottom level(Table 25b).

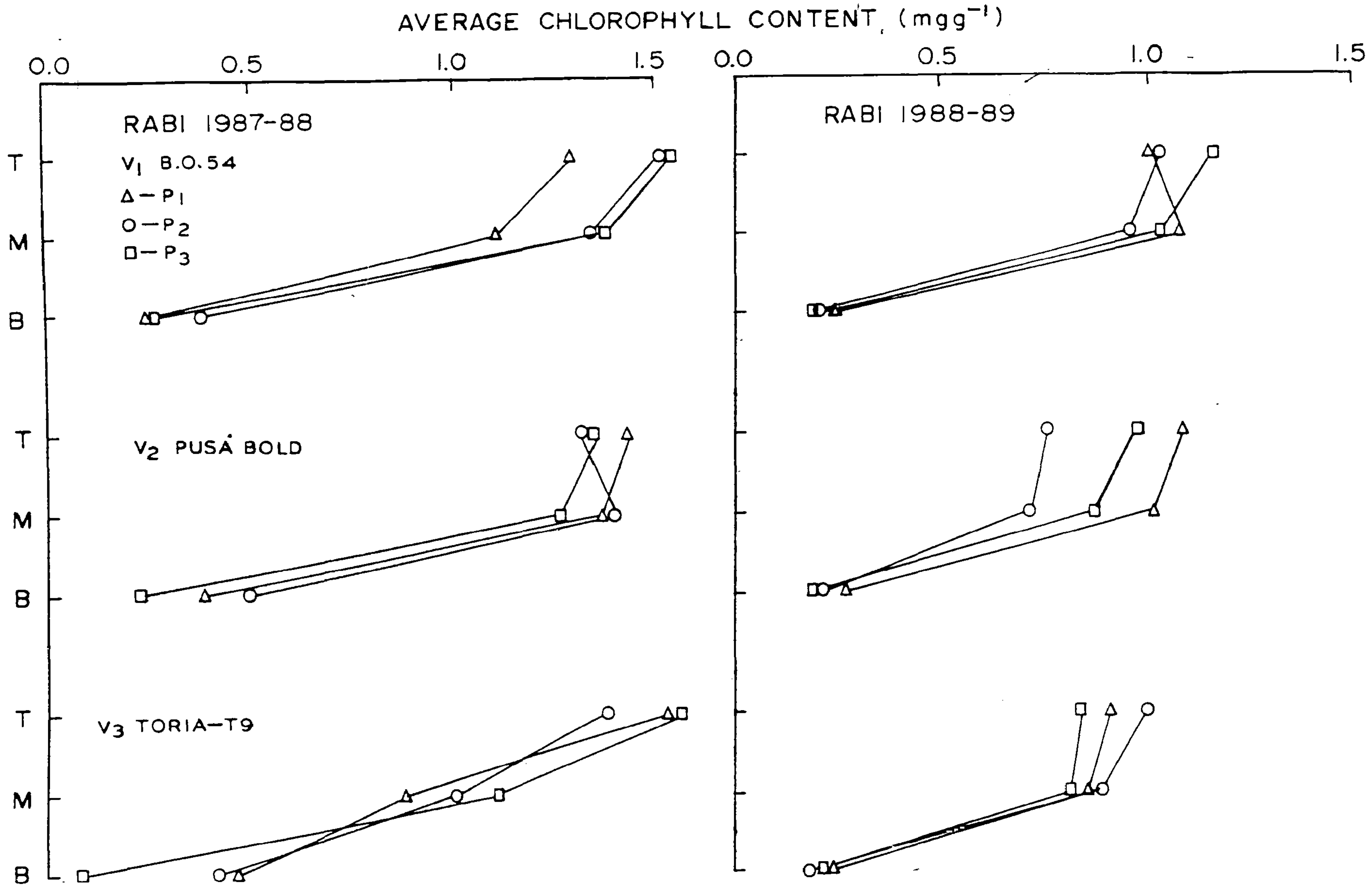


FIG.12. CHLOROPHYLL CONTENT IN TOP (T), MIDDLE (M) AND BOTTOM (B) LEVELS IN BRASSICA SPP.

Table 25a. Seasonal variation of leaf chlorophyll content (mg g^{-1} of fresh wt.) in Brassica spp. at different levels in the canopy of variety Pusa Bold

Date	First sowing			Third sowing		
	Top	Middle	Bottom	Top	Middle	Bottom
			Rabi 1987-88			
25/11	1.470	-	-	-	-	-
3/12	1.878	1.545(82)*	0.678(36)	-	-	-
17/12	1.198	1.136(95)	0.563(47)	1.175	-	-
31/12	1.335	1.288(97)	0.295(22)	1.662	1.662	0.445
18/1	1.521	1.343(88)	0.186(12)	1.049	1.526	0.191
9/2	1.396	1.275(91)	0.240(17)	1.391	1.701	0.071
24/2	-	-	-	0.690	-	-
			Rabi 1988-89			
22/11	1.034	1.034(100)	0.547(53)	0.543	-	-
15/12	1.375	1.310(95)	0.506(37)	0.669	0.669(100)	0.416(62)
3/1	1.321	1.425 (-)	0.071 (-)	1.223	1.104(90)	0.050(4)
18/1	1.034	0.922(89)	0.142(14)	0.961	0.909(95)	0.068(7)
3/2	0.932	0.527(57)	0.106(11)	1.334	0.956(72)	0.083(6)
17/2	0.872	-	-	1.143	0.721(63)	0.153(13)
8/3	-	-	-	0.975	1.199(-)	0.068(-)

*Figures in parentheses are per cent values in relation to the top level.

Table 25b. Seasonal variation of leaf chlorophyll content (mg g^{-1} of fresh wt.) in *Brassica* spp. at different levels in the canopy of variety Toria-T9

Date	First sowing			Third sowing		
	Top	Middle	Bottom	Top	Middle	Bottom
			Rabi 1987-88			
25/11	1.192	-	-	-	-	-
3/12	1.800	1.126(63)*	1.125(63)	-	-	-
17/12	1.353	1.214(90)	0.173(13)	0.979	-	-
31/12	1.459	0.413(28)	0.120(8)	1.551	1.351(87)	0.085(5)
18/1	0.404	-	-	1.586	1.467(93)	0.085(5)
9/2	-	-	-	0.770	-	-
			Rabi 1988-89			
22/11	0.832	0.832(100)	0.169(20)	0.731	-	-
15/12	1.257	1.078(86)	0.352(28)	0.940	0.772(82)	0.15(16)
3/1	1.059	1.027(97)	0.201(20)	1.365	1.213(89)	0.04(4)
18/1	0.516	-	-	0.798	0.620(78)	0.154(19)
3/2	-	-	-	0.545	0.545(100)	0.061(11)

*Figures in parentheses are per cent values in relation to the top level.

In general, top and middle levels of both the varieties Pusa Bold and Toria-T9 attained higher levels of chlorophyll content during 1987-88 as compared to 1988-89 season indicating the effect of seasonal temperature differences.

The leaf chlorophyll contents at middle and bottom level of canopy expressed as percentage of top in case of Pusa Bold are included in Table 25a. The results show that in Pusa Bold chlorophyll at middle level of the canopy constitutes about 80 to 100% of that at the top of canopy. At the bottom level during the early growth stages it got depleted to about 40 to 50% and at later stages it decreased to about 10 to 15% in the first sowing. In the third sowing of Pusa Bold(Table 25a), it was noticed that while at middle canopy level higher chlorophyll contents were maintained(greater than 60%) throughout the growing season, at the bottom level, they got very much depleted(reduced to a value below 10%) unlike in the first sowing. This is attributable to faster leaf senescence in the crop due to influence of higher temperatures.

In the third sowing of Pusa Bold during 1987-88 an increase in chlorophyll content at the middle level of canopy was noticed. However, more observations are needed to confirm such an occurrence since in other treatments such a phenomenon had not been observed.

In the short duration variety Toria-T9(Table 25b) the depletion pattern was similar to that observed in case of variety Pusa Bold. However, during <u>rabi</u> 1988-89 season when weather was relatively more cooler during the growth season, chlorophyll content at the bottom level remained relatively higher than that recorded in the warmer season 1987-88. Thus, there is an indication of the effect of higher temperature on chlorophyll content which operates through faster leaf senescence.

4.14.3 Photosynthetically active radiation interception in the canopy

During *rabi* 1987-88, PAR interception between top to bottom levels of crop ranged from 28.6 to 93.7% during the growth season and in case of top to 50% of height of the crop it ranged from 23.0 to 79.0%(Table 26a). Maximum PAR interception in both the cases(i.e., top to bottom and top to 50% of height of the crop) corresponded to pod formation period.

During *rabi* 1988-89, PAR interception from top to bottom ranged from 59.0 to 98.6% and in case of top to 50% height of the crop it ranged from 12.5 to 88.5(Table 26b). Maximum PAR interception in both the cases corresponded to the pod filling and early maturity phases of the crop growth, whereas it took place during pod formation period during 1987-88 *rabi* season. This is because in *Brassica* spp. even after reduction in leaf area, the pods cover the ground and intercept sufficient radiation upto early maturity stage. Leaf area index values for 1987-88 were examined (Table 4) and the results showed that the time of occurrence of maximum LAI corresponded to maximum PAR interception both in the top to bottom and top to 50% height of the crop. Unlike in other *rabi* crops like wheat and

Table 26a. Photosynthetically active radiation(PAR) interception(per cent with respect to incident PAR at the top of the canopy)
(Rabi 1987-88)

Treatment		Dec.1	Dec.17	Jan.4	Jan.29	Feb.27
V_2P_1	Top to bottom	28.6	87.8	93.3	82.9	59.8
	Top to 50% height	-	47.0	70.5	65.3	-
V_2P_2	Top to bottom	34.7	93.7	87.7	92.7	82.0
	Top to 50% height	-	31.8	69.5	61.5	-
V_3P_1	Top to bottom	63.9	79.1	88.0	74.9	-
	Top to 50% height	37.9	54.0	79.0	-	-
V_3P_2	Top to bottom	37.3	76.3	81.0	62.4	-
	Top to 50% height	29.8	37.3	52.2	31.0	-
V_3P_2	Top to bottom	-	30.0	75.6	86.8	75.0
	Top to 50% height	-	23.0	36.5	67.6	-

V_2 and V_3 are varieties Pusa Bold and Toria-T9, respectively.
P_1, P_2 and P_3 are sowings 1, 2 and 3, respectively.

Table 26b. Photosynthetically active radiation(PAR) interception(per cent with respect to incident PAR at the top of the canopy)

(Rabi 1988-89)

Treatment		Dec.19	Jan.10	Jan.17	Jan.24	Jan.30	Feb.8	Feb.20	Feb.24
V_2P_1	Top to bottom	81.4	88.2	91.1	91.4	95.4	95.9	93.5	92.0
	Top to 50% ht.	41.1	46.6	62.5	86.7	88.2	88.5	87.8	51.5
V_2P_2	Top to bottom	79.0	89.8	91.3	96.2	97.0	89.8	89.8	88.9
	Top to 50% ht	12.5	30.2	38.7	63.4	68.4	77.7	68.9	54.1
V_3P_1	Top to bottom	59.0	65.0	82.8	84.7	75.2	63.3	-	-
	Top to 50% ht	23.4	44.8	52.9	69.9	70.2	41.8	-	-
V_3P_2	Top to bottom	71.3	71.7	75.0	80.0	76.3	-	-	-
	Top to 50% ht	43.7	44.0	60.2	66.1	47.6	-	-	-
V_3P_3	Top to bottom	61.0	90.6	94.9	98.6	97.5	95.4	92.0	-
	Top to 50% ht.	57.9	60.5	62.5	63.7	84.5	57.9	54.0	-

V_2 and V_3 are varieties, Pusa Bold and Toria-T9, respectively.

P_1, P_2 and P_3 are sowings, 1, 2 and 3, respectively.

barley, in <u>Brassica</u> spp. pod surface area also seems to play a significant role in PAR interception even after occurrence of leaf senescence.

Photosynthetically active radiation interception during the 1988-89, <u>rabi</u> season remained high for a longer period than that during the 1987-88 season(Table 26b). This could be attributed to the longer duration of the different treatments for completion of growth cycle due to cooler temperatures in 1988-89.

It was noticed that PAR interception at middle level of canopy was 60 to 70% and at the bottom level the PAR depletion was more than 90%. Thus, it was observed that depletion percentages in PAR and chlorophyll content are not of the same magnitude and differed in their pattern of depletion, though chlorophyll content is dependent on PAR interception.

Thus the results show that temperature plays an important role in influencing chlorophyll content and biomass production in relation to receipt of photosynthetically active radiation.

SUMMARY

6 SUMMARY

The present investigations were carried out at the Indian Agricultural Research Institute to study the response of rapeseed and mustard crops to the thermal environment under Delhi conditions. Three varieties of Brassica B.O.54(V_1), Pusa Bold(V_2) and Toria-T9(V_3) were sown during *rabi* 1987-88 and 1988-89 seasons at 15-day intervals. Irrigations were provided to maintain "not-short of water" conditions in the root zone.

Daily weather, phenological events, weekly biomass and leaf area index of the plants were recorded in the different treatments. Five-day (pentad) crop growth rates were derived from the growth curves. Daily canopy temperatures were recorded from flowering to maturity at 1300 hrs(IST). Chlorophyll content and photosynthetically active radiation at three canopy levels were recorded periodically during crop growth. Oil content in seeds was estimated both by chemical and NMR techniques.

A study of environmental conditions showed near normal temperatures during 1987-88 season. During *rabi* 1988-89, they were on an average, 4 to 5°C below normal associated with the passage of western disturbances over north India. *Rabi* 1988-89 received 93.6 mm of rainfall during pod development stage and was characterized by lower saturation deficit and bright sunshine hours and a relatively cooler season than 1987-88.

Salient features observed from phenological events were:

i) During the cooler season, vegetative phase in the third sowing in all the treatments was of longer duration when compared with the other two sowings, indicating the influence of temperature. The period corresponded to the lowest mean air temperatures during the growth season under Delhi conditions. (ii) Average maximum temperatures and duration of vegetative phase were negatively correlated, with higher correlation(-0.806) in the cooler season than that (-0.332) in a season with near normal temperatures. Thus, significant differences could occur in the duration of vegetative phase due to influence of cold and warm spells. (iii) Between flowering and pod filling stages in spite of temperature differences between the seasons, Toria-T9 did not show significant variation in duration of phenological events unlike Pusa Bold where variations were large. Thus Toria-T9 proved to be insensitive to short period variations in temperature. (iv) When the duration of total growth season was considered, during the cooler season, while variety B.O.54 was little affected, growth periods in Pusa Bold and Toria-T9 were extended by two and one week, respectively. Flowering stage seemed to be more subject to influence of 4-5°C lower temperature spells which resulted in prolonging the duration of the growth periods.

Results on biomass production showed the production patterns to be highly influenced by thermal environment irrespective of the variety. Depending upon the prevailing temperatures, peak biomass production occurred either at pod formation or early maturity stages while under normal conditions, it would be expected to coincide with pod filling stage. The extent to which higher temperatures during pod filling stage would affect biomass production is illustrated in case of variety B.O.54 where 22 and 30% reduction in biomass was recorded in 1987-88 and 1988-89 rabi seasons, respectively in the second planting compared to the first with a higher reduction in cooler season.

Leaf area index(LAI) was affected by date of sowing, delayed sowing resulting in lower LAI. Time of occurrence of peak LAI was also affected due to temperature differences.

Crop growth rates(CGRs) were seen to be highly influenced by the prevailing temperature regime. During 1987-88, in Pusa Bold peak growth rates of 3.4, 2.1 and 1.2 g/plant/day were recorded compared to 2.0, 1.4 and 1.14 g/plant/day during 1988-89. Peak CGRs occurred either at pod formation or pod filling stages in most of the 18 sowings in this investigation. However, under the influence of short period variation in temperatures, in V_2P_2, V_3P_1 and V_3P_3 peak growth rates were noticed at early maturity stage while in V_1P_2 they occurred as early as late flowering period.

The CGR values during 1988-89 season remained higher for longer period in 6 out of 9 treatments thus compensating for lower temperatures except in V_2P_2, V_2P_3 and V_3P_3 which recorded low CGRs than those in 1987-88.

Case studies for specific periods of occurrence of significantly higher/lower temperatures than normal showed that (i) during late flowering period of the crop, warmer minimum temperatures(7-10°C higher) in this phase led to decrease in CGR by 50 and 30%, respectively in Pusa Bold and Toria-T9. (ii) At the pod development stage of the crop, below normal (4 to 6°C) temperatures during 1988-89 season decreased the CGRs by 50 and 30%, respectively in the second and third sowings of Pusa Bold. (iii) During the pod filling stage, lowering of temperature by 4 to 6°C below normal, resulted in decreasing the CGRs by 30% irrespective of variety or date of sowing.

Studies on the seasonal influence on crop growth patterns showed that in Brassica spp. cooler temperatures not only prolonged the growth period with a slight decrease in CGRs, but also resulted in shifting the time of occurrence of peak growth rates.

Seed yield decreased in Pusa Bold and Toria-T9 in P_3 by 41 and 58%, respectively with reference to P_1, during 1987-88, showing the extent to which higher temperatures at pod filling stage due to delayed sowing would affect the seed yield. Analysis of variance revealed significant differences in yield during the normal season for both varieties and sowing dates whereas during the cooler season, significant differences were confined only to the dates of sowing.

Among all the varieties, Toria-T9 recorded higher harvest index(HI) ranging from 0.3 to 0.39 followed by Pusa Bold(0.24 to 0.33) and B.O.54(0.18 to 0.28). Toria-T9 proved to be superior to other varieties irrespective of seasonal temperature differences. Results on harvest index showed the period around 20th October as the most suitable date for sowing of variety B.O.54 whether the subsequent season was cooler or warmer. In the cooler season, <u>rabi</u> 1988-89, HI increased in the range 27 to 33% in B.O.54.

In the different varieties maximum oil content ranged from 34.7 in Pusa Bold to 42.7% in Toria-T9.

Three different accumulated heat unit systems viz., growing degree days, photo-thermal units and helio-thermal units were computed for studying crop response to thermal environment. Accumulated heat units during the cooler season 1988-89 were higher than those recorded in 1987-88 in case of Pusa Bold and Toria-T9. This was in accordance with the longer duration of phenological stages during this season.

Pheno-thermal index(growing degrees per day) showed a high variation (10.75 to 24.48) during the vegetative stage. The results indicate that in both the seasons much variation in the environmental thermal regime occurred during the vegetative stage.

Phenothermal index(PTI) for the total growth season was found to be nearly constant around a value of 14.3, similar to those reported in wheat and barley crops. Coefficient of variation of PTI was 3.1 and 5.9, respectively during 1987-88 and 1988-89 seasons indicating, relatively more uniform thermal environment during the former season. Pod formation and pod filling stages showed higher "Heat Use Efficiency"(biomass produced per degree day) in Brassica spp.

Oil accumulation in seeds increased linearly with accumulated degree days in long duration varieties. It showed inverse but linear relationship in respect of the short duration variety, Toria-T9 and this is attributable to the progressive decrease in temperatures during the period of oil accumulation in this variety.

Highly significant linear relationships were obtained between biomass, cumulative evaporation and accumulated heat units. From these, biomass production at different 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 different rapeseed and mustard growing seasons.

The regressions showed that for establishment of the crop B.O.54 needed 800 units followed by 750 for Pusa Bold and 650 units in Toria-T9 and 121 mm of evaporation for B.O.54, 118 for Pusa Bold and 106 mm for Toria-T9.

Regression equations were developed for estimation of canopy temperatures using maximum temperatures and mean air temperatures. They reflect the micro- and macro climatic relationships. Canopy temperatures showed highly significant correlations with (a) saturation deficit($r = 0.530$ to 0.901 at 1% level of significance); (b) ambient temperature($r = 0.725$ to 0.933 at 1% level and (c) maximum temperature ($r = 0.187$ to 0.892 at 5% level of significance).

Magnitudes of correlation coefficients were higher in the relatively cooler season 1988-89 in all the varieties.

The relationship between accumulated stress degree days (ΣSDD) during pod filling stage and seed yield indicated SDD at pod filling stage to be a better indicator of seed yield rather than accumulation of SDD from pod filling to maturity stage.

Leaf-canopy temperature differences ranged from 4 to 6°C in early hours of day and decreased to 3 to 4°C in afternoon hours and were the lowest between 1345 to 1545 hours under Delhi conditions. This coincided with the time of highest transpirational cooling in the crop.

Periodic measurement of leaf chlorophyll content at the top, middle and bottom levels of the canopy showed higher values during 1987-88 season as compared to 1988-89 season indicating the effect of seasonal temperature differences. In the earlier growth stages, chlorophyll got depleted by 20% at middle canopy level and 50% at bottom level. An interesting feature was during <u>rabi</u> 1988-89 season, when weather was relatively cooler during the growth season, chlorophyll content at the bottom level remained higher than that recorded during the warmer season, indicating the effect of temperature.

Measurement of photosynthetically active radiation (PAR) at three levels in the crop canopy showed maximum interception during the pod filling and early maturity stages of the crop during the cooler season, whereas it occurred during the pod formation stage in the warmer season. PAR interception during the cooler season remained high for a longer period than during the 1987-88 season. Time of maximum LAI occurrence corresponded to maximum PAR interception at all levels. Unlike in the other <u>rabi</u> crops, wheat and barley, in Brassica, pod surface area also seems to play a significant role in PAR interception as it covers the ground even after occurrence of leaf senescence.

The results thus brought out quantitatively the extent to which biomass accumulation, oil content accumulation crop growth rates, canopy and ambient temperatures at different growth stages were influenced by short period temperature changes that occurred in association with western disturbances over north India. The results also showed significant correlations between accumulated temperatures, evaporation and biomass, canopy and maximum temperatures and dependence of PAR interception on leaf area index which is highly influenced by temperature regime prevailing during different growth stages of rapeseed and mustard crop.

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APPENDICES

Appendix I. Standard meteorological weeks

Week No.	Month	Date
40	October	01 - 07
41		08 - 14
42		15 - 21
43		22 - 28
44		29 - 04
45	November	05 - 11
46		12 - 18
47		19 - 25
48		26 - 02
49	December	03 - 09
50		10 - 16
51		17 - 23
52		24 - 31
1	January	01 - 07
2		08 - 14
3		15 - 21
4		22 - 28
5		29 - 04
6	February	05 - 11
7		12 - 18
8		19 - 25
9		26 - 04
10	March	05 - 11
11		12 - 18
12		19 - 25
13		26 -01
14	April	02 - 08

Appendix II. Environmental conditions during *rabi* 1987-88 season(weekly means)

Met. week	Temperature(°C) Max.	Min.	Mean	Pan Evp. (mm)	S.S(hrs day^{-1})	S.D. (mm)	W.spd. (km hr^{-1})	Weekly rainfall (mm)
1	2	3	4	5	6	7	8	9
40	36.9	20.1	28.5	5.8	8.7	12.7	2.0	0.0
41	36.7	21.1	28.9	5.4	8.2	13.7	3.5	0.0
42	33.7	17.9	25.8	5.3	8.1	10.4	6.5	0.0
43	31.7	13.5	22.6	4.3	2.5	9.1	2.5	0.0
44	31.9	14.5	23.2	4.1	9.3	9.2	3.3	0.0
45	30.2	10.7	20.5	2.9	8.8	8.6	0.7	0.0
46	30.3	10.0	20.2	2.7	8.9	8.8	0.2	0.0
47	29.0	8.0	18.5	2.7	8.9	8.6	2.0	0.0
48	28.2	8.2	18.2	3.0	9.2	8.5	2.7	0.0
49	24.1	5.3	14.7	2.9	8.5	5.9	3.6	0.0
50	21.9	7.8	14.9	1.2	4.9	3.9	3.2	6.0
51	23.4	5.6	14.5	1.5	7.6	4.8	2.2	0.0
52	25.4	6.2	15.8	1.1	6.8	5.6	2.7	0.0

Appendix continued....

Appendix II continued......

1	2	3	4	5	6	7	8	9
1	22.5	7.5	15.0	1.4	4.7	3.9	3.1	0.0
2	22.6	7.7	15.2	1.5	6.5	3.9	3.2	0.0
3	22.5	5.8	14.1	2.3	7.9	4.6	4.1	0.0
4	21.8	4.9	13.4	3.1	8.7	5.4	5.8	0.0
5	23.3	7.0	15.2	3.7	8.4	5.7	7.3	0.0
6	27.2	8.4	17.8	3.5	9.0	6.8	3.4	0.0
7	23.5	10.4	17.0	2.5	7.0	4.6	5.9	9.2
8	25.1	11.4	18.2	4.3	7.3	6.0	7.2	0.0
9	26.2	11.4	18.8	4.3	8.4	6.6	7.0	8.2
10	29.4	13.9	21.7	4.4	6.8	7.0	4.9	19.8
11	27.3	14.5	20.9	4.9	7.9	6.2	7.2	32.8
12	29.4	12.9	21.2	6.1	9.5	10.1	6.5	0.0
13	31.2	14.6	22.9	7.3	8.6	11.6	7.7	3.8
14	35.3	17.3	26.3	7.7	9.6	15.1	6.0	0.0

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(1988-89 season(weekly means)

Met. week	Temperature(°C) Max.	Min.	Mean	Pan Evp. (mm)	S.S(hrs day^{-1})	S.D. (mm)	W.spd. (km hr^{-1})	Weekly rainfall (mm)
1	2	3	4	5	6	7	8	9
40	33.3	20.1	26.7	4.8	8.9	10.6	3.8	0.0
41	32.8	17.9	25.4	4.9	9.4	13.2	3.6	0.0
42	33.9	17.2	25.6	4.5	9.7	14.1	2.3	0.0
43	33.5	16.8	25.2	4.3	9.4	12.6	1.3	0.0
44	30.8	13.6	22.3	2.9	8.4	9.1	0.7	0.0
45	31.1	13.1	22.1	2.6	8.6	9.8	0.8	0.0
46	29.1	11.6	20.4	2.3	7.8	7.9	0.9	0.0
47	27.3	12.1	19.7	1.5	7.5	7.9	2.0	0.0
48	25.1	6.8	16.0	2.4	8.8	6.9	4.1	0.0
49	25.2	15.7	15.4	2.1	8.7	6.6	3.0	0.0
50	25.0	7.0	16.0	1.5	6.6	6.5	1.3	0.0
51	23.6	12.0	17.8	1.6	4.3	4.9	3.1	0.0
52	24.5	8.2	16.4	1.9	6.7	5.8	4.1	1.0

Appendix continued......

Appendix III continued....

1	2	3	4	5	6	7	8	9
1	20.9	10.0	15.4	1.2	4.6	3.3	6.4	35.6
2	16.7	5.1	10.9	2.2	7.3	2.8	6.5	28.0
3	18.9	4.4	11.7	2.2	9.0	3.9	3.9	0.0
4	21.5	4.0	12.8	3.0	9.6	5.2	3.5	0.0
5	23.2	8.3	15.8	3.6	8.4	6.2	5.7	0.0
6	21.6	6.0	13.8	3.7	8.9	4.7	3.7	0.0
7	22.3	7.9	15.1	3.6	8.3	5.1	3.2	0.0
8	23.2	6.8	15.0	3.8	8.6	6.3	4.8	0.0
9	28.0	11.0	19.5	4.5	10.1	9.0	6.2	0.0
10	28.8	11.4	20.0	4.3	8.2	8.0	4.8	0.0
11	27.3	14.0	20.6	4.0	8.2	7.3	4.5	4.2
12	30.3	16.9	23.6	5.1	8.3	10.4	4.3	0.0
13	29.1	15.1	22.1	3.8	6.8	7.7	3.1	24.8
14	30.9	14.4	22.7	7.3	10.9	12.8	10.8	0.0

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 (°C)

Day of month	October		November		December		January		February		March		April	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1			29.6	14.0	24.6	9.9	21.8	6.6	21.5	9.5	26.8	12.0	34.5	18.5
2			29.6	14.0	24.6	8.7	22.4	7.3	22.0	9.0	26.6	12.9	34.1	18.2
3			29.6	14.0	25.3	9.3	21.6	6.5	22.3	9.3	27.5	13.3	34.2	18.1
4			30.4	14.1	25.0	9.3	21.8	7.1	22.7	9.4	27.0	12.8	34.4	18.4
5	34.4	20.7	29.6	14.3	24.9	9.1	21.5	7.0	22.9	8.6	26.6	13.0	33.9	17.6
6	34.3	21.4	30.3	14.3	24.6	8.8	20.7	7.5	23.4	9.3	26.8	12.7		
7	34.5	20.7	30.2	12.8	23.9	8.8	20.9	6.0	22.6	8.6	28.0	13.5		
8	33.9	19.8	30.0	12.7	23.5	9.3	20.8	7.0	22.8	9.3	28.0	13.5		
9	34.0	19.5	30.0	12.7	23.5	8.8	20.6	7.2	22.7	8.8	28.1	14.0		
10	34.4	20.1	30.0	12.7	23.8	8.9	21.4	7.1	23.0	9.7	28.4	14.0		
11	33.7	19.8	30.1	13.3	23.9	9.0	21.5	6.7	22.5	10.0	28.0	13.6		
12	32.5	20.3	29.3	11.8	24.0	8.2	21.2	7.1	23.0	9.7	30.0	14.9		
13	31.8	18.6	28.5	11.8	24.4	7.8	20.8	10.8	23.3	9.5	30.0	13.0		
14	33.4	19.5	29.4	12.4	23.6	8.0	20.8	7.1	22.6	10.3	30.0	15.0		
15	33.0	19.0	29.5	12.5	23.8	8.3	20.5	6.8	24.0	9.6	29.8	15.4		
16	33.0	18.6	27.7	12.4	24.1	8.1	20.8	7.5	23.6	10.2	29.3	15.5		
17	33.0	18.6	28.0	10.6	23.4	8.0	21.5	7.1	24.0	9.5	30.7	15.4		
18	32.6	18.3	27.6	11.0	22.9	8.4	21.5	7.0	24.3	9.7	30.6	18.8		
19	32.9	18.0	28.4	11.0	23.1	8.5	20.5	6.6	24.0	10.2	31.5	19.1		
20	33.1	18.4	28.0	10.6	22.5	7.0	20.6	6.7	24.6	11.0	31.3	15.5		

Appendix continued.......

Appendix IV continued......

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
21	32.6	15.6	27.9	10.8	25.3	8.5	21.2	8.5	25.5	11.3	32.0	15.1		
22	33.0	17.5	27.0	9.6	22.5	8.3	21.0	7.8	25.0	11.1	32.0	15.3		
23	32.2	16.6	26.6	9.9	22.6	8.4	21.4	7.8	25.3	10.9	31.8	15.5		
24	31.8	17.5	27.5	9.5	23.5	8.0	21.5	7.7	25.0	10.8	32.3	16.2		
25	31.5	17.4	27.5	10.1	23.1	7.5	22.0	8.5	25.9	12.2	31.7	15.7		
26	32.5	16.6	25.7	9.8	22.1	7.7	22.5	7.6	25.6	11.9	33.2	15.8		
27	32.0	17.1	26.5	9.9	21.6	7.0	22.0	8.3	25.9	12.5	33.2	16.8		
28	31.6	16.5	26.1	9.9	22.3	7.3	22.3	8.1	25.6	11.5	33.4	17.5		
29	31.7	15.7	25.6	10.0	22.5	7.4	21.6	8.2			32.9	18.3		
30	31.5	15.9	26.4	9.7	21.8	7.3	22.2	7.7			33.2	17.0		
31	32.0	16.5			22.5	7.4	22.0	8.8			33.4	16.6		

Max. = Maximum; Min. = Minimum.

Appendix V(a). Soil moisture(% gravimetric) in variety B.O.54 at vegetative and pod filling stages

Depth (cm)	Vegetative			Pod filling		
	P_1	P_2	P_3	P_1	P_2	P_3
			Rabi 1987-88			
00-15	5.9	5.3	18.6	4.6	10.0	9.2
15-30	9.3	9.5	17.3	7.3	9.7	9.7
30-45	9.4	8.5	17.4	10.5	4.7	13.2
45-60	12.9	11.0	17.5	11.3	8.8	14.2
60-90	15.7	15.5	17.4	12.0	8.8	14.7
90-120	16.7	16.0	17.2	12.9	8.6	14.7
			Rabi 1988-89			
00-15	7.7	11.3	17.2	16.9	9.8	10.4
15-30	17.3	12.4	16.2	20.0	12.4	13.1
30-45	13.7	14.0	17.1	17.6	13.8	13.2
45-60	16.0	16.2	18.8	18.4	14.0	17.7
60-90	16.9	16.3	19.7	18.7	15.8	18.5
90-120	18.1	18.9	19.7	19.1	17.9	19.7

Appendix V(b). Soil moisture(% gravimetric) in variety Pusa Bold at vegetative and pod filling stages

Depth (cm)	Vegetative			Pod filling		
	P_1	P_2	P_3	P_1	P_2	P_3
			<u>Rabi 1987-88</u>			
00-15	3.5	4.6	8.0	8.7	6.6	8.5
15-30	11.1	8.6	13.0	7.1	8.0	8.7
30-45	14.2	8.6	15.8	7.9	8.9	12.4
45-60	15.1	11.2	16.5	8.9	8.8	13.7
60-90	15.9	12.3	17.2	11.0	9.2	14.6
90-120	15.8	15.4	17.2	12.0	12.2	15.6
			<u>Rabi 1988-89</u>			
00-15	7.0	9.8	12.0	7.7	10.9	7.3
15-30	10.6	10.3	10.9	8.7	11.5	10.3
30-45	12.8	13.3	12.4	12.2	13.6	12.5
45-60	15.8	16.2	15.7	14.6	15.9	16.3
60-90	19.9	17.4	15.6	16.0	17.4	18.4
90-120	18.2	18.0	17.1	17.3	18.5	19.6

Appendix V(c). Soil moisture(% gravimetric) in variety Toria-T9 at vegetative and pod filling stages

Depth (cm)	Vegetative			Pod filling		
	P_1	P_2	P_3	P_1	P_2	P_3
			Rabi 1987-88			
00-15	6.3	10.4	14.6	5.3	8.7	5.2
15-30	10.4	16.7	11.2	8.6	8.0	8.5
30-45	11.9	20.6	13.5	16.6	9.8	9.8
45-60	13.8	21.5	15.6	15.1	12.0	11.9
60-90	15.9	23.5	16.4	14.8	12.6	13.2
90-120	16.0	23.6	15.9	16.5	13.1	14.1
			Rabi 1988-89			
00-15	8.8	8.4	9.6	14.5	8.2	8.4
15-30	10.2	9.6	11.0	14.4	11.8	8.2
30-45	14.1	13.0	13.7	13.8	14.3	13.0
45-60	16.7	15.6	16.5	16.1	16.1	16.2
60-90	17.9	17.3	18.7	12.7	18.2	18.5
90-120	19.0	18.3	18.6	13.5	18.3	19.4