STUDIES ON SIMULATING BIOMASS ACCUMULATION AND ITS PARTITIONING IN WHEAT (*Triticum aestivum* L.)

Dissertation

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By

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(L-2007-BS-23-D)

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CERTIFICATE I

This is to certify that the dissertation entitled**, "STUDIES ON SIMULATING BIOMASS ACCUMULATION AND ITS PARTITIONING IN WHEAT (*Triticum aestivum* L.)"** submitted for the degree of **Doctor of Philosophy,** in the subject of **Botany** (Minor Subject: Agricultural Meteorology) of the Punjab Agricultural University, Ludhiana, is bonafide research work carried out by **Tilak Raj (L-2007-BS-23-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

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

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CERTIFICATE II

This is to certify that the dissertation entitled**, "STUDIES ON SIMULATING BIOMASS ACCUMULATION AND ITS PARTITIONING IN WHEAT (*Triticum aestivum* L.)"** submitted by **Tilak Raj (L-2007-BS-23-D)** to Punjab Agricultural University, Ludhiana in partial fulfillment of the requirement for the degree of **Doctor of Philosophy**, in the subject of **Botany** (Minor Subject : Agricultural Meteorology) has been approved by the student's Advisory Committee after an oral examination of the same, in collaboration with an external examiner.

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ABSTRACT

Field and laboratory experiments were carried out at Punjab Agricultural University, Ludhiana during *rabi* season to study the simulating biomass accumulation and its partitioning in wheat (*Triticum aestivum* L). The 15th Nov. sowing utilized maximum energy (1230507 CEDU) as compared to 15th Oct. and 15th Dec. sowing. The maximum number (12) of leaves appeared in 15th Oct. and 15th Nov. sowing as compared to late sowing. The maximum cumulative thermal and photo thermal units was recorded in cv. PBW-343 for the appearance of twelve leaves. The maximum leaf emergence rate 0.245 leaves/day was observed by using 100 GDD (growing degree days). The first tiller was observed when the third leaf on the main shoot appeared. Grain growth duration is strongly responsive to temperature one degree rise in temperature during grain filling result in 2.56 days decrease in the grain filling irrespective of cultivars. Validation of CERES-wheat model and Infocrop models showed that the CERES wheat predicted phenological stages satisfactorily based on RMSE from seedling emergence to physiological maturity. The yield and yield contributing attributes like number of effective tillers (m^{-2}) (RMSE=5.8), number of grain (m^{-2}) (RMSE = 3647), test-weight (RMSE=1.9), grain yield (RMSE=1.2) and harvest index (RMSE=1.1) calculated by the CERES - wheat model are smaller than the values calculated from the Infocrop model effective tillers (RMSE = 110) number of grain (m^{-2}) (RMSE = 80296), 1000-grain weight (RMSE = 25), grain yield (RMSE = 13) and harvest index (RMSE =2.2). Path coefficient analysis indicated that dry matter at 90 days had direct effect on grain yield. Components viz. a viz. dry matter at 105 days, grain: spike weight and ear: stem ratio had indirect effect on grain yield through dry matter at 90 days. Dry matter at 90 days showed significant correlation with grain yield. Multiple linear regression analysis showed highly significant correlation with the grain yield and there was strong interaction between thermal, photothermal and grain yield as ACCDU ($r = 0.91$), CEDU ($r = 0.95$), PTU ($r = 0.98$) and HTU ($r = 0.98$). The multiple regression equation can be used to predict the yield by using these independent variable as $Y = 10563.8 + 6.94 (GDD) - 15.04 (ACCDU) + 0.23 (CHETA) - 0.0875 (CEDU) + 0.481 (PTU) + 0.094 (HTU)$. The CERES-wheat model showed lower value of RMSE for grain at grain formation stage (0.5), dough stage (0.63), physiological maturity (2.0) while the Infocrop model gave RMSE value of grain at grain formation stage (1.04), dough stage (1.37) and at physiological maturity (2.1). CERES - wheat model predicted the yield satisfactorily but the Infocrop model was under estimating the grain yield. Infocrop model was also unable to give satisfactorily result for the source - sink time series.

Key words. Phenology, Thermal unit, CERES-wheat, Infocrop, regression models, source-sink

Signature of Major Advisor **Signature of the student**

CONTENTS

CHAPTER - I

INTRODUCTION

Wheat occupies prime position in modulating the economy of India. Yield of wheat is the final product of a complex system consisting of several sub–systems, involving weather, soil production technology. Improvements in production as well as productivity of wheat are being masked by the multitude of agronomic constants, degradation of soil fertility and alarming shift in climate and weather conditions. Future forecast suggest that gradual increase in ambient temperature, alteration in rain pattern coupled with drought and flood are going to have alarming impact on agriculture (Sadaras and Monzan 2006).

Grain number is basically a consequence of the ability of the plant to accumulate resources. Plants have an elegant ability to adjust grain number to match the accumulated resources within the limited range size (Sadras 2007). Amongst various approaches linked up with crop improvement, major emphasis has to be given to develop crop varieties suitable for sustainable agriculture. Mohan *et al* (2001) suggested that top most priority should be given to develop normal as well as late sown varieties for the northwestern region and northeastern planes of India. Amongst various researches, approaches and simulation models are being used extensively and are being equipped aggressively to be and for crop improvement. The ability of crop simulation models to predict growth and yield as influenced by the agronomic practices, crop traits and environmental factors, suggests that these can identify the traits to realize the potential yield (Huang and Tang 2006). Growth model seem ideal for studying variations in cultivation response x environment x genotypes interaction. These are also instrumental in providing references for quantitative insight in crop raising under given climatic conditions (Evers 2004).

The models consider the key processed related to crop growth, effect of water deficit, flooding, nitrogen management, temperature and frost stress, crop- pest interactions, soil water and nitrogen balance and organic carbon dynamics. In order to develop better understanding about the significances of number of organs, their determinants and the consequence of specific physiological responses, models are needed that are capable of describing the morph genesis and ontogeny of the crop in more detail than can be done in empirical simulation models. In wheat, development of grain is primarily dependent on starch synthesis and accumulation, which will determine the yield and quality of produce. There is little information on the sensitivity of grain weight of other cereals to variation in source-sink ratios at post-anthesis in barley (Drecer *et al* 1997). The association between grain size and degree of source limitation during grain filling is based on association between grain size and degree of source limitation (Ma *et al* 1990). The degree of source limitation in wheat would be related to the environmentally determined limitation to assimilation rate during the grainfilling period Daniel *et al* (2006). Rate of starch accumulation and increase in dry weight of the grain are affected by factors, such photosynthates assimilation in leaf, biomass accumulation and remobilization in the stem and starch synthesizing ability of the grain sink (Pan, Zhu and Cao 2007). A dynamic approaches for developing a simulation model on grain starch accumulation vis-à-vis grain growth in wheat, is intended to quantify the process of carbon assimilation and remobilization and to predict starch concentration of wheat under growing condition.

Leaf appearance is a critical process involved in canopy development, structure, and dynamics (McMaster and Wilhelm 1995). Many factors influence the rate of wheat leaf appearance, or phyllochron, including light (quality, quantity, and photoperiod), water, nutrient availability, salinity, and CO_2 (McMaster 1997). The phyllochron increased exponentially with increasing temperature for all the eight genotype. The relationship between phyllochron and temperature fit exponential equation. As the temperature increased, more thermal energy was needed to produce a leaf, and the thermal efficiency decreased (Cao and Moss.1989). The time interval between the emergences of successive leaves in cereals varies with temperature (Gallagher 1979). The degree-days required to produce a leaf is an important parameter of many dynamic crop growth simulation models (Klepper *et al* 1985 and Porter 1985). Baker *et al* (1980) and Kirby *et al* (1982) suggest that the phyllochron in wheat and barley is different for different planting dates because the phyllochron is fixed by the rate of day length change at crop emergence.

Greater pre anthesis nitrogen accumulation usually results in stimulation of area development (Banzier *et al* 1994), as well as allowing high leaf photosynthetic rates The resource accumulation prior to anthesis is critical to determining grain number (Sinclair and Jmieson 2008). Wheat plant produces a large number of floret primordial during early spring, and the number of component florets essentially determines grain number at anthesis. However, most florets promodia suddenly degenerate at booting, around the time for meiosis in anthers: thus only a small proportion of florets survives and completes their development to produce fertile florets (Langer and Hanif 1973). Demotes – Mainard *et al* (1996) have been reported that partly degenerate florets can nevertheless set a grain when cross fertilized by exogenous pollen. However, most degenerate florets usually compete their necrosis and disappear before anthesis. Miralles *et al* (2000) they observed that photoperiodic treatment accelerated plant and spike development this hastened and increased florets death. Thus both the source and the source: sink ratio may affect the timing and extent of florets death. Spike/stem competition is frequently claimed to be the cause of florets death. The reduction of stem length lead to increase in grain number (Shearman *et al* 2005). Peltoman (1993) reported that maximum number of florets primordial and floret survival in the whole spike to grain. The spike water-soluble carbohydrate concentration does not follow dry matter partitioning: it was unexpectedly but consistently higher in tall genotypes than in corresponding isoline.

Aggarwal *et al* (1994) observed that comparison of simulated and measured quantities indicated satisfactory performance of the infocrop model in reference of the model in reference to nitrogen uptake, dry matter growth and grain yield in potential as well as water and N limited environment. The model is useful tool for optimizing use of water and nitrogen. Crop growth simulation models are quantitative tools based on scientific knowledge that can evaluate the effect of climatic, edaphic, hydrologic and agronomic factors on crop yield and stability (De Wit 1978; Loomis *et al* 1979; Whisler *et al* 1986). The total amount of carbohydrate partitioned into leaves, stems, spike structure, grains and roots as function of development stage based on field experiment of Aggarwal (1983) and Fischer (1983). Arora and Gajri (1998) reported analysis of grain yield indicates low yields with large variance in rain fed environments. Supplement irrigation and higher soil water retentivity increases mean grain yield and reduces the effects of annual rainfall variability. This study suggests that the model can be applied for optimizing water use at field scale. Sink size post –anthesis is still the main factor controlling grain yield by Richards (1996). Aggarwal *et al* (2006) Dynamic of growth parameter have been found suitable to analyze and design ‘ plant type’ and to explain interaction between tillering, canopy structure and yield performances of the crop.

The characteristics of leaf area index development associated with nitrogen accumulation in the leaves determine the nitrogen content per unit leaf area that is one of the major determinants of radiation-use efficiency (Sinclair and Horie 1989). There fore accurate understanding of the leaf area index dynamics during crop growth is necessary to quantify the photosynthetic productivity. Many mathematical models for explaining LAI dynamics have been developed as apart of process based crop growth model to predict biomass growth and yield in many major crops Kropff *et al* (1994). Semchenko and Zobel (2005) showed that the allometric relation ship between leaf area and biomass growth in Oat was affected by genotypes and environment. Crop Leaf Area Index (LAI) dynamics was relates leaf area index development with plant or leaf nitrogen accumulation (Yin *et al* 2003). The rate of leaf area index development is governed by two plant factors i.e. RGR (Relative Growth Rate) and LNC (Leaf Nitrogen Content) Yoshida *et al* (2007).

CERES- wheat predictions of dates of flowering and physiological maturity were reasonably good for use in crop management application and research. Generic crop model RZWQM does not predict phenology explicitly for application in crop management by (Saseendran *et al* 2004). Ritchie and Otter (1985) has given description and performance of CERES-wheat model. Simulation of various crop and fertilizers management strategies using such models can lead to better fertilizer decision making (Paz *et al* 1998, 1999). The quantitative impact of temperature on photosynthesis in wheat has been described only weekly (Versteeg and van Keulen 1986). Spitters *et al* (1989) reported that the impact of non-unioform canopy N profiles on total above ground biomass was analyzed with a crop growth simulation model SUCROS. The leaf assimilation rate at light saturation – leaf nitrogen relation strongly depends upon the leaf status it appears curvi –linear with variation in leaf nitrogen (N) induced by nitrogen availability, and linear with variation in leaf N caused by light regime Bindrabam (1999). Multiple regression models have been developed to determine irrigation and N fertilizer requirement of crops (Gajri *et al* 1993). Crop simulation can serve as a useful tool to optimize use efficiency of water and nitrogen in environments varying in both climatic factors and input resources Aggarwal and Kalra (1994).

Models can use leaf number and a constant phyllochron to predict time of flowering as in CERES- Maize (Jones and Kiniry 1986). Phyllochron is fairly stable at individual locations while differing greatly among tropical, warm temperate and cool temperate latitudinal zones. Typically, maize phyllochron is 30% longer in tropical than in temperate area (Kiniry and Bonhomme 1991). Birch *et al.* (1998) showed a relationship between phyllochron and mean temperature from emergence to tassel initiation, and a coefficient for the effects of irradiance on phyllochron should improve the modeling of leaf number during canopy growth and thus the time of flowering. Mainard *et al* (1999) reported that there was strong linear relationship between kernel number per spike and spike dry matter at anthesis.

Ritchie (1987) simulated the wheat development model using the temperature to calculate thermal time for leaf and tiller appearance and the time of seedling emergence, terminal spikelets and of leaf growth, anthesis, beginning of grain and physiological maturity. Leaf area development is a function of number of tillers per unit land area; number of leafs per tiller and leaf size. Maximum leaf area index reached its peak before flowering Fiscuer and Kohn (1995). Cruz-Agudo *et al* (2000) reported that dry matter reduction from the second internodes during grain filing was positively correlated with yield, mass per grain, number and mass of grain per ear head and harvest index. Sekhon (1987) reported that the rate of dry matter accumulation increased but the duration decreased with delay in sowing. Maximum dry matter accumulation in grain took place between 30 to 52 days after anthesis (DAA) in early sowing; 21 to 30 days after anthesis in normal sowing and 10 to 20 days after anthesis in late sowing. Dhingra (1990) reported that high positive correlation between leaf area index and grain yield and obtained a quadratic equation between two. Leaf area index of 7.5 is optimum for maximum yield. A simulation model developed by Van Keulen and DeMillin (1984) predicted that increase of 20% in total global radiation resulted in 10-20% increase in grain yield. Similarly an overall 20% decrease in solar radiation depressed the yield by 30% due to incomplete light interception during anthesis phase.

Jamieson *et al* (1998) reported the Sirius Wheat simulation model that calculated biomass production from intercepted photosynthetically active radiation and grain growth from simple partitioning rules. Leaf area index was developed from a thermal time sub model. The model proved useful in investigating the effect of stress in setting grain number. Fischer (2008) Argues that grain yield in modern cultivars is still limited by post anthesis sink and that understanding sink determination is therefore useful for predicting physiological routes to higher yield. Sink determination appears to be strongly related to dry matter accumulation in spikes at anthesis, governed by events in the last 20-30 days before anthesis.

Slafer and Savin (1994) reported that during post- anthesis period, grain yield of wheat is either sink – limited or co – limited by both source and sink but never source limited. Savin and Slafer (1991) proposed that the capacity of the grains to accumulate assimilates (i.e. sink strength) is more important in determining yield potential than the supply of assimilates (i.e. source strength). The ratio of shoot dry – weight 10 DAA to potential ear productivity shows the degree of ear provision with biomass, and enables a quantitative evaluation of source/sink relations. There is close positive correlation between potential productivity and leaf area duration from tillering to flowering. 100 grains weight, grain N concentration increased markedly with decreasing sink size Koshkin and Tararina (1989). Borras *et al*, (2004) reported that growth of wheat seed is apparently more sink- than limited in most conditions.

Grain number was poorly predicted by partitioning to spike of either mass or shoot growth rate at critical time. In contrast, florets surviving proportion was highly correlated to partitioning and multiple correlations did not indicate a significant effect on survival of non-spikes growth rate Bancal (2008). These result showed that on- the-go, optical sensor technology can used to accurately estimate winter wheat tiller density for determining and applying appropriate ground N fertilization rates at a 1 m^{-2} resolutions with minimal ground thruthing required (Phillipes *et al* 2004). Patel and Shekh (2005) reported that the model used had the potential for assessing the impact of climate change on wheat production. Large yield reductions were noted under increasing plant population both in optimal and sub optimal condition this provided strong evidence in respect of robustness of the model to account for the effects of plant population.

Objectives:

1. To evaluate the relationship between agronomic practices, weather parameter, growth and yield of wheat.
2. To explore time trend in ontogeny, phenology, growth and yield as affected by warming trend.
3. To generate source and sink functions by calibrating growth models, embodying time- series and development of plant organs.

CHAPTER-II

REVIEW OF LITERATURE

Wheat is thermosensitive long-day crop. Various parameters get affected by temperature stress. The information pertaining to "Studies on simulating biomass accumulation and its partitioning in wheat (*Triticum aestivum* L.)" has been reviewed in this chapter under following headings:

2.1 Phenological Growth Models
2.2 Effect of Thermal and Photothermal units on Phenological Development
2.3 Physiological Traits
2.4 Source - Sink Relationship
2.5 Yield and Yield Contributing Attributes
2.6 Biochemical Analysis

2.1 Phenological Growth Models

Understanding crop phenology is fundamental to crop management, where timing of management practices is increasingly based on stages of crop development. Simulating canopy development is also critical for crop growth models, whether to predict the appearance of source and sinks, determining carbon assimilation and transpiration, partitioning carbohydrates and nutrients or determining critical life cycle events such as anthesis and maturity. A new generation of wheat models began to emerge in the 1980's that changed from energy/carbon-driven to more development driven (ARCWHEAT, Weir *et al* 1984, SHOOTGRO, McMaster *et al* 1992, MoDWht, Rickman *et al* 1996) simulations. Regardless all growth models benefit from good` phenology submodels. Modifying existing plant growth models to simulate other crops in agroecosystem analyses if developmental sequences are available.

Ritchie (1986), Khichar and Niwas (2007) and Bazgeer *et al* (2008) used growing degree days to predict phenology. Place and Brown (1987), Singh and Pal (2003) estimated crop phenology on the basis of crop thermal time. Some used photothermal and other used heliothermal units to construct crop growth simulations models (Narwal *et al* 1986). Haun (1973) gave the visual quantification of wheat growth and suggested that the rate of development was determined by substraction of the previous stage of the development from the current stage and sub-dividing the growth units into decimal fractions. Zadocks *et al* (1974) recorded ten different growth stages in cereals i.e. germination (0) seed growth (1) tillering (2) stem elongation (3) booting (4) inflorescence emergence (5) anthesis (6) milk development (7) dough development (8) ripening (9). Whereas eleven growth stages of wheat were described by Waldren and Flowerday (1979). Bruns and Croy (1983) gave description of the key developmental stages of winter wheat which are easily identifiable.

Weir *et al* (1984) inferred that the interval between emergence and double ridges shortens with increased delay in sowing and this trend continued in the next phase upto anthesis. The observed period from anthesis to maturity varied from 49-63 days. The longest grain filling periods were for the early and late sown crops in cooler summer. Phenological models of CERES-wheat, TAMW and Robertson, 3 winter wheat were compared for estimating jointing, heading, dough and ripe stage accurately. Vikki and Tom (1985) concluded that the CERES-wheat model estimates were consistently more accurate for all stages.

The rapid change in the agricultural industry driven by continuously arising challenges (climate change, market globalization, environmental concern) requires the development of new methods of productions in order to guarantee sustainable agriculture, among the tools available for evaluating cropping systems or investigating alternative cropping system, field based approaches such as regional agronomic diagnosis and prototyping have been tested and used successfully.

Providing accurate estimates of the benefits and risks of alternative crop management system with knowledge of expected yield before final harvest has placed an increasing demand on crop simulation models. Assess ting the individual decision – makers to manage production risks in a more effective manner is of utmost importance (Anderson, 1974).To provide such assistance a detailed quantification of production risks is required.

In many cases, quantitative information on production can only be obtained through crop simulation studies and long term climatic records (MacDonald and Hall 1980, Matis *et al* 1985, Bouman *et al* 1995) understanding the impact of weather on crop productions by applying simulation models provides a credible basis for a quantitative estimate of the range of yields farmers can expect for a given set of management conditions (Arkin and Dugas 1981, Hammer *et al* 1996, Tsuji *et al* 1998).

The use crop simulation models for predicting crop yield as functions of weather and climate has been studied extensively (Hoogenboom 2000). These applications range from predicting yield at a farm levels to predicting regional and national yield levels although large scales predictions are normally more common (Travasso and Delecolle 1995, Supit 1997). Most of these predictions application includes forecast that are conducted before planting while some simulations are conducted during the growing season. Recently there has been increased interest in the use of crop simulation model in associations with spatial variability and precision farming (Paz *et al* 2001). The application of crop models to optimized in season management for spatially variable fields in particular provides farmers with the options to reduce the input and increase net returns (Booltink *et al* 2001). High accuracy of the yield forecast would attract more farmers and others associated with agribusiness. Weather forecast services tailored for the specific needs of the farming community are now becoming more readily available around the world (Georgiev and Hoogenboom 1998, Fox *et al* 1999). Evaluation of these services to farmers is increasing important to help set budget priorities. If crop models would be able to predict final yield with the reason able accuracy within the growing season, it might justify the cost of supplying weather forecast in a competitive market. As a further extension of this approach, stochastic modeling can be used to determine the probability of distribution of yield and risks associated with the certain management decisions. This in the contrast to deterministic model where the predicted values are computed without consideration of their variability.

CSM-CERES-Rice and CSM-CERES-Wheat models are process based, management-oriented models that can simulate the growth and development of rice and wheat as affected by varying levels of weather, water, nitrogen, and cultivar characteristics (Jones *et al* 2003). The model processes indicate the effects of elevated CO_2 and changed climatic parameters such as increased or decreased temperatures, rainfall and solar radiation. These models have been validated and tested across the world, including many countries in Asia (Timsina and Humphreys 2003) and in North-West India (Timsina *et al* 2004), and hence are suitable for investigating the sensitivity of both rice and wheat yields to CO_2 and climate change parameters.

Travis and Day (1988) modelled the early apical development of Avalon winter wheat using ARC WHEAT. The sub model of ARCWHEAT expressed the developmental rate as the separate responses to temperature and photoperiod as compared with various alternative models. None of these models fitted better than the ARCWHEAT, when tested against data, predicting double ridge stage more accurately and terminal spikelet as accurately as the original parameter values.

Kanchan (2009) observed that the regression model showed significant positive correlation grain yield and growing degree days accumulated during different phenophases. The correlation coefficient analysis of different agrophysiological traits like 1000 grain weight, biological yield showed positive correlation with the grain yield (Aman 2008). The regression model showed significant positive correlation grain yield and growing degree days accumulated during different phenophases (Pahawa 2002).

McMaster *et al* (1986) reported a winter wheat simulation model named SPIKEGRO-1.0. This model extended the period of simulation of SHOOTGRO from booting through physiological maturity. Individual floral development and growth within each spike was simulated with a daily time step. The model simulated yield on land area, plant, culm, spikelet and kernel basis. Ritchie and Otter (1985) simulated the effects of crop genotypes, soil physical properties and the weather on growth and yield from CERES (Crop Environment Resource System)- wheat model. The simulation of growth and development and yield was based on the quantification of the various physiological processes i.e. phenological behaviour as affected by genotype x environment interaction.

Sirius is a wheat simulation model that calculates biomass from intercepted photosynthetically active radiation (PAR) and grain growth from simple partitioning rules. Leaf area index (LAI) is developed from a simple thermal time sub-model. Phenological development is calculated from the main stem leaf appearance rate and final leaf number, with the latter determined by responses to daylength and vernalisation. Effects of water and N deficits are calculated through their influences on LAI development and radiation-use efficiency. Despite there being no calculation of tiller dynamics or grain number, the model accurately simulated the behavior of crops exposed to a wide range of conditions (Semenov *et al* 2007).

Ritchie (1987) simulated the wheat development model using the temperature to calculate thermal time for leaf and tiller appearance and the time of seedling emergence, terminal spikelet and leaf growth, anthesis, beginning of grain growth and physiological maturity. Ritchie and Hanks (1991) described a model adapted from the CERES-wheat model and using weather and genetic information to calculate the dates of different phases of wheat development. Shah and Haider (1995) from their field experiment observed that the number of days to seedling emergence ranged from 11 with sowing on 25 October to 21 days with sowing on 25 December. The number of days to emergence increased as the temperature decreased. Model for predicting wheat seedling emergence was developed where the average temperature and photoperiod were the most accurate parameters for predicting the days to emergence of wheat seedlings.

Robertson *et al* (1996) developed a predictive model of final leaf number in response to a range of temperatures imposed at different plant age. Which accounted for the balance between the concurrent processes of leaf primordium initiation and the rate of saturation of vernalization. Shayewich (1995) reviewed the responses of phenological development of cereal crops to environmental conditions and concluded that the development rate of most species was a sigmoidal rather than a linear function of temperature.

A method was developed by Harrison (2000) for scaling-up the AFRCWHEAT2 model of phenological development from the site to the continental scale. Four issues were addressed (i) the estimation of daily climatic data from monthly values, (ii) the estimation of spatially variable sowing dates, (iii) the simulation of multiple cultivars, and (iv) the validation of broad-scale models. Three methods for estimating daily minimum and maximum temperatures from monthly values were compared using AFRCWHEAT2: a sine curve interpolation, a sine curve interpolation with random daily variability, and two stochastic weather generators (WGEN and LARS-WG). The sine curve interpolation was selected for the continental scale application of AFRCWHEAT2 because computational time was short and errors were acceptably small. The average root mean square errors (RMSEs) for the dates of double ridges, anthesis and maturity were 6.4, 2.2 and 2.1 days, respectively. The spatial variability of European sowing dates was reproduced using a simple climatic criterion derived from the AFRCWHEAT2 vernalization curve. The use of several cultivar calibrations enabled the broad-scale model to capture current responses and compare responses to future climate change. Results from the continental scale model were validated using a geographically-referenced database of observed phenological dates, output from other site-based models and sensitivity analysis. The spatial model was able to emulate a similar spatial and temporal variability in phenological dates to these sources under the present climate. The predominant effect of an increase in mean temperature was a reduction in the emergence to double ridges phase. The shift in the timing of subsequent development stages to earlier in the season meant that changes in their duration were relatively minor. Changes in inter-annual temperature variability resulted in only small changes in the mean date of development stages, but their standard deviation altered significantly.

Jamieson *et al* (1996) presented a model which used the rate of appearance of leaves, the number of leaves, and their responses to daylength and temperature to determine the timing of anthesis in wheat. Cao and Moss (1997) described a conceptual model of wheat based on phenological principles as affected by vernalization, photoperiod, thermal response and intrinsic earliness. The model predicted when the plant will reach double ridge, terminal spikelet and heading.

Nerozzi *et al* (1998) combined existing mathematical models of phenology to obtain comprehensive models for wheat and maize which predicted the dates of emergence, floral induction, spike development in wheat. Wang and Engel (1998) developed a wheat phenology model based on the effects of temperature, vernalization and photoperiod by introducing a temperature response function for development rate and vernalization, and the concepts of physiological development days and physiological vernalization days. The model also included the prediction of the development of leaves, internodes and tillers.

Mulholland *et al* (1997) discussed the AFRCWHEAT 2 growth simulation model for wheat on the basis of detailed information on the timing of terminal spikelet formation, anthesis, maturity and the rate of leaf appearance. Sanderson *et al* (1997) described the developmental stages for cereals and oil seed crops. The system was termed as “BBCH” scale. Joneja (1999) described the developmental stages for wheat and *Phlaris minor* crops by following “BBCH” scale.

Singh *et al* (2001) reported from the field experiment that the crop sown on 25 November took more number of days from sowing to maturity than the late sowings. Late sowing reduced the duration of vegetative and reproductive growth by 17 days. The thermal units that accumulated upto physiological maturity ranged from 1542.9 to 1610.3°C for different genotypes. All the phenophases except emergence exhibited higher accumulated growing degree days under earlier sowing (25 November), followed by 10 December sowing and decreasing trend was observed with delay in sowing.

Feng and Gao (1999) described a crop phenological theory model (CPTM) expressed as multiplications of exponential functions. It was based on the analysis of crop development and its relation to environmental factors. Kirby *et al* (1999) reported that vernalization was a major factor which affected the duration of phase from sowing to double ridge stage in winter cultivars. Delecolle *et al* (1995) determined that CERES-wheat simulated apparently correct yield through a compensatory effect between poorly simulated yield components. The first version of CERES-wheat was released in 1982 and the response of daily carbon assimilation and stomatal resistance to atmospheric CO_2 concentration were added in 1989 (Hoogenboom *et al* 1995).

2.2 Effect of Thermal and Photothermal Units on the Phenological Development

The term phenology derive from Greek and can be translated as “knowledge of phenomenon”. It studies the laws of periodic phases in the development of cycle of plants and established their dependence on environmental factors. Phenology is the study of the seasonal timings of different developmental stages and long term changes in phenology provide strong evidence of the biological impact of warmer climate (Sadras and Monzon 2006). Accurate prediction of crop phenology is a key requirement for crop development models. Saiyed *et al* (2009) reported that the prediction of wheat yield and quality from meteorological data can be improved by quantifying heat and moisture conditions during specified phenological phases; therefore, accurate prediction of phenological development is important for estimating weather impacts on wheat quality.

Phenological development from seeding to maturity is related to the accumulation of heat or temperature units above a threshold or base temperature below which no growth occurs. Development is orderly and predictable (Hay and Kirby 1991, Rickman and Klepper 1995). The genetics determines the order and sequence of events, and the environment (primarily temperature and photoperiod) is used to predict this sequence. Plant responses to environmental factors, depends on the timing, degree, and history of the environmental factor being considered. For instance, gradual changes in the factors allowing acclimatization usually are not as stressful to the plant as sudden significant changes, or the timing and intensity of the stress may result in greater plant responses at certain growth stages.

The extent and speed of photosynthate translocation and the rate of photosynthesis depends upon the structure of the plants, particularly the location, size and activity of a photosynthetic sink (Rawson *et al* 1983) and, in the case of photosynthesis. If current rates of anthropogenic greenhouse gas emission continue, it is projected that global mean temperature will increase 1.5^{o}C to 4.5^{o}C in the coming century (Intergovernmental Panel on Climate Change, 1995). The over affect of increase temperature effect the plant productivity in several ways. They could modify the incidence of winterkill and reduce the vernalisation. Temperature increases will tends to reduce the length of the growing period, potentially depressing overall biomass accumulation and yield (Butterfield and Morison 1992). Finally temperature could modify the rates of photosynthesis and respiration. Thus affecting the crop growth rate (Lang, 1991).

The productivity of wheat is strongly influenced by the temperature, which both determine both phenological development (Bauer *et al* 1984) and growth rates (Grace, 1988). Temperature also effect the cold hardening and winter kill (Gusta and Fowler, 1976), vernalisation (Trione and Metzer 1970) leaf appearance (Baker *et al* 1980) carbohydrate fixation and respiration (Goudriaan *et al* 1985), rate of grain filling (Wardlaw 1994)and eavapotranspiration and stress (Ritchie, 1972). Because these processes are interconnected throughout the crop life cycle via a number of feed backs, it is difficult to separate their overall effect on the grain yield into distinct components. However, three main types or temperature – crop relationship can be roughly defined:

- Direct relationship, e.g. those governing winterkill, veranlaisation, and water stress.
- Phenological relationship, e.g. those governing duration of vegetative and reproductive growth stages and overall length of growing period; and
- Physiological relationship, e.g. those governing rate of photosynthrsis and respiration, as well as grain filling.

Temperature is the most important climatic variable, which affects the plant life in terms of its sowing time, germination, growth, phenological development and quality of crop (Gill and Kingra 2007). Under high temperature conditions, earlier heading is advantageous in the retention of more green leaves at anthesis, leading to a smaller reduction in yield (Tewolde *et al* 2006). Dubey (1990) reported that the rate of germination and emergence of wheat accelerated when the soil temperature was high. Furthermore, high temperatures during grain filling can modify flour and bread quality and other physico-chemical properties of grain crops such as wheat (Perrotta *et al* 1998), including changes in protein content of the flour (Wardlaw *et al* 2002). Thus, for crop production under high temperatures, it is important to know the developmental stages and plant processes that are most sensitive to heat stress, as well as whether high day or high night temperatures are more injurious. Such insights are important in determining heat-tolerance potential of crop plants.

Development occurs in plants through changes in function and form. Functional changes are often associated with the transition between different ontogenetic phases while morphological development involves the initiation and size growth of the different organs. Final yield and araeal distribution of crops depends to a large extent on their development rate. This is shown very well by wheat which is grown worldwide at ranging from 40^{o}S and 65^{o}N, from below sea levels in the Netherlands upto 5000m in Tibet. Such a wide distribution of wheat depends mostly on the very large developmental variability that exists among the varieties used for cultivation. This variability reflects a wide range of adaptive responses of cultivars to local climates is very important in obtaining high yields whatever the climate. Varieties which are well adapted to a particular environment tend to reach anthesis around the optimal period thus avoiding major stress.

For a given cultivar, an increase in air temperature may effect development. By shortening the period from sowing to emergence (Addae and pearson 1992), by changing the duration of the vegetative phase (Angus *et al* 1981) and by reducing the duration of grain filling (Vos 1981, Amir and Sinclair 1992). However, the direction and magnitude of the effect of an increase in air temperature on wheat development are uncertain due to the strong interaction that exists between vernalisation and photoperiodic responses. This is particularly true for winter wheat varieties that strong vernalisation responses. Another area of uncertainty relates to amplitude and variability of expected changes in climate; an increment of 2^{o}C in annual mean temperature with atmospheric CO_2 doubling, as currently predicted by majority of General Circulation Models (GCMs), may have different impact on wheat development depending on associated changes in diurnal and seasonal variability (Semenov *et al* 2007).

Recent interest in assessment of the effects of climate changes has a direct bearing on agriculture: how will even minute changes in temperature influence crop growth? As a consequence, there has been a general upsurge in the study of periodic agricultural or biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions (Thompson and Clarks, 2006; Roberts, 2008).Environmental factors have a great influence on the occurrence of bolting (Heide 1973). Some of the important factors are vernalisation, photoperiod, day length, light quality, spectral composition, and the light quantity photon flux density among others (Milford, 2006). Vernalization, which is assumed to have to have a key role in bolting, is the process by which floral inductions in plants is promoted due to the plants being exposed to chilling for a certain period of time. The exposure of plants to low temperature will accelerate or switch on the development of flowers. The hitherto used models mostly link vernalization to the temperature range lying between 1 and 12^{o}C during the first part of the growing season.

Phenology can be analysed using the model proposed by Jamieson *et al* (1998a), in which time to antheisis is functions of leaf number, phyllochron and time between flag and appearance and anthesis. According to this model, the final leaf number on main stem responds to variations in day length and vernalization and the phyllochron is specially dependent on temperature. In bread wheat and barley, the phyllochron of later appearing leaves is also dependent on photoperiod (Miralles and Richards, 2000).The intervals between flag leaves and anthesis is both temperature dependents (Slafer and Rawson, 1994; Porter and Gawith, 1999) lasting fixed thermal time equivalent to three phyllochrons (Brooking *et al*

1995)- and genotype- specific (Amir and Sinclair, 1991). Changes in phenology, in particular a re-partitioning of the vegetative (before terminal spikelets) and reproductive (after terminal spikelets) phases, can also exert profound effects on yield potential (Slafer *et al* 2001).Thus for example, the number of fertile florets, and hence also grain number and grain yield was increased, when the stem elongations phase was lengthened by exposure to low inductive photoperiods in photoperiod –sensitive bread wheat cultivars (Gonzales *et al* 2003).

Temperature response curves for various wheat physiological processes normally follow a curvilinear response (Friend *et al* 1962, Cao and Moss 1989, Yan and Hunt 1999) with a frequent simplification of a linear segmented model approach often sufficient for many purposes (Porter 1993, Jamieson *et al* 2007). Regardless of the function assumed, a minimum temperature exists (T_{base}), below which the rate of the process is zero. A linear development or process rate from T_{base} to a lower optimum temperature (T_{optu}) is often observed, and from T_{optu} to an upper optimum temperature (T_{optu}) the development or process rate is maximum, and the rate declines from T_{optu} to an upper maximum temperature (T_{max}, the temperature above which again the rate of the process is assumed to be zero).

Esfandiary *et al* (2009) proposed that temperature unit or growing degree days can be used to express the relationship between period of every phenological stage and temperature degree. In this definition, it is assumed that there is linear relation between growth and temperature. Growing degree days can be used as best indices to predict different stages of wheat phenology. McMaster and Wilhelm (2004) reported that temperature is the primary factor controlling phenological development rates, with photoperiod and vernalization often being important for some crop as well. Factors such as water, nutrients, salinity, CO_2 etc. are generally important as secondary factors. Thermal time is used to drive phenology. Depending on the level of resolution, understanding and available information, the stresses if they have any effect, will generally hasten phenological development.

Fukushima *et al* (2005) reported that with increase in mean temperature and photoperiod the duration of crop growth from double ridge to anthesis get decreased. An increase in air temperature may affect development by shortening the period from sowing to emergence by changing the duration of vegetative phase and by reducing the duration of grain filling (Angus *et al* 1981, Vos 1981, Addae and Pearson 1992, Amir and Sinclair 1992). Slafer and Savin (1991) suggested that linear relationship between temperature and developmental rate can be found because thermal units (the summation of daily mean temperature above a base temperature) can predict phenological development of a crop.

Late sown wheat crop often face a high post-anthesis temperature that proved to be determinental to grain development which results in lower production with poor grain quality. High temperature not only affects grain growth and yield but also affects phasic development and flour quality of wheat as well (Asana and William 1965, Stone and Nicolas 1998, Blum *et al* 2001, Sharma-Natu *et al* 2005).In wheat, the occurrence of anthesis depends on rate of leaf emergence and final leaf number on the main stem.

Temperature, day length and vernalization are the main environmental factors that govern the rate of development in wheat, and determine the duration of the different phenological phases (Davidson *et al* 1985, Slafer and Rawson 1994). Wheat is vulnerable to high temperature stress during grain development phase of the crop (Nagarajan and Rane 2002). Strand (1987) reported that early sowing in wheat increased the heat sum requirement by the crop. Changes in seasonal temperature affect the grain yield, mainly through phenological development processes (Kalra *et al* 2008). Winter crops are especially vulnerable to high temperature during reproductive stages and differential response of temperature change (rise) to various crops has been noticed under different production environment.

Mitra and Bhatia (2008) proposed that high temperature affects all phases of crop growth, accelerate floral initiation, reduce the period of spike development, resulting in shorter spike with lower number of spikelets and adversely affecting pollen development. The late sown crop was forced to mature early without fulfilling its requirements during vegetative and reproductive periods due to rise in temperature in the month of February, resulting in lower grain as well as biological yield (Mishra *et al* 2003). Giunta *et al* (2001) reported that the number of spikelets per spike was associated with leaf number, but their relationship was affected by the thermal conditions during spikelet primordium initiation. Rahman and Wilson (1977) revealed from a controlled study on wheat that the rate of spikelet initiation increased but duration of spikelet and elongation phases decreased as temperature increased from 16/9 to 23/16°C. Spikelet numbers continued to increase upto a later stage of development of ear at 10°C, while spikelet numbers stopped increasing at about anther development at 30°C. The environmental changes caused by different sowing dates mainly affected the development of intermediate spikelets. The enhanced seed setting of intermediate spikelets (from 5th to 15th spikelet) and grain development from 1st to 3rd floret position were key factors for realizing large spikes and grain (Li *et al* 2001).

The duration of grain filling is highly variable, depending on cultivar and environmental conditions, particularly temperature (Ford *et al* 1975, Darroach and Baker 1995). Wiegand and Cuellar (1981) observed a decrease of 3.1 days in duration for every ^{0}C increase in temperature. If GDD approach is used, a nonlinear relationship with temperature is found; as temperature increases, the accumulated GDD for grain filling duration decreases (Asana and William 1965, Al-Khatib and Paulsen 1984).

Wang *et al* (1992) found that increased temperature hastens the phenological development of crop, reduces total duration of crop growth, grain filling and finally lowering the grain yield and its quality. Genotypes with early physiological maturity mostly escaped from the effect of high post anthesis temperature thus proved to be more heat tolerant compared to longer duration genotypes (Singh *et al* 2005). Sharma-Natu *et al* (2006) reported that by late sowing of crop, pre-anthesis phenological events determining potential yield components would also be affected which were then carried over to grain growth phase and influenced the grain growth and yield.

Sharma *et al* (2003) reported that wheat crop grown in Northern India under late sown condition is exposed to very low temperature up to booting stage, but later stages have to face warm temperature, that enables grain development under high temperature conditions leading to poor grain yield. Chakravarty and Sastry (1983) postulated that the thermal indices could be better indices than any other index to quantify the crop- weather interactions in different varieties of wheat. Bishnoi and Taneja (1990) showed that with the increase of average temperature in the crop season, phenological stages appeared rapidly due to availability of higher thermal units over a short period of time.

Earliness is an important factor for adaptation to heat stress since early maturing varieties escape late occurring heat stress (Zhong-Hu and Rajaram 1994, Lillemo *et al* 2005). Late sowing decreased the days to anthesis. The reduction in days to anthesis under late sowing indicated that the duration of phenological phases before anthesis was decreased (Sharma-Natu *et al* 2006). In wheat, pre anthesis phenological phases which determine potential yield components are quite sensitive to high temperature (Shpiler and Blum 1991, Abrol and Ingram 2005).

Paikaray and Chakravarty (2003) reported that early sowing which allow for the highest accumulation of heat sum and photothermal units resulted in better growth and yield of crops. Prevailing relatively higher ambient temperature conditions leading to a reduction in crop growth period resulted in lower heat use efficiency. The thermal time units could be utilized for modeling studies in place of the number of actual days more effectively to quantify the yield and phenological development because of the low coefficient of variation values. Khichar and Niwas (2007) reported that timely sown crop consume more growing degree days in comparison to late sown crop at physiological maturity. This could be explained by the fact that delayed sowing resulted in forced maturity of wheat because high temperature prevailed during reproductive phase of the late sown crop.

Radiation use efficiency of a crop is functions of several interacting physiological phenomena, each which can be tackle independently. The generally non significant association observed between yield and biomass (Slafer *et al* 1994; Calderini *et al* 1995, 1999) suggested that the radiation use efficiency has not been significantly improved. Light interceptions by canopies and RUE have been examined in materials representing the progress made in yield over time (Calderini *et al* 1999). In irrigated environments, no difference in RUE or light interception were found, while more modern lines were shown to have higher

RUE after anthesis. Three aspects of solar radiations are important for plant processes: intensity, duration (i.e. photoperiod or day length), and quality. Intensity is mostly involved in influencing growth by altering the size of organs by influencing photosynthesis. Kemp and Whingwiri (1980) and McMaster *et al (*1987) reported that the positive relationship between radiation, yield and various yield attributing attributes.

Herndl *et al* (2008) showed that cultivar differences in pre-anthesis development are mainly determined by vernalization requirement, photoperiod sensitivity and earliness per se. The interactive effects of increasing temperature and decreasing radiation revealed a cumulative adverse effect on growth and yield of rice and wheat. In wheat the growth and yield was highly sensitive to temperature increase while it was relatively less sensitive to decrease in radiation (Hundal and Kaur 1995).

Baker *et al* (1980) reported that both photoperiod and quality are primarily involved in developmental events such as leaf appearance rates and phenology, although duration of day length is positively related to amount of daily radiation that can be important in total assimilation. Photoperiod is primarily influential in the phenological stages of flower formation (signaling the switch at the shoot apex from producing vegetative primordial to reproductive primordial) and timing of flag leaf appearance. Elevated CO_2 increase the photosynthetic rate in wheat over a wide range of radiation (Long *et al* 2006).Kasajima *et al* (2007) suggested that green and red lights play important roles in the regulation of the developmental rate independent of photoperiodism and vernalization. Longer duration of stem elongation would increase spike dry weight in wheat due to higher accumulated intercepted radiation during that period (Akbar *et al* 2006). Higher radiation increases the amount of photosynthates available for spike growth and lower temperatures prolong the period of spikelet growth and decrease competition for carbohydrates (Gonzalez *et al* 2005).

Light has a determinantal effect on the physiology and yield of the plants (McMaster *et al* 2003). The effect is more predominant at the reproductive stage than at the vegetative stage. Ewert (1996) observed significant positive correlation between thermal rate of spikelet and floret initiation and photoperiod in wheat and these relationships were consistent for all tiller numbers. Reduction in the duration of grain filling due to rise in incident radiations was reported by Richard (2000). This could be due to acceleration of grain growth at higher levels of radiation and photosynthesis or to the higher temperatures which are often associated with higher radiations. Rahman and Wilson (1977) observed that reducing light increased the length of vegetative phase. They also discovered that the length of vegetative phase, spikelet and ear elongation phases increased but the rate of spikelet initiation decreased as the photoperiod decreased from 24 to 8 hrs. Shading decreased the rate of spikelet initiation, resulting in a significant decrease in spikelet number.

Tikhomirov and Ushakova (2001) proposed that it is possible to enhance thermal tolerance by varying light intensity. Increase of air temperature to 35°C or 45°C with light intensity of 60 Wm^{-2} PAR has been shown to substantially inhibit the photosynthesis processes; at 150 Wm^{-2} PAR photosynthesis decreases from 50 to 100% respectively when light intensity is increased to 240 Wm^{-2} PAR photosynthesis increased more than 70% at 35°C and decreased at 45°C by only 20%. Thus, light intensity can be increased to avoid or decrease the inhibiting effect of high temperatures.

2.3 Physiological Traits

The literature on physiological parameters has been reviewed under the following subheadings:

2.3.1 Leaf Area Development
2.3.2 Plant Biomass Accumulation
2.3.3 Ear: Stem Ratio
2.3.4 Crop Growth Rate (CGR)
2.3.5 Phyllochron Index
2.3.6 Grain Filling rate and Duration

2.3.1 Leaf Area Development

Flag leaf is of utmost importance in wheat since it provides the maximum amount of photosynthesis assimilates to be stored in the grain and it directly influences the source- sink relationship. A greater flag leaf area will eventually increase the photosynthetic efficiency by increasing the production of assimilates and hence flag leaf area has a direct relationship with enhanced grain yield (Riaz and Chowdhry 2004, Sahin and Yildirim 2006, Singh *et al* 2008). Evans and Dunstone (1970) studied the importance of flag leaf area with respect to grain yield. Timely sown crop produced more leaf area index and biological yield than late sown crop. This was due to more consumption of photothermal units by timely sown crop. Mishra *et al* (2003) reported that low temperature experienced by late- sown crop during early growth or immediately after seedling emergence might have resulted in poor leaf development.

Bavec *et al* (2007) reported that leaf area index can be useful for prediction of grain yield and grain quality in practice. Reduction of LAI (leaf area index) by 7.6 percent in wheat and 5.9 percent in rice was due to decrease in solar radiation by 100 percent from normal. Further, with increase in solar radiation by 10 percent, leaf area index increases by 7.1 percent in wheat (Hundal and Kaur 1995). The slightly greater leaf area index of plants at high temperature could increase the far-red: red light ratio within the canopy, leading to leaves appearing faster (Barnes and Bugbee 1991).

Singh *et al* (2005) reported that longer duration wheat genotypes had relatively higher values of photosynthetic rate compared to short duration genotypes. It seems that longer duration genotypes suffered a lot in respect of grain development under rising temperature compared to short duration cultivars. Leaf area index showed a significant positive correlation with grain yield (Singh *et al* 2006). Reynolds *et al* (1994) also reported a significant correlation between flag leaf photosynthesis measured after anthesis and grain yield in spring wheat genotypes grown in hot, irrigated conditions. This indicates that variation in photosynthetic rate of genotype at high temperature could be used to select for heat tolerance.

Temperature is one factor affecting specific leaf area under field conditions i.e. as temperature from 8 to 26 ^{o}C, specific leaf area increased to a maximum value. Saini and Nanda (1987) indicated that increased temperature hastened the rate of leaf senescence resulting lower-leaf area and total biomass. Slafer *et al* (1994) reported that the photoperiod or its rate of change significantly affected the rate of leaf appearance and final number of leaves in wheat. Foltyn *et al* (1990) reported that leaf area index (LAI) increased as the amount of light incident upon the first leaf increased. LAI reached its peak well before anthesis as studied by Fiscuer and Kohn (1965).

Jadav (1989) reported that the highest value of leaf area occurred at 42 days after sowing. LAI was higher in case of November sown crop and it decreased significantly with each delay in sowing. (Dhaliwal 1992). Similar results were reported by Chowdhary (1978) and Sekhon (1987). Sarkar *et al* (1987) observed that the LAI (at 70 days of growth) was 5.6 when the crop was sown on 14 November and with each delay in sowing the LAI decreased significantly.

Davidson (1965) reported that leaf stripping at ear emergence had no significant effect on grain yield. Leaf area maintenance at leaf area index values 3 or 1 greatly decreased grain yield by reducing both grain number per spikelet and mean grain weight by 50 percent. Plants with maximum leaf area index (LAI) trap more solar radiations which contribute to maximum photosynthesis. LAI is proportionately higher for high yielding varieties (Khawas *et al* 1999). Jat and Singhi (2004) reported that superior cultivars in respect of grains/ear, grain weight /ear and thousand grain weights seems to be on account of higher LAI and efficient translocation of metabolites towards grain formation, as evident from higher harvest index.

Koc *et al* (2008) proposed that flag leaf traits are associated with performance of wheat (*Triticum aestivum* L.) genotypes in heat stress environments. It became possible to access a heat susceptibility index (HIS) for each cultivar by altering the sowing date, exposing crops to different temperatures. Dhiman *et al* (1980) reported a significant reduction in grain yield (27.9%) as well as flag leaf area (13%) under delayed sowing. A positive correlation between grain yield and flag leaf area was observed under different dates of sowing. Similarly Dhingra (1990) reported high positive correlation between leaf area index and grain yield and obtained a quadratic equation between two. Leaf area index of 7.5 is optimum for maximum yield.

Elevated temperature accelerates senescence, reduce duration of viable leaf area and diminish photosynthetic activity (Harding *et al* 1990). Herzog (1982) reported that source activity was damaged by heat because both leaf area duration and photosynthesis get reduced. Leaf area duration after anthesis, correlated to grain yield. Induction of senescence could also be the reason for the stagnation of yield (Nagarajan 2005).Flesch and Dale (1985) used corn heat units to predict the leaf area whereas Jones *et al* (1986) used the dry matter of leaves for LAI prediction. Koh *et al* (1978) found that photosynthetic efficiency of the wheat crop increased with increased leaf area index i.e. upto 5.

Khichar and Niwas (2007) reported that timely sown crop produced more leaf area index and biological yield than late sown crop. This was due to more consumption of photo-thermal units by timely sown crop. The maximum leaf area index in wheat decreased by 4.5 to 33.8%, in rice by 1.5 to 15.9% and in groundnut by 1.2 to 5.3% when the temperature increased from 0.5 to 3.0^{o}C above normal. Reynolds *et al* (2005) demonstrated high, positive correlation coefficient between grain weight and the components of photosynthetic area above the flag leaf node, both on per tiller and on per plant basis. On per tiller basis both grain weight and grain number gave correlation coefficient greater than +0.72 when correlated with spike area, flag leaf sheath area, total photosynthetic area or total leaf area duration. Amir and Sinclair (1991) from field experiment reported that leaf area index in wheat was more in warmer environment during the year 1985-86 than the cooler ones (1986-87). It was due to better radiation use efficiency. In contrary, Foltyn and Sporik (1988) reported that LAI was higher in cooler environment.

2.3.2 Plant Biomass Accumulation

The greater reduction in total dry matter and its partitioning into different plant organs under delayed sowing was due to sudden drop in temperature during early vegetative phase and sharp rise in temperature at maturity. Comparatively lesser heat units consumed by the late sown crop were due to supraoptimal thermal regime in month of April, which hastened the maturity (Tyagi *et al* 2004).

Cruz-Agudo *et al* (2000) reported that dry matter reduction from the second internode during grain filling was positively correlated with yield, mass per grain, number and mass of grains per ear head and harvest index. By contrast, dry matter reduction was negatively correlated with relative growth rate of main shoots during grain filling and mean temperature from sowing to anthesis.

Wahid *et al* (2007) proposed that high temperature caused significant decline in shoot dry mass, relative growth rate and net assimilation rate in maize, wheat and sugarcane. Dry matter partitioning to leaves in wheat decreased throughout the growth season while to that of stem increased upto anthesis and thereafter it decreased upto physiological maturity (Akbar *et al* 2006).

Aase (1978) studied the relationship between dry matter production and leaf area. Results showed that dry matter could be substituted for the leaf area in any model as there was a high positive correlation between them. Amir and Sinclair (1991) compared simulated biomass accumulation and reported that initial biomass accumulation was favoured by high temperature and low temperature reduced the biomass accumulation. The model over-predicted the biomass accumulation rate early in the season and predicted it late in the season, indicating thereby the sensitivity of the model to environmental conditions.

Nagarajan and Rane (2002) inferred that tolerant genotypes produce significantly higher amount of biomass under stress environment. Rapid phenology, poor biomass production and sterility are major factors leading to the poor yields of wheat grown from sowing to maturity at high temperature (Rawson 1986). Reduction in dry matter production of wheat under late sown condition also reported by Dhiman *et al* (1985).

Breeding efforts during the 20th century have increased wheat yield under different environment with rates of grains ranging from 5 to 71 Kg ha^{-1} Y^{-1}(Calderini *et al* 1999). These genetics grains in yield contributed ca. 50% to the total gains in wheat productivity (Slafer *et al* 1994). As biomass partitioning to reproductive organs was the main attribute responsible for yield gains through the years (Siddique *et al* 1989b; Slafer and Andrade, 1989; Calderini *et al* 1995), modern cultivars in many regions have already reached harvest index values close to the upper theoretical limits of about 62% (Austin *et al* 1980).

The physiological bases responsible for genetic gains in wheat yield throughout the 20th century seemed similar across almost all the environments where they are estimated (Calderini *et al* 1995). Plant height was negatively associated with harvest index. No further reduction in height would be expected as moderns cultivars have a stature Miralles and Slafer (1997).

The relationship between the grain yield and number of grains per m^{-2} of different times. There is positive association between these traits (Calderini *et al* 1999). This is likely due to evolutionary and breeding influences (Sadars, 2007) determining the critical importance of the number of grains for yield determination (Fishcer, 2008). The yield was strongly associated with the number of grains per m^{-2}, agree with many physiological studies in that grain yield is mostly sink limited during post anthesis in wheat (Slafer and Savin, 1994; Borras *et al* 2004). There is also slight negative relationship between the average grain weight and the number of grains per m^{-2}. The reflected the increased contribution of grains per m^{-2}. The yield was linearly and positively associated with number of grains per m^{-2}, while average grain weight did not exhibit any clear trend with the year of release of the cultivars. The increase in number of grains was more associated with that in grains per spike than with differences in spikes per m^{-2}. Finally increase in number of grains per m^{-2} was associated with both number of grains per unit of spike dry weight at anthesis, or fruiting efficiency and spike dry weight at anthesis.

Kirby (1969) proposed that potential for biomass yield in winter and spring wheat was reduced as sowing was delayed. Ford and Thorne (1975) revealed that the warm treatment from 5 to 35 days after anthesis reduced the shoot and root dry matter by 24% as compared to control.

Increase in leaf area index, dry matter production and yield components in early sown crop than the late sown crop because of maintenance of cooler environment for longer period by early sown crop (Bahera 1994). The rise in temperature at grain development stage in very late sown crop have accelerated the rate of dry matter accumulation in spikes and reduced the length of reproductive period (Sardana *et al* 2003). Tewari and Singh (1995) also reported that the normal sown crop continued to produce dry matter at early stages and with delay in sowing, the rate of dry matter production decreases. The production efficiency of semi-dwarf wheat genotypes enhanced markedly under better crop nourishment mainly due to marked increase in their harvest index without significant improvement in biomass production (Reynolds *et al* 1999).

Ford *et al* (1975) found that high temperature treatment (25^{o}C) after anthesis caused reduction in shoot dry matter but slight increase in ear dry weight up to 13 days after anthesis, during the later period of grain growth ear dry matter partitioning decreased under controlled conditions. Warrington *et al* (1977) reported that the shoot dry matter reduced by 30 to 40% when the crop was exposed to 15-25^{o}C temperature from double ridge stage to anthesis. They also found that flag leaf dry matter was higher at 15^{o}C than at 25^{o}C. High temperature did not reduce the rate of accumulation of dry matter in grain but it accelerate the rate of grain development i.e. high temperature fastened the rate of dry matter accumulation but shortened the duration of accumulation (Nicolas *et al* 1985).Schapendonk *et al* (2007) reported that the effects of the heat shock on biomass yield were more pronounced when the shock has been applied at early growth filling. Sarkar *et al* (2001) emphasize that selection for high biomass should bring about positive improvement in grain yield of wheat under late planting.

Sharma- Natu and Ghildiyal (2005) reported that since, HI is approaching a ceiling value; further increase in yield has to come through increase in crop biomass. Khalifa *et al* (1977) reported that the total dry matter production decreased m^{-2} with delay in sowing from November 3 to December 15. Early attainment higher biomass production is essential under late sown condition to maintain proper balance between source and sink (Deshmukh *et al* 2006).Total dry matter accumulation per plant gradually decreased with crop age and attained maximum at maturity. Further dry-matter accumulation decreased with delay in sowing from timely to very late sown crop (Shivani *et al* 2003).

The dry matter accumulation after anthesis was affected by source and sink changes. Source reduction caused a decrease in the allocation of dry matter to sheath and stem, and promoted the reserve phtotsynthates to be reallocated to grain. The effect of source and sink changes on the grain mass was in order to upper > basal>middle spikelets on spike. As for a spikelet the effect was found mainly in the grain mass at the positions 3 and 4 from base of the spikelets. (Yin *et al* 1998).

Grain has a fixed growth rate, while the increase rate of culm reserved material altered depending on the influence of radiation The increased in wheat grain yield for the variable treatment of Nitrogen fertilizers compared with the normal rate of fertilization. Crop biomass lowest increased 20 percent and highest increased 60 percent increase of crop biomass (Mayfield and Trengove, 2009). The effects of source /sink relation on photosynthates production, allocation and grain growth varies with wheat cultivars, environment and cultivations (Ma *et al* 1990, Wang *et al* 1997). Grain filling in wheat depends on two major sources of carbon, namely current photosynthesis in leaves and to some extent in spikes, and mobilization of stored water-soluble carbohydrates from the stem into the growing grain. Potential stem reserve accumulation and subsequent mobilization in wheat depend on stem length and stem specific weight.

Storage increases with the longer stem and greater specific weight (Blum *et al*., 1994). The amount of accumulated and mobilized stem reserves are estimated either by monitoring the changes in dry stem weight (Haun 1979, Borrel *et al* 1993 and Ehdaie *et al* 2006a) or directly measuring stem WSC content during the grain filling period (Ehdaie *et al* 2006b). Stem carbohydrate reserve have been estimated to contribute from 10 to 62% of the final grain weight in wheat under normal conditions (Bonnet and Incoll, 1992).

2.3.3 Ear: Stem Ratio

The ratio of ear: stem growth rate was generally higher in modern varieties than old varieties. The dwarf variety had a higher rate of ear stem growth than tall variety. The ratio of ear: stem dry matter increased from terminal spikelets stage to values ranging from about 20-50% at anthesis. There fore generally the grain yield and harvest index were generally higher in current varieties tan in old varieties. There is greater partitioning of dry matter to the ear during early stages of development in the dwarf varieties and thus competitive relationship between ear and stem is believed to determine florets survival and hence grain number per spikelet and ear. The result indicate that improvement in grain number have come about because the stem competed less strongly than the ear for dry matter. This reduced competition resulted in either the initiation of more florets and or greater survival of florets to form grains. The grain yield of cereals has been reported to increase with increase in allocation to the reproductive organs with little increase in biological yield (Donald and Hamblin 1976). Strong source (leaves and stems) helps to produce higher grain yield due to their larger capacity to mobilize more pre-anthesis assimilates to grains (Pannu *et al* 1996).Siddique and Whan (1994) showed that ear:stem ratio had a significant positive correlation with grain yield, harvest index, grains/ear. Thus ear: stem ratio could be used to identify superior parental genotypes and early generations selections from special crosses in term of its ability to partition assimilate.

Partitioning of dry matter among the organs at anthesis determines the subsequent operation and orientation of the source-sink system in the period of grain formation and filling. Ratio between the weights of source and sink at grain filling shifted towards sink (Kumakov *et al* 2000, Egli and Bruening 2001). Assimilates stored in stem prior to anthesis plays an important role under stress environments thus, accumulation of biomass in stem was observed at higher rate at initial stages of reproductive growth and gradual decrease at later stages (Stroh 1992, Bishop and Bigmee 1998, Borras *et al* 2004).

Poorter and Nagel (2000) proposed that Partitioning of total dry matter into leaves, stems, roots and reproductive organs give a better indication of different functions of leaves and stems. The grain filling of wheat (*Triticum aestivum* L.) is seriously impaired by heat stress due to reductions in current leaf and ear photosynthesis. Ear: stem ratio largely reflects potential of genotypes to form bolder grains rather than yield per se (Dencic *et al* 2000, Rane and Nagarajan 2001).Wang *et al* (2000) found that bigger the spike size, faster the floret initiation rate, which initiated more florets per spike and produced more fertile florets and grains, thus increasing yield. Sink capacity is a major limiting factor for crop productivity; a physiological stress related decrease in sink activity directly affects the grain yield in wheat (Reynolds *et al* 2005).

Mobilization of stored stem reserves into the growing grain is an important source of carbon for supporting grain filling under heat stress. During grain filling heat tolerant genotypes exported more dry-matter from stems than susceptible, under both non-stressed and stressed conditions (Blum *et al* 1994).

Increased mobilization efficiency of reserves from leaves, stem or other plant parts has been suggested as a potential strategy to improve grain filling and yield in wheat under heat stress (Wahid *et al* 2007). Siddique *et al* (1989) inferred that allometric relationship occurred between ears and stem dry matter, indicating a constant ratio between relative growth rates of the ear and stem. The greater ear: stem ratio was mainly due to bigger intercept of the regression of ln ear dry matter versus ln stem dry matter. The allometric relationship showed that when ear weight was 1 mg there was a difference in stem dry matter which ranged from about 50 mg in modern variety to 200 mg in an old variety.

Miralles *et al* (2000) reported that the duration of the late reproductive phase during which the spike and shoots compete for assimilates was associated with the number of fertile florets per spike suggested that extending the stem elongation period in cereals could be a way to reduce assimilate competition and to increase the grain yield.

2.3.4 Crop Growth Rate (CGR)

At full interception, whether the crop growth rate (CGR) reaches a plateau or passes an optimum depends on the crop and on radiation and temperature. The CGR may be more or less proportional to the intercepted radiation, as with wheat (Fischer 1983, Bugbee and Salisburry 1988). The effect of temperature on crop growth rate varies between crops and with stage of development of crop (Suzuki 1983).

Shivani *et al* (2003) reported that CGR increased with increase in crop age, and attained its peak at 90 days after sowing and thereafter decreased till maturity. The CGR of timely seeded crop was significantly higher than all other dates of sowing. Gran and Vaidyanathan (1986) revealed that crop growth rate was highly responsive to nitrogen supply. Higher canopy photosynthetic rates, lead to the expectation of higher crop growth rate.

Crop yield is determined by biomass accumulation and its partitioning within the plant (Vander Werf 1996). Crop biomass and crop growth rate (CGR) are dependent on the ability of the canopy to (i) intercept incoming photosynthesis active radiation (IPAR), which is the functions of leaf area index (LAI) and canopy architecture, and (ii) convert this radiation into new biomass, i.e. radiation use efficiency (RUE) (Sinclair and MUchow 1999). Evidences in literature show that one or both physiological components of biomass of productions may be modified by genotype (Calderini *et al* 1999), temperature (Andrade *et al* 1993) or water availability (Jamieson *et al* 1995). Nutrient deficiency may effect both IPAR and RUE. Crop LAI was reduced in crops grown under N (Caviglia and Sadras, 2001) or P (Rodriguez *et al* 2000) shortage. The light extinction coefficient (k) is determined primarily by canopy architecture, and seems to be less variable than LAI when the crop is affected by nutritional deficiency (Hasegawa and Horie, 1996). Radiation use efficiency appears to be a more conservative (i.e. less variable) attribute compared to LAI or IPAR (Kiniry *et al* 1989). However, there is evidence that RUE declines in response to N (Caviglia and Sadras 2001, Garcia *et al* 1988).

Since foliar expansion is more sensitive to an environmental stress than the photosynthetic capacity of the crop (Fitter and Hay, 2002), reduction in leaf area index and IPAR are expected when the crop is grown under N and S deficiency. Radiation use efficiency is dependent on net CO_2 assimilation (Loomis and Amthor, 1999) and N is a source of variation for this process by increasing the Rubisco content in leaves (Sinlair and Horie 1989). Likewise, an increase in leaf photosynthesis is expected when S supply is increased (Terry, 1976). Nitrogen and sulfur increased the biomass at anthesis, with the increment of 62 and 13% in LAI, and 20 and 7% in IPAR, due to N and S addition, respectively the effect of S on LAI and IPAR were higher as nitrogen fertilizer increased .

Nitrogen addition increased Biomass at physiological maturity from 7 to 19% at the lower S rate but at the highest S supply, these increments ranged from 20 to 35%, evidencing a clear interaction between both the nutrients. This increased in biomass was sustained by a large fertile spike population that increased grain number per unit area and consequently, grain yield (Salvagiotti and Miralles 2008).The time course of change of the nitrogen nutrition index on a wheat crop allows one to determine precisely the period of occurence of a N deficiency, and its intensity during the vegetative phase of the crop cycle. According to period of deficiency, the grain number of the wheat crop was reduced, either because of a reduction in spike number, a reduction of grain number per spike, or both (Jeuffroy and Bouchard, 1999). (Abbate *et al* 1995) have shown that if nitrogen nutrition is limiting and continuous, i.e. is the wheat crop is subjected to n deficiency from early in the crop cycle until after anthesis, grain number is strongly and linearly correlated with the amount of N in the spikes at anthesis.

Hasan and Ahmad (2005) proposed that post-anthesis heat stress in wheat induces several physiological effects which eventually results in smaller kernel size due to reduced grain filling period and reduced grain filling rate or combined effect of both. Potential number of grains determined at early stages of plant development and yield after anthesis period depends on grain weight which resulted from grain filling process. Grain filling can be described by two parameters: duration and rate (Mou *et al* 1994, Whan *et al* 1996).

Tewolde *et al* (2006) inferred that early heading cultivars had longer grain filling period than the later heading cultivars. Early heading cultivars computed a greater fraction of the grain filling when the air temperatures were lower and generally more favorable. Thus, early heading is most important characteristics defining wheat cultivars adapted to production systems prone to high temperature stress during grain filling. The link between grain filling parameters (rate and duration) generally adapted as inverse: faster accumulation of temperature units reduces grain filling duration and increases grain filling rate (Johnson and Kanemasu 1983).

The highest grain yield of modern wheat cultivars was achieved with high RGR during the vegetative phase and greater CGR from ear emergence to harvest (Karimi and Siddique 1991). Nagarajan and Rane (2002) reported that biomass m^{-2}, grain weight per spike, grain yield m^{-2} and grains/spike showed reduction under late sown conditions. Salman and Brinkman (1992) showed that crop growth rate was positively correlated with yield. The cultivars difference in crop growth rate was found to be less (Abbate *et al* 1998, Fischer *et al* 1998).

2.3.5 Phyllochron Index

The initiation and appearance rates of main stem leaves are functions of temperature and independent of day length (Miglietta 1989), and that the time between initiation and appearance of a leaf increases linearly with leaf number (Miglietta 1991a). Phasic development of wheat is described in terms of the number emerged leaves. The final number of leaves depends on the photoperiodic response of the variety and on flower synchronization, which in turn also depends on temperature and vernalization (Miglietta 1991b). The photoperiodic response of spring wheat and fully vernalised winter wheats is described by exponential decrease in the final number of main stem leaves, with increasing day length, to a minimum of 6 leaves.

Leaf appearance rate is controlled mostly by the temperature of the apical meristem and leaf expansion zones (Jamieson *et al* 1995, McMaster *et al* 2003). Final leaf number is largely controlled by responses to vernalization and photoperiod (Brooking 1996, Mahfoozi *et al* 2001, Brooking and Jamieson 2002). Thermal time intervals between flag leaf ligule appearance and anthesis and from sowing to emergence are much more constant among genotypes and environments than time from emergence to flowering (Jamieson *et al* 1998).

The fundamental concept involved in predicting organ morphology is the phyllochron, defined as the time, in growing degree days (GDD), for successive leaves to pass through the same developmental stage. (Baker *et al* 1980) phyllochron has been related to daily change of photoperiod at emergence .

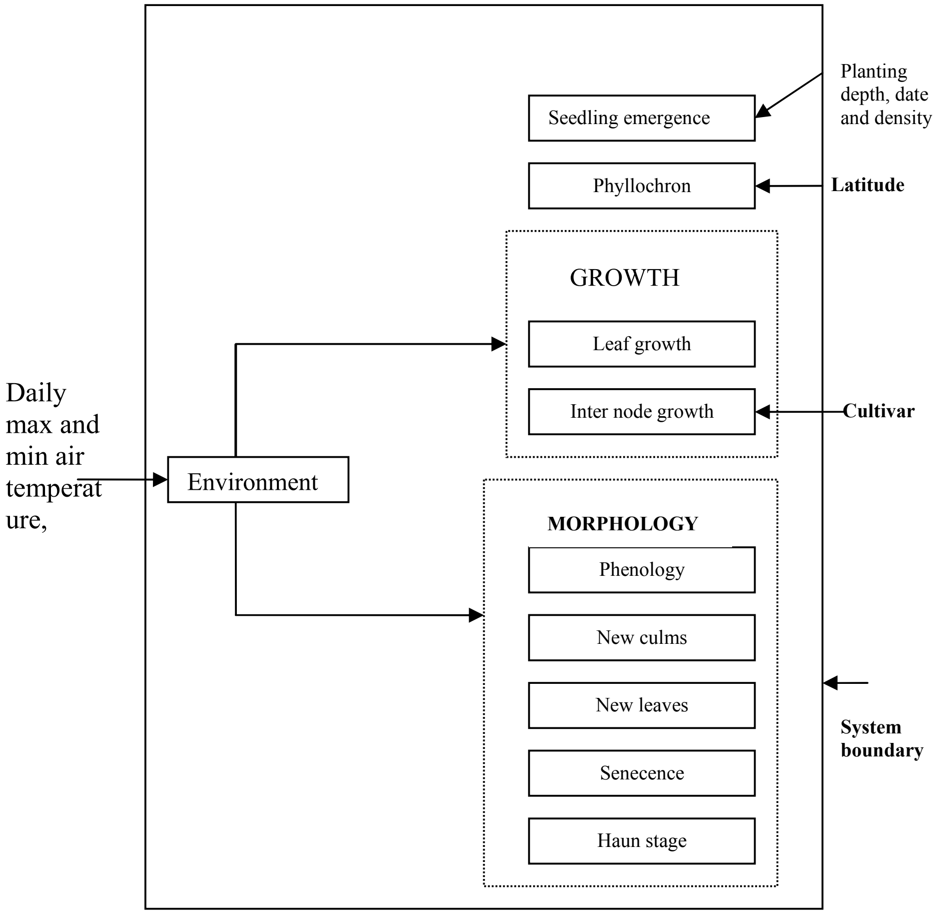
Phyllochron $= \left(\left(0.026 * \Delta d\right) + 0.0104\right)^{-1}$

Change in photoperiod Δd is determined from the latitude and emergence date using WGEN, and its is in hours (Richardson and Wright, 1984)

Phenology submodel this submodel predicts the jointing, the time when a node of the main stem can be felt 25mm above soil surface freeks scale (Large 1954). Jointing is assumed to be occur at the 470 GDD with 0^{o}C base temperature after 1 January, the mean value which Mcmaster and Smika (1988) found for four cultivars at sevens sites in the central great plains.

Equation determines internode length beginning two phyllochron before 470 GDD after 1 January. A typical arrangement of node and internodes with respects to the soil surface. About 1.5 to 2 phyllochron units are required from the onset of the use of the main stem node to rise 25 mm above the soil surface. The Haun growth stage (Haun, 1973) is scale of phenological development based on the number of fully expanded leaves on a culm.

Under unstressed conditions, tillers appear in an orderly predictable pattern (Klepper *et al* 1982; Masle-Meylend and Sebillotte, 1981; Rickman *et al* 1983). Tiller appearance is related to MS Haun stage (Kirby *et al* 1985b; Klepper *et al* 1982). For example , tiller T3, T01, and T10 will be appear when MS has four leaves that have fully expanded , or a Haun stages of 4.0. Because the first tiller leaf is hidden by the sheath of subtending leafs on the parent tiller, the model predicts the appearance of each tiller about 0.3 phyllochron before it is visible in the field.



SHOOTGRO (1.0 submodel)

$$\text{Haun stage} = \frac{L_n}{L_{n-1}} + (n-1)$$

Where

$(n-1)$ Blade length of the youngest leaf (*n*) above the collar leaf (*n*-1)

L_{n-1} The blade length of the penultimate leaf (*n*-1) and n is the number of the leaves that has appeared on a culm. The maximum leaf length ratio $\frac{L_n}{L_{n-1}}$

A tiller can be appearing only at a specific MS Haun stage. No new culms appear following jointing (Kirby *et al* 1985; Rawson, 1971). SHOOTGRO limits the maximum number of culms that can appear to the 16. A new leaf appears on the culm each phyllochron. The phyllochron is the same for the leaves on the all culms of a cohort (Klepper *et al* 1982; Klepper *et al* 1983; Masle- Meynard and Sebillotte, 1981). No more than 20 leaves are allowed to appear on culm. Two new leaves are allowed to appear after jointing.

Leaf appearance rate depends only on the temperature of the apex and current Haun Stage (Haun, 1973), and is independent of day length or its rate of change. Miglietta (1989, 1991a) analysed that from a range of experiments and showed that temperature alone could explain the variation in leaf appearance rates, but that there was a decline in the rate as the number of leaves that had appeared increased. From the field experiments with day length extension, Slafer *et al*., (1994) showed that there was no effect of rate of change of day length on leaf productions rates that was independent of day length itself. Slafer and Rawson (1995b) provided evedience of decline in leaf appearance rate at temperature above about 22°C, but showed that the rate of leaf appearance depended only on mean temperature, and not the amplitude of the variation during the daily cycle. This latter result showed that only mean daily temperature are required to calculate leaf appearance rates.

2.3.6 Grain Filling Rate and Duration

The availability of Photosynthate reduced under drought conditions because of simaltanoeus demand of grain growth during grain filling and respiration and the decrease the photosynthetic capacity of leaves (Asana 1966; Gent 1994). The amount of accumulated and mobalised stem reserves are estimated either by monitoring the changes in stem dry weight (Hunt 1979, Borrel *et al* 1993 and Cruz-Aguado*et al* 2000). Post anthesis changes in dry weight (Ehdaie *et al* 2006a) and in water soluble carbohydrate content (Ehdaie *et al* 2006b) of the main stem of a diverse set of wheat cultivars indicated the estimation of the amount of stem reserves accumulated and mobalised was dependent on genotype, experiment conditions and the method of measuring the stem reserves. Duration of grain filling strongly responsive to temperature each degree rise in temperature during grain filling resulting in a about 3 days decrease in duration of filling regardless of cultivars (Wegand and Cuellar 1981). The rate of grain growth (mg kernel^{-1} day $^{-1}$) during the linear period increase moderately with temperature (Chowdhary and Cuellar 1978) and is mildly responsive to illumination (Evans *et al* 1977) and is cultivars dependent (Bagga and Rawson 1977). Thorne (1970) reported a 1.04 mg decrease in kernel weight for each degree Celsius increase in temperature during grain filling for Russian spring wheat region. Elevated temperatures during grain filling have a detrimental effect on kernel weight and subsequently on grain yield through shortening of grain filling duration (Wattal 1965).

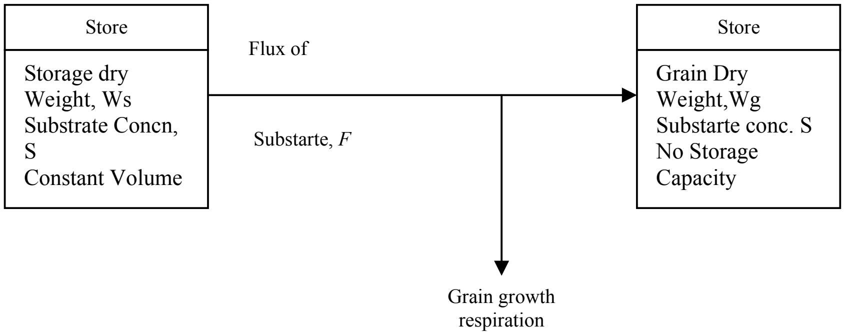
Randhawa *et al* (1992) reported flowering time of crop shortened under delayed conditions because by the time it comes to flowering, the atmospheric temperature starts rising. Therefore, the late sown crop forced to mature early. This is the main reason for reduction in yield under late sown conditions. Singh *et al* (2003) reported that delayed sowing significantly had lower grain yield.

2.4 Source- Sink Relationship

In cereals , water soluble carbohydrates stored in stems have been acknowledged as contributing to maintenance of grain filling rate when photosynthesis declines due to various stresses, e.g. drought (Bidinger *et al* 1977); Palta *et al* 1994), heat stress (Blum *et al* 1994).

Fructans synthesized from sucrose, constitute the main fraction of the WSC pool (Kuhbauch and Thome 1989, Vijn and Smeekens 1999). The reported contribution of WSC to yield varies greatly with environment, growing conditions and cultivars and can range from 10 to 20% under non stressed conditions (Gebbing *et al* 1999, Shearman *et al* 2005) to up to 50% under severe conditions. Genetic variation exists for WSC accumulation in the stems at anthesis (Van Herwaarden and Richards, 2002; Ruuska *et al* 2006) and it has been suggested that breeding for high WSC should be possible due to its high heritability (Ruuska *et al* 2006) although the traits appears to be controlled by complex polygenic regulation (Rebetzke *et al* 2008).

In the context of breeding, it is important to determine what penalties may affect yield or its components during selections for high stem WSC concentrations. Yield has been frequently correlated with grain number (Fischer, 2007) grain number is largely influenced by the patterns of carbon and N accumulation by the crop and more importantly by the spike (Fischer 1985), between the stages of emergence of the penultimate leaf to first anthesis (Fischer, 2008; Sinclair and Jamieson, 2008) there are several feature of WSC accumulation that could compromise grain number determination, one of them is timing; the period of rapid stem growth and WSC accumulation partially overlaps with the period of rapid spike growth. Fructans begins accumulating while internodes are still extending and this continues into grain filling depending the environmental conditions (Bonnett and Incoll 1993, Gebbing 2003)



Source – Sink relationship

The peduncle and the penultimate internode that is the internode closest to the spike, contain the majority of storage compound under potential conditions (Wardlaw and Willebrink 1994). In this context, investment in stem WSC could be seen as an alternative competitive sink for the spike, with the potential to lower yield via a reduced grain number. This would also seem logical based on the successful use of dwarf genotypes, which shifted resource capture towards the spike during the period of rapid spike growth (Brooking and Kirby 1981, Fischerman and Stockman 1986), and were particular advantageous in irrigated environments. Another possible path for trade off between grain number and WSC is related to N. Grain number has been positively correlated with N accumulation and partitioning to the spike during the period of rapid spike growth (Abate *et al* 1995; van Herwaarden 1995; Demotes – Maynard *et al* 1999; Demotes – Maynard and Jeuffroy, 2004). In the studies manipulating N supply, van Herwaarden *et al (*1998b) observed that a high concentration or amount of WSC at anthesis was negatively correlated with the proteins concentration or amount in the above ground biomass. Thus it is possible that lower spike N could compromise grain number per spike in lines that accumulates WSC.

In striving to increase the yield potential of cultivated plants it is important to determine the physiological factors limiting yields. The first step towards this is to assess whether the growth of harvested organs is limited by the availability substrates (source limited) or by the capacity of the organ to assimilate and utilize the available substance for growth (sink limited) (Patrick, 1988). Although there is much experimental data on the effect of the source: sink ratio after anthesis in wheat (Evans and Wardlaw 1996).

Results from the response of kernel weight and grain set to source-sink manipulations suggested yield limitation by both the sink (the number grains mm^{-2}) and the source, depending on the seasons time of the day, (Evan and Wardlaw 1996). However, the time courses of source and sink control have not been well documented. Some author (Evans and Rawson, 1970); Richards, 1996) suggested that grain yield in irrigated spring wheat may not be limited by the supply of carbon at any time during grain filling. However, there are data showing significant increases in mass per grain associated with the reductions in grain number (Fischer and HilleRsi lambers, 1978; Ledents and Stoy, 1985; Koshkin and Tararina, 1989), implying source limitations at least on some occasions after anthesis. Source limiting situations are more important in high temperature environments (Fisher, 1983; Blum *et al* 1994). The physiological processes limiting yield in temperate areas can not be directly extrapolated to subtropical or tropical environments.

Analysis of source – sink interactions should also consider the role of alternative sinks in the plants (Schnyder, 1993; Marcelis and Koning, 1995). In wheat, particularly , special attention should be given to the stems, since competitions exists between the growing upper internodes and reproductive organs in the weeks before anthesis (Wardlaw, 1968; Bingam, 1972; Patrick ,1972; Brooking and Kirby, 1981; Siddique Kirby and Perry, 1989), the outcomes of which depends on the both genotypes and environment. Besides there is good evidence that temporary storage is very important under stress conditions (Bidinger, Musgrave and Fischer, 1977; Blum *et al* 1994; Wardlaw and Willenbrink, 1994; Seidel, 1996). Recently, genotypic differences in the patterns of allocation and mobalisation of dry matter in the stem of wheat have been demonstrated (Blum *et al* 1994).Therefore, the inclusions of alternative carbohydrate storage pools in the analysis of source-sink interactions should be of major importance under tropical environment.

The modification of sink size could inhibit photosynthesis in such a manner that evens the filling of the remaining grains and whole plants dry matter grains could be affected by the availability of photo assimilates i.e. the rate of photosynthesis would be diminished to a greater extent than the demands.

The principal cause of such inhibitions of photosynthesis might be the degree of reductions in size of the sink or the position of the trimmed grains or both. The modifications of sink size may affect canopy photosynthesis more than proportionally is supported by the following facts: first, the mechanism of sucrose regulation is not likely to be via a mass – actions effects (Pollock and Farrar, 1996), so there is no reason to expect the direct relationship between sink reductions and photosynthesis inhibitions.

The significant change in flag leafs carbon exchange rate occurs in response to changing demands by the wheat ear during grain filling when alternative sinks for flag leafs assimilates are limited to such an extent that carbohydrates accumulates in the leaves (Evans and Wardlaw, 1996). This is in consistent with the results of Fischer and Hillerislambers (1978) who found a positive correlationship across the cultivars between the grains mass in the remaining kernels of modified spikes and potential kernels weight, determined by a substantial increase in light received in intacts plants. This relationship correlated well evens when the mass of the grains in modified spikes was spikes was lower than that of unmodified plants, meaning that those cultivars with a greater decrement in grain weight after reductions in the number of spikelets shoed the smaller response to the increment in received light.

Distribution of photoassimilates between organs may change during the filling in relations to the part of the plants, source or sink organs that exert control on the partitioning at a given moment (Marcelis and Koning 1995). (Evans and Rawson, 1970; Richards, 1996) reported that photosyntheisis of the spikes and flag leafs blade alone could meet the requirement of the grains at all times grain filling.

Richards (1996) suggested that grain yield of irrigated spring wheat may not be limited by the supply of carbon. However, there are data in the literature showing a significant increase in the in mass of grains associated with reductions in grain number after anthesis Fischer and HillerRisLamber 1978; Ledents and Stoy 1985) implying source limitations, at least some time during grain filling.

These conflicting results suggest a strong environmental and genotypic interaction in the response of grain mass to modifications in source – sink relationship (Ma, Mackonown and Vansandford, 1990; Blade and Baker, 1991). This also underlines the importance of analysis of source – sink interactions at different times during grain filling. The patterns of distribution of ^{14}C – photosynthesis in control plants changed from 7 to 21 day after anthesis the increase in relative radioactive concentrations of the flag leafs, sheath and upper part of peduncle from 7 to 21 days after anthesis. In control plant reflects a shift from source to sink control on partitioning.

This is supported by comparison with the partitioning in plants with reduced sink size. 7 days after anthesis, the grains of plants with the half spikes showed higher RRC than the control plant grains. With the reduction in the number of spikelets to four, the RRC of the grain was reduced, an effect that was reflected in the final grains. The RRC of the flag leaf blade was lower in plants with the modified spikes at 7 DAS (Cruz-aguado *et al*., 1999), perhaps the consequence of inhibitions of plant photosynthesis (Plaut, Mayoral and Reinhold, 1987; Koch, 1996) and translocation of the reduced amount of ^{14}C – photo assimilates to the internodes.

The RRC of internodes did not rise with the decrement in sink size as this could be due to a diminished ability of the internodes to form the fructans at the latter phase of the grain filling (Schnyder, 1993). (Evans, 1993) suggested that interaction of genotypes with the environments can be related to both source and sink constraints, supporting the notion that spare on both sides (i.e. excess source and sink) is probably the best against environmental fluxes, so the crop is not too sensitive to fluctuations.

Wheat grain can be limited by source (the supply assimilates) or sink (the capacity of the grains to accumulate assimilates), both. This results of different studies by manipulating source-sink relationships during grain filling through removing leaves or grains, and shading leaves or grains, and shading have shown inconsistent conclusions (Winzeler *et al.,*1989; Jedel and Hunt, 1990; Savin and Slafer, 1991; Slafer and Savin, 1994; Cruz-Agudo *et al*., 1999).wheat growth in tropics is more source limited than a in temperate areas. Slafer and Savin (1994) suggested that during post anthesis period grain yield of wheat is either sink limited or co-limited by both source and sink but never source limited. This inconsistency reflects the genotypes and environments interaction in the availability of assimilates for grain growth (Ma *et al.,* 1990).

Grain weight has been a most important factorsin increasing yield potential (Liu and Meng, 1994). According to source –sink theory, grain filling rate can be limited by source or sink, including sink size (grain number hectare) and sink strength (example, enzyme activity, phloem loading, hormone control etc.) (Farrar, 1993).

2.5 Yield And Yield Contributing Attributes

Literature related to yield and yield contributing traits are discussed under the following headings:

2.5.1 Effective Tillers (m^{-2})
2.5.2 Grain Spike Weight ratio
2.5.3 1000 Grain weight (g)
2.5.4 Number Grain (m^{-2})
2.5.5 Biological yield
2.5.6 Grain yield
2.5.7 Harvest Index

2.5.1 Effective Tillers (m^{-2})

The effective tillers are very important parameters in determining the grain yield. The effective tillers (m^{-2}) have the relation ship with date of sowing, cultivars as well as with the nitrogen levels. The decrease in grain number was attributed to a drop in effective tillers per unt area, the number of grains per spike or both (Abbate *et al* 1995 and Fischer 1993) Aman (2008) reported that the decrease in the in effective tillers with the date of sowing from 7th Nov. to 6th Dec. The decrease in effective tillers seems to be associated with initial plant density under late sowing (Singh and Ahmad 1997). The interaction of the date of sowing and cultivars were also significant relationship were reported by Akhtar *et al* (2006). Mc Donald (1992) number of effective tillers varies with the cultivars and the application of nitrogen, the number of tillers increase with application of nitrogen. The analysis of growth and phenology of wheat and oats has identified tiller development; tiller duration has important interaction between the crop varieties and dates of sowing. (Kelman and Dove 2009)

2.5.2 Grain Spike Weight Ratio

Better understanding of the variable responses of wheat to the environment is gained by considering the development and growth of the wheat plant. This is necessary because wheat has great plasticity (i.e., there are many ways that final yield can be reached), and both the environment and management influence the path taken to final yield. The important yield components of wheat are number of plants per hectare and tiller number per plant (resulting in number of spikes/heads/ears per unit area), number of spikelets per spike and kernels per spikelet (resulting in number of kernels per spike), and kernel weight. Post flowering growth was positively and directly related to the number of grains m^{-2} (Cossani *et al* 2009). Kanchan (2009) reported that grain spike weight ratio is decrease with the date of sowing but vary among the varieties.

Plant age is important in thermotolerance studies due to varying sensitivity of the plant at different growth stages. Exposing wheat plants to high temperature at early stages can affect factors such as node extension and ear development, while temperature stress at anthesis and later can cause premature leaf senescence and can affect the fertility of the plant leading to reduced grain development (Wardlaw *et al* 1980). Mirallfs *et al* (2008) suggested that changes in final grain weight, associated with changes in rate of grain growth, but nor with duration of the grain filling period, demonstrating that rate of grain growth was the main factor responsible for final grain weight. High temperature significantly decreased grain yield by decreasing grain weight (Tahir *et al* 2006).

2.5.3 1000 Grain Weight

The 1000 grain weight is also called the test weight this is very important parameters in determining the grain yield of particular cultivars. This is one of the parameters which are estimated during the trial of the releasing varieties for the regional or national cultivars. 1000 grain weight is decrease with the delay in sowing as reported by the (Aman 2008, Kanchan 2009 and Shalini 2001). Wardlaw *et al* (1989) reported that grain number showed more sensitivity to temperature after anthesis. They indicated general reduction in yield ear^{-1} of 3-4 percent for each 1^0C rise in temperature above a mean of 15^0C.

Tahir and Nakata (2005) revealed that genotypic differences in high temperature tolerance were more pronounced in grain yield than in biomass yield. Number of grains per spike and 1000 grain weight had significant and positive correlation with grain yield (Sen and Toms 2007). High temperature lasting only 5-6% of the grain filling period demonstrate the extent to which short period of very high temperature may effect wheat yield and quality (Stone and Nicolas 1995).

2.5.4 Grain Number (m^{-2})

The increase in number of grains m^{-2} was associated with both number of grains per unit of spike dry weight at anthesis and spike dry weight at anthesis (Acrche *et al* 2008). The relationship between grain yield and number of grains per m^{-2} of cultivars at different date of sowing (Slafer *et al* 1994 and Calderini *et al* 1999). Grain yield was strongly associated with the number of grain per m2, agree with many physiological studies in that grain yield is mostly sink limited during post anthesis in wheat (Slafer and Savin 1994 and Borras *et al* 2004). Mitra and Bhatia (2008) inferred that net canopy photosynthesis, translocation of the assimilates and sink capacity in the developing grains determined the grain yield. High temperature at earlier stages reduced the spike length and number of spikelets (sink capacity). Heat stress after anthesis reduced grain number and weight. Singh *et al* (2008) proposed that higher leaf orientation, early flowering, canopy temperature depression and seed hardness possessed positive correlation with yield under late sowing, thereby, indicating their involvement in process of terminal heat stress. Thus, these traits which are simple and easily measurable can be used as screening techniques to identify thermotolerant wheat genotypes under late sown conditions.

Sudden increases in temperature during March coincide with grain development phase and in loss of 4.6 million tones of grain at national level due to advancement of maturity and reduction in 1000- grain weight (Samra and Singh 2005). Shpiler and Blum (1991) reported that reduction in grain weight in response to heat stress during growth was related to reduction in grain growth duration rather than grain growth rate.

Nagarajan *et al* (2008) reported that adapted genotypes escaped the heat by maturing early and compensated the reduced grain growth period by enhanced grain growth rate or tolerate the heat stress with minimum change in their grain growth duration and grain growth rate as compared to cool season. Singh and Pal (2003) showed that significant reduction in grain yield of wheat cultivars by delayed sowing could mainly have resulted from marked reduction in sowing to anthesis to maturity durations which inturn reduced the build up of growth and yield components such as tillering, photosynthetic surface per shoot, biological yield, number of grains per spike and 1000-grain weight markedly without marked reduction in harvest index and grain growth rate.

Araus *et al* (2002) proposed that the grain number is positively correlated with number of fertile florets at anthesis increasing spikelet rachilla rachis (floret stalk) fertility to improve wheat yield potential. Lower kernel weight of heat stressed wheat is due to reduction in duration rather than reduction in the rate of grain growth. Heat stress during grain filling hastens maturation of the crop, resulting in small, shrunken grains (Nainwal and Singh 2000). The variety which gives more number of effective tillers even under late to very late sown conditions will eventually give higher yield (Sardana *et al* 2003).

2.5.5 Biological Yield

Royo *et al* (2006) proposed that grain weight can be described as a function of the rate and duration of dry weight accumulation. Genotypes showing high 1000 grain weight under late sown condition revealed the existence of temperature tolerance mechanism (Singh *et al* 2005).An increase in the rate of grain filling in wheat with a rise in temperature above 20^0C commonly observed (Hunt *et al* 1991, Zahedi *et al* 2003). Slafer *et al* (1996) reported that duration of grain filling in wheat decreased by high temperature.

High temperature following anthesis adversely affects the grain development, grain growth rate and grain growth period consequently the final grain weight is reduced (Sofield *et al* 1977, Tashiro and Wardlaw 1990). Environmental conditions before anthesis influence both the number and size of ears in a wheat crop, and thus determine the potential number of grains. Conditions at anthesis and during the next few days then determine how many grains are set, high temperature, low luminance and water stress at this stage being particularly unfavorable (Wardlaw 1970; Fischer 1973).Dry matter (mainly starch and protein) accumulating in the endosperm of cereals grain is produced from precursor (predominantly) sucrose and amino acids which are transported to the grains from their respective sources elsewhere in the plant (Wardlaw 1975).Termination of this accumulation as the grain matures could conceivably, be attributable to loss of synthetic capacity of the endosperm, or to cessation of the supply of assimilates to the grain, or both. Partly developed endosperm that is only 17 days old after booting stage contained very little amount of sucrose that is about 0.13 to 0.3 mg per grain. Between 51 to 56 days the apparent concentration of sucrose rose from the 6.5 to 13.7mg per ml of water (Jenner and Rathjen, 1977).

Welbank *et al*. (1968) indicate fall in the duration of grain filling as incident radiation rises this could be due to an abbreviation of grain growth at higher levels of solar radiation and photosynthesis, or to higher temperature which are often associated with higher radiation (Sofield *et al* 1974; Spiertz 1974). Rawson and Evans in (1970) have already explained that the position of grains within the ear influences its growth rate. Grains in the middle spikelets of the ear grow rather faster than those in apical or basal spikelets, and second florets grains tends to grow faster than grains in the florets, (Bremerner 1972).

The effect of temperature on growth rate per grain was similar almost for all the wheat genotypes. Increase in temperature from 15/10°C to 21/16°C increased the growth rate per grain in florets first by more than 70%. Under high incident radiation the rates of increased by further 20% as the temperature rose to 30/25°C. Differences among cultivars in the rate of growth per ear were usually much greater than those per grain because of substantial difference in the grain number per year. The growth rate per ear and final grain yield per ear were both broadly proportional to grain number per ear. The rate of grain growth ranged from 1.16mg per day to 2.32mg per day (Sofield *et al* 1977).

The great effect of temperature on duration of grain growth and also a major determinate of the yield. Increase in temperature from 21/16°C to 30/25°C almost halved the duration of grain growth, and reduced grain size proportionally (Sofield *et al* 1977). Adjustment of grain number per year occurred almost entirely within the first 10 days after anthesis. There fore, grains maintained linear growth at a rate dependent on luminance, temperature, cultivars and positions in the ears. Only with distal florets grains under very low irradiance was linear growth not sustained. The consistence of growth rate for most grains over a prolonged period, during which the photosynthetic rate of the leaves and the extent of reserves in the stem are declining, could suggest that grain growth is not limited by assimilate supply. In The Mexican wheat like Sonara which do not their upper florets grains so readily, growth rate per grains is more responsive radiance (Sofield *et al* 1977).

2.5. 6 Grain Yield

In wheat production, there are several constraints which limit its productivity. Out of them, one of the major constraints being its late planting which ultimately results in exposure of plants to high temperature at grain development stage (Mishra *et al* 2003). Grain yield of wheat is a complex trait determined by number of grains per unit area and grain weight. Grain yield is mainly determined during pre-anthesis growth but is also influenced by the duration after anthesis (Richard 2000, Martre *et al* 2003 and Slafer 2003). In the major wheat producing areas of northern India, the crop if is occasionally exposed to post anthesis high temperature stress, which constitutes a major yield constraint especially under late sown conditions (Sharma *et al* 2004). Darwinkle *et al* (1977) proposed that the decrease in grain yield was closely associated with lower 1000-grain weight in late sown crop.

Yield is the function of many components which when modified has direct influence on the productivity. For instance, higher grain yield in wheat have been obtained by early sowing (Arain *et al* 2001, Sial *et al* 2005). Wang *et al* (2008) reported that increasing temperature during the vegetative period positively affected winter wheat growth but increasing maximum temperature during reproductive period negatively affected kernel weight and grain yield. Abou-Salam and Ismail (1995) reported that the best regression model for describing family yield included straw weigh, days to anthesis and harvest index, while the best model for describing plant yield included total chlorophyll, harvest index and straw weight per plant.

High temperatures decrease grain set, increase the grain filling rate, and decrease the duration of grain filling with the usual result being lower yield under high temperature (Wardlaw *et al* 1980) Wiegand and Cuellar 1981, Herzog 1986). High temperatures during grain filling also often have a negative effect on grain quality (Asseng *et al* 2002, Martre *et al* 2006).

Yield of wheat declined at high temperature because firstly, organ production was accelerated without any increase in net photosynthesis (Bagga and Rawson 1977). So, there was less daily assimilates to be allocated to each organ and the organs are smaller. Second, because phenological development is accelerated there were fewer days to accumulate assimilates during the life cycle and total production of biomass declines (Fischer and Maurer 1976).

Munjal *et al* (2004) proposed that the mean performance of grain yield and days to heading, significantly higher under normal conditions than under late sown conditions. The quick rise in temperature from late February, during grain filling stage, significantly reduced the value of ear length, grains/ear and 1000 grain weight, resulting in lower grain yield under delayed sowing (Jain *et al* 1992).

Wheat yield in warm environment can be raised significantly by modifying agronomic practices, such as adding farm yard manure to improve soil physical and chemical conditions and to increase the conservation of soil moisture (Sial *et al* 2005). Kalra *et al* (2008) suggested that simple and empirical relations between yield and seasonal temperature change can be well used for a crude estimate of yield dependence of temperature rise of winter crops.

Late sown crop get exposed to high temperature during the reproductive growth.

Temperature had complex relationship with spikelet formation, ripening and grain yield than other weather parameters (Saini *et al* 1988). Akhtar *et al* (2006) found that late sown crop had lowered grain yield than timely sown crop as late sown crop gets exposed to high temperature during reproductive phase. High temperature stresses during anthesis and grain filling period of wheat which results from late sowing are a constraint of productivity (Chawdhury and Wardlaw 1978). Al- Khatib and Paulsen (1984) also reported the effect of temperature stress during reproductive phase on crop productivity. The duration of the reproductive phase during which the spike and shoots competing for assimilates was associated with the number of fertile florets per spike suggesting that extending the stem elongation period in cereals could be a way to reduce assimilate competition and thereby to increase the number of fertile florets and grain yield (Ghosh *et al* 2000).

Mahanta (1967) reported a steady decrease in yield of wheat NP-799. Randhawa and Singh (1968) recorded maximum yield in 15th November sown crop and after this the yield reduced significantly. Heat stress has become an increasingly important factor in limiting wheat yields (Viswanathan and Khanna 2001). Singh and Uttam (1994) studied that grain yield decreased with delay in sowing date and it varied from variety to variety. Warrington *et al* (1977) studied the adverse effect of high temperature on grain yield.

Ibrahim and Abdalla (2000) studied the effect of delayed sowing which were often associated with substantial grain yield losses, estimated at upto 86% at farm level and found that delayed sowing time by one month reduced grain yield by 27% and genotypes exhibited significant differential response to sowing time.

Dhaliwal *et al* (2006) found that wheat yield decreased by 5% for each 1^0C rise in post anthesis daily temperature in the range between 17.7^0 C and 32.7^0 C. Hundal (2004) observed that a 2^0C increase in temperature in wheat and rice resulted in 15-17% decrease in grain yield of both crops but beyond that the decrease was very high in wheat. Ferris *et al* (1998) suggested that temperature of 31^0C or higher, prior to anthesis, can considerably reduce the number of grains per ear, reducing significantly the yield. Short episode of high temperature around flowering can substantially reduce the grain yield (Wheeler *et al* 2000).

Nagarajan *et al* (2008) showed that both grain growth rate and grain growth duration were affected by high temperature and responsible for reduced yields. Singh *et al* (2006) reported that marked increase in grain yield of wheat cultivars occurred due to significant improvement in their harvest index without remarkable change in biological yield.

2.5.7 Harvest Index

The harvest index is indication of ratio of grain mass and biomass. Sarma-Natu *et al* (2006) reported that the decrease in the harvest index indicated that grain mass was more affected than biomass under late sown conditions. Harvest index is positively associated with that of physiological parameters and grain yield (Bilagi *et al* 2008). Constantly high temperature cause an array of morpho- anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield (Wahid *et al* 2007).

In many production environments, particularly semiarid environments, number of spikes per unit area is the most important yield component, followed by number of kernels per spike, and least important is kernel size (Fischer *et al* 1977, Shanahan *et al* 1984, McMaster 1997). Final yield is the result of development creating the yield potential (the number of spikes and kernels present in the plant) and the ability of the plant interacting with the environment to realize that potential by filling the grain (i.e., kernel size).

Ugarte *et al* (2007) reported that yield of grain crops integrates two main components i.e. grain number per square meter and average grain weight. The most probable effect of high temperature on grain yield was due to: (1) Decrease in grain weight when high temperature applied only to spikes between heading and anthesis (Calderini *et al* 2001). (2) Decrease in the growth rate of florets at high temperature. (3) Decrease in final grain weight which was associated with carpel weight at anthesis.

Mian *et al* (2007) reported that high temperature after anthesis upto maturity adversely affects fertilization and grain development. Rise in temperature decreases grain size due to high respiration rate which reduces grain weight because of forced grain development. It was also reported that different varieties showed different response for grain weight when temperature hits after anthesis.

Mishra *et al* (2003) reported that late sown crop get exposed to high temperature during the period of grain filling and therefore, forced to mature early and attained the lower spike dry weight than timely sown crop. A heat wave for 3-4 days at 35-36^{0}C reduced grain size in wheat (Wardlaw and Wrigley 1994). The pre-anthesis high temperature may also affect grain weight potential through its effect on growth of the ovaries which may impose an upper limit for potential grain weight (Calderini *et al* 1999).

2.6 Biochemical Analysis

Literature regarding biochemical parameters is discussed under following heading:

2.6.1 Chlorophyll Content at milky ripe stage
2.6.2 Starch content
2.6.3 Sugar content

2.6.1 Chlorophyll Content at Milky Stage

Among the pigments, the chlorophyll plays an important role in photosynthesis, and its content, as a predictor of the nutritional status of vegetation, is clue of the main factors to evaluate the environment and growth conditions for winter wheat (Xiang *et al* 2004). The development of source and sink activity during grain filling can be represented by chlorophyll content of flag leaf and grain growth (Herzog 1982). Jason *et al* (2004) proposed that the capacity of plant to acclimate and maintain photosynthesis under high temperature is critical factor in heat tolerance. Heat induced damage to thylakoid membranes and chlorophyll loss observed in many crop plants including wheat (Fokar *et al* 1998).

Alterations in various photosynthetic attributes under heat stress are good indicators of thermotolerance of the plant as they show correlations with growth. Any constraint in photosynthesis can limit plant growth at high temperatures. Photochemical reactions in thylakoid lamellae and carbon metabolism in the stroma of chloroplast have been suggested as the primary sites of injury at high temperatures (Wise *et al* 2004). Chlorophyll fluorescence, the ratio of variable fluorescence to maximum fluorescence ($F\text{v}/F\text{m}$), and the base fluorescence (F_0) are physiological parameters that have been shown to correlate with heat tolerance (Yamada *et al* 1996). Increasing leaf temperatures and photosynthetic photon flux density influence thermotolerance adjustments of PSII, indicating their potential to optimise photosynthesis under varying environmental conditions as long as the upper thermal limits do not exceed (Salvucci and Crafts-Brandner 2004, Marchand *et al* 2005).

The main effect of heat stress on the chloroplast is on the proteins of the thylakoid membrane. The thylakoid membranes become disoriented relative to the long axis of the chloroplasts, and the membrane unstacking causes loss of chloroplasts (Xu *et al* 1995). The higher productivity of semi- dwarf wheat cultivars has been attributed to their greater leaf photosynthetic rate, stomatal conductance and canopy temperature depression (Fischer *et al* 1998).

Consequence of elevated temperature in plants is the damage caused by heat-induced imbalance in photosynthesis and respiration; in general the rate of photosynthesis decreases while dark- and photo-respiration rates increase considerably under high temperatures. Also, rate of biochemical reactions decreases and enzyme inactivation and denaturation take place as the temperature increases leading to severely reduced photosynthesis (Nakamoto and Hiyama 1999). However, the magnitude of such alterations in response to heat stress differs with species and genotypes (McDonald and Paulsen 1997). Furthermore, it has been determined that the photosynthetic CO_2 assimilation rate is less affected by heat stress in developing leaves than in completely developed leaves. Heat stress normally decreases the duration of developmental phases leading to smaller organs, reduced light perception and carbon assimilation processes including transpiration, photosynthesis and respiration (Stone 2001). Nonetheless, photosynthesis is considered as the physiological process most sensitive to high temperatures, and that rising atmospheric CO_2 content will drive temperature increases in many already stressful environments. This CO_2-induced increase in plant high-temperature tolerance may have a substantial impact on the productivity of crop.

PSII is highly thermolabile, and its activity is greatly reduced or even partially stopped under high temperatures (Bukhov *et al* 1999, Camejo *et al* 2005), which may be due to the properties of thylakoid membranes where PSII is located (McDonald and Paulsen 1997). Heat stress may lead to the dissociation of oxygen evolving complex (OEC), resulting in an imbalance between the electron flow from OEC toward the acceptor side of PSII in the direction of PSI reaction center (De-Ronde *et al* 2004). Heat stress causes dissociation of a manganese (Mn)-stabilizing 33-kDa protein at PSII reaction center complex followed by the release of Mn atoms (Yamane *et al* 1998). Heat stress may also impair other parts of the reaction center, e.g., the D1 and/or the D2 proteins (Rivas and Barber 1997). In wheat, high temperatures and excessive light damaged different sites of PSII, which implied different pathways for the recovery of its functional activity (Sharkova 2001). This implied that the degradation of the impaired PSII units occurred in the light during this period of time. Following this, *de novo* synthesis of PSII units in the light gave a gradual rise to the observed PSII activities. These effects can result from different events, including inhibition of electron transport activity and limited generation of reducing powers for metabolic functions (Allakhverdieva *et al* 2001).

Chlorophyll a fluorescence assesses damage to photosystem II (PS II) and thylakoid membranes caused by heat (Maxwell and Johnson 2000, Sayed 2003). Reynolds *et al* (2005) reported a significant correlation between flag leaf photosynthesis measured after anthesis and grain yields in spring wheat genotypes.

Ristic *et al* (2007) inferred that cultivars that showed chlorophyll loss differed in their ability to retain chlorophyll under heat stress. Chlorophyll loss can occur in plants undergoing senescence (Thimann 1987) and it can also prematurely occur in plants experiencing heat stress (Al- Khatib and Paulsen 1984, Reynolds *et al* 1994).

The response of yield to high temperature was more closely related to changes in flag leaf chlorophyll concentration than loss of thylakoid activity (Graham and McDonald 1990). Blanco (1999) reported that higher chlorophyll a/b ratio indicates a higher concentration of photosystems per chlorophyll. This condition could be advantageous in high light intensity environment.

Chlorophyll loss under heat stress can be used to indicate heat tolerance and that measurements of chlorophyll content using chlorophyll meter will be useful as a method for high throughput screening for heat tolerance in wheat (Ristic *et al* 2007). The ability of plant to retain chlorophyll under stress is generally known as the “stay- green trait” (Thomas and Howarth 2000) and the identification of plants displaying this trait could aid in producing new wheat cultivars with improved tolerance to heat stress.

Mitra and Bhatia (2008) proposed that most of the carbohydrates in the wheat grain are derived from the photosynthates produce in the flag leaf after anthesis. A positive correlation between rate of photosynthesis and grain yield was observed in diverse germplasm. Harding *et al* (1990) have suggested that a major effect of high temperature on wheat is acceleration of senescence, which is manifested by an increase in the activity of proteolytic enzymes leading to protein degradation and chlorophyll loss.

Tahir *et al* (2005) proposed that high temperature of soil alone or high temperature of both air and soil decreased the chlorophyll content and grain filling duration and increased carbohydrates remobilization. Wheat may experience heat stress and suffer injury during vegetative or reproductive phases depending on the location and season, but most commonly it encounters stress in the later part of the growing season (Wardlaw *et al* 1989).

Mullarkey and Jones (2000) suggest that under field conditions initial measurements of chlorophyll content should be taken when wheat begins to experience temperature that are generally considered as heat stress temperature for wheat .

Ristic *et al* (2008) proposed a model on the basis of correlation between heat induced damage to photosynthetic membranes (thylakoid membranes) and chlorophyll loss. This model can adequately predict ratio of constant chlorophyll a fluorescence and peak of variable fluorescence (P) and thereby the heat stability of thylakoid membranes in all genotype groups with high coefficient of determination.

2.6.2 Starch Content

Starch accumulation and starch granule size were reduced at high temperature in barley, but amylose contents were little affected and no change in amylopectin fine structures was detected (MacLeod and Duffs 1988). Shi *et al* (1994) reported that with increasing temperature during grain filling, amylose content was slightly increased and starch gelatinization temperatures increased. Environmental temperature affects grain yield, protein content, size and number of starch granules (Bhullar and Jenner 1985). Maize grown at higher temperature during endosperm cell division had reduced kernel mass due to reduced number of endosperm cells, starch granules or both (Jones *et al* 1985). Zhao-Hui *et al* (2006) reported that the contents of total starch and amylopectin were markedly reduced but amylose content was slightly affected and the ratio of amylopection to amylose was reduced significantly in higher temperature treatments.

Yong Cheng (1994) reported that growth of wheat at higher temperature resulted in shrivelled kernels, reduced kernel weight, reduced starch accumulation and reduced starch granule size. Deformed starch granules were observed in wheat grown at 40^0C. Starch-lipid levels increased with increasing grain filling temperature, amylose levels were slightly increased. It has been shown by Chaudhary *et al* (1994) that the soluble form of starch synthase exhibits enhanced activity in developing seeds of tolerant types under post-anthesis heat stress and this was not accompanied by an expected increase in the dry weight of the grain although the reduction in grain weight was insignificant under heat stress as compared to control.

The increase in amylopectin percent in starch in the tolerant types appears to be atleast on two counts, first to partition and accommodate more carbon in the grain under heat stress which is known to reduce the grain development time considerably and may involve both the soluble starch synthase and the branching enzyme. Second, the starch with higher amylopectin content is capable of holding more water effectively (Pande *et al* 1998).

2.6.3 Sugar content

In general factors controlling grain growth may include two aspects. One is carbohydrate supply from the current photosynthates or sugar stored in vegetative organs (mainly stems and leaf sheaths) pre-or/and post anthesis, other is carbohydrate utilization in grain (sink) (MiGuohua *et al* 2009). *In vitro* soybean seed growth rates are related to media sucrose concentration, increasing from essentially zero with no sucrose in the media to a maximum rate at approximately 100 mM, which is maintained at concentrations upto 200 mM (Thompson *et al* 1977). The response of seed growth rate *in vivo* to a change in assimilate supply may depend on the concentration of assimilates or sucrose in the seed (Jenner *et al* 1991). The dependence of seed number on canopy photosynthesis and assimilate supply may tend to maintain seed number at level where the sugar concentration in the individual seed is near the critical level producing maximum seed growth rate as suggested by Farrar and Gunn (1996).

The leaf sheaths of upper leaves accumulate large amount of starch before heading, and the accumulated starch before heading, and the accumulated starch is converted to sucrose and translocated to the panicle after heading. Thus, sink-sucrose transition occurs in rice leaf sheath during the heading period (Cock and Yoshida 1972).

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled, “Studies on Simulating biomass accumulation and its partitioning in the wheat (*Triticum aestivum* L.)” was carried out at the experimental area of the Department of Botany in Punjab Agricultural University, Ludhiana during the *rabi* season of 2008-2009 and 2009-2010.

3.1 LOCATION AND CLIMATE

Ludhiana representing the Trans Indo-Gangetic alluvial plains is situated at 30º-56’N latitude and 75º-52’E longitude and at an altitude of 247 m above mean sea level. Ludhiana is characterized by subtropical semi-arid type of climate with hot and dry early summers (March-June), hot and humid summer monsoon (July-September), mild winter (October-November) and very cold winters (December-February). The mean maximum and minimum temperature, therefore, shows considerable fluctuation during summer and winter. Maximum air temperature above 40ºC is not uncommon during summer. The meteorological data from meteorological observatory, Punjab Agricultural University, Ludhiana for the season 2008-09 and 2009-2010 are given in (Appendix I).

3.2 SOIL STATUS

Representative samples of the soil at the depth of 15-75 cm from the experimental field were randomly selected from five places at the start of the experiment to determine the physico-chemical properties of the soil. The composite samples were subjected to mechanical and chemical analysis. The physico-chemical properties of the soil are given in Table 3.1

Table 3.1 Physico-chemical analysis of experimental field soil

Soil depth	**15 cm**	**30 cm**	**45 cm**	**60 cm**	**75 cm**
Lower limit drained cm cm^{-3}	0.06	0.06	0.05	0.04	0.04
Upper limit drained cm cm^{-3}	0.22	0.22	0.22	0.21	0.20
Upper limit saturated cm cm^{-3}	0.40	0.38	0.35	0.34	0.33
Root growth factor soil only	1.0	0.9	0.75	0.5	0.25
Bulk density moist g cm cm cm^{-3}	1.58	1.72	1.68	1.68	1.68
Organic carbon (%)	0.39	0.14	0.21	0.13	0.11
Clay (<0.002mm)	8	8	7	6	6
Silt (0.05 to 0.002mm)	15	18	10	4	8
Coarse fraction	77	74	83	90	86
Cation exchange capacity cmol kg^{-1}	10.3	9.8	8.4	7.7	7.2
pH in water	6.5	7.1	7.1	7.2	7.2

The analysis of the soil status was performed at department of soil, Punjab Agricultural University, Ludhiana.

3.3 EXPERIMENTAL DETAILS AND LAY OUT

3.3.1 Experiment 1. Studies on Simulating biomass accumulation and its partitioning in the wheat (*Triticum aestivum* L.)

The dates of sowings and wheat cultivars used in experiment are presented as under:

i) Dates of Sowing: Three

a)15th Oct. (D_1) b)15th Nov. (D_2) c) 15th Dec. (D_3)

ii) Varieties: Four

a) PBW-343 (V_1) b) PBW-502 (V_2) c) PBW-550 (V_3) d) WH-542 (V_4)

iii) Nitrogen levels (kg ha^{-1}): Three

a) N_{90} b) N_{120} c) N_{180}

iv) Total number of treatments : 36

v) Design : Split plot design

vi) Number of replications : 3

vii) Total number of plots : 108

3.3.2 Agronomic practices

3.3.2.1 Field Preparation

The field was ploughed twice with a cultivator and then planked. The package of practices for wheat crop was followed (Anonymous 2008).

3.3.2.2 Sowing and Harvesting

Three sowing dates viz. 2nd week October, 2nd November, and 2nd December, four cultivars PBW-343, PBW-502, PBW-550 and WH-542 and three nitrogen levels were included in the study. The sowing was done with a manual drill keeping row to row distance at 22.4 cm. The harvesting was done with sickles and threshed manually.

3.3.3 OBSERVATIONS RECORDED

3.3.3.1 Phenological Development

Understanding, predicting crop phenology and canopy development is important for many reasons including improving the efficacy of management practices and accuracy of simulation models and decision support systems. The different phenological stages were recorded by tagging four plants from each replication.

a) **Seedling Emergence**: The coleoptile is the first structure of the shoot which emerges from the seed at germination. This stage was noticed when coleoptile had emerged from the soil.

b) **Crown Root Initiation (CRI)**: This stage was recorded generally after 15 days of sowing. Crown was visible at 2-3 cm below soil surface and usually separated from the seed by a sub-crown internode.

c) **Tillering**: Tillering is the development of shoots at the base of main stem. This stage was recorded from the appearance of first tiller to the last tiller.

d) **Jointing (Stem Elongation)**: The Jointing stage was noticed when a thickening, a knob (first node) can be felt at the bottom of the main stem as low as just at the soil surface till the appearance of last node.

e) **Booting**: This stage begins when the flag leaf sheath completes the growth and the spike starts swelling within the flag leaf sheath. The stem reached the full boot stage when awns poking out of the flag leaf whorl and the leaf sheath just started to split.

f) **Inflorescence (Emergence and Heading):** This stage was noticed when the terminal spikelet of the spike became visible. Heading continues till the complete spike has emerged, still without yellow anthers extruding from its florets.

g) **Anthesis:** Anthesis stage was noticed from the emergence of first anthers from the spike till the anthers stop emerging.

h) **Watery Ripe:** Watery ripe stage was noticed when the grains yielded a watery fluid on pressing between the thumb and the forefingers.

i) **Milky Ripe:** When the grains yielded a milky fluid on pressing between the thumb and the forefingers, it represented the milky ripe stage.

j) **Soft Dough:** In soft dough stage, waxy ripe gluten like sticky feel obtained upon pressing the developing seed between the fingers.

k) **Hard Dough:** This stage was noticed when the grain hard to puncture and started dry off.

l) **Physiological Maturity:** This stage was attained when the inflorescence lost the entire green colour, the peduncle turned yellow, but the uppermost node still remained green and grains become hard.

3.3.3.2 Growth Parameters

The following various growth parameters were studied:

a) **Emergence Count m^{-2}:** One m^{2} area was marked in each replication of all plots. Emergence count from one m^{-2} area of each replication was recorded after the completion of germination.

b) **Phyllochron index:** leaf, tiller and node appearance was measured from the initially tagged plant from each plot in replication. As given under in the Fig 1.

c) **Dry matter production at 15 days intervals:** Plants harvested from premarked uniform area in each replication at 15 days of intervals. The plants were first sun dried and then dried at 65^{0}C till a constant weight was attained.

d) **Plant Biomass at Anthesis and Maturity Stage m^{-2}:** Plants were harvested from pre marked uniform area in each replication at anthesis and maturity stage. The plants Were first sun dried and then dried at 65^{0}C till a constant weight was attained.

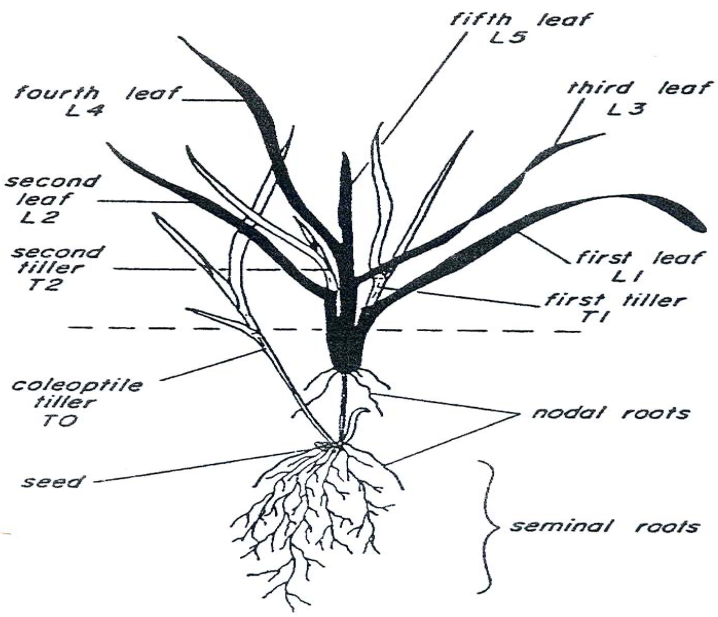


Fig 1. Drawing of a young wheat plant showing identified leaves, tillers, and roots (Klepper *et al* 1982)

e) **Leaf Area**: Leaf area of uniform plants was measured from each replication at all stages:

The following formula was used to calculate leaf area:

Leaf area = L x B x 0.81

L – Length B – Breadth 0.81 – constant factor for wheat

f) **Pre-anthesis Dry Matter Production (%):** It was determined by using the method of Singh and Pal (2003).

$$\text{Pre-anthesis dry matter Production (\%)} = \frac{\text{Total dry wt. at anthesis}}{\text{Total dry wt. at maturity}} \times 100$$

g) **Crop Growth Rate (mg cm^{-2} day^{-1})**: Dry weight of uniform plants from each replication was taken at booting, inflorescence (emergence and heading) and after anthesis stages to calculate crop growth rate (CGR) at following stages:

(i) Before anthesis (ii) After anthesis

The crop growth rate was calculated by using the following formula:

$$CGR = \frac{W_2 - W_1}{SA\,(T_2 - T_1)}$$

W_2-W_1 = Weight of plant at two different time intervals (ΔW)

T_2-T_1 = Time intervals (ΔT)

SA = Soil surface area covered by plant

h) **Grain Filling Rate (mg/grain/day)**: A sample of five uniform spikes from each replication after every 10 days from anthesis till maturity, was collected from each plot. Samples were dried at 55^0C for 48 hrs and then threshed and dry grain weight (mg/grain/day) was calculated (Randhawa *et al* 1992).

i) **Grain Growth Duration**: The duration of grain growth period (days) was calculated from anthesis to physiological maturity stag. (Randhawa *et al* 1992).

f) **Ear: Stem Ratio (weight basis)**: Ear: Stem ratio was measured at maturity in four plants from each replication by using following formula:

$$\text{Ear: Stem ratio} = \frac{\text{Ear weight}}{\text{Total plant dry weight}}$$

3.3.3.3 Yield and Yield Contributing Attributes

The following yield and yield contributing attributes were studied:

a) **Effective Tillers/ Number of Spikes m^{-2}**: At the time of harvest, the effective tillers/ ear bearing tillers were counted from one m^2 area of each replication in all plots.

b) **Grain-Spike Weight Ratio:** The grain-spike weight ratio was determined at maturity by dividing grain weight per spike over total spike weight. The following formula represent grain-spike weight ratio:

$$\text{Grain-spike weight ratio} = \frac{\text{Grains weight per spike (g)}}{\text{Total spike weight (g)}}$$

c) **Number of Grains m^{-2}**: Number of grains of one plant were counted from each replication and then they were multiplied with number of plants m^{-2} to get number of grains m^{-2}.

d) **Root : Shoot Ratio (weight basis)**: Root: Shoot ratio was measured at anthesis in four plants from each replication by using following formula:

$$\text{Root: Shoot ratio} = \frac{\text{Root weight}}{\text{Total plant dry weight}}$$

e) **1000 Grain Weight (g):** Random sample of one thousand grains from bulk produce was taken from each replication and weighed accurately using weighing balance.

f) **Biological Yield (q ha^{-1}):** Each replication of one m^2 area were harvested and tied into bundles. Biological yield was recorded by weighing the bundles of each replication with spring balance. The biological yield was recorded in kg and then subsequently converted into q ha^{-1}.

g) **Grain Yield (q ha^{-1}):** Grain yield was recorded after harvesting and threshing the crop. The crop was threshed manually. It was recorded in kg and then subsequently converted into q ha^{-1}.

h) Harvest Index (HI): Harvest index considered as best index for screening heat tolerant genotypes of wheat. It was calculated by dividing grain yield with the biological yield, using the following formula:

$$\text{Harvest index (HI)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.3.3.4 Thermal and photo thermal units for describing phenological developments

a) Growing degree days (GDD) = $(n) \dfrac{(Tmax + T\ min)}{2} Tb$ (Cross and Zuber 1972)

Where,

(n) = Number of days in between two successive phenological stages

T max = Maximum temperature (°C) of the days.

T min = Minimum temperature (°C) of the days.

Tb = Base temperature at which leaf appearances rate reached zero (Tb = 5°C)

b) The Accumulated Running Average Temperature (Baker *et al* 1986)

ACCDG =ΣTAVGi

Where TAVG = (TDAY x DAYTM + TNYT x NYTTM)/24

c) CHETA = Σ TAVGi – Tbi (Baker *et al* 1986)

Where as CHETA is accumulative GDD using TAVG and TAVG is the average weighted 24hr temperature

d) Energy Degree Unit (Baker *et al* 1986)

CEDU = Σ [(Tmax +Tmin) / 2] * Rs

Where as CEDU is accumulative energy degree units and Rs is Solar Radiation on a day Cal / m^2

e) Helio thermal units (HTU) = GDD X actual sunshine hours (Baker *et al* 1986)

f) Photo thermal units (PTU) = GDD X maximum possible sun shine hours (Baker *et. al* 1986)

Development of crop growth model -

Following approaches was adopted for simulation of model: -

- Statistical regression models (Scian 2004)
- Tillering and leaf area index (LAI) (Evers *et al* 2004)
- CERES-wheat model (Jones *et al* 2003)
- INFOCROP model (Aggarwal *et al* 2001)

3.3.3..5 Statistical analysis

In order to see significance of results, the data will be subjected to standard statistical technique of analysis according to split plot design.

3.4 EXPERIMENTAL DESIGN AND LAY OUT

Experiment No. 2 : Studies on Source – sink relationship of plant architecture manipulation and biomass partitioning

3.4.1 Location: Field/ Lab

Experiment was conducted at the research farm, during *rabi* season, 2008-2009 and 2009-2010.

3.4.2 Research Methodology and experimental Design

Physico- chemical properties of the soil (pH, EC, organic carbon (%) available N, P, K (kg/ ha)) of the experimental field was determined as given in table 3.1.

The one cultivar (PBW-343) was sown at 2nd week of November; optimum level of nitrogen application and optimum planting distances during *rabi* (winter) season with recommended packages and practices, in randomized block design with three replicates. For observation of different phenological phases of one wheat cultivar under normal dates of sowing, optimum level of nitrogen and for optimum population plant from each plot was tagged after seedling emergence. For biological / grain yield and yield contributing traits uniform area ($1m^2$) was marked at the beginning in each plot. Plant growth and yield parameters time series data on: ontogeny, phenology and growth stages starting from seedling emergences to maturity was collected. Meteorological parameters *i.e.* Meteorological parameters *i.e.* Maximum, Minimum and mean temperature, Relative humidity, soil temperature, vapour pressure, wind speed, rain fall, Evaporation, night length, day length, Actual sun shine hours and Maximum possible sun shine hours etc. Was collected from observatory, Department of Agricultural Meteorology, Punjab Agricultural University, Ludhiana.

The dates of sowings and wheat cultivars used in experiment are presented as under:

i)	Dates of sowing (1)	:	2nd Week of November
ii)	Cultivars (1)	:	Cv. PBW-343
iii)	Nitrogen level (1)	:	$120Kgha^{-1}$
iv)	Total number of treatments	:	4
v)	Design	:	Randomized Block Design
vi)	Number of replications	:	3

3.4.3 Source - sink manipulation

a) Source manipulation: Sources manipulation at heading stage, flag stage from each ear-bearing tiller was surgically removed from one meter square area in three replications.

b) Sink manipulation: Sink manipulation two days after anthesis 1/3rd of each spike from the top was removed from one meter square area in three replications.

c) Source - Sink manipulation: both Sources manipulation at heading stage, flag stage from each ear-bearing tiller and Sink manipulation two days after anthesis 1/3rd of each spike from the top was removed surgically from one meter square area in three replications.

3.4.4 Observations recorded

Schedule work flow diagram

Quantification of plant growth, yield and starch composition

Dry Biomass

Growth stages		**Plant parts**
• Crown root initiation		Green leaves
• Tillering	:	Sheath
• Jointing		Blade
• Booting stage		
• Ear emergence		Stem
• Flowering	:	Nodal portion
		Peduncle
• Anthesis	:	Spikes
• Grain formation		Grain
		Husk
• Milky stage		Grain
• Dough stage	:	Sugar
• Physiological maturity		Starch

3.4.5 Statistical analysis

The data was subjected to standard statistical analysis for calculating critical difference.

Development of crop growth model -

- Following approaches was adopted for simulation of model: -
- Statistical regression models (Scian, 2004)
- Tillering and leaf area index (LAI) (Evers *et al* 2004)
- CERES-wheat model (Jones *et al* 2003)
- INFOCROP model (Aggarwal *et al* 2001)
- Source and Sink function (Pan *et al* 2007)

3.4.6 Biochemical analysis

The biochemical analysis of the following were performed:

3.4.6.1 Estimation of Chlorophyll

3.4.6.2 Estimation of Sugar

3.4.6.3 Estimation of Starch

3.4.6.1 Estimation of Chlorophyll

The method of Anderson and Boardman (1964) was followed to estimate chlorophyll content from first week of March till maturity at 7 days interval.

Extraction: 50 mg of fresh flag leaves were taken and crushed in 5 ml of 80% acetone in a pestle and mortar. The extract was centrifuged at 3 x 1000 rpm for 10 min. The supernatant was retained and the residue again crushed in 3 ml of 80% acetone. The two supernatant were pooled and the final volume was adjusted to 10 ml with 80% acetone.

Estimation: Absorbance was recorded at 645 and 663 nm.

Chlorophyll content (mg chl g^{-1} fresh weight) was calculated by using following formulae:

$$\text{Chlorophyll a} = [12.7\ (A\ 663) - 2.69\ (A\ 645)] \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll b} = [22.9\ (A\ 645) - 4.86\ (A\ 663)] \times \frac{V}{1000 \times W}$$

$$\text{Total Chlorophyll} = [20.2\ (A\ 645) + 8.02\ (A\ 663)] \times \frac{V}{1000 \times W}$$

where:

V = Total volume of the extract (ml)

A 663 = Absorbance at 663 nm

W = Fresh weight of the sample (g)

A 645 = Absorbance at 645 nm

The chlorophyll content is expressed as mg chl g^{-1} FW.

3.4.6.2 Total Starch

Total starch was extracted by the method of Clegg (1956).

Extraction: 200 mg of dried residue, that left after extraction of sugar was used to determine starch. In this residue 5ml distilled water and 6.5 ml chilled 52% perchloric acid was added and stirred continuously for 10 minutes, and then added 10 ml distilled water and centrifuged for 20 minutes. Supernatant was poured in volumetric flask. The extraction was repeated twice with pellet for 30 minutes. Supernatant was diluted to 100 ml with water and this solution was then filtered through Whatman filter paper, discarded the first 5 ml of the filtrate.

Estimation: Estimation of sugar by Dubois *et al* (1956). 1 ml extract was taken and added 1 ml of 5% phenol and 5 ml concentrated H_2SO_4. Absorbance of the colour thus obtained was read at 490 nm (SL-159 UV-VIS Spectrophotometer).

3.4.6.3 Sugar content

Total sugar were determined by the method of Dubios *et al* (1956)

Reagent

(i) 95% Sulphuric Acid
(ii) 5% Phenol

Procedure

To 1 ml of sugar extract, 1 ml of 5% phenol was followed by the addition of 5 ml of sulphuric acid. The sulphuric acid was poured directly in the centre of the test tube to ensure proper mixing. After 10 minutes the absorbance was read at 490nm against reagent blank. The concentration of total sugars was read from the standard curve prepared by using glucose in the range of 20-100 microgram.

3.5 STATISTICAL REGRESSION MODEL

The relation between the expected value of Y and X in a bivariate population can be given in the form of mathematical equation know as the regression equation.

$$Y = a + bX$$

Where as a and b coefficient constant. Y is dependent variable and X is independent variables.

3.6 TILLERING AND LEAF AREA INDEX

Leaf and tiller appearance and length of the appeared part of each leaf of 3 individual plants were monitored every three or four days. These measurements were done on main stems and all primary and higher order tillers. The dimensions of all full-grown organs (blades, sheaths) were measured destructively on two sampling occasions using separate batches of plants. The first occasion was at maturity of the each main stem leaf; the second sampling occasion was at maturity of the flag leaves of all shoots. Note that leaves were regarded to be full-grown when the ligule had appeared. For both the experiment

3.7 CERES MODEL DESCRIPTION

3.7.1 CERES Input Parameters
3.7.2 CERES Genetic Coefficients
3.7.3 CERES Parameters Simulate
3.7.4 CERES Model Calibration
3.7.5 CERES Validation of Model
3.7.6 CERES Relational flow Diagrams for Different Processes

The CERES-Wheat model simulates phenological development of the crop; growth of grains, leaves, stems, and roots; biomass accumulation based on light interception and environmental stresses; soil water balance; and soil N transformations and uptake by the crop. It has the ability to evaluate different options of water and nitrogen management for increasing yield of wheat. The model describes the progress through the crop life cycle using degree-day accumulation. The duration of growth stages in response to temperature and photoperiod varies between species and cultivars, and genetic coefficients are used as model inputs to describe these differences. The phenology component also simulates the effect of water or N deficit on the rate of lifecycle progress (Singh *et al* 1999). The model predicts daily photosynthesis using the radiation-use efficiency approaches a function of daily irradiance for a full canopy, which is then multiplied by factors ranging from 0 to 1 for light interception, temperature, leaf N status, and water deficit. Growth of new tissues depends on daily available carbohydrate and partitioning to different tissues as a function of phenological stage, which is modified by water deficit and N deficiency stress indices. Leaf area expansion depends on leaf appearance rate, photosynthesis and specific leaf area. The soil water balance model computes the daily changes in soil water content of various soil layers as a result of infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, plant transpiration, and root water uptake (Ritchie, 1998). The soil has parameters that describe its surface condition and layer-wise soil water-holding and conductivity characteristics. The model uses an overflow or ‘‘cascading bucket’’ approach for computing soil water drainage when a soil layer’s water content is above the drained upper limit.

3.7.1 CERES Input Parameters

Input requirements for CERES-Wheat include weather and soil conditions, plant characteristics, and crop management (Hunt *et al*., 2001). The minimum weather input requirements of the model are daily solar radiation, maximum and minimum air temperature, and precipitation. Solar radiation can be approximated from other observations, such as the number of sunshine hours, which is sometimes more readily available. Soil inputs include drainage and runoff coefficients, first-stage evaporation and soil albedo, water-holding characteristics for each individual soil layer, and rooting preference coefficients at several depth increments. The model also requires saturated soil water content and initial soil water content for the first day of simulation. Required crop genetic inputs are coefficients related to photoperiod sensitivity, duration of grain filling, conversion of mass to grain number, grain filling rates, vernalization requirements, stem size, and cold hardiness (Hunt *et al*., 1993). Main management input information includes plant population, planting depth, and date of planting. If the crop is irrigated, the date of application and amount is required. Latitude is required for calculating day length. The model can use different weather, soils, genetic, and management information within a growing season or for different seasons in a single model execution. The model simulates phonological development, biomass accumulation and partitioning, leaf area index (LAI), root, stem, leaf, and grain growth, and the soil and plant water and N balance from planting until harvest maturity based on daily time steps (Godwin and Singh, 1998; Ritchie, 1998; Ritchie *et al*., 1998).

3.7.2 CERES Genetic Coefficients

i) CERES P1V -Vernalization Coefficient
ii) CERES P1D - Photoperiod Coefficient
iii) CERES P5 - Grain filling duration Coefficient
iv) CERES G1 - Kernel number Coefficient
v) CERES G2 - Kernel weight Coefficient
vi) CERES G3 - Spike number Coefficient

There are a number of coefficients that can be adjusted in the CERES-Wheat model. The "genetic coefficients" describe the phenology and grain yield components of a particular variety, they are located in the file "genetics.wh9"; the calibration of these coefficients is described below.

A number of coefficients are fixed internally in the CERES-Wheat model that are in general standard for all wheat varieties. There are six coefficients that need to be adjusted to calibrate the model for each wheat variety in a particular climatic area. These coefficients are scalar values that are converted into physiological meaning values within the model.

i) CERES P1V - Vernalization Coefficient

"Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars".

This coefficient reflects the differing vernalization requirements of varieties. The input value is a 0 to 9 scalar which is used internally within the model to compute the required number of vernalizing days. The following table can be used as a guide.

ii) CERES P1D - Photoperiod Coefficient

"Relative amount that development is slowed when plants are grown in a photoperiod 1 hour shorter than the optimum (which is considered 20 hours)." This coefficient is used to describe the sensitivity of varieties to photoperiod. It is input as a scalar value between 1 and 5 which is used internally within the model to scale the rate at which development to terminal spikelet occurs. Use 1 for an insensitive variety and 5 for a highly sensitive variety.

iii) CERES P5 - Grain filling duration Coefficient

"Relative amount of degree days above a base of 1°C that are needed from 20 after anthesis to maturity". This is a 1 to 5 scalar which is used internally within the model to alter the duration from anthesis to physiological maturity.

iv) CERES G1 - Kernel number Coefficient

A scalar value of 1 to 5 that indicates the relative kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (kernel number g-1).

v) CERES G2 - Kernel weight Coefficient

A scalar value from 1 to 5 that indicates the relative kernel filling rate under optimum conditions (mg day-1).

vi) CERES G3 - Spike number Coefficient

A scalar value from 1 to 5 that indicates the relative amounts of non-stressed dry weight of a single stem (less leaf blades and sheaths) and spike when elongation ceases (g).

3.7.3 CERES Parameters Simulate:

i) Crop and soil status at main development stages
ii) Main growth and development variables
iii) Environmental and stress factors at different growth stages
iv) Water balance
v) Nitrogen balance
vi) Organic matter
vii) Phosphorus balance

i) Crop and soil status at main development stages:

BIOMASS (kg ha^{-1}), LAI, LEAF NUM, ET (mm), RAIN (mm), IRRIG (mm), SWATER (mm), CROPN(kg ha^{-1} as well as %),N and water stress at different dates, crop age and growth stages as per requirement.

ii) Main growth and development variables:

Flowering date (days after planting DAP), physiological maturity (DAP), grain yield (kg ha^{-1}; dry), weight per grain (g; dry), grain number (grainm^{-2}), grains/ear, maximum LAI (m^2/ m^2), biomass (kg ha^{-1}) at anthesis, biomass N (kg N ha^{-1}) at anthesis, biomass (kg ha^{-1}) at harvest, stalk weight (kg ha^{-1}) at harvest, harvest index (kgkg^{-1}), final leaf number, grain N (kg N ha^{-1}), biomass N (kg N ha^{-1}), stalk N (kg N ha^{-1}) and seed N (%).

iii) Environmental and stress factors at different growth stages

Environmental factors are maximum and minimum temperature, solar radiation and photoperiod. Stress factors include water and N stress at different growth stages.

iv) Water balance: water table, potential evapotranspiration, water available in root zone.

v) Nitrogen balance: Ammonia volatilization, grain nitrogen soil nitrogen.

vi) Organic matter: Soil carbon in different layers

vii) Phosphorus balance: Phoporous in different layers

3.7.4 CERES Model Calibration

Model calibration or parameterization is the adjustment of parameters so that simulated values compare well with observed values. The genetic coefficients of the wheat variety HD 2687 that influence the occurrence of developmental stages in the CERES models were derived using the GENCALC software of DSSAT v 3.5. This program estimates the coefficients for a genotype by iteratively running the crop model with an approximate value of the coefficients concerned. It compares the simulated and measured data, and then automatically altering the cultivar coefficient until the simulated and measured values match or are within predefined error limits. The required crop measurements are the key phenological dates, such as anthesis and harvest maturity, and yield and yield components (Hunt *et al*., 1993). Then other crop parameters were derived manually by changing 5% of the default value of each crop parameter till a satisfactory level of agreement between predicted and observed value of yield, biomass was achieved. For calibration of both models the N_{120} treatment was considered.

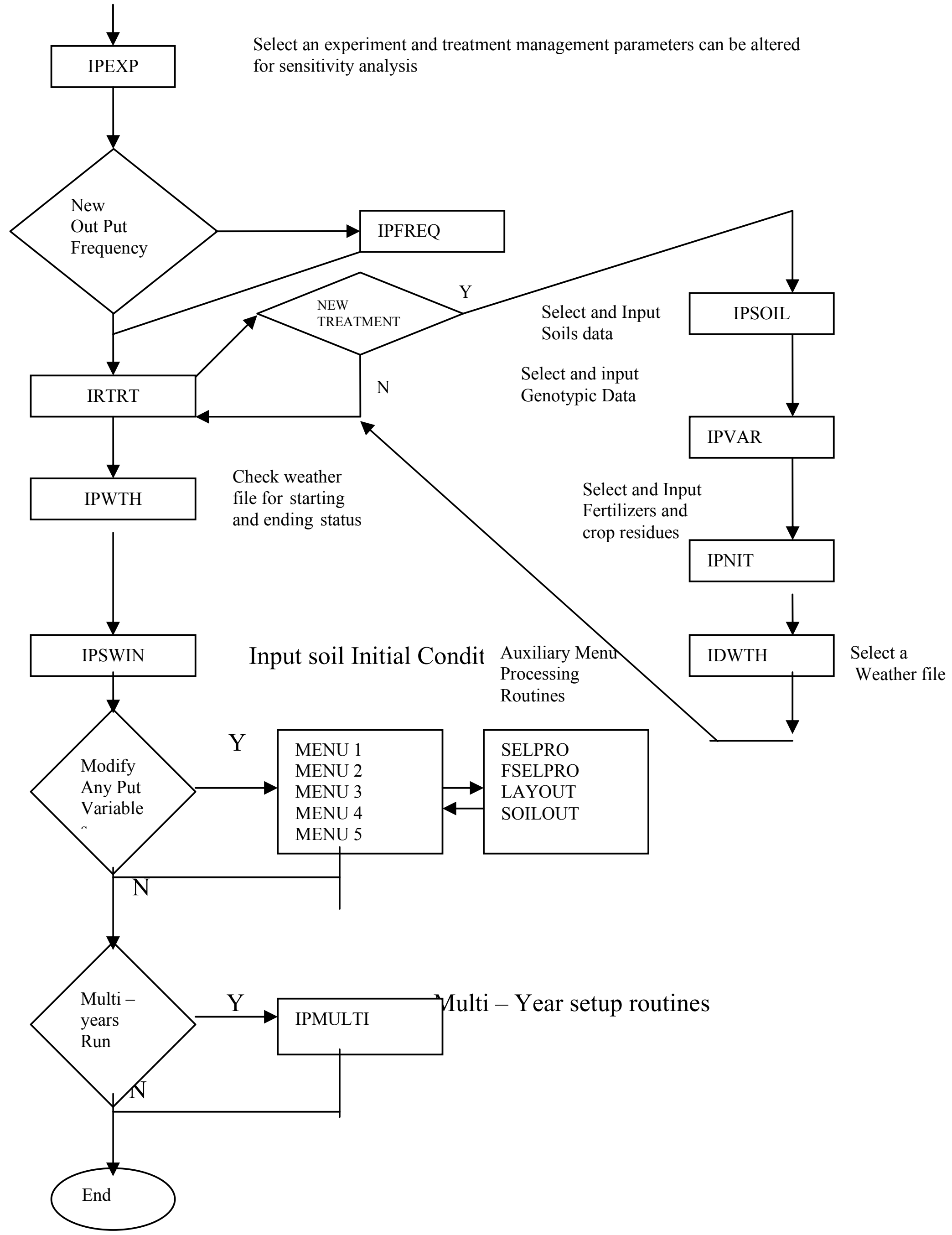
3.7.5 CERES Validation of Models

Before any model can be used with confidence, adequate validation or assessment of the magnitude of the errors that may result from their use should be performed. Model validation, in its simplest form, is a comparison between simulated and observed values. Beyond comparisons, there are several statistical measures available to evaluate the association between predicted and observed values, among them are the correlation coefficient (r) and its square, the coefficient of determination (R^2). Wilmot (1982) has pointed out that the main problem with this analysis is that the magnitudes of r and R2 are not consistently related to the accuracy of prediction where accuracy is defined as the degree to which model predictions approach the magnitudes of their observed counterparts. Further, as R2 often is unrelated to the sizes of the difference between observed and predicted values, high or statistically significant R2 may be misleading. Hence, two different groups of test criteria, called summary measures and difference measures have been used to evaluate the performance evaluation of the two models. While summary measures describe the quality of simulation, difference measures try to locate and quantify errors. Summary measures include the mean of observed values (O) and predicted values (P), the standard deviations of observations (So) and the predictions (Sp), the slope (a) and intercept (b) of the least-squares regression (P = a + bO). The difference measures include the mean absolute error (MAE) and the root mean square error (RMSE). These indices take the following form.

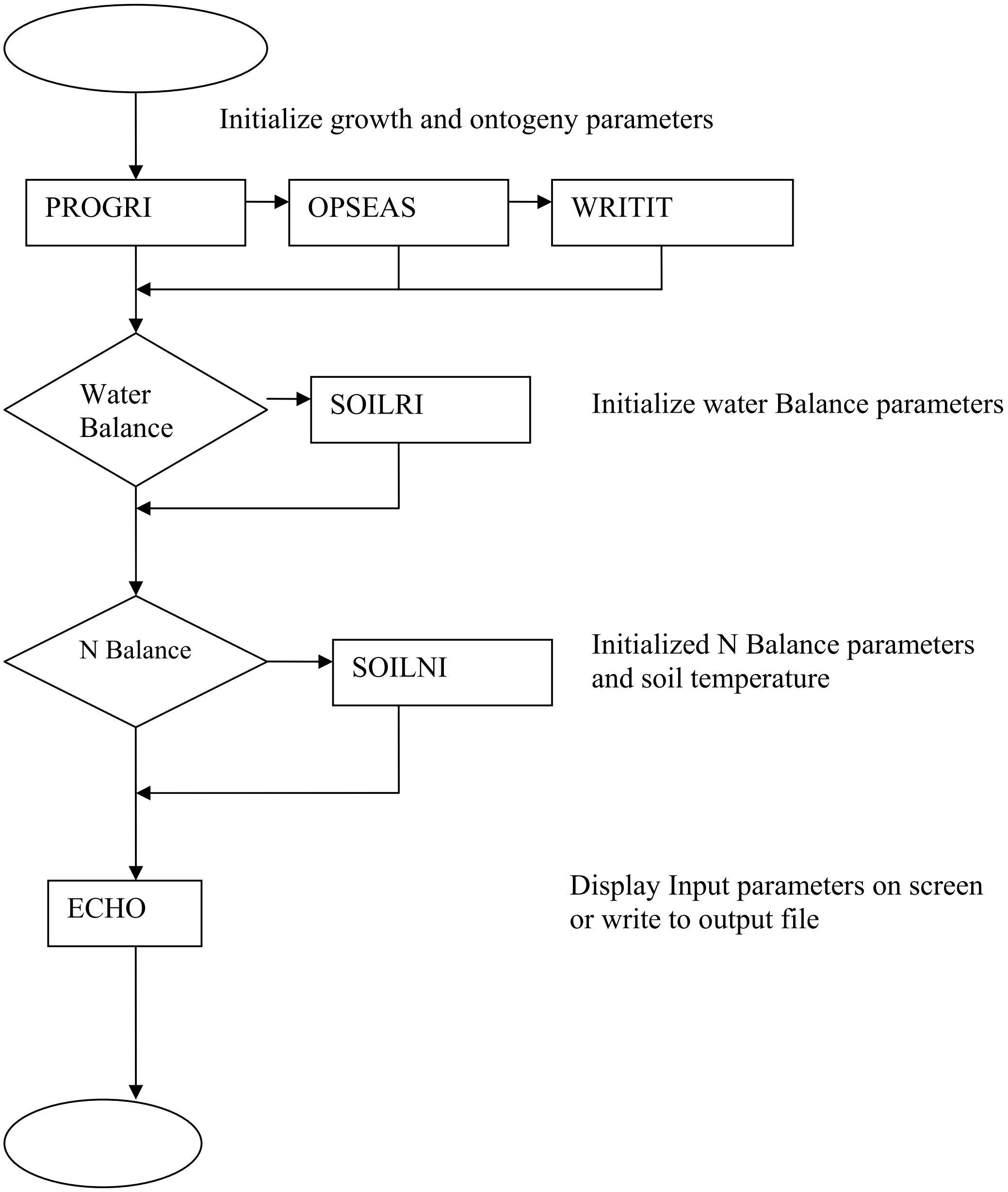
$$\mathrm{RMSE} = \left[n^{-1} \sum_{i=1}^{n} (Pi - Oi)^2 \right]^{0.5} \; ; \quad \mathrm{MAE} = n^{-1} \sum_{i=1}^{n} |Pi - Oi|$$

Where, n is the number of cases. RMSE is the best measures of model performance evaluation as they summarize the mean difference in the units of observed and predicted value. However, this measure gives only the estimates of average error not the relative size of the average difference and the nature of the differences.

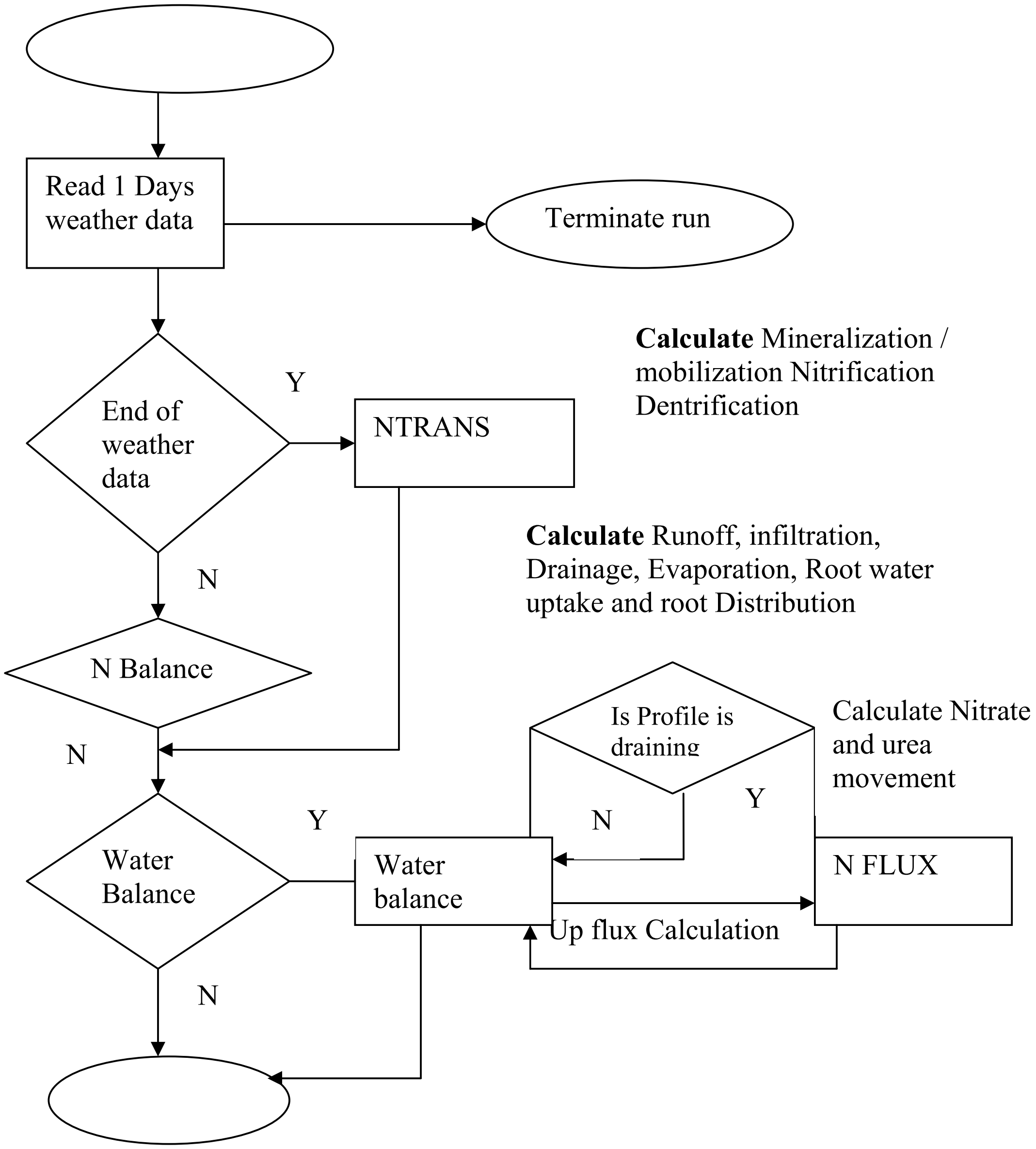
3.7.6 CERES Relational flow Digrams for Different Processes



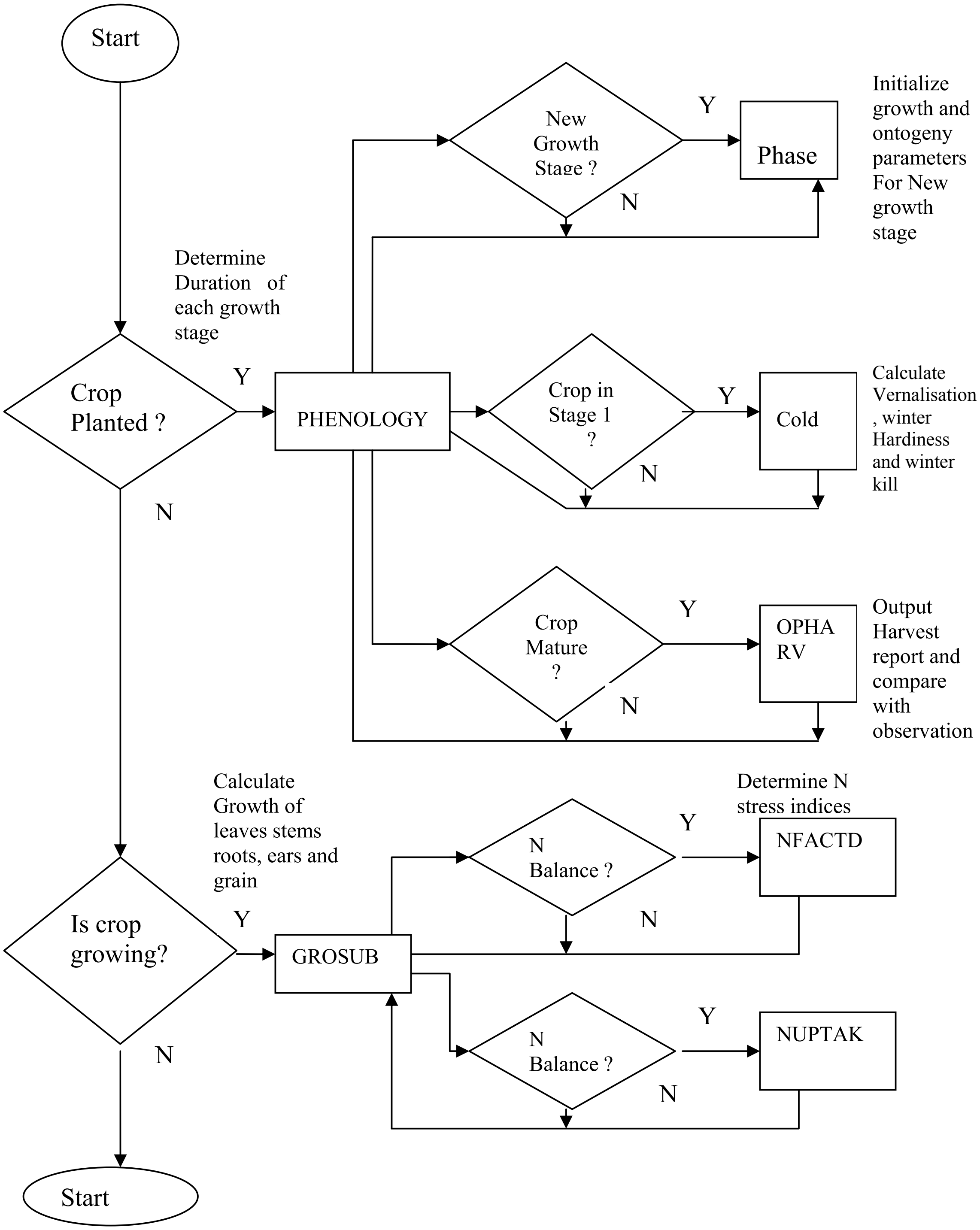
Flow chart describing structure and format of all required model input



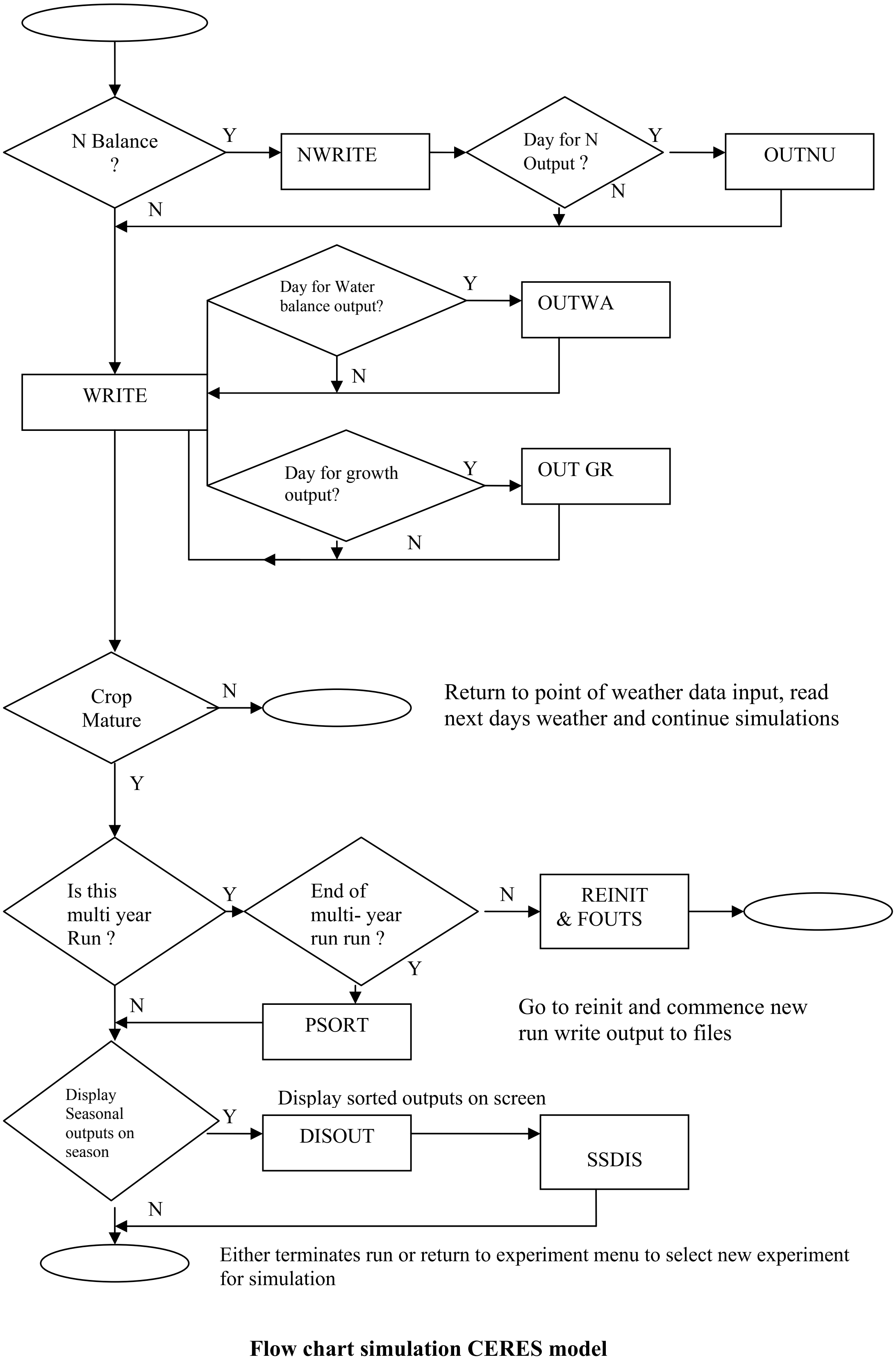
Flow chart for initialization of model



Flowchart for Nitrogen balance and water balance CERES model



Flow chart of crop modules in CERES model



Flow chart simulation CERES model

3.8 INFOCROP MODEL DESCRIPTION

3.8.1INFOCROP Input Parameters

3.8.2 INFOCROP Genetic Coefficients

3.8.3 INFOCROP Parameters Simulate

3.8.4 INFOCROP Model Calibration

3.8.5 INFOCROP Validation of Model

3.8.6 INFOCROP Relational flow Diagrams for Different Processes

InfoCrop is a generic crop model developed to meet these specific requirements. It is designed to simulate the effects of weather, soils, agronomic management (including planting, nitrogen, residues and irrigation), and major pests on crop yield and its associated environmental impacts. Its general structure is based primarily on SUCROS (van Laar *et al*., 1997) and further supported by MACROS (Penning deVries *et al* 1989), WTGROWS (Aggarwal *et al* 1994), and ORYZA1 (Kropff *et al* 1994) models. The model is user-friendly, requires easily available inputs, and is targeted to increase applications of crop models in research and development. The objective of this paper is to describe the key details of the model as applicable

The basic model is written in Fortran Simulation Translator programming language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands; van Kraalingen, 1995), also recommended by the International Consortium for Agricultural Systems Applications (ICASA) as a standard languages for systems simulation (Jones *et al*., 2001). Another version of the model has also been developed to accelerate its applications in agricultural research and development by the stakeholders not familiar with programming. The user-interface of this software has been written using Microsoft. Net framework while the back-end has FSE models and databases in MS-Access.

3.8.1 INFOCROP Input Parameters

InfoCrop first considers the influence of weather, followed by soil factors, and pests, respectively, as has earlier been described by Rabbinge *et al*. (1994). The following processes are considered in the model:

- Crop/Variety coefficient: Phenology, photosynthesis, partitioning, leaf area growth, storage organ numbers, source: sink balance, transpiration, uptake, allocation and redistribution of nitrogen.
- Weather, climate change scenario, daily basis maximum temperature, minimum temperature, rain fall and wind speed.
- Crop–pest interactions: Damage mechanisms of insects and diseases.
- Soil water balance: Root water uptake, inter-layer movement, drainage, evaporation, runoff, ponding.

- Soil nitrogen balance: Mineralization, uptake, nitrification, volatilization, interlayer movement, denitrification, leaching.
- Soil organic carbon dynamics: Mineralization and immobilization.
- Emissions of green house gases: Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O).

The relationship among the various processes is shown in Fig. 7. In the following pages, a brief description of different components is provided. Relatively more details are given for those processes, which are different from the base model, such as crop–pest interactions, greenhouse gas (GHG) emissions, and soil organic carbon (SOC) dynamics. Additional details about the basic crop model can be referred in van Laar *et al*. (1997) and Penning de Vries *et al*. (1989).

3.8.2 INFOCROP Crop/Variety Coefficient

3.8.2.1 Infocrop Phenology Parameters

3.8.2.2 Infocrop Growth Parameters

3.8.2.3 Infocrop Source:Sink Balance

3.8.2.1 INFOCROP Phenology Parameters

i) Base temperature for sowing to germination: The value of base temperature in °C for sowing to germination.

ii) Thermal time for sowing to germination: The value of thermal time in °C days for sowing to germination.

iii) Base temperature for germination to 50% flowering: The value of base temperature for germination to 50% flowering in °C.

iv) Thermal time for germination to 50% flowering: The value of thermal time for germination to 50% flowering in °C days.

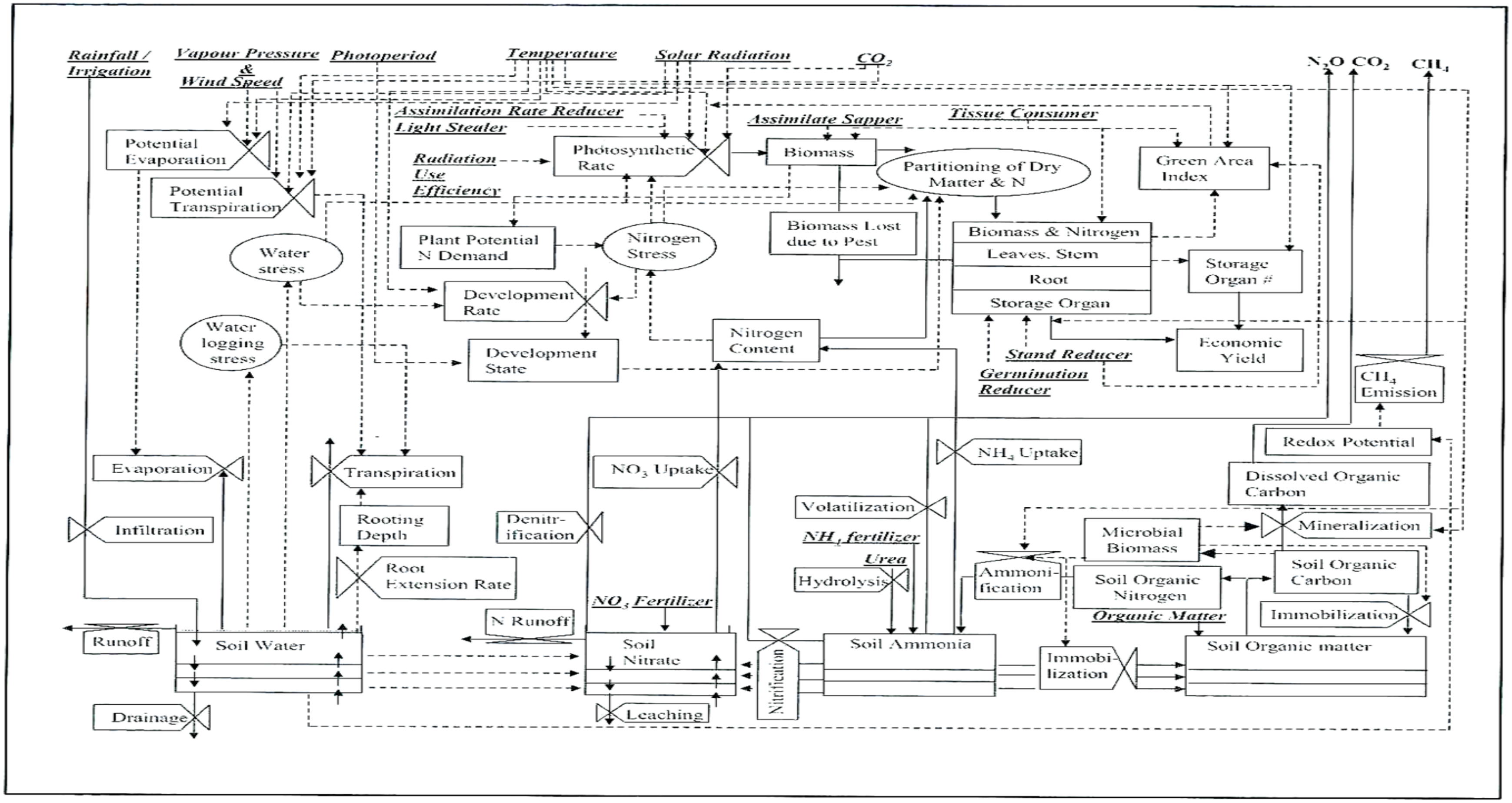
v) Base temperature for 50% flowering to physiological maturity: The value of base temperature for 50% flowering to physiological maturity in °C.

vi) Thermal time for 50% flowering to physiological maturity: The value of thermal time for 50% flowering to physiological maturity in °C days

vii) Optimal temperature: The value of optimal temperature in °C.

viii) Maximum temperature: The value of maximum temperature in °C .

xi) Sensitivity to photoperiod: The sensitivity to photo-period. The values are on a scale of 0.5 to 1.5.



Infocrop Relational Diagram

3.8.2.2 INFOCROP Growth Parameters

i) Relative growth rate of leaf area: The value of relative growth rate of leaf area in degree C/d.

ii) Specific leaf area: The value of relative growth rate of leaf area in dm^2 /mg.

iii) Extinction coefficient of leaves at flowering: The value of extinction coefficient of leaves in ha soil/ha leaf fraction at flowering.

iv) Radiation use efficiency: The value of radiation use efficiency in g/MJ/day.

v) Root growth rate: The value of root growth rate in mm/d.

vi) Index of greenness of leaves: The value of index of greenness of leaves. The values are to be given in a scale of 0.8 to1.2.

vii) Sensitivity of crop to flooding: The value of sensitivity of crop to flooding. The values are to be given in a scale of 0.1 -1.2.

viii) Index of N fixation: The value of index of N fixation for leguminous crops. The values are to be given in a scale of 0.7 to 1.

3.8.2.2 INFOCROP Source: Sink Balance

i) Slope of storage organ number/m^2 to dry matter during storage organ formation stage: The value of the Slope of the relationship between storage organ number/m^2 to dry matter (kg/ha) during storage organs formation stage in storage organ/kg/day.

ii) Potential storage organ weight: The value of potential weight of the storage organs in mg/storage.

iii) Nitrogen content of storage organ: The value of maximum nitrogen content of the storage organs (fraction).

iv) Sensitivity of storage organ setting to low temperature: The value of sensitivity of storage organ setting to low temperature. The values are to be given in a scale of 0 to 1.5 to change the sensitivity.

v) Sensitivity of storage organ setting to high temperature: The value of sensitivity of storage organ setting to high temperature. The values are to be given in a scale of 0 to 1.5 to change the sensitivity

3.8.3 INFOCROP Parameters Simulate

i) Crop and soil status.

ii) Main growth and development variables

iii) Crop pest interactions

iv) Environmental and stress factors at different growth stages.

i) Crop and soil water status at main development stages:

Biomass (BIOMASS) (kg ha^{-1}), leaf area index (LAI), leaf Number (LEAF NUM), evapotranspiration (ET) (mm), Rain (mm), Irrigation (IRRIG) (mm), soil water (SWATER) (mm), Crop nitrogen (CROPN) (kg ha^{-1} as well as %),N and water stress at different dates, crop age and growth stages as per requirement.

ii) Main Crop growth and development variables:

Flowering date (days after planting DAP), physiological maturity (DAP), grain yield (kg ha^{-1}; dry), weight per grain (g; dry), grain number ($grainm^{-2}$), grains/ear, maximum leaf area index (LAI) (m^2/m^2), biomass (kg ha^{-1}) at anthesis, biomass N (kg N ha^{-1}) at anthesis, biomass (kg ha^{-1}) at harvest, stalk weight (kg ha^{-1}) at harvest, harvest index ($kgkg^{-1}$), final leaf number, grain N (kg N ha^{-1}), biomass N (kg N ha^{-1}), stalk N (kg N ha^{-1}) and seed N (%).

iii) Crop pest interactions: Light stealer, germination reducers, assimilate reducers and assimilate sappers.

iv) Environmental and stress factors at different growth stages:

Environmental factors are maximum and minimum temperature, solar radiation and rain fall and wind speed. Stress factors include water and N stress at different growth stages.

3.8.4 INFOCROP Calibration

Model calibration or parameterization is the adjustment of parameters so that simulated values compare well with observed values. This program estimates the coefficients for a genotype by iteratively running the crop model with an approximate value of the coefficients concerned. It compares the simulated and measured data, and then automatically altering the cultivar coefficient until the simulated and measured values match or are within predefined error limits. The required crop measurements are the key phenological dates, such as anthesis and harvest maturity, and yield and yield components (Hunt *et al.*, 1993). Then other crop parameters were derived manually by changing 5% of the default value of each crop parameter till a satisfactory level of agreement between predicted and observed value of yield, biomass was achieved. For calibration of both models the N_{120} treatment was considered.

3.8.4 INFOCROP Validation

Before any model can be used with confidence, adequate validation or assessment of the magnitude of the errors that may result from their use should be performed. Model validation, in its simplest form, is a comparison between simulated and observed values. Beyond comparisons, there are several statistical measures available to evaluate the association between predicted and observed values, among them are the correlation coefficient (r) and its square, the coefficient of determination (R^2). Wilmot (1982) has pointed out that the main problem with this analysis is that the magnitudes of r and R2 are not consistently related to the accuracy of prediction where accuracy is defined as the degree to which model predictions approach the magnitudes of their observed counterparts. Further, as R2 often is unrelated to the sizes of the difference between observed and predicted values, high or statistically significant R^2 may be misleading. Hence, two different groups of test criteria, called summary measures and difference measures have been used to evaluate the performance evaluation of the two models. While summary measures describe the quality of simulation, difference measures try to locate and quantify errors. Summary measures include the mean of observed values (O) and predicted values (P), the standard deviations of observations (So) and the predictions (Sp), the slope (a) and intercept (b) of the least-squares regression (P = a + bO). The difference measures include the mean absolute error (MAE) and the root mean square error (RMSE). These indices take the following form.

$$\mathrm{RMSE} = \left[n^{-1} \sum_{i=1}^{n} (Pi - Oi)^2 \right]^{0.5} \quad ; \quad \mathrm{MAE} = n^{-1} \sum_{i=1}^{n} |Pi - Oi|$$

Where, n is the number of cases. RMSE is the best measures of model performance evaluation as they summarize the mean difference in the units of observed and predicted value. However, this measure gives only the estimates of average error not the relative size of the average difference and the nature of the differences.

CHAPTER-IV

RESULTS AND DISCUSSIONS

Warming trend is a major constraint in improving productivity of wheat under hot environments that prevail Northern plains. Crop growth models can simulate the growth and yield of crops under various abiotic stresses and can be conveniently used for heat tolerance studies. However, the response of crops to the temperature and other weather variations needs to be studied in detail so that it can subsequently be used for evaluating the impact of climate-change by linking with the future climate change scenarios. It was observed during crop season 2008-2010 that high temperature occurred even at terminal growth stage of timely sown wheat. Both the cropping intensity sequence and the late-harvest of the remunerative preceding crops in the cropping sequence, force farmers to delay sowing of wheat. Hence, it is necessary to find out the main effect of changing climate on the growth pattern of the wheat crop under different growth conditions. In the present study, results of the field and laboratory experiments are presented and discussed under following headings.

I Experiment No. 1 Studies on simulating biomass accumulation and its partitioning in Wheat (*Triticum aestivum* L.).

4.1 Relationship between Phenological Development and Thermal and Photothermal Units

4.2 Physiological traits

4.3 Yield and yield contributing attributes

4.4 Biochemical analysis

4.5 CERES-Wheat and Infocrop Calibration and Validation of Models

4.6 Regression Equation

4.7 Path Coefficient Analysis

II. Experiment No. 2: Source-sink relationship of plant architecture manipulation and biomass partitioning.

4.8 Relationship between source, sink, source-sink manipulation

4.9 Regression equation

4.10 CERES-Wheat and Infocrop Calibration and Validation of Models

I Experiment No. 1 : Studies on Simulating Biomass Accumulation and its Partitioning in Wheat (*Triticum Aestivum* L.).

4.1 Relationship Between Phenological Development and Thermal and Photothermal Units

4.1.1 Seedling emergence

The number of days taken for seed emergence for different cultivars, different levels under different date of sowing. Table 4.1.1 showed that with seedling emergence was observed (5) days after sowing for 15th Oct. sowing, 8 days for 15th Nov. and 9 days for 15th Dec. Days for seedling emergence increased but thermal and photo thermal unit was decreased with delay in sowing. This decrease was 40% for thermal and photo thermal units. The cultivars also gave different response of thermal and photo thermal unit for seedling emergence as the data showed in Table 4.1.1 was 6 days for PBW 550 whereas 7 days for rest of cultivars that is PBW-343, PBW-502 and WH-542. The seedling emergence was also influenced by the application of nitrogen level as observed in table 4.1. 5 days was took by cultivars at N_{180} nitrogen level for seedling emergence whereas with decrease in nitrogen level the days for seedling emergence was increased this was because high nitrogen level increases the temperature of soil which caused the early seedling emergence. Number of days taken for seedling emergence depends mainly on soil temperature (Paikaray and Chakravarty 2003). With delay in sowing seedling emergence took more number of days due to decreased soil temperature which was resulted in reduced metabolic activity of seed (Dhillon *et al* 1978). The cumulative thermal and photothermal unit decreased with delay in sowing from 15th Oct. to 15th Dec. The maximum thermal and photothermal units required for the seedling emergence was for 15th Nov. and minimum for 15th Dec.

Table. 4.1.1 Growing energy units taken by different wheat cultivars for seedling emergence under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	5	90	99	77	45730	1272	2482
2	15th Nov.	8	103	119	83	49235	1470	4120
3	15th Dec.	9	99	115	75	32092	1416	3542
4	PBW-343	7	92	107	75	45830	1309	3089
5	PBW-502	7	92	107	75	45830	1309	3089
6	PBW-550	6	85	96	70	38763	1123	2243
7	WH-542	7	92	107	75	45830	1309	3089
8	N_{90}	8	103	119	83	49235	1470	4120
9	N_{120}	6	85	96	70	38763	1123	2243
10	N_{180}	5	90	99	77	45730	1272	2482

4.1.2 Crown root initiation (CRI)

The number of days taken for different wheat cultivars (PBW-343, PBW-502, PBW-550 and WH-542) for attainment of tillering stage increased with delay in sowing from 15th Oct. to 15th Dec. All date of sowing took 16, 18 and 24 days, for all cultivars 20, 21, 19 and 20 days and at all nitrogen level 21, 20 and 24 days from sowing to CRI. There was decreased in thermal and photothermal with delay in sowing. The significant difference occurs between dates of sowing, different cultivars and at different nitrogen level for attainment of crown root stage. The difference in thermal and photothermal from sowing to CRI was due to prevalence of very low temperature conditions in delayed sowing such observation of lower value of thermal unit have earlier been reported by Ghadeker *et al* (1992). The accumulated thermal unit and photothermal unit was maximum in D_1 (15th Oct.) and minimum 15th Nov. The number of days and cumulative thermal and photothermal unit for different cultivars under different dates of sowing at different nitrogen level. There was 16.46 per cent reduction in accumulated thermal and photo thermal units with delay in sowing from 15th Oct. to 15th Dec. Thermal and photothermal requirement was lower in delayed sowing which was probability due to prevailed low temperature (Kochar and Niwas 2007).

Table. 4.1.2 Growing energy units taken by different wheat cultivars for crown root initiation under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	16	287	315	243	136239	3795	16055
2	15th Nov.	18	219	250	168	100275	3135	15608
3	15th Dec.	24	234	283	175	83629	3493	17165
4	PBW-343	20	266	351	212	93205	3716	19644
5	PBW-502	21	278	316	232	62716	3890	21115
6	PBW-550	19	253	287	202	110274	3531	59643
7	WH-542	20	266	351	212	93205	3716	19644
8	N_{90}	21	278	316	232	62716	3890	21115
9	N_{120}	20	266	351	212	93205	3716	19644
10	N_{180}	29	369	425	294	158625	5222	33522

4.1.3 Tillering stage

The number of days and accumulated thermal and photothermal unit taken up by different cultivars, at different dates of sowing, at different nitrogen level.

The number of days taken for attainment of tillering stage increased with delay in sowing from 15th Oct. 15th Dec. in all cultivars. The increase in number of days taken for tillering stage might be due to the reduction in mean air temperature under alter dates of sowing which was reflected in lesser of accumulated thermal and photothermal units. Sharma *et al* (2007) and Hundal and Sandhu (1992) also reported increased number of days with delay in sowing for tillering stage. The accumulated thermal and photothermal units were maximum for all cultivars under 15th Oct. The cv. PBW-502 accumulated more no. of thermal and photothermal unit. The cv. PBW-550 accumulated less no. of thermal and photothermal unit among the cultivars.

Table. 4.1.3 Growing energy units taken by different wheat cultivars for tillering under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	68	934	1059	753	414352	12983	205750
2	15th Nov.	59	593	712	446	241573	8853	126001
3	15th Dec.	61	580	718	443	251152	8744	98363
4	PBW-343	63	706	833	550	303838	10248	141002
5	PBW-502	66	737	871	571	318688	10649	152928
6	PBW-550	59	667	786	520	289011	9606	407232
7	WH-542	63	706	833	550	303838	10248	141002
8	N_{90}	65	727	859	569	317418	10551	151951
9	N_{120}	68	758	901	593	241167	11064	167252
10	N_{180}	70	777	921	606	341641	11311	174789

The data showed that with increased nitrogen level the number of days taken for attainment of tillering stage increased. This also lead to increased in accumulated thermal and photothermal units. This was might be because of avail ability of nitrogen, for longer period than that of other level of nitrogen (N_{90}).

4.1.4 Jointing stage (Stem Elongation)

The number of days taken up by the crop to complete joining stage varied with variety, date of sowing and level of nitrogen (Table 4.1.4). The number of days taken by different cultivars decrease with delay in sowing. Maximum number of days taken was 69 days for the (D_2) 15th Oct. and minimum number of days was 59 days (D_3) 15th Dec. The four cultivars gave different response for different dates of sowing. Maximum number of days (73) took by cv. WH-542 and minimum number of days was took by cv. PBW-550. With increase in nitrogen level the number of days was also increased. Maximum number of days (72) for jointing stage at N_{180} of nitrogen level and minimum number of days (67) at N_{90} of nitrogen application. This might be due to wheat plant gave response to higher level of nitrogen and increases period for jointing stage. Similar result was given by (Lemaire *et al* 2007).

The accumulated thermal and photothermal units were decreased with delay in sowing in all cultivars. Nearly 14% less energy was required for jointing stage at (D_3) 15th Dec. level of nitrogen (N_{180}) also gave the pronounced effect as 6 per cent more thermal and photothermal unit is required as compared to level of nitrogen (N_{90}).

Table. 4.1.4 Growing energy units taken by different wheat cultivars for jointing under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	69	943	1069	759	417568	13117	212651
2	15th Nov.	65	653	787	494	267070	9754	143505
3	15th Dec.	59	560	693	428	240784	8450	93589
4	PBW-343	67	747	884	582	326307	10852	159459
5	PBW-502	68	788	897	591	331450	11008	164908
6	PBW-550	55	627	738	490	271518	9076	112528
7	WH-542	73	808	984	629	357107	11742	186920
8	N_{90}	67	747	884	582	326307	10852	159459
9	N_{120}	69	767	908	598	336277	11155	170269
10	N_{180}	72	798	946	622	352354	11626	183964

4.1.5 Booting stage

The number of days and accumulated thermal and photothermal unit taken by different wheat cultivars different nitrogen level under different date of sowing from sowing to booting stage are prescribed as under (Table 4.1.5).

Table. 4.1.5 Growing energy units taken by different wheat cultivars for jointing booting stage under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	97	1173	1367	931	507843	16795	325999
2	15th Nov.	88	895	1081	685	384858	13271	244872
3	15th Dec.	78	773	946	595	385421	11675	199859
4	PBW-343	92	1009	1201	787	475359	14866	298427
5	PBW-502	92	1009	1201	787	475359	14866	298427
6	PBW-550	76	837	995	653	374115	12235	185030
7	WH-542	89	974	1160	760	455010	14345	275215
8	N_{90}	80	874	1041	681	396232	12821	222312
9	N_{120}	83	976	1141	768	422766	14032	246936
10	N_{180}	86	942	1121	734	436367	13845	256557

The number of days taken for the attainment of booting stage decreased as the sowing of wheat was delayed from 15th Oct. to 15th ec. The further decrease in number of days by delayed sowing were due to prevalence of high temperature. The reduced growth period under late sowing has also been reported by Kumar (1982). The number of days taken for the attainment of booting stage was different for different cultivars. Maximum number of days took (92) by cv. PBW-343 and cv. PBW-502 and minimum number of days took by (76) PBW-550. Then results showed that cv. PBW-343 accumulated more thermal and photothermal unit than other cultivars. At (N_{90}) level of nitrogen cvs. took (80) days for booting stage. 83 for (N_{120}) and 80 days for (N_{180}). The result showed that with increase in nitrogen level period to attain booting stage also increased. For nitrogen level (N_{180}) the cvs. took 75 per cent more thermal and photothermal unit than nitrogen level (N_{90}).

4.1.6 Inflorescence emergence and heading

The number of days taken for completion of this stage decrease with delay in sowing. The number of days taken were maximum in 15th Oct. (104) while minimum (87) day in 15th Dec. of sowing. The accumulated thermal and photothermal unit decreased in delaying in sowing. From 15th Oct. to 15th Dec. sowing. The number of days taken for completion of inflorescence emergence and heading stage was different for different cultivars as the maximum number of days (100) took by cv. PBW-502 and minimum number of day (82) taken by cv. PBW-550.

The data pertaining to number of days and accumulated thermal and photothermal unit for attaining this stage under different date of sowing, different cultivars and under different nitrogen (N_{90} to N_{180}) are as follows (Table 4.1.6).

Table. 4.1.6 Growing energy units taken by different wheat cultivars for inflorescence heading and emergence under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	104	1249	1461	993	542371	17894	369240
2	15th Nov.	95	969	1170	742	434760	14363	300908
3	15th Dec.	87	899	1092	700	477461	13604	268121
4	PBW-343	98	1085	1291	850	523302	16021	344904
5	PBW-502	100	1113	1324	873	542130	16434	363439
6	PBW-550	82	896	1067	698	408792	13157	232099
7	WH-542	97	1072	1279	839	514832	15832	336212
8	N_{90}	101	1126	1339	885	550676	16636	369558
9	N_{120}	102	1140	1355	896	559141	16844	377266
10	N_{180}	104	1168	1387	919	878706	17258	393727

The number of days taken for the completion of this stage increases with increase in nitrogen level (N_{90} to N_{180}). The number of days were taken maximum at nitrogen level of N_{180} while minimum in N_{90} (101). The cv. PBW-502 accumulated maximum thermal (1113)

GDD, (1324) ACCDU, (873) CHETA and photothermal unit (542130) CEDU, (16434) PTU and (363439) HTU followed by cv. PBW-343 (1085) GDD, (1291) ACCDU (850) CHETA and photo thermal unit (523302) CEDU, (10021) PTU and (34494) HTU, WH-542 (1072) GDD, (1279) ACCDU, (839) CHETA and photothermal unit (514832) CEDU, (15832) PTU and (336212) HTU and cv. PBW-550 (896) GDD (1067) ACCDU, (698) CHETA and photothermal unit (408792) CEDU, (13157) PTU and (232099) HTU. The decrease in number of days and GDD at this stage were due increased day length and air temperature. The data also showed that with increase in nitrogen level the thermal and photothermal unit has increased. The N_{90} accumulated minimum unit (1126) GDD, (1339) ACCDU, (885) CHETA and photothermal unit (550676) CEDU, (16636) PTU and (369558) HTU followed by N_{120} (1140) GDD, (1355) ACCDU, (896) CHETA and photothermal unit (559141) CEDU, (16844) PTU and (377266) HTU and N_{180} (1168), GDD, (1387) ACCDU, (919) CHETA and photothermal unit (878706) CEDU, (17258) PTU and (393727) HTU. The increase in thermal and photothermal unit at this stage due to increase dry matter that is duration of phenophase was increased.

4.1.7 Anthesis stage

The table below showed the number of days, thermal and photo thermal units taken by different cultivars (PBW-343, PBW-502, WH-542 and PBW-550) for different nitrogen level (N_{90}, N_{120} and N_{180}) from 15th Oct. to 15th Dec. sowing (Table 4.1.7).

The number of days taken from sowing to anthesis stage decreased with delay in sowing from 15th Oct. and 15th Dec. The maximum no. of days (115) and thermal unit (D_1), 15th Oct. were (1367) GDD, (1601) ACCDU, (1083) CHETA and photothermal units (606294) CEDU, (19584) PTU and (468947) HTU followed by (107) days and thermal unit 15th Nov. were (1124) GDD, (1349) ACCDU, (798) CHETA and photothermal unit (542251) CEDU, (16734) PTU and (411551) HTU and minimum was (95) days at 15th Dec. with thermal unit (1018) GDD, (1226) ACCDU, (798) CHETA and photothermal units (559885) CEDU, (15437) PTU and (343432) HTU. The cultivars PBW-550 showed (16.66%) less in accumulated thermal and photothermal unit followed by WH-542 (5.84%) and cv. PBW-502 (1.69%). With the delay in sowing in the present study decreased the days to anthesis. The reduction in days to anthesis under (D_3) date of sowing indicated that the duration of phenological phases before anthesis was decreased. When the crop was sown in 15th Dec. (D_3), its flowering time was shortened because by the time it comes to flowering, the atmospheric temperature start rising. Similar result were also reported by Randhawa *et al* (1992) and Sharma-Natu *et al* (2006).

The data of Table 4.7 showed that with increase in nitrogen level from N_{90} to N_{180} there was increase in number of day to attain anthesis stage. Higher level of nitrogen N_{180} required (5.5%). More thermal and photothermal unit as compared to N_{90}. This was because high level of nitrogen increased the duration of anthesis stage.

Table. 4.1.7 Growing energy units taken by different wheat cultivars for anthesis under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	115	1367	1601	1083	606294	19584	468947
2	15th Nov.	107	1124	1349	868	542251	16734	411551
3	15th Dec.	95	1018	1226	798	559885	15437	343432
4	PBW-343	110	1250	1480	986	637534	18512	456972
5	PBW-502	109	1235	1464	973	625794	18281	445255
6	PBW-550	97	1072	1276	839	514832	15822	363257
7	WH-542	105	1181	1402	929	587898	17456	404793
8	N_{90}	109	1235	1464	973	625754	18281	445255
9	N_{120}	112	1281	1516	1012	65778	18976	476561
10	N_{180}	115	1325	1569	1051	689255	19663	509066

4.1.8 Watery ripe stage

The data pertaining to the number of days and accumulated thermal-photothermal unit to complete watery stage are given below (Table 4.1.8).

The number of days to reach watery ripe stage decreases with delay in sowing from 15th Oct. to 15th Dec. The number of days required 115 (15th Oct.), 107 (15th Nov.) and 95 days (15th Dec.). The thermal and photothermal unit followed the decreasing trend from 15th Oct. to 15th Dec. This is due to prevalence of high temperature under delayed sowing. The cvs. PBW-343, PBW-502 accumulated more thermal unit (1313) GDD, (1582) ACCDU, (1039) CHETA and photothermal unit (679213) CEDU, (19443) PTU and (498076) HTU followed by cv. WH-542 thermal unit (1291) GDD, (1516) ACCDU, (1072) CHETA, and photothermal (65778) CEDU (18976) PTU and (476861) HTU and cv. PBW-550 required thermal unit (1047) GDD, (1246) ACCDU, (818) CHETA and photothermal unit (498413) CEDU, (15434) PTU and (319466) HTU. The more number of decrease was observed in PBW-550 (25.40%) while less in WH-542 (1.89%).

The different level of nitrogen also showed different response to watery ripe stage. The maximum number of days and thermal-photothermal unit were observed at N_{180} (1297) GDD, (1535) ACCDU, (1026) CHETA, (668778) CEDU, (19211) PTU and (486748) HTU whereas similar response was observed for N_{90} and N_{120} level. This may be due to higher level of nitrogen have prolonged effect as compared to other level of nitrogen.

Table. 4.1.8 Growing energy units taken by different wheat cultivars for watery stage under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	119	1415	1656	1120	634301	20256	509397
2	15th Nov.	111	1184	1417	918	582232	17636	448729
3	15th Dec.	97	1052	1263	827	585274	15950	363257
4	PBW-343	114	1313	1582	1039	679213	19443	498076
5	PBW-502	114	1313	1582	1039	679213	19443	498076
6	PBW-550	95	1047	1246	818	498413	15434	319466
7	WH-542	112	1291	1516	1072	657778	18976	476861
8	N_{90}	111	1265	1499	999	646694	18737	467099
9	N_{120}	111	1265	1499	999	646694	18737	467099
10	N_{180}	113	1297	1535	1026	668778	19211	486748

4.1.9 Milky ripe stage

The following number of days and accumulated thermal and photothermal were taken up by a crop to reach milky stage under different date of sowing (Table 4.1.9).

The number of days taken for milky ripe stage are decrease with delaying sowing more number of days (131), 15th Oct., (125) 15th Nov. and (110) taken 15th Dec. that means (25.47%) less thermal and photothermal unit was required as delay in sowing. The number of days taken for this stage were more in PBW-343 (126), PBW-502 (127), PBW -550 (111) and WH-542 (124) under different date of sowing and at different level of nitrogen. The maximum thermal unit utilised by PBW-343 (1508) GDD, (1772) ACCDU, (1205) CHETA and photothermal units (835243) CEDU (22669) PTU and (670432) HTU and minimum in cv. PBW-550 (1265) GDD, (1499) ACCDU, (999) CHETA and photothermal unit (646694) CEDU, (18737) PTU and (467102) HTU. The decrease in number of days and thermal photothermal unit.

The number of days taken for milky ripe stage increases with increases in nitrogen level N_{90} to N_{180}. The maximum number of days (123) and accumulated thermal unit (1482) GDD, (1709) ACCDU, (1156) CHETA and photothermal unit (790121) CFDU, (21549), PTU and (611767) HTU followed by N_{120} (120) days thermal unit (1400) GDD, (1652) ACCDU, (1112) CHETA and photothermal unit (790121) CEDU, (21549) PTU and (611767) HTU and (121) days (1416) GDD, (1671) ACCDU, (1126) CHETA and photothermal units (7611608) CEDU, (20773) (PTU) and (582419) HTU at N_{90}. This is because of higher nitrogen level increases duration of milky ripe stage.

Table. 4.1.9 Growing energy units taken by different wheat cultivars for milky stage under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	131	1596	1861	1271	753790	22849	673109
2	15th Nov.	125	1411	1671	1108	759926	21081	624519
3	15th Dec.	110	1272	1511	1016	760537	19352	495750
4	PBW-343	126	1508	1772	1205	835243	22397	657804
5	PBW-502	127	1826	1793	1221	835280	22669	670432
6	PBW-550	111	1265	1499	999	646694	18737	467102
7	WH-542	124	1471	1731	1173	805616	21835	627208
8	N_{90}	121	1416	1671	1126	761608	21021	582419
9	N_{120}	120	1400	1652	1112	748478	20773	569711
10	N_{180}	123	1482	1709	1156	790121	21549	611767

4.1.10 Soft dough stage

The number of days and accumulated thermal and photothermal unit vary with different cultivars PBW-343, PBW-502, PBW-550 and WH-542 at different nitrogen level N_{90}, N_{120} and N_{180} in all date of sowing (Table 4.1.10).

Table. 4.1.10 Growing energy units taken by different wheat cultivars for soft dough stage under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	143	1793	2083	1439	889043	25754	850401
2	15th Nov.	139	1658	1950	1325	947478	24882	817470
3	15th Dec.	120	1450	1714	1174	913795	22151	628623
4	PBW-343	137	1707	1996	1380	992745	25463	809235
5	PBW-502	138	1728	2019	1398	1005690	25780	825270
6	PBW-550	126	1559	1830	1248	868258	23144	702155
7	WH-542	135	1668	1953	1345	959655	24864	781282
8	N_{90}	130	1581	1854	1269	891234	23502	709540
9	N_{120}	132	1816	1893	1299	91800	24045	734148
10	N_{180}	136	1687	1974	1362	975206	25154	795856

The number of days and thermal-photothermal unit decreased with delay in sowing all wheat cultivars. The maximum number (143) day at 15th Oct., followed by (139) days at 15th Nov. and minimum number of days (120) at 15th Dec. The 23.46 per cent less thermal and photothermal unit was required by 15th Dec. from 15th Oct. The cv. PBW-502 took more

(138) days for soft dough stage as compared to PBW-343 (137), PBW-550 (126) and WH-542 (135). The different response of different cultivars for soft dough stage was because of genetic variation this why the genetic coefficient for each cv. was different. Soft dough stage was observed under different dates of sowing in a PBW-343, PBW-502, PBW-550 and WH-542 and N_{90}, N_{120} and N_{180} level of nitrogen as follow. Similar results were reported by Vikki and Tom *et al* (1985). The accumulated thermal and photothermal unit also showed increasing trend with increase in nitrogen level from N_{90} to N_{180}. Maximum thermal units (1687) GDD, (1974) ACCDU, (1632) CHETA and photothermal unit (975206) CEDU, (25154) PTU and (795850) HTU while the minimum amount of accumulated thermal unit (1581) GDD, (1854) ACCDU, (1269) CHETA and photothermal unit (891234) CEDU, (23502) PTU and (709540) HTU.

4.1.11 Hard dough stage

The number of days, cultivars of wheat, nitrogen levels and thermal and photothermal unit and different dates of sowing are presented below (Table 4.1.11).

The maximum number of days taken for the attainment of hard dough stage in 15th Oct. (155) followed 15th Nov. (148) and 15th Dec. (129). The number of days decreases with delay in sowing from 15th Oct. to 15th Dec. The decrease in number of days with delay in sowing was due to prevalence of high temperature under delayed sowing conditions which forces the grain to develop early. Bahera and Jena (1998) also reported decrease in grain filling duration with delay in sowing. Maximum accumulated thermal and photothermal unit recorded cvs. PBW-343, PBW-502 and WH-542 (147) followed by PBW-550 (135) there was (9.89%) less thermal and photothermal unit required for cv. PBW-550 as compound to other cultivars.

Table. 4.1.11 Growing energy units taken by different wheat cultivars for hard dough stage under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	155	2023	2335	1638	1067747	29146	1073325
2	15th Nov.	148	1827	2141	1474	1104960	27528	970197
3	15th Dec.	129	1639	1922	1342	1082832	25102	771993
4	PBW-343	147	1833	2133	1477	1074111	26990	937260
5	PBW-502	147	1833	2133	1477	1074111	26990	937260
6	PBW-550	135	1668	1953	1345	939125	24864	781282
7	WH-542	147	1668	1953	1345	939125	24864	781282
8	N_{90}	154	1982	2300	1607	1141881	29219	1075654
9	N_{120}	154	1982	2300	1607	1141881	29219	1075654
10	N_{180}	156	2026	2348	1645	1178490	29891	1114380

The higher level of nitrogen also showed the number of days increases from 154 to 160 for the attaining of hard dough stage for wheat cultivars. The maximum number of days was 160 at nitrogen level N_{180} whereas the number of days remains the same for rest of nitrogen levels. The 2.21 per cent thermal and photothermal unit was required by higher nitrogen level as compared to other levels of nitrogen.

4.1.12 Physiological maturity

The growth duration (Days) cultivars, dates of sowing, nitrogen level and thermal/photothermal units are given below (Table 4.1.12).

Table. 4.1.12 Growing energy units taken by different wheat cultivars for physiological maturity under different dates of sowing and nitrogen level

Sr. No.	Treatment	DAS	GDD	ACCDU	CHETA	CEDU	PTU	HTU
1	15th Oct.	160	2125	2448	1728	1146405	30661	1168020
2	15th Nov.	154	1960	2286	1593	1230507	29959	1093428
3	15th Dec.	131	1680	1968	1379	1120583	25754	790048
4	PBW-343	152	1938	2282	1868	1103194	28563	1033351
5	PBW-502	152	1938	2282	1868	1103194	28563	1033351
6	PBW-550	138	1839	2142	1521	1259264	28263	905131
7	WH-542	152	1938	2282	1868	1103194	28563	1033351
8	N_{90}	156	2026	2348	1642	478490	29891	1114380
9	N_{120}	158	2072	2399	1687	1215427	30578	1150118
10	N_{180}	160	2114	2445	1745	1248807	31231	1186635

The wheat cv. PBW-343, PBW-502 and WH-542 took similar number of days (152). Sowing dates had differential effect on cv. for the number of days taken from sowing to maturity. Shifting of sowing from 15th Oct. (D_1), 15th Dec. (D_2) reduced the period from sowing to hard dough. The number of days 160, 154 and 131 took under different dates of sowing 15th Oct., 15th Nov. and 15th Dec. respectively. The 156, 158 and 160 days took under different nitrogen level N_{90}, N_{120} and N_{180} respectively. The thermal and photothermal unit decreased with delay in sowing. The percentage decrease in thermal and photothermal from 15th Oct. to 15th Dec. (26.46%). The cvs. PBW-343, PBW-502 and WH-542 accumulated thermal unit (1938) GDD, (2282) ACCDU, (1808) CHETA and (1103194) CEDU, (28563) PTU and (103335) HTU followed by cv. PBW-550 (1839) GDD, (2142) ACCDU, (1521) CHETA and photothermal unit (1259264) CEDU, (28263) PTU and (905131) HTU. Thus the cv. PBW-550 is thermosensitive as it showed more decline in thermal and photothermal unit with delay in sowing and among the cultivars. The cv. PBW-550 took comparatively (10.66%) number of days and accumulated thermal and photothermal units from sowing to maturity. Due to accumulation of more thermal and photothermal unit under 15th Oct. sowing, all cultivars produce more grain yield as compared to crop sowing under delayed conditions with different nitrogen levels which took comparatively lesser number of days and accumulated GDD and hence, resulted in lower grain yield, high temperature reduces the availability of assimilate, reduces grain number and weight (Mitra and Bhatia 2008).

With delay in sowing from 15th Oct. (D_1) to 15th Dec. (D_3), the decline in grain yield was found to be (36.36%) with lowest level of nitrogen with delay in sowing. Wang *et al* (1992) reported that temperature during late sowing hastens the phenological development of crop, reduces the duration of crop growing, grain filling and finally lowering the grain yield. The grain yield decreases with increase in temperature during grain filling period due to decrease in dry matter accumulation in the panicle at ripening stage (Saitoh *et al* 2006). Nagarjan *et al* (2008) showed that both grain growth rate and grain growth duration were affected by high temperature.

4.1.13 Ontogeny

4.1.13.1 Leaf appearance
4.1.13.2 Tiller appearance
4.1.13.3 Node appearance

4.1.13.1 Leaf appearance

1st leaf

The number of days taken for first leaf development by different wheat cvs, at different nitrogen level under different date of sowing showed variable behaviours with delay in sowing first leaf took more number of days due to decrease in low temperature. The cv. PBW-343, PBW-502, WH-542 took similar number of days (7) where a PBW-550 took 6 number of days. The higher level of nitrogen (N_{180}) took 5 no. of days to appear first leafs this is because of higher level of nitrogen increase the soil temperature and therefore appearance of leaf was early as compared to other levels of nitrogen. Maximum number of days (9) followed by (8) days and (5) days under 15th Oct. (D_1), 15th Nov. (D_2) and 15th Dec. (D_5) respectively. No doubt no. of days are increases but the thermal and photothermal units are decreases with delay in sowing because of low temperature during the development of leafs. Similar result has been reported (Maglictta 1989).

2nd leaf

The number of days taken by different cultivars PBW-343, PBW-502, PBW-550 and WH-542 for attainment of sound leaves with delay in sowing from 15th Oct. to 15th Dec. (D_3). But the thermal and photo thermal unit decreases with delay in sowing. The thermal unit utilized by D_3 (15th Dec.) (136) GDD, (159) ACCDU (101) CHETA and photothermal unit (45301) CEDU, (1975) PTU, (8076) HTU followed by D_2 (15th Nov.) (149) GDD, (171),

Table 4.1.13.1 Growing energy units taken by different wheat cultivars for leaf appearance (Phyllochron Index) under different dates of sowing and nitrogen levels

	15th Oct.	15th Nov.	15th Dec.	PBW-343	PBW-502	PBW-550	WH-542	N_{90}	N_{120}	N_{180}
1st Leaf										
Days	5	8	9	7	7	6	7	8	6	5
Energy units										
GDD	90	94	99	98	98	85	98	111	85	72
ACCDU	99	104	115	111	111	96	111	126	98	81
CHETA	77	83	74	80	80	69	80	90	69	61
CEDU	45730	49235	32092	44686	44686	38764	44686	50537	38764	34083
PTU	1272	1470	1416	1395	1395	1207	1395	1585	1207	1067
HTU	2482	4119	3542	3401	3401	2550	3406	4314	2556	2023
2nd Leaf										
Days	13	12	9	11	12	12	10	11	12	13
Energy units										
GDD	101	149	136	150	150	163	138	150	163	176
ACCDU	176	171	159	170	170	184	150	170	184	199
CHETA	136	117	101	121	121	130	111	121	130	140
CEDU	82519	69499	45301	67102	67102	72272	62204	67102	72272	18619
PTU	2169	2130	1975	2109	2109	2253	1925	2109	2253	2440
HTU	7097	7933	8076	7518	7518	8762	0302	7518	8762	10001

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	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
3rd Leaf										
Days	18	10	12	15	15	16	15	14	16	16
GDD	214	196	182	202	202	216	202	189	216	216
ACCDU	233	223	215	228	228	244	223	213	244	244
CHETA										
CEDU	106516	91479	61842	88170	88170	94623	88170	83388	94623	94623
PTU	2788	2804	2668	2812	2812	2998	2812	2626	2998	2998
HTU	11627	12444	13046	12109	12109	13407	12109	11284	13407	13407
4th Leaf										
Days	23	19	16	19	20	19	19	15	16	19
GDD	287	230	225	254	266	254	254	202	216	254
ACCDU	815	262	272	287	302	287	287	228	244	287
CHETA	243	177	168	202	212	202	202	161	172	202
CEDU	13629	105331	80540	110280	116185	110280	110280	88170	94623	110280
PTU	3795	3296	3346	3539	3717	3539	3539	2812	2998	3539
HTU	160552	17765	15962	17809	19644	17809	17809	12109	13407	17809
5th Leaf										
Days	30	25	21	25	25	25	26	24	23	25
GDD	371	305	277	327	327	337	314	302	327	359
ACCDU	407	348	341	373	373	386	359	345	373	412

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	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
CHETA	313	235	206	260	260	269	251	241	260	260
CEDU	179025	131228	101715	141643	141643	146147	137149	138547	141643	153764
PTU	4942	4336	4221	4587	4587	4749	4416	4239	4587	5065
HTU	25619	27610	22812	26812	26812	28812	25199	23134	26812	31735
6th Leaf										
Days	36	31	26	31	32	31	30	29	31	32
GDD	446	365	327	390	400	390	380	369	390	400
ACCDU	498	420	406	450	462	450	438	425	450	462
CHETA	370	281	244	311	318	311	303	294	311	318
CEDU	212802	150786	125195	167727	172080	167727	163558	158625	167727	172086
PTU	5998	5548	5017	5535	5685	5535	5381	5222	5535	5685
HTU	36464	509899	32757	37520	40689	37520	35505	33522	37520	40687
7th Leaf										
Days	43	38	32	36	38	37	38	42	42	44
GDD	533	439	390	444	463	454	463	512	502	520
ACCDU	593	510	480	515	538	527	538	595	584	608
CHETA	449	339	292	353	367	360	367	402	395	412
CEDU	254024	176076	150136	191414	200554	196402	200554	218090	214638	222099
PTU	7206	6296	5991	6317	6615	6469	6615	7328	7188	7472
HTU	48979	67678	42694	51586	58214	54949	58214	7330	70721	75753

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	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
8th Leaf										
Days	52	47	40	45	46	46	45	44	45	48
GDD	629	505	482	531	540	540	531	520	531	560
ACCDU	702	597	599	620	632	632	620	607	620	656
CHETA	522	386	365	417	425	425	417	412	417	440
CEDU	300240	204887	196307	226704	232109	232109	226704	222099	226704	240824
PTU	8584	7379	7337	7625	77874	7774	7774	7625	7472	7625
8068	83130	98665	69421	79077	82859	82859	79077	75753	79077	88435
9th Leaf										
Days	58	55	47	54	53	54	53	49	51	54
GDD	712	562	551	617	607	617	607	570	588	617
ACCDU	795	673	682	725	713	725	713	668	690	785
CHETA	584	425	421	482	474	482	474	447	460	482
CEDU	335145	229101	235748	266754	262421	266754	262421	244785	253621	266754
PTU	9764	8347	8306	8925	8774	8925	8774	8210	8492	8925
HTU	108328	118992	88795	73845	106770	73845	106770	92402	100843	93845
10th Leaf										
Days	66	65	54	62	62	61	61	58	60	62
GDD	793	653	632	695	695	686	686	637	670	695
ACCDU	888	787	778	821	821	809	809	775	797	821

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	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N$_{90}$**	**N$_{120}$**	**N$_{180}$**
CHETA	645	494	481	542	542	535	535	547	527	542
CEDU	366775	267010	284424	301046	301046	297420	297420	285083	292749	182540
PTU	10912	9784	9492	10096	10096	9984	9984	9524	9809	10096
HTU	134890	143505	125317	136585	136585	134249	134249	121855	130225	136585
11th Leaf										
Days	78	93	-	65	69	67	66	65	68	70
GDD	886	736	-	727	767	747	737	727	758	717
ACCDU	999	891	-	859	908	884	871	887	897	921
CHETA	715	562	-	566	598	582	574	566	591	606
CEDU	397982	297868	-	316161	336277	326307	321103	316161	331450	341641
PTU	12266	10976	-	10551	11155	10852	10701	10551	11008	11311
HTU	179286	161985	-	150814	170269	159459	154727	150814	164908	174787
12h Leaf										
Days	73	62	-	77	75	74	76	75	73	79
GDD	975	621	-	846	828	818	837	828	808	865
ACCDU	1110	746	-	1007	984	972	995	984	959	1030
CHETA	782	467	-	660	646	639	653	646	630	674
CEDU	430611	258032	-	378915	369118	363370	374113	369118	358057	390692
PTU	13632	9282	-	12380	12088	11935	11235	12088	11783	12670
HTU	233414	132033	-	206181	196714	192766	201039	196714	188108	217076

ACCDU (117) CHETA and photothermal unit (69499) CEDU (21030) PTU and (7933) HTU and D_1 (15th Oct.), (161) GDD, (176) ACCDU, (136) CHETA, (82579) CEDU (2169) PTU and (7097) HTU. The cv. PBW-550 took maximum number of days (12) and thermal and photothermal unit followed by cv. PBW-343, PBW-502 and cv. WH-542 days. The maximum number of days taken for 2nd leaf emergence 12, 12 and 11 days at different level of nitrogen N_{80}, N_{120} and N_{90} respectively.

There was (14.7%) reduction in thermal and photothermal unit with increase in nitrogen level from N_{90} to N_{180}. The thermal and photothermal unit requirement was lower in delayed in which was probably due to prescribed low temperature (Khichar and Niwas 2007).

3rd leaf

The number of days taken for the appearance of third leaf increase with the delay in sowing. The maximum number of days (18) followed by (16) days and (12) days under dates of sowing D_3 D_2 and D_1 respectively. But the thermal unit and photothermal unit decrease by (17.54%) with delay in sowing. The cultivars PBW-343 PBW-502 and WH 542 accumulated same thermal units (202) GDD, (228) ACCDU, (61) CHETA and phototrermal unit (88170) CEDU, (2812) PTU and (12109) HTU. Photothermal unit (88170) CEDU, (2812) PTU and (12109) HTU as compared cv PBW-550 (206) GDD, (244) ACCDU, (172) CHETA, (94623) CEDU, (2998) PTU and (19407) HTU the maximum number of days (16) taken at nitrogen level (N_{180}) and N_{120} followed by 14 days at N_{90} level. Maximum accumulated thermal and photothermal units are at N_{180} and N_{120} (216) GDD, (244) ACCDU, (142) CHETA and (94623) CEDU, (2998) PTU and (13407) HTU.

4th leaf

The number of days taken to the development of fourth leaf increase with delay in sowing. But the thermal and photo thermal unit decreases with delay in sowing. The maximum number of thermal unit and photo thermal units are (287) GDD, (315) ACCDU, (243) CHETA, (136239) CEDU, (3795) PTU and (16055) HTU (D_1) followed by (230) GDD (262) ACCDU, (177), CHETA (105331) CEDU (3296) PTU and (17765) HTU (D_2) and (225) GDD, (272) ACCDU, (168) CHETA (80540) CEDU, (3346) PTU and (15962) HTU (D_3). The cvs PBW-343, PBW-550 and WH-542 took similar number days (19) and thermal photothermal unit where as cv PBW-502 took (20) days. The cv. PBW-502 requires (4.72%) more thermal and photothermal unit as compared to other cultivars. The maximum number of days (19) at nitrogen level of (N_{180}) and minimum number of days (15) at N_{90}. This was because of higher level of nitrogen increases period for development of fourth leaves by providing more nutrient from the soil.

5th leafs

The maximum number of days (26) by cv PBW 550 followed (25) cv. PBW-543, PBW-502 and (24) days cv. WH-542. The maximum number of days 30 days (D_3) followed by (25) days 15th Nov. (D_2) and (21) days (D_3). But the maximum thermut and photothermal units are utilized by (D_1) (371) GDD, (401) ACCDU, (313) CHETA and (179025) CFDU, (4942) PTU and (25619) HTU followed (15th Nov.) (305) GDD, (348) ACCDU, (235) CHETA (131238) CFDU (4942) PTU and (25619) HTU and 15th Oct. (277) GDD, (341) ACCDU, (235) CHETA, (13138) CFDU (4942) PTU and (25619) HTU and D_1 (277) GDD, (341) ACCDU (206) CHETA and (101715) CEDU, (4221) PTU and (22812) HTU. The maximum number of days (28) took at N_{180} level for appearance of fifth leaf. The more (12.00%) thermal and photothermal unit is required for appearance of fifth leaf at N_{180} level of nitrogen.

6th leaf

The number of days taken up by the crop to completion of fifth leaf and appearance of sixth leaf increase with delay in sowing. this is because of prevailed low temperature. The maximum number of days (36) followed (31) days and (26) days under dates of sowing 15th Dec. (D_3) 15th Nov. (D_2) and 15th Dec. (D_1) respectively. But the thermal unit and photothermal unit decreases with delay in sowing as (D_3) GDD, (406), ACCDU (244), CHETA (125195), CEDU (5017) PTU and (32757) HTU (D_2) (365) GDD, (420) ACCDU, (281) CHETA, (150786) CFDU, (5548) PTU and (50999) HTU and D_1 (446) GDD, (498) ACCDU (370) CHETA, (212802) CEDU, (5998) PTU (36464) HTU. The cvs PBW-343, PBW-550 took same number of days and similar thermal and photothermal units as compared to other cvs. The maximum number of days (32) and maximum thermal unit and photothermal unit are (460) GDD, (462) ACCEDU, (318) CHETA (172080) CEDU (5685) PTU and (40689) HTU at N_{180} level of nitrogen similar result has been reported by (Miglietta 1991b).

7th leaf

The number of days increases with delaying sowing but the thermal and photothermal unit decrease with delaying sowing this is probable due to prevented low temperature (Khichar and Niwas 2007). The maximum thermal and photothermal unit accumulated at date of sowing 15th Oct. (D_1) and (533) GDD, (593) ACCDU (449) CHETA, (254024) CEDU, (7206) PTU and (49979) HTU. The cvs PBW-502 and PNH-542 took same number of days (38) and same thermal and photothermal unit (463) GDD, (538) ACCDU, (367) CHETA (200554), CEDU (6615) PTU and (58214) HTU followed by cv PBW 550 and cv. PBW-343. The maximum number of days (44) dt Nitrogen level of (N_{180}) and utilized maximum number of thermal and photothermal unit (520) GDD, (607) ACCDU, (412) CHETA, (222099) CEDU, (7472) PTU and (75753) HTU. The men (2.93%) energy is required for level of nitrogen (N_{90}) for appearance of seventh leaf. The results are in close conformity with those of (Akbar *et al* 2000).

8th leafs

The maximum number of days observed under 15th Dec. and minimum number of days (40) under 15th Oct. but the thermal and photothermal unit decreases with delay in sowing as the maximum thermal and photothermal units was (629) GDD, (702) ACCDU, 522 CHETA, (300240) CEDU, (8584) PTU and (83130) HTU. The cv. PBW-343 and WH 542 took similar number of days (45) and same thermal units (531) GDD, (620) ACCDU, (417) CHETA (226707) CEDU, (7625) PTU and (79077) HTU followed by cv. PBW 502 and PBW 550. The maximum number of days (48) at nitrogen level of (N_{180}) and decreases with decrease in nitrogen level. The (7.67%) more thermal and photo thermal energy required for the appearance of eight leafs as compared to other nitrogen levels.

9th leaf

The number of days (54) taken for cv. PBW-343 and cv PBW-550 followed by (53) days for cv. PBW-502 and WH-542. The maximum number for appearance of ninth leaf (58) days and maximum thermal units are (712) GDD, (795) ACCDU, (584) CHETA (335154) CEDU, (9700) PTU and (108328) HTU. The number of days increases with delay in during but the thermal unit decreases with delaying sowing this of prevailed low temperature (Khichar and Niwas 2007). The maximum number of days (54) took at nitrogen level of N_{180} for appearance of ninth leafs and maximum number of thermal and photothermal unit (617) GDD, (725) ACCDU, (482) CHETA, (266754) CEDU, (8925) PTU and (73845) HTU.

10th leaf

The thermal and photothermal unit decreases with delay in sowing. The maximum thermal unit (793) GDD, (888) ACCDU, (645) CHETA, (366775) CEDU, (10912) PTU and (134890) HTU under date of sowing 15th Oct. (D_1). the number of days increase with delay in sowing. The cultivars PBW-343 and PBW-502 took (62) days and accumulated (695) GDD, (821) ACCDU, (542) CHETA, (301046) CEDU, (10096) PTU and (136585) HTU followed by cv. PBW-556 and WH-542 (61) days (680) GDD, (809) ACCDU, (535), CHETA (297420) CEDU, (9954) PTU and (134249) HTU. The maximum number of days utilized (62) days at nitrogen level (N_{180}) and maximum number of thermal and photothermal unit utilized (695) GDD, (821) ACCDU, (542) CHETA, (182540) CEDU, (10096) PTU and (136585) HTU followed by nitrogen level N_{120} and N_{90}.

11th leaf

The number of days increase with delay in sowing but the thermal unit and photothermal unit decreases. This is because of prevailed low temperature. The eleventh leafs was not observed in crop for third date of sowing. That means as the date of sowing delayed by one month the decrease in leaf number. Maximum number of days took (69) by cv. PBW-502 followed by cv. PBW-550 (67), cv. WH-542 (66) and (65) days for cv. PBW-343. The maximum thermal unit was utilized by cv. PBW -502 (767) GDD, (908) ACCDU, (598) CHETA, (336277) CEDU, (11155) PTU and (170269) HTU. The minimum thermal units accumulated by cv. PBW-343, (727) GDD, (859) ACCDU, (566) CHETA, (316161) CEDU, (10551) PTU and (150814) HTU. The maximum number of days (70) utilized under N_{180} level of nitrogen for the appearance of elevenths leaf. The maximum heat / thermal land photothermal utilized was (777) GDD, (921) ACCDU, (606) CHETA (341641) CEDU, (113111) PTU and (174789) HTU. The above data for eleventh leaf pooled for two date of sowing. There was not appearance of 11th leaf in 15th Dec. 20 sowing.

12th leaf

The 12th leaf has not appeared in 15th Dec. (D_3). That means the total number of leaves decrease with delay in sowing. As the maximum number of days took (73) and maximum thermal and photo thermal unit (975) GDD, (1110) ACCDU, (782) CHETA (430611) CEDU, (13632) PTU and (233414) HTU under 15th Oct. (D_1). The maximum number of days (77) took by cv. PBW-343 followed by cv WH-542 (76) days, (75) a PBW-502 and (74) cv PBW-550. The maximum accumulated thermal and photothermal unit was for cv. PBW-343. (846) GDD, (1007) ACCDU, (660) CHETA (378915) CEDU, (12380) PTU and (206181) HTU. The more (7.01%) accumulated thermal and photothermal unit was required for nitrogen level at (N_{180}). There was decrease in Total leaf number as there was delay in sowing this was because with delay in sowing crop try to complete its all stages as early as possible so that able to complete its life cycle. This results is in conformity with (Lamoreaux *et al* 1978).

RELATIONSHIP WITH THERMAL AND PHOTOTHERMAL UNITS

Leaf emergence rate

Leaf emergence rate plotted against growing degree days (data pooled for all date of sowing for all cultivars of different nitrogen). The graph showed sigmoid growth with increase in growing degree days the leaf emergence rate first increases and then become constant and then decreases. The maximum leaf emergence rate was observed between (500-600 GDD) with 0.245 leaves/day. The filling of curve with line of regression the ($R^2 = 0.98$). This shows that there was significant relationship between growing degree days and leaf appearance rate work well in most of situations (McMaster and Hunt 2001). The above graph showed that there were slight variations amongs cultivars in response, that temperature and phultoforwal interacted and leaf emergence rate linear from 350 GDD - 550 GDD, either reaching as asymptote or decreasing slightly after about 550 GDD. (Fig.1)

Tiller and leaf area

Relationship between final leaf length sheath versus relative tiller number. The final blade length give linear relationship between leaf length blade including sheath. The graph showed that highly positive correlation between the leaf length of main sheath which the tiller number. Maximum leaf length is observed when there is maximum leaf length (50 cm) beyond this the graph is asymptote (decreases). Similar relation was found by Gallagher (1979). (Fig. 2 and 3)

Leaf blade length and tillers, serial functions that would likely to fit the final blade length date were tested for linear, exponential and logistic functions. The best approximation was made by fitting the logistic functions as linear and exponential function fit on graph (R^2=0.92) for linear with equation y = 4.20x + 5.47, and (R^2=0.83) with equation 9.36 $\exp^{0.169x}$. The fitting of logistic function (R^2=0.93) was made by fitting the logistic functions.

$$y = \frac{y_m}{1 + e^{a-kx}}$$

The distribution function showed lowest root mean square error (1.50) and contains only four parameters y_m maximum value of final blade length, a, lag coefficient, k is slope (from graph) coefficient x is relative tiller number. Similar result has been reported by Gallagher (1979) and Evers *et al* (2007).

The maximum blade width of full grown leaves did not yield single association with tiller number. In wheat cvs. maximum blade width appeared to correlate well to final blade length as the graph showed that maximum blade length 50 cm and maximum width (2.7 cm) after that further increase in blade with decrease in the length of blade.

Tiller number and accumulated thermal units

The maximum number of tillers appeared on plants are (14) and (875) GDD. There as direct relationship between the appearance of tiller and accumulated thermal units as the graph showed the minimum (251) accumulated unit required for the appearance of first tiller. The regression analysis by fitting the regression equation showed (R^2 =0.98) was highly significant relationship of accumulated thermal unit and appearance of tiller with the main stem. Similar result was obtained by Longneeku *et al* (1993) was linear relationship of appearance of tiller and accumulated thermal units.(Fig.9)

Leaf and tiller production in wheat

The graph described above has been based on two year data. The graph showed the relationship between main stem leaves and tiller development of wheat cultivars. The first tiller (T_1) was observed during the time when the (3^{rd}) leaf of main stem has nearly finished. The correlationship between leaves and tiller production was (R^2 = 0.99). The graph also showed that each tiller once produced, develops leaves at the same rate as the main stem. Kepper *et al* (1982) also showed the relationship of tiller and leaves production in wheat (Fig. 4). Best index is cumulative energy degree unit for determination of different phases. This result is in conformatry with (Kumar 1982).

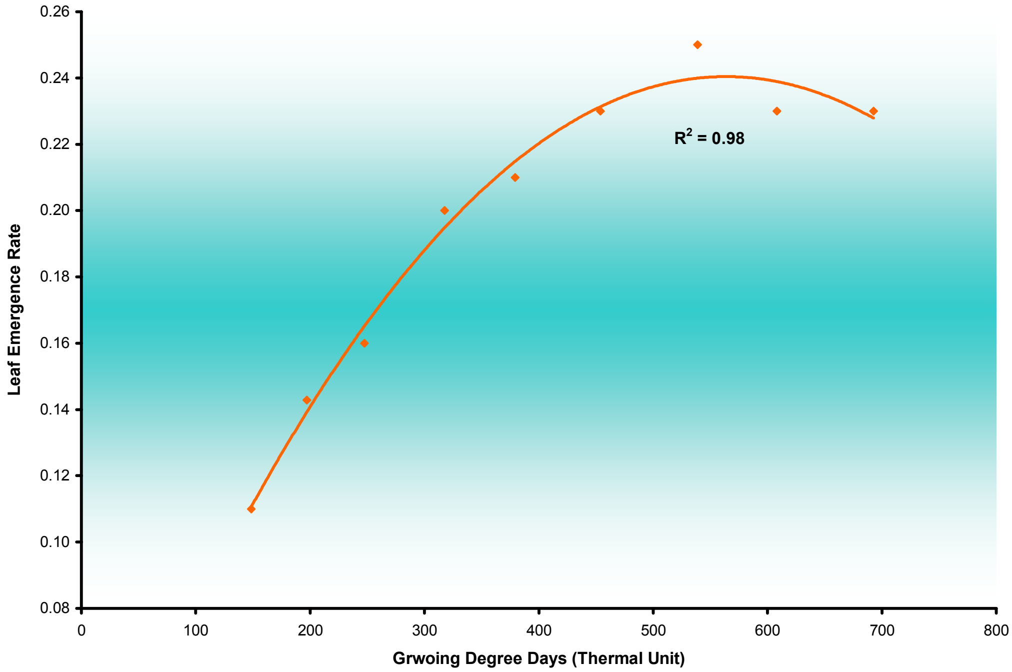


Fig. 1 Leaf emergence rate plotted against Growing Degree days for Dat pooled for all the date of sowing for all cultivars at different nitrogen levels

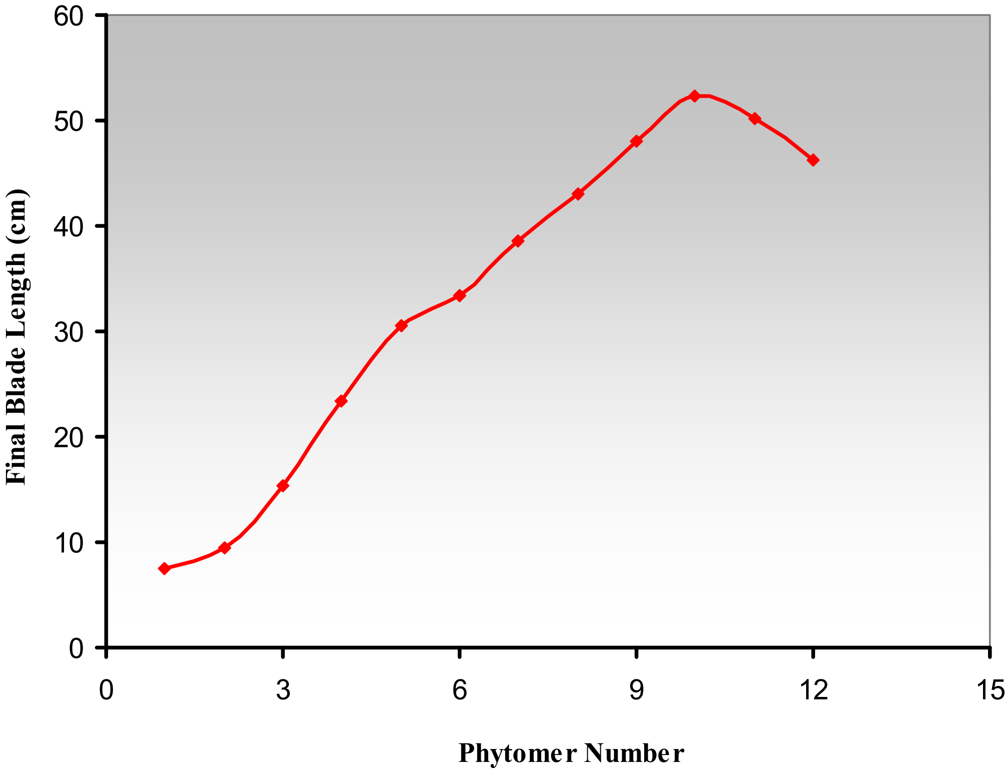


Fig. 2 Final sheath length (cm) versus relative phytomer number of the main stem (ms).

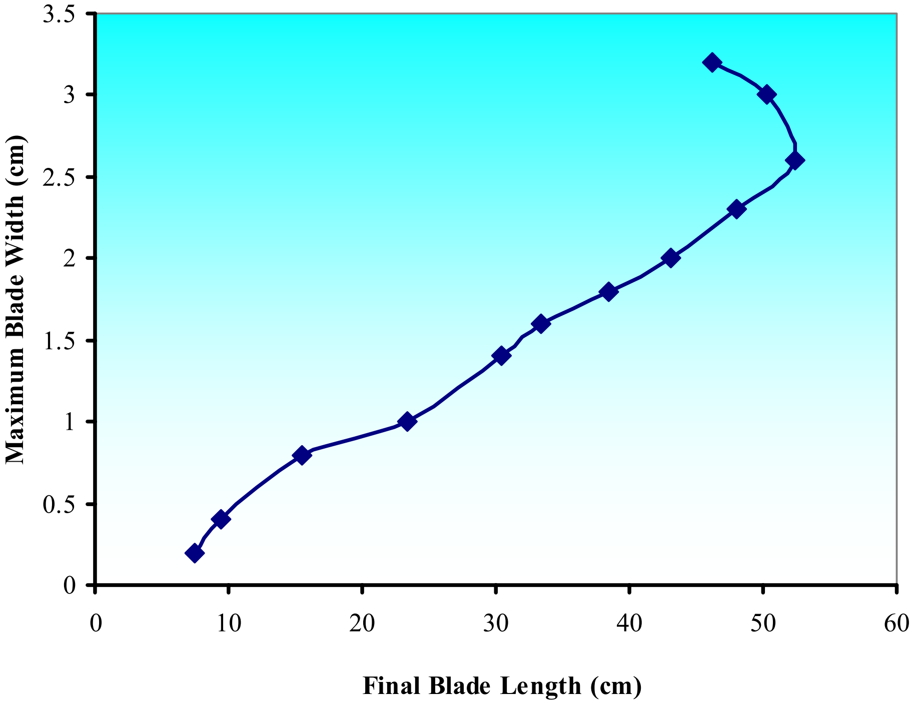


Fig. 3 Final maximum blade width (cm) versus final sheath length of the main stem (ms)

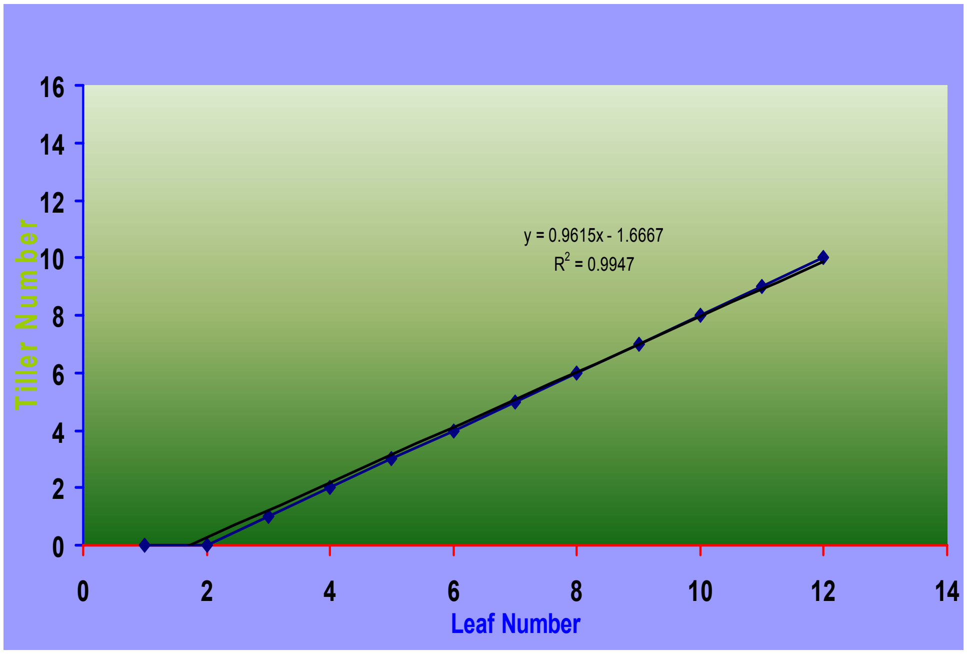


Fig. 4 Relationship between leaf number and tiller number in wheat cultivars

Wheat maximum blade width appeared to correlated well to final blade length using linear function y = ax+b with slope (0.058) and intercept (0.242) (R^2=0.90) Fig. The best fitted function is exponential function with slope (1.24) and intercept (0.021) and (R^2=0.96). A sigmoid shape has been shown by Boss and Neuteboom (1998b) as well who fitted similar sigmoid function to maximum blade length verses tiller number.

Leaf number and growing degree days

The graph showed relationship between leaf number and growing degree unit at three different date of sowing for all cultivars under different nitrogen level. Maximum no. of leaves was reported but the graph different GDD versus (10) number of leaves. Maximum GDD consumed by 15th Oct. (D_1) sowing with (R^2=0.99) followed by 15th Nov. (D_2) (R^2=0.99) and (15th Dec.) sowing (R^2=0.98). Maximum GDD observed (800) followed by (650) GDD and (550) GDD. The data was pooled for all cultivars and different nitrogen levels. The final number of leaves depends on the photo periodic response of the variety and on flower synbcrhonisation which in turn depends also depends on temperature and vernalisation (Miglietta 1991b). (Fig.5, 6, 7 and 8)

The relationship between leaf number and growing degree days at three different nitrogen levels (N_{90}, N_{120} and N_{180}) data pooled for all cultivars and date of sowing.

The maximum number of leaves (12) under N_{120} and N_{180} and (10) leaves N_{90} for all date of sowing, the maximum GDD (850) followed by (809) GDD and (700) GDD. The correlation coefficient was best fitted with linear regression equation with (R^2=0.99) N_{180}, (R^2=0.96) N_{120} and (R^2=0.99) N_{90}. Similar result was reported by Longneetar *et al* (1993).

The relationship between leaf number and different thermal units data pooled for all dates of sowing under different nitrogen level for all the cultivars. The maximum fits correlationship (R^2=0.99) GDD, (R^2=0.95) ACCDU and (R^2=0.93) CHETA. Therefore the above result concluded that growing degree days (GDD) is the best index for determination phenophases of wheat cvs. This result is in conformatory with Jarmar (1982). The relationship leaf number and logic of photothermal unit (CEDU, PTU and HTU) date pooled for all cvs. different nitrogen under different dates of sowing. The maximum (R^2=0.94) CEDU followed by (R^2=0.93) PTU and (R^2=0.90) HTU.

Thermal unit of leaf and tiller appearance

The relationship between thermal unit of tiller and leaf appearance for different dates of sowing for different cvs. of different nitrogen levels There was significant correlationship between appearance of leaf and tiller (R^2=0.88). The graph showed that leaf (98) GDD and tiller (270) GDD was required for appearance of first leaf and first tiller. Similar result observed by Evers *et al* (2007).(Fig.10)

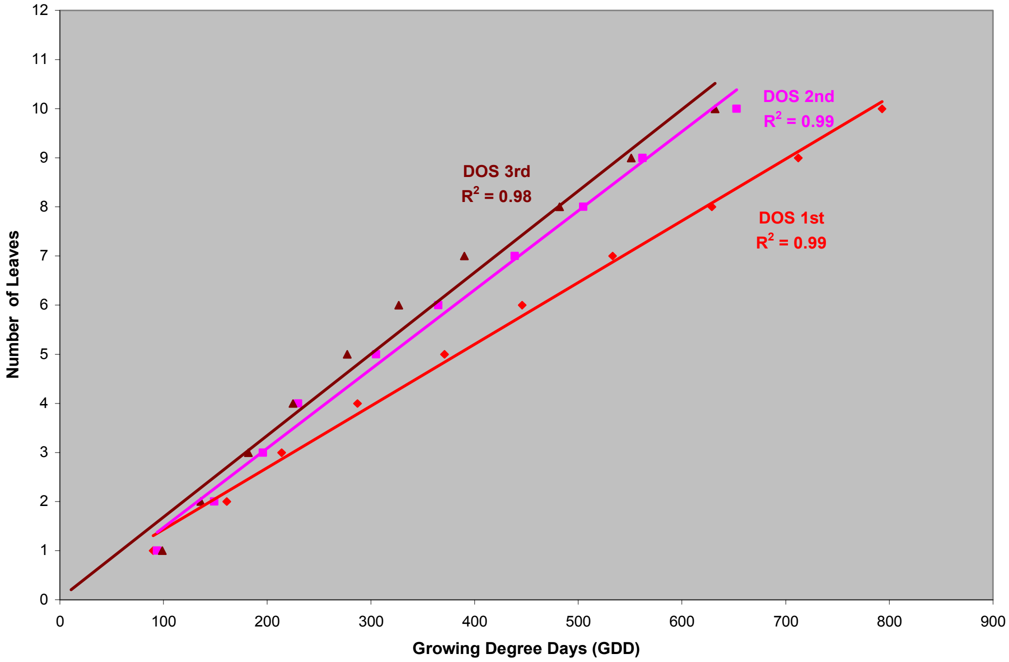


Fig .5 Relationships between Leaf number and growing Degree days [GDD (accumulated thermal units)] at three different dates of sowing data pooled for all cultivars and nitrogen levels.

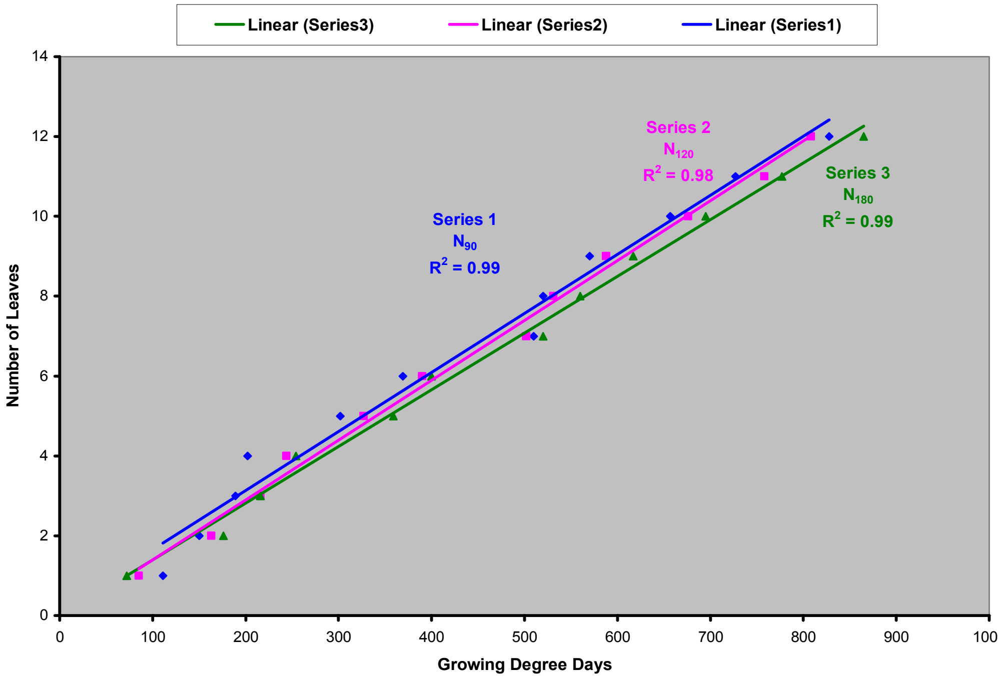


Fig 6 Relationship Between Leaf number and growing Degree days [GDD (accumulated thermal units)] at three different nitrogen levels (N_{90}, N_{120} and N_{180}) data pooled for all cultivars and date of sowings.

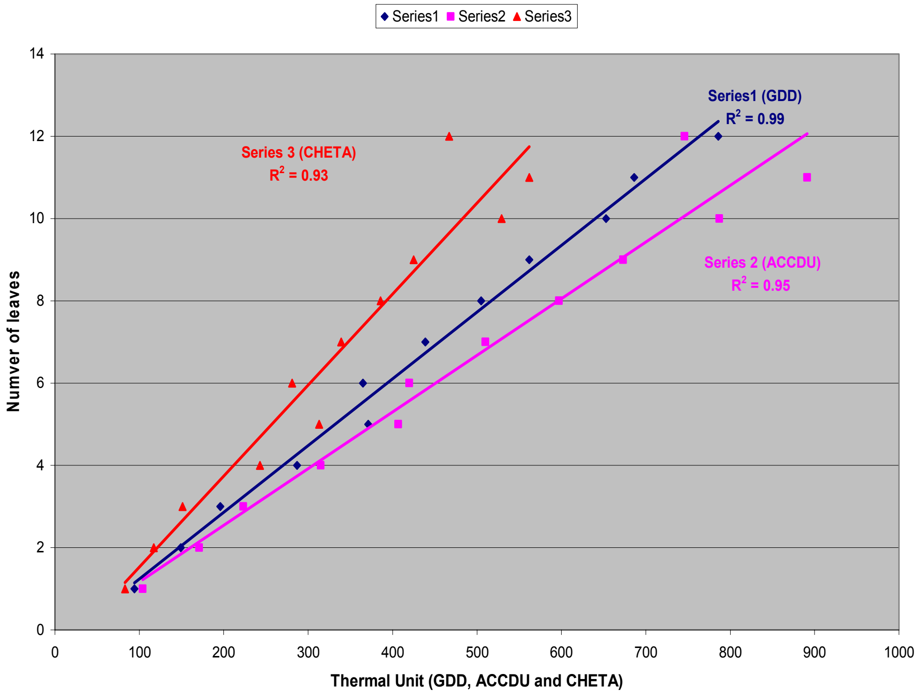


Fig .7 Linear regressions between leaf number and different thermal units (GDD, ACCDU and CHETA)

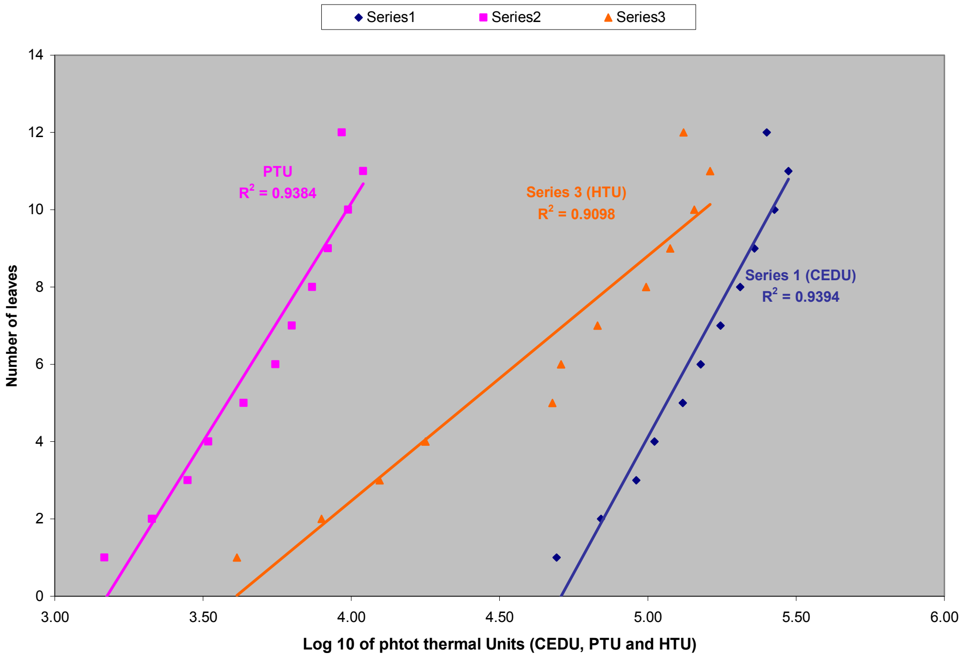


Fig 8 Lines of linear regression between leaf number and Log 10 of photothermal units (CEDU, PTU and HTU)

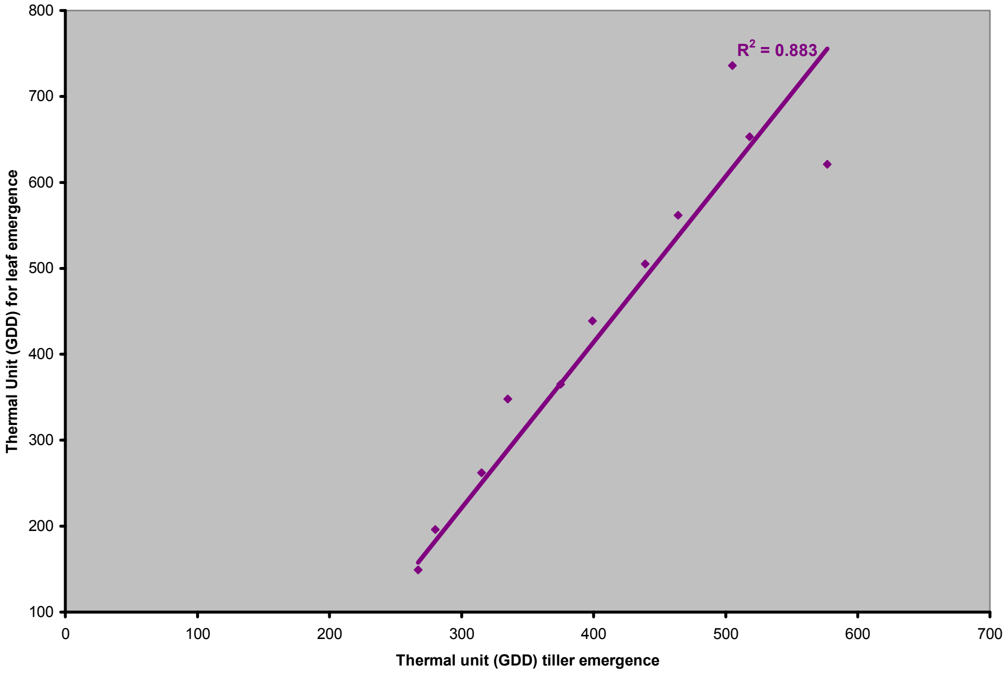


Fig. 9 Relationship between Thermal unit of leaf and tiller appearance

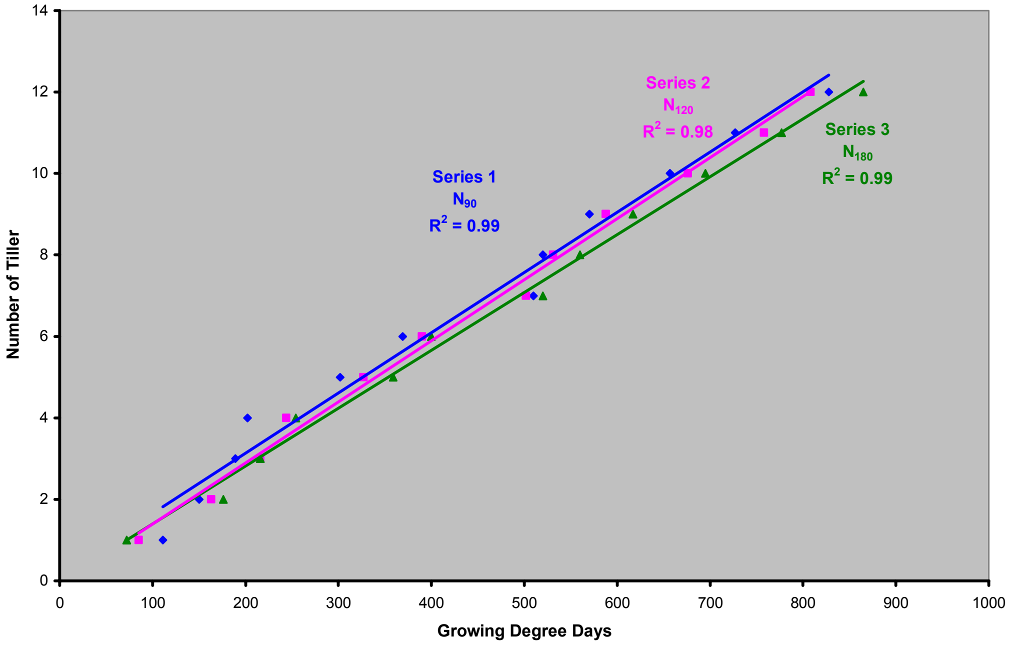


Fig. 10 Relationship between tiller number and growing degree days

4.1.13.2 Tiller appearance

1^{st} tiller

The number of days, cultivars PBW-343, PBW-502, PBW-550 and WH-542. Date of sowing (15th Oct. 15th Nov. and 15th Dec.) and three nitrogen level (N_{90}, N_{120} and N_{180}) for appearance of tillers are as follows in Table 4.13.1.2

The number of days increases with delay in sowing for the appearance of first tiller. The maximum number of days (26) followed by (20) and (17) days for dates of sowing D_3 D_2 and D_1 respectively. But the thermal and photothermal unit decreases with delay in sowing maximum heat / thermal and photothermal consumed by first date of sowing (D_1) 15th Oct. (305) GDD, (334) ACCDU, (258) CHETA, (144288) CEDU, (4037) PTU and (184159) HTU. For the appearance of first tiller there must fourth leaf on the wheat plant. The maximum number of days and thermal and photothermal units are accumulated by cv. WH 542 (24) days (314) GDD, (359) ACCDU, (251) CHETA, (137149) CEDU, (4416) PTU and (25199) HTU followed by cvs. PBW-343 and PBW-502 (21) days (278) GDD, (316) ACCDU, (221) CHETA (122390) CEDU, (3890) PTU and (21114) HTU and cv. PBW-550 (20) days (266) GDD, (302) ACCDU, (212) CHETA, (116185) CEDU, (3717) PTU and (19644) HTU. The maximum number of days and thermal photothermal unit utilized by crop at level of nitrogen (N_{180}). The higher nitrogen level require more (14.50%) energy for the appearance of 1st tiller on plant. The appearance of tiller is related with MS Haun stage (Kirby *et al* 1985b).

2^{nd} tiller

The number of days increases with delay in sowing but the thermal and photothermal unit are decrease with delay in sowing. The maximum heat and photothermal units are utilized by 15th Oct. (339) GDD, (372) ACCDU, (287) CHETA, (160562) CEDU (4505) PTU and (21719) HTU. The maximum number of days took (25) days by cv. WH-542 followed (24) cv. PBW-550 and cv. PBW-502 (24) and (23) day for cv. PBW-343. The maximum thermal and photothermal unit are utilized by cv. WH-542 (327) GDD, (373) ACCDU, (260) CHETA, (141667) CEDU, (4587) PTU and (26812) HTU. The maximum number of days (26) for nitrogen level (N_{180}) followed by (23) N_{90} and (22) for N_{120}). The higher dose of nitrogen utilized more (11.58%) of energy for the appearance of second tiller. This is because of availability of more nitrogen for vegetable growth.

3^{rd} tiller

The number of days increases with delay in sowing but the thermal and photothermal unit decreases with delay in sowing. The maximum thermal unit and photothermal unit accumulated under date of sowing 15th Oct. (387) GDD, (426) ACCDU, (327) CHETA, (185907) CEDU, (5165) PTU and (27402) HTU. The maximum heat / thermal unit and photothermal unit consumed by as (347) GDD, (399) ACCDU, (277) CHETA, (150019)

CEDU, (4908) PTU and (29793) HTU followed cv. PBW-550 and cvs PBW-343 and PBW-502. The maximum number of days (26) at level of nitrogen N_{120}. The maximum accumulated thermal and photothermal was in N_{120} followed N_{180} and N_{90}.

4th tiller

The number of days increases with delay in sowing but the thermal unit and photothermal unit decrease as the delay in sowing. The maximum accumulated thermal and photothermal units was (477) GDD, (528) ACCDU, (402) CHETA, (223371) CEDU, (6415) PTU and (38268) HTU. The maximum number of days (34) for cv. PBW-502 followed by cv. PBW-343 and a PBW-550 and WH-542. The maximum thermal and photothermal unit were utilised by cv. PBW-502 (421) GDD, (488) ACCDU, (335) CHETA, (180727) CEDU, 5996 PTU and (47072) PTU. The maximum number of days (34) utilized by nitrogen level N_{180} for appearance of fifth tiller. It required (5.25%) more energy as compared to other level of nitrogen that is N_{90} and N_{120}.

5th tillers

The maximum thermal and photothermal units are utilised by 15th Oct. (D_1) (546) GDD, (607) ACCDU, (459) CHETA, (260175) CEDU, (7385) PTU (53454) HTU. The accumulated thermal and photothermal unit decreased with delay in sowing. The maximum number of days (36) took by cultivars PBW-502 and PBW550 followed by cv. PBW-343 (39) and cv. WH-542 (34) days. The maximum accumulated thermal and photothermal unit by cv. PBW-502 and cv. PBW-550 (444) GDD, (515) ACCDU, (353) CHETA, (191414) CEDU (6317), PTU and (51580) HTU. The maximum number of days (36) utilized for appearance of sixth leaf at nitrogen level (N_{120}). It required more (5.46%) energy for the appearance of fifth leaf than 15th Dec. sowing.

6th tiller

The thermal and photothermal unit decreases with delay in sowing. The maximum thermal and photothermal unit (570) GDD (635) ACCDU, (477) CHETA, (273030) CEDU (7732) PTU and (59060) HTU under 15th Oct. sowing. The maximum no. of days (38) and thermal and photo thermal unit (463) GDD, (538) ACCDU, (3600) CHETA, (200554) CEDU, (6615) PTU and (58214) HTU for cvs. PBW502 and WH542. The maximum number of days (38) for nitrogen N_{120} and also utilised maximum heat/thermal and photothermal units (463) GDD, (538) ACCDU, (367) CHETA, (200554) CEDU, (6615) PTU and (58214) HTU. Similar result reported by Kumar (1974).

7th tillers

The number of days increases with delayed in sowing as the thermal and photothermal unit decreases with delayed in sowing. The maximum accumulated thermal and

Table 4.1.13.2 Growing energy units taken by different wheat cultivars for tiller appearance (Phyllochron Index) under different dates of sowing and nitrogen levels

	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
1st Tiller										
Days	17	20	26	21	21	20	24	19	20	22
Energy units										
GDD	305	242	251	278	278	266	314	254	266	291
ACCDU	334	275	305	316	316	302	359	287	302	331
CHETA	258	185	188	221	221	242	251	202	242	232
CEDU	144288	109629	89911	122390	122390	116185	117149	110280	116185	127845
PTU	4037	3402	3766	3890	3890	3717	4416	3539	3717	4068
HTU	184159	19943	19475	21114	21114	19644	25199	17809	19644	22288
2nd Tiller										
Days	19	22	29	23	24	24	25	23	22	26
Energy units										
GDD	339	267	270	302	314	314	327	302	291	337
ACCDU	372	304	331	345	359	359	373	345	331	386
CHETA	287	205	201	241	251	251	260	241	232	269
CEDU	160562	120149	98876	132547	137149	137149	141647	132547	129645	146147
PTU	4505	3814	4103	4239	4416	4416	4587	4239	4068	4749
HTU	21719	23604	22215	23134	25199	25199	26812	23134	22208	28512

Contd......

	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
3rd Tiller										
Days	22	23	33	26	26	25	27	26	27	25
Energy units										
GDD	387	280	299	337	337	327	347	337	347	327
ACCDU	426	319	371	380	386	373	399	381	399	373
CHETA	327	215	222	269	269	260	277	269	277	260
CEDU	185907	123628	110887	146417	146417	141647	150019	146147	150019	141647
PTU	5165	3992	4593	4749	4949	4587	4908	4749	4908	4587
HTU	27402	24707	27702	28812	28812	26812	29793	28812	29793	26812
4th Tiller										
Days	25	26	35	29	29	28	27	26	28	27
Energy units										
GDD	431	315	317	369	369	359	348	337	359	347
ACCDU	475	359	393	425	425	412	399	386	412	399
CHETA	363	242	236	294	294	286	277	269	286	277
CEDU	206983	135728	119817	158625	158625	153764	150019	146147	153764	150019
PTU	5785	4483	4968	5222	5222	5065	4908	4799	5065	4908
HTU	34528	30497	32757	33522	33522	31735	29793	28813	31735	29793
5th Tiller										
Days	28	28	38	32	34	31	31	32	33	34

Contd......

	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
26										
GDD	477	335	345	410	421	390	390	400	411	421
ACCDU	528	384	429	462	488	450	450	462	475	488
CHETA	402	258	258	318	335	311	311	318	326	335
CEDU	223371	141814	133804	172086	180727	167727	167727	172086	176228	180727
PTU	6415	4783	5300	5685	5996	5535	5535	5685	5842	5916
HTU	38268	35108	34026	40689	49072	37520	37520	40689	44052	47072
6th Tiller										
Days	33	32	40	35	36	36	33	34	36	34
Energy units										
GDD	546	375	361	432	444	444	411	421	444	421
ACCDU	607	433	449	501	515	515	475	488	515	488
CHETA	459	288	269	344	353	353	376	335	353	335
CEDU	260175	154575	138222	196006	191414	191414	139339	180727	191414	180727
PTU	7385	5377	5548	6156	6317	6317	5842	5996	6317	5996
HTU	53454	47511	37882	49003	51586	51586	44072	47072	51586	47072
7th Tiller										
Days	570	399	390	454	463	432	463	444	463	484
Energy units										
GDD	570	399	390	454	463	432	463	444	463	484

Contd......

	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
ACCDU	635	461	486	527	538	501	538	515	538	527
CHETA	477	308	292	360	367	344	367	353	367	360
CEDU	273030	161451	150136	196342	200554	186006	200584	191414	200554	196342
PTU	7732	5320	5991	6469	6615	6150	6615	6317	6615	6469
HTU	59060	57110	42694	54949	58214	49003	58214	51586	58214	54949
8th Tiller										
Days	39	38	44	41	41	42	38	42	40	41
Energy units										
GDD	619	439	401	492	492	502	463	502	482	492
ACCDU	689	510	499	572	572	584	538	584	560	572
CHETA	514	339	301	388	388	395	367	395	380	388
CEDU	296952	176076	153378	210920	210920	214638	200584	214638	206921	210920
PTU	8420	6296	6144	7044	7044	7188	6615	7188	6896	7044
8068	78083	67678	44198	67973	67973	70721	58214	70721	65611	67973
9th Tiller										
Days	44	41	47	43	44	46	42	46	45	44
Energy units										
GDD	675	464	433	510	520	540	502	540	531	520
ACCDU	754	540	539	595	607	632	589	632	620	607
CHETA	556	355	327	402	412	425	395	425	417	412

Contd......

	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
CEDU	318438	185473	170052	218090	222099	232109	214638	232109	226704	222099
PTU	9245	6680	6614	7328	7139	7774	7188	7774	7625	7139
HTU	94071	79532	50542	73210	76466	82889	70721	82859	79077	76416
10th Tiller										
Days	48	49	49	46	48	47	44	48	47	48
Energy units										
GDD	724	518	455	540	560	550	520	560	550	560
ACCDU	809	614	566	632	656	644	607	656	644	656
CHETA	593	394	345	425	440	432	412	440	432	440
CEDU	339826	210061	179969	232109	240824	236705	222099	240824	236705	240824
PTU	9933	7598	6926	7774	8068	7919	7139	8068	7919	8068
HTU	11102	104181	57099	82859	88435	85845	76466	88435	85845	88435
11th Tiller										
Days	52	47	52	56	51	52	48	-	51	53
Energy units										
GDD	768	505	482	638	588	596	560	-	588	607
ACCDU	859	597	599	751	690	701	656	-	690	713
CHETA	625	386	365	499	460	466	440	-	460	474
CEDU	358852	204887	196307	275707	253621	258426	240824	-	253621	262421
PTU	10571	7379	7337	9234	8492	8625	8068	-	8492	8774

Contd......

	15th Oct.	**15th Nov.**	**15th Dec.**	**PBW-343**	**PBW-502**	**PBW-550**	**WH-542**	**N_{90}**	**N_{120}**	**N_{180}**
HTU	130860	98668	69421	115334	100843	31596	88435	-	100843	106770
12h Tiller										
Days	58	51	55	56	56	55	52	-	54	55
Energy units										
GDD	837	577	514	638	638	427	596	-	617	627
ACCDU	942	692	637	751	757	738	701	-	725	738
CHETA	681	436	390	499	499	490	466	-	482	490
CEDU	381397	234879	213821	275707	275707	271218	258426	-	266754	304552
PTU	11549	8599	7801	9234	9234	9676	8625	-	8925	9076
HTU	153200	121069	82072	115334	115337	112528	315896	-	110725	112628
13th Tiller										
Days	62	54	-	58	61	60	56	-	60	61
Energy units										
GDD	875	555	-	657	686	676	638	-	676	686
ACCDU	987	664	-	775	809	797	751	-	797	809
CHETA	708	421	-	514	535	527	499	-	527	535
CEDU	895019	227020	-	285083	297420	292749	275107	-	292749	297420
PTU	12116	8232	-	9524	9984	9809	9234	-	9809	9984
HTU	174757	117163	-	121855	134249	130225	115334	-	130225	134249

photothermal unit (618) GDD, (689) ACCDU, (514) CHETA, (296952) CEDU, (8420) PTU and (78083) HTU. The cv. PBW 550 took maximum number of days (42) and maximum thermal and photothermal unit (502) GDD, (584) ACCDU, (395) CHETA, (214638) CEDU, (7188) PTU and (70721) HTU. The maximum number of days took (42) by nitrogen level of N_{90} and as the level of nitrogen decrease it took more time for appearance of more number of tiller this might because plant accumulated more no. of thermal and photo thermal unit to produce more tiller.

8th tiller

The maximum accumulated heat thermal and photo thermal unit (675) GDD, (754) ACCDU, (556) CHETA, (318438) CEDU, (9245) PTU and (94071) HTU at 15th Oct. The maximum number of days (46) took by cv. PBW-550 and maximum thermal and photothermal unit (540) GDD (632) ACCDU, (425) CHETA, (232109) CEDU, (7774) PTU and (82859) HTU followed by cvs. PBW-502, PBW-343 and WH-542. The maximum number of days (46) for appearance of ninth tiller at nitrogen level (N_{90}). This was because of prevailing conducible temperature for appearance of tiller.

9th tiller

The number of days for appearance of tenth leaf same (49) days for 15th Nov. and 15th Dec. (D_3) but the thermal and photothermal unit decreased with delayed in sowing. The maximum number of days (49) and maximum thermal and photothermal unit were (724) GDD, (809) ACCDU, (593) CHETA, (339826) CEDU, (9933) PTU and (111102) HTU for first date of sowing (D_1). The cv. PBW-502 utilised more number of days (48) as compared to other cvs. PBW-550 (47), PBW-343 (46) and 44 days for cv. WH-542. The level of nitrogen has unable to alter the appearance of tenth leaf. As the maximum number of days took (48) for appearance of the leaf at levels of nitrogen N_{90} and N_{180}.

10th tillers

The number of days remains same for 15th Oct. and 15th Dec. sowing but the thermal and photothermal unit decreases with delay in sowing. The maximum accumulated thermal unit (788) GDD, (859) ACCDU, (625) CHETA, (358852) CEDU, (10571) PTU and (130680) HTU. The maximum number of days (56) took by PBW-343 and maximum thermal and photothermal unit (638) GDD (751) ACCDU, (499) CHETA (275707) CEDU, (9234) PTU and (115334) HTU followed cv. PBW-550, cv. PBW-502 and cv. WH-542. The maximum number of days and thermal and photothermal unit were accumulated at nitrogen of (N_{180}).

11th tiller

The number of day decrease with delay in sowing. The thermal and photothermal unit also decreases with delay in sowing. As the maximum thermal and photothermal unit (837) GDD, (942) ACCDU, (681) CHETA, (381397) CEDU (11549) PTU and (153208) HTU. The maximum number of days took (56) by PBW-343 and PBW-502 followed by cv.

PBW-550 and cv. WH-542. The number of days increases with as the nitrogen level increase from N_{120} to N_{180}. The low level nitrogen N_{90} unable to produce more number of tillers that was due to non availability of nutrient (N_{120}) from soil.

12th tiller

The number of days decrease with delay in sowing for appearance of thirteen tillers. The maximum accumulated thermal and photothermal unit (875) GDD, (987) ACCDU, (708) CHETA (395019) CEDU (12116) PTU and (174751) HTU. The maximum number of days (G) took by cv. PBW-502 followed by cv. PBW-550 (60), cv. PBW-343 (88) and cv. WH-542 (58) days. Thirteen tiller is unable to appear at N_{90} level. This was because of non availability of nutrient (N) from soil for production new tiller. The number of days (61) took by nitrogen level (N_{180}).

13th tiller

The number of days decrease with delays in sowing the thermal and photothermal unit also decrease with delay in sowing. The maximum number of days and thermal unit was at 15th Oct. (D_1). The late in sowing hamper the appearance of tiller as the temperatures increase during 15th Dec. (D_3). The maximum number of days (67) and maximum thermal and photothermal unit for cv. WH-542. At low level of nitrogen no more tiller would appeared as data showed. At higher level of nitrogen (N_{180}) maximum number of days and maximum thermal and photo thermal utilised for appearance of fourteenth tiller.

4.1.13.3 Node appearance

The node appearance took place after 39 days of sowing. The data pooled for cultivars, different nitrogen under different dates of sowing. There was linear relationship between growing degree days and number of days. There were significantly positively correlations between thermal unit and number of days with ($R^2=0.99$). The maximum GDD >800 but less than 850 production of last node. Maximum number of node present on the wheat cultivars at the time of maturity was four. The rate of appearance can be find out by the by taking the slope from the line of regression. From this we can predicts the appearance of node on the main stem with 99 percent variation as line of regression shown in the graph. The graph also showed that the minimum number Growing dgree days for the appearance of node was 450 GDD. The rate of appearance of node can calculated from the slope of line of regression 0.0214 days per growing degree days is required for the appearance of two node. Similar result was obtained by Longneeku *et al* (1993) was linear relationship of appearance of node and accumulated thermal units.

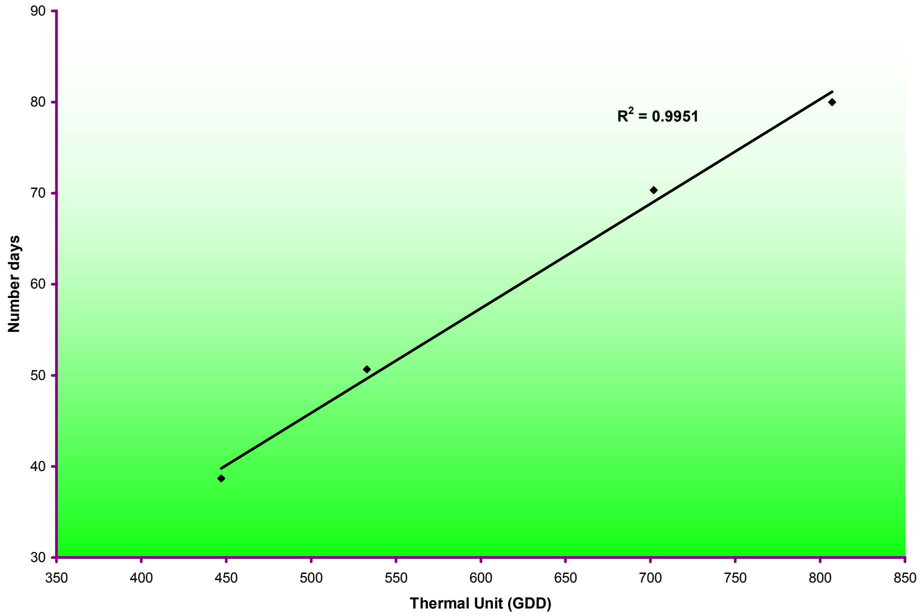


Fig. 11 **Relationship between growing degree day and number of days for the appearance of node on the main stem for the wheat cultivars**

4.2 PHYSIOLOGICAL TRAITS

Physiological traits influencing grain yield recorded at different growth stages are discussed under followed headings :

4.2.1 Emergence count (m^{-2})

4.2.2 Dry matter at 15 days of intervals

4.2.3 Plant biomass at anthesis and maturity

4.2.4 Leaf area $(cm)^2$ at each growth stages

4.2.5 Pre-anthesis dry matter production

4.2.6 Crop growth rate (mg cm^{-2} day^{-1})

- Before anthesis
- After anthesis

4.2.7 Ear : stem ratio at anthesis and maturity

4.2.8 Grain filling rate (mg $grain^{-1}$ day^{-1})

4.2.9 Grain growth duration

4.2.10 Leaf area index

4.2.1 Emergence count (m^{-2})

The data on emergence count of four cultivars, three nitrogen level at different date of sowing are given in Table 4.2.1.

The early (15th Oct.) date of sowing at N_{180} level has maximum emergence count (170.28) and minimum (119.20) at N_{90} in late (15th Dec.) sowing. The 15th Oct. and 15th Nov.

dates of sowing does not differ from each other. Emergence count (m^{-2}) decrease with delay in sowing. The variety PBW-343 and PBW-550 showed significant difference in Emergence count (m^{-2}). The high emergence count at 15th Oct. and N_{180} level of nitrogen was because of rise of soil temperature. During (15th Oct.) the mean temper of air was (25.50°C) where as the mean air temperature at 15th Nov. (19.3°C) and (14.9°C) during (15th of Dec.). As meteorological data showed mean soil temperature during (15th Oct.) 27.6°C, (15th Nov.) 20.5°C and 16.2°C at (15th Dec.) date of sowing as the temperature of soil decrease emergence count (m^{-2}) decreases as data recorded. This showed that emergence count has significant relationship with soil temperature. Higher nitrogen level (N_{180}) might raise the temperature of soil which resulted in higher emergence (m^{-2}) as data revealed. The interaction between dates of sowing, cultivars and nitrogen was more than the dates x nitrogen and dates x cultivars. This result was in conformity with Borojevic and Williams (1982).

Similar result was reported by Nainwal and Singh (2000) also found the decrease in emergence count with delay in sowing. The above result showed that the emergence count is dependent on management factor (Nitrogen level), thermal time (Date of sowing) and cultivars. Similar result was reported by (Wilkon and Singh 2001).

As the data showed in table - high dose of nitrogen (N_{180}) increases the emergence count (m^{-2}) during 15th Oct. sowing this can explained on the basis rise of temperature in soil at high or dose of nitrogen. Temperature rises because of increase in soil respiration. Soil respiration increase because of rise CO_2 concentration in soil which was released from urea [$CO(NH_2)_2$]. Soil respiration increased because rise CO_2 concentration in soil (Moss *et al* 1961).

4.2.2 Dry matter at 15 days of intervals

The graph showed the relationship for dry matter accumulation at 15 days of interval after sowing for different cultivars at different levels of nitrogen. Maximum dry matter accumulation was observed in cultivars PBW-502 and PBW-343 followed by WH-542 and PBW-550 but the maximum dry matter accumulation in cv. PBW-550 at 120 days after sowing. This showed that maximum translocation of dry matter into the seed as compared to other cultivars. The maximum dry matter a cumulation per plant was 65 g at N_{120} level of nitrogen. This is in accordance with the result observed by Aggarwal *et al* (1994). The maximum dry matter accumulation at N_{90} level of nitrogen was (42 kg m) per plant for the cvs. PBW-343, PBW-502 and WH-502 but in case of cv. WH-542 it was (40 g). The 28 gm dry matter accumulation in cv. PBW-502 followed by PBW-550 (25 g), (24 g) PBW-343 and (19 g), WH-542 at 90 days after sowing. The data is pooled for three dates of sowing (15th Oct., 15th Nov. and 15th Dec.) sowing.

Table 4.2.1 Emergence count (m^{-2}) in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	150.43	154.11	638.49	148.40	158.46	160.11	120.41	126.71	130.46	150.70
PBW-502	156.00	162.36	171.40	140.31	148.25	162.40	12.11	133.41	133.14	148.15
PBW-550	160.96	168.30	178.11	139.49	146.43	153.46	110.16	117.18	123.18	144.11
WH-542	147.00	150.41	162.11	130.53	136.46	146.93	120.13	125.42	133.68	140.67
Mean	153.60	158.79	170.28	139.68	159.93	155.72	119.20	126.28	130.11	145.9

CD (P=0.05)
Dates (D) : 3.33
Nitrogen (N) : 2.35
Cultivars (Cv.) : 141
Cultivars x Nitrogen : 1.25
Dates x Nitrogen (N x D) : 1.71
Dates x Cultivars (D x Cv.) : 2.43
Dates x Cultivars x Nitrogen (D x Cv x N) : 0.86

Dry matter accumulation was observed at the three different levels of nitrogen maximum DM was observed at N 180kg/ha that is 90kg/ plant and it decreased with the decreased in the nitrogen levels the regression equation has also simulated the DM at different nitrogen levels the R square value accurately predicted the dry matter production at different nitrogen levels R^2 = 0.99 for all the three graph which showed that simulated valued was exactly predicted by with the observed value. This in accordance with the result observed by Aggarwal *et al* (1994). (Fig.12, 13 and 14)

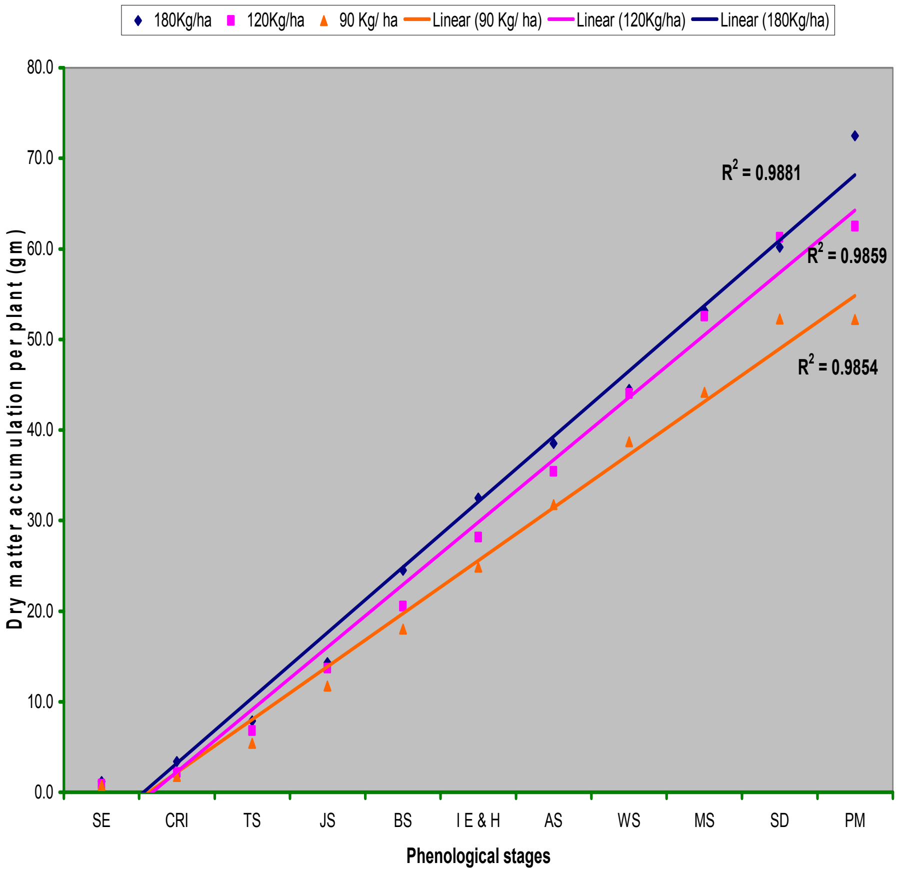
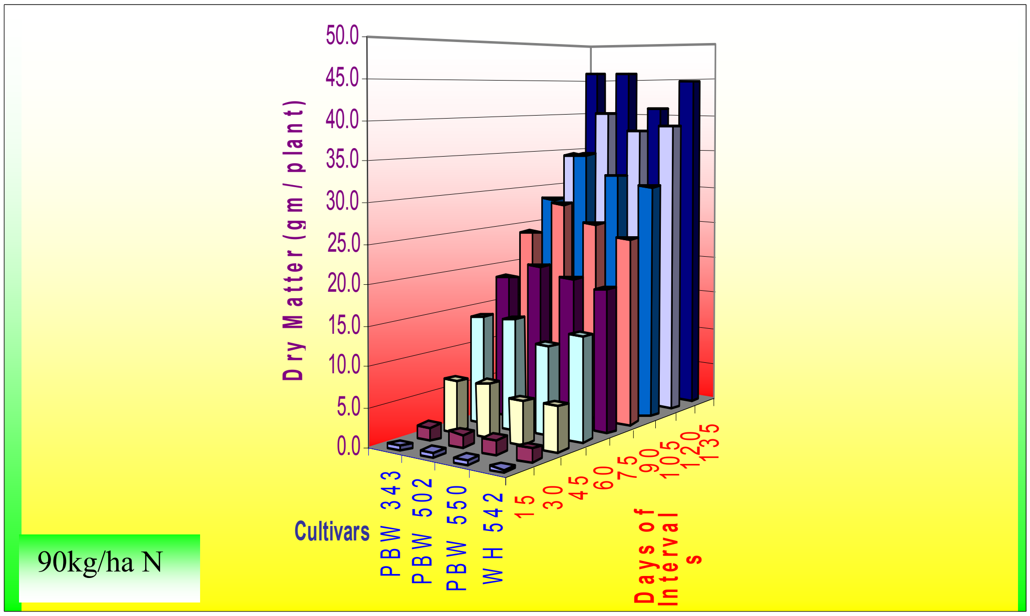


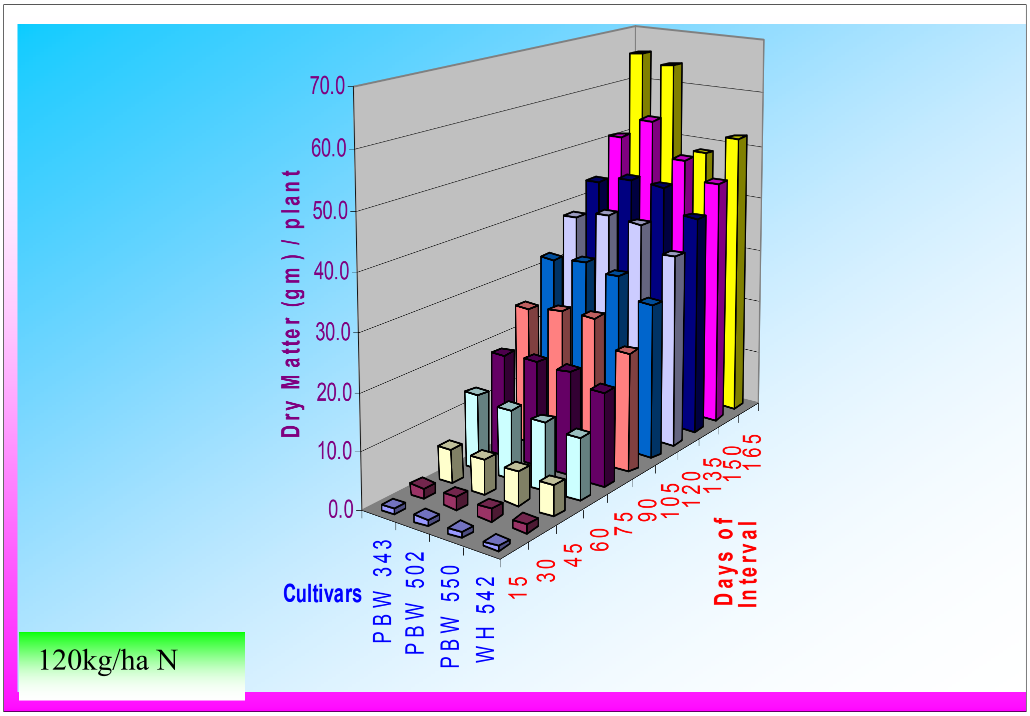
Fig. 12 Dry matter Accumulation per plant (gm) at different growth stages of Wheat cultivars at different levels of nitrogen under three date of sowing.

The dry matter accumulation at N_{180} level of nitrogen (89 gm) was maximum for cv. PBW-343 followed WH-542 and PBW-502. The cv. PBW-550 did not reach at 165 days because physiological maturity was at 150 days after sowing. The regression analysis showed that dry matter accumulation was higher at N_{180} followed by N_{120} and N_{90} at all the phonological stages of wheat cultivars. The R^2 = 0.9981 for N_{180}, R^2 = 0.9859 for N_{120} and R^2 = 0.9854 for $N_{90.}$ showed that there is strong interaction between the phenological stages and dry matter accumulation with the course of time



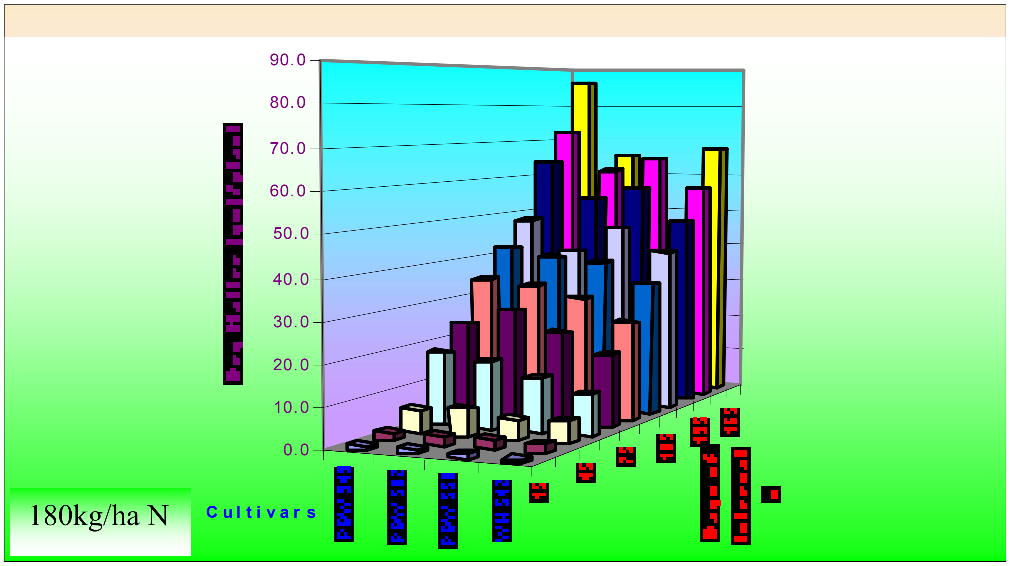
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Dry Matter (gm / plant)
PBW 343
PBW 502
PBW 550
WH 542
Cultivars
15
30
45
60
75
90
105
120
135
Days of Intervals
90kg/ha N

(A)



70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Dry Matter (gm) / plant
PBW 343
PBW 502
PBW 550
WH 542
Cultivars
15
30
45
60
75
90
105
120
135
150
165
Days of Interval
120kg/ha N

(B)



(C)

Fig. 13 **Dry matter accumulation dry matter of different cultivars at A) 90kg/ha B) 120kg/ha and c) 180kg/ha nitrogen levels up to physiological maturity (15 days interval).**

4.2.3 Plant biomass at anthesis and maturity

4.2.3a Plant biomass at anthesis

4.2.3b Plant biomass at maturity

4.2.3a Plant biomass at anthesis

Plant biomass at anthesis stage is given Table No 4.2.3a. Plant biomass at anthesis decrease with delay in sowing from 15th Oct. to 15th Dec. Maximum plant biomass observed (3038 g m^{-2}) at N_{180} level of nitrogen under 15th Nov. date of sowing and minimum in 15th Dec. (1110 g m^{2}) sowing at N_{90} level of nitrogen. The 15th Dec. sowing crop at (N_{90}) level of nitrogen accumulated less (63.3%) dry matter while than (15th Nov.). 15th Nov. accumulate (59.9%) more dry matter than 15th Oct. Maximum plant biomass was observed in case of PBW-550 (2295 g m^{-2}) followed by PBW-343 (2189 g m^{-2}), PBW-502 (2169 g m^{-2}) and WH-542 (2101 g m^{-2}). The cultivars PBW-343 and PBW-502 do not differ significantly from each other. From then result it can be inferred that with delay in sowing and decreases nitrogen level reduced the plant biomass at anthesis. These observations make supportively the similar observations of Deshmukh *et al* (2006) and Schapendonk *et al* (2007). Biomass partitioning to reproductive organs was the main attribute responsible for grain yield (Salfer and Andrade1989; Calderini *et al* 1995). Nitrogen and phosphorous are more important nutrients which affect the assimilate production and distribution and affecting directly or indirectly the source.

Table 4.2.3a Plant biomass at anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	**Dates of sowing**									**Mean**
	15th Oct.			**15th Nov.**			**15th Dec.**			
	N (kg ha^{-1})									
	90	**120**	**180**	**90**	**120**	**180**	**90**	**120**	**180**	
PBW-343	2115	2425	2685	2050	2600	3290	1085	1666	1792	2189
PBW-502	2010	2230	2979	1846	2351	3181	1096	1820	2010	2169
PBW-550	2495	2634	2800	1725	2850	2980	1190	1990	2001	2295
WH-542	2194	2265	2610	1919	2304	2704	1072	1855	1990	2101
Mean	2201	2388	2768	1885	2526	3038	1110	1832	1948	2188

CD (P=0.05) Dates (D) : 40.66
Nitrogen (N) : 15.15
Cultivars (Cv.) : 127.4
Cultivars x Nitrogen : 12.01
Dates x Nitrogen (N x D) : 15.46
Dates x Cultivars (D x Cv.) : 16.98
Dates x Cultivars x Nitrogen (D x Cv x N) : 10.46

Table 4.2.3b Plant Biomass at maturity in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	**Dates of sowing**									**Mean**
	15th Oct.			**15th Nov.**			**15th Dec.**			
	N (kg ha^{-1})									
	90	**120**	**180**	**90**	**120**	**180**	**90**	**120**	**180**	
PBW-343	3475	3545	3586	3371	3915	4543	2039	2661	2790	3280
PBW-502	3477	3220	4112	2911	3409	4215	2089	2898	3166	3351
PBW-550	3190	3587	3583	2926	4383	4178	2371	3340	3211	3434
WH-542	3317	3201	3506	3398	3451	3558	2228	3055	3104	3329
Mean	3582	3613	3696	3151	3789	4361	2181	2899	3067	3349

CD (P=0.05) Dates (D) : 17.8 Dates x Nitrogen (N x D) : 37.3
Nitrogen (N) : 7.1 Dates x Cultivars (D x Cv.) : 15.4
Cultivars (Cv.) : 17.3 Dates x Cultivars x Nitrogen (D x Cv x N) : 8.3
Cultivars x Nitrogen : 12.8

Similar relation (Arudini *et al* 2006). Nitrogen absorption by cereals thought to take place mainly before anthesis (Papakista and Gagianas 1991). Plant biomass at anthesis (dry matter) affected by (environmental factor) by cultivar (Cox *et al* 1985).

The increase in biomass in response to the higher N and S supply was mainly explained by an increase in IPAR driven by a rise in LAI without changes in extinction coefficient (Cavigila and Sadras 2001).

4.2.3b Plant biomass at maturity

The plant biomass at maturity decrease with the delay in sowing 15th Oct. to 15th Dec. and decrease in nitrogen level from (N_{90} to N_{180}). Plant biomass found to be maximum in PBW-550 (3434 gm^{-2}), followed by PBW-502 (3302 gm^{-2}), WH-542 (3329 gm^{-2}) and PBW-343 (3280 gm^{-2}). Under 15th Nov. sowing N_{180} for all cultivars (PBW-343, PBW-502, PBW-5580 and WH-542) are at par with other dates of sowing (15th Oct. and 15th Dec.). In 15th Dec. sowing plant biomass at maturity decreases by (49.99%) at nitrogen level (N_{90}) than 15th Nov. date of sowing while comparative loss fall (35.55%) than 15th Oct. date of sowing. The lowest biomass observed (2181 gm^{-2}) in 15th Oct. sowing at nitrogen level of (N_{90}). Then observations get support from the result of Cruz - Agudo *et al* (2000). The maximum plant biomass at maturity (3708 gm^{-2}) N_{180} followed by (3434 gm^{-2}) N_{120} and (2905 gm^{-2}) N_{90} level of nitrogen N can influence the leaf area development and maintenance as well as photosynthetic efficiency and dry matter partitioning to reproductive organ (maturity) (Prystupa *et al* 2004). Dry matter production is directly related to nitrogen and phosphorus supply. This effect the production of photoassimilates and the distribution of assimilates to the reproductive organs (Elliot *et al* 1997).

4.2.4 Leaf area (cm^2) at each growth stages

The graph showed the line for leaf area (cm^2) at N_{180} levels of nitrogen for all phenological stages. There is remarkable distinction between three level of nitrogen for leaf area (cm^2). These showed that leaf area duration increase for N_{180} level and this might be the reason for relationship with yield of grain and biomass production. The maximum leaf area was found at anthesis stage (AS) after that the leaf are start decreasing with proceeding in stage toward physiological maturity. This might be because of increase in temperature as stage of physiological maturity proceeded. The mean air temperature was (23.2°C) as compared to (18°C) at anthesis. The leaf area (cm^2) has direct relationship with leaf area index. Plenet and Lemair (2000) reported that when nitrogen supply is non limiting and empirical linear relationship between amount of nitrogen accumulated above general biomass and crop leaf area index maize. (Fig 14)

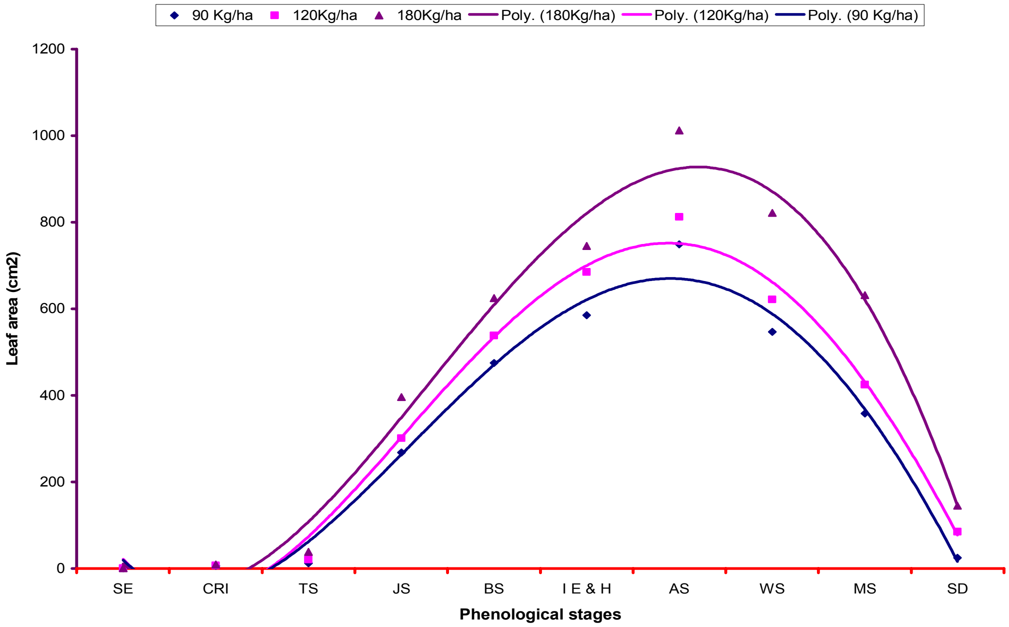


Fig 14 Leaf area (cm^{-2}) at diiferent growth stages of Wheat cultivars at different levels of nitrogen under three date of sowing.

4.2.5 Pre-anthesis dry matter production

The data on pre-anthesis dry matter production of four wheat varieties under different dates of sowing and nitrogen level are given in Table (Table 4.2.5).

The maximum pre anthesis dry matter production (74.95%) was observed under 15th Oct. sowing at (N_{180}) level of nitrogen, it gradually decreases with delaying in sowing and nitrogen level (N_{180} to N_{90}). The difference between 15th Oct. and 15th Dec. sowing were found to be significant at different level of nitrogen. Results of Sarkar *et al* (1987) confirmed our findings regarding decrease in dry matter production with delay in sowing. Pre anthesis dry matter production was found non significant all cultivars. The interaction between dates of sowing and nitrogen level showed significant differences. Similar result explained (Kanchan 2009). At 15th Oct. sowing maximum dry matter production (74.95%), followed by (70.43%) and 62.85 per cent of nitrogen level of N_{180}, N_{120} and N_{90} respectively. Maximum dry matter production (73.80%) followed by (66.89%) and (59.05%) at nitrogen level of N_{180}, N_{120} and N_{90} respectively under 15th Nov. sowing. At 15th Dec. sowing maximum dry matter production (64.10%) followed by (60.7%) and (48.10%) at nitrogen level of N_{180}, N_{120} and N_{90} respectively. Dry matter content of vegetative tissue increased between anthesis and maturity at different levels of nitrogen. The translocation of pre anthesis dry matter production varies in different varieties and environmental condition (dates of sowing) and a large movement of assimilates can occurs under low soil fertility conditions (Nitrogen level) (Yoshida *et al* 1972).

Table 4.2.5 Pre anthesis dry matter production (%) in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	60.86	68.39	74.86	60.81	66.41	72.40	53.20	62.60	64.21	64.68
PBW-502	58.31	69.20	72.39	63.41	68.98	75.46	52.46	62.80	63.48	65.16
PBW-550	65.83	73.42	74.14	58.94	65.01	71.32	50.18	56.88	62.13	64.65
WH-542	66.14	70.74	74.43	56.46	66.81	76.41	48.10	60.72	64.10	64.92
Mean	62.88	70.43	74.95	59.05	66.79	73.89	51.08	60.76	53.55	64.90

CD (P=0.05) Dates (D) : 1.33 Dates x Nitrogen (N x D) : 3.46
Nitrogen (N) : 2.99 Dates x Cultivars (D x Cv.) : 2.436
Cultivars (Cv.) : 1.99 Dates x Cultivars x Nitrogen (D x Cv x N) : 6.84
Cultivars x Nitrogen : 1.34

4.2.6 Crop growth rate (mg cm^{-2} day^{-1})

4.2.6a Before anthesis

The data on crop growth rate before and after anthesis for different varieties under different dates of sowing and in different cultivars are given table 4.2.6a and 4.2.6b respectively.

The 15th Oct. showed maximum crop growth rate before anthesis than other date of sowing. The cultivars WH-542 found to had minimum (8.55 mg cm^{-2} day^{-1}) crop growth rate while PBW-343 found to had maximum (9.52 mg cm^{-2} day^{-1}) crop growth rate. There was decrease in crop growth rate with decrease in nitrogen level from (N_{180} to N_{90}). The maximum crop growth rate (12.19 mg cm^{-2} day^{-1}) under 15th Oct. sowing at N_{180} nitrogen level followed by (10.52) under 15th Nov. at N_{120} level of nitrogen and (7.90) crop growth rate under 15th Dec. at N_{180} level of nitrogen.

4.2.6b After anthesis

Crop growth rate after anthesis was found to be maximum under 15th Oct. (9.27) sowing, then it starts with decreasing with delaying in sowing. Maximum crop growth rate was found in (7.95) in PBW-502 followed by (7.94) PBw-343, (7.90) PBE-550 and 7.80 WH-542. With increase in nitrogen level at each date of sowing crop growth rate increases with increase in nitrogen level irrespective of cultivars. Dates of sowing, varieties and nitrogen different significantly from each other. The decrease in crop growth with delay in sowing was also reported by Shivani *et al* 2003. Crop growth rate (mg cm^{2} day^{-1}) increased in response to nitrogen addition (Salvagiotti and Miralles 2008). The positive effect of nitrogen and sulphur on crop growth rate (Gracia *et al* 1988). As the stem elongation phase begins and, thereby, the crop grows at its maximum rate (Miralles and Slaffer 1997).

The crop before anthesis increased in response to N addition however the small impact of nitrogen on CGR after anthesis. This result is in conformatry with Salvagiotti and Miralles (2008). Crop biomass and crop growth rate are dependent on the ability of the canopy which is function of leaf area index, intercept incoming photosynthetically active radiation and radiation use efficiency (Smclain and Muchoo 1999). The relationship of light interception and crop growth to LAI was curvilinear functions (Williams and William 1968).

4.2.7 Ear : stem ratio at anthesis and maturity

The data on ear: stem ratio after anthesis and maturity for different varieties under different dates of sowing in different nitrogen level are given in Table 4.2.7a and 4.2.7b respectively.

The maximum ear: stem ratio at anthesis was (0.271) under 15th Nov. sowing in N_{120} nitrogen level. The nitrogen level N_{90} found to had maximum ear: stem ratio (0.199) under 15th Nov. followed by (0.181) under 15th Oct. and 15th Dec. sowing. The 15th Oct. sowing had (1.2%) more ear stem ratio while (3.3%) less ear stem ratio compare to 15th Nov. ear : stem

Table 4.2.6a Crop growth rate (mg cm^{-2} day^{-1}) before anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	9.46	11.8	12.3	7.6	11.6	10.2	7.2	8.3	7.2	9.52
PBW-502	9.53	12.1	12.8	7.7	10.06	9.7	7.0	6.9	8.3	9.40
PBW-550	9.91	10.9	12.3	6.9	10.7	10.3	6.6	7.5	8.2	9.14
WH-542	8.20	11.5	11.36	8.01	9.2	9.0	6.6	6.2	7.9	8.55
Mean	9.02	11.32	12.19	7.57	10.52	9.81	6.85	7.22	7.90	9.15

CD (P=0.05)

Dates (D) : 0.33

Nitrogen (N) : 0.35

Cultivars (Cv.) : 0.41

Cultivars x Nitrogen : 0.43

Dates x Nitrogen (N x D) : 0.71

Dates x Cultivars (D x Cv.) : 0.61

Dates x Cultivars x Nitrogen (D x Cv x N) : 0.85

Table 4.2.6b Crop growth rate after anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	7.7	8.9	9.6	7.6	9.6	8.9	6.7	6.6	7.9	7.94
PBW-502	8.1	8.9	9.1	7.1	8.8	8.7	6.7	6.9	7.3	7.95
PBW-550	8.0	9.3	8.9	7.3	8.8	8.7	6.4	6.7	7.0	7.90
WH-542	7.1	9.2	9.5	7.0	8.1	8.4	7.0	6.0	6.6	7.01
Mean	7.72	9.07	9.27	7.25	8.32	8.67	6.71	7.05	7.26	7.91

CD (P=0.05)

CD (P=0.05)	Dates (D)	: 0.42	Dates x Nitrogen (N x D)	: 0.03
	Nitrogen (N)	: 0.41	Dates x Cultivars (D x Cv.)	: 0.12
	Cultivars (Cv.)	: 0.11	Dates x Cultivars x Nitrogen (D x Cv x N)	: 0.09
	Cultivars x Nitrogen	: 0.14		

Table 4.2.7a Ear stem ratio at anthesis before anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	0.161	0.269	0.201	0.211	0.301	0.273	0.202	0.214	0.254	0.233
PBW-502	0.194	0.272	0.191	0.182	0.263	0.192	0.193	0.244	0.194	0.214
PBW-550	0.173	0.203	0.211	0.209	0.321	0.243	0.173	0.144	0.204	0.215
WH-542	0.192	0.271	0.191	0.201	0.191	0.233	0.154	0.204	0.184	0.202
Mean	0.181	0.269	0.199	0.199	0.271	0.235	0.191	0.202	0.209	0.216

CD (P=0.05)				
	Dates (D)	: 0.041	Dates x Nitrogen (N x D)	: 0.023
	Nitrogen (N)	: 0.038	Dates x Cultivars (D x Cv.)	: 0.039
	Cultivars (Cv.)	: 0.024	Dates x Cultivars x Nitrogen (D x Cv x N)	: 0.046
	Cultivars x Nitrogen	: 0.03		

Table 4.2.7b Ear stem ratio at maturity before anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	0.493	0.546	0.613	0.473	0.521	0.578	0.421	0.501	0.521	0.579
PBW-502	0.575	0.611	0.643	0.568	0.581	0.601	0.401	0.546	0.551	0.564
PBW-550	0.573	0.631	0.661	0.549	0.601	0.621	0.381	0.571	0.589	0.575
WH-542	0.499	0.569	0.601	0.466	0.543	0.581	0.371	0.521	0.561	0.520
Mean	0.535	0.589	0.630	0.514	0.562	0.595	0.379	0.543	0.556	0.545

CD (P=0.05)
Dates (D) : 0.029
Nitrogen (N) : 0.0028
Cultivars (Cv.) : 0.0038
Cultivars x Nitrogen : 0.012
Dates x Nitrogen (N x D) : 0.0009
Dates x Cultivars (D x Cv.) : 0.0093
Dates x Cultivars x Nitrogen (D x Cv x N) : 0.0046

ratio at anthesis decreases with delay in sowing from 15th Oct. to 15th Dec. sowing. Ear: stem ratio taken at maturity in four wheat cultivar under different dates of sowing and in different nitrogen level presented in table. Ear: stem ratio decreases under delayed sowing, as dry matter accumulation under delayed sowing get decreased. Partitioning of total dry matter into leaves, stem, roots and reproductive organ given a better indication of different functions of leaves and stem (Poorter and Nagel 2000). The N_{180} found to had maximum ear: stem ratio (0.130) at 15th Oct. sowing decreased as nitrogen level decreases from (0.630-0.535). The maximum ear: stem ratio found in cv. PBW-550 (0.575) followed by cv. PBW-502 (0.564), PBW-343 (0.519) and WH-542 (0.520). There was interaction between the dates of sowing varieties and nitrogen level. There was (32.55%) decrease in ear: stem ratio at maturity for 15th Dec. sowing at (N_{90}) nitrogen level and (4.80%) less in 15th Oct. compared to 15th Nov. sowing.

4.2.8 Grain filling rate (mg grain^{-1} day^{-1})

The grain filling rate (mg grain^{-1} day^{-1}) of different cv., different nitrogen level and under different dates of sowing are presented (Fig. 15,16 17 and 18).

Maximum grain filling rate (0.72) cv. PBW-550 followed by (0.67) PBW-502, (0.62), PBW-343 and (0.58) WH-542 at nitrogen levels. The maximum grain filling rate (0.76) at N_{180} nitrogen level followed by (0.62). N_{120} and (0.57) N_{90} levels of nitrogen for all the cultivars. This showed that there were significant effect nitrogen levels on all the cultivars (PBW-343, PBW-502, PBW-550 and WH-542). The grain filling rate decrease with delay in sowing for first (10 day) and after 10 days of anthesis for all the cultivars as the mean temperature (21.7°C) for 10 days after anthesis at 15th Dec. sowing, (20.1°C), 15th Nov. and (17.7°C) 12th Oct. sowing. There was sharp increase in grain filling rate as the grain filling rate proceeded to physiological maturity because the mean temperature rises from 21.8C to 23.23°C. The mean temperature (19°C), 15th Oct., (21°C) 15th Nov. and (22°C) 15th Dec. sowing for next 20 days after anthesis. The maximum grain filling rate (1.3) at N_{180} level at 15th Dec. sowing the corresponding mean temperature was (22°C) followed (1.1 mg grain^{-1} day^{-1}) 19°C at 15th Oct. of sowing. There is significant difference in grain filling rate in all the cultivars. The maximum grain filling rate was (1.27 mg grain^{-1} day^{-1}) cv. PBW-550 followed by (1.2) cv. PBW-502 and (1.12 mg grain^{-1} day^{-1}) cv. PBW-343 and PBW-542. The graphs depicted that wheat have an approximately linear grain phase that begins after anthesis and lost until grain filling is nearly complete (Sofied *et al* 1974). There ware considerable differences between cultivars not only in the rates of growth of their spikelet grains but also in the way these are influenced by environmental conditions (Sofield *et al* 1977). Growth rate per grain depends florets position within the ear, varied between cultivars and increased with rise in temperature (Sofield *et al* 1977). The grain filling rate maximum (1.83 mg grain^{-1} day^{-1}). 15th Dec. followed by (1.4) 15th Nov. and (1.08) 15th Oct. sowing.

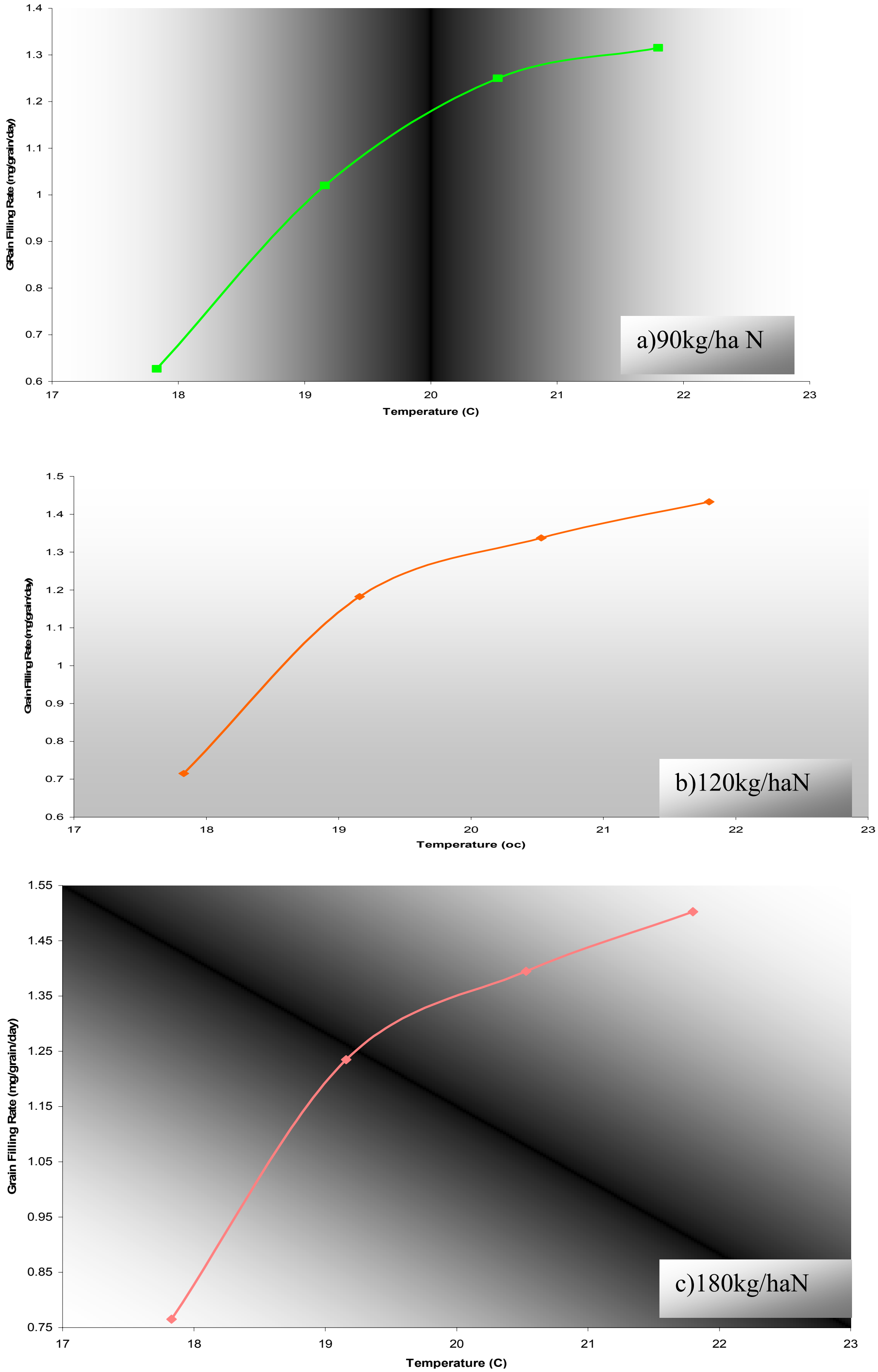
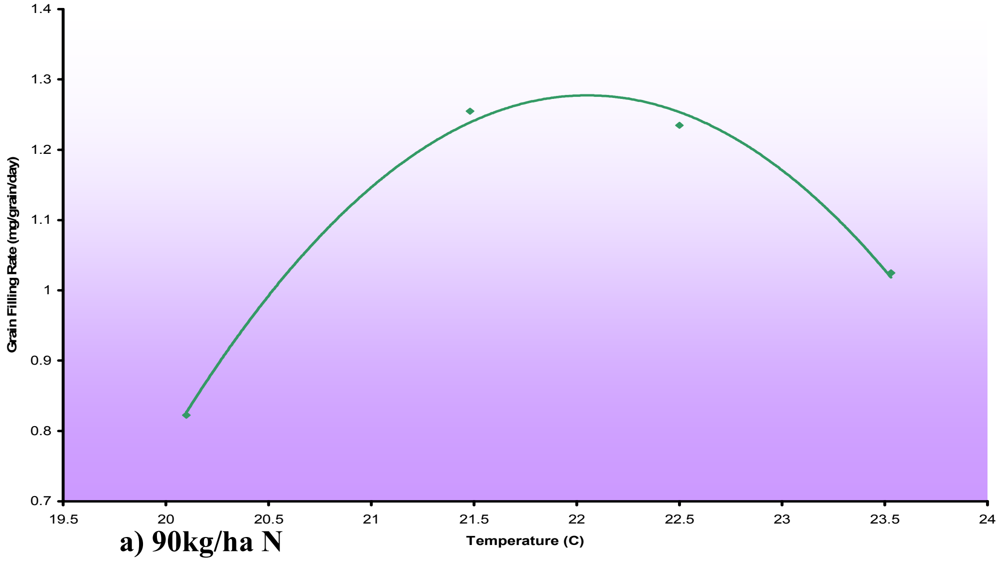
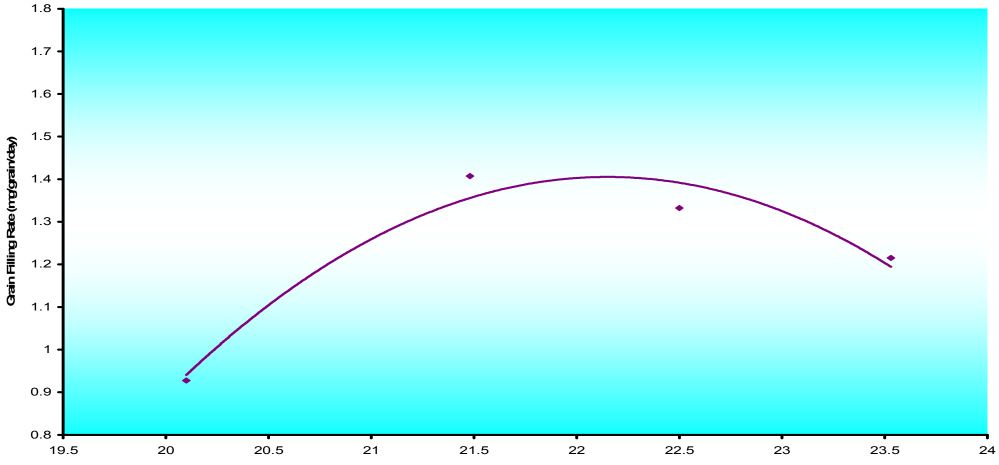


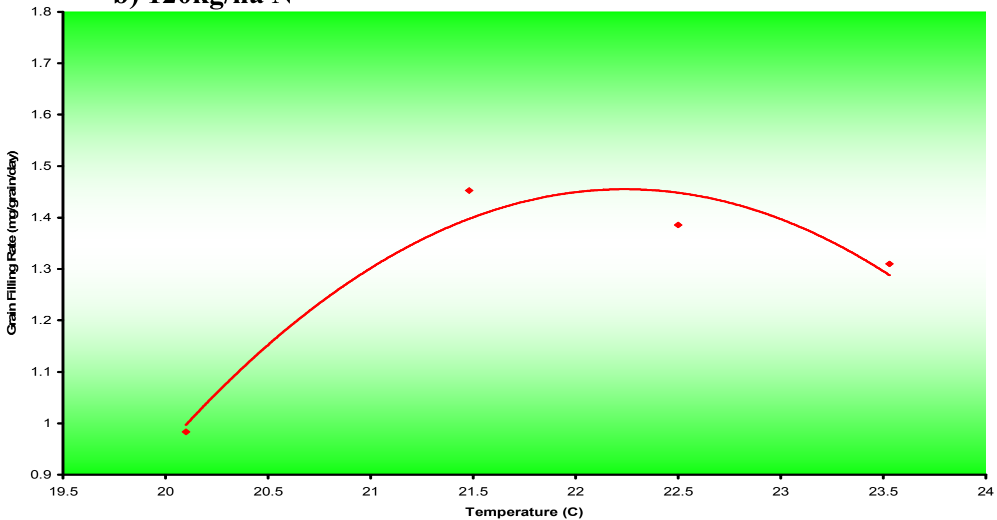
Fig. 15 **Relation ship between Grain Filling Rate and temperature (^{o}C) during grain filling period at 15th Oct. sowing for (a) 90 kg ha^{-1} (b) 120 kg ha^{-1} (c) 180 kg ha^{-1} in wheat cultivars**



a) 90kg/ha N



b) 120kg/ha N



c) 180kg/ha N

Fig. 16. Relation ship between Grain Filling Rate) and temperature (^{o}C) during grain filling period at 15th Oct. sowing for (a) 90 kg ha^{-1} (b) 120 kg ha^{-1} (c) 180 kg ha^{-1} in wheat cultivars

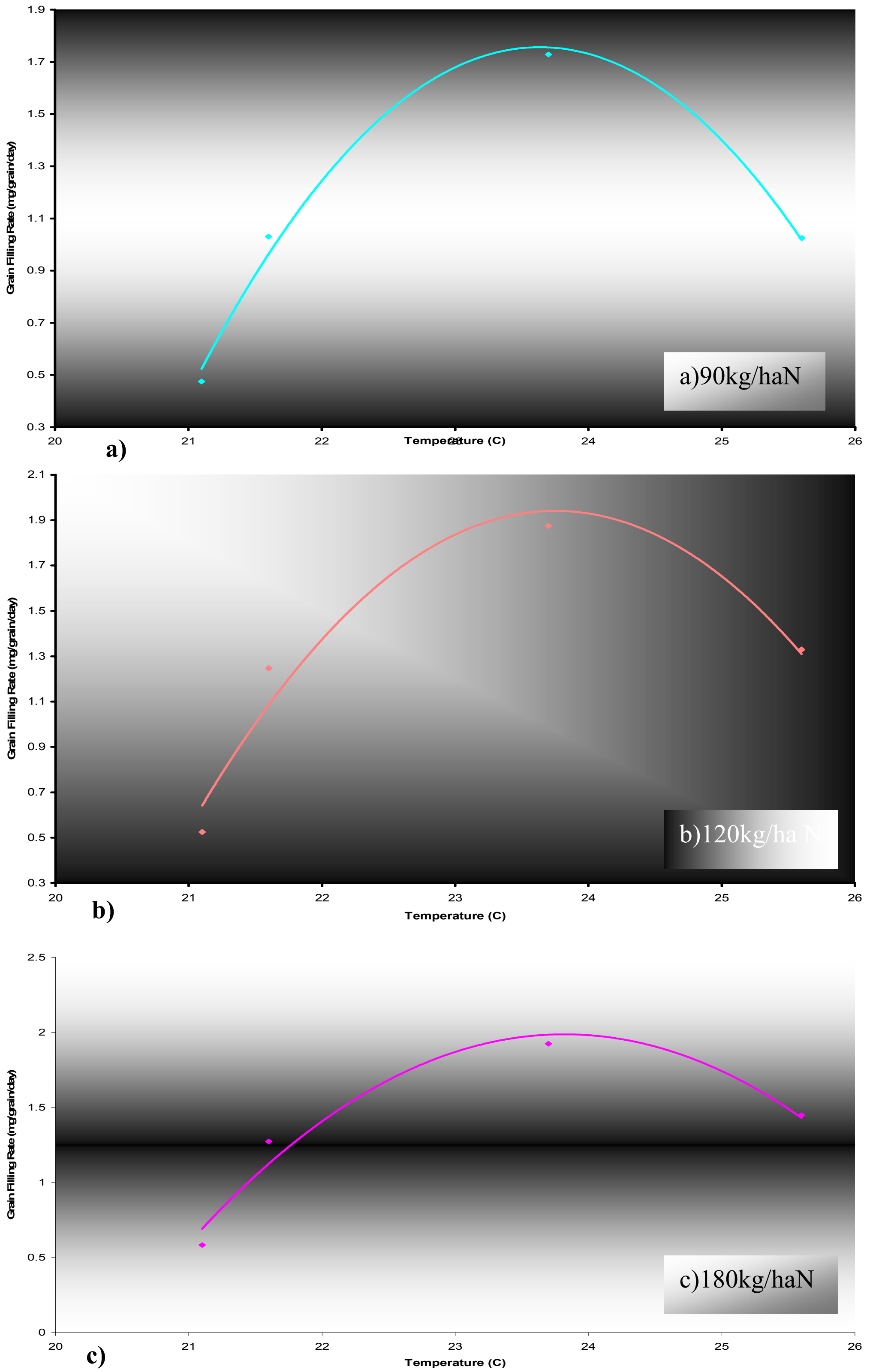
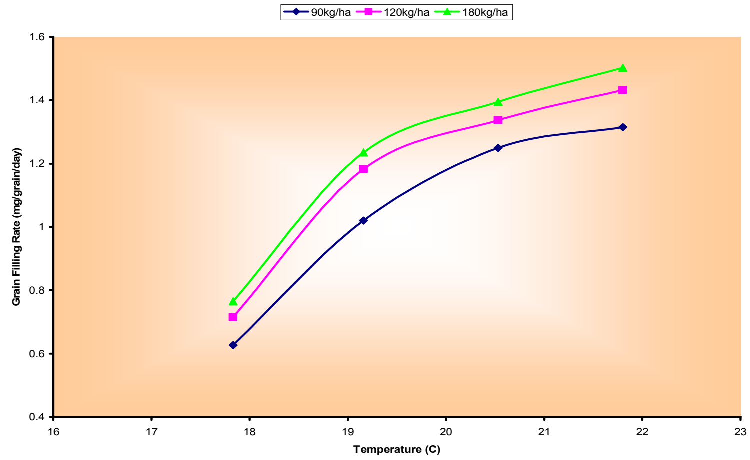
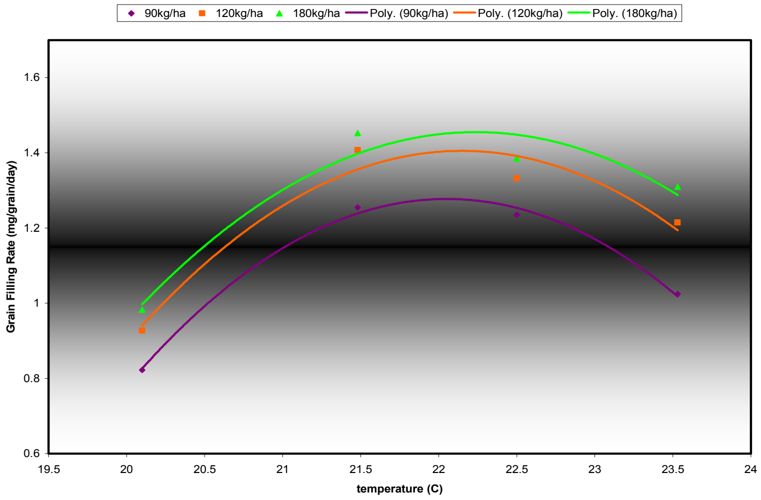


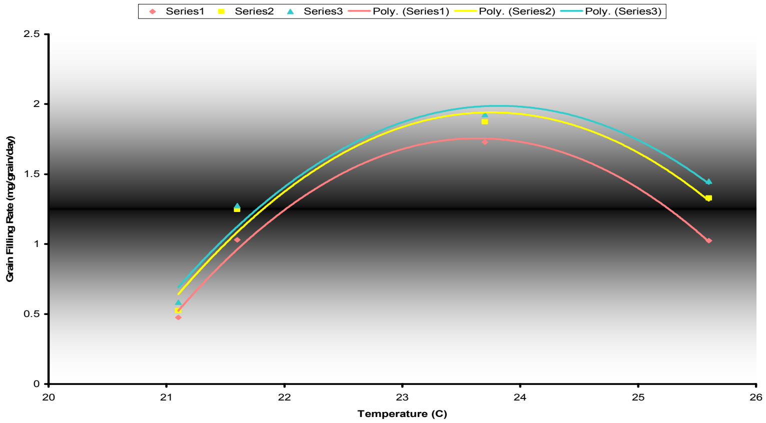
Fig. 17. **Relation ship between Grain Filling Rate and temperature (°C) during grain filling period four cultivars at 15th Oct. sowing for (a) 90 kg ha^{-1} (b) 120 kg ha^{-1} (c) 180 kg ha^{-1} in wheat cultivars**



a) 90 kg/ha N



b) 120kg/ha N



c) 180kg/ha N

Fig. 18. **Relationship between Grain Filling Rate and temperature (^{o}C) during grain filling period four cultivars at (a) 15th Oct. (b) 15th Nov. (c) 15th Dec. in wheat cultivars**

There was not significant interaction between cultivars under different dates of sowing. The effect of temperature on grain filling rate was similar on all cultivars (Sofield *et al* 1977). Maximum grain filling rate (1.8 mg grain^{-1} day^{-1}). N_{180} level of nitrogen followed by (1.5) N_{120} and (1.39 mg grain^{-1} day^{-1}) N_{90} of nitrogen levels. Throne *et al* (1968) examined day length and temperature effects on the vegetative, ear development and post period and found that grain weight was effected environmental differences in all periods. There was significant interaction between dates of sowing and levels of nitrogen after 30 days of anthesis. As the mean temperature (20°C) 15th Oct., (21.0), 15th Nov. and (23°C), 15th Dec. of sowing. The maximum grain filling rate (18) 15th Dec. followed by (1.4) 15th Nov. and (1.2 mg grain^{-1} day^{-1}) 15th Oct. of sowing. There was (33.33%) reduction in grain filling rate at (20°C) 15th Oct. as compared to mean temperature (23°C) 15th Dec. sowing. The graph showed. The wheat grain filling rate decreases as the mean temperature falls below 25°C. The result from data can be drawn that grain filling rate will better if the temperature fluctuation loss during the filling period.

4.2.9 Grain growth duration

The maximum grain growth duration (51.3 days) was found in 15th Oct. sowing at N_{180} and after that there was significant reduction with delay in sowing and decrease in nitrogen level. The average of growth duration of grain filling in wheat varieties under different dates of sowing in different nitrogen level are given in (Table 4.2.8.) The variety WH-542 had longest grain growth duration that is (48.2) days followed by PBW-550, PBW-502 and PBW-343. The difference between all varieties was significant. The maximum grain filling duration (50.2) at N_{180} level of nitrogen followed by (45.7) N_{120} and (43.4) days (N_{90}) levels of nitrogen at different levels of nitrogen grain filling duration for all varieties are not significantly varied. This is because the grain filling duration was influenced mainly mean temperature of that period (Slafer *et al* 1996, Randhawa *et al* 1992). Fig. 5 also showed that maximum grain filling duration (51.64) days mean temperature (20.97°C) followed by (46.12) days (22.62°C) and (41.52) days (23.65°C) mean temperature with the increase in temperature grain growth duration decreases with increase in temperature. The result showed that 1°C increase in temperature (2.56) days decrease in grain growth duration. Duration of grain filling is strongly responsibe to temperature, each degree rise increase in temperature during grain filling resulting a about 3 days decrease in duration of grain filling regardless of cultivars (Weigand and Cuellar *et al* 1981).(Fig 19)

4.2.10 Leaf area index

Data presentation in Table No. 4.2.9 showed significant reduction in leaf area index with delay in sowing from 15th Oct. to 15th Dec. The maximum leaf area index (3.30) was recorded in 15th Oct. at N_{180} level of nitrogen. The minimum leaf area index (1.85) was observed in case

Table 4.2.8 Grain growth duration in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	46.3	47.3	47.5	46.3	46.0	38.1	36.6	36.1	36.6	36.43
PBW-502	44.4	45.0	46.3	47.5	51.3	50.3	30.6	38.2	42.2	37.45
PBW-550	49.5	53.2	54.5	44.6	49.6	44.6	35.3	44.3	44.3	41.30
WH-542	42.5	42.3	43.3	51.4	40.3	54.4	38.3	48.6	48.6	45.16
Mean	45.65	46.95	47.90	47.45	46.80	46.85	35.21	41.82	49.25	39.97

CD (P=0.05)				
	Dates (D)	: 1.19	Dates x Nitrogen (N x D)	: 1.62
	Nitrogen (N)	: 0.98	Dates x Cultivars (D x Cv.)	: 1.54
	Cultivars (Cv.)	: 0.69	Dates x Cultivars x Nitrogen (D x Cv x N)	: 2.31
	Cultivars x Nitrogen	: 1.45		

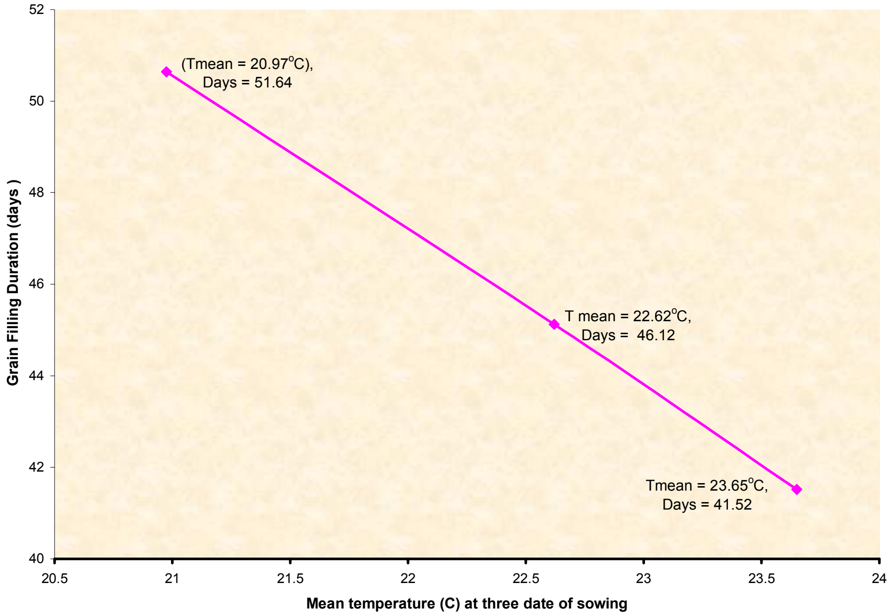


Fig.19 Influence of temperature on grain filling duration in the four cultivars under three date of sowing (15th Oct., 15th Nov. and 15th Dec. at three levels of nitrogen (N_{90}, N_{120} and N_{180}).

of 15th Dec. at N_{90} nitrogen level. The maximum leaf area index (2.87) of cv. PBW-550 followed by cv. PBW-343, PBW-502 and WH-542 (2.06). Significant reduction in leaf area index was reported in Table 4.2.9 There is direct relationship between nitrogen uptake and leaf area index during the vegetative stage growth period can thus explained by the fact that leaf area index expansion provide larger supply to root and also increases the nitrogen storage capacities within leave as Rubisco (Millard 1988, Lemaire *et al* 2007). The interaction of all varieties with nitrogen level under different dates of sowing showed the significant difference. Data showed as the level of nitrogen increases all dates of sowing (15th Oct. to 15th Dec.) the leaf area index was increased. There was (16.60%) decreased in leaf area index from 15th Oct. to 15th Dec. date of sowing at N_{90} level of nitrogen (33.33%) more leaf area index was observed at (2nd Oct.) at N_{180} level of nitrogen as compared to LAI of 15th Oct. and N_{90} nitrogen level.

4.3 YIELD AND YIELD CONTRIBUTING ATTRIBUTES

The important yield contributing attributes are discussed as under :

4.3.1 Effective tiller (m^{-2})
4.3.2 Grain spike weight ratio
4.3.3 Number of grain (m^{-2})
4.3.4 1000-grain weight
4.3.5 Root shoot ratio
4.3.6 Dry weight of spikes at anthesis

Table 4.2.9 Leaf area index in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	2.41	2.93	3.04	2.36	2.98	3.03	1.91	2.02	2.22	2.57
PBW-502	2.36	2.90	3.08	2.29	2.86	3.08	1.86	2.06	2.26	2.55
PBW-550	2.56	3.01	3.30	2.46	2.99	3.48	1.79	2.54	2.88	2.87
WH-542	2.01	2.56	2.91	2.00	2.03	2.65	1.86	2.04	2.06	2.20
Mean	2.23	2.90	3.35	2.27	2.71	3.06	1.85	2.16	2.20	2.54

CD (P=0.05)
Dates (D) : 1.34
Nitrogen (N) : 1.96
Cultivars (Cv.) : 1.21
Cultivars x Nitrogen : 1.40
Dates x Nitrogen (N x D) : 2.46
Dates x Cultivars (D x Cv.) : 0.91
Dates x Cultivars x Nitrogen (D x Cv x N) : 1.81

4.3.7 Biological yield (q/ha)

4.3.8 Grain yield (q/ha)

4.3.9 Harvest index (HI)

4.3.1 Effective tillers (m^{-2})

There was significant difference between dates of sowing as well as varieties and nitrogen level as far as number of spikes are concerned. Table No. 4.3.1 showed the decreased the number of spikes (m^{-2}) with delay in sowing and decrease in nitrogen level. There was (14.10%) reduction (15th Oct.) sowing as compared (18.49%) 15th Dec. number of spikes (m^{-2}). The (15th Nov.) sowing found to produce maximum no. of effective tillers (546.6) followed 15th Oct. (492.6) and 15th Dec. (406.6). The cv. PBW-343 produced maximum no. of effective tiller while WH-542 and PBW-550 less no. of effective tiller in each date of sowing in different level of nitrogen. The cv. showed significant interaction with level of nitrogen for production of effective tillers. There was (14.57%) increase in effective tillers at (N_{180}) followed decreased in (16.21%) as compared to N_{120} at 15th Oct. The number of effective tillers (477.9) at 15th Nov. followed (460.3) at 15th Oct. and (365.2) at 15th Dec. at nitrogen level (N_{90}). The data showed that the optimum date of sowing play important role in determining effective tillers which lead to increased in yield. The result showed that there was interaction between the nitrogen level and dates of sowing. The number of effective tiller increased significantly with the increasing level of nitrogen. The increase in number of effective tillers with increase in nitrogen level can be attributed to the reduction in mortality of tillers and enabling the production of more tiller from main stem. Akhtar *et al* (2006) reported that with delay in sowing no. of effective tillers decreased. Similar finding were reportedly Pradhavirs and Saini (1992) and Singh and Ahmad (1999).

4.3.2 Grain spike weight ratio

The cv. PBW-550 produced maximum (0.776) grain-spike ratio followed by PBW-343 (0.775), PBW-502 (0.769) and WH-542 (0.726) variety. Grain spike weight ratio of four wheat cultivars under three dates of sowing in different nitrogen level is presented in table No. 4.3.2. The grain spike ratio increase with rise in nitrogen level for particular date of sowing. Maximum grain spike ratio was produced (0.837) at N_{180} level of nitrogen for 15th Nov. of sowing. Significant difference was observed in varieties as well as dates of sowing and nitrogen level. Similar result was reported by Kanchan (2009).

4.3.3 Number of grains (m^{-2})

Average number of grains was found maximum in cv. WH-542 (47601) followed by cv. PBW-502 (396214), PBW-343 (39981) and PBW-550 (37451). The data showed that decreased in number of grain (m^{-2}) will delay in sowing in all cultivars at different nitrogen level. There were (13.8%) less number grain m^{-2} at 15th Oct. and (27.5%) reduction grain number (m^{-2}) under 15th Dec. sowing at normal level of nitrogen. The decrease in number of

Table 4.3.1 Effective tiller (m^{-2}) in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	457.2	481.3	528.3	541.6	548.4	520.6	378.2	422.2	456.1	481.5
PBW-502	497.2	426.6	512.4	496.0	533.4	580.4	366.1	425.0	410.2	412.0
PBW-550	458.6	500.6	606.7	434.6	523.5	576.4	313.4	38.6	390.6	466.2
WH-542	428.2	469.8	548.6	439.2	480.2	509.2	366.8	407.1	445.4	466.4
Mean	460.3	469.3	549.4	477.9	546.3	546.6	856.2	411.5	425.57	471.47

CD (P=0.05)				
	Dates (D)	: 29.77	Dates x Nitrogen (N x D)	: 32.8
	Nitrogen (N)	: 28.91	Dates x Cultivars (D x Cv.)	: 30.1
	Cultivars (Cv.)	: 15.8	Dates x Cultivars x Nitrogen (D x Cv x N)	: 19.4
	Cultivars x Nitrogen	: 18.4		

Table 4.3.2 Grain/spike weight ratio in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	**Dates of sowing**									**Mean**
	15th Oct.			**15th Nov.**			**15th Dec.**			
	N (kg ha^{-1})									
	90	**120**	**180**	**90**	**120**	**180**	**90**	**120**	**180**	
PBW-343	0.821	0.860	0.949	0.721	0.132	0.891	0.634	0.643	0.721	0.775
PBW-502	0.841	0.821	0.811	0.684	0.691	0.824	0.664	0.831	0.694	0.769
PBW-550	0.850	0.782	0.864	0.701	0.831	0.831	0.682	0.132	0.713	0.776
WH-542	0.729	0.813	0.832	0.641	0.763	0.801	0.601	0.704	0.651	0.726
Mean	0.810	0.819	0.879	0.687	0.784	0.837	0.645	0.728	0.695	0.762

CD (P=0.05)	Dates (D)	: 0.08	Dates x Nitrogen (N x D)	: 0.012
	Nitrogen (N)	: 0.003	Dates x Cultivars (D x Cv.)	: 0.021
	Cultivars (Cv.)	: 0.004	Dates x Cultivars x Nitrogen (D x Cv x N)	: 0.043
	Cultivars x Nitrogen	: 0.010		

Table 4.3.3 Number of grains (m^{-2}) in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	**Dates of sowing**									**Mean**
	15th Oct.			**15th Nov.**			**15th Dec.**			
	N (kg ha^{-1})									
	90	**120**	**180**	**90**	**120**	**180**	**90**	**120**	**180**	
PBW-343	25800	34011	48600	35000	41750	66675	30214	26080	33733	37981
PBW-502	29300	36300	66960	33454	43250	56400	24780	26020	36500	39214
PBW-550	28880	31305	51900	39250	35050	64200	27217	27345	32000	37457
WH-542	37600	49960	61500	34633	56250	5800	41466	48250	40750	47601
Mean	30387	37894	57240	35584	44075	61318	30911	31916	35745	40563

CD (P=0.05)				
	Dates (D)	: 30.10	Dates x Nitrogen (N x D)	: 36.78
	Nitrogen (N)	: 22.72	Dates x Cultivars (D x Cv.)	: 35.39
	Cultivars (Cv.)	: 24.89	Dates x Cultivars x Nitrogen (D x Cv x N)	: 30.41
	Cultivars x Nitrogen	: 30.61		

grains might be due to the fact that with delay in sowing temperature starts rising and it forces the grain development which ultimately lead to fall in grain number higher nitrogen level increase the grain number by increasing the availability of nutrient under all dates of sowing.

4.3.4 1000-grain weight

Grain yield is more influenced by 1000 grain weight. Table No. 4.3.4 showed variation in 1000 grain weight under different dates of sowing from 15th Oct. to 15th Dec. The date revealed that maximum 1000 grain weight (46.8 g) was observed that 15th Oct. sowing followed by 15th Nov. (42.0) and 15th are (33.7) at nitrogen level (N_{180}). Nitrogen level differed significantly for all cultivars at all dates of sowing. There was (17.9%) reduction in two grain weight at 15th Dec. as compared to 15th Nov. sowing. The maximum reduction (7.1%) compared to normal sowing 15th Oct. at N_{90} level of nitrogen similar result was found in 15th Nov. and 15th Dec of sowing. Similar results were reported by Singh *et al* (2005).

Lower kernel weight of heat stress wheat is due to reduction in duration rather than reduction in the rate of grain growth. Heat stress during grain filling hasten the maturity of crop inspite of higher level of nitrogen, resulting in small, this shunken grain (Nainwal and Singh 2000).

4.3.5 Root shoot ratio

The root shoot-ratio decreases with delay in sowing as the maximum 15th Nov. (0.190) followed by (0.168), 15th Oct. and (0.156) 15th Dec. There was interaction between nitrogen and dates of sowing as maximum root shoot ratio at N_{180} (0.189) followed by (0.177) N_{120} and (0.148) N_{90}. The data also showed the significant interaction between dates of sowing and cultivars the maximum root shoot ratio (0.190) 15th Nov., followed by (0.168) 15th Oct. and (0.156) 15th Dec. sowing. The data in table showed that there is interaction between the nitrogen level and cultivars. Maximum root shoot ratio in cv. PBW-343 (0.179), followed by PBW-502 (0.172), PBW-550 (0.169) and WH-542 (0.166). Maximum root shoot ratio and N_{120} level (0.189) followed by (0.177) N_{120} and (0.148) N_{90} level of nitrogen Table No. 4.3.5.

4.3.6 Dry weight of spikes at anthesis

The data on dry weight of spikes at anthesis in different wheat varieties under different date of sowing and different nitrogen levels are presented in Table No. 4.3.6.

The maximum dry weight of spikes (m^{-2}) at anthesis observed (705.5 g) at N_{180} followed by (659.0 gm) N_{120} and (500.7 g) N_{90}. The data showed with delay in sowing dry weight of spikes (m^{-2}) at anthesis decreases. Maximum was observed (759.2 g) at 15th Oct. (651.0) 15th Nov. and (455.0) 15th Dec. of sowing. The data also showed the significant relationship between date of sowing and varieties. The maximum dry weight of spike (m^{-2}) at anthesis was (663.5) PBW-343 followed by (656.1 g) PBW-550, (606.6 g) PBW-502 and (560.7 g) WH-542 variety. There was (14.22%) increase dry weight of spike at 15th Oct. and (30.10%) decrease in dry weight of spike (m^{-2}) at anthesis at 15th Dec. sowing as compared to

Table 4.3.4 1000 grain weight in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	45.1	43.1	50.3	37.1	39.1	42.7	33.0	31.3	33.1	38.97
PBW-502	40.1	41.73	46.5	38.3	42.6	44.6	31.8	29.8	36.3	38.92
PBW-550	38.1	47.6	49.4	36.9	38.3	42.6	33.8	31.9	31.9	38.98
WH-542	38.0	38.7	41.2	32.5	36.2	38.9	33.6	34.4	31.3	35.67
Mean	40.3	43.1	46.8	36.1	39.05	42.0	29.2	32.3	33.7	38.1

CD (P=0.05)

Dates (D) : 1.71
Nitrogen (N) : 1.04
Cultivars (Cv.) : 1.84
Cultivars x Nitrogen : 1.48

Dates x Nitrogen (N x D) : 1.24
Dates x Cultivars (D x Cv.) : 2.15
Dates x Cultivars x Nitrogen (D x Cv x N) : 3.12

Table 4.3.5 Root shoot ratio in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	0.1391	0.1641	0.2264	0.1688	0.2291	0.2374	0.1481	0.1787	0.1463	0.179
PBW-502	0.1461	0.1561	0.2047	0.1676	0.2347	0.1704	0.1604	0.1614	0.1918	0.172
PBW-550	0.1348	0.1616	0.1819	0.1730	0.1962	0.1946	0.1446	0.1541	0.1848	0.169
WH-542	0.1522	0.1684	0.1810	0.1782	0.1698	0.2011	0.1978	0.1584	0.1840	0.166
Mean	0.142	0.163	0.198	0.172	0.206	0.192	0.129	0.162	0.177	0.171

CD (P=0.05)

Dates (D) : 0.02

Nitrogen (N) : 0.03

Cultivars (Cv.) : 0.06

Cultivars x Nitrogen : 0.08

Dates x Nitrogen (N x D) : 0.19

Dates x Cultivars (D x Cv.) : 0.07

Dates x Cultivars x Nitrogen (D x Cv x N) : 0.23

Table 4.3.6 Dry weight of spikes m^{-1} at anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	745.3	795.9	884.5	541.2	714.5	888.8	341.6	488.2	512.8	663.5
PBW-502	557.5	825.0	669.3	496.6	689.1	706.6	467.2	507.54	540.7	606.6
PBW-550	609.3	965.3	995.2	523.6	711.1	723.4	345.5	402.3	519.5	656.1
WH-542	536.4	706.6	820.2	478.5	639.5	669.4	366.3	372.3	457.2	560.7
Mean	612.2	823.5	842.3	509.9	696.2	747.0	380.1	457.7	527.2	621.7

CD (P=0.05)
Dates (D) : 20.54
Nitrogen (N) : 19.56
Cultivars (Cv.) : 39.56
Cultivars x Nitrogen : 30.43
Dates x Nitrogen (N x D) : 51.4
Dates x Cultivars (D x Cv.) : 48.6
Dates x Cultivars x Nitrogen (D x Cv x N) : 40.46

15th Nov. sowing. The interaction between nitrogen and cultivar also showed significant relationship. The maximum dry weight spike (m^{-2}) at anthesis was (705.5 g) at N_{180} followed by (639.0) N_{120} and (800.7 gm) at N_{90} level of nitrogen. The cv. difference was observed. From above result we can say that there was sowing interaction between nitrogen, level, cvs. and dates of sowing for dry weight of spike (m^{-2}) at anthesis.

4.3.7 Biological yield (q/ha)

There was significant reduction in biological yield with decrease in nitrogen level. The maximum biological yield was observed (168.0 q ha^{-1}). at N_{180} followed (181.2 q ha^{-1}) N_{120} and (141.7 q ha^{-1}) at N_{90} level of nitrogen. The biological yield decrease with delay in sowing as the maximum biological yield at (166.2 q ha^{-1}) at 15th Oct. followed by (162.6 q ha^{-1}) 15th Nov. and (138.6 q ha^{-1}) at 15th Dec. sowing. The table 4.3.7 revealed that there is interaction between the variety and dates of sowing with delay in sowing. Biological material decreases by (14.73%) from normal sowing. The data also revealed that there was interaction between levels of nitrogen and cultivars. The maximum biological yield was (162.1 q ha^{-1}) PBW-343 followed by (160.2 q ha^{-1}) PBW-343, (153.0 q ha^{-1}) WH-542 and (146.4 q ha^{-1}) PBW-550 variety. Similar result was found by Dogiwal *et al* (2004). The above result revealed that there is strong interaction between dates of sowing, cultivars and level of nitrogen for biological material.

4.3.8 Grain yield (q ha^{-1})

The significant reduction in grain yield was seen with delay in sowing at three different levels of nitrogen. There was (26.78%) decrease in grain yield from 15th Nov. of sowing. There was 14.99 per cent increase in yield with N_{180} level of nitrogen (17.66%) decrease in yield with N_{90} level of nitrogen from N_{120} (normal). There was also interaction between varieties and dates of sowing. Maximum grain yield (56.29 q ha^{-1}) at Nov. followed by (54.80 q ha^{-1}) and (41.80 q ha^{-1}) at 15th Dec. sowing. The data in table 4.3.8 also revealed that there was interaction between nitrogen level and variety for grain yield. The maximum grain yield (60.0 q ha^{-1}) at N_{180} followed by (51.2 q ha^{-1}) N_{120} and (42.4 q ha^{-1}) N_{90} level of nitrogen.The interaction between dates of sowing, varieties and nitrogen level found to be significant our finding are in confermity with Dhaliwal *et al* (2006) and Kalra *et al* (2008).

4.3.9 Harvest Index

The dates of sowing varieties and nitrogen level differed significantly from each other as far as harvest index was concerned in table No.4.3.9.

The maximum harvest index was observed (33.4%) N_{80} followed (32.4%) N_{120} and (31.0%) at N_{90} level of nitrogen maximum harvest index was observed (33.8%) 15th Nov. followed (32.7%) 15th Oct. and (30.2) 15th Dec. sowing. Dates of sowing and cultivars showed significant interaction. The cv. PBW-343 had found to maximum harvest index (33.3) PBW-550 followed by (31.8%) PBW-343 and WH-543 and (32.3%) PBW-502. There

Table 4.3.7 Biological yield (q/ha) at anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	**120**	**180**	**90**	**120**	**180**	**90**	**120**	**180**	
PBW-343	160.4	170.8	184.0	138.9	176.6	188.8	128.4	144.1	148.9	160.1
PBW-502	180.3	171.0	225.0	157.6	172.3	171.3	121.0	141.3	151.5	162.4
PBW-550	129.6	159.1	169.4	132.0	162.1	181.6	122.3	127.2	162.4	146.3
WH-542	143.0	164.0	168.3	143.3	182.4	174.1	123.8	145.1	120.0	153.4
Mean	145.80	166.20	186.6	142.9	165.9	179.0	1326.5	139.4	138.5	155.62

CD (P=0.05)				
	Dates (D)	: 48.71	Dates x Nitrogen (N x D)	: 74.9
	Nitrogen (N)	: 61.2	Dates x Cultivars (D x Cv.)	: 12.98
	Cultivars (Cv.)	: 35.62	Dates x Cultivars x Nitrogen (D x Cv x N)	: 20.46
	Cultivars x Nitrogen	: 24.36		

Table 4.3.8 Grain yield (q/ha) at anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	43.8	60.1	66.0	45.0	56.7	64.6	35.11	42.6	49.3	51.4
PBW-502	46.3	58.7	63.98	48.2	56.5	66.0	35.0	43.5	51.2	52.1
PBW-550	43.2	51.3	62.8	48.5	55.55	69.0	37.0	41.3	51.1	51.0
WH-542	44.6	55.2	62.5	47.4	53.3	64.8	35.4	40.5	49.7	50.3
Mean	44.4	56.3	63.8	47.2	55.5	66.1	35.6	41.9	50.2	51.6

CD (P=0.05)

Dates (D) : 35.6

Nitrogen (N) : 11.05

Cultivars (Cv.) : 12.14

Cultivars x Nitrogen : 16.3

Dates x Nitrogen (N x D) : 25.7

Dates x Cultivars (D x Cv.) : 24.1

Dates x Cultivars x Nitrogen (D x Cv x N) : 30.46

Table 4.3.9 Harvest index HI (%) at anthesis in wheat cultivars under different dates of sowing and nitrogen levels

Cultivar	Dates of sowing									Mean
	15th Oct.			15th Nov.			15th Dec.			
	N (kg ha^{-1})									
	90	120	180	90	120	180	90	120	180	
PBW-343	27.83	35.1	35.8	32.1	32.1	34.2	31.2	29.5	33.1	31.8
PBW-502	30.8	34.3	28.3	31.8	32.7	35.8	31.4	30.8	33.1	32.3
PBW-550	33.4	32.2	37.0	36.7	34.1	37.9	30.2	32.3	23.0	33.00
WH-542	31.2	33.6	38.9	33.0	34.4	37.2	28.5	27.9	27.8	31.8
Mean	29.0	33.8	35.0	33.4	33.3	34.7	30.3	30.1	30.2	32.2

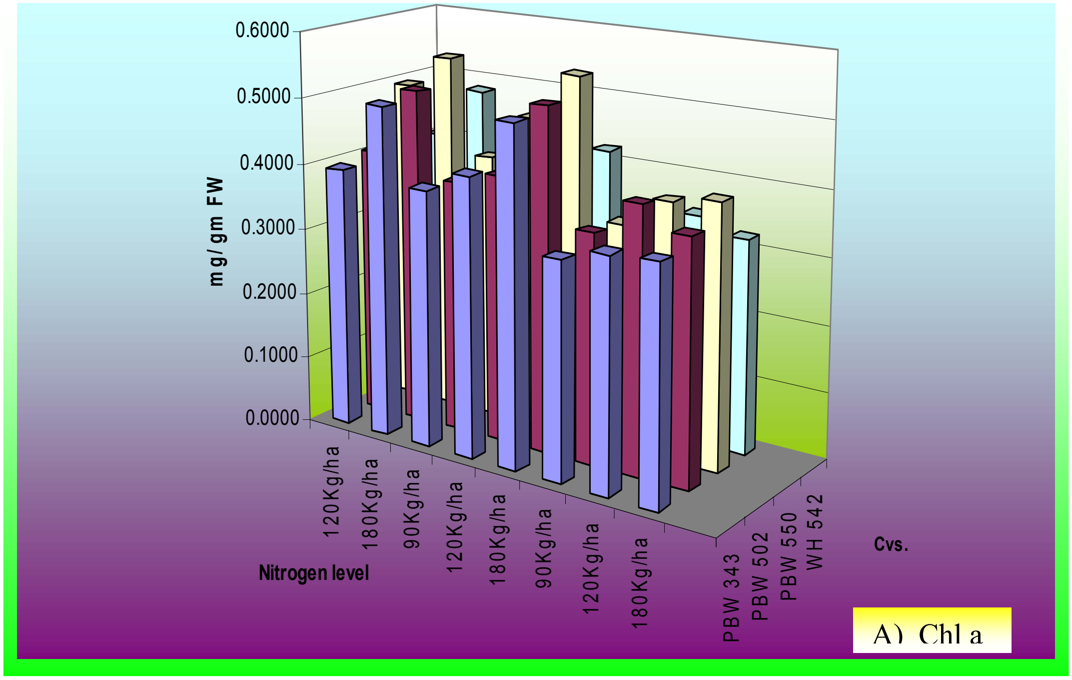
CD (P=0.05)	Dates (D)	: 3.5	Dates x Nitrogen (N x D)	: 4.3
	Nitrogen (N)	: 17.3	Dates x Cultivars (D x Cv.)	: 15.4
	Cultivars (Cv.)	: 7.8	Dates x Cultivars x Nitrogen (D x Cv x N)	: 18.48
	Cultivars x Nitrogen	: 6.4		

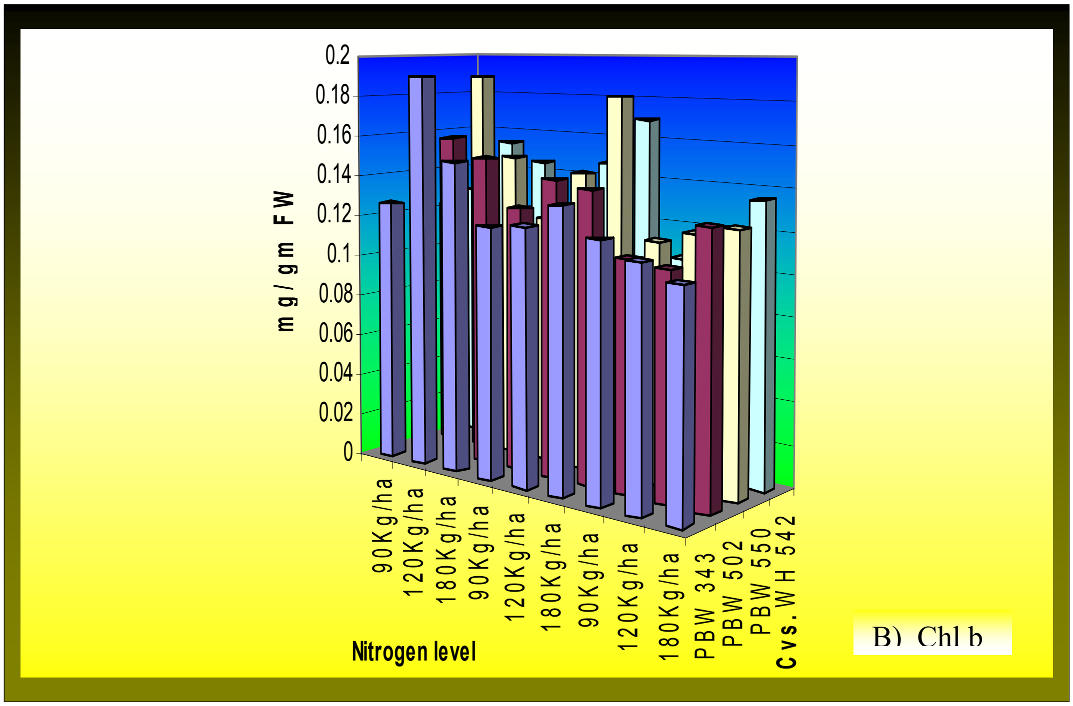
was (6.6%) decrease in harvest index from normal level of nitrogen. The above interaction showed positive significant relationship. Sharma Natu *et al* (2006) suggested that decrease in (HI) occurred because grain mass was more affected than biomass under delayed sowing.

4.4 BIOCHEMICAL ANALYSIS

The maximum chlorophyll a content was observed at (N_{180}) level of nitrogen for cv. PBW-550 followed PBW-502, PBW-343 and WH-542. The increase in nitrogen level the chlorophyll content will increase by (40%) at 15th Oct. as compared to 15th Dec. of sowing same tend has been shown by all cvs at all nitrogen under different dates of sowing similar result by Kanchan (2009). Whereas maximum chlorophyll b at N_{120} for 15th Oct. of sowing.

The chlorophyll b content also very amongs cultivars the maximum chl-b content was observed in cv. PBW-550 (0.16 mg/g FW) at N_{120} nitrogen level for 15th Nov sowing. The graph showed there was strong interaction between dates of sowing at different nitrogen level for all the cultivars for Chl-b at milky stage high nitrogen content might increase the chlorophyll content which also increase the leaf area index as well as with leaf duration. This lead to increase in yield of wheat cv. at all nitrogen levels. Total chlorophyll content was maximum in (0.72 mg/g FW) PBW-550 at N_{180} under 15th Nov. of sowing as compared (0.07 mg/g FW) at N_{180} under 15th Nov. of sowing. There was variation in total chlorophyll for all the air at different nitrogen level under different date of sowing Fig 20.





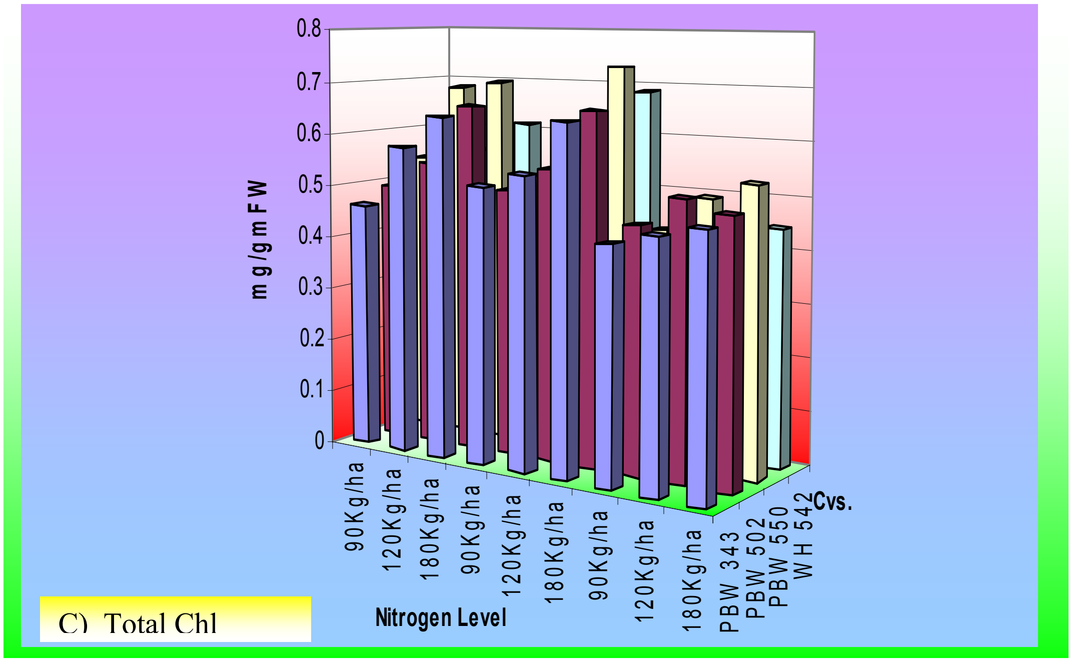


Fig. 20 Chlorophyll a (A) and Chlorophyll b (B) and Total chlorophyll in wheat cultivars under different nitrogen levels for different cultivars at milky ripe stage

4.5 CERES-Wheat AND INFOCROP CALIBRATION AND VALIDATION OF MODELS

4.5.1 Calibration

The calibrated genetic coefficient as derived by Gencale for CERES-Wheat and Infocrop are given in Table 4.5.1 and 4.5.2. Only CERES-Wheat model simulated the grain yield satisfactorily but biomass, leaf area index, grain yield are not satisfactorily simulated by Infocrop model.

Table 4.5.1 Genetic coefficient for different wheat cultivars by using CERES-Wheat model 4.0.1.0 (data pooled for 2 years)

Genetic coefficient	PBW343	PBW502	PBW550	WH 542
Days to optimum Vernalising (PIV)	0	0	0	0
Photoperiodic Coefficient (PID)	3.19	3.31	3.02	3.7
Grain Filling Coefficient (P5)	750.6	805.6	780.8	854.1
Kernel Number Coefficient (G1)	22	23	22.3	25
Kernel Weight Coefficient (G2)	45	45	47	40
Spike Number Coefficient (G3)	1.54	1.94	1.5	1.54
Phyllochron index (PHINT)	89.5	83.4	78.4	96.3

Table 4.5.2 Genetic coefficient for different wheat cultivars by using Infocrop model

Sr. No.	Genetic Coefficient	PBW343	PBW502	PBW550	WH 542
1	Sowing to Germination	109.8	102	95	110
2	Germination to 50% flowering	1213	1178.5	1009	1013
3	50% flowering to physiological maturity	702	752	660	823
4	Relative Growth Rate	0.0075	0.0078	0.008	0.0076
5	Specific Leaf Area	0.0023	0.0023	0.0025	0.002
6	Index Of Green ness	1	1	1	1
7	Extinct Coefficient of Leaves at Flowering	0.6	0.6	0.6	
8	Radiation Use Efficiency	2.8	2.8	2.8	2.8
9	Root Growth Rate	30	30	30	30
10	Sensitivity of Crop to Flooding	1	1	1	1
11	Index of N Fixation	1	1	1	1
12	Slope Of Storage Organ Number/m2 to Dry Matter During Storage	28000	28000	28000	29000
13	Potential Storage Organ Weight	40	38	42	34.5
14	Nitrogen Content Of Storage Organ	0.0203	0.002	0.025	0.019

Required crop genetic inputs are PHINT (thermal time between the appearance of leaf tips), G3 (tiller death coefficient), G2 (potential kernel growth rate), G1 (kernel number per unit weight of stem+ spike at anthesis), P5 (thermal time from the onset of linear fill to maturity), P1D(Photoperiod sensitivity coefficient), P1V (vernalization sensitivity coefficient). Management input information includes plant population, planting depth, and date of planting. Latitude is required for calculating day length. The model simulates phenological development, biomass accumulation and partitioning, leaf area index, root-, stem-, and leaf-growth and the water- and N-balance from planting until harvest at daily time steps

Table 4.5.3 Calibration result for CERES- wheat and Infocrop model

Sr. No	**Variables**	**CERES-Wheat**		**Infocrop**	
		Observed	**Predicted**	**Observed**	**Predicted**
1	Anthesis (Days)	118 (GDD =1401)	116 (GDD =1377)	118 (GDD=1401)	101 (GDD =1046)
2	Physiological maturity (Days)	160 (GDD =2126	158 (GDD =2031)	160 (GDD =2126)	154 (GDD =1937)
3	Maximum leaf area index	2.68	2.86	2.86	1.68
4	Leaf number	12	13	12	16
5	Effective tiller	745	765	745	
6	Grain number	56245	68794	56245	
7	Grain Duration Days	48	53	48	46
8	1000 Grain weight	41	43	41	42
9	Total dry matter (kg/ ha)	16171	17894	16971	
10	Grain yield (kg/ ha)	6315	6505	6315	
11	Harvest index	0.34	0.36	0.34	0.32

The calibearated genetic coefficient Cv. PBW -343, PBW- 502, PBW -550 and WH-542 are derived by adjusting variables as under given in the table for the CERES-Wheat and Infocrop models for the validation of the models The CERES-Wheat model was calibrated and evaluated for spring wheat under Punjab environmental conditions, for which it had been evaluated. Studies with similar purposes have already been carried out in neighboring countries in the Mediterranean (Pecetti and Hollington, 1997; Rinaldi, 2004; Heng *et al* 2007; Ouda *et al* 2005).

The model correctly predicted the ranking of cultivars in terms of grain yield the field trials. In the remaining year, it could only partly render the differences between cultivars, and this limitation could not be overcome by a recalibration of genetic coefficients A more robust determination of these parameters may have been achieved by using several experimental sites rather than only one.

In the future, the model may be used as a management tool to determine an optimum planting date or cultivar choice, taking into account the variability of weather and the associated yield loss risks. It may also be used to predict crop performance in regions where the crop has not been grown before, by predicting probabilities of grain yield levels for a given soil type and rainfall distribution. Such analysis may be carried out to evaluate the effect of global climate change on crop production. Assessing such effects is important at the producer as well as at the government level for planning purposes, and models such as DSSAT are expected to play a major role in that area.

4.5.2 Validation

- Phenological phase
- Growth parameters
- Yield and yield attributes characteristics

The phenological phases

Three different phenological phase seedling emergence seedling emergence to anthesis and anthesis to maturity. The growing degree days simulated for seedling emergence (90 GDD as against observed 92 GDD seedling emergences to anthesis (1209 GDD as against observed 1269 GDD) and physiological maturity (704 GDD against observed 720 GDD). Simulated phenology of different cultivars varied sowing dates matched well with observed value with RMSE value to 2.0, 3.6 and 4.0 for seedling emergence, anthesis and anthesis to physiological maturity respectively. But phenological stages were not simulated satisfactorily for infocrop model.

Growth parameters

The growth parameters simulated leaf number, crop growth rate before anthesis and maturity, grain filing rate, grain duration, well matched with observed value with RMSE value of 1.2, 1.3, 1.4, 0.7, and 1.7, respectively.

As biomass partitioning at 15 days of intervals is under estimated. Therefore, components of biomass were just further analysed to study which component was no simulated as expected. Both the models infocrop and CERES-Wheat model under estimated with RMSE value of 4.4 and 3.9 respectively. Pre-anthesis dry matter production that plant biomass at anthesis and maturity are also under estimated by infocrop model a compared to CERES-Wheat model. The RMSE value of Inforcrop (16.3 and 39.7), CERES-Wheat (2.6

and 11.2) respectively for plant biomass (at anthesis and maturity).

Yield and yield attributing characteristics

Effective tillers

Effective tillers matched well with CERES-Wheat model with RMSE value of (5.8) whereas Inforcrop was not able to predict accurated. Number of effective tiller (m^{-2}) with RMSE of value (110.0).

Number of grains

The number of grains simulated by CERES-Wheat are overstimulated as compared to observed with root mean squares errors value of (10.4) whereas similar trend is shown by infocrop model having root mean square error value of (283.3).

1000-grain weight

The simulated weight of 1000-grain was well matched observed value for both the models with RMSE value of 1.9 and 2.5, CERES-Wheat and infocrop respectively. Biological yield simulated by infocrop and CERES-Wheat with root mean square error value of 6.5 and 4.8. Simulated biological yield was much lower than observed value. Saseendran *et al* (2004) reported that CERES-Wheat model resulted the under estimation of the biomass.

Grain yield

Grain yield simulation showed that simulated values are well matched with observed value with root mean square error value of (1.2). The Bannyan *et al* (2003) and Jemieson *et al* (1998) reported good accuracy for simulated grain yield and larger error for simulated biomass production prediction by CERES-wheat model.

4.6 REGRESSION EQUATIONS

The regression equations in wheat are discussed under the following headings

4.6.1 Dates of sowing and grain yield

4.6.2 GDD and grain yield

4.6.3 Nitrogen and grain yield

4.6.4 Multiple regressions

4.6.1 Date of sowing and grain yield

Linear regression equation indicating no. of day's data pooled over four varieties and three nitrogen levels were decreased for finding the yield based on the number of days taken for achieving particular growth stages. Regression analysis indicated a significant positive correlation between grain yield and dates of sowing during crown root initiation (R^2 = 0.98).

Table 4.5.4 Statistical indices derived from the validation of CERES- wheat and infocrop models in predicting the phonological sategs, growth parameters and yield and yield contributing attributes.

	CERES -Wheat				Infocrop model			
Phenological stages	**Observed**	**Simulated**	**MAE**	**RMSE**	**Observed**	**Simulated**	**RMSE**	**MAE**
Sowing to Seedling emergence	92.0	90.0	2.0	2.0	92.0	70.0	4.6	22.0
Seedling emergence to anthesis	1269.0	1256.0	13.0	3.6	1269.0	1170.0	9.9	99.0
Anthesis to maturity	720.0	704.0	16.0	4.0	720.0	813.0	9.6	-93.0
Growth Parameters								
Leaf number	12.0	13.6	1.6	1.2	12.0	16.0	2.0	4.0
Dry matter plant basis (gm)	70.5	73.2	2.6	1.6	70.5	55.1	3.9	15.4
Crop Growth rate at anthesis (mg /day /m^2)	12.5	14.3	1.8	1.3	12.5	9.4	1.7	3.0
Crop growth rate at maturity (mg/day /m^2)	8.2	10.4	2.2	1.4	8.2	7.1	1.0	1.1
Ear:stem ratio at anthesis	0.2	NS	NS	NS	NS	NS	NS	NS
Ear:stem ratio at maturity	4.5	NS	NS	NS	NS	NS	NS	NS
Grain filling rate (mg/grain/day)	1.1	1.7	0.6	0.7	1.1	1.0	0.4	0.2
Grain duration	45.0	42.0	3.0	1.7	45.0	43.0	1.4	2.0
Plant biomass at anthesis (g/m^2)	2142.0	2214.0	72.0	2.6	2142.0	1425.0	26.3	717.0
Plant biomass at maturity (g/m^2)	4125.0	4251.0	126.0	11.2	4125.0	2541.0	39.7	1584.0
Grain spike ratio	0.9	-	-	-	-	-	-	-
Dry weight of spikes (g/m-)	745.0	-	-	-	-	-	-	-
Yield and yield attributing characteristics								
Effective tillers (m-2)	533.0	566.0	33.0	5.8	533.0	423.0	10.4	110.0
Root shoot ratio	0.2	-	-	-	-	-	-	-
Number of grains (m-2)	43250.0	46897.0	3647.0	60.3	43250.0	123546.0	283.3	80296.0
1000 grain weight	42.6	44.5	1.9	1.3	42.6	45.1	1.5	2.5
Biological yield	225.2	245.5	20.2	4.5	225.2	147.2	8.8	78.0
Grain yield	57.1	58.7	1.5	1.2	57.1	43.6	3.6	13.6
Harvest index	33.3	32.1	1.2	1.1	33.3	31.1	1.5	2.2

Anthesis stage (R^2=0.92), watering stage (R^2= 0.94), milky stage (R^2 = 0.97), soft dough (0.99), hard dough (0.97) and physiological material (R^2 = 0.99). The models shows that maximum variation in grain yield can be explained with regression equation of grain yield on number of days to grain development stage. At crown root initiation anthesis, watery ripe, milky ripe, soft dough, hard dough physiological material stages 98, 92, 94, 97, 99, 97 and 99 variation in grain yield can be explained with regression equations of yield on number of days taken to reach that stages. From the regression equation one can be predict the yield of crop if the number of days to reach the particular stage is known. The results in confirmated with Kanchan (2009). There was increase temperature during anthesis stage if required lesser days to complete growth stage.(Table 4.6.1)

Table 4.6.1 Relationship between grain yield (Y) and Dates of sowing (x) during different phenophases of wheat

Serial No.	Growth Stages	Linear Regression	R^2
1	Seedling Emergence	-324.04X + 7452.6	0.60
2	Crown root initiation	-207.44X + 9086.9	0.98
3	Tillering	76.97X + 252.4	0.17
4	Jointing stage	165.76X – 5587.9	0.92
5	Booting stage	85.27X - 399.4	0.86
6	Inflorescence initiation and heading	92.71X – 3761.3	0.82
7	Anthesis stage	82.88X – 3681.5	0.92
8	Watery stage	75.74X + -3183.1	0.94
9	Milky stage	79.41X + 4611.7	0.97
10	Soft dough	70.74X – 4400.1	0.99
11	Hard dough	64.01X – 4142.5	0.97
12	Physiological Maturity	56.67X – 330.1	0.99

4.6.2 Growing degree days and grain yield

The regression equation indicating the relationship of grain yield with GDD units accumulated during different phenophases of wheat are presented in Table No. 4.6.2. The regression analysis revealed a significant positive correlation between grain yield and GDD accumulated during grain ripening stages. From table it can be inferred that 70, 96, 86 and 71 per cent variation in grain yield can be explained with help of regression equation of grain yield on anthesis stage, watery stage, milky stage and soft dough stage. It confirmed the result of Pahwa (2002) that grain yield in wheat increased by 149 q hq^{-1} for an increase of 100 GDD units during ripening phase of grains. Similar results were reported by Tewari and Singh (1993). (Table 4.6.2)

From the growing degree days we can predict the yield of wheat crop in a particular season. The GDD depends on variation in maximum and minimum temperature of the air so growing degree days gives a better prediction of yield. From these equations we can also explain the variation in the yield on the basis of accumulated growing degree days. French *et al* (1979) linear regression equation for (dependent variable) grain yield for independent variable growing degree days.

Table 4.6.2 Relationship between grain yield (Y) and growing degree days of different cultivars (X) during different phenophases of wheat.

Serial No.	Growth Stages	Linear Regression	R^2
1	Seedling Emergence	-0.1245X + 62.92	0.70
2	Crown root initiation	0.0354x + 42.42	0.65
3	Tillering	-0.094X + 43.73	0.53
4	Jointing stage	-0.0036X + 54.64	0.18
5	Booting stage	0.0059X + 46.01	0.46
6	Inflorescence initiation and heading	0.0024X + 49.11	0.28
7	Anthesis stage	-0.0422X + 98.38	0.70
8	Watery stage	-0.027X + 86.65	0.96
9	Milky stage	-0.0293X + 95.31	0.86
10	Soft dough	-0.0412X + 121.5	0.71
11	Hard dough	-0.0151X + 79.62	0.19
12	Physiological Maturity	-0.0721X + 19.91	0.94

4.6.3 Nitrogen and grain yield

Regression analysis indicated that a significant positive correlation between grain yield and different nitrogen level during crown root initiation (R^2 = 0.87), watery stage (R^2 = 0.99), milky stage (R^2 = 0.99) and hard dough stage (R^2 = 0.99). The model shows maximum variation in grain yield can be explained with regression equation of grain yield and nitrogen at grain developmental stages. Crown root initiation, anthesis, watery ripe, milky ripe and hard dough stage 87, 65, 99, 99 and 99 per cent variation in grain yield can be explained with regression. Equation of yield on nitrogen levels from their equation one can predict the grain yield of crop if the number of days to reach the particular stage is known as particular level of nitrogen. (Table 4.6.3). Nitrogen and sulfur increased the biomass at anthesis, with the increment of 62 and 13% in LAI, and 20 and 7% in IPAR, due to N and S addition, respectively the effect of S on LAI and IPAR were higher as nitrogen fertilizer increased (Salvagiotti and Miralles 2008).

Table 4.6.3 Relationship between grain yield (Y) and nitrogen (X) during different phenophases of wheat.

Serial No.	Growth Stages	Linear Regression	R^2
1	Seedling Emergence	-0.694X + 115.2	0.5
2	Crown root initiation	0.308X – 28.7	0.87
3	Tillering	-0.216X + 214.2	0.53
4	Jointing stage	-0.256X + 249.3	0.77
5	Booting stage	-0.013X + 63.97	0.28
6	Inflorescecnce initiation and heading	-0.319X + 416.8	0.83
7	Anthesis stage	-0.134X + 223.4	0.65
8	Watery stage	-0.404X + 566.9	0.99
9	Milky stage	-0.171X + 297.4	0.99
10	Soft dough	-0.096X + 34.91	0.63
11	Hard dough	-0.029X +638.2	0.99
12	Physiological Maturity	-0.138X + 335.3	0.63

4.6.4 Multiple regression

Multiple regression equation at different growth stages indicated that significant positive correlation occurs between growth duration (days) growing degree days and level of nitrogen. Table indicates that grain yield can be predicted with help of these regression equation if growth duration (days), growing degree days and nitrogen level by the crop is known. Value R^2 indicated that maximum variation in grain yield can be explained with the help of regression equations of yield variation on duration, accumulated thermal unit and nitrogen level. At milky ripe stage 92% variation in grain yield can be explained Gill and Kingra (2007) also reported that strong relationship occurs between accumulated thermal units and yield.(Table 4.6.4)

The maximum correlation was observed at physiological maturity (R^2 =0.98), jointing stage (R^2=0.93), milky stage (R^2 =0.92), hard dough stage (R^2 =0.89) and inflorescence emergence and heading (R^2 =0.86) stages. Similar results were reported by Tewari and Singh (1993). The result also confirmated with Kanchan (2009). The quadratic regression equation give better production of yield (French *et al* 1979).

4.7 PATH COEFFICIENT ANALYSIS

Table 4.7.1 revealed that component such as dry matter at 90 days after sowing (DM90), dry matter at 105 days after sowing (DM105) and grain spike weight ratio (GNPERS) showed significant positive correlation with grain yield, whereas ear stem ratio (EAR:STEMR) showed negative correlation with grain yield.

Table 4.6.4 Relationship between grain yield (Y), independent variable (dates of sowing, growing degree days of different cultivars and nitrogen level) during different phenophases of wheat.

Serial No.	Growth Stages	Multiple Linear Regression	R^2
1	Seedling Emergence	$98.50 + 4.50X_1 - 6.84X_2 + 1.63X_3$	0.67
2	Crown root initiation	$28.50 + 0.05X_1 + 0.12X_2 + 0.68X_3$	0.21
3	Tillering	$4.15 + 0.15X_1 - 0.06X_2 + 0.12X_3$	0.59
4	Jointing stage	$5.31 + 0.03X_1 - 0.03X_2 + 0.08X_3$	0.93
5	Booting stage	$-22.21 + 0.07X_1 + 0.27X_2 + 0.06X_3$	0.26
6	Inflorescecnce initiation and heading	$93.07 + 0.02X_1 - 0.08X_2 + 0.03X_3$	0.86
7	Anthesis stage	$35.72 + 0.03X_1 - 0.03X_2 + 0.01X_3$	0.72
8	Watery stage	$-47.27 + 0.01X_1 - 0.18X_2 + 0.05X_3$	0.81
9	Milky stage	$129.83 + 0.07X_1 - 0.09X_2 + 0.02X_3$	0.92
10	Soft dough	$82.56 + 0.012X_1 - 0.03X_2 + 0.07X_3$	0.36
11	Hard dough	$87.29 - 0.01X_1 - 0.07X_2 + 0.06X_3$	0.89
12	Physiological Maturity	$-10.20 + 0.02X_1 - 0.03X_2 + 0.03X_3$	0.98

The results of path analysis demonstrate that dry matter at 90 days had direct effect on grain yield. Components viz. a viz. dry matter at 105days, grain weight ratio and ear stem ratio had indirect effect on GY through dry matter at 90 days. It suggests that dry matter at 90 days is the character of prime importance because this component has shown significant association with grain yield.

Table 4.7.2 Coefficient of Correlation between of thermal and photothermal unit with the Grain yield

Serial No.	GDD	ACCDU	CHETA	CEDU	PTU	HTU	Grain Yield
GDD	1.00	0.99	-0.02	0.37	0.84	0.970	0.66
ACCDU		1.00	0.37	0.92	0.97	0.97	0.91
CHETA			1.00	0.37	0.48	0.44	0.68
CEDU				1.00	0.99	0.93	0.95
PTU					1.00	0.97	0.98
HTU						1.00	0.98
Grain yield							1.00

Degree of freedom = 23 at R^2 = 0.83

It is evident from data in table 4.7.2. That correlation between grain yield and independent variables was positively significant for all the characters in pooled data for all date of sowing, wheat cultivars and nitrogen levels. Multiple linear regression analysis showed that (R^2 = 0.83). There is strong interaction between the thermal and photothermal unit with the grain yield like ACCDU (r = 0.9192), CEDU (0.9526), PTU (r = 0.9806) and HTU (r = 0.9801) showed highly significant correlation with the grain yield. So they are emerged as the important environmental variables influencing grain yield in wheat. The multiple regression equation can be used to predict the yield in advance by using these independent variable are given as under Y = 10563.8 + 6.94(GDD) – 15.04 (ACCDU) + 0.23 (CHETA) – 0.0875 (CEDU) + 0.481 (PTU) + 0.094 (HTU)

Multiple regression equation with standard errors:

Y = 10563.8 (+- 5450) + 6.94 [+- 7.04(GDD)] – 15.04 [+- 9.86 (ACCDU)]+ 0.23 [+- 0.174 (CHETA)]– 0.0875[+- 0.0038 (CEDU)] + 0.481 [+- 0.024 (PTU)] + 0.094 [+- 0.005 (HTU)]

The above equation can be used for the prediction of grain yield with the variation 83 per cent in GDD, ACCDU, CHETA, CEDU, PTU and HTU.

Table 4.7.1 Path coefficient analysis among yield and physiological traits in wheat under different dates of sowing and nitrogen level

Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GDD															
Crown root initiation	0.05														
Milky stage	-0.11	-0.20													
Soft dough	-0.17	-0.24	**0.92**												
Dry Matter at 90 days	0.02	0.06	0.12	**0.41**											
Dry Matter at 105 day	0.11	-0.00	0.10	0.39	**0.92**										
Ear:Stem Anthesis	-0.11	0.17	0.31	0.23	0.41	0.04									
Ear:Stem at maturity	-0.20	0.14	-0.03	-0.45	-0.33	-0.29	0.10								
Grain spike: weight ratio	-0.38	0.12	0.37	**0.42**	0.34	0.09	0.12	-0.28							
DW of spike	-0.56	0.04	-0.52	-0.13	-0.24	-0.39	0.40	0.10	0.29						
Effective till	-0.29	0.35	0.11	0.04	-0.11	-0.10	0.30	0.29	-0.03	0.14					
Root: shoot ratio	-0.13	0.24	-0.04	-0.05	-0.17	-0.26	0.25	0.05	0.00	0.00	-0.36				
Number of grain	**0.64**	-0.02	0.44	0.39	0.10	0.13	0.21	-0.60	0.03	-0.49	-0.40	0.09			
1000 Grain	-0.45	0.2655	-0.11	-0.07	0.05	0.04	**0.52**	0.24	0.15	0.61	0.29	-0.17	-0.63		
Grain yield	-0.31	0.10	0.23	-0.31	**0.62**	**0.49**	0.27	**0.43**	**0.40**	0.20	0.10	-0.37	0.02	0.33	1.00

Crtical Differences r at 5% = 0.4044

II. Experiment No. 2: Source-Sink Relationship of Plant Architecture Manipulation and Biomass Partitioning

4.8 Relationship between Source, Sink, Source-Sink Manipulation

The Table 4.8.1 depicted the there was maximum green leave (5.82 g), (3.56 g) and blade (1.997 g) which significant differ from each other. There was significant difference of jointing stage between green leaves, sheath and blade as the maximum weight of green leaves (9.26 gm) and (5.20 g) sheath and (3.67 g) blade. The maximum weight (11.89 g) followed by (6.7 g) and (6.33 g) for green leaves, sheath and blade respectively at booting stage. The ear emergence.

The accumulation of dry matter of stem, nodal portion and peduncle for ear emergence and flowering stage presentation. The data showed that the maximum weight of stem is (1.85 g) at ear emergence followed by (7.52 g) at flowering stage. The weight of nodal portion is also decrease from (0.61 g) to 1.01 for ear emergence and flowering stage respectively. The weight of peduncle is decrease from (0.88 g) to (0.84 g) ear emergence to flowering. The decrease in weight of peduncle is due to translocation of source material to sink start from flowering stage. The accumulation of dry matter for spike, grain and husk at anthesis and grain formation stage is presented in Table. The maximum weight of spike (0.64 g) followed (0.51 g) at grain formation and anthesis stage respectively. The weight of grain (0.021 g) anthesis and (0.042 g) at grain formation stage. The weight of husk is also increased (0.42 g) to (0.53 g) anthesis to grain formation stage. This is because of increase photosynthetic assimilates also translocate from husk to grain in addition to translocation of stems and leaves. There was strong relationship between source: sink.

The accumulation of dry weight of grain, source sucrose and starch for milky, soft dough and physiological maturity are presented in below. The dry weight of grain at (0.81), (2.61) and (2.92 g) at milky, soft dough and physiological maturity stage. There was also increase in starch concentration but decrease in sugar concentration among all the treatment that there is relationship source: sink. From above result we can say that the grain yield of wheat is either sink limited or co limited by both source: sink between source limited. Maximum grain weight (0.92g) at milky ripe stage in sink manipulation followed by (0.90g) at no manipulation, (0.80g) at source and (0.61g) at source –sink manipulation. This result showed that sink is limited. Evans *et al (*1993) showed that source and sink are not independent and therefore both may be limit the yield. Sugars and starch content maximum in the sink manipulation (15.55mg/g) sugars and (60.00%) starch in the grain at physiological maturity. Above result revealed that grain filling is interrupted under source and source-sink manipulation during the grain filling stages. Grain filling rate can be limited by source or sink including sink size and sink strength that is ability to store the starch by converting the sugar into starch by enzymatic reaction.

Table 4.8.1 Relation ship between source, sink and source–sink manipulation for different plants [arts at different growth stages.

Treatment	**Green leaves**	**Leaves sheath**	**Leaf Blade**	**Mean**
Tillering				
Control	5.74	2.85	2.01	3.53
Source	5.42	4.21	2.02	3.88
Sink	4.56	3.54	2.12	3.40
Source –sink	5.41	3.65	1.85	3.63
Mean	5.82	3.56	1.99	
CD (p = 0.05)	**0.829**			
Jointing stage				
Control	8.12	5.1	3.02	5.41
Source	9.21	5.45	4.21	6.29
Sink	10.5	5.42	4.23	6.71
Source –sink	9.23	4.85	3.24	5.77
Mean	9.26	5.20	3.67	
CD (p = 0.05)	**0.819**			
Booting stage				
Control	12.2	6.98	5.85	8.74
Source	12.5	7.98	5.98	8.85
Sink	11.2	6.95	4.97	7.70
Source –sink	12.02	5.26	4.52	7.26
Mean	11.98	6.79	5.33	
CD (p = 0.05)	**8.031**			
Ear emergence				
Control	8.53	0.69	1.02	3.40
Source	9.21	0.79	0.55	3.61
Sink	7.45	0.52	0.78	2.41
Source –sink	6.21	0.45	0.92	2.53
Mean	7.85	0.61	0.88	
CD (p = 0.05)	**1.245**			
Flowering				
Control	9.12	1.08	0.98	3.73
Source	7.85	1.19	0.92	3.32
Sink	7.13	0.98	0.78	2.96
Source –sink	6.71	0.79	0.66	2.49
Mean	7.52	1.01	0.84	3.12
CD (p = 0.05)	**1.178**			

Conti….

Treatment	**Spike**	**Grain**	**Husk**	**Mean**
Anthesis				
Control	0.603	0.027	0.611	0.413
Source	0.555	0.008	0.431	0.330
Sink	0.475	0.052	0.354	0.286
Source –sink	0.422	0.053	0.291	0.286
Mean	0.122	0.034	0.421	
CD (p = 0.05)	**0.056**			
Grain formation				
Control	0.719	0.064	0.701	0.283
Source	0.551	0.038	0.059	0.215
Sink	0.634	0.040	0.059	0.244
Source –sink	0.575	0.025	0.023	0.194
Mean	0.641	0.042	0.053	
CD (p = 0.05)	**0.076**			
Milky stage	**Grain**	**Sugar**	**Starch**	**Mean**
Control	0.902	4.78	43.8	16.55
Source	0.805	3.43	34.16	15.10
Sink	0.921	6.06	50.8	19.18
Source –sink	0.713	4.05	29.6	14.75
Mean	0.841	4.79	43.95	
CD (p = 0.05)	**4.667**			
Dough stage				
Control	3.03	14.35	54.52	24.06
Source	2.03	11.89	53.01	20.80
Sink	3.14	14.41	62.16	26.88
Source –sink	2.22	11.48	43.33	19.01
Mean	2.61	13.03	52.19	22.61
CD (p = 0.05)	**7.22**			
Physiological maturity				
Control	3.47	12.76	55.83	24.08
Source	2.35	11.42	50.26	21.33
Sink	3.45	15.55	60.21	26.43
Source –sink	2.58	9.96	45.66	19.01
Mean	2.92	13.24	52.46	22.61
CD (p = 0.05)	**5.27**			

Mi *et al* (2009) suggested that insufficient photosynthate supply rather than weak sink strength was the main reason limiting grain filling rate.

4.9 REGRESSION EQUATION

The regression equation for grain yield on growth duration are presented in Table No.4.9.1, 4.9.2 and 4.9.3. Regression analysis indicated that a significant positive correlation between grain yield and different source and sink parameters from different parts of plants.

4.9.1 Regression equation for source manipulation

Regression analysis showed a significant positive correlation between grain yield and source dry weight of blade (R^2 =0.98) at crown root initiation, dry weight of blade (R^2 =0.83) at tillering stage. dry weight of nodal portion (R^2 =0.94), dry weight of husk (R^2 =0.89), dry weight of spike (R^2 =0.84), dry weight of grain (R^2 =0.93) at milky and (R^2 =0.88) soft dough stage, sugar content (R^2 =0.99) at physiological maturity.

The model shows that maximum variation in grain yield can be explained with regression equation of grain yield and source: sink manipulation.The dry weight of blade at crown root initiation and tillering stage, dry weight nodal portion (Ear emergence), dry weight of husk (anthesis stage), dry weight of spike grain formation stage), dry weight of grain (physiological maturity) 98, 83, 94, 89, 84, 93, 88 and 99 per cent variation in grain yield can be explained with the regression equations. Data showed that growth of wheat is more sink limited than source limited similar result given by (Borras *et al* 2004). (Table 4.9.1)

The regression equation indicating the relationship of grain yield with dry mass at different phenophases of wheat. Table revealed that (R^2 = 0.93) at green leaves at booting stage (R^2 = 0.91) at tillering for the green leaves (R^2 = 0.88) for the sheath leaves.(R^2 = 0.81) at flowering stage (R^2 = 0.77) at anthesis stage. n striving to increase the yield potential of cultivated plants it is important to determine the physiological factors limiting yields. The first step towards this is to assess whether the growth of harvested organs is limited by the availability substrates (source limited) or by the capacity of the organ to assimilate and utilize the available substance for growth (sink limited) (Patrick, 1988).

Source sink relationship showed that there is strong relationship of leaf sheath while tillering stage and blades have also strong interaction with the tillering as the tillering stage have (R^2 = 0.84) the maximum weight of stem was observed at ear emergence and (R^2 = 0.99) which is significant. Milky stage also significant (R^2 = 0.99) which showed biomass of grains very important at milky stage as compared to other stages because of milky stage is very sensitive to temperature.

4.9.2 Regression equation for sink manipulation

The regression equation indicating the relationship of grain yield and sink manipulation during different phenophase of wheat presented in Table. Regression analysis revealed that a significant positive correlation between grain yield and sink manipulation during grain formation stage. From table it can be inferred that 87, 85, 91, 85 and 89 per cent

Table 4.9.1 Relationship between grain yield (Y), dry weight (X) of different components at different phenophases of wheat for source manipulation

Serial No.	Growth Stages	Dry weight of plants parts	Linear Regression	R^2
1	Crown root initiation			
		Green leaves	0.0028 X – 0.024	0.89
		Green sheath	0.0024X – 0.089	0.24
		Blades	0.0033X – 0.101	0.98
2	Tillering			
		Green leaves	0.1198X – 0.008	0.27
		Green sheath	0.2415X – 8.735	0.85
		Blades	0.2017X -8.442	0.83
3	Jointing stage			
		Green leaves	0.2523X – 3.786	0.74
		Green sheath	0.1218X – 0.363	0.64
		Blades	0.2526X – 9.746	0.65
4	Booting stage			
		Green leaves	0.2629X – 0.808	0.24
		Green sheath	0.148X + 0.3769	0.64
		Blades	0.2414X – 7.061	0.73
5	Flowering			
		Stem	0.283X – 6.425	0.75
		Nodal Portion	0.023X – 0.007	0.40
		Peduncle	0.108X – 4..854	0.63
6	Ear Emergence			
		Stem	0.0305X – 1.126	0.80
		Nodal Portion	0.0132X – 0.709	0.52
		Peduncle	0.007X – 0.031	0.89
7	Anthesis stage			
		Spike	0.030x – 1.126	0.80
		Grain	0.013x – 0.709	0.52
		Husk	0.007x – 0.031	0.89
8	Grain Formation			
		Spike	0.038x – 1.574	0.84
		Grain	0.003x – 0.128	0.73
		Husk	0.054x – 2.43	0.56
9	Milky Stage			
		Grain	0.018x – 0.250	0.93
		Starch	0.300x – 12.31	0.79
		Sugar	1.840x – 59.53	0.76
10	Dough stage			
		Grain	0.073x – 19.925	0.88
		Starch	0.384x – 9.277	0.56
		Sugar	1.020x – 13.64	0.71
11	Physiological maturity			
		Grain	0.068x – 1.257	0.63
		Starch	0.564x – 14.48	0.99
		Sugar	1.619x -37.805	0.64

variation in grain yield can be explained with help of regression equation of grain yield on dry weight of spike (anthesis), dry weight of grain and sugar content (milky stage) and sugar and starch content (soft dough) stages. The above result gave interpretation for the concept of sink demand. The ability of the sink to cause mobilization of storage carbohydrate from the source may inappropriate for a sink. (Table 4.9.2)

4.9.3 Regression equation source: sink manipulation with grain yield

The regression analysis indicated a significant positive correlation between grain yield and source sink manipulation at different growth stages. Dry weight of blade (Crown root initiation), (R^2 = 0.89), dry weight of sheath blade (R^2 = 0.85), dry weight of nodal portion (ear emergence), dry weight of spike (anthesis) R^2 = 0.86, dry weight of spike (growth formation) (R^2 = 0.82), dry weight of grain (milky stage) (R^2 = 0.85), sugar content (milky stage) (R^2 = 0.83), dry weight of grain (soft dough) (R^2 = 0.85) and sugar content physiological maturity (R^2 = 0.95). The regression model shows that maximum variation in grain yield can be explained with the regression equation of grain yield on source: sink manipulation. The results presented here suggest that source limitation, sink limitation and source sink limitation occurs relatively. Sink limitation may be more common at sink manipulation. The dependence of seed number on canopy photosynthesis and assimilate supply may tend to maintain the seed weight (number) at a level where the sucrose concentration prevailing maximum seed growth rate (Frar and Gun 1996). (Table 4.9.3)

4.9.4 Multiple regression equation

The multiple regression equation indicating the relationship of grain yield with source, sink and source: sink manipulation at different growth stages. Table 4.9.4 indicated that the relationship of source manipulation, sink manipulation and source: sink manipulation, sink manipulation and source: sink manipulation with grain yield. Value of R^2 indicated that maximum variation in grain yield can be explained with the help of regression equation of yield variable source, sink and source: sink manipulation. At the dry weight blade (crown root initiation) (R^2 =0.98) dry weight of sheath (tillering stage) (R^2 =0.97), dry weight of green leafs (Jointing stage) (R^2 =0.98), dry weight of sheath (booting stage) (R^2 =0.99) showed source: sink manipulation and dry weight of spike, grain and husk (grain formation). These equation can be used to predict the yield of crop in advance by using dry weight of different plants components at different growth stages for wheat cultivars. The first step towards this is to assess whether the growth of harvested organs is limited by the availability substrates (source limited) or by the capacity of the organ to assimilate and utilize the available substance for growth (sink limited) (Patrick, 1988).

Table 4.9.2 Relationship between grain yield (Y), dry weight (X) of different components at different phenophases of wheat for sink manipulation

Serial No.	Growth Stages	Dry weight of plants parts	Linear Regression	R^2
1	Crown root initiation			
		Green leaves	0.003X – 0.042	0.86
		Green sheath	0.002X - 0.102	0.23
		Blades	0.003X – 0.114	0.96
2	Tillering			
		Green leaves	0.114X + 0.871	0.24
		Green sheath	0.238X – 8.532	0.83
		Blades	0.190X – 8.251	0.80
3	Jointing stage			
		Green leaves	0.246X – 3.594	0.73
		Green sheath	0.116X – 0.167	0.61
		Blades	0.251X – 9.54	0.62
4	Booting stage			
		Green leaves	0.268X – 1.331	0.23
		Green sheath	0.145X - 0.621	0.55
		Blades	0.2381X – 8.059	0.67
5	Flowering			
		Stem	0.162X -0.8223	0.44
		Nodal Portion	0.0485X – 1.962	0.94
		Peduncle	0.046X – 1.628	0.62
6	Ear Emergence			
		Stem	0.2806X – 7.421	0.69
		Nodal Portion	0.017X + 0.185	0.31
		Peduncle	0.103X – 4.651	0.60
7	Anthesis stage			
		Spike	0.028X – 1.098	0.87
		Grain	0.001X – 0.048	0.39
		Husk	0.027X – 1.117	0.82
8	Grain Formation			
		Spike	0.027X – 0.865	0.80
		Grain	0.003X – 0.132	0.82
		Husk	0.043X – 1.851	0.53
9	Milky Stage			
		Grain	0.0884X – 3.842	0.85
		Starch	0.132X – 1.331	0.90
		Sugar	1.546X -33.25	0.74
10	Dough stage			
		Grain	0.100X – 2.413	0.56
		Starch	0.512X – 13.85	0.85
		Sugar	1.843X – 39.122	0.89
11	Physiological maturity			
		Grain	0.082X – 1.032	0.72
		Starch	0.477X – 9.533	0.77
		Sugar	0.889X + 11.634	0.68

Table 4.9.3 Relationship between grain yield (Y), dry weight (X) of different components at different phenophases of wheat for source-sink manipulation

Serial No.	Growth Stages	Dry weight of plants parts	Linear Regression	R^2
1	Crown root initiation			
		Green leaves	0.0022X + 0.0175	0.53
		Green sheath	0.0032X – 0.1328	0.32
		Blades	0.0029X – 0.0935	0.89
2	Tillering			
		Green leaves	0.1142X – 0.812	0.25
		Green sheath	0.2306X– 9.8451	0.85
		Blades	0.1961X – 9.257	0.81
3	Jointing stage			
		Green leaves	0.2080X – 2.539	0.70
		Green sheath	0.1355X – 2.158	0.73
		Blades	0.3374X – 14.951	0.64
4	Booting stage			
		Green leaves	0.6882X – 1.33	0.26
		Green sheath	0.1452X– 0.623	0.55
		Blades	0.2381X– 0.822	0.67
5	Ear Emergence			
		Stem	0.1623X– 0.822	0.44
		Nodal Portion	0.0485X– 1.962	0.98
		Peduncle	0.0466X– 1.628	0.55
6	Flowering			
		Stem	0.2806X– 7.421	0.69
		Nodal Portion	0.01751X + 0.188	0.68
		Peduncle	0.1032X – 4.625	0.50
7	Anthesis stage			
		Spike	0.0028X – 0.8396	0.86
		Grain	0.0012X – 0.006	0.78
		Husk	0.0351X – 1.457	0.70
8	Grain Formation			
		Spike	0.0351X - 1.285	0.82
		Grain	0.0032X – 0.1451	0.66
		Husk	0.0522X – 2.451	0.71
9	Milky Stage			
		Grain	0.0621X – 2.841	0.85
		Starch	0.2419X – 9.572	0.83
		Sugar	2.674X – 108.45	0.77
10	Dough stage			
		Grain	0.1597X – 6.5321	0.85
		Starch	0.6218X – 22.962	0.76
		Sugar	2.1482X – 74.831	0.71
11	Physiological maturity			
		Grain	0.0831X – 2.278	0.25
		Starch	0.7075X – 27.741	0.97
		Sugar	2.0067X – 65.85	0.74

Table 4.9.4 Relationship between grain yield (Y) , dry weight (X) of different components at different phenophases of wheat for control, source, sink source: sink manipulation

Sr. No.	Growth Stages	Dry weight of plants parts	Multiple Linear Regression	R^2
1	CRI			
		Green leaves	$-8.11 + 212.26X_1 - 50.21X_2 + 139.7X_3 + 139.7X_4$	0.95
		Green sheath	$52.15 + 36.36X_1 - 36.73X_2 - 570.4X_3 + 707.2X_4$	0.68
		Blades	$33.66 + 0.91X_1 + 146.94X_2 + 97.52X_3 + 38.14X_4$	0.98
2	Tillering			
		Green leaves	$14.41 + 1.95X_1 - 59.41X_2 + 33.2X_3 + 26.8X_4$	0.74
		Green sheath	$53.25 + 1.43X_1 - 30.54X_2 - 17.6X_3 + 16.8X_4$	0.97
		Blades	$40.06 + 1.24X_1 + 4.09X_2 + 10.11X_3 + 1.71X_4$	0.87
3	Joint. stage			
		Green leaves	$35.00 + 1.94X_1 - 0.209X_2 + 4.26X_3 + 4.88X_4$	0.98
		Green sheath	$24.06 + 1.68X_1 - 6.85X_2 - 6.43X_3 + 4.65X_4$	0.84
		Blades	$35.55 + 7.23X_1 + 2.74X_2 + 1.38X_3 + 6.61X_4$	0.83
4	Boot. stage			
		Green leaves	$40.92 + 1.27X_1 - 3.84X_2 + 3.16X_3 + 0.758X_4$	0.91
		Green sheath	$47.72 + 2.61X_1 - 4.38X_2 - 11.50X_3 + 17.06X_4$	0.99
		Blades	$21.02 + 0.99X_1 + 13.24X_2 + 9.64X_3 + 1.32X_4$	0.93
5	Ear Emerg.			
		Stem	$30.02 + 3.10X_1 - 0.32X_2 + 3.61X_3 + 4.20X_4$	0.99
		Nodal Portion	$40.17 + 3.09X_1 - 8.71X_2 - 0.52X_3 + 8.17X_4$	0.99
		Peduncle	$38.02 + 9.66X_1 + 3.98X_2 + 5.25X_3 + 2.55X_4$	0.90
6	Flowering			
		Stem	$17.33 + 3.11X_1 + 3.11X_2 + 2.66X_3 - 6.08X_4$	0.96
		Nodal Portion	$48.40 + 10.66X_1 - 12.84X_2 - 7.94X_3 - 0.26X_4$	0.99
		Peduncle	$44.92 - 7.37X_1 + 19.06X_2 - 4.04X_3 + 2.83X_4$	0.67
1	Anthesis			
		Spike	$40.94 + 25.6X_1 - 16.66X_2 + 30.28X_3 + 13.22X_4$	0.96
		Grain	$48.88 + 128.9X_1 - 198.63X_2 - 277.4X_3 + 658.1X_4$	0.98
		Husk	$44.18 + 18.65X_1 + 40.58X_2 + 14.27X_3 + 2.43X_4$	0.95
2	Grain Form.			
		Spike	$43.65 + 18.23X_1 - 13.79X_2 + 31.68X_3 + 21.58X_4$	0.98
		Grain	$43.77 + 170.8X_1 - 202.6X_2 - 118.9X_3 + 127.9X_4$	0.99
		Husk	$52.93 + 143.11X_1 + 14.62X_2 + 11.31X_3 + 31.30X_4$	0.82
3	Milky Stage			
		Grain	$38.26 + 12.51X_1 - 0.49X_2 + 3.52X_3 + 4.179X_4$	0.96
		Starch	$30.81 + 0.013X_1 - 0.15X_2 - 2.70X_3 + 1.92X_4$	0.91
		Sugar	$43.79 + 0.41X_1 + 0.11X_2 + 0.256X_3 + 0.275X_4$	0.99
4	Dough stage			
		Grain	$39.84 + 4.68X_1 - 1.68X_2 + 0.879X_3 + 3.41X_4$	0.91
		Starch	$32.83 + 1.51X_1 - 0.66X_2 - 0.50X_3 + 0.05X_4$	0.96
		Sugar	$9.70 + 0.31X_1 + 0.59X_2 + 0.25X_3 + 0.42X_4$	0.96
5	Physiol. mat.			
		Grain	$23.01 + 11.01X_1 - 0.698X_2 + 30.02X_3 + 9.88X_4$	0.99
		Starch	$39.93 + 0.04X_1 - 0.196X_2 - 0.019X_3 + 1.09X_4$	0.97
		Sugar	$42.96 + 0.35X_1 + 0.074X_2 + 0.34X_3 + 0.20X_4$	0.96

(R^2 =0.98, 0.99 and 0.82), dry weight of grain, sugar content and starch content (milky stage) (R^2 =0.96, 0.91, 0.99) and dry weight of grain, sugar content and starch content (soft dough) (R^2 = 0.91, 0.96, 0.91) showed sink source manipulation. Above relation showed that grain yield of wheat is either source limited, or sink limited or co-limited by both source and sink but never source limited. This results inconsistence with Savin and Slafer (1991).

4.9.5 Grain growth process

Relationship between grain weight and reproductive stage of wheat cultivars in control, source, sink and source: sink manipulation present in Fig.21 and 22 and 23 Linear correlation appeared to fit at different treatment. The maximum grain weight was observed at control (3.5 gm) followed by sink (3.2 gm), (2.8 gm) source and (2.00 gm) source sink manipulation. Maximum (R^2=0.99) control followed by (R^2=0.98) sink (R^2=0.98) source and (R^2=0.96) source: sink manipulation. Wheat grain weight can be limited by source (the supply of assimilates) or sink (the capacity of the grains to accumulate the assimilates) or both (Evans *et al* 1975). The result suggested that during post-anthesis period grain yield of wheat is either sink-limited or cv. cv. limited by both source: sink but never source limited. This result is consistent with Savin and Slafer (1991).

The graph showed that maximum soluble sugar concentrate in control, followed by sink, source and source: sink manipulation. The linear regression equation showed maximum fits at (R^2=0.99) followed (R^2=0.96) and (R^2=0.97). The graph showed with proceeded in physiological maturity the soluble sugar concentration on decrease this might be because of the conversion sugar to starch almost certainly involves metabolism of sugar nucleotides. ADP and UDP glucose and ADP glucose is thought to be the principle precursor for starch (Akazava 1965).

The relationship between starch cone and reproductive stages of cv. PBW-343 under control, source, since and source: sink manipulation presented in Fig. 23. The graph showed that concentration of starch is increase, as wheat proceeded towards physiological maturity. The maximum correlation coefficient (R^2= 0.99) followed by (R^2=0.98) and (R^2=0.96). The graph depicted that when sink is limited the concentration of starch is more than source limited and source: sink limited. This results in conformatory with Mi Guohua *et al* (2009). The increase in concentration of starch this might be because of the conversion sugar to starch almost certainly involves metabolism of sugar nucleotide ADP and UDP glucose and ADP glucose thought to be the principle precursor for starch (Akazawa 1965).

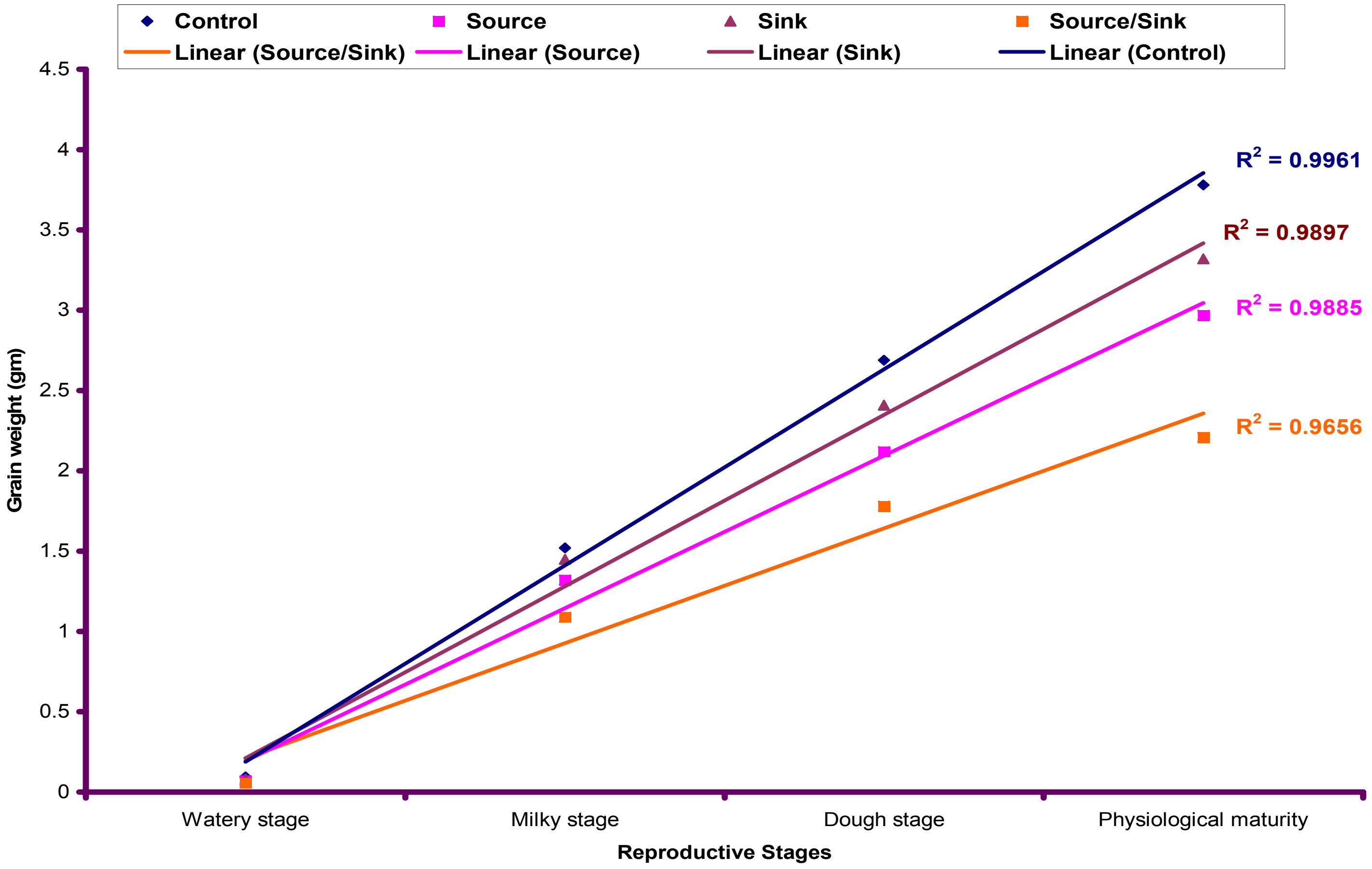


Fig 21. Sink Growth process (Grain Growth process) of Wheat Cultivar (PBW-343) in control, source manipulation, sink manipulation and source: sink manipulations.

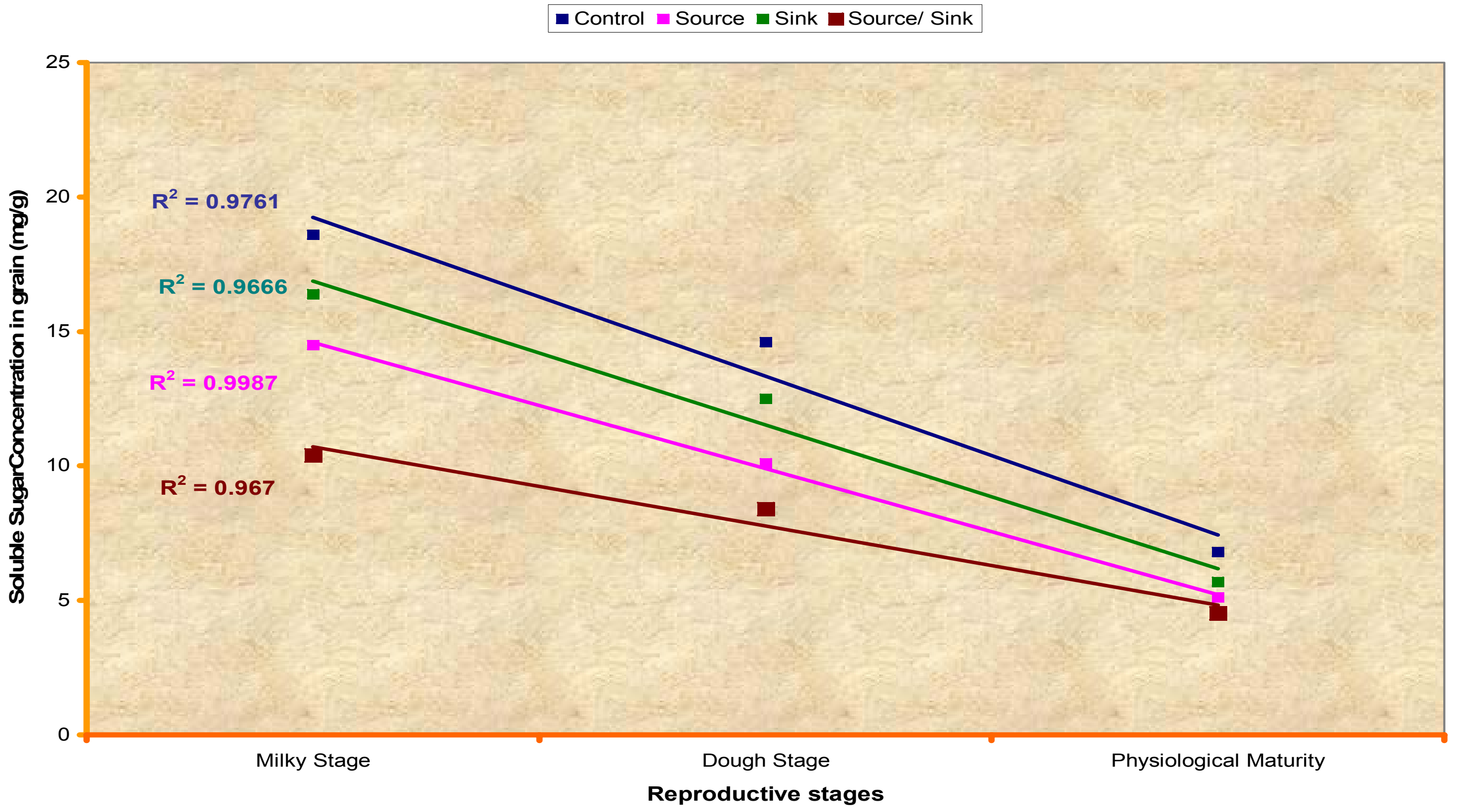


Fig. 22 Soluble sugar concentration in grain (mg/g) in grain during Different reproductive stages of Cv. PBW-343 under control source, sink and source: sink manipulation.

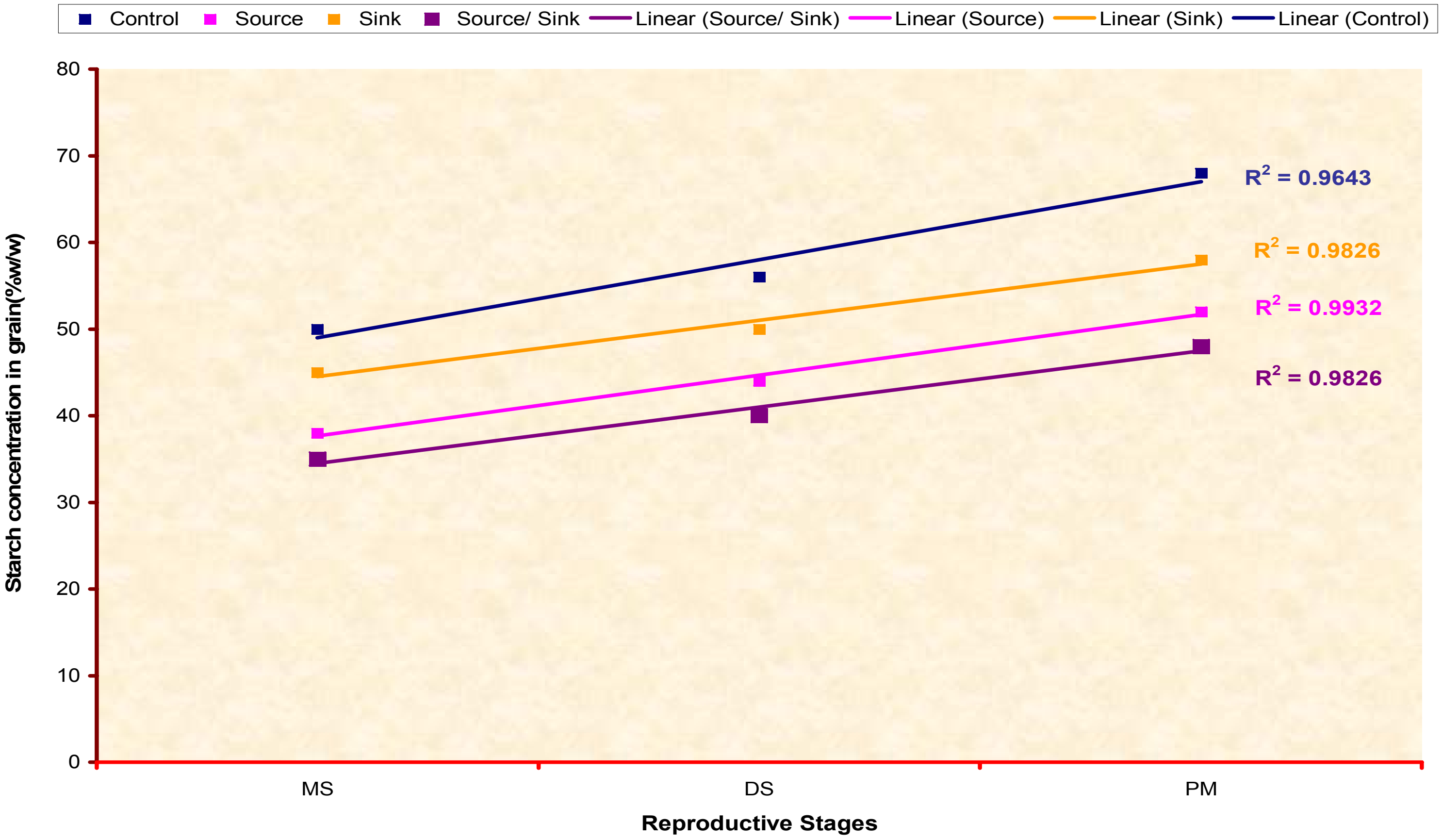


Fig.23 Starch accumulation in Grains at Different reproductive stages of Cv. PBW-343 under control source, sink and source: sink manipulation.

4.10 CERES-Wheat and Inforcrop Calibration and Validation of Models

Validation for source: sink

The both models unable to simulate the biomass of green leaves sheath and blade for crown root initiation, Tillering jointing and booting stages. The models are also unable to simulate the stress, nodal portion and peduncle at ear emergence and flowering stages. The infocrop model has simulated well for stages from anthesis to physiological maturity for the weight of grain but not for the starch and sugar content. CERES-Wheat model has also simulated weight grain but not starch and sugar content. The value of RMSE from all the simulated parameters has been given in Table 4.10. The CERES wheat model have lower root mean square error value (RMSE = 0.5) of grain for grain forming stage, (RMSE = 0.63) of grain at Dough stage, (RMSE = 2.0) of grain at physiological maturity as compared to the (RMSE = 1.18) of grain at grain formation, (RMSE = 1.04) of grain at milky stage and (RMSE = 1.37) of grain at dough stage and (RMSE = 2.1) of grain at physiological maturity for the Infocrop model.

FORMULA FOR THE LEAF AREA MODEL

Maximum blade length (mm) = 90 EXP 0.085X

Maximum blade width (mm) = 3.76 EXP 0.085X

Then leaf area can be calcultedas following

Leaf area = 90EXP0.085X * 3.76EXP0.085X

Table 4.10. Statistical indices derived from the validation of CERES-Wheat and Infocrop Models for source-sink function time series

Growth stages	Dry weight of plant parts	Inforcrop				CERES model			
		Observed	Simulated	MAE	RMSE	Observed	Simulated	MAE	RMSE
Crown root initiation	Green leaves	18.15	-	-	-	18.15	-	-	-
	Leaves sheath	8.1	-	-	-	8.1	-	-	-
	Leaf blades	10.05	-	-	-	10.05	-	-	-
Tillering stage									
	Green leaves	891	-	-	-	291	-	-	-
	Leaves sheath	517.5	-	-	-	165	-	-	-
	Leaf blades	372	-	-	-	126	-	-	-
Jointing stage									
	Green leaves	1127.25	-	-	-	1127.25	-	-	-
	Leaves sheath	742.5	-	-	-	742.5	-	-	-
	Leaf blades	352.5	-	-	-	352.5	-	-	-
Booting stage									
	Green leaves	1458	-	-	-	1458	-	-	-
	Leaves sheath	918	-	-	-	918	-	-	-
	Leaf blades	690	-	-	-	690	-	-	-
Ear Emergence									
	Stem	1192.5	-	-	-	1192.5	-	-	-
	Nodal portion	67.5	-	-	-	67.5	-	-	-
	peduncle	113.25	-	-	-	113.25	-	-	-
Flowering									
	Stem	1515	-	-	-	1515	-	-	-
	Nodal portion	141	-	-	-	141	-	-	-
	peduncle	135	-	-	-	135	-	-	-
Anthesis									
	Spike	116.7	-	-	-	116.7	-	-	-
	Grain	4.35	-	-	-	4.35	-	-	-
	Husk	111	-	-	-	111	-	-	-

Growth stages	Dry weight of plant parts	Inforcrop				CERES model			
		Observed	Simulated	MAE	RMSE	Observed	Simulated	MAE	RMSE
Grain Formation									
	Spike	130.8	-	-	-	130.8	-	-	-
	Grain	12.6	11.2	1.4	1.18	12.6	11.8	0.8	0.5
	Husk	117	-	-	-	117	-	-	-
Milky stage									
	Grain	14.7	13.6	1.1	1.04	14.78	14.25	0.53	0.03
	Sugar	825	-	-	-	825	-	-	-
	Starch	7200	-	-	-	7200	-	-	-
Dough stage									
	Grain	42.1	40.2	1.9	1.37	42.1	42.5	0.4	0.63
	Sugar	1860	-	-	-	1860	-	-	-
	Starch	9000	-	-	-	9000	-	-	-
Physiological maturity									
	Grain	54.1	50.6	4.5	2.1	54.1	58.12	4.02	2
	Sugar	2340	-	-	-	2340	-	-	-

- = Not simulated

CHAPTER V

SUMMARY

Plants are non linear, dynamic time varying system, with memory. Their interaction with inputs and environments together with their mutual interdependence make crop plants an extremely complex system. The growth and development processes although genetically determined to a large extent are influenced by the set of inputs, environments and management practices. Simulation of crop growth involves understanding and quantification of net productivity and its allocation to different plants organs based on the supply demand ratios. Plant sensitivity to inputs and environment vary with stage of their development. Shortage and excess stay in their memory and exercise their influence on plant life quantitatively as well as qualitatively. To make subject matter comprehense one has to resort to fragmentation of crop plants into crop components that can be studied separately and when integrated appropriately yield the response of the crop as a whole. Periodically sampled crop biomass and components constitute the effect of inputs and environments during the whole life cycle and for the intervals and therefore can be treated as a measure of crop productivity.

Field and laboratory experiment were conducted during season 2008-2009 and 2009-2010. for the evaluate the relation ship between agronomic practices, weather parameters, growth and yield of wheat to explore time trend ontogeny, phenology, growth and yield as affected by warming trend and to generate source and sink function by calibrating growth models embodying time series and development of plant organs. Results obtained from the experiments are summarized below:

- The total thermal unit utilized (2125) GDD, (2448) ACCDU, and (1728) CHETA and photo thermal units (1146405) CEDU, (30661) PTU and (1168020) HTU. For the completion of phonological stages from seedling emergence to physiological maturity under 15th Oct. sowing. The dates of sowing 15th Nov. utilized maximum energy (1230507 cal/cm^2/day) CEDU as compared to 15th Oct. and 15th Dec. sowing. The maximum number of leaves (12) appeared twelve in 15th Oct. and 15th Nov. sowing as compared to 15th Dec. of sowing (10 leaves).The maximum accumulated thermal and photo thermal units was for cv. PBW-343 (846) GDD, (1007) ACCDU, (660) CHETA and (378915) CEDU, (12380) PTU and (206181) HTU for the appearance of maximum twelve leaves.
- The maximum leaf emergence rate was observed between (100 GDD) with 0.245 leaves/ day. The first tiller was observed when the third leaf on the main shoot appeared
- High level of nitrogen N_{180} increase seedling emergence count per meter square under

15th October sowing.

- Grain growth duration is strongly responsive to temperature one degree rise in temperature during grain filling result in 2.56 days decrease in the grain filling irrespective of cultivars.
- The yield and yield contributing attributes number of effective tillers, grain spike weight ratio, number of grain m^{-2}, 1000 grain weight, root shoot ratio dry weight of spikes at anthesis and maturity, biological yield and grain yield decrease with delay in sowing with decrease in nitrogen levels.
- Calibration of CERES-Wheat and Infocrop model has been done by using variables days to anthesis, days to physiological maturity, leaf area index, leaf number, number of effective tillers, grain number (m^{-2}), grain growth duration, 1000 grain weight, total dry matter, grain yield and harvest index. CERES-Wheat and Infocrop simulate harvest index satisfactorily but the rest of the above parameters variable are not calibrated satisfactorily with Infocrop model.
- Validation of CERES-Wheat predicted phenological stages satisfactorily with the root mean square error value (RMSE) sowing to seedling emergence (RMSE = 2.0), seedling emergence to anthesis (RMSE = 3.6) and anthesis to maturity (RMSE = 4.0) which are smaller than the infocrop model values i.e. root mean square error value (RMSE = 22) sowing to seedling emergence, (RMSE = 99) seedling emergence to anthesis and (RMSE = 93) anthesis to physiological maturity.
- The yield and yield contributing attributes like number of effective tiller (m^{-2}) (RMSE = 5.8), number of grain (m^{-2}) (RMSE = 60), 1000 grain weight (RMSE = 1.9), grain yield (RMSE = 1.2) and harvest index (RMSE = 1.1) calculated by the CERES-Wheat model which are far lower than the calculated from the infocrop model as effective tiller (m^{-2}) (RMSE = 110) number of grain (m^{-2}) (RMSE = 283.9) 1000 grain weight (RMSE = 25) , grain weight (RMSE = 13) and harvest index (RMSE =2.2).
- Regression analysis indicated that a significant positive correlations between grain yield and dates of sowing at crown root initiation ($R^2 = 0.98$) , anthesis stage ($R^2 = 0.92$) , watery ripe stage ($R^2 = 0.94$), milky stage ($R^2 = 0.99$), soft dough ($R^2 = 0.99$), hard dough stage ($R^2 = 0.97$) and physiological maturity ($R^2 = 0.99$). Regression analysis indicated that a significant positive correlation between grain yield and different nitrogen level during crown root initiation ($R^2 = 0.87$), watery ripe stage ($R^2 = 0.99$), milky stage ($R^2 = 0.99$) and hard dough stage ($R^2 = 0.99$).
- Multiple regression analysis showed that the maximum correlation was observed at physiological maturity ($R^2 =0.98$), jointing stage ($R^2=0.93$), milky stage ($R^2 =0.92$),

hard dough stage (R^2 =0.89) and inflorescence emergence and heading (R^2 =0.86) stages.

- Path analysis demonstrates that dry matter at 90 days had direct effect on grain yield. Components viz. a viz. dry matter at 105 days, grain: spike weight and ear stem ratio had indirect effect on GY through DM90. It suggests that dry matter at 90 days is the character of prime importance because this component has shown significant association with grain yield.
- Multiple linear regression analysis showed highly significant correlation with the grain yield. ACCDU (r = 0.9192), CEDU (0.9526), PTU (r = 0.9806) and HTU (r = 0.9801) So they are emerged as the important environmental variables influencing grain yield in wheat. The multiple regression equation can be used to predict the yield in advance by using these independent variable are given as under Y = 10563.8 + 6.94(GDD) – 15.04 (ACCDU) + 0.23 (CHETA) – 0.0875 (CEDU) + 0.481 (PTU) + 0.094 (HTU)
- Source manipulation, sink manipulation and source: sink manipulation, source manipulation regression analysis showed a significant positive correlation between grain yield and source dry weight of blade (R^2 =0.98) at crown root initiation, dry weight of blade (R^2 =0.83) at tillering stage. Dry weight of nodal portion (R^2 =0.94), dry weight of husk (R^2 =0.89), dry weight of spike (R^2 =0.84), dry weight of grain (R^2 =0.93) at milky and (R^2 =0.88) soft dough stage, sugar content (R^2 =0.99) at physiological maturity. Regression analysis for sink manipulation revealed that a significant positive correlation between grain yield and sink manipulation during grain formation stage. The regression model shows that maximum variation in grain yield can be explained with the regression equation of grain yield on source: sink manipulation.
- Wheat grain weight can be limited by source (the supply of assimilates) or sink (the capacity of the grains to accumulate the assimilates or both source: sink limited.
- The CERES-wheat model have lower root mean square error value at grain forming stage (RMSE = 0.5) of grain, at Dough stage (RMSE = 0.63) of grain, at physiological maturity (RMSE = 2.0) of grain as compared to the at grain formation (RMSE = 1.18) of grain, grain at milky stage (RMSE = 1.04) of and (RMSE = 1.37) of grain at dough stage and at physiological maturity (RMSE = 2.1) of grain for the Infocrop model.
- CERES-wheat model predict the yield satisfactorily but the infocrop model is under estimating the grain yield. Infocrop model also unable give satisfactorily result for the source sink time series growth model.

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ANNEXURE 1

Weather Data for 2008

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
1	18.4	2.6	1.4	0.4	8.8	0.0
2	17.4	0.2	2.4	0.7	8.8	0.0
3	18.6	0.8	2.5	0.7	7.2	0.0
4	19.0	3.8	2.9	0.8	8.8	0.0
5	15.6	7.5	4.8	1.3	0.4	1.5
6	18.2	10.2	2.5	0.7	0.0	0.0
7	25.8	6.4	3.6	1.0	5.5	0.0
8	18.6	12.6	5.9	1.6	0.0	6.6
9	20.0	12.8	6.1	1.7	2.5	1.4
10	18.4	9.8	3.7	1.0	2.1	0.0
11	16.0	6.2	5.7	1.6	6.6	0.0
12	14.8	4.2	4.8	1.3	5.1	0.0
13	17.6	4.0	6.5	1.8	9.3	0.0
14	16.0	4.2	6.7	1.9	6.2	0.0
15	18.6	7.4	5.3	1.5	7.7	0.0
16	17.6	9.0	3.9	1.1	0.6	0.0
17	16.0	10.4	8.0	2.2	0.0	6.8
18	17.2	10.4	4.4	1.2	6.4	0.0
19	16.0	3.4	3.4	0.9	9.4	0.0
20	16.0	2.4	5.4	1.5	6.3	0.0
21	14.6	-1.0	4.8	1.3	9.5	0.0
22	15.4	-1.0	2.9	0.8	9.7	0.0
23	14.4	-0.2	3.6	1.0	9.7	0.0
24	14.8	-1.6	2.5	0.7	8.1	0.0
25	13.8	3.0	4.9	1.4	3.3	0.0
26	14.5	3.5	4.9	1.4	9.2	0.0
27	15.4	-1.2	2.1	0.6	9.8	0.0
28	15.4	4.0	1.7	0.5	2.5	0.0
29	16.2	1.4	3.2	0.9	7.8	0.0
30	17.4	1.8	2.5	0.7	8.0	0.0
31	17.0	2.0	3.4	0.9	9.0	0.0
32	17.4	1.4	3.8	1.1	9.3	0.0
33	17.8	0.6	4.4	1.2	4.4	1.2
34	11.8	8.5	3.4	0.9	0.0	1.2
35	19.0	4.5	6.0	1.7	6.3	0.0
36	13.0	7.8	3.3	0.9	0.0	0.8
37	15.6	8.0	2.6	0.7	0.0	0.0
38	13.0	4.6	5.1	1.4	0.0	0.0
39	14.5	2.8	5.5	1.5	7.3	0.0
40	16.4	2.8	6.7	1.9	9.2	0.0
41	17.0	2.6	4.1	1.1	9.8	0.0
42	18.0	0.8	3.3	0.9	10.4	0.0
43	18.0	1.2	6.7	1.9	10.4	0.0
44	19.0	1.6	4.3	1.2	10.7	0.0
45	20.6	2.2	3.6	1.0	10.3	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
46	21.6	5.2	4.1	1.1	9.1	0.0
47	20.8	6.2	4.0	1.1	5.3	0.0
48	22.5	9.0	3.3	0.9	7.8	0.0
49	22.5	6.8	3.2	0.9	9.7	0.0
50	23.6	7.4	3.0	0.8	10.5	0.0
51	25.4	7.0	2.0	0.6	9.6	0.0
52	24.2	10.2	9.4	2.6	8.2	0.0
53	22.6	14.6	13.3	3.7	0.0	0.0
54	23.8	15.2	5.3	1.5	0.0	0.0
55	23.0	10.8	3.3	0.9	4.3	0.0
56	22.6	9.4	5.0	1.4	7.4	0.0
57	22.2	7.2	4.2	1.2	10.2	0.0
58	25.4	7.6	3.2	0.9	10.4	0.0
59	27.0	8.8	2.5	0.7	10.5	0.0
60	27.8	10.0	2.5	0.7	9.5	0.0
61	30.0	10.6	3.5	1.0	9.7	0.0
62	29.8	14.8	4.1	1.1	8.7	0.0
63	29.0	14.5	2.9	0.8	5.1	0.0
64	28.6	11.4	2.6	0.7	9.8	0.0
65	28.8	12.0	2.5	0.7	10.0	0.0
66	30.4	11.4	6.6	1.8	10.5	0.0
67	28.2	16.4	4.7	1.3	5.0	0.0
68	27.5	16.0	2.4	0.7	3.6	0.0
69	27.2	12.8	2.7	0.8	9.6	0.0
70	28.0	13.0	3.6	1.0	9.7	0.0
71	28.8	13.2	4.9	1.4	9.2	0.0
72	28.8	14.4	3.8	1.1	7.5	0.0
73	29.2	14.6	4.8	1.3	7.3	0.0
74	28.8	15.4	2.5	0.7	9.8	0.0
75	28.8	13.4	3.5	1.0	9.3	0.0
76	31.8	13.8	2.5	0.7	10.2	0.0
77	33.6	13.6	2.3	0.6	9.8	0.0
78	34.0	15.0	2.6	0.7	10.1	0.0
79	32.2	16.5	4.1	1.1	8.8	0.0
80	31.2	12.8	2.8	0.8	10.7	0.0
81	31.2	12.8	4.2	1.2	10.3	0.0
82	31.5	13.6	3.8	1.1	10.2	0.0
83	30.8	13.6	3.8	1.1	11.3	0.0
84	31.4	14.0	3.3	0.9	10.8	0.0
85	32.0	14.2	1.7	0.5	10.6	0.0
86	31.0	15.2	4.3	1.2	9.6	0.0
87	32.4	15.6	3.4	0.9	9.7	0.0
88	32.5	14.8	3.3	0.9	11.0	0.0
89	31.8	15.8	3.1	0.9	8.8	0.0
90	33.4	15.0	2.4	0.7	10.5	0.0
91	29.6	15.4	7.0	1.9	6.3	0.0
92	29.6	19.8	8.0	2.2	8.6	0.0
93	32.0	16.8	13.1	3.6	10.0	5.4

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
94	23.5	16.8	3.6	1.0	0.0	4.2
95	26.6	15.5	11.3	3.1	8.5	10.2
96	23.4	16.6	12.1	3.4	4.1	30.4
97	25.0	13.2	4.0	1.1	11.8	0.0
98	28.5	14.0	3.2	0.9	10.9	0.0
99	31.4	16.8	5.4	1.5	10.8	0.0
100	32.5	18.6	5.3	1.5	7.5	0.0
101	33.3	17.4	6.4	1.8	9.3	0.0
102	33.8	19.6	5.7	1.6	10.8	0.0
103	35.0	20.0	3.8	1.1	11.6	0.0
104	35.2	18.4	3.6	1.0	12.0	0.0
105	34.6	17.6	8.4	2.3	6.2	0.0
106	32.8	19.4	8.5	2.4	9.3	0.0
107	29.4	17.9	7.4	2.1	10.6	0.0
108	32.2	13.4	4.2	1.2	12.3	0.0
109	35.0	15.2	4.9	1.4	11.8	0.0
110	36.4	16.0	3.4	0.9	11.8	0.0
111	37.2	16.8	4.7	1.3	12.0	0.0
112	38.8	17.2	4.9	1.4	11.8	0.0
113	38.8	18.5	4.8	1.3	12.0	0.0
114	39.5	19.8	3.8	1.1	11.4	0.0
115	39.2	20.4	4.0	1.1	11.8	0.0
116	39.2	18.8	5.3	1.5	12.0	0.0
117	40.0	20.0	4.2	1.2	9.0	0.0
118	38.0	19.6	5.1	1.4	12.0	0.0
119	39.8	18.2	2.5	0.7	12.2	0.0
120	41.0	19.5	3.8	1.1	11.8	0.0
121	41.5	20.0	2.9	0.8	12.0	0.0
122	41.6	20.4	4.4	1.2	10.3	0.0
123	40.0	22.4	4.1	1.1	9.5	0.0
124	42.2	21.5	3.7	1.0	11.8	0.0
125	41.7	23.0	7.6	2.1	9.2	1.6
126	35.8	23.8	9.9	2.8	5.5	2.7
127	38.4	21.6	4.1	1.1	11.4	0.0
128	38.5	22.8	5.3	1.5	10.7	0.0
129	40.5	26.0	7.3	2.0	5.4	0.0
130	36.4	22.2	5.4	1.5	10.0	0.0
131	36.2	23.6	4.7	1.3	8.4	0.0
132	37.5	22.6	5.7	1.6	7.6	0.0
133	39.0	24.0	6.7	1.9	9.9	0.2
134	34.6	23.5	4.7	1.3	7.2	0.0
135	35.5	23.4	5.3	1.5	5.5	0.0
136	39.0	25.4	3.3	0.9	8.5	0.0
137	41.0	26.2	3.4	0.9	8.7	0.0
138	41.2	24.4	5.8	1.6	10.5	0.0
139	38.6	27.4	11.0	3.1	1.5	0.0
140	29.8	24.4	12.7	3.5	0.0	24.4
141	22.5	18.8	6.0	1.7	0.0	32.4

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
142	28.4	20.6	8.6	2.4	3.0	5.6
143	27.5	22.6	9.1	2.5	1.1	0.0
144	32.6	22.6	9.6	2.7	11.3	0.0
145	33.8	22.2	4.5	1.3	11.1	0.0
146	31.2	23.8	6.0	1.7	4.2	0.0
147	35.7	21.8	4.3	1.2	9.5	0.4
148	36.2	22.4	9.5	2.6	8.9	0.0
149	37.7	19.6	3.1	0.9	12.8	0.0
150	39	21.6	4.2	1.2	8.6	0.0
151	39.2	21.4	3.6	1.0	12.8	0.0
152	40.0	24.0	5.7	1.6	7.2	0.0
153	31.8	26.8	5.6	1.6	1.2	0.0
154	36.6	24.8	3.9	1.1	3.4	0.0
155	39.5	25.6	5.7	1.6	4.6	0.0
156	39.2	26.0	7.1	2.0	7.8	2.2
157	36.2	25.0	10.0	2.8	7.2	0.0
158	35.5	25.0	9.3	2.6	3.5	4.2
159	37.6	28.0	10.3	2.9	3.6	0.0
160	36.4	26.0	10.9	3.0	10.5	0.0
161	33.6	24.8	6.2	1.7	6.4	0.0
162	36.8	26.5	6.9	1.9	7.0	0.0
163	39.0	28.8	8.3	2.3	7.6	0.0
164	38.0	29.4	8.0	2.2	4.4	4.8
165	34.5	28.2	8.7	2.4	3.8	13.6
166	28.4	23.8	4.5	1.3	0.0	29.0
167	26.6	24.8	9.8	2.7	0	32.6
168	32.5	24.2	4.4	1.2	5.4	0.0
169	34.5	26.4	9.7	2.7	10.8	0.0
170	34.0	26.4	10.7	3.0	8.7	0.0
171	32.6	27.0	9.5	2.6	0.0	13.8
172	32.4	22.0	4.2	1.2	0.0	0.0
173	33.2	23.8	5.3	1.5	10.7	0.0
174	34.0	23.6	3.2	0.9	9.7	0.0
175	36.5	26.8	2.5	0.7	11.3	21.8
176	34.4	22.0	6.8	1.9	5.5	55.0
177	32.5	23.0	3.5	1.0	3.7	0.6
178	36.4	28.2	5.5	1.5	6.4	93.0
179	32.0	23.0	9.0	2.5	4.2	1.6
180	31.6	25.4	8.2	2.3	8.2	0.0
181	31.6	24.2	6.6	1.8	6.6	5.1
182	31.6	24.0	3.5	1.0	8.1	0.0
183	34.6	26.0	2.7	0.8	10.6	10.6
184	36.2	28.0	3.6	1.0	10.5	10.5
185	35.8	29.6	9.2	2.6	3.3	3.3
186	33.4	29.0	9.7	2.7	0.7	0.7
187	33.0	29.2	7.4	2.1	0	0
188	32.0	27.0	7.7	2.1	0	0
189	32.0	27.4	4.5	1.3	3	3

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
190	36.6	26.6	6.6	1.8	9	9
191	33.5	27.0	7.3	2.0	6.8	6.8
192	35.0	26.0	3.0	0.8	2.8	2.8
193	34.5	24.0	4.7	1.3	7.3	7.3
194	30.8	24.4	6.1	1.7	0	0
195	33.5	25.0	3.3	0.9	9.9	9.9
196	34.2	24.2	2.5	0.7	8.2	8.2
197	35.6	27.4	3.9	1.1	9.5	9.5
198	35.5	27.6	3.6	1.0	6.3	6.3
199	35.8	27.0	5.0	1.4	8.3	8.3
200	36.0	26.4	3.0	0.8	9.6	9.6
201	33.6	29.4	5.3	1.5	5.2	5.2
202	34.0	27.2	6.7	1.9	4	4
203	32.0	23.6	2.8	0.8	2.8	2.8
204	34.0	25.8	2.7	0.8	11.6	11.6
205	35.7	30.6	3.5	1.0	11.1	11.1
206	36.0	29.4	5.1	1.4	11	11
207	36.6	28.4	4.3	1.2	10	10
208	36.0	28.0	6.9	1.9	6.8	6.8
209	33.4	27.5	7.7	2.1	10	10
210	31.6	27.0	3.3	0.9	1.9	1.9
211	34.5	27.4	3.1	0.9	9.2	9.2
212	32.4	26.4	7.6	2.1	0.5	0.5
213	30.7	27.4	10.3	2.9	0.9	0.9
214	32.5	26.0	5.6	1.6	9.5	0.0
215	34.8	27.0	4.5	1.3	10.5	0.0
216	31.5	24.0	4.1	1.1	1.9	51.6
217	34.3	25.0	6.1	1.7	9.2	0.6
218	30.0	25.6	4.1	1.1	1.3	0.0
219	32.6	25.6	3.0	0.8	5.7	3.0
220	33.0	25.8	4.2	1.2	4.5	0.0
221	30.0	27.0	6.2	1.7	4.4	0.0
222	34.0	26.4	3.0	0.8	8.5	0.0
223	35.0	27.8	4.2	1.2	10.4	0.0
224	32.4	25.5	5.3	1.5	3.9	44.4
225	31.4	25.0	7.9	2.2	0.0	61.4
226	29.5	22.5	6.3	1.8	0.0	84.2
227	26.5	23.0	5.7	1.6	0.8	81.4
228	30.5	23.0	5.2	1.4	11.5	2.0
229	31.8	25.0	3.6	1.0	4.7	9.0
230	32.8	25.0	4.2	1.2	10.7	0.0
231	33.8	25.8	2.7	0.8	8.9	0.0
232	34.2	25.0	3.3	0.9	11.3	0.0
233	33.2	26.6	4.9	1.4	9.6	0.0
234	34.2	26.6	5.3	1.5	8.3	0.0
235	34.0	26.4	5.1	1.4	3.2	6.2
236	33.5	26.6	2.7	0.8	7.7	0.0
237	34.0	25.4	2.7	0.8	10.4	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
238	35.2	28.0	3.1	0.9	11.0	0.0
239	36.0	27.8	2.9	0.8	11.0	0.0
240	36.4	27.6	3.1	0.9	11.0	0.0
241	35.0	26.0	4.9	1.4	11.7	0.0
242	34.8	27.6	4.0	1.1	10.6	0.0
243	33.0	27.2	4.2	1.2	5.2	49.0
244	28.8	21.0	3.5	1.0	3.4	0.0
245	32.0	22.2	3.1	0.9	11.3	0.0
246	33.2	24.4	3.3	0.9	10.3	0.0
247	34.4	25.6	4.8	1.3	11.3	0.0
248	35.0	24.6	2.4	0.7	11.4	0.0
249	35.0	26.4	10.5	2.9	10.5	21.7
250	30.2	19.2	1.8	0.5	8.7	3.2
251	29.2	22.0	3.9	1.1	6.0	0.0
252	31.5	22.6	3.0	0.8	10.1	0.0
253	32.2	22.7	3.1	0.9	11.0	0.0
254	33.2	21.8	2.4	0.7	11.7	0.0
255	34.0	23.2	3.1	0.9	11.5	0.0
256	34.4	24.2	5.9	1.6	11.3	0.0
257	33.6	24.6	2.0	0.6	5.7	0.0
258	34.0	25.8	2.0	0.6	7.0	0.0
259	33.8	25.0	1.6	0.4	7.9	0.0
260	34.0	26.0	1.9	0.5	8.5	0.0
261	31.0	22.6	3.9	1.1	2.0	12.0
262	31.8	22.4	5.9	1.6	1.7	0.0
263	22.6	21.0	6.5	1.8	0.0	7.8
264	28.4	19.0	4.7	1.3	11.2	0.0
265	31.0	20.7	2.7	0.8	11.2	0.0
266	31.2	21.6	5.1	1.4	9.7	0.0
267	30.4	18.8	5.6	1.6	10.7	0.0
268	31.6	18.6	1.6	0.4	10.9	0.0
269	32.0	20.5	3.3	0.9	10.0	0.0
270	33.0	21.0	2.5	0.7	9.8	0.0
271	34.0	22.2	2.1	0.6	9.0	0.0
272	34.0	23.0	2.5	0.7	9.5	0.0
273	34.0	23.6	2.7	0.8	9.3	0.0
274	33.8	24.4	2.2	0.6	8.1	0.0
275	35.0	24.4	1.8	0.5	8.2	0.0
276	34.5	24.5	1.3	0.4	7.6	0.0
277	34.2	24.6	1.6	0.4	4.6	0.0
278	34.4	24.6	2.5	0.7	3.0	0.0
279	33.0	24.0	4.0	1.1	3.1	19.8
280	32.0	21.0	5.5	1.5	8.5	0.0
281	32.0	22.4	4.6	1.3	9.0	0.0
282	33.2	22.8	3.0	0.8	7.2	0.0
283	33.2	19.8	1.3	0.4	9.1	0.0
284	33.2	21.5	2.5	0.7	9.1	0.0
285	33.0	19.2	1.9	0.5	8.2	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
286	34.5	21.0	1.7	0.5	8.2	0.0
287	34.4	21.4	4.5	1.3	7.0	0.0
288	31.8	23.4	10.8	3.0	3.6	0.0
289	31.2	21.6	10.3	2.9	9.7	19.2
290	27.2	17.0	2.9	0.8	6.6	0.0
291	30.0	15.4	2.9	0.8	10.3	0.0
292	30.4	15.2	1.7	0.5	10.3	0.0
293	31.0	15.4	1.8	0.5	10.2	0.0
294	30.8	15.5	1.2	0.3	9.0	0.0
295	30.8	17.0	1.5	0.4	8.3	0.0
296	31.6	17.4	1.5	0.4	8.0	0.0
297	30.6	17.4	1.5	0.4	8.1	0.0
298	31.4	16.5	1.4	0.4	7.8	0.0
299	30.8	16.6	1.9	0.5	7.5	0.0
300	29.4	16.2	1.3	0.4	6.0	0.0
301	30.0	16.0	4.5	1.3	6.0	0.0
302	30.0	16.8	5.3	1.5	3.6	0.0
303	30.0	18.8	2.7	0.8	1.8	0.0
304	29.0	16.8	1.7	0.5	0.0	0.0
305	29.6	15.5	3.6	1.0	7.9	0.0
306	31.0	13.8	3.9	1.1	9.4	0.0
307	31.5	13.4	1.5	0.4	8.1	0.0
308	31.0	14.4	2.2	0.6	8.0	0.0
309	30.6	13.5	3.4	0.9	9.5	0.0
310	31.0	11.5	1.9	0.5	8.5	0.0
311	31.0	11.6	1.0	0.3	6.6	0.0
312	29.4	13.2	1.0	0.3	6.3	0.0
313	29.0	12.8	1.2	0.3	6.9	0.0
314	29.0	12.8	0.8	0.2	5.7	0.0
315	29.6	13.0	1.7	0.5	7.3	0.0
316	28.5	13.2	1.0	0.3	0.0	0.0
317	28.8	12.6	3.2	0.9	4.3	0.0
318	27.4	16.4	7.3	2.0	0.0	0.0
319	27.2	16.4	3.5	1.0	0.0	0.0
320	26.6	12.0	1.3	0.4	3.7	0.0
321	27.5	11.2	0.7	0.2	7.4	0.0
322	27.2	11.0	1.7	0.5	6.7	0.0
323	27.5	10.0	1.5	0.4	8.1	0.0
324	27.2	9.4	2.5	0.7	3.7	0.4
325	24.4	13.8	8.9	2.5	6.4	0.0
326	23.5	8.4	3.7	1.0	8.4	0.0
327	23.8	7.0	4.0	1.1	8.6	0.0
328	25.0	7.0	2.8	0.8	9.3	0.0
329	25.4	8.0	3.3	0.9	8.9	0.0
330	25.2	8.4	1.8	0.5	4.1	0.0
331	25.8	7.6	3.9	1.1	6.0	0.0
332	24.4	7.6	1.0	0.3	4.9	0.0
333	26.0	8.0	3.4	0.9	8.1	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
334	26.2	7.0	3.0	0.8	8.2	0.0
335	27.0	7.0	1.6	0.4	8.0	0.0
336	24.4	8.2	1.3	0.4	6.7	0.0
337	24.4	7.6	1.4	0.4	5.8	0.0
338	25.0	7.6	1.8	0.5	7.3	0.0
339	25.6	7.2	1.8	0.5	8.3	0.0
340	26.6	6.5	1.1	0.3	7.5	0.0
341	26.0	8.5	3.4	0.9	5.7	0.0
342	22.0	10.6	2.9	0.8	0.0	0.0
343	24.6	11.5	4.1	1.1	0.0	0.0
344	24.0	11.8	2.0	0.6	6.4	0.0
345	24.0	11.6	2.6	0.7	4.7	0.0
346	21.8	9.4	3.0	0.8	6.9	0.0
347	23.0	6.4	1.6	0.4	8.9	0.0
348	23.0	5.6	1.2	0.3	8.1	0.0
349	21.0	5.2	3.4	0.9	7.3	0.0
350	23.5	7.2	3.9	1.1	8	0.4
351	18.2	8.2	4.0	1.1	0.0	0.0
352	23.0	10.2	3.0	0.8	6.9	0.0
353	24.4	10.0	6.8	1.9	6.1	0.o
354	19.4	16.2	4.6	1.3	0.0	0.0
355	18.2	15.0	4.8	1.3	0.0	0.0
356	21.2	12.0	4.6	1.3	5.5	0.0
357	20.8	8.0	3.4	0.9	9.0	0.0
358	21.2	5.8	2.3	0.6	8.2	0.0
359	21.4	4.8	1.9	0.5	8.1	0.0
360	21.6	7.8	1.5	0.4	6.9	0.0
361	19.6	4.8	1.5	0.4	5.5	0.0
362	18.5	7.0	0.5	0.1	3.7	0.0
363	12.0	7.6	4.3	1.2	0.0	0.0
364	12.5	7.0	3.9	1.1	1.1	0.0
365	11.4	7.5	4.0	1.1	0.0	0.0
366	15	9.0	3.3	0.9	5.2	0.0

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Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
1	15.0	5.4	2.5	0.7	4.7	0.0
2	17.0	4.4	1.6	0.4	2.0	0.0
3	12.5	6.5	3.5	1.0	0.8	1.0
4	21.6	8.2	3.9	1.1	6.0	2.2
5	19.4	7.6	3.6	1.0	8.0	0.0
6	18.2	5.0	2.0	0.6	8.1	0.0
7	18.6	3.8	1.8	0.5	8.0	0.0
8	17.4	4.0	2.3	0.6	7.6	0.0
9	17.8	3.0	3.1	0.9	2.5	0.0
10	18.4	8.0	2.9	0.8	3.8	0.0
11	20.0	6.8	2.3	0.6	7.0	0.0
12	19.6	5.4	3.0	0.8	8.3	0.0
13	20.6	5.0	2.7	0.8	8.0	0.0
14	21.4	7.0	3.6	1.0	8.6	0.0
15	22.0	7.2	3.4	0.9	8.7	0.0
16	19.8	11.0	7.0	1.9	0.0	3.5
17	21.6	12.6	3.9	1.1	4.6	0.6
18	19.2	10.8	5.1	1.4	2.3	10.4
19	19.0	12.0	5.4	1.5	8.1	0.0
20	18.4	5.2	4.0	1.1	8.6	0.0
21	19.6	5.8	3.4	0.9	7.3	0.0
22	20.8	8.4	3.1	0.9	5.8	0.0
23	20.8	10.2	7.1	2.0	5.1	0.0
24	21.0	13.2	6.7	1.9	1.1	0.0
25	21.0	12.0	7.5	2.1	3.2	0.0
26	20.8	13.8	2.9	0.8	4.2	0.0
27	21.4	7.2	5.0	1.4	6.5	0.0
28	20.0	9.8	3.8	1.1	7.7	0.0
29	22.0	7.0	2.1	0.6	9.2	0.0
30	20.8	5.8	3.3	0.9	9.1	0.0
31	20.4	7.5	4.7	1.3	8.3	0.0
32	21.4	5.8	3.5	1.0	10.6	0.0
33	21.5	5.2	2.7	0.8	8.5	0.0
34	23.0	6.6	2.4	0.7	9.2	0.0
35	26.0	6.6	5.4	1.5	7.3	0.0
36	23.8	14.2	8.3	2.3	3.4	2.5
37	21.6	14.2	5.2	1.4	6.5	0.0
38	21.6	7.6	4.1	1.1	10.5	0.0
39	21.5	5.4	2.2	0.6	9.8	0.0
40	21.2	8.4	3.8	1.1	5.9	0.0
41	21.0	10.0	6.4	1.8	1.6	14.0
42	20.0	9.8	2.9	0.8	7.8	0.0
43	21.2	8.4	3.6	1.0	9.3	0.0
44	24.6	7.5	5.4	1.5	10.0	5.2
45	21.4	10.0	3.7	1.0	9.9	0.0
46	20.4	7.6	4	1.1	8.0	0.0
47	21.2	6.4	3.2	0.9	10.5	0.0
48	22.4	7.9	3.7	1.0	10.2	0.0
49	23.4	7.4	4.1	1.1	10.6	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
50	23.8	7.8	4.8	1.3	10.2	0.0
51	26.4	12.0	4.7	1.3	10.1	0.0
52	25.4	10.8	4.4	1.2	9.6	0.0
53	26.0	11.0	3.2	0.9	8.1	0.0
54	27.6	11.4	2.1	0.6	8.5	0.0
55	24.2	11.4	2.5	0.7	0.7	0.0
56	25.4	12.2	5.0	1.4	10.5	0.0
57	24.6	10.2	4.2	1.2	10.5	0.0
58	24.8	8.0	4.7	1.3	10.5	0.0
59	24.2	6.8	5.9	1.6	11.1	0.0
60	25.8	6.6	3.7	1.0	9.0	0.0
61	27.4	11.0	3.4	0.9	9.2	0.0
62	28.6	11.6	10.0	2.8	9.5	0.0
63	28.6	18.2	3.2	0.9	4.3	0.0
64	27.0	15.4	4.7	1.3	8.5	0.0
65	29.4	10.6	5.2	1.4	10.7	0.0
66	28.0	13.8	3.8	1.1	9.8	0.0
67	27.0	10.4	3.3	0.9	9.6	0.0
68	26.8	9.4	2.7	0.8	9.9	0.0
69	27.2	10.6	4.0	1.1	9.8	0.0
70	28.0	9.2	4.5	1.3	10.8	0.0
71	28.4	9.2	4.5	1.3	10.9	0.0
72	31.4	10.2	1.5	0.4	10.5	0.0
73	31.6	12.4	1.7	0.5	8.4	0.0
74	30.0	12.2	3.2	0.9	10.0	0.0
75	31.2	13.2	1.7	0.5	8.2	0.0
76	31.0	13.2	3.2	0.9	10.7	0.0
77	31.6	13.8	2.7	0.8	7.7	0.0
78	31.6	16.4	2.5	0.7	7.9	0.0
79	33.2	17.0	5.2	1.4	10.6	4.2
80	28.2	13.6	2.4	0.7	11.3	0.0
81	30.0	13.6	2.9	0.8	6.9	0.0
82	30.6	15.0	2.7	0.8	9.2	0.0
83	33.0	15.4	6.8	1.9	7.7	6.0
84	25.0	16.2	5.3	1.5	4.9	1.4
85	27.6	12.0	2.9	0.8	11.6	0.0
86	26.0	15.0	3.5	1.0	0.0	3.0
87	27.0	12.6	3.6	1.0	3.1	1.0
88	24.6	16.0	3.1	0.9	5.8	0.4
89	29.2	14.4	4.5	1.3	10.7	0.0
90	31.0	14.0	5.6	1.6	10.5	0.0
91	33.0	14.8	4.1	1.1	10.6	0.0
92	35.0	17.6	7.1	2.0	11.6	0.0
93	34.4	19.0	4.2	1.2	11.4	0.0
94	32.6	17.2	6.5	1.8	8.1	0.0
95	31.8	14.0	4.6	1.3	5.7	0.8
96	26.8	17.6	5.9	1.6	2.6	8.6
97	31.6	12.0	6.8	1.9	11.6	0.0
98	30.2	17.4	8.9	2.5	1.6	15.6
99	24.8	14.6	3.9	1.1	9.0	0.0
100	29.4	12.2	5.0	1.4	12.8	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
101	33.2	14.6	4.5	1.3	12.0	0.0
102	35.6	17.2	3.7	1.0	10.6	0.0
103	35.8	18.2	4.1	1.1	12.0	0.0
104	39.8	18.2	4.2	1.2	12.0	0.0
105	37.4	19.8	8.7	2.4	11.4	0.0
106	34.0	21.5	5.4	1.5	10.0	0.0
107	35.0	17.2	5.8	1.6	12.0	0.0
108	36.8	17.0	8.0	2.2	12.0	0.0
109	39.2	17.4	6.9	1.9	11.7	0.0
110	38.6	20.0	10.7	3.0	11.0	0.0
111	36.8	23.8	7.1	2.0	10.3	0.0
112	36.8	20.0	4.5	1.3	10.7	0.0
113	36.2	18.0	5.7	1.6	11.1	0.0
114	35.2	16.4	5.9	1.6	12.3	0.0
115	35.4	14.4	4.8	1.3	12.5	0.0
116	37.8	15.2	5.9	1.6	11.0	0.0
117	40.8	18.4	3.5	1.0	10.5	0.0
118	40.0	21.2	4.9	1.4	7.8	0.0
119	41.4	21.5	2.9	0.8	8	0.0
120	40.2	21.4	4.1	1.1	11.0	0.0
121	41.2	21.5	6.3	1.8	10.0	0.0
122	42.2	21.2	6.6	1.8	8.3	1.0
123	35.0	27.6	8.7	2.4	5.4	1.2
124	34.0	22.0	12.1	3.4	4.5	4.2
125	33.6	18.6	4.6	1.3	10.0	0.0
126	35.0	18.4	7.8	2.2	11.2	0.0
127	35.5	19.4	5.2	1.4	10.8	0.0
128	37.0	19.8	4.6	1.3	7.2	0.0
129	38.0	20.0	6.3	1.8	9.8	0.0
130	38.0	25.2	5.9	1.6	8.3	0.0
131	37.0	21.0	6.5	1.8	11.2	0.0
132	37.6	19.7	5.0	1.4	12.3	0.0
133	38.0	19.8	9.1	2.5	10.8	0.0
134	39.6	26.0	10.2	2.8	10.4	0.0
135	38.0	27.4	9.3	2.6	8.8	0.0
136	41.0	24.8	5.8	1.6	11.2	0.0
137	42.0	25.8	4.4	1.2	10.7	0.0
138	42.6	24.0	6.2	1.7	10.6	0.0
139	44.0	25.0	10.0	2.8	8.1	0.0
140	43.0	25.4	6.6	1.8	8.7	0.0
141	42.4	28.0	6.2	1.7	7.2	0.0
142	42.0	24.4	7.8	2.2	9.4	0.0
143	40.0	26.2	7.6	2.1	6.8	0.0
144	40.4	25.8	11.1	3.1	8.3	0.0
145	37.6	23.8	5.5	1.5	6.8	0.0
146	39.2	21.4	5.4	1.5	10.3	0.0
147	42.0	22.4	5.8	1.6	9.5	0.0
148	41.5	27.0	9.1	2.5	10.1	0.0
149	39.5	26.2	14.1	3.9	9.0	0.0
150	33.8	24.4	13.7	3.8	10.0	0.0
151	38.2	25.0	7.4	2.1	8.2	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
152	31.6	22.0	4.3	1.2	5.8	0.0
153	32.2	24.8	3.2	0.9	4.1	0.0
154	34.2	26.0	2.7	0.8	6.7	0.0
155	36.6	25.8	3.7	1.0	12.5	0.0
156	36.8	24.6	4.8	1.3	13.0	0.0
157	39.0	26.0	2.9	0.8	13.0	0.0
158	39.4	28.1	7.1	2.0	12.4	0.0
159	36.5	30.5	12.5	3.5	10.3	0.0
160	33.2	22.0	5.4	1.5	3.5	0.0
161	33.0	27.6	6.6	1.8	7.1	0.0
162	31.6	24.0	3.2	0.9	5.2	0.0
163	36.2	27.7	7.5	2.1	9.9	0.0
164	34.0	26.4	8.9	2.5	9.9	0.0
165	30.2	23.4	2.1	0.6	1.6	0.0
166	34.4	26.6	6.5	1.8	11.4	6.0
167	37.0	28.0	2.5	0.7	10.6	0.0
168	35.7	30.0	7.0	1.9	5.8	0.0
169	35.5	26.0	6.4	1.8	8.3	0.0
170	36.2	27.2	4.1	1.1	10.8	0.0
171	33.4	26.6	8.6	2.4	5.5	0.0
172	32.0	23.2	3.3	0.9	4.4	0.0
173	33.8	27.2	5.3	1.5	8.2	0.0
174	30.6	26.4	5.7	1.6	3.0	0.0
175	31.0	27.6	5.4	1.5	5.5	0.0
176	34.0	27.6	1.8	0.5	5.9	0.0
177	35.8	28.0	2.8	0.8	12.6	0.0
178	33.0	26.0	8.4	2.3	2.3	0.0
179	28.4	23.7	6.3	1.8	0.0	0.0
180	26.4	23.8	5.9	1.6	0.8	30.6
181	32.2	22.6	2.2	0.6	7.1	74.0
182	33.6	22.8	2.7	0.8	10.7	0
183	34.0	27.8	4.2	1.2	9.6	2.0
184	34.2	26.4	3.1	0.9	9.4	0.0
185	34.6	29.4	3.2	0.9	4.6	0.0
186	35.5	28.4	4.2	1.2	5.7	0.0
187	34.0	28.6	4.7	1.3	3.4	0.0
188	35.6	28.4	3.5	1.0	7.3	0.0
189	35.4	27.5	4.6	1.3	10.3	0.0
190	37.0	29.2	3.2	0.9	10.3	0.0
191	36.8	29.0	3.8	1.1	7.5	26.4
192	36.8	28.8	3.9	1.1	9.9	4.2
193	34.0	28.4	3.7	1.0	3.6	9.2
194	36.8	28.8	2.3	0.6	7.2	1.6
195	36.8	30.6	4.4	1.2	5.2	20.5
196	36.2	30.4	6.6	1.8	4.6	0.0
197	30.4	27.0	9.4	2.6	0.0	0.0
198	32.0	26.2	4.3	1.2	1.4	0.0
199	33.8	27.8	3.2	0.9	3.1	5.6
200	35.4	26.8	4.6	1.3	7.0	11.0
201	29.2	22.2	2.9	0.8	2.9	1.4
202	33.2	23.6	3.0	0.8	12.0	82.8

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
203	32.5	23.2	3.5	1.0	5.4	1.8
204	33.0	24.0	3.3	0.9	10.0	0.0
205	34.8	26.0	3.3	0.9	11.4	0.0
206	34.8	25.8	3.2	0.9	10.3	0.0
207	33.0	27.0	5.5	1.5	8.9	14.0
208	34.0	26.5	3.9	1.1	11.8	0.0
209	32.4	24.0	3.6	1.0	6.6	157.6
210	34.4	26.4	4.3	1.2	9.4	22.8
211	33.4	26.0	2.0	0.6	0	115.2
212	32.2	24.0	5.2	1.4	3.7	17.0
213	32.4	24.4	5.2	1.4	1.2	0.0
214	32.0	24.0	2.1	0.6	8.1	6.0
215	33.4	25.8	3.3	0.9	8.1	0.0
216	31.8	25.8	7.2	2.0	5.3	0.0
217	30.8	21.4	2.5	0.7	7.1	0.0
218	32.0	23.6	2.5	0.7	11.5	0.0
219	32.0	22.2	3.4	0.9	11.7	0.0
220	33.0	22.6	3.6	1.0	11.7	0.0
221	33.8	23.4.	6.4	1.8	11.2	0.0
222	26.4	24.4	5.0	1.4	0.0	0.0
223	27.6	22.4	7.9	2.2	1.9	0.0
224	23.6	22.0	4.0	1.1	0.0	0.0
225	29.0	22.0	2.2	0.6	5.5	0.0
226	31.6	23.4	2.8	0.8	10.1	0.0
227	33.2	23.4	2.3	0.6	11.0	0.0
228	35.2	21.2	2.1	0.6	10.5	0.0
229	32.4	22.6	3.0	0.8	10.3	0.0
230	33.0	20.5	2.1	0.6	11.3	0.0
231	33.0	22.4	1.8	0.5	10.7	22.4
232	34.6	23.8	2.8	0.8	9.9	2.4
233	35.0	24.4	2.7	0.8	9.5	0.0
234	34.4	26.2	3.1	0.9	8.8	6.2
235	35.0	26.6	3.4	0.9	6.6	0.0
236	34.8	26.0	1.8	0.5	5.9	0.0
237	34.8	26.6	2.3	0.6	7.4	0.0
238	34.4	26.0	3.2	0.9	9.0	0.0
239	34.4	26.0	2.1	0.6	9.0	31.0
240	34.2	24.0	2.0	0.6	10.2	0.0
241	34.2	22.5	2.8	0.8	10.0	2.0
242	35.8	24.5	2.2	0.6	10.0	1.0
243	35.4	23.2	1.6	0.4	11.1	33.6
244	34.6	23.4	2.1	0.6	7.5	13.6
245	35.2	26.0	1.0	0.3	7.9	0.0
246	34.6	25.0	2.9	0.8	10.3	0.0
247	31.8	18.9	3.6	1.0	4.2	6.8
248	31.2	20.7	0.7	0.2	8.5	0.0
249	31.5	21.6	2.0	0.6	9.4	0.0
250	31.8	20.4	2.6	0.7	9.8	0.0
251	32.8	20.4	1.7	0.5	9.8	0.0
252	33.5	19.0	2.1	0.6	9.5	0.0
253	33.6	19.8	1.4	0.4	10.0	0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
254	33.0	18.8	1.2	0.3	8.5	35.6
255	32.0	17.0	1.7	0.5	9.6	26.8
256	32.4	17.4	1.7	0.5	8.8	0
257	32.5	16.8	2.0	0.6	9.2	0.0
258	32.6	17.0	1.6	0.4	8.3	0.0
259	32.2	17.0	2.2	0.6	7.8	0.0
260	31.6	15.2	3.3	0.9	8.6	0.0
261	31.4	16.0	2.7	0.8	7.4	0.0
262	31.0	15.0	2.7	0.8	8.1	0.0
263	31.4	13.8	2.5	0.7	8.2	0.0
264	31.4	13.4	2.5	0.7	8.5	0.0
265	31.0	12.8	2.4	0.7	9.1	0.0
266	30.6	12.0	3.1	0.9	8.9	0.0
267	30.5	11.5	2.3	0.6	9.1	0.0
268	30.0	11.4	1.7	0.5	9.4	0.0
269	30.2	10.7	2.7	0.8	9.3	0.0
270	29.8	10.4	2.4	0.7	8.8	0.0
271	29.8	10.5	2.0	0.6	9.1	0.0
272	31.0	11.8	3.6	1.0	9	0.0
273	30.0	12.5	3.7	1.0	9.1	0.0
274	31.5	12.2	2.4	0.7	7.9	0.0
275	31.4	15.4	1.9	0.5	4.7	0.0
276	30.0	15.0	2.1	0.6	3.9	0.0
277	30.2	14.8	1.2	0.3	4.6	26.2
278	30.4	13.8	0.7	0.2	5.9	0.0
279	27.8	13.6	0.8	0.2	0.0	0.0
280	28.0	12.6	0.8	0.2	3.2	0.0
281	27.4	12.6	1.6	0.4	2.8	0.0
282	22.0	13.2	2.3	0.6	0.0	0.0
283	24.4	15.8	6.5	1.8	2.4	0.0
284	24.2	12.6	3.5	1.0	0.0	0.0
285	25.0	8.5	3.4	0.9	8.6	0.0
286	26.2	8.4	2.7	0.8	6.3	0.0
287	25.0	11.8	2.0	0.6	1.0	0.0
288	20.0	16.8	6.0	1.7	0.0	0.0
289	22.0	15.0	1.6	0.4	3.2	0.0
290	25.0	12.5	1.4	0.4	6.6	0.0
291	24.6	9.5	1.8	0.5	7.6	0.0
292	23.8	8.5	3.4	0.9	8.2	0.0
293	23.0	7.4	4.0	1.1	9.0	0.0
294	23.4	6.4	3.0	0.8	9.9	0.0
295	23.6	6.4	1.5	0.4	7.9	0.0
296	21.0	7.2	0.4	0.1	0.0	0.0
297	24.0	7.2	1.7	0.5	7.8	0.0
298	24.6	7.0	2.1	0.6	7.5	0.0
299	26.4	8.5	1.3	0.4	7.9	0.0
300	24.6	8.6	2.0	0.6	7.2	0.0
301	23.4	6.4	3.6	1.0	7.0	0.0
302	22.0	6.8	0.4	0.1	0.0	0.0
303	23.0	7.4	4.8	1.3	5.1	0.0
304	25.6	8.0	0.4	0.1	4.0	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
305	22.0	7.6	0.5	0.1	0.0	0.0
306	24.0	7.8	1.3	0.4	6.8	0.0
307	25.6	8.0	1.1	0.3	8.0	0.0
308	26.0	10.8	0.6	0.2	2.8	0.0
309	23.5	10.0	1.0	0.3	1.6	0.0
310	25.2	10.0	0.7	0.2	5.7	0.0
311	21.6	6.6	3.4	0.9	8.3	0.0
312	22.5	3.8	0.9	0.3	9.0	0.0
313	20.0	6.8	1.1	0.3	0.0	1.0
314	22.0	11.2	1.2	0.3	4.8	0.0
315	22.6	9.4	2.5	0.7	6.6	0.0
316	20.6	9.2	2.1	0.6	0.0	0.0
317	21.8	8.6	0.9	0.3	8.8	0.0
318	19.5	5.6	1.3	0.4	2.2	1.1
319	22.6	10.6	0.9	0.3	5.9	3.0
320	22.0	6.8	1.9	0.5	7.5	0.0
321	22.0	6.5	2.0	0.6	8.0	0.0
322	21.0	6.2	1.7	0.5	7.2	0.0
323	21.5	5.6	1.7	0.5	4.3	0.0
324	19.5	6.4	2.1	0.6	3.1	0.0
325	19.2	4.0	3.5	1.0	7.8	0.0
326	19.8	4.0	2.3	0.6	8.4	0.0
327	20.2	4.2	0.8	0.2	8.0	0.0
328	19.6	4.8	7.0	1.9	6.9	0.0
329	19.2	2.7	2.8	0.8	7.2	0.0
330	20.5	5.4	1.5	0.4	6.3	0.0
331	19.6	14.8	0.9	0.3	2.5	0.0
332	17.4	2.0	1.9	0.5	5.6	0.0
333	18.4	2.6	2.0	0.6	6.8	0.0
334	18.0	4.8	1.8	0.5	3.6	0.0
335	18.5	3.2	3.0	0.8	5.5	0.0
336	22.0	7.6	0.5	0.1	0.0	0.0
337	24.0	7.8	1.3	0.4	6.8	0.0
338	25.6	8.0	1.1	0.3	8.0	0.0
339	26.0	10.8	0.6	0.2	2.8	0.0
340	23.5	10.0	1.0	0.3	1.6	0.0
341	25.2	10.0	0.7	0.2	5.7	0.0
342	21.6	6.6	3.4	0.9	8.3	0.0
343	22.5	3.8	0.9	0.3	9.0	0.0
344	20.0	6.8	1.1	0.3	0.0	0.0
345	22.0	11.2	1.2	0.3	4.8	0.0
346	22.6	9.4	2.5	0.7	6.6	0.0
347	20.6	9.2	2.1	0.6	0.0	0.0
348	21.8	8.6	0.9	0.3	8.8	0.0
349	19.5	5.6	1.3	0.4	2.2	0.0
350	22.6	10.6	0.9	0.3	5.9	0.0
351	22.0	6.8	1.9	0.5	7.5	0.0
352	22.0	6.5	2.0	0.6	8.0	0.0
353	21.0	6.2	1.7	0.5	7.2	0.0
354	21.5	5.6	1.7	0.5	4.3	0.0
355	19.5	6.4	2.1	0.6	3.1	0.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
356	19.2	4.0	3.5	1.0	7.8	0.0
357	19.8	4.0	2.3	0.6	8.4	0.0
358	20.2	4.2	0.8	0.2	8.0	0.0
359	19.6	4.8	7.0	1.9	6.9	0.0
360	19.2	2.7	2.8	0.8	7.2	0.0
361	20.5	5.4	1.5	0.4	6.3	0.0
362	19.6	14.8	0.9	0.3	2.5	0.0
363	17.4	2.0	1.9	0.5	5.6	0.0
364	18.4	2.6	2.0	0.6	6.8	0.0
365	18.0	4.8	1.8	0.5	3.6	0.0

Weather data 2010

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
1	19.4	04.4	3.9	1.1	05.6	000.0
2	13.4	08.4	3.1	0.9	00.0	008.6
3	13.0	09.8	5.3	1.5	00.0	009.8
4	13.6	08.2	7.2	2.0	00.0	000.0
5	14.0	07.6	3.2	0.9	03.9	000.0
6	12.0	06.7	2.1	0.6	00.0	000.0
7	14.2	04.6	3.0	0.8	00.0	000.0
8	10.2	07.0	3.7	1.0	00.0	000.0
9	10.2	06.7	4.0	1.1	00.0	000.0
10	10.2	07.0	2.7	0.8	00.0	000.0
11	08.6	06.4	3.0	0.8	00.0	000.0
12	10.6	06.5	3.2	0.9	00.0	000.0
13	15.0	07.2	2.0	0.6	02.1	000.0
14	18.2	03.8	4.0	1.1	06.0	000.0
15	17.5	05.4	3.3	0.9	06.7	000.0
16	19.4	03.8	4.3	1.2	08.1	000.0
17	16.0	06.0	3.5	1.0	00.0	000.0
18	12.6	07.4	3.5	1.0	00.0	000.0
19	10.0	06.0	7.8	2.2	00.0	000.0
20	14.6	05.6	1.5	0.4	01.0	000.0
21	13.6	04.2	2.6	0.7	03.0	000.0
22	16.5	06.0	2.0	0.6	03.0	000.0
23	12.8	05.8	2.1	0.6	00.0	000.0
24	18.0	06.0	1.3	0.4	03.3	000.0
25	21.2	05.6	1.2	0.3	06.7	000.0
26	21.4	05.0	1.7	0.5	07.4	000.0
27	22.4	07.6	1.9	0.5	04.6	000.0
28	24.4	09.4	5.4	1.5	04.2	000.0
29	23.0	14.0	5.1	1.4	03.2	000.0
30	21.2	08.0	4.2	1.2	08.7	000.0
31	20.2	05.6	2.1	0.6	09.5	000.0
32	21.0	05.7	1.3	0.4	05.6	000.0
33	20.0	05.4	3.0	0.8	08.7	000.0
34	20.8	04.6	3.0	0.8	09.9	000.0
35	21.2	05.6	3.1	0.9	08.6	000.0
36	22.0	06.8	2.8	0.8	06.9	000.0
37	24.0	09.4	1.2	0.3	03.8	000.0
38	22.4	13.2	9.4	2.6	00.0	002.0
39	18.4	14.4	15.1	4.2	00.0	023.0
40	19.0	14.2	6.8	1.9	07.2	000.0
41	19.0	05.8	1.1	0.3	01.1	000.0
42	20.2	07.2	2.2	0.6	08.0	000.0
43	20.8	08.2	2.2	0.6	07.8	000.0
44	21.6	07.2	2.2	0.6	08.6	000.0
45	20.4	06.6	2.3	0.6	08.9	000.0
46	22.4	07.4	4.4	1.2	08.7	000.0
47	23.8	06.6	2.8	0.8	09.1	000.0
48	20.2	08.4	3.3	0.9	08.0	000.0
49	21.2	06.2	2.7	0.8	10.2	000.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
50	22.6	05.8	2.9	0.8	10.5	000.0
51	23.7	07.4	3.1	0.9	10.2	000.0
52	24.8	08.4	3.6	1.0	10.2	000.0
53	25.4	10.2	3.0	0.8	03.9	000.0
54	24.4	16.0	3.3	0.9	06.5	000.0
55	23.8	11.2	3.2	0.9	08.2	000.0
56	25.5	10.8	3.5	1.0	05.8	000.0
57	27.2	12.6	2.8	0.8	09.9	000.0
58	27.4	13.5	3.3	0.9	09.8	000.0
59	26.8	13.2	3.9	1.1	07.8	000.0
60	29.2	15.8	3.1	0.9	08.7	000.0
61	27.4	13.2	4.1	1.1	10.5	000.0
62	27.6	13.2	3.6	1.0	04.0	000.0
63	23.0	13.4	5.4	1.5	05.2	001.0
64	25.6	11.0	4.2	1.2	11.1	000.0
65	25.8	09.8	5.7	1.6	09.0	000.0
66	24.4	10.4	4.1	1.1	10.6	000.0
67	25.2	10.4	3.6	1.0	10.5	000.0
68	27.6	11.6	3.2	0.9	10.7	000.0
69	26.8	11.8	2.7	0.8	06.0	000.0
70	28.2	11.4	4.0	1.1	10.2	000.0
71	28.0	13.0	3.1	0.9	10.3	000.0
72	29.4	13.2	3.4	0.9	09.3	000.0
73	29.5	13.8	3.2	0.9	10.5	000.0
74	31.2	13.6	2.3	0.6	10.9	000.0
75	31.4	14.0	2.3	0.6	10.5	000.0
76	32.4	15.4	2.1	0.6	10.2	000.0
77	32.0	17.0	2.1	0.6	09.5	000.0
78	32.2	16.6	3.2	0.9	10.1	000.0
79	33.4	16.8	2.0	0.6	10.3	000.0
80	34.6	18.0	1.5	0.4	09.1	000.0
81	35.8	17.6	2.0	0.6	08.6	000.0
82	36.4	17.6	2.5	0.7	09.9	000.0
83	36.4	16.2	2.8	0.8	10.0	000.0
84	35.0	17.2	1.3	0.4	06.0	000.0
85	36.6	16.8	2.3	0.6	08.9	000.0
86	35.6	16.4	2.9	0.8	10.3	000.0
87	33.8	17.2	3.6	1.0	10.5	000.0
88	34.8	22.0	3.5	1.0	10.5	000.0
89	37.0	17.8	3.3	0.9	09.8	000.0
90	35.2	17.8	2.3	0.6	10.9	000.0
91	35.2	15.2	3.1	0.9	11.4	000.0
92	35.0	15.5	2.7	0.8	09.3	000.0
93	35.4	16.2	2.9	0.8	11.5	000.0
94	36.7	16.4	3.2	0.9	10.7	000.0
95	36.8	17.8	2.4	0.7	11.2	000.0
96	35.0	18.2	3.3	0.9	11.8	000.0
97	37.4	14.4	4.9	1.4	11.6	000.0
98	37.4	16.8	4.2	1.2	11.5	000.0
99	40.0	18.2	2.4	0.7	11.1	000.0
100	39.8	18.2	4.7	1.3	09.3	000.0

Days	Tmax	T min	Wind Speed km/hr	Wind Speed m/sec	Sunshine (hr)	Rain (mm)
101	40.8	20.0	4.0	1.1	10.4	000.0
102	36.8	22.4	2.3	0.6	05.3	000.0
103	38.5	18.0	5.9	1.6	11.8	000.0
104	40.6	17.8	6.1	1.7	11.6	000.0
105	42.4	19.0	4.9	1.4	11.4	000.0
106	42.6	20.5	3.0	0.8	09.5	000.0
107	44.0	23.4	4.3	1.2	08.8	000.0
108	41.0	25.7	2.3	0.6	06.3	000.0
109	42.0	27.8	10.4	2.9	07.6	000.0
110	41.8	24.2	6.5	1.8	09.0	004.4
111	33.0	25.8	6.6	1.8	00.9	000.0
112	37.2	21.2	6.2	1.7	00.0	000.0
113	36.5	20.4	3.8	1.1	11.5	000.0
114	36.2	19.8	6.2	1.7	06.6	000.0
115	38.0	18.0	4.9	1.4	12.4	000.0
116	40.6	19.4	3.0	0.8	11.7	000.0
117	40.5	23.6	3.7	1.0	04.8	000.0
118	40.0	22.5	4.3	1.2	01.6	000.0
119	39.2	24.8	4.7	1.3	06.7	000.0
120	39.4	23.4	3.1	0.9	06.8	000.0
121	38.0	22.0	10.0	2.8	02.1	000.0
122	39.0	24.4	5.4	1.5	06.2	000.0
123	40.6	26.0	6.6	1.8	06.2	000.0
124	40.8	26.8	7.3	2.0	03.9	000.0
125	40.8	28.4	8.5	2.4	00.0	000.0
126	34.2	26.2	13.5	3.8	00.0	000.0
127	30.0	23.4	4.0	1.1	04.3	000.0
128	36.6	24.4	6.4	1.8	11.2	000.0
129	37.8	21.8	5.2	1.4	11.6	000.0
130	40.0	23.0	9.0	2.5	09.7	000.0
131	38.8	24.0	4.3	1.2	11.7	000.0
132	40.4	21.2	2.5	0.7	11.4	000.0
133	42.6	23.2	8.8	2.4	07.2	000.0
134	40.6	21.6	8.1	2.3	10.0	000.0
135	41.4	22.6	2.3	0.6	09.4	000.0
136	43.0	22.0	3.5	1.0	09.6	000.0
137	41.0	28.8	10.1	2.8	00.0	000.0
138	39.6	31.5	8.4	2.3	00.0	000.0
139	40.4	22.4	5.4	1.5	11.0	000.0
140	40.0	22.4	6.3	1.8	12.8	000.0

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