

**SELECTION CRITERIA FOR COMBINING HIGH
GRAIN YIELD AND PROTEIN CONTENT BASED ON
NITROGEN PARTITIONING EFFICIENCY IN
WHEAT (*Triticum aestivum* L.)**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
BOTANY
(Minor Subject: Biochemistry)**

By

**Sukhpreet Kaur Sidhu
(L-2008-BS-151-M)**

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CERTIFICATE-I

This is to certify that the thesis entitled, “**SELECTION CRITERIA FOR COMBINING HIGH GRAIN YIELD AND PROTEIN CONTENT BASED ON NITROGEN PARTITIONING EFFICIENCY IN WHEAT (*Triticum aestivum* L.)**” submitted for the degree of **M.Sc.**, in the subject of **Botany** (Minor Subject: **Biochemistry**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Sukhpreet Kaur Sidhu (L-2008-BS-151-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

Major Advisor
(Dr. D.S.Gill)
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CERTIFICATE-II

This is to certify that the thesis entitled, “**SELECTION CRITERIA FOR COMBINING HIGH GRAIN YIELD AND PROTEIN CONTENT BASED ON NITROGEN PARTITIONING EFFICIENCY IN WHEAT (*Triticum aestivum* L.)**” submitted by **Sukhpreet Kaur Sidhu (L-2008-BS-151-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.**, in the subject of **Botany** (Minor Subject: **Biochemistry**) has been approved by the Student’s Advisory Committee along with Head of the Department after an oral examination on the same.

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Major Advisor
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Dean, Post-Graduate Studies
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(Sukhpreet Kaur Sidhu)

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ABSTRACT

This study was designed to identify selection criteria for the simultaneous improvement of grain yield and grain protein concentration in wheat (*Triticum aestivum* L.). Three wheat cultivars namely PBW-550, PBW-502 and PBW-343 were sown on 2nd week of November under two nitrogen levels (120 and 180 kg ha⁻¹). Results showed that Cv.PBW-550 found to have maximum remobilization efficiency (78.98%), grain protein yield (90.33 g m⁻²) and nitrogen harvest index (0.602). This cultivar had higher grain yield (57.34 q ha⁻¹) averaged over both nitrogen level due to maximum number of spikes per plant (7.5), number of kernels per spike (65.67) and 1000- kernel weight (44.43 g) as compared to Cv.PBW-502 and PBW-343. This indicate that Cv. PBW-550 expressed high levels of both traits concurrently. Pearson correlation analysis showed significant positive correlation with grain yield and vegetative nitrogen at anthesis + 12 days ($r = 0.9693^{**}$), vegetative nitrogen at anthesis + 4 days ($r = 0.8527^{**}$), accumulated nitrogen ($r = 0.8596^{**}$), accumulated dry matter ($r = 0.7313^{**}$) at post anthesis stage. Correlation analysis also indicate significant positive correlation between grain protein concentration ($r = 0.8236^{**}$), harvest index ($r = 0.9833^{**}$), total plant nitrogen ($r = 0.9710^{**}$) and grain protein yield ($r = 0.9067^{**}$) at physiological maturity. Regression line between grain yield and grain protein concentration showed significant positive relationship ($R^2 = 0.6948$). The correlation and path analysis revealed that the direct effect of vegetative nitrogen at maturity was more ($P_{9\ 11} = 0.5329$) followed by remobilization efficiency ($P_{10\ 11} = 0.2072$) on grain yield. The regression model showed significant positive correlation between grain yield and growing degree days accumulated during booting stage ($R^2 = 0.4709$). These results indicated that Cv.PBW-550 showed 12.96% increase in grain yield and 19.62% increase in grain protein concentration due to its high nitrogen remobilization and partitioning efficiency. Nitrogen uptake and nitrogen partitioning function as separate and independent physiological systems in wheat plants. Therefore, improvement in both grain protein percentage and grain yield realized by manipulating nitrogen uptake and its partitioning separately.

Keywords: Remobilization efficiency, Grain yield, Grain protein concentration, Nitrogen harvest index, Total plant nitrogen at maturity, Grain protein yield and Partitioning efficiency

Signature of Major Advisor

Signature of Student

ਖੋਜ ਪੱਤਰ ਦਾ ਸਿਰਲੇਖ	: ਨਾਈਟ੍ਰੋਜਨ ਵਿਭਾਜਨ ਦੇ ਅਧਾਰ ਤੇ ਕਣਕ ਦੇ ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਅਤੇ ਉਹਨਾਂ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ਨੂੰ ਇੱਕਠਿਆਂ ਕਰਨ ਲਈ ਸਿਧਾਂਤ ਦੀ ਚੋਣ।
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ਨਿਰਦੇਸ਼

ਇਹ ਅਧਿਐਨ ਅਜਿਹੇ ਸਿਧਾਂਤ ਦੀ ਚੋਣ ਲਈ ਤਿਆਰ ਕੀਤਾ ਗਿਆ ਹੈ ਜਿਸ ਵਿੱਚ ਕਣਕ ਦੇ ਦਾਣਿਆਂ ਦਾ ਝਾੜ ਅਤੇ ਕਣਕ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ਵਿੱਚ ਬਰਾਬਰ ਦਾ ਵਾਧਾ ਹੋਵੇ। ਕਣਕ ਦੀਆਂ ਤਿੰਨ ਕਿਸਮਾਂ ਪੀ ਬੀ ਡਬਲਯੂ 550, ਪੀ ਬੀ ਡਬਲਯੂ 502 ਅਤੇ ਪੀ ਬੀ ਡਬਲਯੂ 343 ਨਵੰਬਰ ਦੇ ਦੂਸਰੇ ਹਫ਼ਤੇ ਬੀਜੀਆਂ ਗਈਆਂ, ਜਿਸ ਵਿੱਚ 120 ਅਤੇ 180 ਕਿਲੋਗ੍ਰਾਮ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ ਨਾਈਟ੍ਰੋਜਨ ਪਾਈ ਗਈ। ਨਤੀਜੇ ਦਰਸਾਉਂਦੇ ਹਨ ਕਿ ਪੀ ਬੀ ਡਬਲਯੂ 550 ਦੀ ਵੱਧ ਤੋਂ ਵੱਧ ਮੁੜ ਸੰਚਾਲਨ ਸਮਰੱਥਾ (78.98%), ਦਾਣਿਆਂ ਦੀ ਪ੍ਰੋਟੀਨ ਦਾ ਝਾੜ (90.33 ਗ੍ਰਾਮ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ ਵਾਢੀ ਸੂਚਕ ਅੰਕ (0.602) ਹੈ। ਦੋਨੋਂ ਨਾਈਟ੍ਰੋਜਨ ਪੱਧਰ ਤੇ ਇਸ ਕਿਸਮ ਦੇ ਦਾਣਿਆਂ ਦਾ ਝਾੜ (57.34 ਕੁਇੰਟਲ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਦੀ ਔਸਤਨ ਦਰ ਜ਼ਿਆਦਾ ਸੀ ਕਿਉਂਕਿ ਇਸ ਵਿੱਚ ਹਰ ਪੌਦੇ ਦੇ ਸਿੱਟਿਆਂ ਦੀ ਸੰਖਿਆ (7.5), ਹਰ ਸਿੱਟੇ ਵਿੱਚ ਦਾਣਿਆਂ ਦੀ ਸੰਖਿਆ (67.67) ਅਤੇ 1000 ਦਾਣਿਆਂ ਦਾ ਭਾਰ (44.43 ਗ੍ਰਾਮ) ਪੀ ਬੀ ਡਬਲਯੂ 502 ਅਤੇ ਪੀ ਬੀ ਡਬਲਯੂ 343 ਦੀ ਤੁਲਨਾ ਵਿੱਚ ਵਧੇਰੇ ਸੀ। ਇਹ ਨਤੀਜੇ ਦਰਸਾਉਂਦੇ ਹਨ ਕਿ ਪੀ ਬੀ ਡਬਲਯੂ 550 ਦੋਨੋਂ ਸਮਵਰਤੀ (ਪ੍ਰੋਟੀਨ, ਝਾੜ) ਗੁਣਾਂ ਦਾ ਉੱਚਾ ਪੱਧਰ ਦਰਸਾਉਂਦੀ ਹੈ। ਪੀਅਰਸਨ ਦਾ ਸਹਿ-ਸੰਬੰਧਿਤ ਮੁਲਾਂਕਣ ਦਾਣਿਆਂ ਦਾ ਝਾੜ ਅਤੇ ਬਨਸਪਤੀ ਨਾਈਟ੍ਰੋਜਨ ਐਂਥੀਸਿਸ + 12 ਦਿਨ ($r=0.9693$), ਬਨਸਪਤੀ ਨਾਈਟ੍ਰੋਜਨ ਐਂਥੀਸਿਸ + 4 ਦਿਨ ($r=0.8527$) ਜਮ੍ਹਾਂ ਹੋਈ ਨਾਈਟ੍ਰੋਜਨ ($r=0.8596$), ਜਮ੍ਹਾਂ ਹੋਇਆ ਖੁਸ਼ਕ ਪਦਾਰਥ ($r=0.7313$), ਪੋਸਟ ਐਂਥੀਸਿਸ ਸਟੇਜ ਤੇ ਮਹੱਤਵਪੂਰਨ ਸਕਰਾਤਮਕ ਸਹਿ-ਸਬੰਧ ਦਰਸਾਉਂਦਾ ਹੈ। ਸਹਿ ਸਬੰਧ ਮੁਲਾਂਕਣ ਸੰਕੇਤ ਕਰਦਾ ਹੈ ਕਿ ਦਾਣਿਆਂ ਵਿੱਚ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ($r=0.8236$), ਪੈਦਾਵਾਰ ਸੂਚਕਾਂਕ ($r=0.9833$), ਪੌਦੇ ਦੀ ਕੁੱਲ ਨਾਈਟ੍ਰੋਜਨ ($r=0.9710$) ਅਤੇ ਪੱਕਣ ਸਮੇਂ ਦਾਣਿਆਂ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦਾ ਝਾੜ ($r=0.9067$) ਵਿੱਚ ਮਹੱਤਵਪੂਰਨ ਸਕਰਾਤਮਕ ਸਹਿ-ਸਬੰਧ ਹੈ। ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਅਤੇ ਦਾਣਿਆਂ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ਦੀ ਪਰਿਵਰਤਨ ਰੇਖਾ ਮਹੱਤਵਪੂਰਨ ਸਕਰਾਤਮਕ ਸਬੰਧ ਦਰਸਾਉਂਦੀ ਹੈ ($R^2=0.6948$)। ਸਹਿ ਸਬੰਧ ਅਤੇ ਮੁਲਾਂਕਣ ਮਾਰਗ ਪ੍ਰਗਟ ਕਰਦਾ ਹੈ ਕਿ ਮੁੜ ਸੰਚਾਲਨ ਦੀ ਸਮਰੱਥਾ ($PI_{1011}=0.2072$) ਦੇ ਫਲਸਵਰੂਪ ਪਕਿਆਈ ਦੇ ਸਮੇਂ ਬਨਸਪਤੀ ਨਾਈਟ੍ਰੋਜਨ ($PI_{911}=0.5329$) ਦਾ ਸਿੱਧਾ ਪ੍ਰਭਾਵ ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਉਪਰ ਵਧੇਰੇ ਸੀ। ਪਰਿਵਰਤਤ ਰੂਪ ਦਰਸਾਉਂਦਾ ਹੈ ਕਿ ਬੂਟੀਂਗ ਸਟੇਜ ਸਮੇਂ ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਅਤੇ ਗਰੇਇੰਗ ਡਿਗਰੀ ਡੇਜ਼ ਵਿੱਚ ਮਹੱਤਵਪੂਰਨ ਸਕਰਾਤਮਕ ਸਬੰਧ ਸੀ ($R^2=0.4709$)। ਇਹ ਨਤੀਜੇ ਇਸ ਗੱਲ ਵੱਲ ਸੰਕੇਤ ਕਰਦੇ ਹਨ ਕਿ ਵਧੇਰੇ ਨਾਈਟ੍ਰੋਜਨ, ਮੁੜ ਸੰਚਾਲਿਤ ਅਤੇ ਵਿਭਾਜਤ ਸਮਰੱਥਾ ਕਾਰਨ ਕਿਸਮ ਪੀ ਬੀ ਡਬਲਯੂ 550 ਦੇ ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਵਿੱਚ 12.96 ਪ੍ਰਤੀਸ਼ਤ ਅਤੇ ਦਾਣਿਆਂ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ਵਿੱਚ 19.62 ਪ੍ਰਤੀਸ਼ਤ ਵਾਧਾ ਹੋਇਆ ਹੈ। ਨਾਈਟ੍ਰੋਜਨ ਗ੍ਰਹਿਣ ਸ਼ਕਤੀ ਅਤੇ ਨਾਈਟ੍ਰੋਜਨ ਵਿਭਾਜਨ ਵਖਰੇ ਕਾਰਜ ਹਨ ਅਤੇ ਇਹ ਕਣਕ ਦੇ ਪੌਦਿਆਂ ਵਿੱਚ ਸੁਤੰਤਰ ਕਿਰਿਆਤਮਕ ਪ੍ਰਣਾਲੀਆਂ ਹਨ। ਇਸ ਲਈ ਨਾਈਟ੍ਰੋਜਨ ਗ੍ਰਹਿਣ ਸ਼ਕਤੀ ਅਤੇ ਇਸਦੇ ਵਿਭਾਜਨ ਦੇ ਵੱਖਰੇ ਪ੍ਰਚਾਲਨ ਦੁਆਰਾ ਦਾਣਿਆਂ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦੀ ਪ੍ਰਤੀਸ਼ਤਤਾ ਅਤੇ ਦਾਣਿਆਂ ਦੇ ਝਾੜ ਵਿੱਚ ਵਾਧਾ ਪਤਾ ਕੀਤਾ ਜਾ ਸਕਦਾ ਹੈ।

ਸ਼ਬਦ ਕੁੰਜੀ: ਮੁੜ ਸੰਚਾਲਨ ਸਮਰੱਥਾ, ਦਾਣਿਆਂ ਦਾ ਝਾੜ, ਦਾਣਿਆਂ ਵਿਚਲੀ ਪ੍ਰੋਟੀਨ ਦੀ ਮਾਤਰਾ, ਨਾਈਟ੍ਰੋਜਨ ਸੂਚਕਾਂਕ, ਪਕਿਆਈ ਸਮੇਂ ਪੈਦੇ ਦੀ ਕੁੱਲ ਨਾਈਟ੍ਰੋਜਨ, ਦਾਣਿਆਂ ਵਿੱਚ ਪ੍ਰੋਟੀਨ ਦਾ ਝਾੜ ਅਤੇ ਵਿਭਾਜਨ ਸਮਰੱਥਾ

CHAPTER-I

INTRODUCTION

Wheat is nature's unique gift to mankind as it produces excellent source of nutrition in terms of carbohydrates, minerals and proteins. Globally, wheat is being cultivated over an area of 227 million hectares with a production of 610 million tones. India occupies 2nd place in the world with a total production of 78.4 million tones which is 12% of the world food production from 28.5 million hectares of land (Mishra 2008).

Grain protein is of primary importance in determining the bread-making quality of wheat. Improvement in grain protein quality is therefore, a major objective in bread wheat breeding programs worldwide (Brown and Petrie 2006). Achieving this goal without concurrent loss in grain yield has been difficult due to well documented negative association between these two economically important traits. Carolina *et al* (2008) concluded that a genetic increase in the amount of grain nitrogen could be accomplished by increasing nitrogen utilization efficiency through (i) increasing the nitrogen uptake efficiency of the crop or (ii) increasing the nitrogen remobilization efficiency of the crop. Whole plant studies of nitrogen uptake, remobilization and partitioning have been extensively used as integrative measures of the complex physiological processes involved in nitrogen utilization efficiency; however, the relationships among these different physiological strategies for enhancing grain nitrogen have been contradictory. The negative correlation between grain yield and grain protein concentration is a very well known phenomenon in crop science. It has been reported in many crops and different hypotheses dealing with the causes of this negative correlation have been proposed. Mainly they are related to genetic incompatibility, partitioning efficiency, and competition between nitrogen and carbon (Triboi *et al* 2006).

Application of nitrogen is known to mainly increase the gluten strength, protein content, protein fractions and sedimentation value etc. Therefore, availability of nitrogen to wheat during various phases of its growth and development is an important factor influencing the yield and quality of grain (Zende *et al* 2005).

Yield and protein content are two major factors for wheat production and marketing. Both yield and protein affect profit, economically motivated growers will desire to apply nitrogen fertilizer to hard red spring wheat at rates that maximize profit considering both grain yield and protein. The grower controls some factors affecting yield and protein: nitrogen application rate, seeding rate and variety (Baker *et al* 2004). Bhatia and Rabson (1976) discussed the correlations between grain yield and grain protein concentration in

terms of bio-energetic requirements for the synthesis of carbohydrates and proteins. They showed the competition between carbohydrates and proteins for energy and carbon skeletons may cause the negative correlation between the grain yield and grain protein concentration.

The selection of genotypes combining high grain yield and high nitrogen concentration is a major objective for wheat breeders. Grain nitrogen concentration and protein quality of wheat grains are important criteria for bread making and baking quality. A wide range of cultivars and breeding lines have been investigated for their genotypic variation in nitrogen uptake, nitrogen partitioning efficiency and final Grain nitrogen concentration (Van Sanford and Macknawn 1987). Grain yield has often been found to be negatively correlated with grain nitrogen concentration among genotypes but this relation is not true for a single genotype because nitrogen supply and irrigation strongly influence the relation between grain yield and grain nitrogen concentration (Fisher *et al* 1993).

Numerous studies indicated that nitrogen fertilization can increase both wheat grain yield and grain protein concentration, but that a lag period in nitrogen response exists between grain yield and grain protein concentration. Grain yields are preferentially increased up to a maximum biological level, with grain protein remaining at a constant value. Only thereafter grain protein increases with additional nitrogen applications. Grain protein thus responds to higher level of nitrogen application than does grain yield (Ma *et al* 2004). Nitrogen plays a vital role in increasing the yield of the crop. Application of proper amount of nitrogen is considered key to obtain bumper crop of wheat. High nitrogen supply favours the conversion of carbohydrates into proteins, which in turn promotes the formation of protoplasm (Arnon, 1972). Nitrogen comprises 7% of total dry matter of plants and is a constituent of many fundamental cell components such as nucleic acids, amino acids, enzymes, and photosynthetic pigments (Bungard *et al* 1999).

Nitrogen uptake and partitioning between straw and grain are the two major components of the nitrogen economy in plants. Partitioning of nitrogen between grain and straw is the more important in crops like wheat, which are extensively grown under the climatic conditions where plants face receding soil nitrogen and moisture during the grain filling period. Partitioning efficiency of nitrogen between grain and straw is expressed as plant nitrogen in grain at harvest (Austin & Jones 1975) or as nitrogen harvest index (Austin *et al* 1977). An inverse genetic relationship is usually reported between grain yield and grain protein concentration in wheat cultivars (Ortiz-Monasterio *et al* 1997), which may be attributed in part to the higher glucose costs for synthesis of protein than of carbohydrates.

This negative relationship is also in part due to the balance between the processes of carbon capture and nitrogen remobilization from the vegetative tissues to the grain. Efforts to overcome the inverse relationship may concentrate on increasing grain protein accumulation per unit land area. In essence, to increase the grain N: C ratio either the capacity of plants to store nitrogen at anthesis and uptake more nitrogen after anthesis must be increased (Triboi *et al* 2006).

The duration of nitrogen uptake is positively associated with grain protein concentration but it was more critical for grain protein yield than for grain protein concentration. Improved translocation efficiency is the basis of high protein in some currently released wheat cultivars. However, several other studies found no relationship between grain protein concentration and translocation efficiency. Nitrogen harvest index has been used by many researchers as a measure of partitioning efficiency in an attempt to link grain protein concentration with grain yield. A significant positive correlation of nitrogen harvest index with grain protein concentration (Löffler *et al* 1985). These inconsistencies in the relationships of nitrogen uptake, translocation and partitioning with grain protein concentration point to the different physiological routes in plants to accumulate grain nitrogen. The earlier studies lacked germplasm expressing high levels of grain yield and grain protein concentration simultaneously. A recently released cultivar PBW-550, suggests that genetic improvement in grain yield and grain protein concentration can occur simultaneously. This cultivar may provide the opportunity to study traits related to nitrogen accumulation, remobilization and partitioning in varieties too in expressing high grain yield and high grain protein concentration simultaneously.

Thus, keeping in view above information, the present study has been designed to assist breeders in their efforts to combine high grain yield along with high grain protein concentration in bread wheat breeding programs with the following objectives:

- To identify an appropriate selection criterion for optimum combination of grain protein content and grain yield,
- To study traits related to nitrogen accumulation, remobilization and partitioning in wheat varieties actually expressing high grain yield and grain protein content simultaneously.
- Analyze grain yield to grain protein relationship.

CHAPTER-II

REVIEW OF LITERATURE

Wheat is the world's most important and most widely grown cereal crop due to many properties and uses of its grains and straw. Wheat is primarily used as a staple food providing more protein than any other cereal crop. It is consumed in many forms like bread, biscuits, bakery products, and many confectionery products. Its straw is used as animal feed and also for manufacturing paper. The information pertaining to "SELECTION CRITERIA FOR COMBINING HIGH GRAIN YIELD AND PROTEIN CONTENT BASED ON NITROGEN PARTITIONING EFFICIENCY IN WHEAT (*Triticum aestivum* L.)" has been reviewed in this chapter under following headings:

2.1 Nitrogen Content and Developmental processes in Plants

2.2 Total Plant Dry Matter Accumulation

2.3 Effect of Nitrogen Levels on Yield and Yield Attributes

2.4 Grain Protein Concentration

2.5 Phenological Development

2.1 Nitrogen Content and Developmental processes in Plants

2.1.1 Total Plant Nitrogen

2.1.2 Vegetative Nitrogen

2.1.3 Accumulated Nitrogen

2.1.4 Remobilized Nitrogen

2.1.5 Remobilization Efficiency

2.1.6 Nitrogen Harvest Index

2.1.1 Total Plant Nitrogen

McMullan *et al* (1988) reported that under some conditions, plant dry weight may not always be the principal influence controlling plant nitrogen content at anthesis. Simonetta *et al* (2009) found no differences among low and high protein wheat cultivars for vegetative nitrogen concentration at anthesis. Austain *et al* (1977) observed significant genotypic differences for vegetative nitrogen concentration at anthesis, yet genotypic variation for total plant nitrogen at anthesis was associated with variation in dry matter. Löffler *et al* (1985) reported significant genotypic variation for total plant nitrogen at anthesis. About 20% of the above ground nitrogen at anthesis is located in the ear (Pask 2009). Approximately a quarter (Demotes- Mainard *et al* 1999) to half of this ear nitrogen ends up in the grain at harvest.

Thus, the nitrogen in the ear at anthesis is high relative to the total amount of nitrogen that will eventually be incorporated into the developing grains. Total nitrogen at anthesis for the average of all genotypes amounted to 93% of total plant nitrogen at maturity. These two traits were positively correlated, but the coefficient of determination was only 0.30 (Löffler *et al* 1985).

Löffler *et al* (1985) found no correlation between total nitrogen at maturity and grain protein concentration but did report that total nitrogen at maturity was highly correlated with grain yield and grain protein yield. Both post anthesis nitrogen accumulation and total nitrogen at maturity were highly correlated with grain yield and grain protein yield and moderately correlated with grain protein concentration (McKendry *et al* 1995).

The nitrogen contents of above ground plant parts at anthesis and maturity are compared, both gains and losses were observed, irrespective of cultivar and nitrogen treatment. The losses ranged from 14.9 to 52.7 kg N ha⁻¹ in 1986 and 18.4 to 76.9 kg N ha⁻¹ in 1987. Nitrogen gains ranged from 9.5 to 13.0 and 4.6 to 44.8 kg ha⁻¹ in 1986 and 1987 (Papakosta and Gagianas 1991). Austin *et al* (1977) considered that 83 percent of the total nitrogen at maturity was already present at anthesis in wheat. Wheat plants accumulate 80-90 percent of their final nitrogen content before anthesis. Pre anthesis processes had a major effect on crop characteristics at maturity e.g. the level of crop nitrogen at anthesis (indicative of pre anthesis nitrogen uptake) was a good predictor of the extent of post anthesis partitioning of nitrogen to the grain. Conversely, high post anthesis nitrogen uptake was generally not related to grain nitrogen concentration (Ruiter and Brooking 1994). Dalling *et al* (1976) reported that the rate of nitrogen accumulation was 0.45 mg nitrogen per ear per day and duration of nitrogen deposition in the grain was approximately 40 days in each wheat variety. According to them, 80 percent of the nitrogen present in the plant at anthesis was redistributed to the grain.

2.1.2 Vegetative Nitrogen

Plants contain more nitrogen than any other essential elements derived from the soil. Plants take up nitrogen from the time the roots begin to function until all uptake of nutrients ceases with maturity. However, the largest amounts are taken up during early stages of growth, held for later use and translocated within the plant where needed, for example, to the kernels from the leaves and stem during maturation. In cultivars with high grain yield and low grain protein concentration, or in cultivars with low grain yield and high protein concentration, vegetative nitrogen reached a maximum after four days of anthesis. Vegetative nitrogen in cultivars with high grain yield and high grain protein concentration

was maximized until twelve days post anthesis, which coupled with higher post anthesis nitrogen accumulation (McKendry *et al* 1995).

An increase in the rate of nitrogen application increased the dry mass, nitrogen concentration of vegetative plant parts, and the rate of nitrogen uptake during the pre-anthesis phase (Peltonen 1993) low straw nitrogen content can also be used as a reliable and cost-effective indicator in the selection of genotypes with higher nitrogen use efficiency. Nitrogen content in stem increased at all the stages of growth with increase in nitrogen levels but decreased with the stages of development (Singh and Ahmad 1997).

Available nitrogen increases plant nitrogen accumulation by increasing leaf area and leaf nitrogen concentration (Bulman and Smith 1993), and leaf area duration (Novoa and Loomis 1981). There are two sources of nitrogen for the developing cereal grain: soil nitrate absorbed and reduced during grain filling, and redistribution of nitrogen assimilated during the vegetative period of growth. Uptake of nitrogen during the grain filling period can be considered to be as a function of the availability of soil nitrogen at this time and the capacity of the roots to absorb and translocate nitrogen to the shoot (Papakosta and Gagianas 1991). According to Dalling (1985), the leaves and stem are the most important sources of nitrogen with high efficiency of nitrogen mobilization, each contributing about 30 percent of the grain nitrogen yield. The roots are a minor source, contributing about less than 10 percent. Tian *et al* (1994) measured nitrogen uptake and nitrogen contents of different organs at various growth stages in four wheat cultivars giving similar yields but differing in grain protein content. They summarised that nitrogen uptake after anthesis was significantly correlated with grain protein content. During grain filling the rate of export from the vegetative organs to the grain was greater in high than in low protein cultivars. Upper leaves are major contributors of nitrogen to the grain. Because of the high nitrogen content of leaves relative to other vegetative parts, the two uppermost leaves of wheat are major sources of nitrogen for developing grain (MacKown *et al* 1992). Greater leaf and stem nitrogen concentration occur when the sink is limiting and greater vegetative nitrogen remobilization occurs when the source is limiting (Reed *et al* 1988).

2.1.3 Accumulated Nitrogen

Both post anthesis nitrogen accumulation and total nitrogen at maturity were highly correlated with grain yield and grain protein yield and moderately correlated with grain protein concentration. Correlations between post anthesis nitrogen accumulation and other traits differed from those reported by Van Sanford and MacKown (1987) who found post-anthesis nitrogen accumulation associated with increased grain nitrogen concentration, but

decreased grain yield, and also differed from those reported by Cox *et al* (1985), who found post-anthesis nitrogen accumulation correlated with both grain yield and grain protein yield, but not correlated with grain protein concentration.

Grain yield, nitrogen accumulation and remobilization in wheat (*Triticum aestivum* L.) may be modified by fertilization timing, tillage system, and environmental conditions. Nitrogen accumulation was generally greater at ear emergence than at anthesis net N accumulation in fertilized plant ceased by ear emergence. Consequently further growth during grain filling depended on remobilization of nitrogen accumulated in the vegetative plant parts (Melaj *et al* 2003).

Increased grain protein concentration at a particular grain yield will be difficult to attain through selection for concurrent increase in the amount of nitrogen accumulated both before and after anthesis (Total nitrogen accumulation at maturity). This may explain why wheat breeding has not substantially increased the amount of biomass nitrogen accumulated by maturity (Calderini *et al* 1995), and implies that increases in grain protein concentration at a high grain yield might be achieved through selection for increased efficiency in nitrogen partitioning. Consequently, nitrogen accumulated after anthesis does not influence grain yield as greatly as nitrogen accumulated before anthesis. Increased grain protein accumulation occurs without dilution by increased grain biomass and grain protein concentration increases. Because vegetative growth ceases at or before anthesis, there is very little demand on the newly accumulated nitrogen for synthesis of structural proteins, and nitrogen accumulated after anthesis is consequently partitioned more efficiently between the straw and grain biomass (Wuest and Cassman 1992).

Nitrogen accumulated before anthesis is less efficiently partitioned to grain, with net remobilization of vegetative nitrogen to the grain typically ranging from 70 to 75% for healthy, modern wheat crops (Barbottin *et al* 2005). Total nitrogen accumulation in both grains and whole aboveground plant is generally more related to biomass production than to nitrogen concentration (Flood and Martin 2001). Austin *et al* (1977) conducted that above ground dry weight was the main factor controlling crop nitrogen accumulation. The capacity of the crop or grains to accumulate nitrogen (Dhugga & Waines 1989), root senescence and nitrogen and water availability during the later growth stages have been suggested to be limiting factors for improving the post-anthesis accumulation of nitrogen in wheat (Ma *et al* 2006). In general, the response of grain protein to higher rates of nitrogen also depends on factors that affect nitrogen supply to the plant and accumulation of nitrogen in the grain. The accumulation of nitrogen in an organ generally depends on soil nitrogen availability, which

determines the growth rate of the organ, its nitrogen composition and, consequently, its demand for nitrogen (Kichey *et al* 2006).

2.1.4 Remobilized Nitrogen

Barbottin *et al* (2005) showed that the differences in the amount of remobilized nitrogen originating from uptake before anthesis were mainly due to the capacity of plant to store nitrogen in sink organs until this period. Remobilization of the nitrogen stored before anthesis and nitrogen uptake after anthesis generally estimated by calculating difference between the amount of total nitrogen present at anthesis and the amount of total nitrogen present at harvest in the different parts of plant. In wheat (Kichey *et al* 2006) and in maize (Hirel *et al* 2005) it has been proposed that glutamine synthetase activity is one of the best physiological markers that allow the depiction of the plant nitrogen status whatever its developmental stage and nitrogen nutrition conditions. Strong correlation between glutamine synthetase activity, the amount of remobilized nitrogen coming from pre-anthesis uptake, and grain yield in different wheat cultivars grown at different level of nitrogen strengthens this concept (Tabuchi *et al* 2005).

The role of nitrogen uptake and remobilization in the simultaneous improvement of grain yield and grain protein concentration outlined by Bhatia and Rabson (1976). Barbottin *et al* (2005) reported that the amount of nitrogen remobilization in wheat depended on two factor plant nitrogen accumulation at anthesis and nitrogen transfer efficiency post anthesis, which were both mostly dominated by genetic differences. Triboi and Triboi -Blondel (2002) proposed that if the nitrogen demands per plant is greater than the nitrogen uptake by the roots, the pre-stored nitrogen in the vegetative tissues would be rapidly remobilized in to the grains. The flow of nitrogen from the vegetative tissue to the grains may also be strongly affected by the weather (temperature, drought etc.) since this will affect the source-sink ratio and by intrinsic properties of the organ. Source-sink relationships between organs reflect the ability of the plant to compensate for limited periods of N shortage, using remobilized N for growth (Vouillot and Devienne-Barret 1999).

Nitrogen taken up late was transported to the tillers in a higher extent than to the main shoots. Thus, the tillers were more dependent on late taken up nitrogen and the main shoot on mobilized and redistributed early taken up nitrogen. This shows a prioritization to main shoot in nitrogen flow of remobilized nitrogen, while to prevent abortion the tillers need to be supplied with newly taken up nitrogen (Andersson *et al* 2005).

2.1.5 Remobilization Efficiency

Meteorological conditions affected not only nitrogen remobilization and post-anthesis nitrogen uptake but also the proportion nitrogen uptake from soil and fertilizer when high temperatures are registered during grain filling, a high accumulation of nitrogen before that period does not ensure an efficient remobilization because nitrogen losses can be promoted (Melaj *et al* 2003). Partitioning of dry matter and nitrogen to the grain are separate processes. Nitrogen remobilization was affected by nitrogen availability (Vouillot and Devienne-Barret 1999).

The major source of nitrogen partitioned to the grain is the remobilization of nitrogen resulting from organ senescence whereas the major source of dry matter partitioned to the grain is current photosynthesis (Deckard *et al* 1996). Cox *et al* (1986) found nitrogen fertilization before anthesis to reduce nitrogen remobilization efficiency after anthesis. It would appear that the same effect occurs when nitrogen is taken up from fertilizers applied after anthesis. Genetic variation in nitrogen remobilization efficiency of the vegetative tissues has been reported in wheat in the overall range 0.52-0.92 (Tahir and Nakata 2005). A decreasing nitrogen amount in the roots and increasing nitrogen amount in other parts of the plant provided direct evidence for nitrogen mobilization and nitrogen redistribution from the roots to other parts of the plant (Andersson *et al* 2005). Good nitrogen mobilization and redistribution leads to low nitrogen concentration in residual plant parts and to high nitrogen-use efficiency (Przulj and Momcilovic 2001).

2.1.6 Nitrogen Harvest Index

Nitrogen harvest index has been used by many researchers as a measure of partitioning efficiency in an attempt to link grain protein concentration with grain yield (Loffler and Busch 1982). Loffler and coworkers did find that nitrogen harvest index was significantly correlated with both higher grain yield and grain protein yield. Higher nitrogen harvest index represents the increased capacity of the genotype to mobilize and translocate nitrogen from the leaves and culm to grain. Nitrogen harvest index varied from 57% to 86%. These values are in the range reported previously for bread wheat (Austin *et al* 1977). Because nitrogen partitioning efficiency contributes to fertilizer nitrogen-use efficiency, evaluation of genotypic variation in nitrogen harvest index and the relationship between this variation and grain protein levels in wheat continue to receive considerable emphasis. Significant cultivar differences in the behaviour of nitrogen partitioning efficiency with respect to the nitrogen supply environment make it difficult to evaluate germplasm for nitrogen harvest index unless the nitrogen supply environment is carefully defined (Dhugga and Waines 1989).

Triboi and Triboi - Blondel (2002) proposed that nitrogen harvest index was often characterized as an index to calculate nitrogen transfer efficiency post-anthesis, but the effects of nitrogen accumulation at anthesis and nitrogen available for remobilization on grain nitrogen accumulation as well as genetic differences were seldom integrated. The nitrogen harvest index values ranged from 0.32 to 0.65, which are within the range reported by Deckard *et al* (1984). Day *et al* (1985) consider that nitrogen harvest index has a positive influence on grain nitrogen percentage while (Cox *et al* 1985) consider that it has no influence, while nitrogen harvest index is a measure of the efficiency of the crop to translocation nitrogen from the vegetative tissue to the grain, grain nitrogen percentage is influenced not only by the amount of nitrogen but also by the relative amount of carbohydrate in the grain. Nitrogen harvest index could be used as a criterion for selecting for higher grain nitrogen percentage.

2.2 Total Plant Dry Matter Accumulation

Literature related to total plant dry matter accumulation are discussed under the following headings:

2.2.1 Total Plant Dry Matter

2.2.2 Accumulated Dry Matter

2.2.1 Total plant dry matter

The extra nitrogen supplied in the nitrogen 120 treatment generated significant increases in above ground dry matter amount at both anthesis and at the end of the growing cycle. The above ground dry matter nitrogen content was also greater at anthesis (Simonetta *et al* 2009). At anthesis dry matter accumulation reached a maximum with 140 Kg N ha⁻¹ applied at planting, while nitrogen accumulation increased with each added increment of preplant nitrogen (Cassman *et al* 1992).

Nitrogen application at tillering enhanced dry matter accumulation in the whole plant and nitrogen accumulation in grain. The greater nitrogen accumulation was associated with grain yield rather than grain protein concentration (Melaj *et al* 2003). Vegetative and total dry matter was not influenced by the timing of nitrogen fertilization. Total biomass increased with the increase in the level of nitrogen (Kaur 2000). Austin *et al* (1977) suggested that plant biomass could be used as a selection criterion to improve nitrogen uptake. In support of this strategy, a strong positive correlation between dry matter accumulation and plant nitrogen was observed by Austin *et al* (1980).

Higher biomass yields should potentially increase the amount of nitrogen to be redistributed at maturity, and coupled with enhanced remobilization efficiency should contribute to a higher grain protein concentration (Costa and Kronstad 1994).

2.2.2 Accumulated Dry Matter

Dry matter accumulation in plants increased with increasing doses of nitrogen at all the stages of growth and maximum accumulation was recorded with 120 kg N ha⁻¹ (Chandra *et al* 1992). Higher nitrogen rates mainly increased dry matter production and leaf area index in growing season and at reproductive growth stage (Giunta *et al* 2009). Grain nitrogen concentration was negatively correlated with post anthesis dry matter accumulation ($r = -0.76$). The positive correlation between yield and post anthesis dry matter accumulation was expected, since grain growth is greatly dependent upon accumulated dry matter (Heiltholt *et al* 1990).

2.3 Effect of Nitrogen Levels on Yield and Yield Attributes

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

2.3.1 Grain Yield

2.3.2 Yield Attributes

2.3.1 Grain Yield

In modern farming nitrogen has critical role in boosting up of grain yield in wheat crop. Economic responses of crops to fertilizer nitrogen additions occur as increased yield or biomass yield, or grain quality improvement. Grain yield increases due to greater nitrogen application were largely due to increases in kernels per spike and tillers per square meter. The correct combination of nitrogen application level and timing of nitrogen application can increase yields and reduce the risk of lodging (Ayoub *et al* 1994). Grain and nitrogen yield at maturity were influenced mostly by the preplant nitrogen regime. Grain yield increased approximately three -fold at each site as the preplant nitrogen rate increased from 0 to 180 Kg ha⁻¹ (Cassman *et al* 1992).

Greater early season nitrogen input levels increased both vegetative dry matter accumulation and grain yield. Supplemental nitrogen applied at anthesis mostly influenced grain yield. Both the uptake efficiency and allocation efficiency to grain was greater from nitrogen applied at anthesis than from preplant nitrogen addition. These effects of nitrogen fertilizer timing are consistent with the results from other field studies when soil moisture did not limit post anthesis nitrogen uptake (Ellen and Spiertz 1980). Grain yield, straw yield, harvest index, number of spikes m⁻² and 1000 grain weight increased with increasing levels of nitrogen (Gami *et al* 1986). Yield attributes e.g. tillers m⁻², ear length, grains per ear head, dry matter per plant were affected favourably upto highest nitrogen rate 120 kg ha⁻¹ except 1000-grain weight which failed to increase beyond 80 kg N ha⁻¹ (Singh *et al* 1987).

Application of increasing nitrogen rates (0, 40, 80 and 120 kg ha⁻¹) increased yield and yield attributes like spike length, grain per spike, and 1000 grain weight (Panda *et al* 1988). Significant increase in grains per ear and grain weight per ear was recorded with application of nitrogen in 3 splits, 25 per cent at crown root initiation, 50 per cent at tillering and 25 per cent at jointing as compared with 2 splits, half at sowing and half at first irrigation (Singh and Singh 1991). Grain yield of wheat was positively and significantly correlated with dry matter accumulation at harvest, grain weight per spike, number of grains per spike and spike length. Singh and Uttam (1994) recorded that increased grain yield with increase in nitrogen level. Number of tillers and ears was increased by nitrogen rates upto 140 and 105 kg ha⁻¹, respectively (Hardy *et al* 1975).

Khan *et al* (2001) studied the response of wheat varieties of different levels of nitrogen. Statistical analysis of the results revealed that different levels of nitrogen had significant effect on the plant height, number of spikes m⁻², spike weight, biological yield and grain yield. Nitrogen applied as urea at the rate 200 kg ha⁻¹ significantly increased yield and yield components over control. Mehmat and Telat (2006) suggested that grain yield depends on number of spikes per unit area, number of grains per spike and 1000 grain weight.

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 cultivar yield included days to anthesis and harvest index, while the best model for describing plant yield included total chlorophyll, harvest index and straw weight per plant.

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). 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.

2.3.2 Yield Attributes

Hayee *et al* (1989) who concluded that by increasing level of nitrogen increased biological yield. Khan *et al* (2000) who obtained maximum biological yield in plots treated with 285 nitrogen per hectare. Hussain *et al* (1984) who observed increasing nitrogen application increased the number of fertile tillers per unit area. Geleto *et al* (1995) reported

that grain yield closely related to the number of spikes per unit ear. Fertilizer plots produced more spikes than control. Such responses attributed to the adequate nitrogen availability which might facilitate the tillering ability of the plants, resulting in a greater population. Ayoub *et al* (1994) reported that spike population increased with increase in nitrogen level.

The supplies of exogenous nitrogen has well known effects on yield and yield components, development and leaf traits of bread wheat. Although Kernel weight generally falls in response to nitrogen fertilization under both dry land (McDonald 1991) and irrigated (Fisher *et al* 1993) conditions, the overall yield response is positive, thanks to the formation of both a higher ear density per unit area, and a greater number of kernels per ear. The behaviour of the yield components corroborated the expected positive grain yield responses to nitrogen fertilizer, which are associated with an increase in the number of kernels set per unit area and a reduction in mean kernel weight (Van Herwaarden 1995). Ashraf (1986) who concluded that nitrogen increased the number of grains per spike.

Meynard (1987) reported that the number of grains per spike is the best indicator wheat response to nitrogen and grains per spike is negatively affected by nitrogen deficiency. The inverse relation between test weight and nitrogen rate is probably due to the increase in the number of grains per ear and the decline in 1000-grain weight prompted by increased nitrogen fertilizer rates (Lopez-Bellido *et al* 2000). Yield attributes i.e. spikes m^{-2} , grains per spike, 1000-grain weight, harvest index and dry matter production were significantly influenced by nitrogen levels. With increasing nitrogen from 50 to 100%, spike m^{-2} , grains per spike and dry matter productions were significantly increased, however 1000-grain weight decreased in different treatment. This may be due to increase in grains per spike and dry matter productions were recorded, when entire nitrogen was applied as basal (Behera *et al* 2008).

The behaviour of the yield responses to nitrogen fertilizer, which are associated with an increase in the number of kernels set per unit area and a reduction in mean kernel weight (Van Herwaarden 1995). The reduction in thousand kernels weight under high nitrogen regimes has generally been explained by assuming that the increase in sink strength is not fully matched by an increase in the source capacity, so that the longer grain filling duration induced by high nitrogen availability is accompanied by a reduction in the rate of grain fill (Yang *et al* 2000).

Improvements in grain yield over the period of scientific breeding have been achieved via increases in harvest index with very little change in dry matter accumulation (Perry and D'Antuona 1989). It is also evident that yield improvements through increases in harvest index are associated with reductions in grain nitrogen percentage (Paccaud *et al*

1985). High harvest index values limit the ability of the plant to depend on pre-anthesis carbon assimilation for grain filling (Mackey 1988).

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).

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. Grain yield was highly related to spike per square meter is the essential component determining the final grain yield in wheat (Mehdi *et al* 2007).

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).

2.4 Grain Protein Concentration

2.4.1 Grain Protein Yield

Wheat (*Triticum aestivum*) used as a staple food providing more protein than any other cereal crop. Protein concentration is known to influence the quality of wheat products. The genetic background and to a large extent environmental factors such as nitrogen supply as well as water and temperature conditions, determines the protein concentration in wheat (Wang *et al* 2003). Guttieri *et al* (2005) and Gallais *et al* (2006) reported that increasing nitrogen fertilizer and reducing irrigation are common strategies to increase grain protein concentration in spring wheat. Lopez-Bellido *et al* (2001) reported that the factor which most influencing wheat quality is nitrogen fertilization, although degree of influence is governed by annual weather condition and by residual soil nitrogen. Sip *et al* (2000) reported that application of nitrogen in split doses increased grain protein content by 1.55%. Triboi *et al* (2000) also reported that nitrogen supply is the most important environmental factor affecting protein content and composition, Ottman *et al* (2000) also reported that nitrogen application at near anthesis stage increases protein content, grain yield and grain weight. Similar results were earlier reported by Patel *et al* (2004) and Lestache *et al* (2004).

This increase in protein content was due to consistent increase in different fractions of proteins. The protein is formed by different amino-acids which are constituted in higher amount due to higher availability of nitrogen in more splits. Fertilizer nitrogen rates had a more consistent effect on durum wheat quality than on grain yield. Grain yield recorded optimum values at an overall nitrogen rate of 100 kg ha⁻¹, whilst maximum grain protein concentration was achieved with 200 kg N ha⁻¹. Foliar application of nitrogen in the form of urea at ear emergence only increased grain protein concentration (Lestache *et al* 2005). If nitrogen in the soil is deficient, application of nitrogen fertilizer can increase both grain yield and protein content (Akman and Kara 2003).

The predominant positive impact of nitrogen on crop quality is in its enhancement of the total nitrogen content of crops, and in grain crops specifically the protein concentration of grain (Olson and Kurtz 1982). Grain protein typically increases with increasing rates of nitrogen above those needed for optimum yields (Jackson *et al* 1973). Delayed applications of fertilizer nitrogen also tend to increase grain protein concentration, especially application at the flag leaf to anthesis growth stages (Löffler *et al* 1985). Soltanpour *et al* (2001) stated that grain protein concentration increased with increasing nitrogen fertilizer applications, but decreased with increased yield potential, especially if the amount of nitrogen fertilizer applied was not proportionately increased. Application of post-emergence nitrogen has been successfully implemented on irrigated wheat to manipulate grain protein and yields (Karamanos *et al* 2005).

The concentration of protein in wheat grain is also influenced by the supply of nitrogen via the soil, the interaction with soil water available, temperature, cultivar and timing of nitrogen application (Karamanos *et al* 2005). The author also found in his study that in contrast to yield, grain protein was influenced by both nitrogen applied at seeding and post emergence. The impact of nitrogen applied at seeding was greater when soil organic matter levels were below 5%. They also confirmed that grain protein does recover once the maximum yield potential provided by the cultivar and the agroecological conditions have been reached. Detrimental effects of excessive nitrogen availability on wheat growth include lodging, delayed maturity, shrivelled kernels with an abnormally high protein concentration and increased susceptibility to diseases, all of which lead to reduced baking quality (Halvorson *et al* 1987). Adequate nitrogen fertilization is necessary to produce high yields of wheat and to increase the quality (grain protein concentration). During grain filling this grain nitrogen content is to a large extent a consequence of the efficiency of this remobilization (Barneix *et al* 1992).

High levels of protein are important for superior wheat flour and baking characteristics Feil (1997), but protein concentration is not the only factor that determines the

baking quality of the flour. The importance of the relative composition of grain protein, i.e. gliadins, glutenins and other fractions, has also been emphasized. The specific proteins that make up the four protein fractions of wheat are genetically determined. However, the proportions of these specific proteins may be affected by environmental factors and soil fertility, especially the level of available nitrogen. It was noted that increasing the protein concentration by nitrogen fertilization frequently decreases the general nutritional content of wheat, mainly because of the increase in the prolamin fractions at expense of the lysine protein fraction (Deckard *et al* 1984), although this effect is variable. In turn, the nitrogen supply is affected by initial levels of soil fertility or total available nitrogen, previous cropping and soil water content (Ma *et al* 2006). Lower grain protein often is the result of relatively higher yield responses to nitrogen application, resulting in the dilution of grain protein. Monaghan *et al* (2001) showed that in Argentina, a country with much warmer and drier summer season, a higher nitrogen accumulation before anthesis coupled with increased ability in nitrogen remobilization could allow an improvement of grain protein concentration without reducing grain yield. Many researchers have found that late season top dressed nitrogen addition as dry fertilizer material were most effective in attaining higher grain protein concentration, yield and increased fertilizer recovery and efficiency (Anthony *et al* 2003).

2.4.1 Grain Protein Yield

Wheat has a protein yield threshold, meaning that at some level of soil nitrogen, increased levels of nitrogen fertilizer will result in higher protein but will not increase yield. The level of originally available soil nitrogen appears to be very important. For example, on soils that originally contain very low levels of nitrogen, if inadequate nitrogen is applied, then the nitrogen will be utilized primarily for vegetative growth and perhaps not enough will be left for maximum protein production.

Grain protein concentration was negatively correlated with grain protein yield. If gains in grain protein concentration were realized by reductions in harvest index, both grain protein yield and grain yield would be reduced. The goal of improving grain protein concentration while maintaining the high grain yield and grain protein yield of wheat would require that total plant nitrogen at maturity or nitrogen harvest index or both be increased (Löffler *et al* 1985). Significant correlations were found between harvest index and both grain yield and grain protein yield (McNeal *et al* 1982). Increasing rates of nitrogen progressively increased protein yields (Johnson *et al* 1973). McNeal *et al* (1982) suggested using grain protein yield as selection criteria instead of grain protein concentration to increase grain yield and stabilize grain protein. He obtained lines with high yield and intermediate protein concentration by selecting for protein yield.

2.5 Phenological Development

Phenology is the study of the seasonal timing of different developmental stages. Wheat is the major *rabi* crop in India and is sensitive to various biotic and abiotic stresses like weather and inter-seasonal climatic variability (in terms of changes in temperature, rainfall, radiation), soil conditions and agricultural inputs like nitrogen, water and pesticides Aggarwal *et al* (1994). The growing conditions affect the possibilities for the plant organs to grow. A slow development gives a long growing period and a good opportunity for the plant organs to develop and survive with high number of tillers per plant, high number of spikelets per spike and a great number of grains per spike (Hay and Kirby 1991). Phenology of wheat crop is adversely affected beyond a minimum and maximum threshold temperature. It refers to the timing of the recurring of biological events, the causes of their timing with regard to biotic and abiotic factors and the inter-relation amongst the phases. Phenological development is an important component of crop simulation models as it determines crop duration (maturity), and regulates partitioning of dry matter between organs.

Various environmental factors that have impact on the Phenological development of crop are reviewed under following sub headings:

2.5.1 Effect of Nitrogen

2.5.2 Role of Temperature

2.5.3 Effect of Light

2.5.4 Phenological Growth Models

2.5.1 Effect of Nitrogen

The crop grown with recommended fertilizer took more days for the onset of phenophases measured beyond the maximum tillering than that with 50% of the recommended fertilizers (Pal *et al* 1996). Consequently, the former delayed the flowering and maturity by 3 and 4 days respectively owing to beneficial effect of nitrogen, which has positive bearing on vegetative and reproductive growth (Awashi and Bhan 1993). Nitrogen starvation, just as does abiotic stress (Royo *et al* 2004), typically hastens maturity as, for example, an acceleration of 3-5 days in maturity when bread wheat was supplied with zero, rather than 186 kg ha⁻¹ nitrogen (Sielgman *et al* 1983). The reduction in thousand kernel weight under high nitrogen regimes has generally been explained by assuming that the increase in sink strength is not fully matched by an increase in the source capacity (Van Herwaarden 1995). So that the longer grain filling duration induced by high nitrogen availability is accompanied by a reduction in the rate of grain fill (Yang *et al* 2000). Environmental parameters which influence grain protein concentration directly are post anthesis water availability, nitrogen supply, temperature and light intensity during grain

filling period (Anderson *et al* 1995). Emergence was faster in plots receiving 60 kg N ha⁻¹ than in those which received 30 kg N ha⁻¹ (Khan *et al* 2008).

The N40 crops were more advanced developmentally, and as a result, the N40 did the N120 ones. The delay to anthesis of the N120 plants was about 3 days in both seasons, in agreement with Angus and Moncur (1985), who noted that nutrient supply can affect flowering date in wheat by a maximum of 3-4 days. The differences between the two nitrogen treatments decreased in both years as development proceeded, falling from 4.2 days at heading to 1.0 at the caryopsis hard stage in 2003 and from 3.2 to 1.7 for the same stages in 2004. This caused the duration of grain filling, to be foreshortened by 2.4 (2003) and 1.1 days (2004) in the higher nitrogen crops. The onset of senescence relative to anthesis date was significantly brought forward by the N 120 treatment in both seasons, with a stronger effect in 2003 (1.9 days) then in 2004 (1.5 days). A lower canopy temperature could explain the delayed development up to anthesis for the higher nitrogen regimes crops, but not their shorter grain filling duration and earlier senescence, both of which were unexpected, given previously observed in bread wheat (Yang *et al* 2000). The rate of leaf emergence was decreased in all N₅₀-treated and some N₂₀₀-treated plants, but not or N₃₀₀-treated plants. Tiller bud initiation was decreased in the treatment. The number of tiller buds was correlated with total number of leaves; if a leaf emerged, nitrogen deficiency did not affect tiller initiation. Nitrogen treatment did not alter the sequence of tiller emergence, but tiller emergence was delayed or did not occur in N₅₀, N₂₀₀, and N₃₀₀ plants (Longnecker *et al* 1993)

Overall effect of higher nitrogen availability on grain filling duration represents a balance between a downward pressure on canopy temperature and an increase in sink strength. Thus where sink strength is the stronger factor, there is a net reduction in grain filling duration, in spite of the lower canopy temperature (Reynolds *et al* 2005). Simulated yield of three sowing dates (1, 15 and 30 October) in combination with nitrogen levels (N₀, N₄₀ and N₈₀ kg fed⁻¹) revealed that all the three sowing dates, increasing levels of nitrogen increased yield (Saseendran *et al* 2004). Late sowing and no application of nitrogen recorded lowest simulated yield (Kaur *et al* 2007). Nitrogen contributes to carbohydrate accumulation in culms and leaf sheaths during the preheading stage and in grain during the grain filling stage by being a component of photosynthesis (Mae 1997).

2.5.2 Role of Temperature

Temperature, a key component of climate, determines seeding time and consequently the rate and duration of growth and thus the productivity of wheat (*Triticum aestivum* L.) in different parts of India. Seasonal temperature is an important climatic factor which can have profound effects on the yield of crops. Changes in seasonal temperature affect the grain

yield, mainly through Phenological development processes. 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 environments (Das and Kalra 1995). 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.

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 (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.

Temperature response curves for various wheat physiological processes normally follow a curve linear response (Streck *et al* 2003) 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_{optl}) is often observed, and from T_{optl} 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).

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 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. 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.

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).

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.

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.

Thermal time is used to drive phenology. Depending on the levels of resolution, understanding and available information, the stresses if they have any effect, will generally hasten phenological development. High temperature during the flowering phase can damage fertilization and seed production, resulting in reduced yield (Poter 2005). High temperature stress has been reported as one of the most important cause of reduction in yield and dry matter production in many crops (Giaveno and Ferrero 2003). The day and night temperature do not affect the plant independently and that the diurnal mean temperature is the better predictor of plant response to high temperature with day temperature having a secondary role (Peet and Whillits 1998). High temperature during seed filling can accelerate senescence, diminish seed set and seed weight and reduce yield. This is because under such conditions plants tend to divert resources to cope with the heat stress and thus limited photosynthates would be available for reproductive development (Wahid *et al* 2007). Tewari and Singh (1993) revealed that temperature cannot be manipulated but seeding time can be adjusted to meet the specific requirements. The effect of climate change on the growing season of plants was also reported from Japan by Matsvmoto *et al* (2003).

One of the main reasons for reduced yield is the decrease in plant water status due to excessive water loss through rapid transpiration caused by high temperature and water deficit (Kumar *et al* 2005). Exposure of late sown crop to high temperature and water deficit during reproductive growth stage also reduces grain filling period and remobilization of photosynthates to developing grains (Fisher 2007). During the past 100 years of modern academic investigations on plant phenology (Reich 1995) two main lines of research have been developed (i) environmental research addressed to the relationship of the timing of plant development stages to abiotic factors such as photoperiod (Guo *et al* 1998) and climatic constraints including temperature averages (Fitter *et al* 1995), temperature accumulation (White 1995), and moisture (ii) evolutionary research, addressed to the genetic basis and natural selection of plant phenology (Geber and Dawson 1993)

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. 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. Mitra and Bhatia (2008) proposed that high temperature affects all phases of growth, acceleration floret initiation, reduce the period of spike development, resulting in shorter spike with lower number of spikelets and adversely affecting pollen development. Changes in seasonal temperature affects the grain yield, mainly through phenological development processes (Kalra *et al* 2008).

High temperatures can cause considerable pre and post harvest damages, including scorching of leaves and twigs, sunburns on leaves, branches and stems, leaf senescence and abscission, shoot and root growth inhibition and reduced yield (Vollenweider and Gunthardt-Goerg 2005). There is significant positive correlation between grain yield and growing degree days (GDD) accumulated during ripening grains (Pahwa 2002). Pal *et al* (1996) reported that all the phenophases except emergence exhibited higher accumulated growing degree days under earlier sowing followed by late sowing. Asana and William (1965) found that increasing day temperature from 21°C to 31°C significantly reduced kernel size, but variation in night temperature between 9° and 12° was apparently unimportant.

Hsia *et al* (1963) were able to show that a reduction in night temperatures from 20°C to 10°C with a constant day temperature of 25°C, did increase kernel size, they did not examine the possible importance of variation in day temperature. A change in optimal temperature during its vegetative or reproductive growth adversely affects the onset and duration of phenophases and yield of crop (Pal *et al* 1996). A heat wave for 4 days at 35-36°C reduced grain size in wheat (Wardlaw and Wrigley 1994). Wardlaw *et al* (1980) reported that single grain weight falls by 3-5% for every 1° rise in temperature above 18°C.

In wheat, pre anthesis phenological phases which determine potential yield components are quite sensitive to high temperature (Abrol and Ingram 2005). The pre anthesis high temperature may also affect grain yield potential through its effect on growth of the ovaries which may in turn impose an upper limit for potential grain weight (Calderini *et al* 1999). The duration of grain filling in wheat, decreased by high temperature. An increase in the rate of grain filling in wheat, a rise in temperature above 20°C is commonly observed (Zahedi *et al* 2003). Growing degree day is a good estimator of wheat growth stages (Pal *et al* 1996). Heat unit (growing degree day) accumulated during the development of different phenophases was estimated from the daily mean temperature above the 5°C base temperature (Moery *et al* 1984). The weather during the grain filling period is of great importance for bread making quality. Poor bread-making quality is obtained when grain filling occurs in cold and wet weather. During grain filling, high temperature of above 20°C result in small grains with high protein concentrations (Ghosh *et al* 2000).

Temperature induces a series of changes in the physiology of the components of ways to change the quality apparent in the mature grain. In many instances, grain nitrogen concentration appears to increase with increasing temperatures and reduced rainfall (Stone and Savin 2000). Gooding and Davies (1997) have reviewed the mechanisms postulated to account for the effects of temperature increasing temperature can reduce carbohydrate accumulation more than nitrogen accumulation as the rate of senescence is increased, thereby reducing photosynthesis and grain growth. High temperatures and water stress in spring,

characteristic of the Mediterranean climate, shorten the grain filling and maturing period, reducing grain yield and increasing protein content (Garrido-Lestache *et al* 2004).

2.5.3 Effect of Light

Light has a determinantal effect on the physiology and yield of the plants (McMaster *et al* 2003). The effect is more prominent than at vegetative stage. 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). 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. Herndl *et al* (2008) showed that cultivar differences in pre-anthesis development are mainly determined by vernalization requirement, photoperiod sensitivity and earliness per seed.

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).

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). 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). 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.

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 of 60 Wm⁻² photosynthetically active radiation has been shown to substantially inhibit the photosynthesis processes; at 150 Wm⁻² photosynthetically active radiation photosynthesis decreases from 50 to 100% respectively when light intensity is increased to 240 Wm⁻² photosynthetically active radiation 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. Elevated CO₂ increase the photosynthetic rate in wheat over a wide range of radiation (Long *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). Baker *et al* (1980) and Nuttonson (1948) 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.

Logistic interpolation accounted for more than 98% of the variation in fraction of intercepted photosynthetically active radiation. The various growing conditions experienced by the crops, resulting from different years, locations and sowing dates generated variation in the intercepted photosynthetically active radiation. The maximum fraction of intercepted photosynthetically active radiation ranged from 87 per cent to 98 per cent, with no inter-varietals differences within environments. The cereals reached their maximum fraction of intercepted photosynthetically active radiation around the booting stage, as at this time all the leaves had emerged, and all were fully expanded. A combination of more intercepted photosynthetically active radiation and higher radiation use efficiency allowed triticale to produce 34 percent more biomass than durum wheat at anthesis. Nitrogen uptake and leaf area expansion are strongly correlated because of their being biologically coordinated and the differences among varieties in the pattern and amount of intercepted photosynthetically active radiation (Giunta *et al* 2009).

2.5.4 Phenological Growth Models

The literature pertaining to methods predict the crop phenology is discussed here. 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 (Porter 1993, 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.

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.

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.

Jamison and Munro (1999) emphasized that crop growth models save time, energy and additional experimentations methods. Intensive simulation analyses are regarded as powerful tools in investigating the effects of various factors on certain quality traits in crop plants (Jamieson and Semenov 2000). Capturing the key physiological processes in a simulation model would greatly aid both the interpretation and extrapolation of experimental studies. So far, several wheat simulation models have been developed to predict the nitrogen accumulation and protein concentration in wheat grains. In some studies, the grain weight and its nitrogen amount were derived from the approach of harvest index and the nitrogen harvest index was formulated as linear function of time or cumulative thermal units during grain filling (Triboi and Triboi-Blondel 2002).

Haun (1973) gave the visual quantification of wheat growth and suggested that the rate of development was determined by subtraction 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).

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 CO₂ 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 CO₂ and climate change parameters. Travis and Day (1988) modeled 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.

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.

Sirius is a wheat simulation model that calculates biomass from intercepted photosynthetically active radiation and grain growth from simple partitioning rules. Leaf area index 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 day length and vernalisation. Effects of water and nitrogen deficits are calculated through their influences on leaf area index 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). Wheat simulation model Sirius V99 (Jamieson and Somenov 2000) to analyze the regulation of grain nitrogen accumulation of the crop from the experimental treatments. In short, in Sirius from emergence to anthesis, nitrogen demand is set in proportion to the increment of green area index and structure each day, whereas extra nonstructural nitrogen can be stored in proportion to stem biomass. The flux rate of nitrogen to the grain in the Sirius model is set at anthesis such as all the nonstructural nitrogen would be transferred by the end of unconstrained grain filling.

CHAPTER -III

MATERIAL AND METHODS

A brief account of material used and methodology adopted during conduct of the present investigation is present in this chapter.

3.1 Location: Field/Lab

The present investigation entitled, “SELECTION CRITERIA FOR COMBINING HIGH GRAIN YIELD AND PROTEIN CONTENT BASED ON NITROGEN PARTITIONING EFFICIENCY IN WHEAT (*Triticum aestivum* L.)” was carried out at the experimental area and laboratories of the Department of Botany in Punjab Agricultural University, Ludhiana during the *rabi* season of 2008-2009. Ludhiana representing the Indo-Gangetic alluvial plains is situated at 30°-54'N latitude, 75°-48'E longitude and at an altitude of 247 m above mean sea level. Ludhiana is placed in South-Central plain region of Punjab having subtropical and semi-arid climate. The mean maximum and minimum temperature, therefore, shows considerable fluctuation during summer and winter seasons. The meteorological data collected from meteorological observatory, Punjab Agricultural University, Ludhiana for the season 2008-09 are given in Fig.3.1 and 3.2 (Appendix I and II).

3.2 Soil Status

Representative samples of the soil at the depth of 0-15 cm from the experimental field were randomly selected from five places at the start of the experiment to determine the physicochemical 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 property	Values	Method employed
Texture	Loamy sand	Piper (1966)
pH	8.2	Jackson (1967)
Electrical conductivity (mm has cm^{-1})	0.17	Jackson (1967)
Organic carbon (%)	0.15	Subbiah and Asija (1956)
Available N (kg ha^{-1})	130	Subbiah and Asija (1956)
Available P (kg ha^{-1})	18.4	Oslen <i>et al</i> (1954)
Available K (kg ha^{-1})	150	Jackson (1967)

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

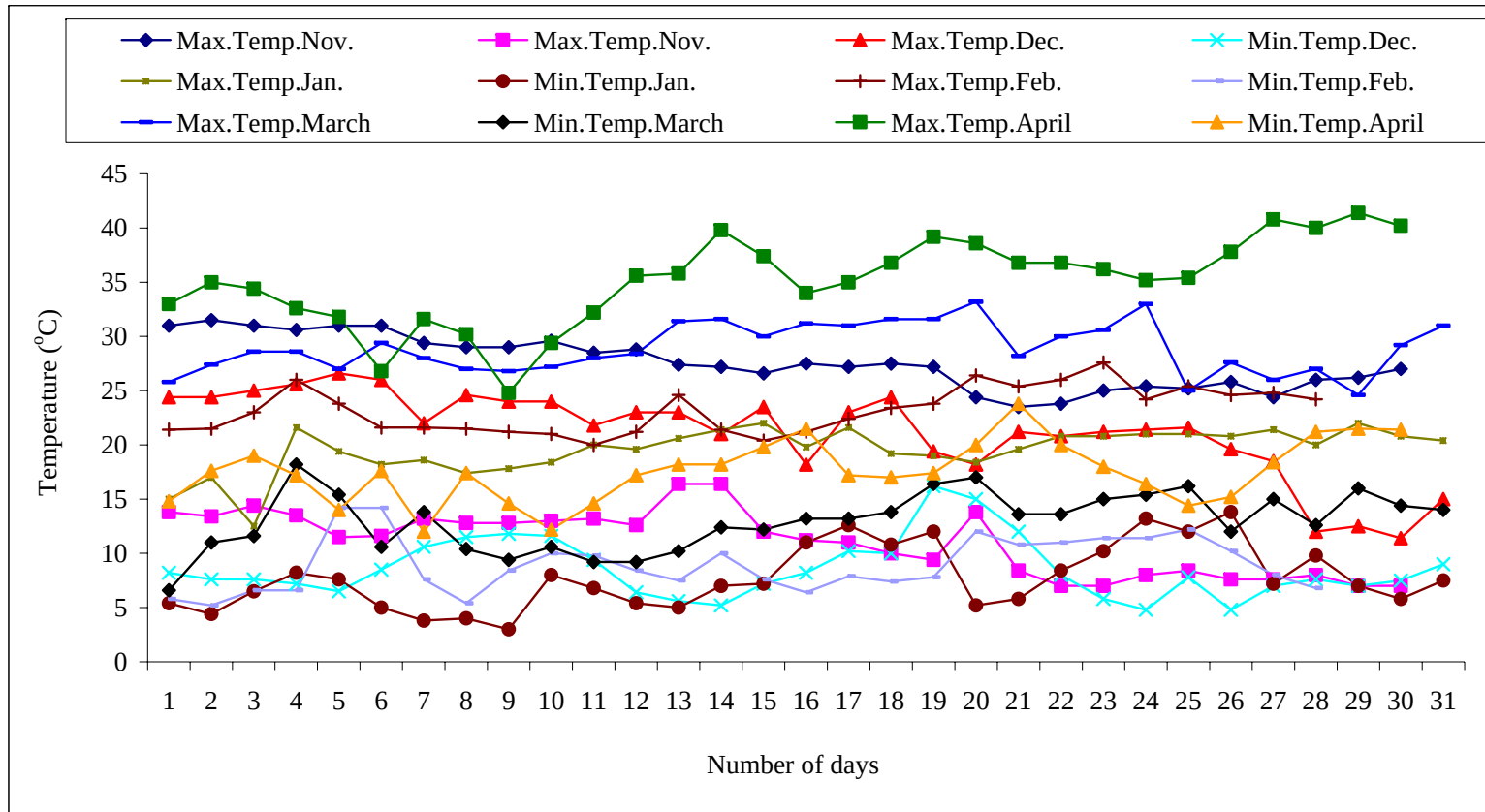


Fig. 3.1: Daily maximum and minimum temperature (November to April)

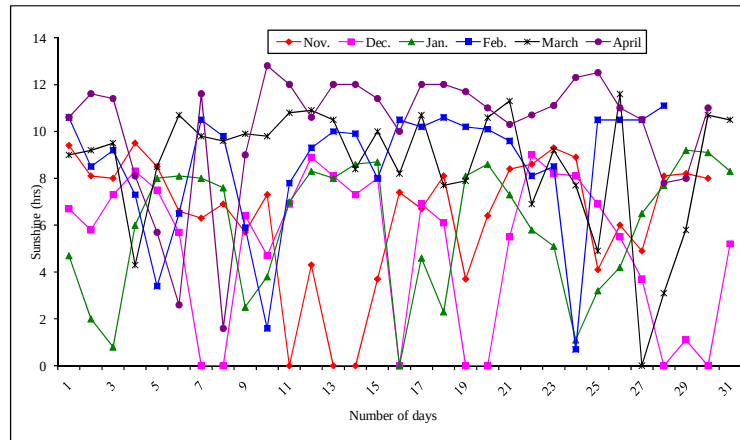


Fig. 3.2: Daily sunshine hours (November to April)

3.3 Methodology

Treatments

- a) Wheat Cultivars: Three (PBW-550, PBW-343, PBW-502)
- b) Nitrogen levels: Two (120 kg ha^{-1} , 180 kg ha^{-1})
- c) Date of sowing: One (Normal - 2nd week of November)

Total number of treatments: 6 Layout design: Split plot design

Number of Replication: 3 Total number of plots: 18

Pedigree and origin of cultivars used in this research programme (Anonymous 2005)

Cultivars	Origin	Pedigree
PBW-550	PAU, Ludhiana	WH 594/RAJ 3856//W485
PBW-343	PAU, Ludhiana	ND/VG 9144//KAL//BB/3/ YACO 'S'/4/VEE#5 'S'
PBW-502	PAU, Ludhiana	W485//PBW-343/RAJ1482

The field was ploughed twice with a cultivator and then planked. The recommended package of practices for wheat crop was followed (Anonymous 2005). The crop was sown on 13 November, 2008. 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.

3.4 Observations recorded

Random 0.5-m samples were cut at ground level from one randomly chosen row of each plot. Samples were taken at the following stages:

- i) Anthesis ii) Anthesis + 4 days iii) Anthesis + 8 days
- iv) Anthesis + 12 days v) Milk stage of kernel development.
- vi) Soft dough stage of kernel development, and
- vii) Physiological maturity

Plant samples were dried to constant moisture (4-5%), weight and separated in a vegetative component (leaves and stems) and a grain component. The vegetative components were weight and ground through 2-mm screen. Vegetative and grain nitrogen concentration were determined by standard Micro-Kjeldhal technique (AOAC 1990). A conversion factor of 5.7 was used to convert grain nitrogen concentration to grain protein concentration (Tkachuk 1969). Dry matter and nitrogen concentration data for vegetative and grain components were used to determine nitrogen accumulation. The following data were collected:

Trait	Method of determination	Units
A) Measured at anthesis		
• Total dry matter	Weight of above ground dry matter dried to constant moisture	g m ⁻²
• Total plant N	$\frac{\text{Total dry matter} \times \text{Total plant N percentage}}{100}$	g m ⁻²
B) Measured post-anthesis		
• Maximum vegetative N	$\frac{\text{Weight of vegetative dry matter (excluding chaff)} \times \text{tissue N percentage}}{100}$ taken at the sample date where the calculation was maximized	g m ⁻²
• Accumulated N	Total plant N at maturity – total plant N at anthesis	g m ⁻²
• Accumulated dry matter	Total dry matter at maturity – total dry matter at anthesis	g m ⁻²
• Remobilized N	Maximum vegetative N – vegetative N at maturity	g m ⁻²
• Remobilization Efficiency	$\frac{\text{Remobilized N}}{\text{Maximum vegetative N}} \times 100$	%
C) Measured at maturity		
• Biological yield	Weight of above ground dry matter at harvesting	g m ⁻²
• No. of spikes/plant		
• No. of kernels/spike		
• 1000-kernels weight		g
• Grain protein concentration	N concentration in grain x 5.7 (Tkachuk 1969)	%
• Grain protein yield	Grain yield x grain protein concentration	g m ⁻²
• Total dry matter	Weight of above ground dry matter dried to constant moisture	g m ⁻²
• Total plant N	$\frac{\text{Total dry matter} \times \text{total plant N percentage}}{100}$	g m ⁻²
• Harvest index	$\frac{\text{Grain yield}}{\text{Biological yield}} \times 100$	
• Nitrogen harvest index	$\frac{\text{Total grain N}}{\text{Total plant N}}$	
• Vegetative N	$\frac{\text{Total vegetative dry matter (excluding chaff)} \times \text{vegetative N percentage}}{100}$	g m ⁻²

Source: McKendry *et al* (1995)

3.5 Biochemical analysis

The biochemical analyses of the following were performed:

3.5.1 Estimation of nitrogen content By Kjeldahl Method (AOAC 1990)

Reagents

1. 98% conc. H_2SO_4 (98 ml H_2SO_4 + 2 ml water)
2. Catalyst mixture (sodium phosphate or potassium sulphate + cupric sulphate) in ratio of 10:1.
3. 40% NaOH (400 g of NaOH dissolved in 1 litre of distilled water).
4. 4% boric acid (40 g of boric acid dissolved in 1 litre of distilled water).
5. Mixed indicator (0.3 g of Bromocresol green and 0.2 g of methyl red dissolved in 400 ml of 90% ethanol) or readymade methyl red indicator.
6. 0.1 N HCl or 0.1 H_2SO_4 (for titration)

Procedure

Digestion: 0.1 g of the dry leaves was taken in digestion tube. To it 0.3 g of catalyst mixture was added followed by 10 ml conc. H_2SO_4 . The digestion tube was then placed in the preheated (350° to 420°C) digestion block along with properly fit manifolds. The digestion tube was then left in the block for 45 minutes to 1 hour to ensure that the colour of the sample turned bluish green. Once the bluish colour appears the tube was then removed from the digestion block and cooled.

Distillation: The digestion tube containing the digested sample was loaded in the steam generating end of distillation apparatus. A conical flask containing 25 ml of 4% boric acid and few drops of indicator (pink colour initially) was loaded at the receiving end of distillatory. Then the appropriate volume of 40% NaOH was added to the sample till sample turns black in colour. Then the sample was processed for a minute in which steam generated was delivered in the conical flask at the receiving end and ammonia released on addition of alkali get condensed and collected in the boric acid at the receiving end and the pink coloured solution turns colourless.

Titration: The colourless solution in the conical flask obtained after distillation was titrated against 0.1 N HCl to get the burette reading (titrant value).

$$\text{Nitrogen percentage} = \frac{(T - B) \times 0.00014 \times V_1}{V_2 \times S} \times 100$$

Where:

T = Volume of N/100 HCl used for sample titration

B = Volume of N/100 HCl used for blank titration

S = Sample weight (g)

V₁ = Total volume made

V₂ = Volume used for distillation

3.6 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 flour plants from each replication. The diagrammatic view of different growth stages in wheat cultivars are given in Fig. 3.3

- 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) **Leaf Development:** Leaf development was noticed starting from the appearance of first leaf upto flag leaf on the main shoot.
- d) **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.
- e) **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.
- f) **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.
- g) **Ear (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.
- h) **Anthesis:** Anthesis stage was noticed from the emergence of first anthers from the spike till the anthers stop emerging.
- i) **Watery Ripe:** Watery ripe stage was noticed when the grains yielded a watery fluid on pressing between the thumb and the forefingers.

- j) **Milky Ripe:** When the grains yielded a milky fluid on pressing between the thumb and the forefingers, it represented the milky ripe stage.
- k) **Soft Dough:** In soft dough stage, waxy ripe gluten like sticky feel obtained upon pressing the developing seed between the fingers.
- l) **Hard Dough:** This stage was noticed when the grain hard to puncture and started dry off.
- m) **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.

Cumulative Growing Degree-Days (GDD) For Describing Phenological Development

Growth stages of wheat can be determined by visual inspection any time, but an alternate method based on air temperature is available to estimate the current growth stage without going to field. Phenological development from seeding to maturity is related to accumulation of temperature units above a threshold or base temperature below which no growth occurs. Phenological development of the wheat Cv. PBW-502, PBW-343, and PBW-550 were computed by using growing degree days units. Growing degree days were calculated by subtracting the lower threshold temperature from the average daily temperature. Average daily temperature was calculated by averaging the daily maximum and minimum air temperatures (Khichar and Niwas 2007). Growing degree days are also known as accumulated growing degree days.

$$\text{Growing Degree Days (GDD)} = \sum_{i=1}^n \left[\frac{(T_{\max} + T_{\min})}{2} - T_b \right]$$

where,

n = Number of days in between two successive phenological stages.

$T_{\max}$ = Maximum temperature (°C) of the day.

$T_{\min}$ = Minimum temperature (°C) of the day.

T_b = Base temperature below which leaf appearance rate reached zero ($T_b = 5^{\circ}\text{C}$)

3.7 Statistical analysis

The data was subjected to standard statistical analysis according to (Gomez and Gomez, 1984).

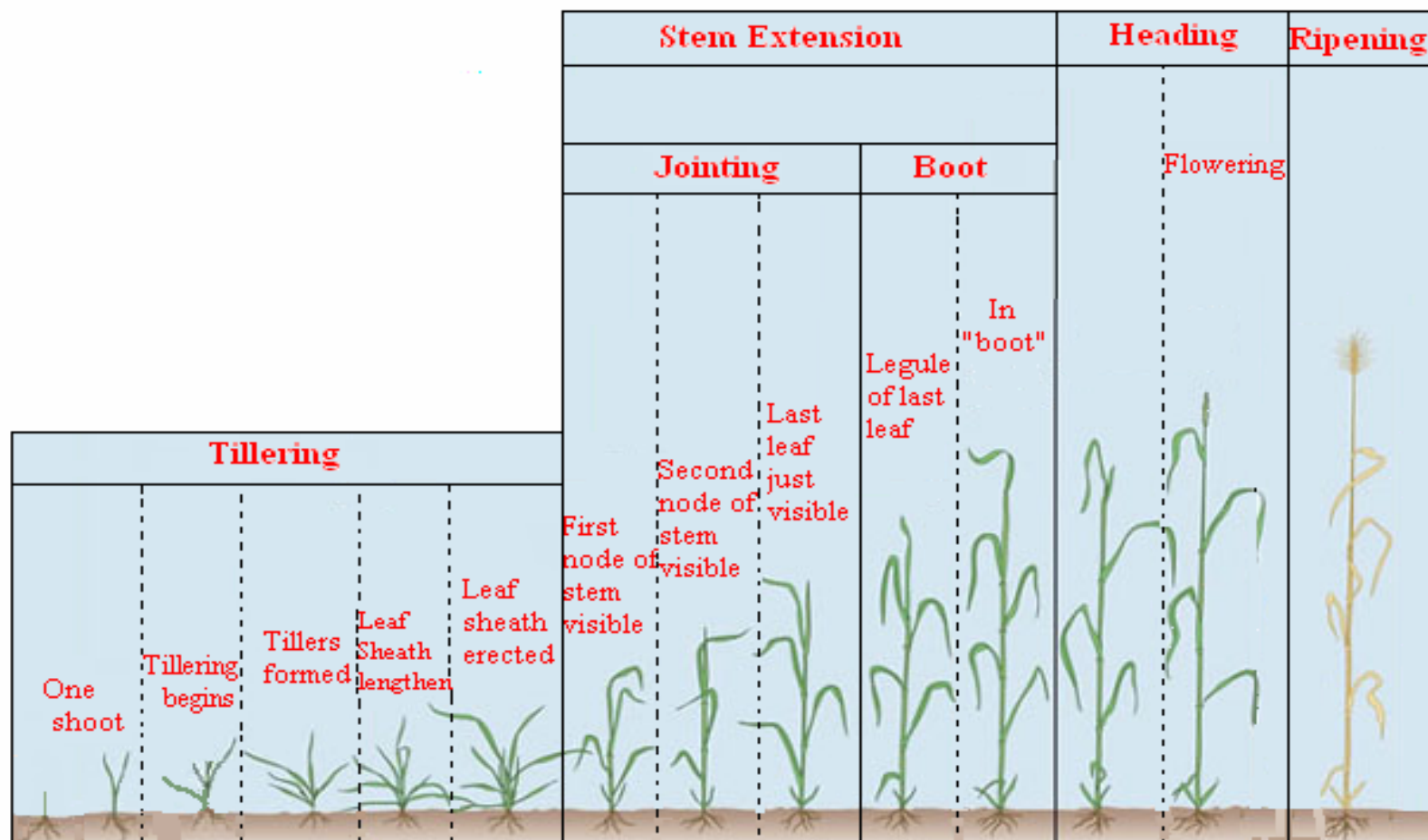


Fig. 3.3 Phenological development of wheat crop

CHAPTER-IV

RESULTS AND DISCUSSION

In the present investigations, various physiological and biochemical changes related with nitrogen partitioning efficiency in wheat grown under different nitrogen levels, have been studied at different development stage. With the increasing levels of nitrogen the different biochemical parameters behave differently and different varieties respond differentially. To find out the suitable, “SELECTION CRITERIA FOR COMBINING HIGH GRAIN YIELD AND PROTEIN CONTENT BASED ON NITROGEN PARTITIONING EFFICIENCY IN WHEAT (*Triticum aestivum* L.)” was studied. The results of the study conducted in this context are presented in this chapter under the following main headings.

4.1 Field Experiment and Biochemical Analysis

4.2 Phenological Development

4.1 FIELD EXPERIMENT AND BIOCHEMICAL ANALYSIS

Traits influencing grain yield and grain protein content at different stages are discussed below:

A) Parameters measured at anthesis stage

4.1.1 Total Plant Dry Matter (g m^{-2})

4.1.2 Total Plant Nitrogen (g m^{-2})

B) Parameters measured at post anthesis stage

4.1.3 Vegetative Nitrogen at Anthesis + 4 days stage (g m^{-2})

4.1.4 Vegetative Nitrogen at Anthesis + 8 days Stage (g m^{-2})

4.1.5 Vegetative Nitrogen at Anthesis + 12 days Stage (g m^{-2})

4.1.6 Vegetative Nitrogen at Milky Stage (g m^{-2})

4.1.7 Vegetative Nitrogen at Soft Dough Stage (g m^{-2})

4.1.8 Maximum Vegetative Nitrogen (g m^{-2})

4.1.9 Accumulated Nitrogen (g m^{-2})

4.1.10 Accumulated Dry Matter (g m^{-2})

4.1.11 Remobilized Nitrogen (g m^{-2})

4.1.12 Remobilization Efficiency (%)

C) Parameters measured at physiological maturity stage

4.1.13 Biological yield (q ha^{-1})

4.1.14 Number of spikes/plant

- 4.1.15 Number of kernels/spike
- 4.1.16 1000-kernels weight (g)
- 4.1.17 Grain yield (q ha^{-1})
- 4.1.18 Grain Protein Concentration (%)
- 4.1.19 Grain Protein Yield (g m^{-2})
- 4.1.20 Total Dry Matter (g m^{-2})
- 4.1.21 Total Plant Nitrogen (g m^{-2})
- 4.1.22 Harvest Index
- 4.1.23 Nitrogen Harvest Index
- 4.1.24 Vegetative Nitrogen (g m^{-2})

A) Parameters measured at anthesis stage

4.1.1 Total Plant Dry Matter

Total dry matter at anthesis stage is presented in Fig. 4.1 Total dry matter increases with increase in nitrogen levels. Maximum dry matter was observed in Cv. PBW-550 (2480 g m^{-2}) followed by Cv. PBW-502 (2420 g m^{-2}) and Cv. PBW-343 (2400 g m^{-2}) under 120 kg N ha^{-1} . All cultivars differ significantly from each other. Nitrogen treatment differs significantly from each other. On the average maximum dry matter was found at 180 kg N ha^{-1} in Cv. PBW-550 (2600 g m^{-2}) and minimum in Cv. PBW-343 (2400 g m^{-2}) under 120 kg N ha^{-1} . At 120 kg N ha^{-1} crop accumulated less (4.57%) dry matter than under 180 kg N ha^{-1} level. From these results it can be inferred that with increase in nitrogen levels increase the total plant dry matter at anthesis stage. These observations make supportive by the similar observations of Simonetta *et al* (2009).

4.1.2 Total Plant Nitrogen

With increase in nitrogen levels from 120 kg to 180 kg ha^{-1} total plant nitrogen increases in all cultivars at anthesis stage (Fig. 4.2). The cultivar Cv. PBW-550 accumulated maximum total plant nitrogen (77.48 g m^{-2}) under 180 kg N ha^{-1} followed by PBW-502 (47.63 g m^{-2}) and PBW-343 (47.31 g m^{-2}). At 120 kg N ha^{-1} Cv. PBW-343 (37.44 g m^{-2}) accumulated less total plant nitrogen as compared to PBW-502 (36.54 g m^{-2}) and PBW-550 (39.43 g m^{-2}). All cultivars at 120 kg N ha^{-1} accumulated (33.89%) less total plant nitrogen than at 180 kg N ha^{-1} level. The cultivars and treatment difference was significant. The interaction of nitrogen and variety is also significant. Under some conditions, total plant dry matter may be the principal influence controlling total plant nitrogen content at anthesis. These result supported by McMullan *et al* (1988).

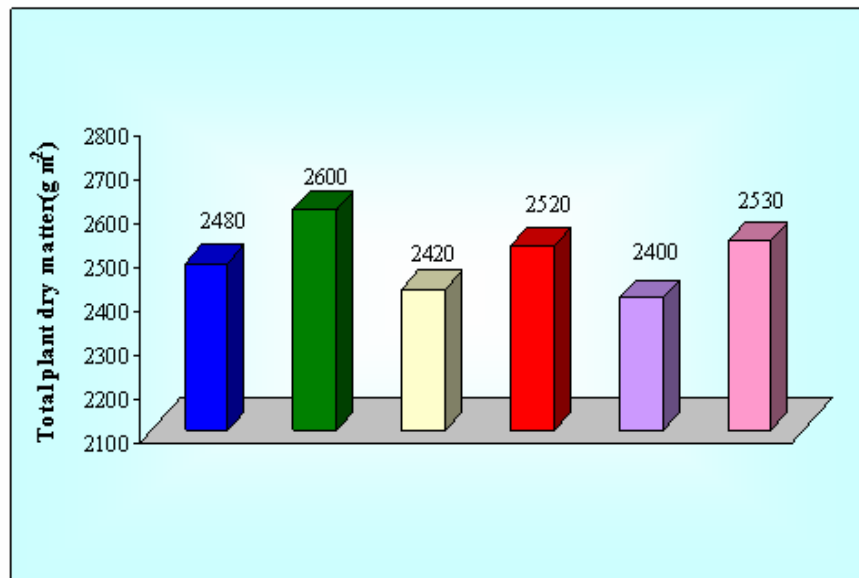


Fig. 4.1: Total plant dry matter accumulation at anthesis stage

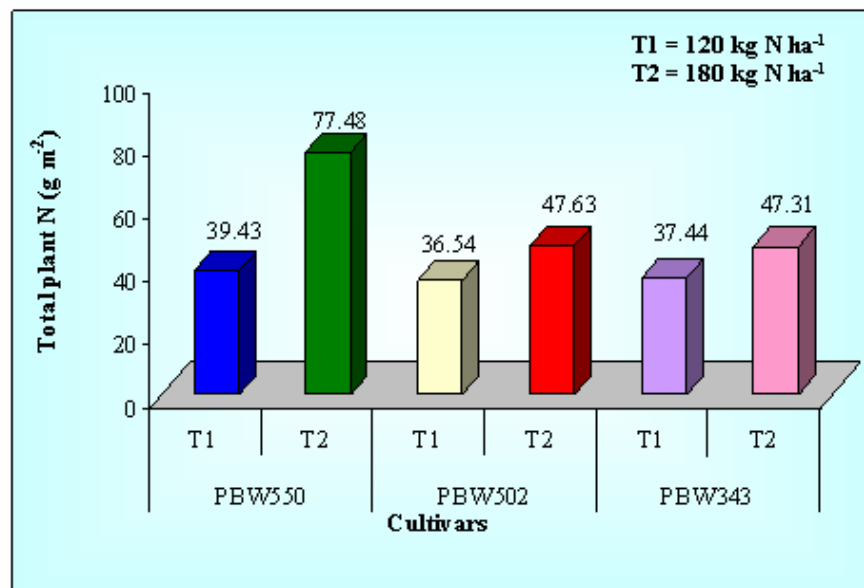


Fig. 4.2: Total plant nitrogen at anthesis stage

B) Parameters measured at post anthesis stage

4.1.3 Vegetative Nitrogen at Anthesis + 4 days stage

The Cv.PBW-502 accumulated more vegetative dry matter (1860 g m^{-2}) after four days of anthesis stage while Cv. PBW-550 (1660 g m^{-2}) at 180 kg ha^{-1} nitrogen level. The cultivars and nitrogen treatments differ significantly from each other. Under 120 kg N ha^{-1} PBW-550 had less vegetative dry matter (1560 g m^{-2}) as compared to PBW-343 (1620 g m^{-2}). Interaction between cultivars and nitrogen treatments found to be non significant.

The cultivars had significant differences in vegetative nitrogen percentage at four days after anthesis. Interaction among the three cultivars and the two nitrogen doses was significant. The Cv.PBW-550 had more nitrogen percentage in vegetative parts (1.98%) while in PBW-343 (1.63%) at 120 kg N ha^{-1} . On the average under both nitrogen levels PBW-550 had maximum nitrogen percentage. At 180 kg ha^{-1} nitrogen level PBW-502 found to be less vegetative nitrogen percentage (3.01%).

Vegetative nitrogen after four days of anthesis of three cultivars under two nitrogen levels is presented in Table 4.1. The Cv. PBW-550 accumulated maximum vegetative nitrogen (63.53 g m^{-2}) at 180 kg N ha^{-1} level followed by PBW-343 (59.81 g m^{-2}) and PBW-502 (55.39 g m^{-2}). At 120 kg N ha^{-1} Cv.PBW-343 found to be minimum vegetative nitrogen (26.49 g m^{-2}) while PBW-550 accumulated maximum vegetative nitrogen (30.94 g m^{-2}). The cultivars and nitrogen treatment differ significantly from each other. Interaction between nitrogen levels and cultivars also significant. The cultivar PBW-343 showed 5.86% reduction in vegetative nitrogen as compared to PBW-550 at 180 kg N ha^{-1} .

4.1.4 Vegetative Nitrogen at Anthesis + 8 days stage

Difference between cultivars and nitrogen treatments found to be significant. On the average Cv.PBW-550 accumulated 3.66% less vegetative dry matter as compare to PBW-343. The Cv.PBW-502 had maximum vegetative dry matter (1680 g m^{-2}) followed by PBW-343 (1580 g m^{-2}) and PBW-550 (1520 g m^{-2}). The Cv.PBW-502 showed maximum response to 180 kg N ha^{-1} and accumulated more vegetative dry matter as compare to others.

There was nitrogen percentage in vegetative parts increased with increased levels of nitrogen levels from 120 to 180 kg N ha^{-1} . Varietal differences irrespective of nitrogen levels were significant. Interaction effects due to nitrogen and cultivars for nitrogen percentage in vegetative parts were also significant. Under 180 kg N ha^{-1} PBW-550 had more nitrogen percentage in vegetative parts as compared to PBW-343 (3.84%).

The Cv. PBW-550 found to be had maximum vegetative nitrogen (68.50 g m^{-2}) followed by PBW-343 (65.04 g m^{-2}) and PBW-502 (64.79 g m^{-2}) under 180 kg N ha^{-1} as shown in table 4.2. With increase in nitrogen levels from 120 to 180 kg N ha^{-1} the vegetative

Table 4.1: Effect of different levels of nitrogen on vegetative dry matter (g m^{-2}), tissue nitrogen percentage (%) and vegetative nitrogen (g m^{-2}) at anthesis + 4 days stage

Cultivars	Traits								
	Vegetative dry matter (excluding chaff)			Tissue N percentage			Vegetative nitrogen		
	Nitrogen levels (kg ha ⁻¹)								
	120	180	Mean	120	180	Mean	120	180	Mean
PBW-550	1560.00	1660.00	1610.00	1.98	3.82	2.91	30.94	63.53	47.24
PBW-502	1720.00	1860.00	1790.00	1.63	3.01	2.32	28.08	55.39	41.74
PBW-343	1620.00	1720.00	1670.00	1.63	3.48	2.56	26.45	59.81	43.13
Mean	1633.33	1746.67		1.75	3.43		28.49	59.58	
CD (P=0.05)	V = 42.26			V = 0.05			V = 1.37		
	N = 34.50			N = 0.04			N = 1.12		
	N x V = NS			N x V = 0.06			N x V = 1.93		

Table 4.2: Effect of different levels of nitrogen on vegetative dry matter (g m^{-2}), tissue nitrogen percentage (%) and vegetative nitrogen (g m^{-2}) at anthesis + 8 days stage

Cultivars	Traits								
	Vegetative dry matter (excluding chaff)			Tissue N percentage			Vegetative nitrogen		
	Nitrogen levels (kg ha ⁻¹)								
	120	180	Mean	120	180	Mean	120	180	Mean
PBW-550	1520.00	1640.00	1580.00	2.19	4.18	3.19	33.33	68.50	50.92
PBW-502	1680.00	1780.00	1730.00	1.73	3.64	2.68	29.01	64.79	46.90
PBW-343	1580.00	1700.00	1640.00	1.77	3.83	2.80	28.03	65.04	46.54
Mean	1593.33	1706.67		1.89	3.88		30.12	66.11	
CD (P=0.05)	V = 42.26			V = 0.04			V = 1.34		
	N = 34.50			N = 0.03			N = 1.09		
	N x V = NS			N x V = 0.06			N x V = NS		

nitrogen also increased in all cultivars. At 120 kg N ha⁻¹ Cv. PBW-343 accumulated minimum vegetative nitrogen (28.03 g m⁻²) as compared to PBW-550 (33.33 g m⁻²).The Cv. PBW-343 accumulated 5.05% less vegetative nitrogen as compared to PBW-550 under 180 kg N ha⁻¹ level. The cultivars and nitrogen treatment differ significantly from each other. Interaction between nitrogen levels and cultivars found to be non significant.

4.1.5 Vegetative Nitrogen at Anthesis + 12 days stage

Vegetative dry matter also maximum in PBW-502 (1700 g m⁻²) at both nitrogen levels. Under 180 kg N ha⁻¹ Cv.PBW-550 found to had 4.59% vegetative dry matter while at 120 kg ha⁻¹ nitrogen level 9.63% less than PBW-502.The cultivars and nitrogen levels differ significantly and interaction between cultivars and nitrogen treatment also significant.

Difference between cultivars and nitrogen treatments found to be significant. On the average Cv.PBW-343 (8.37%) less vegetative nitrogen percentage as compare to PBW-550.The Cv.PBW-550 had maximum nitrogen percentage in vegetative parts (4.18%) followed by PBW-502 (3.64%) and PBW-343 (3.83) under 180 kg N ha⁻¹.The Cv.PBW-550 showed maximum response to 180 kg N ha⁻¹ and more vegetative nitrogen percentage as compare to other cultivars.

With the increase in nitrogen levels vegetative nitrogen also increase under both nitrogen levels in all cultivars (Table 4.3).The Cv.PBW-343 found to had minimum vegetative nitrogen (48.61g m⁻²) as compared to PBW-502 (51.16 g m⁻²) and PBW-550 (71.27 g m⁻²) under 180 kg N ha⁻¹ level. Interaction between cultivars and nitrogen treatment found to be significant. At 120 kg N ha⁻¹ Cv.PBW-550 accumulated more vegetative nitrogen (34.30 g m⁻²) followed by PBW-502 (25.56 g m⁻²) and PBW-343 (22.86 g m⁻²).The Cv. PBW-343 showed 31.79% reduction in vegetative nitrogen in comparison to PBW-550 at 180 kg N ha⁻¹ levels.

4.1.6 Vegetative Nitrogen at Milky Stage

Accumulation of vegetative dry matter was maximum in Cv. PBW-502 (1600 g m⁻²) followed by Cv. PBW-343 (1560 g m⁻²) and Cv. PBW-550 (1460 g m⁻²) at 120 kg N ha⁻¹. The Cv.PBW-502 (1660 g m⁻²) and PBW-343 (1660 g m⁻²) had same vegetative dry matter at milky stage under 180 kg N ha⁻¹ .Vegetative dry matter on the average 4.90% less accumulated in PBW-550 as comparison to PBW-502 and PBW-343.Interaction between cultivars and nitrogen treatment found to be significant.

The interactive effect of cultivars and nitrogen treatment were significant. The cultivars and nitrogen levels differed from each other significantly. Under both nitrogen levels Cv.PBW-550 had (3.76%) maximum vegetative nitrogen percentage followed by

Table 4.3: Effect of different levels of nitrogen on vegetative dry matter (g m^{-2}), tissue nitrogen percentage (%) and vegetative nitrogen (g m^{-2}) at anthesis + 12 days stage

Cultivars	Traits								
	Vegetative dry matter (excluding chaff)			Tissue N percentage			Vegetative nitrogen		
	Nitrogen levels (kg ha ⁻¹)								
	120	180	Mean	120	180	Mean	120	180	Mean
PBW-550	1500.00	1660.00	1580.00	2.29	4.29	3.29	34.30	71.27	52.79
PBW-502	1660.00	1700.00	1700.00	1.54	2.94	2.24	25.56	51.16	38.36
PBW-343	1580.00	1630.00	1630.00	1.45	2.89	2.17	22.86	48.61	35.74
Mean	1580.00	1693.33		1.76	3.38		27.57	57.01	
CD (P=0.05)	V = 42.26			V = 0.04			V = 1.21		
	N = 34.50			N = 0.04			N = 0.99		
	N x V = NS			N x V = 0.06			N x V = 1.72		

Table 4.4: Effect of different levels of nitrogen on vegetative dry matter (g m^{-2}), tissue nitrogen percentage (%) and vegetative nitrogen (g m^{-2}) at milky stage

Cultivars	Traits								
	Vegetative dry matter (excluding chaff)			Tissue N percentage			Vegetative nitrogen		
	Nitrogen levels (kg ha ⁻¹)								
	120	180	Mean	120	180	Mean	120	180	Mean
PBW-550	1460.00	1640.00	1500.00	1.63	3.76	2.69	23.84	61.61	42.73
PBW-502	1600.00	1660.00	1630.00	1.49	2.70	2.10	23.89	44.93	34.41
PBW-343	1560.00	1660.00	1600.00	1.28	2.61	1.95	20.02	43.39	31.70
Mean	1540.00	1653.33		1.47	2.03		22.59	49.98	
CD (P=0.05)	V = 26.9 N = 22.0 N x V = 38.1			V = 0.05 N = 0.04 N x V = 0.08			V = 1.43 N = 1.17 N x V = 2.02		

PBW-502 (2.70%) and PBW-343 (2.61%) under 180 kg N ha⁻¹. The Cv. PBW-343 found to be minimum vegetative nitrogen percentage at 120 kg N ha⁻¹.

Vegetative nitrogen at milky stage in three cultivars under two nitrogen levels (120 to 180 kg N ha⁻¹) are presented in Table 4.4. The Cv. PBW-550 accumulated maximum vegetative nitrogen (61.61 g m⁻²) at 180 kg N ha⁻¹ level followed by PBW-343 (43.39 g m⁻²) and PBW-502 (44.93 g m⁻²). At 120 kg N ha⁻¹ Cv. PBW-343 found to be minimum vegetative nitrogen (20.02 g m⁻²) while PBW-550 accumulated maximum vegetative nitrogen (23.84 g m⁻²). The cultivars and nitrogen treatments differ significantly from each other. Interaction between nitrogen levels and cultivars also significant. The cultivar PBW-343 showed 29.57% reduction in vegetative nitrogen as compared to PBW-550 at 180 kg N ha⁻¹.

4.1.7 Vegetative Nitrogen at Soft Dough Stage

With increase in nitrogen level from 120 to 180 kg N ha⁻¹ vegetative dry matter increased in three cultivars. The interactive effect of cultivars and nitrogen treatment were non significant. Under both nitrogen levels Cv. PBW-550 had 3.70% less vegetative dry matter as compared to other cultivars. The Cv. PBW-502 found to be maximum vegetative dry matter followed by PBW-343 (1540 g m⁻²) and PBW-550 (1480 g m⁻²) at 120 kg N ha⁻¹.

The nitrogen percentage in vegetative parts was maximum in Cv. PBW-550 (2.71%) followed by PBW-502 (1.96%) and PBW-343 (1.89%) at 180 kg N ha⁻¹. The varieties and treatment differed significantly and their interaction is also found to be significant. The nitrogen percentage in vegetative parts was found to be maximum in Cv. PBW-550 (1.42%) followed by Cv. PBW-502 (1.24%) at 120 kg N ha⁻¹. On the average, PBW-550 (2.07%) had maximum vegetative nitrogen than PBW-343 (1.47%). These results supportive with the findings of (Singh and Singh 1991).

The Cv. PBW-550 found to be had maximum vegetative nitrogen (44.41 g m⁻²) followed by PBW-343 (31.75 g m⁻²) and PBW-502 (32.54 g m⁻²) under 180 kg N ha⁻¹ as shown in table 4.5. With increase in nitrogen levels from 120 to 180 kg N ha⁻¹ the vegetative nitrogen also increased in all cultivars. At 120 kg N ha⁻¹ Cv. PBW-343 accumulated minimum vegetative nitrogen (16.17 g m⁻²) as compared to PBW-550 (21.06 g m⁻²). The Cv. PBW-343 accumulated 28.50% less vegetative nitrogen as compared to PBW-550 under 180 kg N ha⁻¹ level. The cultivars and nitrogen treatment differ significantly from each other. Interaction between nitrogen levels and cultivars also found to be significant.

Table 4.5: Effect of different levels of nitrogen on vegetative dry matter (g m^{-2}), tissue nitrogen percentage (%) and vegetative nitrogen (g m^{-2}) at soft dough stage

Cultivars	Traits								
	Vegetative dry matter (excluding chaff)			Tissue N percentage			Vegetative nitrogen		
	Nitrogen levels (kg ha ⁻¹)								
	120	180	Mean	120	180	Mean	120	180	Mean
PBW-550	1480.00	1640.00	1550.00	1.42	2.71	2.07	21.06	44.41	32.73
PBW-502	1580.00	1660.00	1630.00	1.24	1.96	1.59	19.53	32.54	26.04
PBW-343	1540.00	1680.00	1610.00	1.05	1.89	1.47	16.17	31.75	23.96
Mean	1533.33	1660.00		1.24	2.19		18.92	36.23	
CD (P=0.05)	V = 26.90			V = 0.06			V = 1.24		
	N = 22.00			N = 0.05			N = 1.01		
	N x V = 38.1			N x V = 0.08			N x V = 1.75		

4.1.8 Maximum Vegetative Nitrogen

Vegetative nitrogen taken from the various stages i.e four days after anthesis, eight days after anthesis, twelve days after anthesis, milky ripe stage, soft dough stage at which stage the value of vegetative nitrogen maximum taken as maximum vegetative nitrogen. Major source of grain protein is the nitrogenous pool present in the vegetative tissues of the crop before the grain filling period. These maximum values of vegetative nitrogen taken from 4.1 to 4.5. Maximum vegetative nitrogen shown in Table 4.6. These maximum nitrogen values are used for calculating the remobilized nitrogen and remobilization efficiency.

Table 4.6: Effect of nitrogen levels on maximum vegetative nitrogen (g m^{-2}) in wheat cultivars

Variety	Nitrogen (kg ha^{-1})		Mean
	120	180	
PBW-550	34.30	71.27	52.79
PBW-502	29.01	64.79	46.90
PBW-343	28.03	65.04	46.54
Mean	30.44	67.04	

CD (P=0.05)

V = 1.38

N = 1.12

N x V = NS

Maximum vegetative nitrogen recorded in PBW-550 at twelve days after anthesis stage while in PBW-502 and PBW-343 at eight days after anthesis. The Cv. PBW-343 found to have minimum vegetative nitrogen (65.04 g m^{-2}) as compared to PBW-502 (64.79 g m^{-2}) and PBW-550 (71.27 g m^{-2}) under 180 kg N ha^{-1} level. Interaction between cultivars and nitrogen treatment found to be significant. At 120 kg N ha^{-1} Cv. PBW-550 accumulated more vegetative nitrogen (34.30 g m^{-2}) followed by PBW-502 (29.01 g m^{-2}) and PBW-343 (28.03 g m^{-2}). The Cv. PBW-343 showed 8.74% reduction in vegetative nitrogen in comparison to PBW-550 at 180 kg N ha^{-1} levels. These results supported by McKendry *et al* (1995).

4.1.9 Accumulated Nitrogen

The data on accumulated nitrogen under different levels of nitrogen are given in table 4.7.

The amount of nitrogen levels significantly affected the accumulated nitrogen. Interaction among the three cultivars and two nitrogen doses was found to be significant. Maximum accumulated nitrogen was observed in cultivar PBW-502 (74.49 g m^{-2}) followed

by PBW-550 (74.23 g m⁻²) and PBW-343 (70.73 g m⁻²) under 180 kg N ha⁻¹ level. At 120 kg N ha⁻¹.

Table 4.7: Effect of nitrogen levels on accumulated nitrogen (g m⁻²)

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	72.88	74.23	73.56
PBW-502	58.04	74.49	66.27
PBW-343	55.55	70.73	63.14
Mean	62.16	73.15	

CD (P=0.05)

V = 3.05

N = 2.49

N x V = 4.32

Cv. PBW-343 found to had minimum accumulated nitrogen (55.55 g m⁻²) while PBW-550 found to had maximum (72.88 g m⁻²) accumulated nitrogen. Cv. PBW-343 had 4.71% less accumulated nitrogen in comparison to PBW-550 under 180 kg N ha⁻¹. These observations make supportive by the similar observations of Wuest and Cassman (1992).

4.1.10 Accumulated Dry Matter

The data given in Table 4.8 showed that accumulation of dry matter was maximum in Cv. PBW-550 (1460.00g m⁻²) followed by Cv. PBW-502 (1046.67 g m⁻²) and Cv. PBW-343 (1083.33 g m⁻²) at 180 kg N ha⁻¹.

Table 4.8: Effect of nitrogen level on accumulated dry matter production (g m⁻²)

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	1326.67	1460.00	1393.33
PBW-502	933.33	1046.67	990.00
PBW-343	1006.67	1083.33	1045.00
Mean	1088.89	1196.67	

CD (P=0.05)

V = 61.83

N = 50.49

N x V = NS

The cultivar and nitrogen treatment differed significantly. The interaction of nitrogen and variety was non significant. Under 120 kg N ha⁻¹ Cv. PBW-343 accumulated less

(1006.67 g m⁻²) dry matter as compared to PBW-550 (1326.67 g m⁻²). Cv. PBW -343 accumulated 25.97% less dry matter as compared to PBW-550 under 180 kg N ha⁻¹. Similar findings were reported by Chandra *et al* (1992).

4.1.11 Remobilized Nitrogen

The cultivars differed significantly from each other (Table 4.9). Cv. PBW-550 (26.36 g m⁻²) found to have maximum remobilized nitrogen followed by Cv. PBW-502 (18.99 g m⁻²) and Cv. PBW-343 (17.80 g m⁻²) under 120 kg ha⁻¹ level of nitrogen.

Table 4.9: Remobilized nitrogen (g m⁻²) effected by different levels of nitrogen

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	26.36	57.81	42.09
PBW-502	18.99	45.12	32.06
PBW-343	17.80	45.83	31.82
Mean	21.06	49.59	35.33

CD (P=0.05)

V = 1.63

N = 1.33

N x V = 2.29

The treatment effect was significantly different. At 180 kg ha⁻¹ nitrogen level Cv. PBW-550 had maximum remobilized nitrogen (57.81 g m⁻²) followed by PBW-343 (45.83 g m⁻²) and PBW-502 (45.12 g m⁻²). At 180 kg N ha⁻¹ level PBW-343 had 20.72% less remobilized nitrogen compared to PBW-550. The interaction of nitrogen and varieties also significant. The differences in the amount of remobilized nitrogen originating from uptake before anthesis were mainly due to the capacity of plant to store nitrogen in sink organs until this period Barbottin *et al* (2005).

4.1.12 Remobilization Efficiency

The data given in Table 4.10 shows that the Cv. PBW-550 (81.10%) found to had maximum remobilized efficiency followed by Cv. PBW-343 (70.48%) and Cv. PBW-502 (69.63%) under 180 kg N ha⁻¹.

At 120 kg N ha⁻¹ Cv. PBW-550 had maximum nitrogen remobilization efficiency (76.86%) as compared to PBW-502 (65.48%) and PBW-343 (63.48%). The difference between all the cultivars was significant. The interaction of nitrogen and varieties were found to be non significant. High remobilization efficiency of cultivar means the cultivar more efficient to partitioning of remobilized N from vegetative part to grain. Similar finding had been reported earlier by Kichey *et al* (2006).

Table 4.10: Effect of different levels of nitrogen levels on remobilization efficiency (%)

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	76.86	81.10	78.98
PBW-502	65.48	69.63	67.56
PBW-343	63.48	70.48	66.98
Mean	68.60	73.74	

CD (P=0.05)

V = 2.47

N = 2.02

N x V = NS

C) Parameters measured at physiological maturity stage**4.1.13 Biological yield**

The biological yield recorded in Cv. PBW-550 (161.50 q ha⁻¹) found to have maximum followed by PBW-502 (156.00 q ha⁻¹) and PBW-343 (153.67 q ha⁻¹) at 180 kg N ha⁻¹. The cultivars differed significantly. The interaction between nitrogen and varieties was also significant (Table 4.11).

Table 4.11: Effect of nitrogen levels on biological yield (q ha⁻¹)

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	150.83	161.50	156.17
PBW-502	150.17	156.00	153.08
PBW-343	147.33	153.67	150.50
Mean	149.44	157.06	

CD (P=0.05)

V = 1.35

N =1.11

N x V = 1.91

At 120 kg ha⁻¹ nitrogen level PBW-343 had minimum biological yield (147.44 q ha⁻¹) as compared to PBW- 502 (150.17 q ha⁻¹) and PBW-343 (147.33 q ha⁻¹). Under 180 kg ha⁻¹ PBW-343 had 4.85% less biological yield than PBW-550. Biological yield increased with increase in nitrogen levels. These findings are similar with those given by Khan *et al* (2000).

4.1.14 Number of spikes per plant

There was significant difference between treatment and varieties. Table 4.12 shows

that the Cv. PBW-550 (8.00) had maximum number of spikes per plant as compared to Cv. PBW-502 (7.67) and Cv. PBW-343 (7.00) at 180 kg ha⁻¹.

Table 4.12: Effect of nitrogen levels on number of spikes per plant in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	7.00	8.00	7.50
PBW-502	6.33	7.67	7.00
PBW-343	6.00	7.00	6.50
Mean	6.40	7.56	

CD (P=0.05)

V = 0.47

N = 0.38

N x V = NS

Cv.PBW-343 found to be minimum (6.00) number of spikes per plant at 120 kg ha⁻¹ nitrogen level than PBW-550 (7.00) Interaction between nitrogen and variety was non significant. Rizwan *et al* (2007) argued that nitrogen fertilizer significantly increased the number of spikes per unit area.

4.1.15 Number of kernels per spike

The data presented on number of kernels/spike for different varieties under two nitrogen levels (120 and 180 kg N ha⁻¹) are given in Table 4.13.

Table 4.13: Effect of nitrogen levels on number of kernels per spike in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	63.67	67.67	65.67
PBW-502	60.00	64.00	62.00
PBW-343	58.67	62.33	60.50
Mean	60.78	64.67	62.73

CD (P=0.05)

V = 1.67

N = 1.36

N x V = NS

The Cv. PBW-550 (67.67) had maximum number of kernels per spike followed by Cv. PBW-502 (64.00) and PBW-343 (62.33) at 180 kg N ha⁻¹ while Cv.PBW-343 had minimum number of kernels (58.67).PBW-550 had maximum number of kernels under both nitrogen levels than other cultivars. The cultivars differed significantly and interaction

between nitrogen and varieties was found to be non significant. The findings are similar to the findings of Van Herwaarden (1995).

4.1.16 1000-kernels weight

There was no significant difference between interaction of nitrogen and varieties. Nitrogen levels differed significantly (Table 4.19). The Cv. PBW-550 (42.88 g) had maximum 1000-kernels weight followed by PBW-343 (39.80 g) and PBW-502 (39.53 g) at 180 kg N ha⁻¹ (Table 4.14)

Table 4.14: Effect of nitrogen levels on 1000-kernels weight (g) in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	45.99	42.88	44.43
PBW-502	42.27	39.53	40.90
PBW-343	40.53	39.80	40.17
Mean	42.93	40.74	

CD (P=0.05)

V = 1.01

N = 0.82

N x V = NS

Under 120 kg ha⁻¹ level PBW-550 (45.99 g) 1000-kernels weight as compared to PBW-502 (42.27 g) and PBW-343 (40.53 g). At 180 kg N ha⁻¹ 5.10% reduction in 1000-kernels weight than 120 kg ha⁻¹ nitrogen level. The inverse relation between test weight and nitrogen rate is probably due to the increase in the number of grains per ear and the decline in 1000-grain weight prompted by increased N fertilizer rates (Lopez-Bellido *et al* 2000).

4.1.17 Grain yield

The data presented on grain yield for three varieties under two nitrogen levels (120 and 180 kg N ha⁻¹) are given in Table 4.15.

Table 4.15: Effect of nitrogen levels on grain yield (q ha⁻¹) in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	53.85	60.83	57.34
PBW-502	51.33	56.50	53.92
PBW-343	48.83	54.83	51.83
Mean	51.34	57.39	

CD (P=0.05)

V = 0.67

N = 0.54

N x V = 0.94

Grain yield shows that there was significant difference in grain yield of all the three wheat cultivars. The amount of nitrogen also significantly affected the grain yield. Interaction among the three cultivars and two nitrogen doses was found to be significant. Grain yield increased as amount of nitrogen increased from 120 to 180 kg N ha⁻¹. The grain yield was maximum in Cv. PBW-550 (60.83 q ha⁻¹) followed by PBW-502 (56.50 q ha⁻¹) and PBW-343 (54.83 q ha⁻¹) at 180 kg N ha⁻¹. The Cv. PBW-550 had 11.76% less grain yield under 120 kg N ha⁻¹ than 180 kg ha⁻¹ nitrogen level.

The Cv. PBW-343 showed 9.86% less grain yield as compare to PBW-550 under 180 kg N ha⁻¹. These results agree with the results of Khan *et al* (2001).

4.18 Grain Protein Concentration

The data regarding the grain protein concentration given in Table 4.16 showed that there were significant difference between the cultivars and treatment.

The interactive effect of cultivars and nitrogen treatment were significant. The cultivars and nitrogen levels differed from each other significantly. The Cv. PBW-550 (2.99%) had minimum grain nitrogen percentage at maturity. The Cv. PBW-550 (2.49%) had maximum grain nitrogen followed by Cv. PBW-502 (2.05%) at 120 kg N ha⁻¹. The Cv. PBW-343 showed 29.09% reduction in grain nitrogen percentage as compared to PBW-550 at maturity.

Table 4.16: Relationship between grain protein concentration (%) and nitrogen levels

Variety	Grain nitrogen percentage			Grain protein concentration		
	Nitrogen (kg ha ⁻¹)					
	120	180	Mean	120	180	Mean
PBW-550	2.49	2.99	2.74	14.27	17.07	15.67
PBW-502	2.05	2.22	2.14	11.63	12.67	12.15
PBW-343	2.01	2.12	2.07	11.37	12.03	11.70
Mean	2.19	2.44		12.42	13.92	
CD (P=0.05) V = 0.05 N= 0.04 N x V= 0.08				CD (P=0.05) V = 0.32 N = 0.26 N x V = 0.45		

The interaction of nitrogen treatments and varieties was also significant. Evidently protein content increased as amount of nitrogen was increased from 120 to 180 kg N ha⁻¹ maximum grain protein concentration (17.07%) was found to be in Cv. PBW-550 followed by PBW-502 (12.67%) and PBW-343 (12.03%) 180 kg N ha⁻¹. The minimum grain protein concentration was recorded in the PBW-343 (11.37%) at 120 kg ha⁻¹ nitrogen level. These

results agree with the findings of Chaudhary and Singh (1991) who reported that grain protein concentration significantly affected by levels of nitrogen. Banziger *et al* (1992) reported that genotypic variability in grain protein content may be affected by physiological traits also by nitrogen supply in the soil.

4.1.13 Grain Protein Yield

The data given in Table 4.17 shows that the cultivars and nitrogen treatment differed significantly. The interaction between nitrogen and variety was also significant. The grain protein yield was found to be maximum in Cv. PBW-550 (103.82 g m⁻²) followed by PBW-502 (71.56 g m⁻²) and PBW-343 (65.99 g m⁻²) under 180 kg N ha⁻¹.

Table 4.17: Effect of nitrogen levels on grain protein yield ((g m⁻²) in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	76.83	103.82	90.33
PBW-502	59.71	71.56	65.64
PBW-343	55.51	65.99	60.75
Mean	64.02	80.46	

CD (P=0.05)

V= 1.79

N= 1.47

N x V = 2.54

At 120 kg ha⁻¹ nitrogen level Cv. PBW-343 found to had less (55.51g m⁻²) grain protein yield as compared to PBW-550 (76.83 g m⁻²).Cv. PBW -343 had 36.44% less while PBW-502 had 31.07% less grain protein yield as compared PBW-550 under 180 kg N ha⁻¹ . Similar findings were reported by Chandra *et al* (1992).

4.1.16 Total Dry Matter

With increase in nitrogen levels from 120 kg ha⁻¹ to 180 kg ha⁻¹ total plant dry matter increases in all cultivars at maturity (Fig. 4.3). Total dry matter found to have maximum in PBW-550 (3880 g m⁻²) at 180 kg ha⁻¹ levels of nitrogen followed by PBW-502 (3660) and PBW-343 (3613.33 g m⁻²). On the average PBW-550 accumulated more dry matter than PBW-502 and PBW-343 at both levels of nitrogen .PBW-550 accumulated (6.01%) less dry matter at 120 kg N ha⁻¹ as compared 180 kg N ha⁻¹ level. Cv. PBW-343 accumulated (6.87%) less total dry matter than PBW-550 at 180 kg ha⁻¹ nitrogen levels. The nitrogen treatment and varieties difference was significant. Interaction effect due to nitrogen x variety were also significant .These observations get support from the result of Kaur (2000).

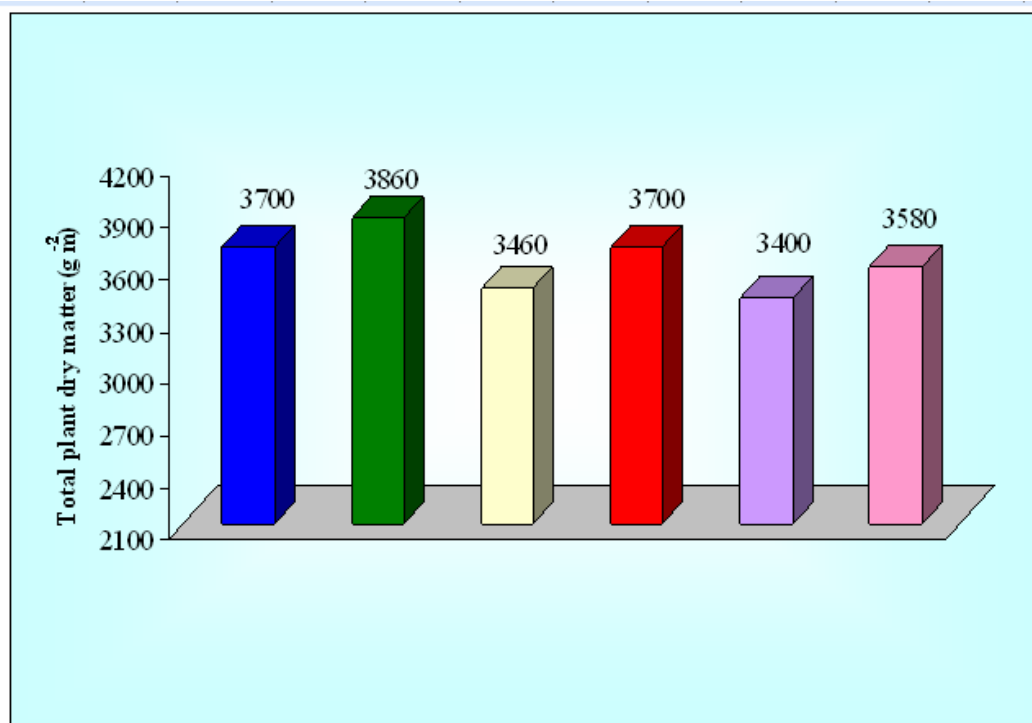


Fig. 4.3: Total plant dry matter accumulation at physiological maturity

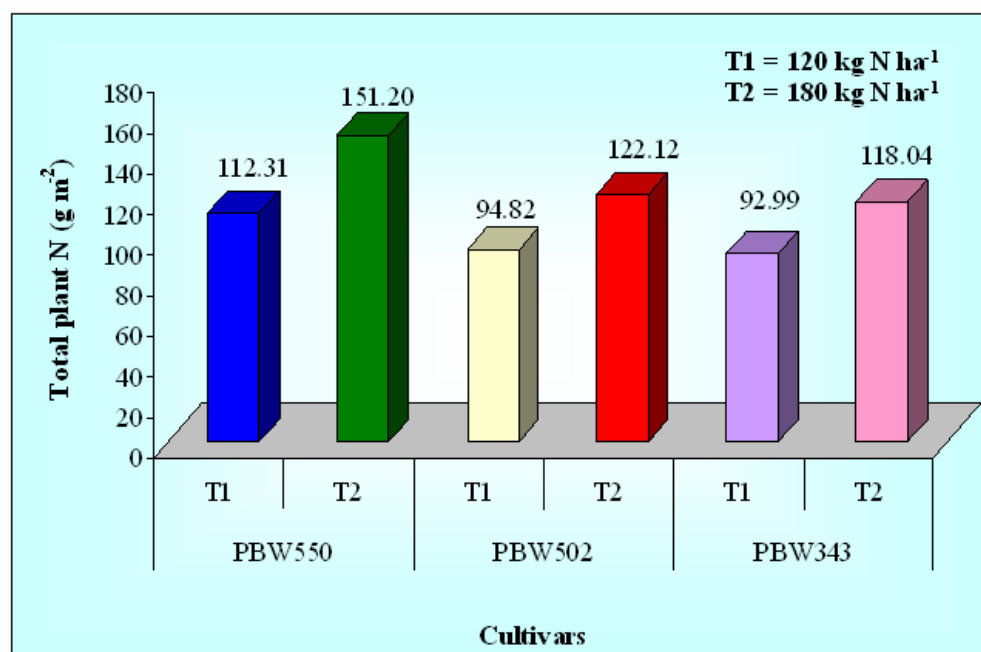


Fig 4.4: Total plant nitrogen at physiological maturity

4.1.17 Total Plant Nitrogen

The cultivar PBW-550 (151.19 g m⁻²) found to have maximum plant nitrogen under 180 kg ha⁻¹ nitrogen levels at maturity stage followed by PBW-502 (122.12 g m⁻²) and PBW-343 (118.04 g m⁻²). At 120 kg N ha⁻¹ PBW-343 (92.99 g m⁻²) accumulated less plant nitrogen than PBW-502 (94.82 g m⁻²) and PBW-550(112.31 g m⁻²). With increase in nitrogen levels from 120 kg to 180 kg ha⁻¹, total plant nitrogen increase at both nitrogen levels in all cultivars (Fig.4.4). The cultivars and treatment difference was significant. The Cv. PBW-343 accumulated total plant nitrogen (21.92%) less than PBW-550 at 180 kg N ha⁻¹ level. There was 23.31% reduction in total plant nitrogen in 120 kg N ha⁻¹ in comparison to 180 kg N ha⁻¹ level. The interaction of nitrogen and variety was also significant. These result supported by Papakosta and Gagianas (1991)

4.1.18 Harvest Index

The harvest index was maximum in Cv. PBW-550 (37.70%) followed by PBW-502 (36.20%) and PBW-343 (35.70%) at 180 kg N ha⁻¹. The varieties and treatment differed significantly and their interaction is also found to be significant (Table 4.18).

Table 4.18: Effect of nitrogen levels on harvest index (%) in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	35.70	37.70	36.70
PBW-502	34.20	36.20	35.20
PBW-343	33.10	35.70	34.40
Mean	34.30	36.50	

CD (P=0.05)

V = 0.002

N = 0.002

N x V = 0.003

The Cv. PBW-550 found to had maximum harvest index (35.70%) than PBW-343 (33.10%). These results are close with the results of Perry and D'Antuono (1989).

4.1.19 Nitrogen Harvest Index

The data presented on nitrogen harvest index for three varieties under two nitrogen levels (120 and 180 kg N ha⁻¹) are given in Table 4.19.

The nitrogen harvest index was found to be maximum in Cv. PBW-550 (.0574) followed by Cv. PBW-502 (.0388) and Cv. PBW-343 (0.378) at 180 kg N ha⁻¹. The Cv. PBW-550(0.629) had maximum nitrogen harvest index than PBW-343 (0.489). The cultivars

and nitrogen differed significantly. The interaction of nitrogen and varieties was also significant. These results supported by Triboi and Triboi - Blondel (2002).

Table 4.19: Effect of nitrogen levels on nitrogen harvest index in wheat cultivars

Variety	Nitrogen (kg ha ⁻¹)		Mean
	120	180	
PBW-550	0.629	0.574	0.602
PBW-502	0.513	0.388	0.451
PBW-343	0.489	0.378	0.434
Mean	0.544	0.447	

CD (P=0.05)

V = 0.02

N = 0.01

N x V = 0.02

4.1.20 Vegetative Nitrogen

The Cv.PBW-502 accumulated maximum vegetative dry matter (1720 g m⁻²) while PBW-550 had minimum vegetative dry matter (1480 g m⁻²) at 180 kg N ha⁻¹. The interactive effect of cultivars and nitrogen treatment found to be significant. The Cv. PBW-550 showed 13.95% reduction in vegetative dry matter as compared to PBW-502 at 180 kg N ha⁻¹. Under 120 kg ha⁻¹ nitrogen level Cv.PBW-550 had minimum (1360 g m⁻²) vegetative dry matter than PBW-502 (1480 g m⁻²). These results close with the finding of McKendry *et al* (1995).

The Cv.PBW-550 had minimum (0.91%) while PBW-550 had maximum vegetative nitrogen percentage (1.14%) at 180 kg N ha⁻¹. The cultivars and nitrogen difference was significant and interaction of nitrogen and varieties was also significant. The Cv. PBW-550 (0.58%) had minimum vegetative nitrogen at maturity. The Cv. PBW-343 (0.68%) had maximum vegetative nitrogen followed by Cv. PBW-343 (0.70%) at 120 kg N ha⁻¹. Cv. PBW-550 showed 20.17% reduction in vegetative nitrogen percentage as compared to PBW-343 at maturity.

The cultivars and nitrogen difference was significant and interaction of nitrogen and varieties was also significant (Table 4.20). Cv. PBW-550 (13.47 g m⁻²) had minimum vegetative nitrogen at maturity. The Cv. PBW-502 (19.67 g m⁻²) had maximum vegetative nitrogen followed by Cv. PBW-343 (19.21 g m⁻²) at 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ Cv.PBW-343 had maximum vegetative nitrogen while PBW-550 had minimum (7.94 g m⁻²). Cv. PBW-550 showed 29.88% reduction in vegetative nitrogen as compared to PBW-343 at maturity. Nitrogen content in stem increased at all the stages of growth with increase in nitrogen levels but decreased with the stages of development (Singh and Singh 1991).

Table 4.20 Effect of different levels of nitrogen on vegetative dry matter (g m^{-2}), tissue nitrogen percentage (%) and vegetative nitrogen (g m^{-2}) at physiological maturity stage

Cultivars	Traits								
	Vegetative dry matter (g m ⁻²) (excluding chaff)			Tissue N percentage (%)			Vegetative nitrogen (g m ⁻²)		
	Nitrogen levels (kg ha ⁻¹)								
	120	180	Mean	120	180	Mean	120	180	Mean
PBW-550	1360.00	1480.00	1420.00	0.58	0.91	0.75	7.94	13.47	10.70
PBW-502	1480.00	1720.00	1600.00	0.68	1.14	0.91	10.01	19.67	14.84
PBW-343	1460.00	1680.00	1570.00	0.70	1.14	0.92	10.22	19.21	14.71
Mean	1433.33	1626.67		0.65	1.07		9.39	17.45	
CD (P=0.05)	V = 24.4			V = 0.06			V = 1.08		
	N = 19.9			N = 0.05			N = 0.87		
	N x V = 34.5			N x V = NS			N x V =1.52		

CORRELATION AND PATH COEFFICIENT ANALYSIS

The following characters were used for correlation and path analysis.

1. Grain protein concentration
2. Grain protein yield at maturity
3. Remobilized nitrogen at post anthesis
4. Biological yield
5. Number of spikes per plant
6. Number of kernels per spike
7. 1000-kernels weight
8. Total plant nitrogen at maturity
9. Vegetative nitrogen at maturity
10. Remobilization efficiency at post anthesis
11. Grain yield

The grain yield was highly positively correlated with biological yield ($r = 0.9766$) followed by total plant nitrogen at maturity ($r = 0.9688$), remobilized nitrogen at post anthesis ($r = 0.9296$), number of kernels per spike ($r = 0.9195$), grain protein yield ($r = 0.9069$), number of spikes per plant ($r = 0.8973$), grain protein concentration ($r = 0.8236$), remobilization efficiency ($r = 0.8068$), while vegetative nitrogen at maturity ($r = 0.4517$) had no correlation with grain yield (Table 4.21).

The correlation of remobilization efficiency was high with grain protein concentration ($r = 0.9183$) followed by grain protein yield ($r = 0.9093$), number of kernels per spike ($r = 0.8652$), total plant nitrogen at maturity ($r = 0.8232$), number of spikes per plant ($r = 0.7574$), biological yield ($r = 0.7111$). Vegetative nitrogen at maturity showed no correlation with remobilization efficiency. Number of kernels highly correlated with grain protein yield ($r = 0.9092$). 1000-grain weight had no correlation while biological yield showed maximum correlation ($r = 0.9490$) with total plant nitrogen at maturity followed by grain protein yield ($r = 0.9358$). Correlation between number of kernels per spike and grain protein yield was maximum ($r = 0.9092$).

Path coefficient analysis divides the correlation coefficient analysis into direct and indirect effects (Khan *et al* 2005). It allows, then the separation of direct influence of each yield components themselves. For that purpose, a cause effect system (Fig.4.5) was formed.

Table 4.21: Pearson correlation analysis between grain yield and different traits in wheat

Characters	1	2	3	4	5	6	7	8	9	10	11
1. Grain protein concentration	1.000										
2. Grain protein yield	0.9847**										
3. Remobilized N	0.6511**	0.7622**									
4. Biological yield	0.7741**	0.8703**	0.9298**								
5. No. of spikes per plant	0.7079**	0.7859**	0.8600**	0.8646**							
6. No. of kernels per spike	0.8668**	0.9092**	0.8121**	0.8589**	0.8449**						
7. 1000-kernel weight	0.5024*	0.3802	-0.2054	-0.0209	0.0144	0.3009					
8. Total nitrogen at maturity	0.8720**	0.9358**	0.9306**	0.9490**	0.8621**	0.9202**	0.0953				
9. Vegetative nitrogen at maturity	0.0818	0.0755	0.6764**	0.4974*	0.4649	0.2656	-0.7189	0.4112			
10. Remobilization efficiency	0.9183**	0.9093**	0.6727**	0.7111**	0.7574**	0.8652**	0.5250*	0.8232**	0.0272		
11. Grain yield	0.8236**	0.9067**	0.9296**	0.9766**	0.8973**	0.9195**	0.0925	0.9688**	0.4517	0.8068**	1.000

** Significant at 5% level

* Significant at 1% level

Table 4.22: Path coefficient analysis of grain yield with different traits

Characters	1	2	3	4	5	6	7	8	9	10
1. Grain protein concentration	-0.0207	0.0345	-0.1638	-0.1146	0.0021	0.0177	0.0336	-0.4767	-0.0435	0.01903
2. Grain protein yield	-0.0204	0.0350	-0.1918	-0.1289	0.0023	0.0186	0.0254	-0.5116	0.0402	0.1884
3. Remobilized N	-0.01351	0.0267	-0.2516	-0.1377	0.0025	0.0166	-0.0137	-0.5088	0.3605	0.1394
4. Biological yield	-0.0161	0.0305	-0.2339	-0.1481	0.0026	0.0176	-0.0014	-0.05189	0.26510	0.1473
5. No. of spikes per plant	-0.0147	0.0275	-0.2164	-0.1280	0.0029	0.0173	0.0008	-0.4713	0.2478	0.1569
6. No. of kernels per spike	-0.0179	0.0319	-0.2044	-0.1272	0.0025	0.0205	0.0201	-0.5031	0.1416	0.1793
7. 1000-kernel weight	-0.0104	0.0133	0.0517	0.0031	0.0003	0.0062	0.0670	-0.0521	-0.3813	0.1088
8. Total nitrogen at maturity	-0.0181	0.0328	-0.2341	-0.1406	0.0026	0.0188	0.0064	-0.5467	0.2193	0.1706
9. Vegetative nitrogen at maturity	0.1698	0.2647	-0.1702	-0.0737	0.0013	0.0055	-0.0481	-0.2248	0.5329	0.0056
10. Remobilization efficiency	-0.0191	0.0319	-0.1693	-0.1053	0.0023	0.0178	0.0318	-0.4501	-0.0145	0.2072

(Bold values shows direct effect)

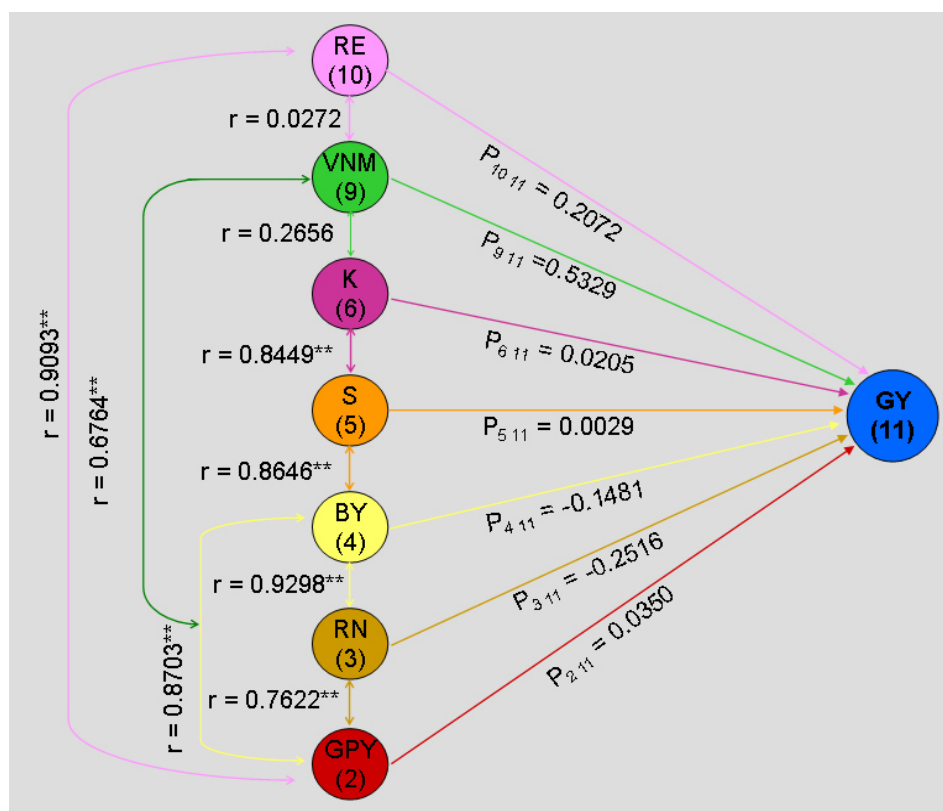


Fig. 4.5: Path coefficient of the direct effects of grain protein yield (GPY), remobilized nitrogen (RN), biological yield (BY), number of spikes per plant (S), number of kernels per spike (K), vegetative nitrogen at maturity (VNM) and remobilization efficiency (RE) on grain yield.

**(The single headed arrows indicate path correlation coefficient.
The double headed arrows indicate simple correlation coefficient.
** Significant values).**

Path analysis of grain yield showed that the vegetative nitrogen at maturity stage had significant positive direct effect ($P_{9\ 11} = 0.5329$) on grain yield. Vegetative nitrogen at maturity had significant positive correlation with remobilized nitrogen ($r_{93} = 0.6764$) and it contribute more indirectly through grain protein yield ($r_{92} P_{2\ 11} = 0.0267$). The direct effect of grain protein yield found to be low ($P_{2\ 11} = 0.0350$) while its correlation in correlation analysis was due to its indirect effect through remobilization efficiency ($r_{210} P_{2\ 11} = 0.1884$). Remobilized nitrogen had negative direct effect on grain yield ($P_{3\ 11} = -0.2516$). However, its lower value of correlation in correlation analysis due to its indirect contribution through vegetative nitrogen at maturity ($r_{39} P_{3\ 11} = 0.3605$). The direct effect of biological yield was negative but in correlation coefficient it shows the positive correlation. Number of spikes per plant contribute directly ($P_{5\ 11} = 0.0029$), its direct effect on grain yield in the correlation analysis was masked by the indirect effect through vegetative nitrogen at maturity ($r_{59} P_{5\ 11} =$

0.2478). Number of kernels per spike had direct effect on grain yield ($P_{6\ 11} = 0.0205$) while the indirect effect through remobilization efficiency was more ($r_{6\ 10} P_{6\ 11} = 0.1793$). Remobilization efficiency contribute more directly ($P_{10\ 11} = 0.2072$) than indirectly ($r_{10\ 5} P_{10\ 11} = 0.0023$) through number of spikes per plant.

From this path analysis it can be concluded that grain protein yield, remobilized nitrogen, biological yield, number of spikes per plant, number of kernels per spike, vegetative nitrogen at maturity and remobilization efficiency contribute towards yield. Vegetative nitrogen at maturity had significant direct effect on grain yield (Table 4.22).

The following traits were used for correlation between grain yield and traits at different stages in wheat:

1. Total Plant Dry Matter at anthesis stage (TDMA)
- 2.Total Plant Nitrogen at anthesis stage (TPNA)
- 3.Vegetative Nitrogen at Anthesis + 4days stage (VG4D)
- 4.Vegetative Nitrogen at Anthesis + 8 days Stage (VG8D)
- 5.Vegetative Nitrogen at Anthesis + 12 days Stage (VG12D)
- 6.Vegetative Nitrogen at Milky Stage (VGM)
- 7.Vegetative Nitrogen at Soft Dough Stage (VGS)
- 8.Maximum Vegetative Nitrogen at post anthesis stage (MXN)
- 9.Harvest index at physiological maturity stage (HI)
- 10.Nitrogen harvest index at physiological maturity stage (NHI)
- 11.Sum of harvest index and nitrogen harvest index (SUM)
12. Total Plant Dry Matter at physiological maturity stage (TDMM)
13. Accumulated Nitrogen at post anthesis stage (ACCN)
14. Accumulated Dry Matter at post anthesis stage (ACCDM)
15. Grain yield at physiological maturity stage (GY)

In order to quantitatively analyze the relationship among physiological traits and grain yield, Pearson analysis was applied (Table 4.23). A significant high and positive correlation of grain yield with harvest index ($r = 0.9833$) followed by vegetative nitrogen at milky stage ($r = 0.9693$). Grain yield had no correlation with total dry matter at anthesis. Correlation between accumulated dry matter with total dry matter at maturity was significantly positive ($r = 0.8543$). Accumulated nitrogen at anthesis was negatively correlated with total dry matter at anthesis ($r = -0.0236$). Nitrogen harvest index, sum of harvest index and nitrogen harvest index, total dry matter at maturity negatively correlated with total dry matter at anthesis. Correlation of maximum vegetative nitrogen significant

Table 4.23: Correlation analysis between grain yield and traits at different growth stages (Data pooled for wheat cultivars and nitrogen levels)

Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. TDMA	1.000														
2. TPNA	0.1853														
3. VG4D	0.5014*	0.8270**													
4. VG8D	0.5528*	0.8027**	0.9921**												
5. VG12D	0.2661	0.9414**	0.9298**	0.9204**											
6. VGM	0.3595	0.9475**	0.9530**	0.9394**	0.9833**										
7. VGS	0.3253	0.9506**	0.9404**	0.9262**	0.9920**	0.9941**									
8. MXN	0.5171*	0.8281**	0.9930**	0.9986**	0.9390**	0.9534**	0.9424**								
9. HI	0.1283	0.8128**	0.8198**	0.8127**	0.9343**	0.8766**	0.9074**	0.8351**							
10. NHI	-0.8575	0.0152	-0.3985	-0.4389	-0.723	-0.1910	-0.1217	-0.3951	0.1155						
11. SUM	-0.8122	0.1402	-0.2602	-0.3005	0.0740**	-0.0501	0.0219	-0.2546	0.2664	0.9882**					
12. TDMM	-0.0029	0.8530**	0.7766**	0.7579**	0.9318**	0.8697**	0.9007**	0.7871**	0.9774**	0.2289	0.3729				
13. ACCN	-0.0236	0.6337**	0.6969**	0.7010**	0.8097**	0.7127**	0.7449**	0.7220**	0.9184**	0.1809	0.3172	0.9107**			
14. ACCDM	-0.4374	0.6435**	0.4566	0.4240	0.6846**	0.5793*	0.6304**	0.4624	0.7740**	0.5626*	0.6653**	0.8543**	0.8008**		
15. GY	0.1991	0.8897**	0.8527**	0.8472**	0.9693**	0.9311**	0.9538**	0.8701**	0.9833**	0.0625	0.2124	0.9710**	0.8596**	0.7313**	1.000

** Significant at 5% level,

* Significant at 1% level

positive with vegetative nitrogen at eight days after anthesis ($r = 0.9986$). Vegetative nitrogen at anthesis + 4 days positively correlated with total plant nitrogen at anthesis ($r = 0.8270$). Nitrogen harvest index and negative correlation with maximum vegetative nitrogen at past anthesis stage ($r = -0.3951$). Sum of harvest index and nitrogen harvest index had no correlation with vegetative nitrogen four days after anthesis. Correlation were especially strong for total dry matter at maturity and grain yield, accumulated dry matter and total dry matter at maturity, total dry matter at maturity and vegetative nitrogen twelve days after anthesis. Harvest index and total dry matter at maturity more significant positive correlation with grain yield. Our results are in close agreement with McKendry *et al* (1995).

RELATIONSHIP BETWEEN GRAIN YIELD (GY) AND GRAIN PROTEIN CONCENTRATION (GPC)

Linear regression equations for grain yield and grain protein concentration are presented in Fig.4.6

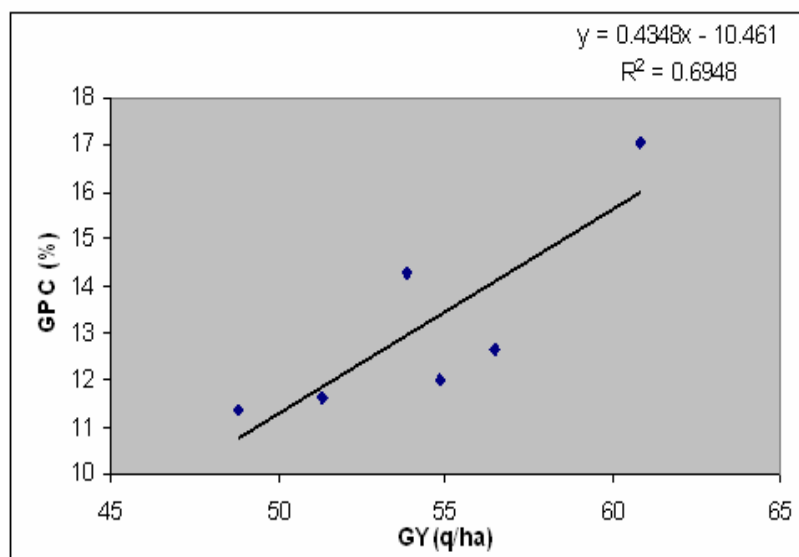


Fig. 4.6 Relationship between grain yield and grain protein concentration.

Regression equation, taking grain yield and grain protein concentration data pooled over three cultivars i.e. PBW-550, PBW-502 and PBW-343 with two nitrogen levels (120 to 180 kg N ha⁻¹). The regression line indicated a significant positive correlation between grain yield and grain protein concentration ($R^2 = 0.6948$). Fig.4.5 Showed that grain yield and concentration increased simultaneously. Relationship between grain yield and grain protein concentration affected by physiological traits i.e. remobilization efficiency, grain protein yield, total plant nitrogen at physiological maturity and nitrogen harvest index but also by nitrogen applications. Debaeke *et al* (1996) also reported that strong relationship between grain yield and grain nitrogen concentration.

4.2 PHENOLOGICAL DEVELOPMENT

Changes in seasonal temperature affect the grain yield, mainly through phenological development processes. Phenological development from seedling to maturity is related to the accumulation of heat or temperature units above a base temperature below which no growth occurs. Phenological development of the cultivars PBW-550, PBW-502 and PBW-343 under two levels of nitrogen presented in Fig. 4.7 i.e. from seedling emergence to physiological maturity.

4.2.1 Seedling emergence

In all varieties seedling emergence took 6 days under 120 kg N ha⁻¹. The number of days increased with increase in the nitrogen level from 120 to 180 kg N ha⁻¹. Under 180 kg N ha⁻¹ PBW-550 and PBW-343 took 7 days while PBW-502 took 8 days. Number of days taken from seedling emergence depends on nitrogen and temperature. With increase in nitrogen level the crop took more days for the seedling emergence (Khan *et al* 2008). The cumulative growing degree days increase with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. The GDD required for the seedling emergence were maximum (116.8) in PBW-343 under 180 kg N ha⁻¹.

4.2.2 Crown root initiation (CRI)

The number of days taken by different wheat cultivars (PBW-550, PBW-502 and PBW-343) for attainment of crown root initiation stage increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. Cv. PBW-550 took 16 days from sowing to CRI. Under 120 kg N ha⁻¹ Cv. PBW-502 and PBW-343 took 17 days from sowing to CRI under 120 kg N ha⁻¹. Under 180 kg N ha⁻¹ Cv. PBW-550 took 18 days while PBW-502 and PBW-343 took 19 days from sowing to CRI. There was increase in accumulated growing degree days (AGDD) with increase in nitrogen level. The significant difference occurred between nitrogen levels for attainment of crown root stage. Such observations of GDD have earlier reported by Anderson *et al* (1995). The accumulated, growing degree days were maximum (24.32) under 180 kg N ha⁻¹.

4.2.3 Leaf initiation

The number of days taken for leaf initiation by different wheat varieties varied under different nitrogen levels. The varieties PBW-343 and PBW-502 took 24 days under 180 kg N ha⁻¹ level while PBW-550 took 23 days under same level. Under 120 kg N ha⁻¹ PBW-550 took less days (21) as compared to PBW-502 (22) and PBW-343 (22). The accumulated GDD units increased with increase in nitrogen levels. PBW-502 and PBW-343 varieties took maximum (300) GDD units followed by PBW-550 (287.5) at 180 kg N ha⁻¹. The results are in conformity with Migletia (1991).

4.2.4 Leaf development completion

The number of days taken for leaf development stage by different wheat varieties varied under different nitrogen levels. The variety PBW-343 took more number of days i.e. 84 under 180 kg N ha⁻¹ followed by PBW-502 (83) and PBW-550 (82) varieties. The PBW-550 took lesser (79) days under 120 kg N ha⁻¹ from sowing to complete leaf development stage. The number of days for leaf development increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. The accumulated GDD units increased with increase in nitrogen level. PBW-343 variety took maximum (840) GDD units followed by PBW-502 (830) and PBW-550 (820) variety under 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ PBW-343 (787.8) took more GDD as compared to PBW-502 (797.9) and PBW-550 (797.7). These results are close with the findings of Miglietta (1991).

4.2.5 Tillering initiation

The number of days taken for the attainment of tillering initiation increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹ in all varieties. The increase in number of days taken for tillering initiation due to increase in nitrogen level. Longnecker *et al* (1993) also reported increased number of days with increase in nitrogen levels. The accumulated growing degree days were maximum for all cultivars under 180 kg N ha⁻¹. The Cv. PBW-343 accumulate more (359.6) GDD which was followed by PBW-502 (350) and PBW-550 (337.5) under 180 kg N ha⁻¹, the accumulated (287.5) under 120 kg N ha⁻¹.

4.2.6 Tillering completion

The number of days taken for the completion of tillering stage increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. The accumulated growing degree days were maximum in Cv. PBW-343 (787.8) followed by PBW-502 (777.7) and PBW-550 (767.6) under 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ PBW-550 (757.5) accumulated maximum growing degree days than PBW-502 (747.4) and PBW-343 (747.4). Cv. PBW-343 (78) took more days than PBW-550 (76) and PBW-5025 (77) from sowing to tillering completion. These results are in conformity with Longnecker *et al* (1993). The results indicate the effect of nitrogen, temperature and sunshine hours during the crop growing season.

4.2.7 Jointing (stem elongation)

The number of days taken up by the crop to complete jointing stage varied with both variety and nitrogen levels. The number of days increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. The Cv. PBW-353 and PBW-502 took maximum number of days (80) under 180 kg N ha⁻¹ level while PBW-550 took 79 number of days from sowing to

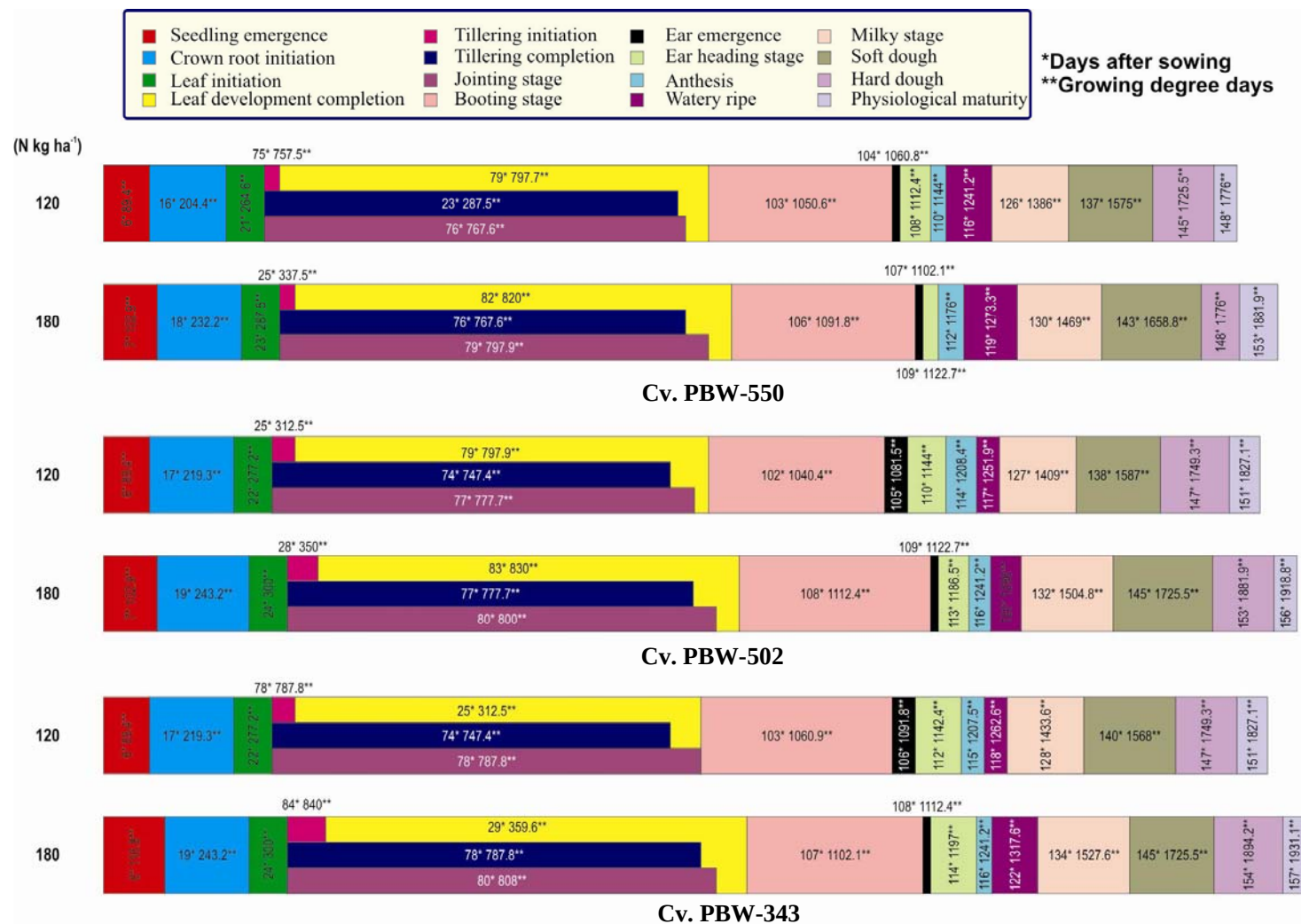


FIG. 4.7: PHENOLOGICAL DEVELOPMENT OF WHEAT CULTIVARS

jointing stage. PBW-550 requires minimum number of days (76) for attainment of jointing stages under 120 kg N ha⁻¹. The number of days increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. The accumulated GDD were increased with increase in nitrogen levels. PBW-343 accumulated maximum GDD (808) followed by PBW-502 (800) and PBW-550 (797.9) under 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ PBW-343 (787.8) accumulated maximum GDD then PBW-502 (777.7) and PBW-550 (767.6). The results are in close conformity with Qi *et al* (2009).

4.2.8 Booting

The number of days taken for the attainment of booting stage increased as the level of nitrogen increased from 120 to 180 kg N ha⁻¹. The Cv. PBW-502 took more (108) days followed by PBW-343 (107) and PBW-550 (106) under 180 kg N ha⁻¹. The increased days with increase in nitrogen levels has also been reported by Maranville (1994). The maximum accumulated GDD recorded in Cv. PBW-502 (1112.14) followed by PBW-343 (1102.1) and PBW-550 (1091.8) under 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ Cv. PBW-550 (1050.6) accumulated lesser growing degree days as compared to PBW-343 (1060.9) and PBW-502 (1040.4).

4.2.9 Ear emergence

The number of days taken for the emergence of inflorescence increases as the nitrogen levels increased. The number of days taken were maximum in PBW-502 (109) while minimum in PBW-550 (107) cultivar under 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ number of days taken were maximum in PBW-343 (106) followed by PBW-502 (105) and PBW-550 (104) cultivars. The Cv. PBW-502 (1122.7) accumulated more growing degree days (GDD) while PBW-343 (1112.4) and PBW-550 (1102.1) under 180 kg N ha⁻¹. Cv. PBW-343 (1091.8) accumulated more GDD than PBW-502 (1081.5) and PBW-550 (1060.8) at 120 kg N ha⁻¹.

4.2.10 Ear heading

The number of days taken for completion of this stage increased with increase in nitrogen levels. The accumulated growing degree days maximum in PBW-343 (1197) while minimum in PBW-550 (1122.7) under 180 kg N ha⁻¹. The Cv. PBW-343 (1142.4) accumulated more GDD, followed by PBW-502 (1144) and PBW-550 (1144). These results are in conformity with Miglietta (1991).

4.2.11 Anthesis

The number of days taken from sowing to anthesis stage increased with increase in nitrogen levels. The GDD units were more accumulated in PBW-502 (1241.2). Cv. PBW-353

(1241.2) also accumulated same GDD than PBW-550 (11.76) under 180 kg N ha⁻¹. At 120 kg N ha⁻¹ Cv. PBW-343 (1207.5) accumulated more GDD followed by PBW-502 (1197) and pBW-550 (1144). Similar results were also reported by Angus and Mancur (1985).

4.2.12 Watery ripe

The number of days to reach watering ripe stage increases with increase in the levels of nitrogen. The lesser number of days were observed in Cv. PBW-550 (116) followed by Cv. PBW-502 (117) and Cv. PBW-343 (118) under 120 kg N ha⁻¹. At same level Cv. PBW-343 (1262.6) accumulated more growing degree days followed by PBW-502 (1251.90 and PBW-550 (1241.2). The GDD followed the increasing trend from 120 to 180 kg N ha⁻¹. At 180 kg N ha⁻¹ PBW-343 (1317.6) accumulated more GDD as compared to PBW-502 (1296) and PBW-550 (1273.3).

4.2.13 Milky ripe

The number of days taken for milky ripe stage are more in PBW-343 (134) followed by PBW-502 (132) and PBW-550 (130) under 180 kg N ha⁻¹. The maximum accumulated GDD units were observed in PBW-343 (1527.6) followed by PBW-502 (1504.8) and PBW-550 (1469) under 180 kg N ha⁻¹. At 120 kg N ha⁻¹ accumulated growing degree days are less in PBW-550 (1386) followed by PBW-502 (1409.7) and PBW-343 (1433.6). Gooding and Davies (1992) also reported increase in number of days by the effect of higher nitrogen levels.

4.2.14 Soft dough

The number of days and accumulation GDD increased with increase in nitrogen levels in all varieties. The Cv. PBW-502 and PBW-343 took same days (145) for soft dough stage followed by PBW-550 (143) under 180 kg N ha⁻¹ while at 120 kg N ha⁻¹ PBW-343 took more days (140) followed by PBW-502 (138) and PBW-550 (137). Accumulated GDD more in PBW-343 (1725.5) followed by PBW-502 (1725.5) and PBW-550 (1658.8). The Cv. PBW-550 accumulated less growing degree days (1575.5) as compared to PBW-502 (1587) and PBW-343 (1568) at 120 kg N ha⁻¹ level. Similar results were reported by Khan *et al* (2008).

4.2.15 Hard dough

The maximum number of days taken for the attainment of hard dough stage was observed in PBW-343 (154) followed by PBW-502 (153) and PBW-550 (148) under 180 kg N ha⁻¹. Under 120 kg N ha⁻¹ PBW-550 took less days (145) as compared to PBW-502 (147) and PBW-343 (147). Maximum accumulated GDD were recorded under 180 kg N ha⁻¹ in

PBW-343 (1894.2) followed by PBW-502 (1881.9) and PBW-550 (1776). The Cv. PBW-550 accumulated minimum GDD (1725.5) under 120 kg N ha⁻¹ as compared to other cultivars.

4.2.16 Physiological maturity

The wheat Cv. PBW-502 and PBW-343 took similar number of days (151) under 12 kg N ha⁻¹ while PBW-550 took (148) days from sowing to physiological maturity. The Cv. PBW-343 took maximum day (157) for physiological maturity followed by PBW-502 (156) and PBW-550 (153) under 180 kg N ha⁻¹. The accumulated growing degree days in all wheat varieties increased with increase in nitrogen levels from 120 to 180 kg N ha⁻¹. The Cv. PBW-502 and PBW-343 accumulated same GDD (1827.1) at 120 kg N ha⁻¹. At 180 kg N ha⁻¹ Cv. PBW-550 accumulated less GDD (1881.9) as compared to other varieties. Yang *et al* (2000) showed that both grain growth rate and grain growth duration were affected by different nitrogen levels.

REGRESSION EQUATIONS FOR PHENOLOGICAL DEVELOPMENT

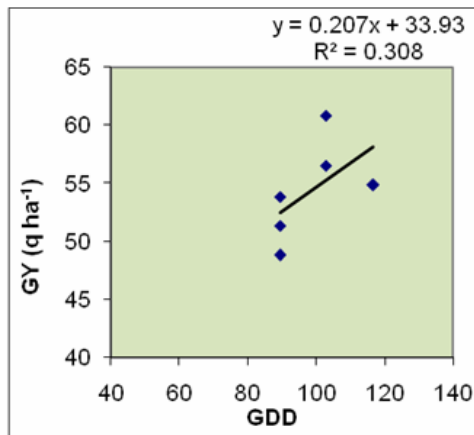
The regression equations in wheat are discussed under the following heading

Growing Degree Days

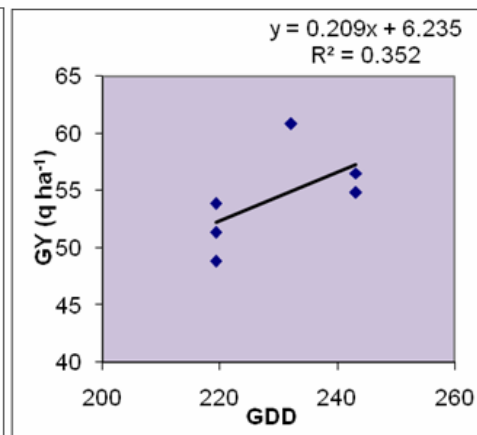
The regression equation indicating the relationship of grain yield with growing degree days units accumulated during different phenophases of wheat are presented in Fig. 4.8. Regression analysis revealed a significant positive correlation between grain yield and growing degree days accumulated during grain ripening stages. Linear regression equations, taking phenophasic data pooled over two nitrogen levels (120 and 180 kg N ha⁻¹) and three varieties were derived for predicting the yield bases on number of days taken for achieving particular growth stage.

Regression analysis indicated a significant positive correlation between grain yield and growing degree days during booting stage ($R^2 = 0.470$), crown root initiation ($R^2 = 0.441$) and soft dough ($R^2 = 0.372$).

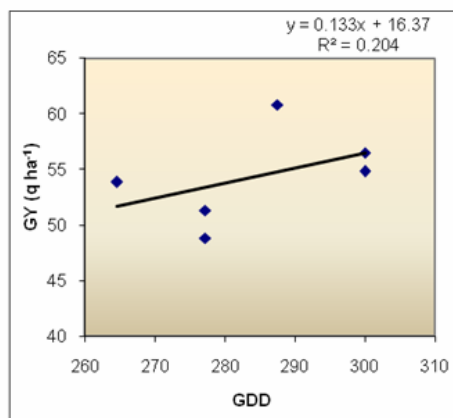
From the data of growing degree days we can predict the yield of wheat crop in a particular season. The GDD depends on variation in maximum and minimum temperature of the air. So, growing degree days give better prediction of yield. From these equations we can also explain the variation in yield on the basis of accumulated growing degree days.



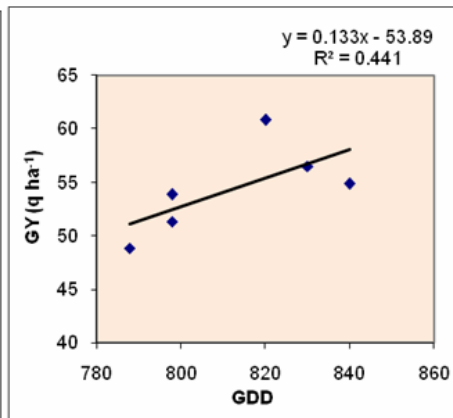
Seedling emergence



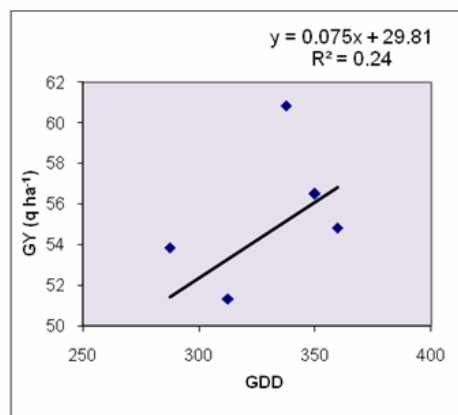
Crown root initiation



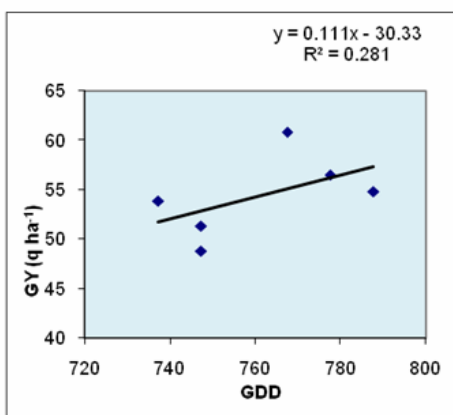
Leaf initiation



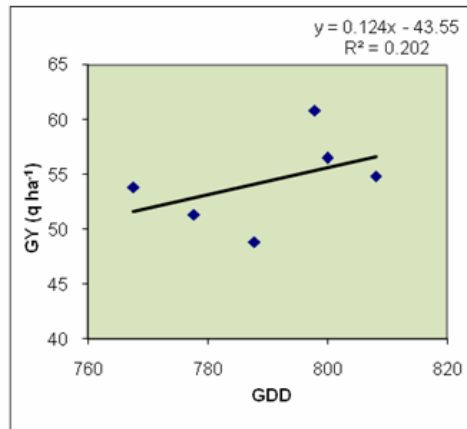
Leaf development completion



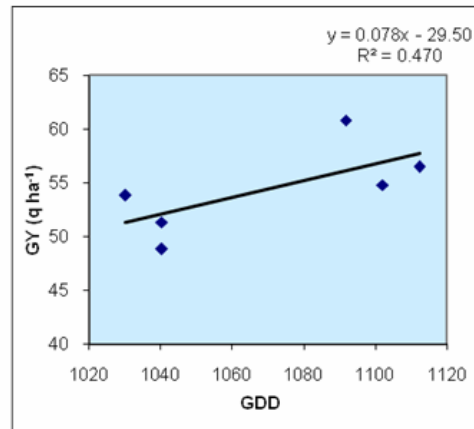
Tillering initiation



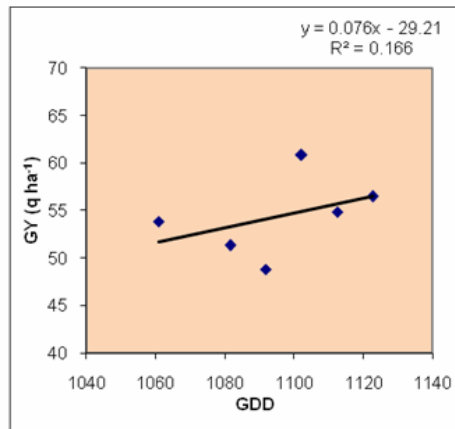
Tillering completion



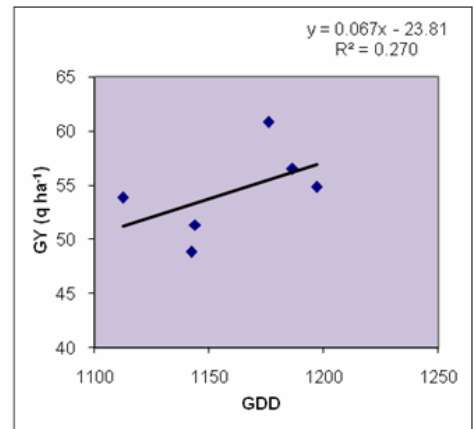
Jointing stage



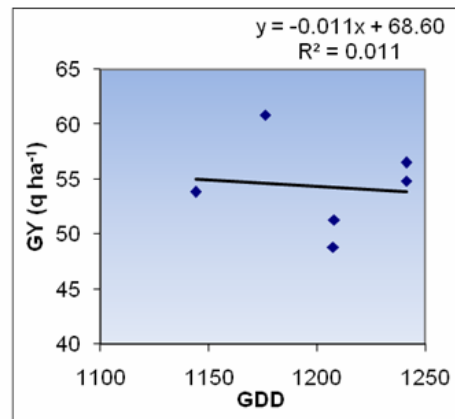
Booting stage



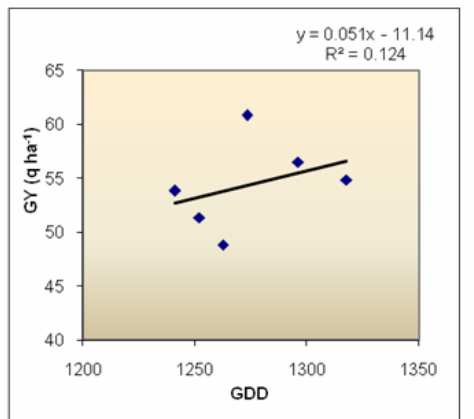
Ear emergence stage



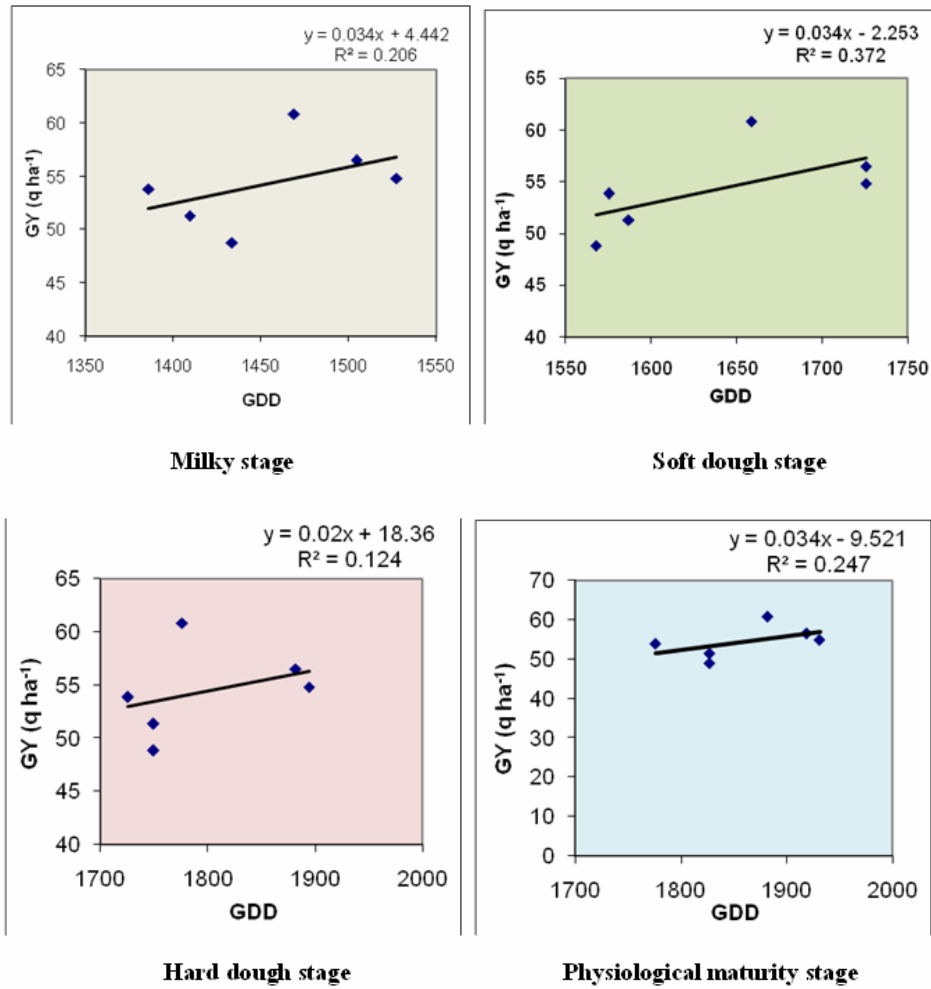
Ear heading stage



Anthesis stage



Watery ripe stage



ig 4.8: Relationship between grain yield and growing degree days accumulated during different growth stages in wheat

CHAPTER-V

SUMMARY

Grain protein partially determines both baking and nutritional properties of bread wheat (*Triticum aestivum* L.). Thus, it constitutes an important economic trait that receives considerable attention in many breeding programmes of this cereal. Simultaneous increase in grain yield and protein content may have been associated with increased uptake and reduction of nitrogen and increased efficiency in mobilizing nitrogenous compound from vegetative parts to grain. Nitrogen uptake and nitrogen partitioning function as separate and independent physiological systems in wheat plants. Therefore, improvement in both grain protein percentage and grain yield realized by manipulating nitrogen uptake and its partitioning separately. Field and laboratory experiments were conducted during *rabi* season of 2008-09 to:

- To identify an appropriate selection criterion for optimum combination of grain protein content and grain yield,
- To study traits related to nitrogen accumulation, remobilization and partitioning in wheat varieties actually expressing high grain yield and grain protein content simultaneously and to analyze grain yield and grain protein relationship.

Results obtained from the experiment are summarized below:

- Cv. PBW-550 accumulated 6.92 percent more dry matter at anthesis stage than Cv. PBW-343 at 180 kg N ha⁻¹. Cv. PBW-550 at 180 kg N ha⁻¹ accumulated 38.92 percent more total plant nitrogen at anthesis stage as compared to Cv. PBW-343.
- Maximum vegetative nitrogen was recorded in PBW-550 at anthesis + 12 days stage while in Cv. PBW-502 and PBW-343 at anthesis + 8 days stage. Cv. PBW-343 showed 8.74 percent reduction in vegetative nitrogen as compared to PBW-550 at 180 kg N ha⁻¹.
- Cv. PBW-550 accumulated 4.95 percent more nitrogen at post anthesis stage at both nitrogen levels than PBW-502 and PBW-343.
- PBW-550 accumulated 40.74 percent more dry matter at post anthesis stage than Cv. PBW-343.
- At post anthesis stage Cv. PBW-550 had maximum remobilized nitrogen (57.81 g m⁻²) followed by PBW-343 (45.83 g m⁻²) at 180 kg N ha⁻¹.

- Maximum remobilization efficiency was found in Cv. PBW-550 (76.86%) at post anthesis stage in comparison to PBW-343 (63.48%) at 120 kg N ha⁻¹ level. At 180 kg N ha⁻¹ level Cv. PBW-550 had 81.10 per cent remobilization efficiency.
- Studies on yield attributing traits revealed that there were 4.85, 15.34 and 6.02 per cent significant reduction in biological yield, number of spikes per plant and number of kernels per spike respectively with decrease in nitrogen level.
- Grain yield maximum in Cv. PBW-550 under both nitrogen levels. At 180 kg N ha⁻¹ Cv. PBW-550 had (60.83 q ha⁻¹) grain yield while Cv. PBW-343 (54.83 q ha⁻¹).
- Grain protein concentration was found to be maximum grain protein concentration (17.07%) in Cv. PBW-550 as compared to PBW-502 (12.67%) and Cv. PBW-343 (12.03%) under 180 kg N ha⁻¹.
- Grain protein yield found to be maximum in Cv. PBW-550 (103.82 g m⁻²) followed by PBW-502 (71.56 g m⁻²) and PBW-343 (65.99 g m⁻²) under 180 kg N ha⁻¹. At 120 kg N ha⁻¹ Cv. PBW-343 found to have less (55.51 g m⁻²) grain protein yield as comparison to PBW-550 (76.83 g m⁻²).
- Cv. PBW-550 accumulated 7.38 percent more total dry matter at 180 kg N ha⁻¹ while PBW-343 had less dry matter. At maturity Cv. PBW-550 found to have maximum (151.40 g m⁻²) total plant nitrogen under 180 kg N ha⁻¹ followed by PBW-502 (122.12 g m⁻²) and PBW-343 (118.04 g m⁻²).
- Nitrogen harvest index was maximum in Cv. PBW-550 (0.602) followed by PBW-502 (0.451) and PBW-343 (0.434).
- Vegetative nitrogen at physiological maturity stage on the average in Cv. PBW-550 low (10.07 g m⁻²) as compared to PBW-502 (14.84 g m⁻²) and PBW-343 (14.71 g m⁻²). Cv. PBW-550 is more efficient to remobilize nitrogen from vegetative parts to grain.
- Linear regression equation showed that there was significant positive correlation ($R^2 = 0.6948$) between grain yield and grain protein concentration in wheat cultivars.
- The correlation analysis showed significant positive correlation of biological yield ($r = 0.9766^{**}$), total plant nitrogen at physiological maturity ($r = 0.9688^{**}$), grain protein yield ($r = 0.9069^{**}$) and grain protein concentration ($r = 0.8236^{**}$) on grain yield.
- Further path analysis was performed to partition the Pearson correlation into direct and indirect effects. Path analysis revealed that vegetative nitrogen had more direct ($P_{9\ 11} =$

0.5329) significant positive influence on grain yield. Vegetative nitrogen at maturity significant positively correlated with remobilized ($r_{93} = 0.6764$) and it contribute more indirectly through grain protein yield ($r_{92P_{211}} = 0.2607$). Remobilized nitrogen had negative direct effect on grain yield ($P_{311} = -0.2516$).

- A significant positive correlation of grain yield with harvest index ($r = 0.9833^{**}$) followed by vegetative nitrogen at milky stage ($r = 0.9693^{**}$). Correlation between accumulated dry matter at post anthesis stage had significantly positive ($r = 0.8543^{**}$) correlation.
- There was 18.94 per cent, reduction in growing degree days at physiological maturity under 120 kg ha^{-1} nitrogen level cumulative in comparison to 180 kg N ha^{-1} . Studies also showed that Cv. PBW-343 accumulated more growing degree days under both nitrogen levels. The reduction in growing degree days from 180 kg N ha^{-1} to 120 kg N ha^{-1} was 9.27 per cent in Cv. PBW-502 followed by Cv. PBW-550 (8.63%).
- The regression model revealed significant positive correlation between GDD and yield at booting ($R^2 = 0.4709$), leaf development completion ($R^2 = 0.4415$) and soft dough ($R^2 = 0.3729$).

Results showed that grain yield and protein content increased simultaneously by timely application of nitrogen and by selecting lines with high grain yield and grain protein content that have high total plant nitrogen at maturity, nitrogen harvest index, remobilization and partitioning efficiency. At 180 kg N ha^{-1} Cv. PBW-550 expressed high grain yield and grain protein concentration simultaneously due to its high nitrogen remobilization efficiency, nitrogen harvest index, grain protein yield and total plant nitrogen at physiological maturity. Grain protein concentration improved without reducing grain yield by selecting cultivars with both high grain protein yield and remobilization efficiency.

REFERENCES

- AOAC (1990) *Official methods of analysis*. 15th ed. Association of Official Analytical Chemists, Washington, D.C 125-139.
- Abou-Salam A M and Ismail A A (1995) Application of multiple regression modelling based on some physiological and yield related traits in selection for yield in wheat. *Assuit J Agric Res* **26**:9-17.
- Abrol Y P and Ingram K T (2005) Effect of higher day and night temperatures on growth and yields of some crop plants. In: Bazzaz F and Sombrock W(ed) *Global climate change and agricultural production*. Daya Publ House, Delhi, India, pp 123-40.
- Aggarwal P K, Kalra N, Singh A K and Sinha S K (1994) Analyzing the limitations set by climatic factors, management and genotype on productivity of wheat. I. The model documentation , parameterisation and evaluation. *Field Crops Res* **38**: 73-91.
- Akbar H, Idrees M, Ahmad M F, Arif M and Zakirullah M (2006) Dry weight of spike at anthesis determines grain weight of spike at maturity. *J Agric and Biol Sci* **1**:55-61.
- Akman Z and Kara B (2003) Genotypic variations for mineral content at different growth stages in wheat (*Triticum aestivum* L) *Cereal Res commun*, **31**: 459-66.
- Amir J and Sinclair T R (1992) A model of the water limitation on spring wheat growth and yield. *Field Crops Res* **28**:59-69.
- Anderson W K, Crosbie G B and Lemsom K (1995) Production practices for high protein, hard wheat in Western Australia. *Aust J Exp Agric* **35**: 589–95.
- Andersson A, Johansson E and Oscarson P (2005) Nitrogen redistribution from roots in post-anthesis plants of spring wheat. *Plant and Soil* **269** : 321-32.
- Angus J F and Moncur M W (1985) Models of growth and development of wheat in relation to plant nitrogen. *Aust J Agric Res* **36** : 537-44.
- Anonymous (2005) *All India Coo-ordinated Wheat and Barley Improvement Project*. Directorate of Wheat Research Prog Rep 1 pp 4.2-4.14.
- Anthony G, Woodard B and Hoard J (2003) Foliar N application timing influence on grain yield and protein concentration of hard red winter and spring wheat. *Agron J* **95**: 335-38.
- Arnon I (1972) Plant Population and Distribution Patterns in Corp Production in Dry Regions. Vol. 1. Islamabad, Pakistan: National Book Foundation; pp. 359–60.
- Asana R D and William R A (1965) The effect of temperature stress on grain development in wheat. *Aust J Agric Res* **16**:1-3.

- Ashraf A H (1986) *Studies on interaction relationship of two wheat genotype and N P K Application under late sown condition*. M.Sc Thesis Agronomy Department, University of Agriculture, Faisalabad.
- Austin R B and Jones H G (1975) The physiology of wheat. Annual Report Plant Breeding Institute, Cambridge, England 327-55.
- Austin R B, Ford J A Edrich and Blackwell R D (1977) The nitrogen economy of winter wheat. *J Agric Sci* **88**: 159-67.
- Austin R B , Bingham J, Blackwell R D, Evans L T , Ford M A, Morgan C L, and Taylor M (1980) Genetic improvements in winter wheat yields since 1900 and associated physiological changes. *J Agric Sci* **94**: 675-689.
- Awashi V D and Bhan S (1993) Performance of wheat (*Triticum aestivum*) varieties with different levels of nitrogen in moisture scarce condition. *Ind J Agron*. **38**: 200-03.
- Ayoub M, Guestin S, Lussia S and Smith D L (1994) Timing and level of nitrogen fertility effects on spring wheat yield in Eastern Canada. *Crop Sci* **34**: 748-56.
- Bagga A K and Rawson H M (1977) Contrasting responses of morphologically similar wheat cultivars to temperatures appropriate to warm temperate climates with hot summers: a study in controlled environment. *Aust J Plant Physiol* **4**: 877-87.
- Baker C K, Gallagher J N and Monteith J L (1980) Day length change and leaf appearance in winter wheat. *Plant Cell and Environ* **3**: 285-87.
- Baker D A, Young D L, Huggins D R and Pan W L (2004) Economically optimal nitrogen fertilization for yield and protein in Red spring wheat. *Agron J* **96**: 116-23.
- Banziger M, Feil B and Stanp P (1992) Effect of nitrogen supply on genotypic variability in grain protein content of wheat. *Crop Sci* **34**: 446-48.
- Barbottin A, Lecomte C, Bouchard C, Jefferoy M H (2005) Nitrogen remobilization during grain filling in wheat: genotype and environmental effects. *Crop Sci* **45**: 1141-50.
- Barneix A J, Arnoz P A and Guitman M R (1992) The regulation of nitrogen accumulation in the grain of wheat plants (*Triticum aestivum*). *Plant Physiol* **86**: 609-15.
- Behera U K, Saiprasad S V and Pradhan S (2008) Nitrogen scheduling for improving productivity and quality of durum wheat (*Triticum turgidum*) in Central India. *Indian J Agric Sci* **78**: 599-603.
- Bhatia C R and Rabson R (1976) Bio-energetic consideration in cereal breeding for protein improvement. *Crop Sci*. **194**: 1418-21.
- Bilagi S A, Jirali D I, Chetti M B, Hiremath M B and Patil B N (2008) Biophysical,

- biochemical parameters and their association with yield in dicoccum wheat genotypes. *Karnataka J Agric Sci* **21**: 176-80.
- Brown B D and Petrie S (2006) Irrigated hard winter wheat response to fall spring, and late season applied nitrogen. *Field crops Res* **96**: 260-68.
- Bulman P and Smith D L (1993) Accumulation and redistribution of dry matter and nitrogen by spring barley. *Agron J* **85**: 1114-21.
- Bungard R A, Wingler A, Morton J D and Andrews M (1999) Ammonium can stimulate nitrate and nitrite reductase in the absence of nitrate in *Clematis vitalba*. *Plant Cell and Environment*. **22**: 859-66.
- Calderini D F, Taries - Leon and Slafer G A (1995) Consequences of wheat breeding on nitrogen and phosphorus yield, grain nitrogen and phosphorus concentration and associated traits. *Ann Botany* **76**: 315-22.
- Calderni D F, Abeledo L G, Savin R and Slafer G A (1999) Carpel size and temperature in pre anthesis modify potential grain weight in wheat. *Camb J Agric Sci* **132**: 453-59.
- Carolina S P, Peterson C J, Ross A S, Ohm J B, Verhoeven M C, Larson M and Hoefer B (2008) White wheat grain quality changes with genotype, nitrogen fertilization and water stress. *Agron J* **100**: 415-19.
- Cassman K G, Bryant D C, Fulton A E and Jackson L F (1992) Nitrogen supply effects on partitioning of dry matter and nitrogen to grain of irrigated wheat. *Crop Sci* **32**: 1251-58.
- Chandra S, Varshney M L, Singh J and Singh S K (1992) Response of wheat vareities to different levels of nitrogen. *Narendra Deva J Agric. Res.* **7**:169-71.
- Chaudhary J B and Singh C M (1991) Correlation between yield and yield attributes on wheat. *Himachal J Agric Res* **17**: 1-3.
- Costa J M and Kronstad W E (1994) Association of grain protein concentration and selected traits in hard red winter wheat populations in the Pacific Northwest. *Crop Sci* **34**: 1234-39.
- Cox M C, Qualset C O and Rains D W (1985) Genetic variation for nitrogen assimilation and translocation in wheat. II Nitrogen assimilation in relation to grain yield and protein. *Crop Sci* **25**: 435-40.
- Cox M C, Qualset C O and Rains D W (1986) Genetic variation for nitrogen assimilation and translocation in wheat. III Nitrogen assimilation in relation to grain yield. *Crop Sci* **26**: 737-40.

- Dalling M J (1985) The physiological basis of nitrogen redistribution during grain filling in cereals. In: *Exploitation of physiological and genetic variability to enhance crop productivity*. (eds. Harper J E, Schrader L E and Howell R W). American Society of Plant Physiologists, pp 55-71.
- Dalling M J, Boland G and Wilson J H (1976) Relation between acid proteinase activity and redistribution of nitrogen during grain development in wheat. *Aust J Plant Physiol* **3**: 721-30.
- Das, D K and Kalra N (1995) Adjustments to weather variation through cropping systems and fertilizer use. *Fert News* **40**: 11-21.
- Davidson J L (1985) Some effects of leaf area control on yield of wheat. *Aust J Agric Res* **16**:121-31.
- Day G E, Paulsen G M and Seans R G (1985) Nitrogen relations in winter wheat cultivars differing in grain protein percentage and stature. *J Plant Nutr* **8**: 556-66.
- Debaeke P, Aussenac, Fabre J L, Hilaire, Pujol B and Thuries L (1996) Grain content of winter bread wheat (*Triticum aestivum* L.) as related to crop management and to the previous crop. *Eur J Agron* **5**:273-86.
- Deckard E L, Tsai C Y and Tucker T C (1984) Effect of nitrogen nutrition on quality of agronomic crops. In R.D. Hauck (Ed.), *Nitrogen in crop production*, pp 601-615. ASA, CSSA, SSSA, Madison, Wisconsin, USA.
- Deckard E L, Joppa L R, Hammond J J and Land G A H (1996) Grain protein determinants of the Langdon Durum-dicoccoides chromosome substitution lines. *Crop Sci* **36**: 1513-16.
- Demotes-Mainard S, Jevffroy M H and Robin S (1999) Spike dry matter and nitrogen accumulation before anthesis in wheat as affected by nitrogen fertilizer: relationship to kernels per spike. *Field Crops Res* **64**: 249-59.
- Dhugga K S and Waines J (1989) Analysis of nitrogen accumulation and use in bread and durum wheat. *Crop Sci* **29**: 1232-39.
- Dubey Y P (1990) Effects of soil temperature on the germination and emergence of wheat. *Crop Res* **3**: 137-43.
- Ellen J and Spiertz J H J (1980) Effects of rate and timing of nitrogen dressings on grain yield formation of winter wheat. *Fert Res* **1**: 177-90.
- Esfandiary F, Aghaie G and Mehr A D (2009) Wheat yield prediction through agromterological indices for Aredebil District. *Proceedings of World Academy of Sci* **37**: 32-35.

- Ewert F (1996) Spikelet and floret initiation on tillers of winter wheat in different years and sowing dates. *Field Crops Res* **47**:155-66.
- Feil B (1997) The inverse yield - protein relationship in cereals: possibilities and limitations for genetically improving the grain protein yield. *Trends in Agron* **1**: 103-19.
- Fischer R A and Maurer O R (1976) Crop temperature modification and yield potential in a dwarf spring wheat. *Crop Sci* **16**:855-59.
- Fisher R A, Howe G N and Ibrahim Z (1993) Irrigated spring wheat and timing and amount of nitrogen fertilizer I Grain yield and protein content. *Field Crops Res* **33**: 37-56.
- Fisher R A (2007) Understanding the physiological basis of yield potential in wheat. *J Agric Sci* **145**: 99-113.
- Fitter A H, Fitter R S R, Harris I T B, Williamson M H (1995) Relationships between first flowering date and temperature in the flora of a locality in central England. *Funct Ecol* **9**: 55-60.
- Flood R G and Martin P J (2001) Nitrogen accumulation and distribution at anthesis and maturity in ten wheat grown at three sites in north-western Victoria. *Aust J Exp Agric* **41**: 533-40.
- Fukushima A, Kusuda O, Furuhashi M and Nakano H (2005) Phenological development in relation to temperature of winter wheat Iwainodaichi seeded early in Southwestern Japan. *Plant Prod Sci* **8**:152-56.
- Gallais A, Coque, Quilleret Prioul J L and Hirel B (2006) Modeling post anthesis N fluxes in wheat using N labeling field experiments. *New phytol* **172**: 696-707.
- Gami J K, Parmar M T, Patel J C and Malavia D D (1986) Effects of rates, time and method of nitrogen application on dwarf wheat. *Ind J Agron* **31**: 401-02.
- Garrido-Lestache E, Lopez-Bellido R J and Lopez-Bellido L (2004) Effect of N rate, timing and splitting and N type on bread-making quality in hard red spring wheat under rainfed Mediterranean-Conditions. *Field Crops Res* **85**: 213-36.
- Geber M A and Dawson T E (1993) Evolutionary responses of plants to global change. In Kareiva P M, Kingsolver J G, Huey R B(eds) *Biotic interaction and global change*. Sinauer, USA, pp. 179-97.
- Geleto T, Tanner D G, Mamo T and Gebeyehu G (1995) Response of rain fed bread and durum wheat to source level and timing of nitrogen fertilizer Ethiopian vertisole S I yield and yield components. *Comm in soil sci and plant analysis* **26**: 1773-94
- Ghosh D C, Nandi P and Deb (2000) Phenological development and productivity of wheat

- (*Triticum aestivum* L.) at different dates of sowing. *Ind J Agric Res* **70**:393-95.
- Giaveno C and Ferrero J (2003) Introduction of tropical maize genotypes to increase silage production in the central area of Santa Fe, Argentina. *Crop Breed Appl Biotechnol* **3**: 89-94.
- Gill K K and Kingra P K (2007) A climatological study on minimum temperature its relationship with wheat yield at Ludhiana. *J Res Punjab Agric Uni* **44**: 181-84.
- Giunta F, Giovanni P and Rosella M (2009) Radiation interception and biomass and nitrogen accumulation in different cereal and grain legume species. *Field Crops Res* **110**: 76-84.
- Giunta F, Motzo R and Viridis A (2001) Development of durum wheat and triticale cultivars as affected by thermo-photoperiodic conditions. *Aust J Agric Res* **53**:387-96.
- Gomez K A and Gomez A A (1984) *Statistical procedures for agricultural research*. 2nd ed. John Wiley and Sons. New York.
- Gonzalez F G, Slafer G A and Miralles D J (2005) Photoperiod during stem elongation in wheat and its impact on fertile floret and grain number determination similar to what of radiation. *Func Plant Biol* **3**: 181-89.
- Gooding M J and Davies W P (1997) *Wheat production and utilization*. CAB Int., Wallingford, UK.
- Guttieri M J, McLean R, Stark J C and Sovza E (2005) Managing irrigation and nitrogen fertility of hard spring wheat for optimum bread and noodle quality. *Crop Sci* **45**: 2049-59.
- Guo H, Yang H, Mockler T C and Lin C (1998) Regulation of flowering time by *Arabidopsis* Photoreceptors. *Sci* **279**:136-63.
- Halvorson A D, Alley M M and Murphy L S (1987) Nutrient requirements and fertilizer use. In: B. Tucker (Ed.), *Wheat and wheat improvement*, pp 345-83. Agronomy Monograph 13, 2nd edition. ASA, CSSA, SSSA, Madison, Wisconsin, USA.
- Hardy R W, Filner F P and Hageman R H (1975) *Nitrogen input In: Crop productivity research imperatives*. Michigan Agricultural Experimental station, East Lansing 133-76.
- Haun J R (1973) Visual quantification of wheat development. *J Agron* **65**:116-19.
- Hay R K M and Kirby E J M (1991) Convergence and synchrony- a review of the coordination of development in wheat. *Aust J Res* **42**: 661-70.

- Hayee M A, Shah S H, Malik M A, Rafiq M and Ali A (1989) Effect of different level of NPIC on the growth and grain yield of two wheat varieties, Pak-81 and Punjab-85. *Pak J Agri Sci* **26**: 236.
- Heiltholt J J, Croy L I, Maness N O and Nguyen H T (1990) Nitrogen Partitioning in Genotypes of Winter Wheat Differing in Grain Nitrogen Concentration. *Field Crops Res* **23** :133-144.
- Herndl M, White J W, Graeff S and Claupein W (2008) The impact of vernalization requirement, photoperiod sensitivity and earliness per se on grain protein content of bread wheat (*Triticum aestivum* L.). *Euphytica* **163**:309-20.
- Hirel B, Martin A, Terce-Laforgue T, Gonzalez-Moro M B and Estavillo J N (2005) Physiology of maize I A comprehensive & integrated view of nitrogen metabolism in a plant. *Plant Physiol* **124**: 167-77.
- Hsia C A, Wan H S and Wang P T (1963) The influence of temperature on the physiological changes in wheat during the grain formation stage. *Acta Bot Sinica* **11**: 338-47.
- Hundal S S and Kaur P (1995) Effect of environmental stresses on potential production of major cereal crops in Punjab. *Proc International Conference on "Sustainable Agriculture and Environment"*. pp 11-13. HAU Hisar.
- Hussain M A, Ibrahim S A and Zaitoon M I (1984) Effect of nitrogen levels on growth, yield and mineral composition of wheat crop under different seed rates. *Egypt J Sci* **24**: 7-18.
- Jackson M L (1967) *Soil Chemical Analysis*. Prentice Hall of India Pvt Ltd, New Delhi.
- Jackson W A, Flesher D and Hageman R H (1973) Nitrate uptake by dark grown corn seedlings: Some characteristics of apparent induction. *Plant Physiol* **51**: 120-27.
- Jamieson P D and Munro C A (1999) A simple method for the phenological evaluation of new cereal cultivars. *Agron New Zealand* **29**:63-68.
- Jamieson P D and Somenov M A (2000) Modelling nitrogen uptake and redistribution in wheat. *Field Crops Res* **68**: 21-29.
- Jamieson P D, Brooking I R, Semenov M A, McMaster G S, White J W and Porter J R (2007) Reconciling alternative models of phenological development in winter wheat. *Field Crops Res* **103**:36-41.
- Johnson V A, Dreier A F and Grabouski (1973) Yield and protein responses to nitrogen fertilizer of two winter wheat varieties differing in inherent protein content of their grain. *Agron J* **65**:259-63.

- Jones J W, Hoogenboon G, Porter C H, Boot K J, Batchelor W D, Hunt L A, Wilkens P W, Singh V, Gijssman A V and Ritchie J T (2003) The DSSAT cropping system model. *Eur J Agron* **18**: 235-65.
- Kalra N, Sharma A, Rai H K, Chander S and Barman D (2008) Effect of increasing temperature on yield of some winter crops in northwest India. *Curr Sci* **94**: 82-88.
- Karamanos R E, Flore N A and Harapiak J T (2005) Effect of post-emergence nitrogen application on the yield and protein content of wheat. *Can J Plant Sci* **85**: 327-42.
- Kasajima S, Inoue N, Mahmud R, Fujita K and Kato M (2007) Effect of light quality on developmental rate of wheat under continuous light at a constant temperature. *Plant Prod Sci* **10**: 286-91.
- Kaur P (2000) *Impact of nitrogen levels on lodging and yield in wheat varieties*. M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India.
- Kaur M, Singh K N, Singh H, Singh P and Tabasum S (2007) Evaluation of Models (ERES-Wheat (Ver. 4.0) under temperate conditions of Kashmir Valley. *World J Agric Sciences* **3**: 825-32.
- Khan M A, Hussain I and Baloch M S (2000) Wheat yield potential current status and future strategies. *Pak J Bio Sci* **3**: 82-86.
- Khan M A, Ahmed K, Hussain I and Baloch M A (2001) Response of wheat varieties to different levels of nitrogen. *Pak J Bio Sci* **4**: 276-78.
- Khan A J, Azam F, Ali A, Tariq M and Amin M (2005) Inter-relationship and path coefficient analysis for biometric traits in drought tolerant wheat (*Triticum aestivum* L.). *Asian J Plant Sci* **4**:540-43.
- Khan A, Jan M T, Arif M, Marwat B and Jan A (2008) Phenology and crop stand of wheat as affected by nitrogen and tillage systems. *Pak. J. Bot* **40**:1103-12.
- Khichar M L and Niwas R (2007) Thermal effect on growth and yield of wheat under different sowing environments and planting systems. *Ind J Agric Res* **41**: 92-96.
- Kichey T, Heumez E, Pocholle D, Pageau K, Vanacker H, Dubois F, Le Gouis J, Hirel B (2006) Combined agronomic and physiological aspects of nitrogen management in wheat highlight a central role for glutamine synthetase. *New Phytol* **169**:265-78.
- Kumar A, Omal H, Kashiuraba K and Shono M (2005) Influence of water and high temperature stresses on leaf water status of high temperature tolerant and sensitive cultivars of snap bean (*Phaseolus Vulgaris* L.). *J Trop Agric* **49**:109-18.

- Lestache E G, Bellido R J L and Bellido L L (2004) Effect of nitrogen rate, timing and splitting and N type of bread making quality in hard red spring wheat under rainfed Mediterranean conditions. *Field Crops Res* **85**: 213-36.
- Lestache E G, Bellido R J L and Bellido L L (2005) Durum wheat quality under Mediterranean conditions as affected by N rate, timing and splitting, N form on S fertilization. *Europ J Agron* **23**: 265-78.
- Li C D, Cao W X, Zhang Y C and Dai T B (2001) Floret position differences in seed setting characteristic after different sowing dates and varieties. *Acta Agric Boreali Sinica* **16**:1-7.
- Loffler C M and Busch R H (1982) Selection for grain protein, grain yield and nitrogen partitioning efficiency in hard red spring wheat. *Crop Sci* **23**: 1097-1101.
- Loffler C M, Rauch T L and Busch R H (1985) Grain and plant protein relationships in hard red spring wheat. *Crop Sci* **25**: 521-24.
- Long S P, Ainsworth E A, Leakey A D B and Ort D R (2006) Food for thought-lower -than expected crop yield stimulation with rising CO₂ concentration. *J Sci* **312**: 1918-21.
- Longnecker N, Kirby E J M and Robson A (1993) Leaf Emergence, Tiller Growth, and Apical Development of Nitrogen-Dificient Spring Wheat. *Crop Sci* **33**:154-160
- Lopez-Bellidol L, Lopez-Bellido R J, Castillo J E and Lopez-Bellido F J (2000) Effects of tillage, crop rotation and nitrogen fertilization on wheat under rainfed Mediterranean conditions *Agron J* **92**: 1054-63.
- Lopez-Bellido L, Lopez-Bellido R J, Castillo J E and Lopez-Bellido F J (2001) Effects of long term tillage, crop rotation and nitrogen fertilization on bread making quality of hard red spring wheat. *Field Crops Res* **72**: 197-210.
- Ma B L, Yan W, Dwyer L M, Fregeau-Reid J, Voldeng H D, Dion Y and Nass H (2004) Graphic analysis of genotype, environment, nitrogen fertiliser, and their interactions on spring wheat yield. *Agron J* **96**: 169-80.
- Ma B L, Subedi K D and Dwyer L M (2006) Timing and method of ¹⁵Nitrogen-labelled fertilizer application on grain protein and nitrogen use efficiency of spring wheat. *J Plant Nutr* **29**: 469-83.
- MacKown C T, Van Sanford D A and Zhang N (1992) Wheat vegetative nitrogen compositional changes in response to reduced reproductive sink strength. *Plant Physiol* **99**: 1469-74.

- Mackey (1988) Correlated constraints of the wheat plant. In 'Proceedings of 7th International wheat genetics symposium.' **1** (Eds T E Killer, RMD Koebner) 565-69 (Institute of Plant Sciences Research: Cambridge)
- Mae T (1997) Physiological nitrogen efficiency in rice: nitrogen utilization, photosynthesis, and yield potential. *Plant Soil* **196**: 201-10.
- Maranville J W (1994) Response of wheat cultivars to different soil nitrogen and moisture regimes: I. Dry matter partitioning and root growth. *J Plant Nutr* **17**:729-44.
- Matsvmoto K, Onta T and Nakamura T (2003) Climate Change and extension of the *Grinkgo bioloba* L. growing season in Japan. *Glob Chang Biol* **9**: 1634-42.
- McDonald G K (1991) *Factors affecting the responses to nitrogen fertilizer in wheat*. Waive Agricultural Research Institute, Glen Osmond, South Australia.
- McKendry A L, McVetty P B E and Evans L E (1995) Selection criteria for combining high grain yield and high grain protein concentration in bread wheat. *Crop Sci* **35**:1597-1602.
- McMaster G S, Wilhelm W W and Morgan J A (1992) Simulating winter wheat shoot apex phenology. *Camb J Agric Sci* **119**:1-12.
- McMaster G S, Wilhelm W W, Palic D B, Porter J R and Jamieson P D (2003) Spring wheat leaf appearance and temperature: extending the paradigm? *Ann Bot* **91**:697-705.
- McMaster G S and Wilhelm W W (2004) Phenological responses of wheat and barley to water and temperature: improving simulation models. *Camb. J Agric. Sci.* **119**: 1-2
- McMullan P M, McVetty P B E and Uraquhart A A (1988) Dry matter and nitrogen accumulation and redistribution and their relationship to grain yield and grain protein in wheat *Can J Plant Sci* **68**: 311-22.
- McNeal F H, Berg M A and Klindwarth D L (1982) Agronomic and quality characteristics of spring wheat lines selected for protein content and protein yield. *Euphytica* **31**: 377-81.
- Mehdi S M, Sarfaraz M and Ibrahim M (2007) Fertilizer requirement of wheat in recently reclaim soils. *World Appl Sci J* **2**: 559-68.
- Mehmet A and Telat Y (2006) Path coefficient analysis of yield in bread wheat genotypes. *Pak J Bot* **38**: 417-24.
- Melaj M A, Echevevia H E, Lopez S C, Studdeat G, Andrade F and Barbare N O (2003) Timing of nitrogen fertilization in wheat under conventional and No-tillage system. *Agron J* **95**: 1525-31.

- Meynard J M (1987) The analysis development for the efficiency of essays about nitrogen fertilization *Perspective Agric* **115**: 76-83.
- Mian M A, Mahmood A, Ihsan M and Cheema N M (2007) Response of different wheat genotypes to post-anthesis temperature stress. *J Agric Res* **45**:269-77.
- Miglietta F (1991) Simulation of wheat ontogenesis. III. Effect of variety, nitrogen fertilization and water stress on leaf appearance and final leaf number in the field. *Clim Res* **1**:233-42.
- Mishra B (2008) In "Project Director Report (2007-08)" Issued by the Project Director, Directorate of Wheat Research, Karnal Presented at the 47th India Wheat and Barley Research Workers Meet held at Hisar (India) during 17-20.
- Mitra R and Bhatia C R (2008) Bioenergetic cost of heat tolerance in wheat crop. *Curr Sci* **94**: 1049-53.
- Monaghan J M, Snape J W, Chojecki A J S and Kettlewell P S (2001) The use of grain protein deviation for identifying wheat cultivars with high grain protein concentration and yield. *Euphytica* **122**: 309-17.
- Morey D K, Patil M S and Khedekar P K (1984) Determination of base temperature at different crops. *Research Journal, Punjabrao Krishi Vidyapeeth Akola* **8**: 26-28.
- Nagarajan S and Rane J (2002) Physiological traits associated with yield performance of spring wheat (*Triticum aestivum* L.) under late sown conditions. *Ind J Agric Sci* **72**: 135-40.
- Nerozzi F, Zinoni F and Marietto V (1998) Calibration and validation of two operational phenological models for wheat and maize in Emilia-Romagna. *Rivista-di-Agronomia* **32**: 112-23.
- Novoa R and Loomis R S (1981) Nitrogen and plant production. *Plant and Soil* **58**: 177-204.
- Nuttonson M Y (1948) Some preliminary observations of phenological data as a tool in the study of photoperiodic and thermal requirements of various plant material. *Chronica Botanica* **29**:1-43.
- Olson R A and Kurtz L T (1982) Crop nitrogen requirements, utilization and fertilization. In F.J. Stevenson (Ed.), *Nitrogen in agricultural soils*, pp 567-604. Agronomy Monograph 22. ASA, CSSA, SSSA, Madison, Wisconsin, USA.
- Ortiz-Monasterio J I, Sayure K D, Rajaram S and McMahon M (1997) Genetic progress in wheat yield and nitrogen use efficiency under four nitrogen rates. *Crop Sci* **37**: 898-904.

- Olsen S H, Cole C V, Watenable F S and Dean L A (1954) Estimation of available phosphorus by extraction with sodium bicarbonate. *USDA Circ* **39**:1-9.
- Ottman M J, Doerge A and Martin E (2000) Wheat durum grain quality as affected by nitrogen fertilization near anthesis and irrigation during grain fills. *Agron J* **92**: 1035-41.
- Paccaud F X, Fossati A and Cao H S (1985) Breeding for yield and quality in winter wheat: consequences for nitrogen uptake and partitioning efficiency *Zeitschrift fur pflanzenzuchtung* **94**: 89-100.
- Pahwa S (2002) *Temperature based phenological growth models in wheat (Triticum aestivum L.)*. M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India.
- Paikaray N K and Chakravarty N V K (2003) Characterization of thermal time requirement of five wheat cultivars under varied weather conditions. *Ann Agric Res* **24**:266-72.
- Pal S K, Verma U N, Singh M K and Thakur K (1996) Heat unit requirement for phenological development of wheat (*Triticum aestivum*) under different levels of irrigation, seeding date and fertilizer. *Indian J Agric Sci* **66**: 397-400.
- Panda S C, Gulati J M L and Misra B (1988) Effect of water regimes and nitrogen on wheat. *Indian J Agron* **33**: 364-67.
- Papakosta D K and Gagianas F (1991) Nitrogen and dry matter accumulation, remobilisation, and losses for Mediterranean wheat during grain filling. *Agron J* **83**: 864-70.
- Pask A J D (2009) *Optimising nitrogen storage in wheat canopies for genetic reduction in fertiliser nitrogen inputs*. Ph.D. thesis, University of Nottingham.
- Patel A M, Augustine N and Patel D R (2004) Nitrogen management for productivity of macroni wheat (*Triticum durum*). *Indian J Agron* **49**: 168-70.
- Peet M M and Whillits D H (1998) The effect of night temperature on greenhouse grown tomato yields in warm climate. *Agric Forest Meteorol* **92**: 191-202.
- Peltonen J (1993) Grain yield of high and low-protein wheat cultivars as influenced by timing of nitrogen application during generative development. *Field Crops Res* **33**: 385-97.
- Perrotta C, Treglia A S, Mita G, Giangrande E, Rampino P, Ronga G, Spano G and Marmiroli N (1998) Analysis of mRNAs from ripening wheat seeds : the effect of high temperature. *J Cereal Sci* **27**: 127-32.

- Perry M W and D' Antuona M F (1989) Yield improvement and associated characteristics of some Australian spring wheat cultivars introduced between 1860 and 1982. *Aust J Agric Res* **40**: 457-72.
- Piper C S (1966) Soil and Plant Analysis. Hans Publishers, Bombay.
- Porter J R (1993) AFRCWHEAT2: a model of the growth and development of wheat incorporating responses to water and nitrogen. *Eur J Agron* **2**:69-82.
- Porter J R (2005) Rising temperature are likely to reduce crop yields. *Nature* **436**: 174.
- Przulj N and Momcilovic V (2001) Genetic variation for dry matter and nitrogen accumulation and translocation in two-rowed spring barley.II.Nitrogen translocation. *Eur J Agron* **15**: 255-65.
- Qi Y L,Zhang F C and Li K F(2009) Effects of water deficit and nitrogen fertilization on winter wheat growth and nitrogen uptake. *J. Appl. Eco.***20**:2399-405.
- Rahman H S and Wilson J H (1977) Determination of spikelet number in wheat I. Effects of varying photoperiod on ear development. *Aust J Agric Res* **28**:565-73.
- Reed A J, Singletary G W, Schussler J R, Williamson D R and Christy A L (1988) Shading effects on dry matter and nitrogen partitioning, kernel number and yield of maize. *Crop Sci* **28**: 819-25.
- Reich P B (1995) Phenology of tropical forests; patterns, causes and consequences. *Can J Bot* **73**: 164-74.
- Reynolds M P, Pellegrineschi A, and Skovmand B (2005) Sink limitation to yield and biomass: a summary of some investigations in spring wheat. *Ann Appl Biol* **146**: 39-49.
- Richard R A (2000) Selectable traits to increase crop photosynthesis and yield of grain crops. *J Exp Bot* **51**:447-58.
- Rickman R W, Waldman S E and Klepper B (1996) MODWht3: a development driven wheat growth simulation. *J Agron* **88**:176-85.
- Ritchie J T (1987) Modelling wheat development. 79th Annual Meeting of ann Soc of Agron. Michigan State University.
- Ritchie J T and Hanks J (1991) Wheat phasic development. *Modeling Plant and Soil systems* **31**:31-54.
- Rizwan A, Shahzad S M, Khalid A, Arshad M and Mahmood M H (2007) Growth and yield response of wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) to nitrogen and L-tryptophan enriched compost. *Pak J Bot* **39**:541-49.

- Royo C, Aparico N, Blanco R and Villegas (2004) Leaf and green area development durum wheat genotypes grown under Mediterranean conditions. *Eur J Agron* **20**:419-30.
- Ruiter J M and Brooking I R (1994) Nitrogen and dry matter partitioning of barley grown in a dryland environment. *NZJ Crop Hortic Sci* **22**: 45-55.
- Saseendran S A, Nielsen D C, Ma L, Ahuja L R and Halvorson A D (2004) Modelling nitrogen management effects on winter wheat production, using RZWQM and CERES wheat. *Agron J* **96**:615-30.
- Sielgman N G, Loomis R S, Burke J and Abshahi A (1983) Nitrogen nutrition and canopy temperature in field grown spring wheat. *J Agric Sci* **101**:691-97.
- Semenov M A, Jamieson P D and Martre P (2007) Deconvoluting nitrogen use efficiency in wheat: a simulation study. *Eur J Agron* **26**:283-94.
- Shah P and Haider S (1995) Temperature, heat indices and photoperiod based mathematical model for emergence of wheat. *Sarhad J Agr* **11**: 429-39.
- Sharma M, Sohu V S and Mavi G S (2003) Gene action for grain yield and its components under heat stress in bread wheat (*Triticum aestivum* L.). *Crop Improv* **30**:189-97.
- Sharma- Natu P, Sumesh K V, Lohot V D and Ghildiyal M C (2006) High temperature effect on grain growth in wheat cultivars: an evaluation of responses. *Ind J Plant Physiol* **11**:239-45.
- Simonetta F, Motzo R and Giunta F (2009) The effect of nitrogenous fertilizer application on leaf traits in durum wheat in relation to grain yield and development. *Field Crops Res* **110**:69-75.
- Singh M, Gupta G R and Singh M P (1987) Response of wheat to nitrogen, phosphorus and potassium. *Ind J Agron* **32**: 52-55.
- Singh B and Singh C P (1991) Effect of time of nitrogen application in wheat (*T aestium*) in north-hill condition. *Ind J Agron* **36**: 326-28.
- Singh V P N and Uttam S K (1994) Effect of different sowing dates on yield attributes and yields of different cultivars in late sowing condition. *Bharatiya Krishi Anusandhan Patrica* **8**:158-62.
- Singh B N and Ahmad Z (1997) Response of wheat (*Triticum aestivum*) varieties to different dates of sowing. *Ind J Agric Sci* **71**:363-66.
- Singh A K, Mishra S R and Tripathi P (2001) Phenology, growing degree days and phasic development model of wheat (*Triticum aestivum* L.) under rice (*Oryza sativa* L.) wheat cropping system. *Ind J Agric Sci* **71**: 363-66.

- Singh N B, Singh Y P and Singh V P N (2005) Variation in physiological traits in promising wheat varieties under late sown conditions. *Ind J Plant Physiol* **10**:171-75.
- Sip V, Skorpik M, Chrpova J, Sonttaikova U and Bartova S (2000) Effect of cultivar and cultural practices on grain yield and bread quality of winter wheat. *Rostinna vyroba* **46**:159-67.
- Slafer G A and Rawson H M (1994) Sensitivity of wheat phasic development to major environmental factors: a re-examination of some assumptions made by physiologist and modelers. *Aust J plant Physiol* **21**:393-426.
- Slafer G A and Savin R (1991) Developmental base temperature in different phenological phases of wheat (*Triticum aestivum*). *J Exp Bot* **42**:1077-82.
- Soltanpour P N, Cardon G E and Westfall D G (2001) Protein enhancement as affected by N and grain yield. Proceedings 'Wheat protein enhancement with N intervention'. ASA Annual Meeting, Charlotte NC, Idaho.
- Stone P J and Savin R (2000) *Grain quality and its physiological determinants*. In : Satorre M H, Slefer G A (eds), *Wheat, Ecology and Physiology of Yield Determination* Food Products Press, New York, pp 85-120.
- Strand E C (1987) Causes of variation in the length of growth periods and the heat sum requirement of cereal cultivars. *J Agric Sci* **1**:119-29.
- Streck N A, Weiss A, Xue Q, and Baenziger P S (2003) Improving predictions of developmental stages in winter wheat: a modified Wang and Engel model. *Agri and For Meteorology* **115**:139-50.
- Subbiah B U and Asija (1956) A rapid procedure for estimation of available nitrogen in soil. *Curr Sci* **25**:259-66.
- Tabuchi M, Sugiyama T, Ishiyama, Inove E S and Takashi T (2005) Severe reduction in growth and grain filling of rice mutants lacking OSGSI 1, a cytosolic glutamine synthetase 1. *Plant J* **42**: 641-55.
- Tahir I S A and Nakata N (2005) Remobilization of nitrogen and carbohydrate from stems of bread whet in response to heat stress during grain filling. *J Agron* **191**: 106-15.
- Tewari S K and Singh M (1993) Yielding ability of wheat (*Triticum aestivum*) at different dates of sowing a temperature dependent performance. *Ind J Agron* **38**:204-09.
- Tewolde H, Fernandez C J and Erickson C A (2006) Wheat cultivars adapted to post-heading high temperature stress. *Crop Sci* **192**:111–20.
- Tian J C, Zhang Z Y and Liang Z Q (1994) Studies on the differences in nitrogen absorption,

transportation and distribution in high and low protein wheat cultivars. *Acta Agron Sin* **20**: 76-83.

Tikhomirov A A and Ushakova S A (2001) Manipulating light and temperature to minimize environmental stress in the plant component of bioregenerative life support systems. *Adv Space Res* **27**:1535-39.

Timsina J and Humphreys E (2003) Performance and application of CERES and SWAGMAN. destiny models for rice-wheat cropping systems of Asia and Australia: a review. *CSIRO Land and Water Technical Report*. Pp 1-49.Griffith, NSW, Australia.

Timsina J, Pathak H, Humphreys E, Godwin D, Singh B, Shukla A K and Singh U (2004) Evaluation of yield gap analysis in rice using CERES-Rice vers. 4.0 in north-west India. *Proc 4th International Crop Science Congr.*, Brisbane, Australia.

Tkachuk R (1969) Nitrogen to protein conversion factors for cereals and oil seed meals. *Cereal Chem* **46**:419-23.

Travis K Z and Day W (1988) Modelling the timing of early development of winter wheat. *Agric For Meteorol* **44**:67-79.

Triboi E and Triboi-Blondel A M (2002) Productivity and grain or seed composition: a new approach to an old problem. *Eur J Agron* **16**:163-86.

Triboi E, Abad A, Michelena A, Lioveras J, Other J L and Danid C (2000) Environmental effects on the quality of two wheat genotypes. I Quantitative and qualitative variations of storage proteins. *Eur J Agron* **13**:47-64.

Triboi E, Marte P, Girousse C, Ravel C, Triboi-Blondel A M (2006) Unravelling environmental and genetic relationships between grain yield and nitrogen concentration for wheat. *Eur J Agron* **25**:108-18.

Van Herwaarden A F (1995) *Carbon, nitrogen and water dynamics in dryland wheat with particular reference to paying off*. Ph.D thesis, Australian National University, December 1995.

Van Sanford D A and MacKnown C T (1987) Cultivar differences in nitrogen remobilization during grain fill in soft red winter wheat. *Crop Sci* **27**: 295-300.

Vollenweider P and Gunthardt-Goerg M S (2005) Diagnosis of abiotic and biotic stress factors using the visible symptoms in foliage. *Environ Pollut* **137**: 455-65.

Vouillot M O and Devienne-Barret F (1999) Accumulation and remobilization of nitrogen in a vegetative winter wheat crop during of following nitrogen deficiency. *Ann.Bot.*

83:569-75.

- Wahid A, Gelanis S, Ashraf M and Feelad M R (2007) Heat tolerance in plants. Plants : An Overview. *Env and Exp Botany* **61**:199-223.
- Waldren R P and Flowerday A D (1979) Growth stages and distribution of dry matter, N, P, K in winter wheat. *J Agron* **71**: 391-97.
- Wang E L and Engel T (1998) Simulation of phenological development of wheat crops. *Agric Sys* **58**: 1-24.
- Wang H L, Gan Y T, Wang R Y, Niu J Y, Zhao H and Yang Q G (2008) Phenological trends in winter wheat and spring cotton in response to climate changes in northwest China. *Agric For Meteor* **148**:1242-51.
- Wang Y F, Jiang D, Yu Z W and Cao W X (2003) Effects of nitrogen rates on grain yield and protein content of wheat and its physiological basis. *Scientia Agricultura Sinica* **36**: 513-20.
- Wardlaw I F, Sofield I and Cartwright P M (1980) Factors limiting the rate of dry matter accumulation in the grain of wheat grown at high temperatures. *Aust J Plant Physiol* **7**:387-400.
- Wardlaw I F and Wrigley C W (1994) Heat tolerance cereals: an overview. *Australian J Plant Physiol* **21**: 695-703.
- Wardlaw I F, Blumenthal C, Larroque O and Wrigley C (2002) Contrasting effects of chronic heat stress and heat shock on kernel weight and flour quality in wheat. *Funct Plant Biol* **29**: 25–34.
- Weir A H, Bragg P L, Porter J R and Rayner J H (1984) A winter wheat crop simulation model without water or nutrient limitations. *Camb J Agric Sci* **102**:371-82.
- White L M (1995) Predicting flowering of 130 plants at 8 locations with temperature and day length. *J Range Manage* **48**: 108-14.
- Wuest S B and Cassman K G (1992) Fertilizer-nitrogen use efficiency of irrigated wheat: II Partitioning efficiency of pre-plant versus late-season application. *Agron J* **84**: 689-94.
- Yang J, Zhang J, Huang Z, Zhu Q and Wang L (2000) Remobilization of carbon reserves is improved by controlled soil-drying during grain filling of wheat. *Crop Sci* **40**: 1645-55.
- Zadocks R C, Chang T T and Konzale C F (1974) A decimal code for the growth stages of cereals. *Weed Res* **14**:415-21.

- Zahedi M, Sharma R and Jenner C F (2003). Effects of high temperature on grain growth and on metabolites and enzymes in the starch synthesis pathway in the grains of two wheat cultivars differing in their response to temperature. *Func Plant Biol.* **30**: 291-300.
- Zende N B, Sethi H N, Kasunakar A P and Jiotode D J (2005) Effect of time and fertility levels on yield and quality of durum wheat genotypes. *Res on crops* **6**: 194-96.

APPENDIX I

Daily maximum and minimum temperature (°C) (November to April)

Dates	November		December		January		February		March		April	
	T _{max}	T _{min}	T _{max}	T _{min}	T _{max}	T _{min}	T _{max}	T _{min}	T _{max}	T _{min}	T _{max}	T _{min}
1	31	13.8	24.4	8.2	15	5.4	21.4	5.8	25.8	6.6	33	14.8
2	31.5	13.4	24.4	7.6	17	4.4	21.5	5.2	27.4	11	35	17.6
3	31	14.4	25	7.6	12.5	6.5	23	6.6	28.6	11.6	34.4	19
4	30.6	13.5	25.6	7.2	21.6	8.2	26	6.6	28.6	18.2	32.6	17.2
5	31	11.5	26.6	6.5	19.4	7.6	23.8	14.2	27	15.4	31.8	14
6	31	11.6	26	8.5	18.2	5	21.6	14.2	29.4	10.6	26.8	17.6
7	29.4	13.2	22	10.6	18.6	3.8	21.6	7.6	28	13.8	31.6	12
8	29	12.8	24.6	11.5	17.4	4	21.5	5.4	27	10.4	30.2	17.4
9	29	12.8	24	11.8	17.8	3	21.2	8.4	26.8	9.4	24.8	14.6
10	29.6	13	24	11.6	18.4	8	21	10	27.2	10.6	29.4	12.2
11	28.5	13.2	21.8	9.4	20	6.8	20	9.8	28	9.2	32.2	14.6
12	28.8	12.6	23	6.4	19.6	5.4	21.2	8.4	28.4	9.2	35.6	17.2
13	27.4	16.4	23	5.6	20.6	5	24.6	7.5	31.4	10.2	35.8	18.2
14	27.2	16.4	21	5.2	21.4	7	21.4	10	31.6	12.4	39.8	18.2
15	26.6	12	23.5	7.2	22	7.2	20.4	7.6	30	12.2	37.4	19.8
16	27.5	11.2	18.2	8.2	19.8	11	21.2	6.4	31.2	13.2	34	21.5
17	27.2	11	23	10.2	21.6	12.6	22.4	7.9	31	13.2	35	17.2
18	27.5	10	24.4	10	19.2	10.8	23.4	7.4	31.6	13.8	36.8	17
19	27.2	9.4	19.4	16.2	19	12	23.8	7.8	31.6	16.4	39.2	17.4
20	24.4	13.8	18.2	15	18.4	5.2	26.4	12	33.2	17	38.6	20
21	23.5	8.4	21.2	12	19.6	5.8	25.4	10.8	28.2	13.6	36.8	23.8
22	23.8	7	20.8	8	20.8	8.4	26	11	30	13.6	36.8	20
23	25	7	21.2	5.8	20.8	10.2	27.6	11.4	30.6	15	36.2	18
24	25.4	8	21.4	4.8	21	13.2	24.2	11.4	33	15.4	35.2	16.4
25	25.2	8.4	21.6	7.8	21	12	25.4	12.2	25	16.2	35.4	14.4
26	25.8	7.6	19.6	4.8	20.8	13.8	24.6	10.2	27.6	12	37.8	15.2
27	24.4	7.6	18.5	7	21.4	7.2	24.8	8	26	15	40.8	18.4
28	26	8	12	7.6	20	9.8	24.2	6.8	27	12.6	40	21.2
29	26.2	7	12.5	7	22	7	-	-	24.6	16	41.4	21.5
30	27	7	11.4	7.5	20.8	5.8	-	-	29.2	14.4	40.2	21.4
31	-	-	15	9	20.4	7.5	-	-	31	14	-	-

APPENDIX II

Daily sunshine (hours) (November to April)

Date	November	December	January	February	March	April
1	9.4	6.7	4.7	10.6	9	10.6
2	8.1	5.8	2	8.5	9.2	11.6
3	8	7.3	0.8	9.2	9.5	11.4
4	9.5	8.3	6	7.3	4.3	8.1
5	8.5	7.5	8	3.4	8.5	5.7
6	6.6	5.7	8.1	6.5	10.7	2.6
7	6.3	0	8	10.5	9.8	11.6
8	6.9	0	7.6	9.8	9.6	1.6
9	5.7	6.4	2.5	5.9	9.9	9
10	7.3	4.7	3.8	1.6	9.8	12.8
11	0	6.9	7	7.8	10.8	12
12	4.3	8.9	8.3	9.3	10.9	10.6
13	0	8.1	8	10	10.5	12
14	0	7.3	8.6	9.9	8.4	12
15	3.7	8	8.7	8	10	11.4
16	7.4	0	0	10.5	8.2	10
17	6.7	6.9	4.6	10.2	10.7	12
18	8.1	6.1	2.3	10.6	7.7	12
19	3.7	0	8.1	10.2	7.9	11.7
20	6.4	0	8.6	10.1	10.6	11
21	8.4	5.5	7.3	9.6	11.3	10.3
22	8.6	9	5.8	8.1	6.9	10.7
23	9.3	8.2	5.1	8.5	9.2	11.1
24	8.9	8.1	1.1	0.7	7.7	12.3
25	4.1	6.9	3.2	10.5	4.9	12.5
26	6	5.5	4.2	10.5	11.6	11
27	4.9	3.7	6.5	10.5	0	10.5
28	8.1	0	7.7	11.1	3.1	7.8
29	8.2	1.1	9.2	-	5.8	8
30	8	0	9.1	-	10.7	11
31	-	5.2	8.3	-	10.5	-

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