Nutrient use efficiency of various genotypes of bread wheat under low and optimum input conditions

By
Akshay Kumar Vats
[2011A21D]

Thesis submitted to the Chaudhary Charan Singh Haryana Agricultural University, Hisar in the partial fulfilment of the requirements for the degree of

Doctor of Philosophy

In

Genetics and Plant Breeding

COLLEGE OF AGRICULTURE
CCS HARYANA AGRICULTURAL UNIVERSITY
HISAR – 125 004 (HARYANA)

2015

CERTIFICATE – I

This is to certify that this thesis entitled, **"Nutrient Use efficiency of various genotypes of bread wheat under low and optimum input conditions"** submitted for the degree of **"Doctor of Philosophy"** in the subject of **Genetics and Plant Breeding** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Mr. Akshay kumar vats** 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 duly acknowledged.

Dr. R.P. Saharan
(Major Advisor)
Project Director
Directorate of Research
CCS Haryana Agricultural University, Hisar

CERTIFICATE – II

This is to certify that this thesis entitled **“Nutrient Use efficiency of various genotypes of bread wheat under low and optimum input conditions”** submitted by **Mr. Akshay Kumar vats** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of **“Doctor of Philosophy”** in the subject of **Genetics and Plant Breeding** has been approved by the Student’s Advisory Committee after an oral examination on the same, in collaboration with an external examiner.

MAJOR ADVISOR **EXTERNAL EXAMINER**

HEAD OF THE DEPARTMENT

DEAN, POSTGRADUATE STUDIES

Acknowledgements

First and foremost, I offer my obeisance to the almighty for having bestowed his grace up on me to complete this piece of work for which I am extremely indebted.

I express my deep sense of gratitude and sincere thanks to my Advisor, Dr. R.P. Saharan, Project Director, Directorate of Research, Chaudhary Charan Singh Haryana Agricutultural University,Hisar for his constant encouragement and support throughout my study. His splendid and meticulous guidance, suggestions and constructive criticisms throughout my research work are highly acknowledged.

I owe my profound thanks to members of my Advisory committee, namely, Dr. I.S.Panwar *Principal Scientist (Wheat), Department of Genetics and Plant Breeding;* Dr. R.C. Punia, *Principal scientist cum Director (Farms), Directorate of Farms;* Dr. R.K. Jain, *Professor (Department of MBBB) and Dean, College of Basic sciences and Humanities,* Dr. K.S. Boora, *Retd. Principal Scientist (Department of MBBB) and* Dr. V.K. Sikka, *Principal Scientist, (Department of MBBB) for their keen interest, guidance, useful suggestions, learned councel and valuable help during the course of this investigation.*

I extend my sincere thanks to Dr. S.S.Dhanda Principal scientist (Wheat), Dr. R.K. Behl, Retd. Prof.(Wheat), Dr. (Mrs.)Renu Munjal Principal Scientist,Department of Botany and Physiology, Dr. S.R. Verma (Prof. and Head, department of Genetics and Plant Breeding, Dr. Vikram singh, Asstt.Scientist (Wheat), Dr. O.P. Bishnoi (Asstt. Scientist (Wheat), Dr. M. S.Dalal, Asstt. Scientist (Bajra), Dr. S.K. Pahuja, Prof. and head of Forage section, Department of Genetics and Plant Breeding Dr. Bhagat singh, Asstt. Agronomist (Wheat) and other faculty members of Genetics and Plant Breeding Section for sharing their knowledge, expertise and technical assistance provided during the course of investigation. Thanks are also due to the field and laboratory staff of the department for providing affectionate and efficient help throughout the studies.

Friends are invaluable treasurers indeed because of their precious help; constant support and encouragement. I take this opportunity to extend my gratitude to My senior Dr. Mukesh Kanwal my companions PukhrajKataria, Vipin, Jagdeep, Anzer-ul-islam, Nabin Bhusal, Sandeep rawal, Amit pippal, Rahul Sehara, Ravi Mehndiratta, Sumit, Amit, Ajay Yadav, jitender, Hemender, Harikesh, Vishal Johar, Anil Sharma, Sumit athwal, Satender Yadav, along with all my friends of CCS HAU Hisar for their cultural and friendly attachment during the period of my study.

Mere words cannot express my deepest indescribable heartfelt feeling for my beloved parents, Smt. Poonam vats and Sri. Naresh Kumar Vats, My brother, Gaurav Vats and My sister Priyanka Vats and other family members for their sacrifice, affectionate encouragement and moral support, without which I would not have completed my study successfully.

Date

Akshay Kumar vats

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER - I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world. The area, production and productivity of wheat in India is approximately 31.34 million ha, 95.91 million tones and 30.61qtl/ha, respectively during the year 2012-13. The corresponding figures in Haryana are 24.97 lakh ha, 116.64 lakh tones and 47.22 qtl/ha (Anonymous, 2014-15). Crops and varieties within a crop often differ in their yield potential, nutrient requirement and efficiency in nutrient uptake, making it difficult to formulate general fertilizer recommendations. During the last four decades under a global wheat improvement programme, a number of high yielding varieties of wheat have evolved and been introduced in the cropping system which has helped in increasing food production, hereby greatly reducing starvation and protein malnutrition. However, this has caused greater depletion of micronutrient reserves in soil and thereby accentuated wide spread deficiencies of micronutrients (i.e. Zn, Fe, Mn, Cu, B, Mo and S) (Alloway, 2008). Due to high demand of food and increasing population the increased productivity of wheat is an urgent requirement and to achieve high productivity the use of fertilizer also increases.

Importance of research topic:

- Number of micronutrient deficient people particularly in developing countries are increasing day by day.
- Up to one third of the population is at risk of Zn deficiency.
- Food fortification and supplementation seems to be an alternate but this strategy is considered too expensive.
- Cereal do not only contain relatively low levels of Zn, But are also rich in compounds limiting bioavailability of Zn.
- Animal based food products with high level of micronutrients are very rarely consumed.
- Public concerns over the potential environmental hazards of intensive agriculture have renewed an interest in the low-input nitrogen (N) fertilization practices for wheat (*Triticum aestivum* L.)

In aerobic soils, the major form of inorganic N is nitrate; in flooded wetland or acidic soils, the major form is ammonium. In the rhizosphere, the root can release oxygen and exudates that greatly influence local redox potential and the density and activity of microbial populations, which can interconvert soil N forms, including those derived from fertilizer. Mineral nutrients are distributed in no-uniform manner in the soil. Plasticity in root responses to the availability of mineral nutrients is believed to be important for optimizing nutrient acquisition. The response of root architecture to heterogeneous nutrient availability has been documented in various plant species, and the molecular mechanisms coordinating these responses have been investigated particularly in Arabidopsis, a model dicotyledonous plant (Peng yu *et al.* 2014) .An understanding of genotypic variation in the responses of root system architecture to the heterogeneous distribution of nutrients in the field will determine the potential for the exploitation of such traits to increase crop yields and nutrient use efficiency. The amount of N finally present in the grain depends on uptake, distribution in the plant and losses occurring after uptake. Uptake ability may be affected by root development, (Wiesler and Horst 1994), Physiological factors, (Eilrich and Hagemann, 1973). The increase in the use of nitrogen (N) and phosphorous (P) fertilizers between 1960 and 2000 by intensive agricultural practices has led to degradation of air and ground water quality (Tilman *et al*. 2001). Even though N is among the most abundant elements on earth, yet it is the critical limiting element for growth of most plants due to its unavailability (Graham and Vance, 2000). According to an estimate, about 54% soils in Haryana are deficient in zinc. Soils with extractable Zn less than 0.6% mg/ kg soil will require the application of particular nutrient to sustain production. About 50% of the soils used for cereal production in the world contain low levels of the zinc available to plants which reduces not only grain yield, but also nutritional quality of grains. P is second only to N as the most limiting nutrient for the plant growth (Biellski, 1973, Vance *et al*. 2000). Although bound P is quite abundant in many soils, it is largely unavailable for uptake (Biellski, 1973, Schctman *et al*. 1998). Crop yield on 40% of the world’s arable land is limited by P availability. P is unavailable in soils with low or high pH values, because it rapidly forms insoluble complexes with cations and is incorporated into organic matter by microbes. Sustainable management of P in agriculture requires that plant biologists discover mechanisms in plants that enhance P acquisition and exploit these adaptations to make plants more efficient germplasm and advance crop management schemes that increase soil P availability.

Genotypic differences in the major components of nitrogen uptake and use efficiency between bread wheat (*Triticum aestivum* L.) landraces were evaluated in field conditions under varied N fertilization levels (0, 200 Kg N ha^{-1}) based on RCB design with three replications. All characters showed significant genotypic differences. Results showed high variation between the genotypes by reducing nitrogen in almost all trials. Nitrogen uptake efficiency contributed to about 85% of variation at both levels of N (Khalilzadeh *et al.* 2011). Since the development of semi dwarf and dwarf bread wheat (*Triticum aestivum*) and durum wheat (*T. turgidum*, Var. *durum* Desf.) cultivars, application of nitrogen fertilizer has been increased tremendously to elevate production of grain yield. Nitrogen use efficiency (NUE) for cereal production worldwide was estimated up to 33%, loss of fertilizer N takes place from surface runoff, leaching, soil denitrification, volatilization and gaseous plant emission. Also N fertilizer is one of the most expensive input used in present day wheat production. Thus, efficiency of wheat cultivars in N use has become increasingly important, because of the cost of N fertilizer and of the potential for nitrate pollution of underground water and the atmosphere. Research has shown that modern semi dwarf cultivars respond more to available nitrogen than the old, tall cultivars, which translates into higher returns to farmers (Ortiz-Monasterio *et al*. 1997). In addition, semi dwarf wheats do not necessarily require more nitrogen than older cultivars at lower levels of fertility (Ortiz – Monasterio *et al*. 1997). Graham *et al*.(1992) reported that deficiencies of zinc are well known in all cereals and cereal growing countries. From physiological evidence reported elsewhere, it would appear that a critical level for zinc is required in the soil before roots will either grow into it or function effectively (Graham *et al*.1992). Zinc efficient genotypes absorb more zinc from deficient soils, produce more dry matter and more grain yield but do not necessarily have the highest zinc concentrations in tissue or grain. Although high grain zinc concentration also appears to be under genetic control, it is not tightly linked to agronomic zinc efficiency traits and may have to be selected for independently (Graham *et al*.1992). High grain zinc is considered a desirable quality factor which not only contributes to the seedling vigour of the next generation but could increase the nutritional value of the grain in areas where a high dependence on grains for food may result in zinc deficiency in humans (Graham *et al*.1992).

Bread wheat (*Triticum aestivum*) possesses a fibrous root system comprising 6 to 7 seminal (primary) axile roots and about 20 nodal (adventitious) roots (axiles) per stem. Seminal roots initiate from the coleorhiza, are thinner, grow deeper into the soil and are important for seedling moisture absorption and establishment, as well as tolerance to drought stress (Gregory *et al*., 1978; Percival, 1921; Watt *et al*., 2008). Nodal roots are thicker and emerge horizontally from the coleoptile and stem nodes at the tillering stage (Grando *et al*., 1995; Kirby, 2002). They represent younger, newly emerged roots, thus are more reflective of root growth vigor and soil nutrient status (Sullivan *et al*., 2000; Tennant., 1976). Agronomic improvements and genetic variation in bread wheat have been achieved by means of alien genome transfers such as chromosome substitutions and translocations from species of related *genera* like rye (*Secale cereale*) (Merker, 1984). The root system is rapidly emerging as central to environmentally sound, sustainable approaches to addressing wheat crop productivity challenges including declining soil fertility that threaten to raise prices by 2050 (Rosegrant and Agcaoili, 2010; Gewin, 2010; CIMMYT, 2011). The plant root system's roles as the suppliers of water and minerals, provision of anchorage, competitiveness, adaptation to abiotic and biotic stress are well documented (Russell, 1971; Barraclough, 1986). Plant roots are also critical to crop improvement efforts due to their role in belowground carbon sequestration, soil structure improvement and maintenance of soil fertility through regulation of microbial processes (White *et al*., 2013). Longer and thinner roots had higher uptake rates of zinc and phosphorus in durum (*Triticum turgidum durum*) and bread wheat (Dong *et al*., 1995; Gregory, 2006; Rengel and Graham, 1995). Higher wheat root biomass has also been associated with reduced leachate nitrate concentrations and more efficient N acquisition (Ethdaie *et al*., 2010).

Therefore, keeping in view the above facts, the present investigation was planned with following objectives:-

1) To evaluate the various genotypes of bread wheat for various characters under low and optimum input conditions.
2) To determine the genotypic and phenotypic variability for the grain yield, its components and morpho- physiological traits under low and optimum input conditions.
3) To determine the various indices of yield, its components and other morpho-physiological traits for nutrient use efficiency.
4) To determine the promising genotypes for nutrient uptake and use efficiency.

CHAPTER-II

REVIEW OF LITERATURE

Large number of studies have been conducted on response of nutrients applied to wheat genotypes. The most relevant literature of the past few decades pertaining to the present investigation entitled “Nutrient use efficiency of various genotypes of bread wheat under low and optimum input conditions” has been reviewed under following heads.

2.1 Grain yield and its components

Fraser *et al*. (1982) observed favourable effect of N application on tillering both in tall and dwarf wheat varieties under irrigated conditions. Andrascik and Karibinova (1986) reported the fertilizer rate has no effect on emergence of plant, but number of tillers at harvest were positively influenced. Singh (1991) obtained significant increase in ears per m^2 with N application. Chandra *et al*. (1992) reported the increase in plant height with increased N application. Khalh *et al*. (1994) registered significant increase in plant height and number of tillers per m^2 from 40 kg N + 20 kg P_2O_5 to 70 kg N 50 kg P_2O_5 per ha.

Sen and Swain (1994) concluded that plant height, number of tillers, leaves per plant and chlorophyll content increased with rate of NPK from 40 kg N + 20 kg P_2O_5 + 20 kg K_2O to double or triple of this dose. Significant increase in plant height of wheat with increasing N levels from 60 to 120 kg/ha has also been reported by Yadav *et al*. (1995) and Patel *et al*. (1995). Singh *et al*. (1996) found that the application of 60 kg P_2O_5 per ha significantly increased the plant height, dry matter accumulation and plant tillers over 40 kg P_2O_5 per ha in control.

Parmar and Sharma (1996) stated that dry matter yield of wheat at tillering and flowering stages improved significantly from 0 to 78 P_2O_5 per ha. Choudhary *et al*. (1997) reported that number of tillers per metre row and dry matter yield increased with increased dose of N and P. Azad *et al*. (1998) reported that growth of wheat crop increased significantly with each successive increase in rate of fertilizer. Ewert and Honermeier (1999) observed spikelet initiation in reponse to two levels of nitrogen fertilization on the main stem and the first initiated tiller of winter triticale and winter wheat. The duration of spikelet initiation was not affected by nitrogen application in both cereals. The numbers of spikelets of both main stems and tillers were significantly increased due to nitrogen fertilization at anthesis in wheat. Nitrogen fertilization did not effect spikelets number per ear in triticale but significantly increased spikelet number on main stems and tillers at anthesis, which was explained by the continuation of spikelet initiation in the high- nitrogen treatment and spikelet abortion was observed in both nitrogen treatments in wheat. Main stems initiated more spikelets per spike more spikelets per ear than tillers. Spikelets initiation on main stems and tillers did not respond differently to nitrogen application for triticale or wheat. Variation of spikelet initiation among years was affected by nitrogen application. In wheat, spikelet number per ear varied less among years when nitrogen was applied. In triticale, the variation in the spikelet number increased with nitrogen application. There was a positive relationship between the duration of spikelets initiation and the nitrogen effect on spikelet number per ear for triticale. They concluded that consideration of nitrogen supply is important when analyzing the variation in spikelet initiation and relationships between growth and differentiation processes.

Ortiz- Monasterio *et al*. (2002) reported that phosphorous was the second most widely occurring nutrient deficiency in cereal systems around the world. The effect of phosphorous deficiency was severe i.e., only 43% of the achievable yield was obtained with no application. All modern durum wheat and triticale genotypes were more responsive to P applications. Percent grain protein on average was higher in durum wheat that in triticale. All triticale genotypes had lower perecnt grain protein. Sharma and Kumar (2001) reported that restricting the application of irrigation decreased the canopy temperature depression (CTD), transpiration rate, stomatal conductance and photosynthesis significantly over irrigated control. The grain yield under rainfed condition was reduced by 44.5% and 20.5% over irrigated control and two irrigations respectively. Reduced irrigation application decreased the yield attributes with maximum reduction in number of spikes per m^2 followed by number of spikelets per spike and ear length.

2.2 Biological yield and Harvest index

Tanaka (1994) indicated that harvest index in wheat is closely related to the percentage of productive tillers and generally decreased with increase N application. An increase of N application favours huge vegetative growth and thereby results in the lower percent productive tiller, panicle number and finally lower harvest index (Tanaka, 1994). Decreasing trend of harvest index with increased rate of N application has been confirmed by several studies (Kumar and Rao, 1992; Hari *et al*., 1997). However, with moderate doses of N application increment of harvest index can be achieved (Kanungo and Rout, 1994). Behera (1998) and Thakur(1993) also reported an increasing trend of harvest index to a certain level of N and a decreasing one with further increase in its rate of application. Total dry weight increased significantly with an increase in N application upto 150 kg/ha (Singh and Anderson, 1978). Pokhrel *et al*. (1993) observed that identification of high yielding genotype at early stages of varietal development may be realized through evaluation of the genetic system of dry matter accumulation. Nitrogen fertilization resulted in increase in dry weight of the whole plant and each plant part at successive stage of observation and at harvest. Kaushik and Kaushik and Sharma (1997) reported that wheat yield increased significantly upto 80 kg N /ha. Torabi and Malakuti (1997) found that the application of N (0-80 kg N/ha) increased grain yield but decreased harvest index of wheat, while Srinivas and Satyanarayana (1997) reported that grain yield was the highest with 160 kg N /ha and nitrogen use efficiency decreased with increasing N rate. Singh and Prasad (1998) indicated that N application (0-80 kgN/ha) significantly increased the grain yield of wheat. Azad *et al*. (1998) found significant increase in yield of wheat due to increase in rate of fertilizer application from 100 percent of recommended dose of NPK to 150 percent. White and Wilson (2006) said that variation in grain yield was more strongly associated with variation in biomass.

2.3 Physiological parameters

Sun *et al*. (1989) reported that all chlorophyll fluorescence declined significantly as N, P and K concentrations declined, but thylakoid membrane efficiency was stable at all nutrient levels. Relative units of Fo, Fm and Fv were significantly and positively correlated with growth and N, P, K and Mg concentrations of shoots. Chlorophyll fluorescence may be useful measure of severity of nutrient deficiencies. Qiang *et al*. (2006) revealed that under the field fertility conditions rates of N,P,K and S had obvious effect on canopy photosynthetic rate, chlorophyll content and nitrate reductase activity and all photosynthetic characteristics indices increased with N,P,K and S supply, but the most powerful fertilize factor at different date after anthesis was different.

Ruiz *et al*. (2007) reported that yield differences were statistically significant between N levels and among genotypes at both levels. Fiftyone percent of the landraces yielded significantly higher at high N while 26% had a positive (high – N varieties) and 23% indifferent (indifferent – N varieties) response to N fertilizer. No significant agromorphological differences were found among low and high-N varieties at low N level that conferred some advantage to low- N varieties. In contrast, High-N varieties possessed longer grain- filling period under high N level. Phenological characters showed an important influence on yield and on the performance of the varieties within each subgroup. Paknejad *et al*. (2007) reported that Fv and Fv/ Fm had highest and Fo lowest correlation coefficients with grain yield. Sharma and agarwal (2007) reported that zinc was more beneficial at lower concentrations to total chlorophyll content, total nitrogen content, and grain yield.

Nevena Djukic (2008) indicated that chlorophyll content depended on the presence and ratio of mineral elements in the substrate. The content of chlorophyll a, chlorophyll b, and total chlorophyll (a + b) was measured for each variant. Jamaati-e-somarin *et al*. (2009) reported that with increase in nitrogen application, stem dry weight, number of leaf, stem and tiller along with the leaf chlorophyll content were also increased and with increase in plant population per unit area, vegetative growth period and leaf chlorophyll content were decreased, while the reproductive growth period, leaf and stem dry weight and the number of leaf, stem and tiller were increased. Uprety *et al*. (2009) reported that wheat species responded differentially to the elevated CO_2. The larger leaf area and greater seed weight caused by elevated CO_2 had additive effect in improving the productivity of the hexaploid wheat by changing source sink ratio. Bosquet *et al*. (2009) studied photosynthetic capacity of field grown durum wheat under different N availabilities. A comparative study from leaf to canopy revealed clear increase in photosynthetic gas exchange and chlorophyll contents with N fertilization at both canopy and leaf levels. As a consequence, the increase in yield in response to N fertilization was the result of larger green leaf area combined with a higher photosynthetic capacity of leaves and attributable to an increase in the maximum carboxylation. Zhang *et al*. (2009) reported that chlorophyll content is positively correlated with photosynthetic rate. Parry *et al*. (2010) reported that past increases in yield potential of wheat have largely resulted from improvements in harvest index rather than increased biomass. Further large increases in harvest index are unlikely, but an opportunity exists for increasing productive biomass and harvestable grain. Photosynthetic capacity and efficiency are bottlenecks to raising productivity and there is strong evidence that increasing photosynthesis will increase crop yields provided that other constraints do not become limiting. Even small increases in the rate of net photosynthesis can translate into large increases in biomass and hence yield, since carbon assimilation was integrated over the entire growing season and crop canopy. Mauromicale *et al*. (2010) reported positive linear relationship was established between nitrogen supply and chlorophyll content, Fo (initial chlorophyll fluorescence) in potato crop. Nitrogen supply up to 10 g/m^2 also had positive effect on Fm and Fv, but above this rate it reduced Fv/Fm. Chlorophyll content decreased with increasing plant age, whereas Fo, Fm and Fv increased until complete canopy development and thereafter declined until crop maturity. Rosyara *et al*. (2010) reported that the physiological traits chlorophyll content, chlorophyll fluoresence showed higher correlations with grain yield and thousand kernel weight. Wang *et al*. (2010) reported that among all he traits tested, chlorophyll content had the highest heritability. Fitzgerald *et al*., (2010) found a high significant correlation (0.97) between chlorophyll concentration and nitrogen content on the wheat leaves. Furthermore, these plants usually have slow leaf senescence after anthesis, optimizing grain filling and NUE (Van Oosterom *et al*., 2010; Gaju *et al*., 2011). Da silva *et al.* (2014) reported that the chlorophyll B index was significantly correlated with grain yield (0.49*), thousand kernel weight (0.44*), and NUEg (0.50*), indicating that chlorophyll B index can be used as an effective selection criterion in early segregating generations. Positive correlations of moderate to high magnitude indicated that genotypes with a higher relative chlorophyll index B (ChlB) tend to show high GY (0.49*) and TW (0.44*).

2.4 Nutrient uptake parameters

Kandera (1975) revealed that fertilization with Zn increased the N content of the grain, but had no effect on P and K contents. N fertilization had the greatest influence in raising grain yields, while fertilization with trace elements slightly increased the grain yield. Ryakhovskaya *et al*. (1975) observed that the application of Mn, B and Zn increased the wheat grain yield by 220, 140 and 210 kg/ha, respectively. This increase in grain yield was attributed to increased leaf area dry matter accumulation and grain protein content. Yield and quality was significantly improved when NPK was applied in combination with trace elements (Mn, B and Zn).

Rengel and Graham (1995) observed that zinc may be important for an early establishment of crops on low fertility soil and also for high grain yield. At maturity, plants derived from the high Zn seed had bigger grains and produced more grains than plants grown from the low zinc seed. They also observed that Zn deficient plant produced seed with higher concentration of all inorganic nutrients determined except Zn and concluded that crops grown from seed containing higher Zn content have distinct advantages which culminate in greater yield when grown in soil of low Zn status. Cakmak *et al*. (1997) showed that rye has an exceptionally high Zn efficiency and the rye chromosomes, particularly 1R and 7R carry the genes controlling Zn efficiency. Therefore, the genes controlling Zn efficiency in rye are transferable into wheat and can be used for development of new wheat varieties with high Zn efficiency for severely Zn-deficient conditions. Gouis and Pluchard (1996) showed that a large variation exists for N related traits and for the resistance against N deficiency.

Ortiz-Monasterio *et al.* (1997) reported that progress in NUE resulted in an improvement of both uptake efficiency and utilization efficiency. However, the relative importance of these two components was affected by the level of applied N. These results contradict the belief that modern semidwarf cultivars require more N than older cultivars. Instead, they respond more to N, which translates into higher economic rates and higher returns when N fertilizer is available. Yilmaz *et al*. (1998) showed that wheat plants grown from seed with high Zn content can achieve higher grain yields than those grown from the low-Zn seed when Zn was not applied to the soil. Therefore, sowing seeds with higher Zn contents can be considered a practical solution to alleviate Zn deficiency problem. Sedri and Malakouti (1998) concluded that NPK + Zn application increased average yield, zinc sulphate application increased protein content while Zn sulphate with Fe-EDTA chelate and copper sulphate increased Zn concentration in grain in comparison to control.

Behl *et al*. (1998) conducted a pot experiment with a set of 13 Chinese spring (C 591) DS wheat lines representing all the three genomes A, B, D and their parental genotypes and found that the magnitude of response at 5 mg zinc/kg soil varied from 0 to 89.4% for grain and 0 to 28.4% for straw yield. On the basis of grain yield response the DS lines susceptible to zinc deficiency were Ch-1A, Ch-1B, Ch-1D, Ch-4A, Ch-7B and Ch-7D, moderately resistant lines were Ch-2A, Ch-3D and Ch-5D whereas Ch-6A, 6B and Ch-7A were found to be highly resistant lines. They further observed that Chinese spring was zinc efficient genotype as compared to C591. Akbari *et al*. (1999) concluded that grain and straw yields of wheat increased significantly with increase in the levels of Zn, Fe, S and gypsum.

Cakmak *et al*. (1999) studied six diploid, nine tetraploid and seven hexaploid wheats including wild and primitive genotypes, to study the influence of varied zinc (Zn) supply on the severity of Zn deficiency symptoms, shoot dry matter production and shoot Zn concentrations. Compared with tetraploid wheats, diploid and hexaploid wheats were less sensitive to Zn deficiency. With additional Zn, shoot dry matter production was higher in tetraploid than diploid and hexaploid wheats. However, under Zn-deficient conditions tetraploid wheats had the lowest shoot dry matter production, indicating the very high sensitivity of tetraploid wheats to Zn deficiency. Consequently, Zn efficiency expressed as the ratio of shoot dry matter produced under Zn deficiency to Zn fertilization was much lower in tetraploid wheats than in diploid and hexaploid wheats. Erenglu *et al*. (2002) observed that differential compartmentation of Zn at the cellular levels is a possible factor determining genotypic variation in Zn efficiency within wheat. Differences in Zn efficiency between and within bread and durum wheat are not related to translocation or distribution of foliar applied Zn within wheat plants. Behl *et al*. (2003) reviewed the role of Zn in wheat and observed that several plant metabolic processes and biological functions are impaired under Zn deficit conditions. Most visible symptoms of Zn deficiency are a reduction in shoot growth, decrease in leaf size, chlorophyll degeneration and the emergence of whitish brown necrotic patches on leaves. Genotypes which show the highest response to added Zn are unable to grow and produce grain when Zn availability was low. Breeding cereals with enhanced Zn efficiency can decrease fertilizers dependency, improve seedling vigour, increase resistance to abiotic and biotic stresses and enhance yield and nutritional value of wheat.

Zhang *et al*. (2004) observed that biomass and total nitrogen uptake of wheat plant increased with the N-concentrations. Zn concentration ranges appear to be 16-20 mg/kg in young whole shoots, 12-16 mg/kg in flag leaves, and 20-24 mg Zn /kg in mature grains (Rafique *et al*. 2006). Kiche *et al*. (2006) observed that the use of a marker such as glutamine synthetase (GS) activity can be used to predict N status of wheat, as a function of both plant development and N-availability with the aim of selecting wheat genotypes with better N-use efficiency.

.Svecnjak *et al*. (2007) reported that despite an associated increase in the 1000- grain weights, the use of the low N-fertilization brought about a significant decrease in grain yield and grain N-content. In contrast grain P content was not affected by N-fertilization or growing season. A negative correlation between 1000-grain weight and P content was found because of tendency toward lower P content in heavier grains. When compared to the high N input, the low N fertilization practices for wheat crop were associated with a significant decrease in grain yield and grian N content in all cultivars, but had no effect on grain P content regardless of cultivar. Yildirim *et al*. (2007) observed that it is probable to select promising lines suitable for low N conditions by crossing high N-use efficient parents. Semenov *et al*. (2007) reported that decrease in leaf N increased NUE by 10 – 15%, when N was limiting, but for high N supply the effect on NUE was negligible. So, in any crop, an increased knowledge of the regulatory mechanisms controlling plant nutrient economy is vital for improving nutrient use efficiency and for reducing excessive input of fertilizers while maintaining an acceptable yield. Using plants grown under agronomic conditions at low and high fertilization regimes, it is now possible to develop whole-plant physiological studies combined with gene, protein, and metabolite profiling to build up a comprehensive picture depicting the different steps of nutrient uptake, assimilation, and recycling to the final deposition in the seed (Hirel *et al.* 2007). Moreover, genetic differences among crop genotypes can be exploited for identification of genotypes more suited to a low-input agricultural system. Although it is well known that there is some genetic variability for maximum N uptake in wheat however the physiological and genetic basis for such variability has never been thoroughly investigated. Genetic variability for N uptake in wheat and the physiological and genetic basis for such variability could confer on some species or genotypes the ability to store greater quantities of N during periods of abundant N supply, thus avoiding losses into the soil. This challenge is particularly relevant to cereals for which large amounts of N fertilizers are required to attain maximum yield and for which NUE is estimated to be far less than 50% (Hirel *et al.* 2007). Korkmaz *et al.* (2009) reported that dry matter yield and P content were significantly increased by increasing P rates, with significant differences between soils. Some genotypes performed better under P stress because of better P utilization efficiency. Shoot dry matter was the most sensitive indicator of genetic variability under P deficient conditions. Da silva *et al.* (2014) reported that the total biomass nitrogen concentration (BNC) ranged from 2.38 to 3.27% and grain protein concentration (GPC) varied between 10.81 and 15.53 %.Likewise, Cormier *et al.* (2013) reported genetic progress to a straw nitrogen concentration at physiological maturity of -0.52% year-^{1} due to greater efficiency of nitrogen remobilization in modern cultivars. Thus, genotypes with low BNC and high NHI are essential to improve NUE, because they are more efficiently remobilize the nitrogen from straw to grains (Kichey *et al.*, 2007; Cormier *et al.*, 2013).

2.5 Genetic variability

Kumar *et al.* (2010) reported that Biological yield, harvest index and spikes per plant had significant positive direct effect on grain yield. Grain yield, biological yield and grain per spike had high values of GCV along with heritability and genetic advance. These results indicated that traits like biological yield, grains per spike and grain weight per spike can be used to increase grain yield of bread wheat genotypes. Dharmendra and Singh (2010) reported that phenotypic and genotypic coefficient of variation (PCV and GCV), heritability, genetic advance (GA), correlation and path analysis for 10 characters were estimated in 20 genotypes of bread wheat. High estimates of PCV, GCV, heritability and GA indicated scope for improvement through simple selection for grain yield components namely, grain per spike, grain yield per plant, plant height followed by 1000-grain weight. However, there was little variability and scope for selection in the materials for days to 50 % heading, days to maturity and germination percent. Jalata *et al*. (2011) observed significant variation among materials tested for important quantitative traits across locations indicating the presence of variability. In addition, genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV) was relatively higher for grain yield per plot, number of kernels per spike and spike weight respectively, across locations, and relatively high heritability was obtained for spike length followed by thousand kernel weight, number of kernels per spike, grain yield per plot across locations showing better condition for effective selection in these characters.

2.6 Correlations and path analysis

Kaushik et al. (1996) revealed that 1000-grain weight was significantly and positively correlated with grain yield per plant and biological yield per plant. Paul and ganguli (1996) revealed that number of spikes per plant, grain weight per spike and number of grains per spike were positively and significantly associated with grain yield while 100-grain weight were negatively and significantly correlated with grain yield. Kumar and hunshal (1998) reported that grain yield had significant positive correlation with all the characters studied except ear length. Indirect effect of other characters on grain yield through harvest index and total dry matter were high.

Khan and Mohammad (1999) reported that phenotypic correlations between plant height and grain yield per plant were significant and negative with 1000-grain weight. The path coefficient analysis showed that the harvest index, plant height and grains/spike were the important character in order of magnitude. Thakur *et al*. (1999) showed that grain yield per plant was significantly and positively associated with ear length and tillers per plant. Tillers per plant and spikelets/ear exhibited positive correlation with ear length.

Mondal and Khajuria (2001) and Sudesh *et al*. (2002) reported strong positive association of grain yield with spike length, number of spikelets per spike, 100-grain weight and seed density. Path analysis showed highest direct effect of grains per spike, biomass ratio towards grain yield followed by spike length and spikelets per spike. The indirect effect of grain per spike, biomass ratio through spike length and number of spikelets per spike being negative towards grain yield resulted in lowering the correlation coefficients.

Singh *et al*. (2003) revealed positive and significant correlation between effective tillers per plant, biological yield per plant and harvest index with grain yield per plant. However, days to heading had negative significant correlation with 1000-grain weight. Path coefficient analysis further revealed that biological yield per plant, grains per ear, 1000-grain weight and effective tillers per plant had positive and high direct effect on grain yield per plant. Branccourt Hulmul *et al*. (2005) reported that heritability estimates were higher at high

N than at low N level. This was due to both an increase in error variance and a decrease in genetic variance at low nitrogen level. The relative efficiency of indirect selection to direct selection for each pair of environments ranged from 0.15 to 0.99 indicating that indirect selection was not efficient than direct selection. Therefore, breeding programmes targeting low input environments should include low input selection environments to maximize selection gains. Afzaal *et al*. (2006) reported that it appeared that stomatal conductance, net photosynthesis and transpiration rate are directly and indirectly correlated with grain yield and biomass. .Svecnjak *et al*. (2007) reported that despite an associated increase in the 1000- grain weights, the use of the low N-fertilization brought about a significant decrease in grain yield and grain N-content. In contrast grain P content was not affected by N-fertilization or growing season. A negative correlation between 1000-grain weight and P content was found because of tendency toward lower P content in heavier grains. When compared to the high N input, the low N fertilization practices for wheat crop were associated with a significant decrease in grain yield and grian N content in all cultivars, but had no effect on grain P content regardless of cultivar. Kichey *et al.* (2007) reported moderate correlation between grain yield and chlorophyll contents (r comprised between 0.64 and 0.73) and more strong correlation between grain yield and soluble protein content and almost negligible correlation with thousand kernel weight. Munir *et al*. (2007) reported that grain yield per plant showed a positive and significant correlation with flag leaf area, tillers per plant, spike length, grains per spike and 1000- grain weight. Nofouzi *et al*. (2008) reported that harvest index, plant height and number of tillers had high correlation with grain yield. Path analysis for 1000 seed weight, number of tillers per plant and number of seeds per spike showed that plant height, length of spike, days to flowering were the most effective components of traits, respectively. Bahar *et al*. (2009) reported that stomatal conductance had positive correlations with grain yield, grain numbers per spike, spike yield, and spike length at early stage.

Khan and Dar (2010) studied that grain yield was significantly and positively associated with number of spikelets/ plant followed by number of effective tillers and 100-seed weight at both phenotypic and genotypic levels. Grain yield showed a significant negative association with number of seeds/ spikelet at genotypic level. Among the significant inter-relationships, the association of days to 75% spike emergence with days to maturity and 100-seed weight were significant and positive, but were negative and significantly associated with number of seeds/spikelet and number of grains/spike. Similarly, the associations of spike length with number of seeds/spikelet and number of spikelets/plant and number of effective tillers were negative and significant. The association of number of spikelets/ plant with number of effective tillers was also positive and highly significant. Path coefficient analysis revealed that the magnitude of positive direct effect on seed yield was the highest through number of spikelets/ plant, followed by number of grains/ spike and 100-seed weight. Kumar *et al*. (2010) reported that wheat yield is a complex, quantitative trait directly or indirectly influenced by other plant traits. An understanding of the interrelationships between important agronomic traits and yield of wheat could help to improve breeding results. Positive and significant correlations were observed between grain yield per plant and plant height, spikelets per spike, spikes per plant, grains per spike, biological yield and harvest index. Dharmendra and singh (2010) reported that phenotypic and genotypic coefficient of variation (PCV and GCV), heritability, genetic advance (GA), correlation and path analysis for 10 characters were estimated in 20 genotypes of bread wheat and indicated that the estimates of correlation coefficient indicated that days to maturity, plant height, spike length, spikelets per spike, tillers per plant, grains per spike and 100 grain weight were positively correlated with grain yield. Considering the effects of each character on grain yield, spikelets per spike had highest positive direct effect followed by the tillers per plant, days to maturity and plant height.

Shahryari and Mollasadeghi (2011) reported that in normal irrigation conditions, one-thousand grain yield correlation with number of grain per spike was negative. Also, the correlation between grain yield per spike with number of grain per spike was meaningful and positive. Plant height with a negative direct effect on grain yield has positive indirect effects via days to heading, covering percent and number of spike per square meter. These negative effects have been caused lack of meaningful correlation between plant height and grain yield. Further, biological yield has a meaningful and positive correlation with grain yield, spike length, spike yield and number of grain per spike. Sokoto *et al*. (2012) revealed highly significant positive correlation between spike length with number of spikelets per spike, number of grain per spike, total aerial phytomass and grain yield. However, the relationship between spike length with harvest index was not significant. Similarly, the correlation between spike length with crude protein and gluten was not significant in both seasons. Grain yield was positively correlated with plant height, number of spikelets per spike, number of grain per spike, spike length, 1000-grain weight and harvest index. Andarab *et al.* (2013) reported that Correlation of grains per spike and grain yield under normal irrigation was significant and positive. Similarly, the relationship between grain weight per spike and grain yield was positive and significant. Plant height of both positive and negative can have effects on yield. Plant height having a negative direct effect on grain yield, have positive indirect effects via number of days to heading, coverage percent and number of spikes per square meter. These negative effects caused the lack of significant correlation between plant height and grain yield.

2.7 Nutrient use efficiency

2.7.1 Nitrogen use efficiency: The nitrogen concentration of wheat products determines quality and market value, as it must exceed 18 g kg -1 for acceptable quality for bread or noodles (Cassman *et al*., 2002). A wheat crop thus requires about 168-336 kg ha-1 of fertilizer

N for optimum yields, and contains 15-17 kg of N per 454 kg of grain whose protein content ranges from 12-14% (Ottman and Thompson, 2006). Nitrogen fertilizer use in wheat is however, inefficient; only 27-33% of total N applied is in harvested grains, the rest is immobilized into organic N, lost through run off, leaching or volatilization (Olson and Swallow, 1984; Raun and Johnson, 1999).

Gouis *et al*. (2000) reported that genotype × nitrogen interaction was highly significant except for total N utilization efficiency (total above ground dry weight/ total above ground N) and grain N concentration. The number of kernels/ear explained most of the variations of grain yield at N0 (48%) and N+ (80%); and of the interaction (67%). N uptake efficiency (total above ground N/ soil N supply) accounted for 64% of the variation in N use efficiency (grain yield/ soil N supply, while at N0 and at N+ it accounted for only 30%. N utilization efficiency (grain yield/ total above ground N) was then more important at N+ than at N0. Grain N explained most of the plant N variation at both N levels. The interaction for N use efficiency was best explained by the interaction of N uptake (63%). In wheat, grain N content rather than yield components is largely influenced by the amount of N taken up after anthesis and by the amount of N remobilized originated from pre anthesis N uptake since these two sources of N are used for storage protein synthesis (Dupont and Altenbach , 2003) . In developed economies N use efficiency (NUE: defined as grain dry matter per unit of N available from the soil, fertilizer included) (Raun and johanson, 1999). Sobkowicz and Sniady (2004) studied that increasing N rate from 0-25 kg/ha increased plant biomass yield of triticale. Serret *et al*. (2008) reported that both grain stable N and grain stable carbon correlated positively with NUE and UTE. N fertilizer applications have enabled large increases in grain yields and grain protein (Daigger *et al*., 1976; Garnet *et al*., 2009). The nitrogen concentration of wheat products determines quality and market value, as it must exceed 18 g kg -1 for acceptable quality for bread or noodles (Cassman *et al*., 2002). A wheat crop thus requires about 168-336 kg ha-1 of fertilizer N for optimum yields, and contains 15-17 kg of N per 454 kg of grain whose protein content ranges from 12-14% (Ottman and Thompson, 2006). Nitrogen fertilizer use in wheat is however, inefficient; only 27-33% of total N applied is in harvested grains, the rest is immobilized into organic N, lost through run off, leaching or volatilization (Olson and Swallow, 1984; Raun and Johnson, 1999).

Genotypic differences in stable carbon correlated negatively with total grain N accumulated but only at he intermediate levels of N fertilization. Grain yield and biomass, as well as total N accumulated and NUE, increased in most recent genotypes, only a tendency for higher stable N was observed and there was no clear trend for stable carbon. Changes in NUE were paralleled by changes in uptake efficiency rather than utilization efficiency. Vukovic *et al*. (2008) reported that NUE was decreased with increasing nitrogen fertilization levels. The best use efficiency of applied nitrogen fertilization was at level of 100 kg N per ha.

Svecnjak *et al*. (2008) reported that the use of the low N rate brought about significant losses in grain yields (20%) and reduction in the concentration of N (23%) and had no effect on the concentrations of P and K. Cultivars significantly differed for mineral element concentrations and this variation tended to be similar to or lower than the variation caused by growing conditions or N fertilization. Baresel *et al*. (2008) reported that significant differences for N uptake in three periods (tillering, stem elongation/heading and grain filling) and the quantity of mineralized N during the same sub periods traits and significant interactions among varieties and environments could be detected for nitrogen efficiency and its components. Limiting N availability during grain filling was typical for the more extensive organic environments. Under these conditions, differences became more evident and were mainly due to direct uptake during grain filling. This confirms, that different varieties are necessary in different environments and that breeding may contribute to improve baking quality to a certain extent. However, utilization of mineralized N is still unsatisfactory in organic farming systems in Germany. More N efficient varieties alone will help only little to resolve this problem; this can be achieved only by also improving the cropping systems. Arnall *et al*. (2009) reported that as the N rate increased the resulting slope of the relationship between NUE and RI (response index) was reduced. These analyses also demonstrated that temporal variability in NUE exists and that NUE can be predicted. Lack *et al*. (2009) reported that in 0 – 75 kg per ha treatments, 18% of the difference in wheat yields was due to the N supply component at low N rates; at high N rates and 95% was due to N use efficiency. Kaur *et al*. (2010) reported that there was increase in nitrogen content in grains with delayed sowing whereas, nitrogen uptake decreased with delayed sowing. There was decrease in NUE by 8 % with delay in sowing from 15 november to 25 december. Khalilzadeh *et al.* (2011) reported that the nitrogen uptake rate and the concentration of nitrogen in grains are effective criteria for the selection of wheat with high NUE. Plants well supplied with nitrogen have higher photosynthetic activity.

2.7.2 Phosphorous use efficiency: Ozturk *et al*. (2005) reported that phosphorous efficiency of genotypes, calculated by the ratio of shoot dry matter production under low P to that under adequate P supply. There was no correlation between P efficiency ration and P concentration of plants, but P efficiency of all bread and durum wheat genotypes showed a very significant correlation with the P content (the total amount of P per shoot). The relationship between the P efficiency and total amount of P per shoot was much more significant in bread than in durum wheat. Like shoot P concentrations, also severity of visible leaf symptoms of P deficiency on older leaves, including leaf chlorosis and necrosis, did not correlate with P efficiency. In most cases, genotypes showing higher P efficiency had higher absolute shoot dry weight under P deficient conditions. Under P deficient conditions, the absolute shoot dry weight very significantly correlated with shoot P content, but the correlation between the absolute shoot dry weight and shoot P concentration tended to be negative.

Korkmaz *et al*. (2009) reported that dry matter yield and P content were significantly increased by increasing P rates, with significant differences between soils. Some genotypes performed better under P stress because of better P utilization efficiency. Shoot DM was the most sensitive indicator of genetic variability under P- deficient conditions. Genotypes classified as efficient responsive had above average DM yield when P was not added, and responded well to P applications; efficient- non responsive genotypes had below average DM yield, but responded to P applications; inefficient-non-responsive genotypes had below average DM yield; and no genotypes were in the inefficient responsive category. Such P response categorization is needed for better breeding programmes for nutrient use efficiency. Cao- Hong zing *et al*. (2009) reported that genetic analysis revealed that PUE with higher heritability and genetic advance as well relative genetic advance, which indicated that the variation of PUE were mainly due to genetic factors but not environmental factors. Therefore, genetic breeding of PUE should be selected in early generations. The results can provide some information for further genetic research on PUE in wheat.

2.7.3 Zinc use efficiency: Fageria *et al*. (2008) reported that zinc concentration had a quadratic increase. Zinc uptake followed an exponential quadratic response in four crops. Zinc use efficiency in shoot dry weight production had significant quadratic responses in upland rice and soyabean with increasing plant age. Zinc use efficiency for shoot dry weight production was linear as a function of plant age. Zinc use efficiency for grain production was maximum for corn and minimum for soyabean. Hence, cereals had higher Zn use efficiency than legumes. Zinc concentration in grain dry bean and soyabean was higher than in upland rice and corn, which is a desirable quality factor for human consumption so as to avoid Zn deficiency. Karman *et al*. (2010) reported that there were significant differences among the genotypes used for plant dry weight, zinc concentration and uptake. There was significant correlation between dry matter yield and Zn uptake in Zn treated conditions. The results showed that changes in the Zn utilization characters of barleys were related to the plant genotypes and Zn levels. Dry weight and total Zn content of the plants were used to calculate the efficiency index parameter for classification of genotypes which was evaluated to select barley genotypes with improved Zn utilization characters as ER (efficient responsive).

2.8 Root studies

Bread wheat (*Triticum aestivum*) possesses a fibrous root system comprising 6 to 7 seminal (primary) axile roots and about 20 nodal (adventitious) roots (axiles) per stem. Seminal roots initiate from the coleorhiza, are thinner, grow deeper into the soil and are important for seedling moisture absorption and establishment, as well as tolerance to drought stress (Gregory *et al*., 1978; Percival, 1921; Watt *et al*., 2008). Nodal roots are thicker and emerge horizontally from the coleoptile and stem nodes at the tillering stage (Grando *et al*., 1995; Kirby, 2002). They represent younger, newly emerged roots, thus are more reflective of root growth vigor and soil nutrient status (Sullivan *et al*., 2000; Tennant., 1976). Agronomic improvements and genetic variation in bread wheat have been achieved by means of alien genome transfers such as chromosome substitutions and translocations from species of related *genera* like rye (*Secale cereale*) (Merker, 1984). Zhang *et al.* (1998) reported that reduced irrigation promoted root expansion deep in the soil profile (80±180 cm). I0 and I1 had 9.9% and 6.3%, respectively, of their total dry root mass below 80 cm soil depth, compared to only 2.4% in I4. In the 40±80 cm layer, I1 also had more root mass than I4 crop. As expected, roots of I4 wheat were mainly in the shallow soil (0±40 cm). Non-irrigated plots showed the most yield reduction because kernel numbers were also substantially reduced. Yield of I1 plots was reduced by about 10±15%, mainly due to the reduced kernel weight, but harvest index was greater than both I0 and I4. Yield was not always reduced by single irrigation, when compared to the multiple-irrigated wheat in our large-scale trial. Leaf water potential of I1 was similar to that of well-watered plots at both predawn and mid day. The maintenance of predawn leaf water potential is probably a consequence of the deep root system and the absence of serious midday leaf water deficit a result of the reduced stomatal opening and transpiration. The root system is rapidly emerging as central to environmentally sound, sustainable approaches to addressing wheat crop productivity challenges including declining soil fertility that threaten to raise prices by 2050 (Rosegrant and Agcaoili, 2010; Gewin, 2010; CIMMYT, 2011). The plant root system's roles as the suppliers of water and minerals, provision of anchorage, competitiveness, adaptation to abiotic and biotic stress are well documented (Russell, 1971; Barraclough, 1986). Plant roots are also critical to crop improvement efforts due to their role in belowground carbon sequestration, soil structure improvement and maintenance of soil fertility through regulation of microbial processes (White *et al*., 2013). Longer and thinner roots had higher uptake rates of zinc and phosphorus in durum (*Triticum turgidum durum*) and bread wheat (Dong *et al*., 1995; Gregory, 2006; Rengel and Graham, 1995). Positive correlations between total root length and grain yield have also been reported for winter wheat, oats and barley (Barraclough, 1984; Leon and Schwang, 1992). Additionally, root biomass investments at depth have been associated with adaptation to drought in wheat as they improve the plant's ability to mine a larger soil profile for water and nutrients (Evans, 1977; King *et al*., 2003; Waines *et al*., 2007; Lopes and Reynolds, 2010). In durum wheat, genotypes with the largest root mass under drought had the least yield reduction under severe stress (Motzo *et al*., 1993). Larger root systems also provide greater root-soil contacts that are important for phosphorus (P) uptake and reduced nitrate leaching due to increased nitrate uptake (Geron *et al*., 1993; Gahoonia and Nielsen, 2004). Additionally, higher root weight and volume were found to be associated with increased capacity to absorb nutrients in barley (*Hordeum vulgare*) seedlings (Hackett, 1969). The root system contribution to the plant's NUE although minimally studied is substantial as it comprises about 30% of total plant weight early in growth and 8-15% of total plant mass at harvest (Gallagher and Biscoe, 1978; Gregory *et al*., 1978; Campbell *et al*., 1977; Andersson *et al*., 2005; Garnett *et al*., 2009). Moreover roots have been found to represent 10-20% of total plant N at maturity (Campbell *et al*., 1977; Andersson and Johansson, 2006). Furthermore, Andersson *et al*. (2005) observed that roots retained N transport past wheat grain ripening, suggesting a significant below ground post anthesis contribution to grain N. Roots could therefore substantially influence the plant's N economy. Roots also play a key role in post anthesis N uptake especially under non limiting N and soil moisture conditions and are credited with post anthesis N contributions as high as 24.3% to grain N at maturity (Smith *et al*., 1983; Banziger *et al*.,1994; Andersson *et al*., 2005). Daigger *et al*. (1976) documented a larger demand for N by wheat grains post anthesis than could be met solely by N translocation from shoots. Root architecture, biomass morphology and physiology are especially influential in the plant's NUE (Dawson *et al*., 2008). Higher N uptake efficiency has been associated with early vigorous root growth, larger root densities and more extensive root systems in wheat and perennial grasses (Liao *et al*., 2004; Noulas *et al*., 2010; Jiang *et al*., 2000; Zemenchik and Albrecht, 2002). Higher wheat root biomass has also been associated with reduced leachate nitrate concentrations and more efficient N acquisition (Ehdaie *et al*., 2010).

CHAPTER - III

MATERIAL AND METHODS

The present investigation was conducted during *rabi* season of 2012-13 and 2013-14 in experimental area of Department of Plant breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar.

3.1. Experimental material: Experimental material comprised forty genotypes of bread wheat (*Triticum aestivum* L.em.Thell.). The detail of experimental material is given below.

Genotype	Source	Pedigree	Growing conditions
***T. aestivum* L. *em*. Thell.**			
WH 542	CCSHAU, HISAR	JUP/BJY “S”//URES	Timely sown, high fertility conditions
WH 416	CCSHAU, HISAR	WH147/UP-368	Timely sown, high fertility conditions
PBW 590	PAU, LUDHIANA	WH594/RAJ3814//W485	Recommended for irrigated conditions and late sown conditions
PBW 373	PAU, LUDHIANA	ND/VG9144//KAL/BB/3 /YCO”S’/4/VEE#5 “S”	Recommended for irrigated conditions and late sown conditions
PBW 644	PAU, LUDHIANA	PBW175/HD2643	Recommended for rainfed and low input conditions
WH 1127	CCSHAU, HISAR	Selection from RL6043/4/NAC// PASTOR/3/BABAX	Recommended for rainfed and low input conditions
WH 1140	CCSHAU, HISAR	WBLLI*2/VIVITSI	------------
LOK 54	LOK BHARTI SANSORA	LOK1/J.24/SONALIKA”s”// HW2006/HD2358/HW2002	Recommended for less irrigation and low input conditions
PBW 527	PAU, LUDHIANA	PBW175/PBW389	Recommended for less irrigation and low input conditions
PBW 533	PAU, LUDHIANA	PBW343/PBW138 //PBW343	Recommended for penimsular zone and Late sown conditions
WH 1080	CCSHAU, HISAR	PRL/2*.PASTOR	Recommended for less irrigation and low input conditions
DBW 17	IIWBR , KARNAL	CMH79A.95/3*CN079 //RAJ3777	Dwarf, high yielding , recommended for timely sown conditions

RAJ 3765	RAU, DURGAPURA, JAIPUR	HD2402/VL639	Recommended for irrigated and late sown conditions
DPW 621-50	IIWBR, KARNAL	KAUZ//ALTAR84/AOS/3/ MILAN/KAUZ/4/HUITES	Recommended for high fertility and timely sown conditions
HD 2967	IARI, NEW DELHI	ALD/COC//URES/ HD2160M/HD2278	Recommended for high fertility and timely sown conditions
WH 1063	CCSHAU, HISAR	BARBET 1 Selection	Dry gluten content (11.1 %), Fe (55.7 ppm), Zn (50.7 ppm)
C 518	Llyallpur, University of Agriculture, Faislabad	TYPE9/8A	Recommended for less irrigation and low input conditions
PBW 475	PAU, LUDHIANA		Recommended for less irrigation and low input conditions
WH 1142	CCSHAU, HISAR	CHEN/*Ae.Sq.* (TAUS)//FCT/3/2*WEAVER	Recommended for medium fertility conditions
WH 1061	CCSHAU, HISAR	WEAVER/WL2926//SW89.3064	Promising genotype for Iron (55.2 ppm), Zinc (50.6 ppm) content in grain and bread loaf volume (583cc), grown under late sown conditions.
WH 1098	CCSHAU, HISAR	TILHI/PASTOR	Recommended for less irrigation and low input conditions
WH 711	CCSHAU, HISAR	ALD ‘S’HUAC// HD2285/3/HFW-17	Recommended for high input and and irrigated conditions
WH 1081	CCSHAU, HISAR	PBW65/2*PASTOR	Recommended for medium fertility conditions
WH 1105	CCSHAU, HISAR	MILAN/S87230//BABAX	Recommended for high input and irrigated conditions
HD 2851	IARI, NEW DELHI	CPAN3004/WR426 //HW2007	Recommended for late sown and irrigated conditions
WH 1123	CCSHAU, HISAR	NI5663/RAJ3765 //K9330	Recommended for late sown conditions
WH 1160	CCSHAU, HISAR	WAXWING*2/ VIVITSI	Recommended for low input conditions and less irrigated conditions

PBW 503	PAU, LUDHIANA	WH594/RAJ3814 /W485	Recommended for timely sown conditions
WH 1138	CCSHAU, HISAR	PBW65*2/PASTOR	Recommended for high input and irrigated conditions
HD 2285	IARI, NEW DELHI	249/HD2150//HD2186	Dwarf, suitable for heat stress conditions
WH 1021	CCSHAU, Hisar	GW296/ SONAK	Medium height, suitable for heat stress conditions
WH 1025	CCSHAU, Hisar	PBW 231 / C 591	Medium height, suitable for low input conditions
C 306	CSHAU, Hisar	RGN/CSK3//2*C591/3 /C217/N14//C281	Timely sown, Restricted fertilization
WH 1139	CCSHAU, HISAR	CHIR3/4/SIREN/ALTAR84	Recommended for high input and irrigated conditions
WH 147	CCSHAU, Hisar	E4870-C303/S339-PV18	Medium height, suitable for medium input conditions
WH 1100	CCSHAU, HISAR	PBW65/2*PASTOR	Recommended for late sown and irrigated conditions
SONALIKA	JT*	II54-388/AN/3/ YT54/N10B/LR64	Recommended for late sown and irrigated conditions
PBW 175	PAU, LUDHIANA	HD 2160/WG1025	Recommended for low input and less irrigated conditions
HD 2687	IARI, NEW DELHI	CPAN20099/HD2329	Medium height, suitable for high input conditions
WH 730	CCSHAU, HISAR	CPAN2092/ Improved. LOK1	Heat tolerant

* Joint release by IARI (NEW DELHI) and GBPUAT (Pantnagar)

3.1.1 Environments: The experiment was conducted in following environments

- **Low input**: On the basis of soil test the doses of fertilizer were corrected up to 60 kg N, 30 kg P2O5/ha. In addition to this two irrigations were applied. First irrigation was applied on CRI stage and second irrigation was applied on flowering stage.
- **Optimum input**: On the basis of soil test the doses of fertilizer were corrected up to 150 kg N, 60 kg P2O5/ha. In addition, four irrigations were applied, first irrigation was applied on CRI stage, second irrigation was applied on tillering, third on flowering stage, and fourth on dough stage.

3.1.2 Layout: The design was laid out in split plot design. Plot size was of single row of 3 m length. Observations were taken as 5 plants / entry / replication.

3.2 OBSERVATIONS RECORDED

Grain yield and its components

1. **Grain yield per plant (g)** –Grain yield of five competitive randomly selected plants in each genotype per replication was worked out.
2. **Number of tillers per plant** – Productive tillers from five plants taken for their grain yield were counted and average was recorded.
3. **Number of Spikelets /spike** – Number of spikelets obtained from the 5 spikes were counted and average was taken.
4. **Number of Grains /spike** – Number of grains obtained from the 5 spikes was counted and average was taken.
5. **1000-grain weight (g)** – The weight of 100 grains from five genotype was taken in grams and average was recorded.

Phenological characters

1. **Days to heading-** The numbers of days were counted from date of sowing up to 50% of heading on single plot basis.
2. **Days to maturity-** The numbers of days were counted from date of sowing up to 75% physiological maturity on single plot basis.

Morphological and other traits

1. **Plant height (cm)-**The plant height of five plants was recorded as the length measured from its base up to the apex of plant excluding awns in cm and average was recorded.
2. **Biomass / plant (g) -** Above ground plant biomass of five plants was weighed on balance in grams and average was taken.
3. **Harvest index (%) -**It was recorded by calculating ratio of grain yield to biological yield or biomass per plant and multiply it by 100.

Nutrient uptake and use characters

1. **Estimation of N content and P content-** 0.5 gram of finely grounded samples were taken in digestion tube and 10 ml sulfuric acid + perchloric acid in the ratio of 4:1 poured in digestion tube and left over night. The material was heated from 90 minutes at 160ºC and 30 minutes at 220ºC. After cooling, every digestion tube was filled with 30 ml distilled water and after shaking volume was made 50 ml. Then this end product was filtered into plastic bottle of 100 ml and such digests were analyzed for N content and P content.
2. **Estimation of Zn content-** 0.5 gram of finely grounded samples were taken in digestion tube and 20 ml nitric acid + perchloric acid in the ratio of 4:1 poured in digestion tube and left over night. The material was heated from 90 minutes at 160ºC and 30 minutes at 220ºC. After cooling, every digestion tube was filled with 30 ml distilled water and after

shaking volume was made 50 ml. Then this end product was filtered into plastic bottle of 100 ml and such digests were analyzed for Zn content.

3. **N content (%) -** N content was estimated in plant sample following standard procedure of A.O.A.C. (1970).
4. **N uptake (mg/plant) -** N uptake was calculated by multiplying the N content in shoot by dry weight.
5. **P content in shoot (%)** – P content was measured following standard procedure of A.O.A.C. (1953)
6. **P uptake (mg)** – P uptake was calculated by multiplying the P content in shoot by dry weight.
7. **Zn content (ppm) in shoot-** Zn content was determined by Atomic Absorption Spectro-photometer, GBC 902 plus. Micronutrients uptake was calculated by multiplying content with dry yield of straw.
8. The N,P and Zn use efficiency were determined by the method suggested by Moll (1982).

Physiological parameters

1. **Chlorophyll content -** chlorophyll content was measured by chlorophyll content meter. Five observations per plant were taken and then their average was taken.
2. **Chlorophyll fluorescence -**Chlorophyll fluorescence was measured by IRGA (Infra-red Gas Analyser). Five observations per plant were taken and then their average was taken.

Root parameters

1. **Root biomass (mg/plant):** Roots from the pots were extracted and air dried, then biomass was weighed on the weighing balance in mg/plant.
2. **Root length:** Roots from the pots were extracted and fully straightened on the filter paper and then root length was measured with the meter scale.

3.3 Statistical analysis

1. Analysis of variance (Randomized block design)

The data for different characters were statistically analysed as described by Panse and Sukhatme (1967).

$$Yij = m + a_i + b_j + e_{ij}$$

Where,

Yij = observation in the i^{th} treatment and j^{th} replication

m = general mean

a_i = i^{th} treatment effect

bj = j^{th} replication effect

e_{ij} = random error associated with the i^{th} treatment and j^{th} replication.

Analysis of variance tables for all the characters under study were constructed as given below:

Source	d.f.	Ms.s.	expected m.s.s.	F
replications	(r-1)	mr_{ii}	$\sigma^2_{eii} + t\sigma^2r_{ii}$	mr_{ii}/me_{ii}
Genotypes	(t-1)	mt_{ii}	$\sigma^2e_{ii} + r\sigma^2g_{ii}$	mt_{ii}/me_{ii}
error	(r-1)(t-1)	me_{ii}	σ^2e_{ii}	

Where,

r = number of replications

t = number of genotypes

mr_{ii} = mean sum of squares due to replications

me_{ii} = mean sum of squares due to genotypes

σ^2g_{ii} = genotypic variance of character x_i

σ^2e_{ii} = error variance of character x_i

Analysis of covariance

Analysis of covariance tables were constructed for all possible combinations taking two characters at a time in the following manner

Source	d.f.	M.s.p.	expected m.s.p.
replications	(r-1)	mr_{ij}	
Genotypes	(t-1)	mt_{ij}	$\sigma e_{ij} + r\sigma g_{ij}$
error	(r-1)(t-1)	me_{ij}	σe_{ij}

Where,

r = number of replications

t = number of genotypes

σg_{ij} = genotypic covariance of character x_i and x_j

σe_{ij} = error covariance of character x_i and x_j

Mr_{ij}, mt_{ij} and me_{ij} are the mean sum of products due to replications, genotypes and error respectively from analysis of covariance between character x_i and character x_j.

The genotypic and phenotypic covariance was calculated as follows:

$$\text{genotypic covariance} = \sigma g_{ij} = \frac{mt_{ij} - me_{ij}}{r}$$

$$\text{phenotypic covariance} = \sigma p_{ij} = \sigma g_{ij} + \sigma e_{ij}$$

3.4 Variability parameters

Genotypic and phenotypic variance

The genotypic and phenotypic variance was calculated as follows:

Genotypic variance of character (x_i) = $\sigma^2 g_{ii} = \dfrac{mt_{ii} - me_{ii}}{r}$

Where

mt_{ii} = mean sum of squares due to treatments

me_{ii} = mean sum of squares due to errors

$\sigma^2 g_{ii}$ = genotypic variance

r = replication

Phenotypic variance of character $x_i = \sigma^2 p_{ii} = \sigma^2 g_{ii} + \sigma^2 e_{ii}$

Where

$\sigma^2 p_{ii}$ = phenotypic variance

$\sigma^2 g_{ii}$ = genotypic variance

$\sigma^2 e_{ii}$ = error variance

Similarly,

Phenotypic coefficient of variance and genotypic coefficient of variance

Phenotypic coefficient of variance and genotypic coefficient of variability were calculated by the method explained by Singh and Chaudhary (1982).

Phenotypic coefficient of variation (P.C.V): $= \dfrac{\sqrt{\sigma^2 p} \times 100}{\overline{X}}$

Genotypic coefficient of variation (G.C.V): $= \dfrac{\sqrt{\sigma^2 g} \times 100}{\overline{X}}$

Heritability and genetic advance

Heritability in broad sense and genetic advance were calculated by method given by Burton and Devane 1953 as given below:

Heritability in broad sense H(bs): $V_g \ / \ V_p$ or $V_g \ / \ V_g + V_e$

Where,

V_g = genotypic component of variance

V_p = phenotypic component of variance and

V_e = environmental component of variance

Genetic advance as percent of mean (G_S) =[(K) (σ_p) (H) × 100]/ mean

Where,

K = selection differential

σ_p = phenotypic standard deviation

H = heritability in broad sense

3.5 Correlation coefficient analysis

Correlation coefficients at phenotypic and genotypic level were calculated using the variances and co-variances according to Al-Jibouri *et al.*, (1958).

Phenotypic correlation r_{ij} (P) = $\dfrac{\sigma^2 p_{ij}}{\sqrt{\sigma^2 p_{ii} \times \sigma^2 p_{jj}}}$

Where,

σ^2_{pij} = Phenotypic co-variance of character x_i and x_j

σ^2_{pii} = Phenotypic variance of character x_i

σ^2_{pjj} = Phenotypic variance of character x_j

Genotypic correlation r_{ij} (G) = $\dfrac{\sigma^2 g_{ij}}{\sqrt{\sigma^2 g_{ii} \times \sigma^2 g_{jj}}}$

σ^2_{gij} = Genotypic co-variance of character x_i and x_j

σ^2_{gii} = Genotypic variance of character x_i

σ^2_{gjj} = Genotypic variance of character x_j

Significance of phenotypic correlations was tested at 5 per cent and 1 per cent levels of significance against the expected value from Fisher’s table at (n-2) degree of freedom.

3.6 Path-Coefficient Analysis

The phenotypic correlation coefficients were used to work out path coefficient analysis. Path coefficients were obtained according to Dewey and Lu (1959). Sets of simultaneous equations in the following form are solved.

$$r_{ny} = P_{ny} + r_{n2}P_{2y} \;\; r_{n3}P_{3y} + \text{-------} + r_{nx}P_{xy}$$

Where, r_{ny} represents correlation coefficient between one character and yield

P_{ny} represents path coefficients between the character and yield

r_{n2}, r_{n3}, ------r_{nx} represents correlation coefficient between that character and each of other yield component in turn.

The following correlation matrices were prepared:

Matrix A	**Matrix B**				
r_{1y}	1	r_{12}	r_{13}	....	r_{1n}
r_{1y}	1	r_{12}	r_{13}	....	r_{1n}
....	....	....	....	....	....
r_{1y}	1	r_{12}	r_{13}	....	r_{1n}

Where,

$r_{12} = r_{21}$ and so on

r_{1y} = correlation coefficient between yield one component character. The technique given by Goulden (1964) was followed for the inversion (B^{-1}) of B matrix.

Pij, the path coefficients were obtained as follows:

$Pij = A \times B^{-1}$

The indirect effects for a particular character through other characters were obtained by multiplication of direct path and particular correlation coefficient between those two characters respectively.

$$\text{Indirect effect} = r_{ij} \times Pij$$

The residual factor i.e. the variation in yield unaccounted for those associations was calculated from the following formula:

$$\text{Residual factors}(X) = 1 - R^2$$

Where,

$R^2 = P_{1y}\, r_{1y} + P_{2y}\, r_{2y} \cdots\cdots\cdots\ P_{ny}\ r_{ny}$

R^2 is the squared multiple correlation coefficient and is the amount of variation in yield that can be accounted for by the effect of yield components on yield.

Table 3.1 Definitions and calculations for NUE and related parameters determined in NUE and Nrate experiments.

Term	Definition	Calculation
Nitrogen Use Efficiency (NUE)	Weight of grain per unit of available nitrogen	NUE= grain weight/ total nitrogen supply or NUpE*NUtE
Nitrogen Uptake Efficiency (NUpE)	How efficiently nitrogen is taken up by the plant from the soil	NUpE= Total N uptake/ total N supply
Nitrogen Utilization Efficiency (NUtE)	How efficiently nitrogen absorbed from the soil is used to make grain	NUtE= grain weight/ N taken up by plant or HI*BPE
Harvest Index (HI)	Weight of harvested grain as a percentage of total plant weight	HI= grain weight/ aboveground biomass
Biomass production efficiency (BPE)	Total plant weight compared to total plant N content at maturity	BPE= aboveground biomass/total N at maturity
Nitrogen harvest index (NHI)	Nitrogen content in the grain compared to total plant N content at maturity	NHI= N in grain/ total N at maturity
Nitrogen uptake after anthesis (NUpAA)	Difference in total N from anthesis to maturity	NUpAA= total N at maturity-total N at anthesis
Nitrogen	How efficiently nitrogen at	NRE= (N in grain-NUpAA)/total N

remobilization efficiency (NRE)	anthesis was remobilized to the grain	at anthesis
Fertilizer use efficiency (FUE)	Fraction of nitrogen applied as fertilizer that was absorbed by the plant	FUE= (N uptake with fertilizer-N uptake without fertilizer)/N applied as fertilizer
Agronomic efficiency	Increase in yield per unit of applied nutrient	AgEf= (yield with fertilizer-yield without fertilizer)/ fertilizer rate
Partial factor productivity	Yield produced per unit of applied nutrient	PFP= yield/fertilizer rate
Partial nutrient balance	The fraction of nutrient that is actually used by the plant	PNB= nutrient removed/nutrient applied

CHAPTER - IV

EXPERIMENTAL RESULTS

This study aimed to evaluate genetic variability for grain yield, its components and morpho-physiological traits under low and optimum input conditions in two years i.e. 2012-13 and 2013-14. The experimental results pertaining to the study undertaken are given below under the following heads.

4.1 Analysis of variance

Mean squares due to genotypes were significant for all the characters (Table1). Significant differences due to genotypes for various traits indicated that there was considerable variation among the genotypes. Genotype × fertilizer (G × F) interaction was significant for majority of the characters Except in Plant height, Chlorophyll content and Number of tillers per plant. This indicated that genotypes differed in their response from low to optimum input conditions for the characters under study (Table 1).

4.2 Mean performance of genotypes for various traits under low and optimum input conditions

4.2.1 Plant Height

The genotype DBW 17 (68.51 cm) was found most dwarf among all the forty genotypes followed by WH 711 (68.88 cm),WH 416 (74.22 cm), PBW 503 (75.51 cm), PBW 590 (75.73 cm), HD 2687 (76.01 cm), WH 1138 (77.07 cm), WH 1100 (78.69 cm) and WH 542 (80.09 cm) under low input conditions in year 2012-13, while in year 2013-14, DBW 17 (68.67 cm) was found most dwarf among all the *Triticum aestivum* L.. *em.* Thell. genotypes followed by WH 711 (70.3 cm), HD 2687 (71.53 cm), WH 416 (73.83 cm), WH 1138 (74.7 cm), PBW 503 (75.73 cm), PBW 590 (76 cm), WH 1100 (79.27 cm), DPW 621-50 (80.33 cm), HD 2851 (80.77 cm), WH 1123 (81.07 cm), WH 1098 (81.37 cm) and WH 542 (81.67 cm) respectively under low input conditions (Table 2).

Under Optimum input conditions the genotype DBW 17 (84.52 cm) was found most dwarf followed by PBW 503 (85.67 cm), WH 711 (88.91 cm), WH416 (89.40 cm) and PBW 590 (90.57 cm) in year 2012-13, while in 2013-14 under optimum input conditions genotype HD 2687 (82.30 cm) was found dwarfest among all the genotypes followed by WH 1138 (83.13 cm) and WH 1123 (83.67 cm). Highest response over low input conditions in 2012-13 was observed in WH 711 (29.09 %) followed by C 518 (29.06 %), HD 2687 (26.82%) and WH 1138 (26.01 %), while lowest response over low input conditions was observed in genotype WH 1080 (2.18 %).

Table 1: Mean squares for various characters of wheat genotypes evaluated under Low and optimum input conditions

Sr. No.	Character	Replication †(2)		Genotypes †(39)		Fertilizer †(1)		G x F †(39)		Error †(158)	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
1	**Plant height**	953.84**	136.95**	535.62**	364.67**	9449.07**	99.70**	37.114	253.70	46.87**	84.18**
2	**Biomass per plant**	0.04**	0.37**	12.00**	10.66**	158.77**	125.28**	1.73**	2.05**	0.16**	0.14**
3	**Harvest index**	3.54**	6.18**	29.42**	96.32**	2024.96**	1162.10**	15.64**	34.89**	10.37**	10.66**
4	**Chl. Fluoresence**	0.0005**	0.003**	0.002**	0.003*	1.26**	0.95**	0.001**	0.006**	0.001**	0.001**
5	**Chl. content**	2.91**	77.60**	103.45**	71.18**	15886.22**	2980.31**	50.61**	18.41	5.35**	20.91**
6	**Grain yield**	0.10**	0.001**	2.66**	2.82**	92.87**	62.68**	0.46**	0.55**	0.13**	0.16**
7	**1000-grain weight**	0.24**	1.76**	33.97**	24.99**	1830.43**	2040.27**	9.68**	9.42**	2.69**	2.75**
8	**No. of tillers per plant**	0.21**	0.20**	1.74**	1.38**	35.33**	34.76**	0.08	0.07	0.14**	0.16**
9	**Spikelets per spike**	1.70**	0.33**	17.22**	12.06**	843.75**	1411.35**	2.59	4.78**	2.11**	2.43**
10	**Grains per spike**	0.75**	0.76**	44.48**	40.90**	2666.67**	32.34**	5.97**	7.70**	2.97**	2.41**
11	**Days to heading**	1.55**	0.54**	1.19**	24.03**	116.20**	6.01	1.13**	17.82**	0.70**	1.79**
12	**Days to Maturity**	7.32**	30.68**	29.18**	27.23**	513.34**	315.10**	34.77**	31.69**	2.70**	5.43**
13	**N content**	0.003**	0.009*	0.107**	0.105**	10.70**	6.57**	0.02**	0.02**	0.01**	0.01**
14	**P content**	0.01**	0.004**	3.57**	3.15**	77.04**	82.91**	0.18**	0.20**	0.04**	0.04**
15	**Zn content**	0.33**	14.52**	311.37**	273.88**	7755.24**	7915.79**	21.49**	25.64**	5.35**	5.74**
16	**Root biomass**	0.02**	0.038**	0.52**	0.54**	83.05**	76.90**	0.12**	0.14**	0.04**	0.04**
17	**Root Length**	2.91**	3.10**	41.03**	42.79**	7800.21**	5947.34**	6.04**	6.67**	2.25**	2.57**
18	**NUE**	5.41**	2.47**	348.48**	325.79**	46879.40**	55782.19*	103.31**	73.92**	24.75**	26.55**
19	**PUE**	31.59**	6.61**	1605.43**	1544.31**	94427.16**	122258.36**	379.53**	284.90**	104.11**	114.58**
20	**ZnUE**	126.35**	26.45**	6421.73**	6177.25**	377708.63**	489033.43**	1518.12**	1139.62**	416.45**	458.33**

*, **: significant at 5% and 1% level of significance respectively. †: figure in parenthesis denotes degrees of freedom

Table 2: **Mean performance of genotypes for Plant Height under low and optimum input conditions**

Plant height (cm)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	80.09*	81.67*	92.40*	94.87	15.37	16.16
WH 1080	92.67	88.73	94.69	103.17	2.18	16.27
WH 1098	83.66	81.37*	94.18	97.97	12.58	20.40
WH 1021	83.74	88.63	96.61	101.67	15.36	14.70
WH 416	74.22*	73.83*	89.40*	92.63*	20.45	25.46
DBW 17	68.51*	68.67*	84.52*	86.43*	23.37	25.87
WH 711	68.88*	70.30*	88.91*	90.03*	29.09	28.07
WH 1025	85.92	81.90	97.78	97.23	13.80	18.72
PBW 590	75.72*	76.00*	90.57*	90.30*	19.60	18.82
RAJ 3765	84.36	82.67	94.29	97.60	11.78	18.06
WH 1081	89.14	85.67	101.39	86.17*	13.74	0.58
C 306	117.33	108.00	123.47	119.83	5.23	10.96
PBW 373	85.02	84.00	94.80	99.40	11.50	18.33
DPW 621-50	88.67	80.33*	97.20	101.33	9.62	26.14
WH 1105	84.60	84.17	97.71	98.33	15.50	16.83
WH 1139	88.99	86.67	99.20	110.00	11.47	26.92
PBW 644	89.89	93.00	98.43	104.63	9.51	12.51
HD 2967	83.70	85.07	96.28	100.97	15.03	18.69
HD 2851	85.38	80.77*	92.82*	90.63*	8.72	12.22
WH 147	83.39	82.90	90.71*	99.20	8.78	19.66
WH 1127	90.03	86.67	104.16	104.67	15.69	20.77
WH 1063	88.82	87.33	104.00	94.93	17.09	8.70
WH 1123	84.99	81.07*	98.56	83.67*	15.96	3.21
WH 1100	78.69*	79.27*	96.56	93.73*	22.71	18.25
WH 1140	96.09	92.90	107.14	108.53	11.51	16.83
C 518	90.76	90.00	117.13	104.53	29.06	16.15
WH 1160	86.29	85.00	94.18	94.07	9.14	10.67
SONALIKA	97.01	96.13	105.00	97.00	8.24	0.90
LOK 54	89.37	87.67	107.16	96.00	19.91	9.51
PBW 475	121.41	98.73	131.78	125.13	8.54	26.74
PBW 503	75.51*	75.73*	85.67*	95.87	13.45	26.58
PBW 175	90.26	91.27	112.56	96.57	24.71	5.81
PBW 527	83.14	83.50	92.78*	94.43	11.59	13.09
WH 1142	82.27	77.13*	99.87	95.47	21.39	23.77
WH 1138	77.07	74.70*	97.11	83.13*	26.01	11.29
HD 2687	76.01	71.53*	96.40	82.30*	26.82	15.05
PBW 533	85.62	82.47	97.38	97.17	13.73	17.83
WH 1061	94.76	84.10	100.46	92.63*	6.02*	10.15
HD 2285	85.67	82.40	97.71	98.57	14.06	19.62
WH 730	94.33	90.00	103.00	97.27	9.19	8.07
C.D	11.013	12.859	8.549	11.442		
S.E(d)	5.521	6.446	4.286	5.736		
C.V	7.813	9.394	5.297	7.209		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 3: Mean performance of genotypes for Biomass per plant under low and optimum input conditions

Biomass per plant (g)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	11.60*	11.60*	13.40*	14.37*	15.52	23.85
WH 1080	10.13	8.67	10.53	12.30	3.95	41.92
WH 1098	8.93	10.60	11.60	10.60	29.85	0.00
WH 1021	9.53	11.13*	11.53	11.60	20.98	4.19
WH 416	10.80	10.80	14.07*	12.67*	30.25	17.28
DBW 17	11.80*	11.47*	13.20*	13.93*	11.86	21.51
WH 711	11.87*	12.40*	12.87*	14.53*	8.43	17.20
WH 1025	9.60	9.47	9.33	10.73	-2.78	13.38
PBW 590	11.47*	11.53*	13.47*	12.53	17.44	8.67
RAJ 3765	9.73	8.67	8.80	10.60	-9.59	22.31
WH 1081	9.67	10.87	11.53	10.33	19.31	-4.91
C 306	8.87	9.73	9.13	10.43	3.01	7.19
PBW 373	9.47	9.00	11.27	9.80	19.01	8.89
DPW 621-50	11.80*	11.27*	14.00*	14.80*	18.64	31.36
WH 1105	12.33*	12.93*	14.40*	14.87*	16.76	14.95
WH 1139	10.67	10.73	12.67	12.60/*	18.75	17.39
PBW 644	11.60*	10.67	13.87*	12.60*	19.54	18.13
HD 2967	12.07*	10.93	14.07*	14.33*	16.57	31.10
HD 2851	9.73	8.40	11.53	11.13	18.49	32.54
WH 147	10.53	10.60	13.07*	13.20*	24.05	24.53
WH 1127	9.33	9.00	11.47	11.07	22.86	22.96
WH 1063	9.60	9.73	11.33	11.00	18.06	13.01
WH 1123	8.53	10.20	11.07	11.40	29.69	11.76
WH 1100	8.47	9.33	11.00	11.40	29.92	22.14
WH 1140	9.53	9.33	8.60	10.67	-9.79	14.29
C 518	9.27	9.27	9.67	9.33	4.32	0.72
WH 1160	11.60*	11.40*	13.53*	11.87	16.67	4.09
SONALIKA	8.87	10.67	13.13*	9.60	48.12	-10.00
LOK 54	10.73	12.07*	11.80	12.20	9.94	1.10
PBW 475	11.33*	12.70*	14.00*	12.80*	23.53	0.79
PBW 503	11.47*	10.40	13.47*	14.20*	17.44	36.54
PBW 175	8.93	8.87	9.07	10.67	1.49	20.30
PBW 527	11.93*	11.47*	13.20*	11.93	10.61	4.07
WH 1142	8.80	8.67	9.00	10.13	2.27	16.92
WH 1138	10.93*	10.87	13.53*	12.60*	23.78	15.95
HD 2687	11.07*	11.80*	13.47*	12.67*	21.69	7.34
PBW 533	12.27*	11.27*	13.33*	12.40	8.70	10.06
WH 1061	12.33*	11.13*	13.73*	13.33*	11.35	19.76
HD 2285	9.07	8.53	10.73	8.67	18.38	1.56
WH 730	9.40	9.20	11.27	9.27	19.86	0.72
C.D	0.503	0.539	0.749	0.683		
S.E(d)	0.252	0.270	0.376	0.342		
C.V	2.972	3.173	3.829	3.529		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

In year 2013-14, highest response over low input conditions was found in genotype WH 711 (28.07 %) followed by WH 1139 (26.92 %) and PBW 475 followed by WH 1139 (26.92 %) and PBW 475 (26.74 %), while genotype WH 1081 (0.58 %) was found to be almost negligibly responding to low input conditions in year 2013-14 (Table 2).

4.2.2 Biomass per Plant (g)

The genotype WH 1105 (12.33 g) was found with highest biomass per plant among all the forty genotypes followed by WH 1061 (12.33 g) PBW 533 (12.27 g), HD 2967 (12.07 g), PBW 527 (11.93 g), WH711 (11.87 g), DBW 17 (11.8 g), DPW 621-50 (11.8 g), WH 542 (11.60 g), PBW 644 (11.60 g), WH 1160 (11.60 g), PBW 590 (11.47 g), PBW 503 (11.47 g), PBW 475 (11.33 g), HD 2687 (11.07 g), WH 1138 (10.93 g) under low input conditions in year 2012-13, while in year 2013-14, WH 1105 (12.93 g) was found highest among means of various genotypes for the trait biomass per plant followed by PBW 475 (12.7 g), WH 711 (12.4 g), LOK 54 (12.07 g), HD 2687 (11.80 g), WH 542 (11.60 g), PBW 590 (11.53 g), DBW 17 (11.47 g), PBW 527 (11.47 g), WH 1160 (11.40 g), DPW 621-50 (11.27 g), PBW 533 (11.27 g), WH 1021 (11.13 g) and WH 1061 (11.13 g) respectively under low input conditions (Table 3).

Under Optimum input conditions in year 2012-13 the genotype WH 1105 (14.4 g) was found possessing highest biomass per plant followed by WH 416 (14.07 g), HD 2967 (14.07 g), DPW 621-50 (14.00 g), PBW 475 (14.00 g), PBW 644 (13.87 g), WH 1061(13.73 g), WH 1160 (13.53 g), WH 1138 (13.53 g), PBW 590 (13.47 g), PBW 503 (13.47 g), HD 2687 (13.47 g), WH 542 (13.41 g), PBW 533 (13.33 g), DBW 17 (13.20 g), PBW 527 (13.20 g), Sonalika (13.13 g), WH 147 (13.07 g) and WH 711 (12.87 g) respectively, while in 2013-14 under optimum input conditions genotype WH 1105 (14.87 g) was having highest biomass per plant among all the genotypes followed by DPW 621-50 (14.80 g), WH 711 (14.53 g), WH 542 (14.37g), HD 2967 (14.33 g), PBW 503 (14.20 g), DBW 17 (13.93 g), WH 1061 (13.33 g), WH 147 (13.20 g), PBW 475 (12.80 g), WH 416 (12.67 g),HD 2687 (12.67 g), WH 1139 (12.60 g), PBW 644 (12.60 g) and WH 1138 (12.60 g) respectively (Table 3).

Highest response over low input conditions in 2012-13 was observed in Sonalika (48.12 %) followed by WH 416 (30.25 %) and WH 1100 (29.92 %), while lowest response over low input conditions was observed in genotype PBW 175 (1.49 %). Negative response over low input conditions was also observed in genotypes WH 1025 (-2.78 %) followed by RAJ 3765 (-9.59 %) and WH 1140 (-9.79 %). In year 2013-14, highest response over low input conditions was found in genotype WH 1080 (41.92 %) followed by PBW 503 (36.54 %), HD 2851 (32.54 %) and DPW 621-50 (31.36 %) (Table 3).

Table 4: Mean performance of genotypes for Harvest index under low and optimum input conditions

Harvest Index						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	39.61	33.27	42.09	35.48	6.27	6.64
WH 1080	37.01	28.59	42.23	29.28	14.12	2.41
WH 1098	32.78	33.37	40.14	33.42	22.46	0.15
WH 1021	28.45	31.17	38.21	33.73	34.30	8.20
WH 416	37.23	31.18	35.15	35.09	-5.60	12.53
DBW 17	37.03	35.20	39.94	37.39	7.84	6.22
WH 711	34.65	33.35	39.25	35.17	13.29	5.44
WH 1025	37.39	31.94	40.80	33.74	9.10	5.65
PBW 590	37.20	33.35	43.07	34.51	15.78	3.48
RAJ 3765	34.30	36.45	42.93	39.32	25.14	7.86
WH 1081	29.34	31.32	41.87	38.14	42.70	21.80
C 306	35.11	32.16	40.54	41.24	15.45	28.23
PBW 373	27.18	32.13	40.14	43.57	47.66	35.62
DPW 621-50	31.27	37.08	43.09	42.72	37.80	15.21
WH 1105	38.70	33.24	42.24	45.76*	9.14	37.66
WH 1139	37.46	34.25	41.06	33.31	9.62	-2.74
PBW 644	37.03	43.39*	39.89	42.88	7.72	-1.19
HD 2967	37.24	43.99*	40.02	45.28*	7.49	2.93
HD 2851	36.48	33.12	38.34	32.90	5.09	-0.65
WH 147	37.88	38.94	40.67	41.52	7.36	6.64
WH 1127	33.75	37.13	40.52	41.90	20.08	12.87
WH 1063	30.26	34.31	36.82	35.20	21.67	2.58
WH 1123	31.93	37.16	38.16	40.68	19.49	9.47
WH 1100	30.14	37.03	37.33	45.85*	23.85	23.83
WH 1140	35.09	39.35	38.39	52.42*	9.38	33.22
C 518	29.62	35.51	38.98	44.86	31.59	26.32
WH 1160	33.46	33.15	40.15	53.25*	20.02	60.64
SONALIKA	30.82	42.32*	38.38	51.94*	24.53	22.73
LOK 54	36.16	42.41*	43.78	42.39	21.09	-0.04
PBW 475	36.52	37.31	40.85	40.14	11.87	7.59
PBW 503	34.92	38.26	42.97	37.86	23.06	-1.04
PBW 175	37.15	37.29	42.20	38.48	13.60	3.21
PBW 527	33.11	38.23	41.09	42.88	24.12	12.17
WH 1142	33.10	37.05	39.55	37.31	19.46	0.71
WH 1138	37.29	36.19	41.16	38.65	10.39	6.79
HD 2687	31.05	36.39	42.22	48.47*	35.98	33.19
PBW 533	40.73*	33.61	43.79	38.45	7.51	14.40
WH 1061	37.41	36.18	39.84	35.98	6.49	-0.55
HD 2285	39.06	34.27	41.86	44.21	7.17	29.02
WH 730	33.51	37.38	41.08	38.64	22.61	3.37
C.D	5.9	5.69	NS	4.952		
S.E(d)	2.958	2.853	2.292	2.483		
C.V	10.437	9.787	6.928	7.583		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

4.2.3 Harvest index

For harvest index per plant, under low input conditions genotype PBW 533 (40.73) performed significantly highest among all the genotypes followed by WH 542 (39.61) and HD 2285 (39.06) in 2012-13, while genotype HD 2967 (43.99) was having highest harvest index followed by PBW 644 (43.39), LoK 54 (42.41) and Sonalika (42.32) in 2013-14. Under optimum input conditions genotype WH 1160 (53.25) was possessing highest harvest index followed by WH 1140 (52.42), Sonalika (51.94), HD 2687 (48.47), WH 1100 (45.85), WH 1105 (45.76) and HD 2967 (45.28) respectively in 2013-14. As per percent of increase over low input conditions PBW 373 (47.66) was found highest in response in 2012-13 followed by WH 1081 (42.70 %), DPW 621-50 (37.80 %), HD 2687 (35.98 %), WH 1021(34.30 %) and C 518 (31.59 %), while HD 2851 (5.09 %) was found lowest in response to low input conditions. Genotype WH 416 (-5.67 %) was negatively responding over low input conditions in 2012-13 (Table 4). In 2013-14, percentage of increase over low input conditions was found highest in WH 1160 (60.64 %) followed by WH 1105 (37.66 %), PBW 373 (35.62 %), WH 1140 (33.22 %) and HD 2687 (33.19%), while lowest response over low input conditions was observed in WH 1098 (0.15 %) (Table 4).

4.2.4 Chlorophyll fluorescence

For chlorophyll fluorescence genotype PBW 475 (0.79) was significantly highest among all the genotypes followed by WH 1139 (0.78), HD 2967 (0.78) and WH 1061 (0.78) under low input conditions in 2013-14 (Table 5), While, under optimum input conditions WH 1100 (0.86) was found highest followed by PBW 503 (0.86), PBW 527 (0.86), HD 2687 (0.86), PBW 533 (0.86), WH 1061 (0.86) and WH 730 (0.86) in 2012-13. In 2013-14, PBW 533 (0.94) was found highest among all the genotypes followed by HD 2851 (0.93), WH 1081 (0.91) and WH 1140 (0.91) under optimum input conditions. As per response of genotypes over low input conditions, genotype WH 542 (35.81 %) responded better followed by HD 2687 (31.04 %), C518 (29.38 %), WH 1142 (28.30 %) and LOK 54 (26.91 %) in 2012-13, While WH 1081 (0.91 %) responded lowest. However, in 2013-14, genotypes C306 (48.96 %), WH 1080(32.34 %), WH 1021 (31.28 %) and WH 542 (27.80%) responded better. Lowest response was found in PBW 475 (1.52 %).

4.2.5 Chlorophyll content

In 2012-13 for chlorophyll content under low input conditions, genotype WH 1140 (41.33) was having highest chlorophyll content among all the genotypes followed by WH 1138 (40.47), WH 542 (39.73), PBW 590 (39.67), WH 1021 (38.97), WH 1105(38.93), WH 1063 (38.90), HD 2687 (38.23), WH 1139 (37.63), PBW 503 (37.60) and HD 2967 (37.00), while genotype C 518 (60.40) was found highest in chlorophyll content among all the genotypes under optimum input conditions followed by WH 1100 (58.77), WH 1080 (57.93),

Table 5: Mean performance of genotypes for Chlorophyll fluorescence under low and optimum input conditions

Chlorophyll fluorescence						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	0.66	0.68	0.84	0.87	35.81	27.80
WH 1080	0.67	0.67	0.82	0.88	17.41	32.34
WH 1098	0.72	0.67	0.80	0.86	10.45	27.54
WH 1021	0.68	0.68	0.79	0.89	19.84	31.28
WH 416	0.70	0.77	0.81	0.83	19.76	8.02
DBW 17	0.68	0.77	0.81	0.88	13.82	14.61
WH 711	0.68	0.71	0.80	0.88	15.37	22.87
WH 1025	0.66	0.74	0.80	0.86	13.67	15.00
PBW 590	0.71	0.70	0.81	0.85	12.08	20.28
RAJ 3765	0.68	0.75	0.82	0.87	17.22	15.20
WH 1081	0.66	0.71	0.77	0.91*	10.25	26.73
C 306	0.67	0.64	0.79	0.95	21.90	48.96
PBW 373	0.71	0.76	0.82	0.88	16.45	15.88
DPW 621-50	0.66	0.76	0.79	0.86	14.08	13.37
WH 1105	0.70	0.72	0.83	0.87	15.39	20.24
WH 1139	0.70	0.78*	0.83	0.88	17.71	13.77
PBW 644	0.72	0.72	0.84	0.85	16.90	18.63
HD 2967	0.70	0.78*	0.81	0.86	20.40	11.26
HD 2851	0.69	0.75	0.84	0.93*	22.38	25.23
WH 147	0.64	0.72	0.83	0.89	15.69	24.17
WH 1127	0.70	0.75	0.83	0.88	19.32	17.94
WH 1063	0.68	0.75	0.83	0.90	15.97	20.59
WH 1123	0.70	0.72	0.81	0.83	16.21	15.06
WH 1100	0.69	0.76	0.86*	0.88	22.72	15.71
WH 1140	0.66	0.74	0.83	0.91*	22.17	22.00
C 518	0.67	0.77	0.82	0.81	29.38	6.21
WH 1160	0.67	0.76	0.83	0.89	22.52	16.53
SONALIKA	0.70	0.73	0.85	0.75	25.63	1.82
LOK 54	0.69	0.76	0.83	0.76	26.91	-0.22
PBW 475	0.66	0.79*	0.82	0.80	21.04	1.52
PBW 503	0.69	0.76	0.86*	0.84	25.95	9.77
PBW 175	0.68	0.72	0.84	0.88	26.77	22.40
PBW 527	0.71	0.77	0.86*	0.86	15.21	12.22
WH 1142	0.69	0.76	0.85	0.86	28.30	13.00
WH 1138	0.64	0.73	0.85	0.77	26.91	5.17
HD 2687	0.66	0.77	0.86*	0.84	31.04	9.34
PBW 533	0.67	0.74	0.86*	0.94*	26.66	26.83
WH 1061	0.65	0.78*	0.86*	0.85	23.16	10.11
HD 2285	0.70	0.74	0.84	0.86	18.53	16.76
WH 730	0.70	0.74	0.86*	0.88	25.26	18.03
C.D	NS	0.045	0.034	0.044		
S.E(d)	0.024	0.023	0.017	0.022		
C.V	4.351	3.773	2.546	3.11		

*, **: significant at 5% and 1% level of significance respectively. C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

WH 1021 (57.73), WH 542 (57.20), HD 2851 (56.30), WH 1139 (56.23), WH 711 (55.53), HD 2967 (55.30), PBW 503 (55.27) and WH 1061 (54.60). C 306 (89.43 %) responded best over low input conditions followed by DPW 621-50 (81.62 %), RAJ 3765 (81.06 %), WH 1098 (77.25 %) and WH 1080 (76.45 %) in 2012-13. Lowest response was found in WH 1127 (0.39 %) (Table 6). In 2013-14, WH 1140 (49.17 %) was found highly responding followed by DPW 621-50 (46.27 %), C 306 (45.69 %), WH 147 (41.01 %), HD 2851 (39.28 %) and LOK 54 (36.36 %). Lowest response was found in WH 1123 (2.40 %) (Table 6).

4.2.6 Grain yield per plant (g)

The genotype PBW 533 (5.00 g) was found with highest grain yield per plant among all the forty genotypes followed by WH 1105 (4.77 g), WH 1061 (4.61 g), WH 542 (4.51 g), HD 2967 (4.49 g), DBW 17 (4.37 g) and PBW 644 (4.30 g) under low input conditions in year 2012-13, while in year 2013-14, LOK 54 (5.12 g) was found highest among means of various genotypes for the trait grain yield per plant followed by HD 2967 (4.81 g) PBW 475 (4.73 g), PBW 644 (4.63 g), Sonalika (4.53 g) and PBW 527 (4.39 g) respectively under low input conditions (Table 7).

Under Optimum input conditions in year 2012-13the genotype WH 1105 (6.09 g) was found possessing highest grain yield per plant followed by DPW 621-50 (6.03 g), PBW 590 (5.80 g), PBW 503 (5.78 g), PBW 533 (5.76 g), PBW 475 (5.72 g), HD 2687 (5.67 g), WH 542 (5.64 g), HD 2967 (5.63 g), WH 1138 (5.57 g), PBW 644 (5.53 g), WH 1061 (5.48 g), WH 1160 (5.44 g) and PBW 527 (5.40 g) respectively, while in 2013-14 under optimum input conditions genotype WH 1105 (6.81 g) was having highest grain yield per plant among all the genotypes followed by HD 2967 (6.48 g), DPW 621-50 (6.33 g), HD 2687 (6.13 g), WH 1140 (5.59 g) and PBW 644 (5.40 g) respectively (Table 7).

Highest response over low input conditions in 2012-13 was observed in Sonalika (84.85 %) followed by PBW 373 (76.18 %), WH 1081 (70.21 %) and HD 2687 (65.24 %) while lowest response over low input conditions was observed in genotype WH 1025 (6.02 %). Negative response over low input conditions was also observed in genotype WH 1140 (-1.46 %). In year 2013-14, highest response over low input conditions was found in genotype WH 1160 (67.36 %) followed by WH 1105 (58.40 %), WH 1140 (52.29 %) and DPW 621-50 (51.34 %), however, WH 1098 (0.27 %) was found lowest responding genotype (Table 7).

4.2.7 1000-grain weight (g)

In 2012-13 for 1000-grain weight under low input conditions, genotype WH 1140 (41.80 g) was having highest 1000-grain weight among all the genotypes followed by Sonalika (41.30 g), WH 1105 (40.80 g), PBW 503 (40.30 g), WH 711 (40.00 g), C 518 (39.93 g), WH 730 (39.50 g), HD 2687 (39.43 g), WH 1160 (39.27 g), C 306 (39.20 g), HD 2967 (39.13 g), RAJ 3765 (38.27 g), PBW 373 (38.27 g) and WH 416 (38.20 g) respectively, while genotype Sonalika (41.07 g) was found highest in 1000-grain weight among all the genotypes under low input conditions followed by HD 2687 (40.30 g), PBW 503 (40.10 g), WH 1105

Table 6: Mean performance of genotypes for Chlorophyll content under low and optimum input conditions

Chlorophyll content						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	39.73*	37.60	57.20*	39.67	43.96	5.50
WH 1080	32.83	37.80	57.93*	43.70	76.45	15.61
WH 1098	27.83	30.10	49.33	36.00	77.25	19.60
WH 1021	38.97*	37.73	57.73*	46.07	48.16	22.08
WH 416	27.27	27.07	45.03	36.37	65.16	34.36
DBW 17	32.93	31.47	51.40	41.37	56.07	31.46
WH 711	35.00	32.77	55.53*	43.37	58.67	32.35
WH 1025	34.13	31.57	49.83	36.57	46.00	15.84
PBW 590	39.67*	35.90	44.93	40.80	13.28	13.65
RAJ 3765	22.70	26.60	41.10	29.10	81.06	9.40
WH 1081	35.27	35.27	46.77	41.40	32.61	17.39
C 306	27.43	27.43	51.97	39.97	89.43	45.69
PBW 373	36.03	32.70	52.27	40.27	45.05	23.14
DPW 621-50	26.30	28.60	47.77	41.83	81.62	46.27
WH 1105	38.93*	38.93	52.23	43.30	34.16	11.22
WH 1139	37.63	34.80	56.23*	44.23	49.42	27.11
PBW 644	31.50	34.83	50.33	43.47	59.79	24.78
HD 2967	37.00	35.00	55.30*	43.30	49.46	23.71
HD 2851	34.90	31.57	56.30*	43.97	61.32	39.28
WH 147	31.53	25.77	50.07	36.33	58.77	41.01
WH 1127	34.43	29.23	34.57	35.93	0.39	22.92
WH 1063	38.90*	35.57	46.97	38.30	20.74	7.69
WH 1123	36.13	34.73	44.23	35.57	22.42	2.40
WH 1100	36.13	36.13	58.77*	43.43	62.64	20.20
WH 1140	41.33*	30.10	53.57	44.90	29.60	49.17
C 518	34.83	36.87	60.40*	46.07	73.40	24.95
WH 1160	32.97	32.53	53.23	38.57	61.48	18.55
SONALIKA	31.40	31.40	46.17	34.17	47.03	8.81
LOK 54	33.27	30.43	44.13	41.50	32.67	36.36
PBW 475	30.97	27.23	37.97	29.13	22.60	6.98
PBW 503	37.60	37.60	55.27	43.27	46.99	15.07
PBW 175	30.30	32.97	49.83	40.03	64.47	21.44
PBW 527	35.37	32.03	52.90	40.30	49.58	25.81
WH 1142	32.90	33.50	48.17	36.17	46.40	7.96
WH 1138	40.47*	34.87	49.17	40.50	21.50	16.16
HD 2687	38.23*	34.90	52.03	41.50	36.09	18.91
PBW 533	27.30	26.83	47.63	35.73	74.48	33.17
WH 1061	35.53	31.97	54.60*	42.60	53.66	33.26
HD 2285	31.93	32.77	52.53	37.20	64.51	13.53
WH 730	35.63	32.27	42.70	33.40	19.83	3.51
C.D	3.883	7.868	3.655	7.828		
S.E(d)	1.947	3.945	1.832	3.925		
C.V	6.996	14.594	5.852	12.276		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 7: Mean performance of genotypes for Grain yield per plant under low and optimum input conditions

Grain yield per plant (g)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	4.59*	3.86	5.64*	5.10	22.84	32.08
WH 1080	3.75	2.48	4.44	3.60	18.45	45.25
WH 1098	2.93	3.53	4.66	3.54	58.95	0.27
WH 1021	2.71	3.49	4.40	3.92	62.82	12.12
WH 416	4.02	3.37	4.94	4.45	22.95	32.10
DBW 17	4.37*	4.03	5.27	5.21	20.51	29.14
WH 711	4.11	4.13	5.05	5.10	22.87	23.52
WH 1025	3.59	3.03	3.81	3.62	6.02	19.67
PBW 590	4.27	3.85	5.80*	4.33	35.83	12.38
RAJ 3765	3.34	3.15	3.77	4.16	12.99	32.13
WH 1081	2.84	3.40	4.83	3.94	70.21	15.90
C 306	3.11	3.14	3.71	4.30	19.24	37.09
PBW 373	2.57	2.89	4.52	4.27	76.18	47.61
DPW 621-50	3.69	4.18	6.03*	6.33*	63.53	51.34
WH 1105	4.77*	4.30	6.09*	6.81*	27.50	58.40
WH 1139	4.00	3.68	5.20	4.20	30.14	14.32
PBW 644	4.30*	4.63*	5.53*	5.40*	28.46	16.77
HD 2967	4.49*	4.81*	5.63*	6.48*	25.43	34.86
HD 2851	3.55	2.78	4.42	3.67	24.64	32.22
WH 147	3.99	4.13	5.32	5.48	33.30	32.73
WH 1127	3.15	3.34	4.65	4.65	47.40	39.16
WH 1063	2.90	3.35	4.17	3.86	43.74	15.45
WH 1123	2.72	3.79	4.22	4.65	55.09	22.85
WH 1100	2.55	3.46	4.10	5.23	60.65	51.07
WH 1140	3.34	3.67	3.29	5.59*	-1.46	52.29
C 518	2.75	3.29	3.77	4.20	37.35	27.47
WH 1160	3.89	3.78	5.44*	6.32	39.89	67.36
SONALIKA	2.73	4.53*	5.04	4.99	84.85	10.20
LOK 54	3.87	5.12*	5.17	5.17	33.54	0.92
PBW 475	4.14	4.73*	5.72*	5.14	38.14	8.65
PBW 503	4.00	3.98	5.78*	5.38	44.46	35.11
PBW 175	3.32	3.31	3.81	4.11	14.71	24.26
PBW 527	3.95	4.39*	5.42*	5.11	37.35	16.40
WH 1142	2.92	3.21	3.56	3.78	21.99	17.81
WH 1138	4.07	3.93	5.57*	4.88	36.70	24.06
HD 2687	3.43	4.29	5.67*	6.13*	65.24	42.88
PBW 533	5.00*	3.79	5.76*	4.77	15.29	25.81
WH 1061	4.61*	4.04	5.48*	4.80	18.77	18.67
HD 2285	3.53	2.92	4.50	3.85	27.28	31.81
WH 730	3.16	3.44	4.63	3.57	46.73	3.77
C.D	0.659	0.662	0.517	0.665		
S.E(d)	0.33	0.332	0.259	0.333		
C.V	11.164	10.897	6.523	8.591		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 8: Mean performance of genotypes for 1000 grain weight under low and optimum input conditions

1000 grain weight (g)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	37.10	37.67	44.37	43.57	19.59	15.66
WH 1080	37.27	34.40	39.23	40.83	5.28	18.70
WH 1098	32.00	34.07	35.70	36.97	11.56	8.49
WH 1021	36.97	38.73	39.80	39.35	7.66	1.58
WH 416	38.20*	36.27	42.87	43.73	12.22	20.59
DBW 17	33.70	35.37	43.43	42.73	28.88	20.83
WH 711	40.00*	38.87	41.47	43.00	3.67	10.63
WH 1025	38.77	37.47	40.17	37.73	3.61	0.71
PBW 590	36.47	38.60	39.87	41.17	9.32	6.65
RAJ 3765	38.27*	37.27	43.97	43.30	14.90	16.19
WH 1081	37.37	36.90	44.38	44.23	18.77	19.87
C 306	39.20*	38.77	41.70	42.80	6.38	10.40
PBW 373	38.27*	37.83	42.20	45.93*	10.28	21.41
DPW 621-50	36.00	36.67	44.57	43.93	23.80	19.82
WH 1105	40.80*	39.67*	42.37	44.73	3.84	12.77
WH 1139	31.73	31.83	38.53	40.93	21.43	28.59
PBW 644	32.40	34.20	39.03	42.30	20.47	23.68
HD 2967	39.13*	38.73	45.77*	44.93	16.95	16.01
HD 2851	34.20	33.57	43.23	41.03	26.41	22.24
WH 147	38.00*	36.33	42.47	42.47	11.75	16.88
WH 1127	32.83	34.50	42.83	42.07	30.46	21.93
WH 1063	36.60	36.40	42.27	40.43	15.48	11.08
WH 1123	32.73	32.77	37.40	39.13	14.26	19.43
WH 1100	37.67	37.23	42.83	41.47	13.72	11.37
WH 1140	41.80*	40.43	46.43*	46.13*	11.08	14.10
C 518	39.93*	39.50*	44.10	42.03	10.43	6.41
WH 1160	39.27*	37.80	47.17*	45.73*	20.12	20.99
SONALIKA	41.30*	41.07*	49.03*	50.07*	18.72	21.92
LOK 54	35.97	34.10	47.07*	44.63	30.86	30.89
PBW 475	34.20	33.97	44.43	42.70	29.92	25.71
PBW 503	40.30*	40.10*	45.23	43.70	12.24	8.99
PBW 175	36.37	34.27	40.23	42.13	10.63	22.96
PBW 527	37.10	38.37	40.23	40.14	8.45	4.63
WH 1142	38.00*	37.07	42.27	42.33	11.23	14.21
WH 1138	34.57	34.97	41.07	41.53	18.80	18.78
HD 2687	39.43*	40.30*	44.97	42.87	14.03	6.37
PBW 533	34.80	33.33	42.73	43.47	22.80	30.40
WH 1061	37.27	39.37	41.07	44.87	10.20	13.97
HD 2285	35.40	39.60*	42.20	43.27	19.21	9.26
WH 730	39.50*	36.30	43.11	43.50	9.14	19.83
C.D	2.561	2.608	2.794	2.796		
S.E(d)	1.284	1.308	1.401	1.402		
C.V	8.522	4.344	4.032	4.021		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

(39.67 g), HD 2285 (39.60 g) and C 518 (39.50 g). In 2013-14genotype Sonalika (49.03 g) was highest among all the genotypes under optimum input conditions followed by WH 1160 (47.17 g), LOK 54 (47.07 g), WH 1140 (46.43 g) and HD 2967 (45.77 g), while in 2013-14, Sonalika (50.07 g) was best among all followed by WH 1140 (46.13 g), PBW 373 (45.93 g) and WH 1160 (45.73 g) under optimum input conditions. LOK 54 (30.86 %) responded best over low input conditions followed by WH 1127 (30.46 %) and PBW 475 (29.92 %) in 2012-13. Lowest response was found in WH 1025 (3.61 %) (Table 8). In 2013-14, LOK 54 (30.89 %) was found highly responding followed by PBW 533 (30.40 %) and WH 1139 (28.59 %). Lowest response was found in WH 1025 (0.71 %).

4.2.8 Number of tillers per plant

In 2012-13WH 1105 (4.33) had highest number of tillers per plant under low input conditions followed by WH 1127 (4.33), WH 1098 (4.11),PBW 175 (4.11) and HD 2285 (4.11), while in 2013-14, WH 1081 (4.44) was having highest number of tillers per plant under low input conditions followed by WH 1127 (4.44), RAJ 3765 (4.11), WH 1098 (4.00), DPW 621-50 (4.00), WH 1105 (4.00) and HD 2285 (4.00). Under optimum input conditions in 2012-13, HD 2285 (5.33) was having highest number of tillers per plant followed by WH 1105(5.22), WH 1127 (5.22), WH 1098 (5.11), PBW 533 (5.11), DPW 621-50 (4.89) and PBW 175 (4.89), while in 2013-14, WH 1127 (5.44) exhibited highest number of tillers per plant followed by DPW 621-50 (5.11), WH 1081 (5.00) and WH 1105 (4.89). As per response over low input conditions PBW 533 (35.29 %) responded higher followed by WH 1061 (33.33 %) and WH 1142 (32.14 %), while lowest response was observed in Sonalika (12.50 %) in 2012-13(Table 9). In 2013-14, Highest response was observed in genotype DBW 17 (39.29 %) followed by WH 1100 (32.26 %) and PBW 533 (32.26 %). Lowest response was observed in WH 730 (10 %).

4.2.9 Number of spikelets per spike

For number of spikelets per spike under low input conditions WH 730 (22.33) was found highest among all the forty genotypes followed by WH 542 (22.00) and WH 1081 (21.67) in 2012-13, while in 2013-14 only WH 147 (22.00) was found significantly higher in number of spikelets per spike over the mean of all the forty genotypes (Table 10). Under optimum input conditions WH 542 (27.33) was having highest number of spikelets per spike followed by WH 147 (26.00) and PBW 475 (25.67) in 2012-13, while in 2013-14, WH 147 (28.67) came out to be sole genotype which differed significantly over mean of all the forty genotypes under optimum input conditions. In 2012-13, PBW 590 (38.78 %) responded highest followed by WH 711 (36.21 %) and WH 1025 (29.79 %) over low input conditions while WH 1100 (5.36 %) was found lowest. In 2013-14, WH 1080 (67.39 %) was highly responding genotype over low input conditions followed by WH 1021 (50.91 %) and PBW 175 (38.46 %).

Table 9: Mean performance of genotypes for Number of tillers per plant under low and optimum input conditions

Number of tillers per plant						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	3.67	3.89	4.44	4.67	21.21	20.00
WH 1080	3.22	3.44	3.89	4.33	20.69	25.81
WH 1098	4.11*	4.00*	5.11*	4.56	24.32	13.89
WH 1021	3.44	3.67	4.11	4.33	19.35	18.18
WH 416	2.67	3.33	3.11	3.78	16.67	13.33
DBW 17	3.22	3.11	3.78	4.33	17.24	39.29
WH 711	2.67	3.00	3.11	3.78	16.67	25.93
WH 1025	3.11	3.00	3.78	3.89	21.43	29.63
PBW 590	3.22	3.00	4.00	3.56	24.14	18.52
RAJ 3765	3.44	4.11*	4.44	4.78	29.03	16.22
WH 1081	3.89	4.44*	4.44	5.00*	14.29	12.50
C 306	2.89	3.33	3.78	3.89	30.77	16.67
PBW 373	3.22	3.67	4.11	4.67	27.59	27.27
DPW 621-50	3.89	4.00*	4.89*	5.11*	25.71	27.78
WH 1105	4.33*	4.00*	5.22*	4.89*	20.51	22.22
WH 1139	3.44	3.33	3.89	4.11	12.90	23.33
PBW 644	2.89	3.33	3.33	4.11	15.38	23.33
HD 2967	3.33	3.89	4.00	4.67	20.00	20.00
HD 2851	3.78	3.67	4.67	4.33	23.53	18.18
WH 147	3.44	3.78	4.33	4.67	25.81	23.53
WH 1127	4.33*	4.44*	5.22*	5.44*	20.51	22.50
WH 1063	3.00	3.56	3.78	4.22	25.93	18.75
WH 1123	3.33	3.56	3.78	4.56	13.33	28.13
WH 1100	2.89	3.44	3.78	4.56	30.77	32.26
WH 1140	2.67	2.78	3.44	3.22	29.17	16.00
C 518	3.33	2.89	4.22	3.56	26.67	23.08
WH 1160	3.67	3.33	4.56	4.33	24.24	30.00
SONALIKA	2.67	2.44	3.00	3.22	12.50	31.82
LOK 54	3.00	3.11	3.44	3.89	14.81	25.00
PBW 475	3.33	3.11	3.89	3.78	16.67	21.43
PBW 503	2.89	3.33	3.44	3.89	19.23	16.67
PBW 175	4.11*	3.89	4.89*	4.78	18.92	22.86
PBW 527	2.78	3.00	3.44	3.44	24.00	14.81
WH 1142	3.11	3.11	4.11	4.00	32.14	28.57
WH 1138	3.67	3.56	4.56	4.00	24.24	12.50
HD 2687	3.44	2.89	4.44	3.67	29.03	26.92
PBW 533	3.78	3.44	5.11*	4.56	35.29	32.26
WH 1061	3.00	3.22	4.00	3.89	33.33	20.69
HD 2285	4.11*	4.00*	5.33*	4.78	29.73	19.44
WH 730	3.67	3.33	4.44	3.67	21.21	10.00
C.D	0.571	0.598	0.646	0.665		
S.E(d)	0.286	0.3	0324	0.334		
C.V	10.407	10.609	9.593	9.674		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 10: Mean performance of genotypes for Number of spikelets per spike under low and optimum input conditions

Number of spikelets per spike						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	22.00*	20.67	27.33*	27.00	24.24	30.65
WH 1080	17.67	15.33	20.00	25.67	13.21	67.39
WH 1098	19.00	19.33	22.33	25.33	17.54	31.03
WH 1021	21.00	18.33	23.33	27.67	11.11	50.91
WH 416	18.00	19.33	22.33	23.00	24.07	18.97
DBW 17	18.00	18.00	21.33	24.67	18.52	37.04
WH 711	19.33	18.33	26.33*	23.33	36.21	27.27
WH 1025	15.67	18.00	20.33	22.67	29.79	25.93
PBW 590	16.33	17.00	22.67	22.00	38.78	29.41
RAJ 3765	19.00	18.67	23.67	21.00	24.56	12.50
WH 1081	21.67*	18.67	23.67	21.67	9.23	16.07
C 306	15.33	15.33	19.00	20.33	23.91	32.61
PBW 373	19.33	19.00	24.67	24.33	27.59	28.07
DPW 621-50	20.00	19.33	23.00	25.00	15.00	29.31
WH 1105	20.33	19.33	25.33	24.00	24.59	24.14
WH 1139	20.33	20.00	23.33	24.33	14.75	21.67
PBW 644	19.00	20.33	24.00	25.33	26.32	24.59
HD 2967	20.67	20.00	23.00	23.67	11.29	18.33
HD 2851	19.67	19.67	23.67	25.33	20.34	28.81
WH 147	21.00	22.00*	26.00*	28.67*	23.81	30.30
WH 1127	20.67	19.00	24.67	25.33	19.35	33.33
WH 1063	20.00	17.67	24.33	22.67	21.67	28.30
WH 1123	20.00	19.33	25.00	24.00	25.00	24.14
WH 1100	19.67	18.67	21.00	19.67	6.78	5.36
WH 1140	20.67	19.33	25.33	23.00	22.58	18.97
C 518	17.67	18.67	19.67	20.67	11.32	10.71
WH 1160	18.67	17.67	22.33	22.00	19.64	24.53
SONALIKA	18.00	20.33	20.00	22.67	11.11	11.48
LOK 54	19.00	18.33	22.00	23.33	15.79	27.27
PBW 475	20.00	19.67	25.67*	24.33	28.33	23.73
PBW 503	20.67	18.67	23.33	21.67	12.90	16.07
PBW 175	18.67	17.33	20.33	24.00	8.93	38.46
PBW 527	19.00	19.33	22.00	24.33	15.79	25.86
WH 1142	18.67	18.67	22.33	23.67	19.64	26.79
WH 1138	19.33	19.33	22.67	25.67	17.24	32.76
HD 2687	21.00	18.67	24.33	23.67	15.87	26.79
PBW 533	20.67	19.67	24.00	24.67	16.13	25.42
WH 1061	21.00	19.00	25.00	21.33	19.05	12.28
HD 2285	16.67	16.33	21.33	20.67	28.00	26.53
WH 730	22.33	19.00	25.00	23.00	11.94	21.05
C.D	2.274	2.566	2.274	2.513		
S.E(d)	1.14	1.287	1.14	1.26		
C.V	7.199	8.389	7.199	6.529		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

4.2.10 Grains per spike

For grains per spike under low input conditions in 2012-13 RAJ 3765 (43.33) was having highest number of grains per spike followed by WH 1080 (43.00), HD 2851 (42.33), WH 1061 (42.00), WH 1081 (41.33) and HD 2967(41.33), while in 2013-14 genotype WH 1081 (45.00) was found highest in number of grains per spike followed by HD 2851 (44.67), RAJ 3765 (44.00), WH 730 (43.67), WH 1098 (43.00), WH 1080 (42.67), PBW 644 (40.67) and Sonalika (40.67) (Table 11). Under optimum input conditions HD 2851 (53.67) was having highest number of grains per spike in 2012-13 followed by RAJ 3765 (51.33), WH 730 (50.33), WH 1080 (49.33), WH 1127 (49.33) and WH 542 (48.67), while in 2013-14, HD 2851(51.00) was found highest in number of grains per spike under optimum input conditions followed by WH 1081 (50.33), WH 730 (49.67), PBW 175 (49.33) and WH 542 (49.00). WH 542 (26.96 %) responded higher followed by HD 2851 (26.70), C 518 (26.42) and WH 1063 (26.13) in 2012-13, while DPW 621-50 (8.85 %) responded lowest among all the forty genotypes. In 2013-14, WH 1138 (33.03 %) was highly responding genotype followed by C 518 (32.35 %) and WH 1105 (31.48 %), Lowest responding genotype over low input conditions was found to be WH 1140 (7.08 %) (Table 11).

4.2.11 Days to heading

Under low input conditions Sonalika genotype was found earliest in days to heading (83.67) among all the genotypes followed by LOK 54 (84), HD 2285 (84.67), WH 542 (84.67), PBW 527 (85), WH 1123 (85), PBW 590 (85.33), PBW 533 (86) and WH 1100 (86) in 2012-13, while in 2012-13 for optimum input conditions trend was, Sonalika (81.67) was found earliest followed by C 306 (81.67). Similarly in 2013-14 for optimum input conditions PBW 373 (82.67) was found earliest genotypes with regard to days to heading followed by HD 28.51 (83.67), DPW 621-50 (83.67), WH 1063 (84), C 306 (84), PBW 590 (84.33), WH 1123 (84.67), WH 416 (85), WH 1098 (85), WH 542 (85) and WH 1081 (86). As per response over low input conditions genotype Sonalika (-3.92 %) responded most followed by WH 1127 (-3.88 %) and WH 711 (-3.50 %), while HD 2967 (0 %) and C 518 (0 %) were found least responding genotypes. However, in 2013-14, HD 2285 (8.66 %) was most responding genotype followed by Sonalika (7.97 %) and LOK 54 (7.94 %), lowest responding genotype came out to be WH 1063 (-7.69 %) (Table 12).

4.2.12 Days to maturity

Under low input conditions WH 730 (113.67) genotype was found earliest in days to maturity among all the genotypes followed by HD 2285 (114.67), PBW 527 (114.67) and WH 1140 (114.67) in 2012-13, while in 2013-14 WH 730 (117.67) was found earliest. Similarly for optimum input conditions in 2012-13 WH 1098 (115) was found earliest genotypes with regard to days to maturity followed by HD 2285 (115.33), WH 730 (115.67), WH 1061 (115.67), C 306(115.67), PBW 590 (116), DPW 621-50 (116.33), PBW 373

(116.33),

Table 11: Mean performance of genotypes for Grains per spike under low and optimum input conditions

Grains per spike						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	38.33	37.67	48.67*	49.00*	26.96	30.09
WH 1080	43.00*	42.67*	49.33*	48.33	14.73	13.28
WH 1098	38.33	43.00*	45.67	47.67	19.13	10.85
WH 1021	41.33	39.33	47.00	45.67	13.71	16.10
WH 416	38.33	36.33	42.67	44.33	11.30	22.02
DBW 17	35.67	38.33	40.67	42.33	14.02	10.43
WH 711	34.00	35.00	40.33	42.00	18.63	20.00
WH 1025	36.67	37.67	43.67	42.33	19.09	12.39
PBW 590	35.33	35.00	41.67	43.00	17.92	22.86
RAJ 3765	43.33*	44.00*	51.33*	49.00	18.46	11.36
WH 1081	41.33*	45.00*	45.33	50.33*	9.68	11.85
C 306	32.33	34.67	39.00	39.33	20.62	13.46
PBW 373	38.67	39.67	44.00	47.67	13.79	20.17
DPW 621-50	37.67	36.33	41.00	42.67	8.85	17.43
WH 1105	38.67	36.00	47.00	47.33	21.55	31.48
WH 1139	40.67	39.00	47.00	45.67	15.57	17.09
PBW 644	41.00	40.67*	46.33	44.67	13.01	9.84
HD 2967	41.33*	40.00	46.33	47.00	12.10	17.50
HD 2851	42.33*	44.67*	53.67*	51.00*	26.77	14.18
WH 147	37.00	36.67	42.67	44.00	15.32	20.00
WH 1127	40.67	39.33	49.33*	48.00	21.31	22.03
WH 1063	37.00	36.67	46.67	44.33	26.13	20.91
WH 1123	37.33	34.33	46.00	44.33	23.21	29.13
WH 1100	36.00	34.00	41.00	43.00	13.89	26.47
WH 1140	38.67	37.67	43.67	40.33	12.93	7.08
C 518	35.33	34.00	44.67	45.00	26.42	32.35
WH 1160	40.00	37.00	48.00	44.67	20.00	20.72
SONALIKA	37.00	40.67*	43.33	46.00	17.12	13.11
LOK 54	39.33	37.67	43.33	45.67	10.17	21.24
PBW 475	36.67	39.67	45.67	48.00	24.55	21.01
PBW 503	40.67	39.33	46.33	47.00	13.93	19.49
PBW 175	37.33	38.67	45.33	49.33*	21.43	27.59
PBW 527	38.00	36.33	42.00	45.33	10.53	24.77
WH 1142	37.33	37.00	45.67	45.67	22.32	23.42
WH 1138	38.67	36.33	44.00	48.33	13.79	33.03
HD 2687	41.00	37.67	46.00	45.00	12.20	19.47
PBW 533	40.00	38.67	47.67	48.33	19.17	25.00
WH 1061	42.00*	38.33	47.67	42.67	13.49	11.30
HD 2285	35.67	36.00	40.67	44.33	14.02	23.15
WH 730	40.00	43.67*	50.33*	49.67*	25.83	13.74
C.D	2.727	2.309	2.904	2.746		
S.E(d)	1.367	1.157	1.456	1.377		
C.V	4.338	3.695	3.939	3.689		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 12: Mean performance of genotypes for Days to heading under low and optimum input conditions

Days to heading						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	83.67	84.67*	84.00	85.00*	0.40	0.39
WH 1080	85.00	90.00	83.67	90.33	-1.57	0.37
WH 1098	84.33	89.33	83.33	85.00*	-1.19	-4.85
WH 1021	84.33	89.00	83.67	91.00	-0.79	2.25
WH 416	85.33	88.00	83.00	85.00*	-2.73	-3.41
DBW 17	85.33	88.33	83.67	86.67	-1.95	-1.89
WH 711	85.67	91.00	82.67	90.33	-3.50	-0.73
WH 1025	85.00	91.67	83.00	90.67	-2.35	-1.09
PBW 590	84.00	85.33	82.67	84.33*	-1.59	-1.17
RAJ 3765	84.33	87.00	82.67	90.33	-1.98	3.83
WH 1081	85.33	88.33	83.33	86.00*	-2.34	-2.64
C 306	84.33	88.00	81.67*	84.00*	-3.16	-4.55
PBW 373	84.67	89.00	83.00	82.67*	-1.97	-7.12
DPW 621-50	84.67	87.67	83.00	83.67*	-1.97	-4.56
WH 1105	84.67	90.33	82.67	88.00	-2.36	-2.58
WH 1139	84.00	90.00	83.33	90.00	-0.79	0.00
PBW 644	85.00	89.67	84.00	91.67	-1.18	2.23
HD 2967	84.00	89.67	84.00	87.00	0.00	-2.97
HD 2851	84.00	87.67	83.33	83.67*	-0.79	-4.56
WH 147	84.33	88.00	82.67	89.67	-1.98	1.89
WH 1127	86.00	90.67	82.67	93.33	-3.88	2.94
WH 1063	84.33	91.00	83.00	84.00*	-1.58	-7.69
WH 1123	84.00	85.00*	82.67	84.67*	-1.59	-0.39
WH 1100	83.67	86.00*	83.00	90.67	-0.80	5.43
WH 1140	84.33	90.33	83.67	91.00	-0.79	0.74
C 518	83.00*	89.00	83.00	90.67	0.00	1.87
WH 1160	84.67	87.00	82.33	91.00	-2.76	4.60
SONALIKA	85.00	83.67*	81.67*	90.33	-3.92	7.97
LOK 54	84.33	84.00*	82.00	90.67	-2.77	7.94
PBW 475	84.67	90.67	84.33	90.00	-0.39	-0.74
PBW 503	84.33	88.00	83.67	90.67	-0.79	3.03
PBW 175	84.67	89.33	84.00	87.33	-0.79	-2.24
PBW 527	84.67	85.00*	83.67	87.33	-1.18	2.75
WH 1142	85.33	91.00	84.00	92.33	-1.56	1.47
WH 1138	84.67	89.00	83.67	91.67	-1.18	3.00
HD 2687	85.00	90.67	83.33	89.00	-1.96	-1.84
PBW 533	83.67	86.00*	82.67	90.33	-1.20	5.04
WH 1061	85.00	90.33	83.67	90.33	-1.57	0.00
HD 2285	85.00	84.67*	83.00	92.00	-2.35	8.66
WH 730	84.00	87.67	83.33	92.00	-0.79	4.94
C.D	N.S	2.014	1.211	2.208		
S.E(d)	0.702	1.01	0.607	1.107		
C.V	1.017	1.401	0.894	1.53		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 13: Mean performance of genotypes for Days to maturity under low and optimum input conditions

Days to maturity						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	125.00	126.67	118.33*	124.67	-5.33	-1.58
WH 1080	117.67	124.33	116.67*	127.00	-0.85	2.14
WH 1098	118.00	124.00	115.00*	119.00*	-2.54	-4.03
WH 1021	118.00	124.33	116.67*	120.67*	-1.13	-2.95
WH 416	118.00	122.00	117.00*	121.00	-0.85	-0.82
DBW 17	118.33	122.33	117.33*	121.33	-0.85	-0.82
WH 711	118.33	122.33	118.67	122.67	0.28	0.27
WH 1025	120.67	124.67	119.00	123.00	-1.38	-1.34
PBW 590	116.67	123.00	116.00*	120.00*	-0.57	-2.44
RAJ 3765	117.00	123.33	116.67*	120.67*	-0.28	-2.16
WH 1081	117.33	123.67	116.67*	120.67*	-0.57	-2.43
C 306	119.00	123.00	115.67*	119.67*	-2.80	-2.71
PBW 373	116.33	120.33	116.33*	120.33*	0.00	0.00
DPW 621-50	116.67	120.67	116.33*	122.00	-0.29	1.10
WH 1105	116.67	120.67	117.67	121.67	0.86	0.83
WH 1139	118.33	122.33	126.00	130.00	6.48	6.27
PBW 644	118.00	122.00	126.33	130.33	7.06	6.83
HD 2967	119.67	123.67	121.67	125.67	1.67	1.62
HD 2851	119.00	123.00	117.33	121.33	-1.40	-1.36
WH 147	116.67	120.67	125.00	129.00	7.14	6.91
WH 1127	119.33	125.67	125.00	129.00	4.75	2.65
WH 1063	120.67	124.67	118.67	122.67	-1.66	-1.60
WH 1123	116.67	120.67	124.00	121.33	6.29	0.55
WH 1100	115.67	119.67	124.33	128.33	7.49	7.24
WH 1140	114.67*	118.67	125.67	129.67	9.59	9.27
C 518	121.67	125.67	125.33	129.33	3.01	2.92
WH 1160	116.00	120.00	125.67	129.33	8.33	7.78
SONALIKA	115.00*	119.00	126.67	130.67	10.14	9.80
LOK 54	116.67	120.67	121.00	125.00	3.71	3.59
PBW 475	117.33	121.33	122.33	123.00	4.26	1.37
PBW 503	116.67	120.67	123.33	127.33	5.71	5.52
PBW 175	115.67	119.67	125.33	127.00	8.36	6.13
PBW 527	114.67*	122.00	125.33	129.33	9.30	6.01
WH 1142	117.00	121.00	123.67	127.67	5.70	5.51
WH 1138	115.33	119.33	125.00	126.67	8.38	6.15
HD 2687	116.67	120.67	117.33	121.33	0.57	0.55
PBW 533	116.67	120.67	117.00*	121.00	0.29	0.28
WH 1061	115.67	123.00	115.67*	119.67*	0.00	-2.71
HD 2285	114.67*	118.67	115.33*	119.33*	0.58	0.56
WH 730	113.67*	117.67*	115.67*	119.67*	1.76	1.70
C.D	2.226	3.909	3.043	3.475		
S.E(d)	1.116	1.959	1.525	1.742		
C.V	1.164	1.969	1.553	1.718		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

WH 1081 (116.67), RAJ 3765 (116.67), WH 1021 (116.67), WH 1080 (116.67), PBW 533 (117) and WH 416 (117), While in 2013-14, WH 1098 (119) was found earliest regarding days to maturity followed by HD 2285 (119.33), C 306 (119.67), WH 1061 (119.67), WH 730 (119.67), PBW 590 (120), PBW 373 (120.33), WH 1021 (12067), RAJ 3765 (12067) and WH 1081 (120.67).

As per response over low input conditions genotype Sonalika (10.14 %) responded most followed by WH 1140 (9.59 %) and PBW 527 (9.3 %), while WH 542 (-5.33 %) was found least responding genotype in 2012-13. However, in 2013-14, Sonalika (9.80 %) was most responding genotype followed by WH 1140 (9.27 %) and WH 1160 (7.78 %), lowest responding genotype came out to be WH 1098 (-4.03 %) (Table 13)..

4.2.13 N content in grains (percentage)

Under low input conditions in 2012-13, genotype WH 1123 (1.93 %) was having maximum N content per plant followed by C 306 (1.92) and LOK 54 (1.9 %), while in 2013-14, LOK 54 (1.98 %) was found highest in N content per plant. In 2012-13, under optimum input conditions, maximum N content was found in LOK 54 (2.46 %) followed by WH 1025 (2.40 %), WH 711 (2.37 %), WH 147 (2.36 %), Sonalika (2.35 %), WH 1127 (2.27 %) and WH 1063 (2.26 %), while in 2013-14, LOK 54 (2.46 %) was having highest N content per plant followed by WH 147 (2.27 %), Sonalika (2.21 %) and WH 1025 (2.16 %). As per response over low input conditions WH 1025 (35.63 %) was found highly responding followed by LOK 54 (34.521%) and Sonalika (3.96 %), while lowest responding genotype was found to be WH 1123 (14.9 %) in 2012-13, while in 2013-14 WH 1100 (32.88 %) was found highly responding genotype followed by WH 1061 (32.06 %), PBW 373 (31.09 %) and WH 1139 (29.54 %), while lowest response was of PBW 503 (6.76 %) (Table 14).

4.2.14 P content in grains (ppm)

WH 1105 (6.59 %) was found significantly highest in mean performance on overall mean under low input conditions for P content in grains followed by PBW 373 (6.42 %), Sonalika (6.12 %), PBW 644 (6.1 %), DPW 621-50 (5.88 %), WH 416 (5.73 %), WH 1061 (5.62 %), WH 711 (5.54 %), WH 1025 (5.51 %), WH 1139 (5.4 %), WH 147 (5.31 %), WH 1100 (5.31%), WH 1081 (5.29 %) and WH 1160 (5.27 %) in 2012-13, while in 2013-14, PBW 373 (6.22 %) was found highest in P content in grains followed by Sonalika (6.15 %), WH 416 (5.83 %), WH 1105 (5.3 %), DBW 17 (5.62 %), WH 1100 (5.6 %), WH 711 (5.48 %), WH 1081 (5.47 %), DPW 621-50 (5.45 %), WH 1025 (5.42 %), WH 1061 (5.37 %), WH 147 (5.36 %), PBW 644 (5.35 %), WH 1139 (5.33 %) and WH 1098 (5.28 %).

Table 14: Mean performance of genotypes for N content in grains under low and optimum input conditions

N content (percentage)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	1.70	1.64	1.98	1.85	16.34	13.40
WH 1080	1.73	1.79	2.06	2.13	19.31	18.77
WH 1098	1.60	1.68	2.09	2.03	30.08	20.55
WH 1021	1.51	1.56	1.98	1.92	30.73	23.13
WH 416	1.78	1.80	2.14	2.15	20.25	19.54
DBW 17	1.55	1.53	2.07	1.84	33.20	20.21
WH 711	1.77	1.77	2.37*	2.11	33.38	19.23
WH 1025	1.77	1.79	2.40*	2.16*	35.63	21.01
PBW 590	1.34	1.54	1.68	1.95	25.09	26.60
RAJ 3765	1.67	1.67	2.07	1.94	23.50	15.95
WH 1081	1.63	1.52	1.94	1.64	19.10	8.03
C 306	1.92*	1.68	2.21	2.00	15.17	18.70
PBW 373	1.73	1.58	2.07	2.07	19.79	31.09
DPW 621-50	1.77	1.66	2.24	2.12	26.27	27.15
WH 1105	1.71	1.82	2.18	2.05	27.19	12.56
WH 1139	1.69	1.46	2.14	1.89	26.57	29.54
PBW 644	1.69	1.81	2.23	2.10	31.83	15.64
HD 2967	1.61	1.44	2.03	1.81	26.02	26.14
HD 2851	1.72	1.74	2.18	2.04	26.38	17.38
WH 147	1.84	1.75	2.36*	2.27*	28.40	29.15
WH 1127	1.81	1.77	2.27*	2.10	25.37	18.76
WH 1063	1.83	1.76	2.26*	2.06	23.46	17.44
WH 1123	1.93*	1.76	2.22	2.08	14.90	18.15
WH 1100	1.58	1.46	1.99	1.94	25.59	32.88
WH 1140	1.66	1.75	2.10	2.05	27.09	17.19
C 518	1.46	1.47	1.85	1.71	26.78	16.15
WH 1160	1.78	1.72	2.24	2.14	25.51	24.18
SONALIKA	1.75	1.84	2.35*	2.21*	33.96	20.41
LOK 54	1.90*	1.98*	2.56*	2.46*	34.51	24.12
PBW 475	1.74	1.78	2.06	1.94	18.00	8.91
PBW 503	1.63	1.69	1.93	1.80	18.82	6.76
PBW 175	1.77	1.80	2.06	1.93	15.99	7.30
PBW 527	1.76	1.75	2.15	2.10	22.54	20.08
WH 1142	1.60	1.55	2.07	1.90	29.80	22.18
WH 1138	1.57	1.61	2.07	1.96	32.00	21.33
HD 2687	1.78	1.80	2.23	2.02	25.12	12.61
PBW 533	1.68	1.63	2.15	2.01	27.59	23.47
WH 1061	1.76	1.51	2.10	1.99	19.51	32.06
HD 2285	1.71	1.59	1.97	1.93	15.29	20.82
WH 730	1.68	1.55	1.98	1.85	18.23	19.10
C.D	0.168	0.167	0.126	0.156		
S.E(d)	0.084	0.084	0.063	0.078		
C.V	6.058	6.114	3.628	4.778		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 15: Mean performance of genotypes for P content in grains under low and optimum input conditions

P content in grains (micro gram / gram)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	3.52	3.25	4.52	4.38	28.44	34.87
WH 1080	3.43	3.39	4.25	4.21	23.86	24.07
WH 1098	5.01	5.28*	6.12	6.20	22.07	17.59
WH 1021	4.55	4.39	5.11	5.25	12.23	19.58
WH 416	5.73*	5.83*	6.89*	6.56*	20.17	12.40
DBW 17	5.18	5.62*	7.01*	6.98*	35.24	24.09
WH 711	5.54*	5.48*	7.07*	6.92*	27.47	26.30
WH 1025	5.51*	5.42*	6.93*	6.88*	25.91	26.86
PBW 590	5.24	5.14	6.41*	6.26	22.17	21.87
RAJ 3765	5.01	4.89	6.08	5.96	21.34	21.96
WH 1081	5.29*	5.47*	6.31	6.50*	19.21	18.76
C 306	4.49	4.57	5.38	5.31	19.99	16.35
PBW 373	6.42*	6.22*	7.09*	7.00*	10.55	12.48
DPW 621-50	5.88*	5.45*	6.61*	6.28	12.39	15.36
WH 1105	6.59*	5.73*	7.54*	7.26*	14.47	26.64
WH 1139	5.40*	5.33*	6.28	6.39*	16.43	19.82
PBW 644	6.10*	5.35*	7.13*	7.25*	16.82	35.58
HD 2967	4.35	4.18	5.18	5.23	18.89	24.94
HD 2851	4.49	4.35	5.75	5.36	28.04	23.39
WH 147	5.31*	5.36*	6.33	6.27	19.35	16.97
WH 1127	4.51	4.53	5.96	5.99	31.98	32.33
WH 1063	4.60	4.35	5.51	5.25	19.86	20.71
WH 1123	4.47	4.40	6.02	5.94	34.58	35.03
WH 1100	5.31*	5.60*	6.11	6.19	15.00	10.66
WH 1140	4.47	4.29	6.10	5.90	36.40	37.64
C 518	4.64	4.63	5.27	5.38	13.59	16.13
WH 1160	5.27*	5.05	6.27	6.41*	18.96	27.00
SONALIKA	6.12*	6.15*	7.44*	7.02*	21.50	14.03
LOK 54	4.19	4.29	5.61	5.50	33.95	28.11
PBW 475	3.19	3.18	4.11	4.32	28.67	35.59
PBW 503	4.64	4.43	6.15	6.37*	32.67	43.72
PBW 175	4.44	4.26	5.63	5.53	26.97	29.79
PBW 527	4.09	4.21	5.45	5.26	33.22	24.84
WH 1142	4.45	4.41	5.93	6.43*	33.18	45.99
WH 1138	5.22	5.03	6.22	6.05	19.17	20.13
HD 2687	5.14	5.13	6.99*	6.75	35.99	31.51
PBW 533	4.33	4.49	5.04	5.34	16.23	18.77
WH 1061	5.62*	5.37*	6.22	6.21	10.68	15.51
HD 2285	4.55	4.54	5.96	6.22	30.89	37.03
WH 730	4.53	4.52	6.19	6.09	36.73	34.83
C.D	0.354	0.317	0.332	0.346		
C.D(Interaction)						
S.E(d)	0.177	0.159	0.167	0.173		
C.V	4.413	4.027	3.37	3.532		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Under optimum input conditions WH 1105 (7.54 %) was found highest in P content in grains followed by Sonalika (7.44 %), PBW 644 (7.13 %), PBW 373 (7.09 %), WH 711 (7.07 %), DBW17 (7.01 %), HD 2687 (6.99 %), WH 1025 (6.93 %), WH 416 (6.89 %), DPW 621-50 (6.61 %) and PBW 590 (6.41 %) in 2012-13, while in 2013-14 WH 1105 (7.26 %) was significantly highest in P content followed by PBW 644 (7.25 %), Sonalika (7.02 %), PBW 373 (7.00 %), DBW 17 (6.98 %), WH 711 (6.92 %), WH 1025 (6.88 %), HD 2687 (6.75 %), WH 416 (6.56 %), WH 1081 (6.50 %), WH 1142 (6.43 %), WH 1160 (6.41 %), WH 1139 (6.39 %) and PBW 503 (6.37 %). In 2012-13 WH 730 (36.73 %) was highest responding genotype for P content in grains followed by WH 1140 (36.40 %) and HD 2687 (35.99 %), while lowest response was observed in PBW 373 (10.55 %). In 2013-14, WH 1142 (45.99 %) was found to be highest responding genotype followed by PBW 503 (43.72 %) and WH 1140 (37.64 %), while lowest responding genotype was found to be WH 1100 (10.66 %) (Table 15).

4.2.15 Zinc content in grains (ppm)

DBW 17 (60.09 %) was found significantly highest in mean performance on overall mean under low input conditions for Zn content in grains followed by PBW 175 (57.47 %), HD 2851 (57.03 %), LOK 54 (56.60 %), WH 1100 (56.55 %), WH 1127 (55.70 %), WH 1063 (55.10 %), WH 1021 (54.69 %), PBW 527 (53.65 %) and PBW 644 (50.91 %) in 2012-13, while in 2013-14, DBW 17 (58.96 %) was found highest in Zn content in grains followed by PBW 175 (56.37 %), WH 1100 (55.18 %), LOK 54 (55.13 %), HD 2851 (52.76 %), PBW 527 (52.50 %), PBW 644 (51.68 %), WH 1021 (51.14 %), WH 1127 (50.78 %), PBW 503 (50.47 %), WH 1063 (50.37 %) and WH 711 (50.25 %). Under optimum input conditions WH 1100 (77.10 %) was found highest in Zn content in grains followed by DBW 17 (75.35 %), WH 1021 (7280 %), HD 2851 (71.64 %), WH 1127 (67.65 %), WH 1063 (66.70 %), PBW 644 (65.85 %), LOK 54 (64.87 %), PBW 503 (64.37 %), PBW 175 (64.20 %), PBW 475 (63.67 %), WH 711 (62.77 %) and PBW 527 (62.73 %) in 2012-13, while in 2013-14 DBW 17 (81.63 %) was significantly highest in Zn content followed by HD 2851 (71.72 %), WH 1100 (69.53 %), PBW 175 (69.08 %), PBW 503 (65.72 %), PBW 644 (65.71 %), WH 1127 (65.35 %), LOK 54 (65.20 %), PBW 475 (65.03 %), PBW 527 (64.54 %), WH 1063 (64.51 %), WH 711 (64.23 %) and WH 1105 (63.39 %). In 2012-13 PBW 503 (38.52 %) was highest responding genotype for Zn content in grains followed by WH 1100 (36.34 %) and WH 1142 (35.81 %)., while lowest response was observed in C 306 (3.5 %). In 2013-14, C 306 (42.48 %) was found to be highest responding genotype followed by WH 1081 (40.26 %) and DBW 17 (38.45 %), while lowest responding genotype was found to be WH 1142 (14.87 %) (Table 16).

Table 16: Mean performance of genotypes for Zn content in grains under low and optimum input conditions

Zn content in grains (percentage)						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	26.75	29.32	31.92	34.08	19.33	16.24
WH 1080	44.29	43.68	54.28	52.61	22.55	20.46
WH 1098	46.17	45.94	58.90	57.93	27.58	26.10
WH 1021	54.69*	51.14*	72.80*	61.14	33.11	19.56
WH 416	40.78	40.36	52.07	53.84	27.69	33.38
DBW 17	60.09*	58.96*	75.35*	81.63*	25.39	38.45
WH 711	50.24	50.25*	62.77*	64.23*	24.94	27.83
WH 1025	45.23	41.98	54.40	52.60	20.26	25.29
PBW 590	42.32	46.18	54.67	56.35	29.17	22.02
RAJ 3765	46.13	46.82	53.47	54.88	15.90	17.22
WH 1081	39.80	40.13	52.40	56.29	31.66	40.26
C 306	43.83	44.90	45.37	43.98	3.50	42.48
PBW 373	44.67	39.66	56.60	50.59	26.72	27.54
DPW 621-50	46.56	41.31	54.16	49.06	16.32	18.78
WH 1105	48.20	48.35	62.05	63.39*	28.73	31.10
WH 1139	48.70	42.67	54.01	56.44	10.91	32.26
PBW 644	50.91*	51.68*	65.85*	65.71*	29.35	27.14
HD 2967	48.23	46.31	58.65	61.24	21.59	32.23
HD 2851	57.03*	52.76	71.64*	71.72*	25.61	35.93
WH 147	46.40	47.60	56.43	55.21	21.62	15.98
WH 1127	55.70*	50.78*	67.65*	65.35*	21.45	28.69
WH 1063	55.10*	50.37*	66.70*	64.51*	21.05	28.08
WH 1123	43.70	46.54	56.70	55.42	29.75	19.07
WH 1100	56.55*	55.18	77.10*	69.56*	36.34	26.05
WH 1140	43.87	44.11	52.70	53.70	20.14	21.74
C 518	37.23	41.06	48.33	47.78	29.84	16.36
WH 1160	40.28	42.77	53.40	51.27	32.56	19.87
SONALIKA	45.77	44.90	57.93	54.46	26.58	21.29
LOK 54	56.60	55.13*	64.87*	65.20*	14.61	18.27
PBW 475	48.10	49.29	63.67*	65.03*	32.36	31.95
PBW 503	46.47	50.47*	64.37*	65.72*	38.52	30.22
PBW 175	57.47*	56.37*	64.20*	69.08*	11.72	22.55
PBW 527	53.65*	52.50*	62.73*	64.54*	16.92	22.93
WH 1142	44.38	47.22	60.27	54.24	35.81	14.87
WH 1138	44.01	44.08	53.48	55.34	21.50	25.54
HD 2687	42.01	43.47	56.13	58.79	33.61	35.25
PBW 533	46.13	43.32	56.20	54.29	21.82	25.32
WH 1061	49.77	47.05	56.41	55.84	13.36	18.68
HD 2285	43.83	45.77	54.29	53.53	23.86	16.95
WH 730	44.67	42.75	56.17	56.02	25.75	31.03
C.D	3.463	3.619	4.036	4.209		
S.E(d)	1.736	1.814	2.023	2.11		
C.V	4.509	4.77	4.234	4.45		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

4.2.16 Nitrogen use efficiency (%)

Under low input conditions in 2012-13, PBW 533 (83.28 %) was found highly efficient for nitrogen use among all the forty genotypes followed by, WH 1105 (79.57 %), WH 1061 (76.85 %), WH 542 (76.47 %), HD 2967 (74.79 %), DBW 17 (72.88 %) and PBW 644 (71.71 %), while in 2013-14 LOK 54 (85.33 %) was found highest in nitrogen use efficiency (Fig. 1) followed by HD 2967 (80.13%), PBW 475 (78.91 %), PBW 644 (77.14 %) ansd Sonalika (75.46 %). Similarly, under optimum input conditions WH 1105 (40.58 %) was found most efficient genotype in nitrogen use followed by DPW 621-50 (40.23 %), PBW 590 (38.63 %), PBW 503 (38.56 %), PBW 533 (38.41 %), PBW 475 (38.11 %), HD 2687 (37.81 %), WH 542 (37.58 %), HD 2967 (37.52 %), WH 1138 (37.14 %), PBW 644 (36.85 %), WH 1061 (36.51 %), WH 1160 (36.24 %) and PBW 527 (36.15 %) in 2012-13(Fig. 1), while in 2013-14(Fig. 2) WH 1105 (45.37 %) was found most efficient followed by HD 2967 (43.23 %), DPW 621-50 (42.18 %), WH 1160 (42.14 %), HD 2687 (40.87 %), WH 1140 (37.28 %) and WH 147 (36.54 %) (Fig. 2). In response to low input conditions WH 1140 (-60.58 %) was found most responding genotype followed by WH 1025 (-57.59 %) and RAJ 3765 (-54.80 %) in 2012-13, while lowest responding genotype was found to be Sonalika (-26.06 %). Similarly, WH 1098 (-59.89 %) was found to be the highest responding genotype in 2013-14 followed by LOK 54 (-59.63 %) and WH 730 (-58.49 %), while lowest response was observed in WH 1160 (-33.06 %) (Table 17).

4.2.17 Phosphorous use efficiency (%)

Under low input conditions in 2012-13 (Fig. 3), PBW 533 (166.56 %) was found highly efficient for phosphorous use among all the forty genotypes followed by, WH 1105 (159.14 %), WH 1061 (153.69 %), WH 542 (152.95 %), HD 2967 (149.59 %), DBW 17 (145.75 %) and PBW 644 (143.41 %), while in 2013-14 (Fig. 4) LOK 54 (170.65 %) was found highest in phosphorous use efficiency followed by HD 2967 (160.27%), PBW 475 (157.81 %), PBW 644 (154.27 %) and Sonalika (150.92 %). Similarly, under optimum input conditions WH 1105 (101.45 %) was found most efficient genotype in phosphorous use followed by DPW 621-50 (100.57 %), PBW 590 (96.59 %), PBW 503 (96.39 %), PBW 533 (96.02 %), PBW 475 (95.28 %), HD 2687 (94.53 %), WH 542 (93.94 %), HD 2967 (93.81 %), WH 1138 (92.84 %), PBW 644 (92.12 %), WH 1061 (91.27 %), WH 1160 (90.61 %) and PBW 527 (90.38 %) in 2012-13 (Fig. 3), while in 2013-14 WH 1105 (113.44 %) was found most efficient followed by HD 2967 (108.07 %), DPW 621-50 (105.44 %), WH 1160 (105.36 %), HD 2687 (102.19 %), WH 1140 (93.19 %) and WH 147 (91.36%) (Fig. 4). In response to low input conditions WH 1140 (-50.73%) was found most responding genotype followed by WH 1025 (-46.99 %) and RAJ 3765 (-43.50 %) in 2012-13, while lowest responding genotype was found to be Sonalika (-7.58 %). Similarly, WH 1098 (-49.86 %) was found to be the highest responding genotype in 2013-14 followed by LOK 54 (-49.54 %) and WH 730 (-48.11 %), while lowest response was observed in WH 1160 (-16.32 %) (Table 18).

4.2.18 Zinc use efficiency (%)

Under low input conditions in 2012-13 (Fig. 5), PBW 533 (333.13 %) was found highly efficient for Zinc use among all the forty genotypes followed by, WH 1105 (318.27%), WH 1061 (307.38 %), WH 542 (305.90 %), HD 2967 (299.18 %), DBW 17 (291.51 %) and PBW 644 (286.83 %), while in 2013-14 LOK 54 (341.30 %) was found highest in zinc use efficiency followed by HD 2967 (320.53%), PBW 475 (315.62 %), PBW 644 (308.54 %) ansd Sonalika (301.84 %) (Fig. 6). Similarly, under optimum input conditions WH 1105 (202.90 %) was found most efficient genotype in zinc use followed by DPW 621-50 (201.15 %), PBW 590 (193.17 %), PBW 503 (192.78 %), PBW 533 (192.04 %), PBW 475 (190.56 %), HD 2687 (189.07 %), WH 542 (187.88 %), HD 2967 (187.62 %), WH 1138 (185.68 %), PBW 644 (184.23 %), WH 1061 (182.54 %), WH 1160 (181.21 %) and PBW 527 (180.75 %) in 2012-13 (Fig. 5), while in 2013-14 WH 1105 (226.87%) was found most efficient followed by HD 2967 (216.14 %), DPW 621-50 (210.89 %), WH 1160 (210.72 %), HD 2687 (204.37 %), WH 1140 (186.38 %) and WH 147 (182.72%) (Fig. 6). In response to low input conditions WH 1140 (-50.73%) was found most responding genotype followed by WH 1025 (-46.99 %) and RAJ 3765 (-43.50 %) in 2012-13, while lowest responding genotype was found to be Sonalika (-7.58 %). Similarly, WH 1098 (-49.86 %) was found to be the highest responding genotype in 2013-14 followed by LOK 54 (-49.54 %) and WH 730 (-48.11 %), while lowest response was observed in WH 1160 (-16.32 %) (Table 19).

4.2.19 Root biomass (g)

For root biomass in 2012-13 under low input conditions DBW 17 (5.13 g) was having highest root biomass among all the genotypes followed by Sonalika (4.9 g), PBW 373 (4.8 g) and WH 1142 (4.68 g), while genotype DBW 17 (5.1 g) was having highest mean in 2013-14 followed by WH 1105 (4.73 g), WH 416 (4.7 g), PBW 373 (4.67 g) and Sonalika (4.62 g). Under optimum input conditions trend was WH 1100 (6.17 g) possessed highest root biomass followed by WH 1142 (6.11 g), WH 1138 (6.11 g), PBW 373 (6.04 g), DBW 17 (5.9 g) and WH 542 (5.89 g) in 2012-13, while in 2013-14, WH 147 (6.09 g) was having highest root biomass followed by DBW 17 (6.07 g), PBW 373 (5.98 g), WH 1138 (5.98 g), WH 1142 (5.97 g), WH 1098 (5.89 g), WH 416 (5.87 g), WH 1100 (5.80 g), HD 2285 (5.76 g) and WH 1021(5.75 g). WH 1100 (39.46 %) was found most responding genotype in 2012-13 followed by WH 1138 (39.07 %) and WH 416 (33.60 %), while lowest response was observed in

Table 17: Mean performance of genotypes for N use efficiency under low and optimum input conditions

N use efficiency						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	76.47*	64.34	37.58*	33.99	-50.86	-47.17
WH 1080	62.47	41.27	29.60	23.98	-52.62	-41.90
WH 1098	48.86	58.88	31.06	23.62	-36.42	-59.89
WH 1021	45.09	58.22	29.36	26.11	-34.87	-55.15
WH 416	66.93	56.19	32.92	29.69	-50.82	-47.16
DBW 17	72.88*	67.23	35.13	34.73	-51.80	-48.34
WH 711	68.49	68.83	33.66	34.01	-50.85	-50.59
WH 1025	59.87	50.45	25.39	24.15	-57.59	-52.13
PBW 590	71.11	64.24	38.63*	28.88	-45.67	-55.05
RAJ 3765	55.65	52.51	25.15	27.75	-54.80	-47.15
WH 1081	47.29	56.70	32.20	26.29	-31.91	-53.64
C 306	51.83	52.28	24.72	28.67	-52.30	-45.16
PBW 373	42.78	48.21	30.14	28.47	-29.53	-40.96
DPW 621-50	61.50	69.67	40.23*	42.18	-34.59	-39.46
WH 1105	79.57*	71.62	40.58*	45.37	-49.00	-36.64
WH 1139	66.60	61.29	34.67	28.03	-47.94	-54.27
PBW 644	71.71*	77.14*	36.85*	36.03	-48.61	-53.29
HD 2967	74.79*	80.13*	37.52*	43.23*	-49.83	-46.06
HD 2851	59.13	46.31	29.48	24.49	-50.15	-47.11
WH 147	66.47	68.83	35.44	36.54*	-46.68	-46.91
WH 1127	52.52	55.72	30.97	31.01	-41.04	-44.34
WH 1063	48.40	55.76	27.83	25.75	-42.50	-53.82
WH 1123	45.39	63.09	28.16	31.00	-37.97	-50.86
WH 1100	42.55	57.73	27.34	34.89	-35.74	-39.57
WH 1140	55.72	61.19	21.96	37.28	-60.58	-39.08
C 518	45.76	54.88	25.14	27.98	-45.06	-49.01
WH 1160	64.77	62.95	36.24*	42.14*	-44.04	-33.06
SONALIKA	45.45	75.46*	33.60	33.26	-26.06	-55.92
LOK 54	64.58	85.33*	34.50	34.44	-46.58	-59.63
PBW 475	68.97	78.91*	38.11*	34.29	-44.74	-56.54
PBW 503	66.73	66.34	38.56*	35.85	-42.22	-45.96
PBW 175	55.32	55.12	25.38	27.40	-54.12	-50.30
PBW 527	65.80	73.11	36.15*	34.04	-45.06	-53.44
WH 1142	48.62	53.50	23.73	25.21	-51.20	-52.88
WH 1138	67.92	65.50	37.14*	32.51	-45.32	-50.38
HD 2687	57.21	71.52	37.81*	40.87*	-33.90	-42.85
PBW 533	83.28*	63.18	38.41*	31.79	-53.88	-49.68
WH 1061	76.85*	67.37	36.51*	31.98	-52.49	-52.53
HD 2285	58.88	48.65	29.98	25.65	-49.09	-47.27
WH 730	52.59	57.35	30.86	23.80	-41.31	-58.49
C.D	10.986	11.034	3.451	4.433		
S.E(d)	5.507	5.532	1.73	2.223		
C.V	11.164	10.897	6.527	8.592		

*, **: significant at 5% and 1% level of significance respectively. C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 18: Mean performance of genotypes for P use efficiency under low and optimum input conditions

P use efficiency						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	152.95*	128.68	93.94*	84.98	-38.58	-33.96
WH 1080	124.94	82.54	73.99	59.95	-40.78	-27.37
WH 1098	97.71	117.76	77.66	59.04	-20.52	-49.86
WH 1021	90.17	116.45	73.41	65.28	-18.59	-43.94
WH 416	133.85	112.39	82.29	74.23	-38.52	-33.95
DBW 17	145.75*	134.45	87.82	86.81	-39.75	-35.43
WH 711	136.99	137.65	84.16	85.01	-38.57	-38.24
WH 1025	119.74	100.90	63.48	60.37	-46.99	-40.17
PBW 590	142.22	128.48	96.59*	72.19	-32.08	-43.81
RAJ 3765	111.30	105.03	62.88	69.39	-43.50	-33.93
WH 1081	94.57	113.41	80.49	65.72	-14.89	-42.05
C 306	103.66	104.56	61.80	71.67	-40.38	-31.45
PBW 373	85.55	96.43	75.36	71.17	-11.91	-26.20
DPW 621-50	123.00	139.35	100.57*	105.44*	-18.23	-24.33
WH 1105	159.14*	143.23	101.45*	113.44*	-36.25	-20.80
WH 1139	133.20	122.57	86.67	70.06	-34.93	-42.84
PBW 644	143.41*	154.27*	92.12*	90.07	-35.77	-41.61
HD 2967	149.59*	160.27*	93.81*	108.07*	-37.29	-32.57
HD 2851	118.27	92.62	73.70	61.23	-37.68	-33.89
WH 147	132.93	137.66	88.60	91.36*	-33.35	-33.64
WH 1127	105.05	111.44	77.42	77.54	-26.30	-30.42
WH 1063	96.80	111.51	69.57	64.37	-28.13	-42.28
WH 1123	90.78	126.18	70.39	77.51	-22.46	-38.58
WH 1100	85.10	115.46	68.36	87.22	-19.67	-24.46
WH 1140	111.44	122.38	54.91	93.19	-50.73	-23.85
C 518	91.52	109.75	62.85	69.95	-31.32	-36.27
WH 1160	129.54	125.91	90.61*	105.36*	-30.06	-16.32
SONALIKA	90.89	150.92*	84.01	83.16	-7.58	-44.90
LOK 54	129.16	170.65*	86.24	86.11	-33.23	-49.54
PBW 475	137.95	157.81*	95.28*	85.73	-30.93	-45.68
PBW 503	133.45	132.68	96.39*	89.63	-27.77	-32.44
PBW 175	110.65	110.24	63.46	68.49	-42.65	-37.87
PBW 527	131.60	146.21	90.38*	85.10	-31.33	-41.80
WH 1142	97.24	107.01	59.31	63.03	-39.00	-41.09
WH 1138	135.83	131.01	92.84*	81.26	-31.65	-37.97
HD 2687	114.42	143.04	94.53*	102.19*	-17.38	-28.56
PBW 533	166.56*	126.36	96.02*	79.48	-42.35	-37.10
WH 1061	153.69*	134.74	91.27*	79.95	-40.62	-40.66
HD 2285	117.76	97.31	74.94	64.13	-36.36	-34.09
WH 730	105.18	114.69	77.16	59.51	-26.64	-48.11
C.D	21.971	22.069	8.628	11.84		
S.E(d)	11.015	11.064	4.326	5.557		
C.V	11.164	10.897	6.527	8.592		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 19: Mean performance of genotypes for Zinc use efficiency under low and optimum input conditions

Zinc use efficiency						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	305.90*	257.37	187.88*	169.97	-38.58	-33.96
WH 1080	249.87	165.08	147.98	119.89	-40.78	-27.37
WH 1098	195.43	235.52	155.32	118.08	-20.52	-49.86
WH 1021	180.35	232.89	146.81	130.56	-18.59	-43.94
WH 416	267.71	224.78	164.58	148.46	-38.52	-33.95
DBW 17	291.51*	268.90	175.64	173.63	-39.75	-35.43
WH 711	273.97	275.31	168.31	170.03	-38.57	-38.24
WH 1025	239.48	201.79	126.95	120.74	-46.99	-40.17
PBW 590	284.44	256.97	193.17*	144.39	-32.08	-43.81
RAJ 3765	222.59	210.05	125.76	138.77	-43.50	-33.93
WH 1081	189.15	226.81	160.98	131.44	-14.89	-42.05
C 306	207.32	209.13	123.61	143.35	-40.38	-31.45
PBW 373	171.10	192.85	150.72	142.33	-11.91	-26.20
DPW 621-50	246.00	278.69	201.15*	210.89*	-18.23	-24.33
WH 1105	318.27*	286.46	202.90*	226.87*	-36.25	-20.80
WH 1139	266.39	245.15	173.35	140.13	-34.93	-42.84
PBW 644	286.83*	308.54*	184.23*	180.14	-35.77	-41.61
HD 2967	299.18*	320.53*	187.62*	216.14*	-37.29	-32.57
HD 2851	236.53	185.23	147.40	122.45	-37.68	-33.89
WH 147	265.87	275.33	177.21	182.72*	-33.35	-33.64
WH 1127	210.09	222.88	154.84	155.07	-26.30	-30.42
WH 1063	193.59	223.02	139.13	128.73	-28.13	-42.28
WH 1123	181.55	252.37	140.78	155.02	-22.46	-38.58
WH 1100	170.20	230.93	136.72	174.44	-19.67	-24.46
WH 1140	222.89	244.76	109.82	186.38*	-50.73	-23.85
C 518	183.04	219.51	125.71	139.90	-31.32	-36.27
WH 1160	259.08	251.82	181.21*	210.72*	-30.06	-16.32
SONALIKA	181.79	301.84*	168.02	166.32	-7.58	-44.90
LOK 54	258.32	341.30*	172.48	172.21	-33.23	-49.54
PBW 475	275.90	315.62*	190.56*	171.46	-30.93	-45.68
PBW 503	266.90	265.36	192.78*	179.27	-27.77	-32.44
PBW 175	221.30	220.49	126.92	136.99	-42.65	-37.87
PBW 527	263.21	292.43	180.75*	170.19	-31.33	-41.80
WH 1142	194.48	214.02	118.63	126.07	-39.00	-41.09
WH 1138	271.66	262.02	185.68*	162.53	-31.65	-37.97
HD 2687	228.84	286.08	189.07*	204.37*	-17.38	-28.56
PBW 533	333.13*	252.71	192.04*	158.96	-42.35	-37.10
WH 1061	307.38*	269.48	182.54*	159.90	-40.62	-40.66
HD 2285	235.52	194.62	149.88	128.27	-36.36	-34.09
WH 730	210.35	229.39	154.32	119.02	-26.64	-48.11
C.D	43.942	44.138	17.257	22.168		
S.E(d)	22.03	22.127	8.651	11.113		
C.V	11.164	10.897	6.527	8.592		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Sonalika (10.69 %) , while in 2013-14 WH 1127 (38.17 %) was found most responding genotype above all followed by PBW 503 (37.77 %) and WH 1080 (36.48 %), while lowest response was found in Sonalika (9.38 %) over low input conditions (Table 20).

4.2.20 Root length (cm)

For root length in 2012-13 under low input conditions DBW 17 (44.33 cm) was having highest root length among all the genotypes followed by WH 1100(43.85 cm), WH 1081 (42.33 cm), PBW 373 (42 cm), Sonalika (41.97 cm) and WH 711 (41.67 cm), while genotype DBW 17 (45.33 cm) was having highest mean in 2013-14 followed by WH 1140 (42.03 cm), WH 416 (42 cm), WH 1105 (42 cm) and PBW 373 (41.67 cm). Under optimum input conditions trend was WH 1100 (56.73 cm) possessed highest root length followed by WH 1138 (56.10 cm), PBW 373 (55.43 cm), WH 1142 (55.07 cm), DBW 17 (54 cm), HD 2851 (53.50 cm), WH 1021 (53.27 cm), WH 711 (53.27 cm) and PBW 644 (53.20 cm) in 2012-13, while in 2013-14, WH 147 (53.87 cm) was having highest root length followed by DBW 17 (53.67 cm), WH 1138 (52.83 cm), PBW 373 (52.77 cm), WH 1142 (52.70 cm), WH 1100 (52.03 cm), WH 1098 (51.90 cm) and WH 416 (51.67 cm). WH 147 (37.37 %) was found most responding genotype in 2012-13 followed by WH 1138 (37.00 %) and WH 1142 (35.97 %), while lowest response was observed in WH 1123 (10.41 %) , while in 2013-14 PBW 503 (37.47 %) was found most responding genotype above all followed by WH1138 (33.76 %) and WH 147 (32.46 %), while lowest response was found in Sonalika (9.02 %) over low input conditions (Table 21).

4.3 Variability parameters

The genotypic coefficient of variation (gcv), phenotypic coefficient of variation (pcv), heritability in broad sense (h^2 bs) and genetic advance as percent of mean are given below (Table 22).

4.3.1 Grain yield

Under optimum input conditions the estimates of gcv (15.35 %) and pcv (16.68%) were medium in 2012-13 for grain yield per plant, similarly in 2013-14 gcv (17.76 %) and pcv (19.73 %) came out to be in medium range, while under low input conditions estimates of gcv (17.29 %) and pcv (20.58%) in 2012-13 were on medium side range, similarly in 2013-14, estimates of gcv (14.72 %) and pcv (18.31 %) were medium. The heritability in broad sense was high (84.68%) and genetic advance as percentage of mean was also moderate (29.10%) in 2012-13. In 2013-14, under optimum input conditions heritability in broad sense was high (81.03 %) and genetic advance was on lower side (7.83 %). This indicated considerable scope of selection for grain yield. While under low input conditions the heritability in broad sense was high (70.57%) and genetic advance as percentage of mean was low (5.42%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was moderate (64.61 %) and genetic advance was on lower side (4.55 %) (Table 22).

Table 20: Mean performance of genotypes for Root Biomass under low and optimum input conditions

Root Biomass						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	4.61	4.40	5.89*	5.73*	27.75	30.15
WH 1080	4.40	4.07	5.76	5.55	30.98	36.48
WH 1098	4.37	4.37	5.66	5.89*	29.54	34.89
WH 1021	4.40	4.50	5.83	5.75*	32.42	27.70
WH 416	4.17	4.70*	5.57	5.87*	33.60	24.82
DBW 17	5.13*	5.10*	5.90*	6.07*	14.94	18.95
WH 711	4.57	4.33	5.78	5.51	26.57	27.23
WH 1025	4.30	4.37	5.69	5.42	32.25	24.12
PBW 590	4.00	3.73	4.53	4.80	13.33	28.57
RAJ 3765	4.37	4.30	5.72	5.43	31.07	26.20
WH 1081	4.40	4.43	5.75	5.45	30.76	23.01
C 306	4.47	4.50	5.57	5.41	24.78	20.15
PBW 373	4.80	4.67*	6.04*	5.98*	25.90	28.07
DPW 621-50	4.13	4.27	5.41	5.56	30.81	30.39
WH 1105	4.43	4.73*	5.57	5.27	25.56	11.27
WH 1139	4.13	3.73	5.30	5.07	28.23	35.71
PBW 644	4.37	4.27	5.82	5.31	33.28	24.45
HD 2967	4.27	3.75	5.35	4.92	25.39	31.11
HD 2851	4.51	4.48	5.85	5.43	29.62	21.28
WH 147	4.50	4.57	5.72	6.09*	27.11	33.28
WH 1127	4.34	3.97	5.52	5.49	27.19	38.17
WH 1063	4.33	4.26	5.51	5.68	27.23	33.44
WH 1123	3.79	3.84	4.53	4.45	19.42	15.78
WH 1100	4.43	4.54	6.17*	5.80*	39.46	27.92
WH 1140	4.28	4.04	5.60	5.50	30.94	36.17
C 518	4.30	4.50	5.68	5.19	31.99	15.41
WH 1160	4.27	4.21	5.63	5.13	31.88	21.77
SONALIKA	4.90*	4.62*	5.42	5.05	10.69	9.38
LOK 54	4.58	4.15	5.63	5.33	23.00	28.62
PBW 475	4.33	4.30	5.50	5.05	26.94	17.43
PBW 503	4.51	4.10	5.15	5.65	14.35	37.77
PBW 175	4.42	4.59	5.49	5.06	24.19	10.24
PBW 527	4.23	4.17	4.87	5.08	14.96	22.00
WH 1142	4.68*	4.53	6.11*	5.97*	30.39	31.89
WH 1138	4.39	4.45	6.11*	5.98*	39.07	34.46
HD 2687	4.50	4.20	5.58	5.07	24.17	20.63
PBW 533	4.09	4.05	5.31	5.45	29.75	34.65
WH 1061	3.64	4.02	4.79	5.07	31.62	26.10
HD 2285	4.48	4.37	5.38	5.76*	20.09	31.98
WH 730	4.16	4.37	5.35	5.55	28.42	26.93
C.D	0.3	0.309	0.335	0.302		
S.E(d)	0.15	0.155	0.168	0.152		
C.V	4.211	4.394	3.708	3.408		

*, **: significant at 5% and 1% level of significance respectively. C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

Table 21: Mean performance of genotypes for Root length under low and optimum input conditions

Root length						
T.aestivum						
Genotypes	**Low input**		**Optimum input**		**% of increase over low input conditions**	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WH 542	39.13	39.00	51.27	50.27	31.01	28.89
WH 1080	39.67	38.00	52.63	48.50	32.69	27.63
WH 1098	38.00	40.00	50.90	51.90*	33.95	29.75
WH 1021	40.67	40.00	53.27*	50.47	30.98	26.17
WH 416	37.17	42.00*	49.77	51.67*	33.90	23.02
DBW 17	44.33	45.33*	54.00*	53.67*	21.80	18.38
WH 711	41.67*	38.33	53.27*	50.45	27.84	31.60
WH 1025	40.00	38.67	51.87	47.20	29.67	22.07
PBW 590	37.00	32.33	46.85	42.23	26.63	30.62
RAJ 3765	40.33	38.00	52.23	49.23	29.50	29.56
WH 1081	42.33*	39.33	52.87	49.51	24.88	25.88
C 306	39.00	38.67	50.73	47.07	30.09	21.72
PBW 373	42.00*	41.67*	55.43*	52.77*	31.98	26.64
DPW 621-50	38.17	38.33	49.07	48.63	28.54	26.87
WH 1105	39.00	42.00*	50.67	49.21	29.91	17.16
WH 1139	37.00	36.33	48.00	43.67	29.73	20.18
PBW 644	41.33	37.67	53.20*	49.77	28.71	32.12
HD 2967	38.00	33.83	48.50	44.17	27.63	30.54
HD 2851	40.60	39.80	53.50*	49.00	31.77	23.12
WH 147	38.00	40.67	52.20	53.87*	37.37	32.46
WH 1127	39.67	38.80	50.20	47.90	26.55	23.45
WH 1063	37.27	39.97	49.13	50.80	31.84	27.11
WH 1123	38.27	35.75	42.25	47.17	10.41	31.95
WH 1100	43.85*	40.23	56.73*	52.03*	29.37	29.33
WH 1140	40.27	42.03	50.00	47.97	24.17	14.12
C 518	40.19	40.00	51.80	48.93	28.88	22.33
WH 1160	37.67	37.10	50.27	45.93	33.45	23.81
SONALIKA	41.97*	39.93	49.20	43.53	17.24	9.02
LOK 54	38.80	36.47	51.33	46.33	32.30	27.06
PBW 475	39.30	36.77	49.97	43.53	27.14	18.40
PBW 503	38.07	36.03	46.53	49.53	22.24	37.47
PBW 175	37.23	33.65	49.93	43.60	34.11	29.58
PBW 527	35.33	36.67	43.67	43.83	23.58	19.55
WH 1142	40.50	40.27	55.07*	52.70*	35.97	30.88
WH 1138	40.95	39.50	56.10*	52.83*	37.00	33.76
HD 2687	39.13	37.00	50.83	46.90	29.90	26.76
PBW 533	37.36	36.17	49.07	47.53	31.35	31.43
WH 1061	32.15	35.23	42.87	43.73	33.35	24.12
HD 2285	37.80	38.67	48.80	50.63	29.10	30.95
WH 730	37.18	38.70	48.47	48.47	30.35	25.24
C.D	2.323	2.468	2.501	2.733		
S.E(d)	1.165	1.237	1.254	1.37		
C.V	3.643	3.938	3.037	3.465		

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

4.3.2 Plant height

Under optimum input conditions the estimates of gcv (8.94 %) and pcv (10.39%) were low in 2012-13 for plant height, similarly in 2013-14 gcv (7.84 %) and pcv (10.65 %) came out to be in low range, while under low input conditions estimates of gcv (10.84 %) and pcv (12.16%) in 2012-13 were on medium side range, similarly in 2013-14, estimates of gcv (7.45 %) and pcv (11.99 %) were low and medium respectively. The heritability in broad sense was high (74.04%) and genetic advance as percentage of mean was also moderate (15.84%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (54.19 %) and genetic advance was on medium range side (11.57 %). While under low input conditions the heritability in broad sense was moderate (65.81%) and genetic advance as percentage of mean was moderate (15.68%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was low (38.63 %) and genetic advance was also on lower side (8.02 %) (Table22).

4.3.3 Biomass per plant

Under optimum input conditions the estimates of gcv (14.34 %) and pcv (14.85%) were low in 2012-13 for biomass per plant , similarly in 2013-14 gcv (13.70 %) and pcv (14.14 %) came out to be in low range, while under low input conditions estimates of gcv (11.80 %) and pcv (12.16%) in 2012-13 were on medium side range, similarly in 2013-14, estimates of gcv (11.72 %) and pcv (12.14 %) were medium. The heritability in broad sense was high (93.35%) and genetic advance as percentage of mean was also moderate (28.55%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (93.77 %) and genetic advance was on medium range side (16.23 %). While under low input conditions the heritability in broad sense was high (94.03%) and genetic advance as percentage of mean was moderate (12.24%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was high (93.17 %) and genetic advance was also on moderate side (12.16 %) (Table 22).

4.3.4 Harvest index

Under optimum input conditions the estimates of gcv (2.72 %) and pcv (7.44%) were low in 2012-13 for harvest index, similarly in 2013-14 gcv (13.30 %) and pcv (15.32 %) came out to be in medium range, while under low input conditions estimates of gcv (7.52 %) and pcv (12.86%) in 2012-13 were on low and medium side range respectively, similarly in 2013-14, estimates of gcv (7.98 %) and pcv (12.63%) were also in low and medium range respectively. The heritability in broad sense was low (13.36%) and genetic advance as percentage of mean was also low (2.05%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (75.49 %) and genetic advance was on low range side (9.55 %).

Table 22: Genotypic coefficient of variation, Phenotypic coefficient of variation, Heritability and Genetic Advance for various traits

		G.C.V (%)		P.C.V (%)		Heritability (%)		Genetic advance (as percent of mean)	
Character		**2013**	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**
PH	**O**	8.94	7.84	10.39	10.65	74.04	54.19	15.84	11.57
	L	10.84	7.45	13.63	11.99	65.81	38.63	15.68	8.02
BPP	**O**	14.34	13.70	14.85	14.14	93.35	93.77	28.55	16.23
	L	11.80	11.72	12.16	12.14	94.03	93.17	12.24	12.16
HI	**O**	2.72	13.30	7.44	15.32	13.36	75.49	2.05	9.55
	L	7.52	7.98	12.86	12.63	34.14	39.92	3.14	3.71
CF	**O**	2.37	4.64	3.48	5.58	46.46	68.98	3.33	0.07
	L	1.49	4.08	4.60	5.56	10.43	53.92	0.01	0.05
CC	**O**	11.09	8.12	11.95	14.13	86.10	32.98	21.20	3.81
	L	11.95	7.18	13.85	15.68	74.48	20.94	7.24	2.21
GY	**O**	15.35	17.76	16.68	19.73	84.68	81.03	29.10	7.83
	L	17.29	14.72	20.58	18.31	70.57	64.61	5.42	4.55
1000-Gr. Wt	**O**	6.01	5.07	7.24	6.48	68.99	61.43	10.29	3.50
	L	6.73	6.03	7.96	7.43	71.48	65.82	4.34	3.72
NTPP	**O**	13.91	11.23	16.90	14.82	67.77	57.40	23.60	2.22
	L	12.63	11.55	16.36	15.69	59.56	54.25	2.03	1.82
SPS	**O**	7.69	7.48	10.12	9.93	57.77	56.76	12.05	2.74
	L	7.31	4.96	10.26	9.75	50.78	25.90	2.08	0.98
GPS	**O**	6.77	5.66	7.84	6.75	74.75	70.17	12.07	4.46
	L	6.03	7.32	7.43	8.20	65.89	79.71	3.89	5.17
DTH	**O**	0.56	3.29	1.06	3.63	28.50	82.23	0.62	5.45
	L	0.41	2.36	1.10	2.74	14.02	73.87	0.27	3.68
DTM	**O**	3.27	2.96	3.63	3.42	81.68	74.80	6.10	6.55
	L	1.70	1.35	2.06	2.38	68.00	31.79	3.38	1.90
N content	**O**	7.36	7.09	8.21	8.54	80.49	68.78	13.61	0.24
	L	6.12	6.86	8.61	9.19	50.54	55.75	0.15	0.17
P content	**O**	13.27	12.61	13.7	13.10	93.94	92.72	26.51	1.51
	L	15.37	14.81	15.99	15.35	92.38	93.11	1.50	1.43
Zn content	**O**	14.02	14.12	14.65	14.80	91.65	90.96	27.66	16.10
	L	13.41	11.52	14.15	12.46	89.85	85.36	12.35	10.21
Root biomass	**O**	6.45	6.60	7.44	7.43	75.18	78.96	11.53	0.66
	L	5.54	6.28	6.96	7.66	63.40	67.13	0.40	0.46
Root length	**O**	6.16	6.22	6.87	7.11	80.44	76.27	11.38	5.42
	L	5.43	6.22	6.54	7.36	68.99	71.37	3.64	4.16

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

While under low input conditions the heritability in broad sense was low (34.14%) and genetic advance as percentage of mean was low (3.14%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was low (39.92 %) and genetic advance was also on lower side (3.71 %) (Table 22).

4.3.5 Chlorophyll fluorescence

Under optimum input conditions the estimates of gcv (2.37%) and pcv (3.48%) were low in 2012-13 for chlorophyll fluorescence, similarly in 2013-14 gcv (4.64 %) and pcv (5.58 %) came out to be in lower range, while under low input conditions estimates of gcv (1.49 %) and pcv (4.60%) in 2012-13 were on lower side range, similarly in 2013-14, estimates of gcv (4.08 %) and pcv (5.56%) were also in lower side. The heritability in broad sense was moderate (46.46%) and genetic advance as percentage of mean was also low (3.33%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (68.98 %) and genetic advance was on low range side (0.07 %). While under low input conditions the heritability in broad sense was low (10.43%) and genetic advance as percentage of mean was low (0.01%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was moderate (53.92 %) and genetic advance was also on lower side (0.05 %) (Table 22).

4.3.6 Chlorophyll content

Under optimum input conditions the estimates of gcv (11.09%) and pcv (11.95%) were medium in 2012-13 for chlorophyll content, similarly in 2013-14 gcv (8.12 %) and pcv (14.13 %) came out to be in lower range, while under low input conditions estimates of gcv (11.95 %) and pcv (13.85%) in 2012-13 were low and medium respectively, similarly in 2013-14, estimates of gcv (7.18 %) and pcv (15.68%) were also in low and medium side respectively. The heritability in broad sense was high (86.10%) and genetic advance as percentage of mean was medium (21.20%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (32.98 %) and genetic advance was on low range side (3.81 %). While under low input conditions the heritability in broad sense was high (74.48%) and genetic advance as percentage of mean was low (7.24%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was low (20.94 %) and genetic advance was also on lower side (2.21 %) (Table 22).

4.3.7 1000- grain weight

Under optimum input conditions the estimates of gcv (6.01%) and pcv (7.24%) were low in 2012-13 for 1000 grain weight, similarly in 2013-14 gcv (5.07 %) and pcv (6.48 %) came out to be in lower range, while under low input conditions estimates of gcv (6.73 %) and pcv (7.96%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (6.03 %) and pcv (7.43%) were also in lower side. The heritability in broad sense was high (68.99%) and genetic advance as percentage of mean was low (10.29%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (61.43 %) and genetic advance was on low range side (3.50 %). While under low input conditions the heritability in broad sense was high (71.48%) and genetic advance as percentage of mean was low (4.34%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was moderate (65.82 %) and genetic advance was also on lower side (3.72 %) (Table 22).

4.3.8 Number of tillers per plant

Under optimum input conditions the estimates of gcv (13.91%) and pcv (16.90%) were moderate in 2012-13 for number of tillers per plant, similarly in 2013-14 gcv (11.23 %) and pcv (14.82 %) came out to be in moderate range, while under low input conditions estimates of gcv (12.63 %) and pcv (16.36%) in 2012-13 were moderate, similarly in 2013-14, estimates of gcv (11.55 %) and pcv (16.36%) were also in moderate side. The heritability in broad sense was high (67.77%) and genetic advance as percentage of mean was high (23.60%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (57.40 %) and genetic advance was on low range side (2.22 %). While under low input conditions the heritability in broad sense was moderate (59.56%) and genetic advance as percentage of mean was low (2.03%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was moderate (54.25 %) and genetic advance was also on lower side (1.82 %) (Table 22).

4.3.9 Spikelets per spike

Under optimum input conditions the estimates of gcv (7.69%) and pcv (10.12%) were low in 2012-13 for spikelets per spike, similarly in 2013-14 gcv (7.48 %) and pcv (9.93 %) came out to be in lower range, while under low input conditions estimates of gcv (7.31 %) and pcv (10.26%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (4.96 %) and pcv (9.75%) were also in lower side. The heritability in broad sense was moderate (57.77%) and genetic advance as percentage of mean was low (12.05%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (56.76 %) and genetic advance was on low range side (2.74 %). While under low input conditions the heritability in broad sense was moderate (50.78%) and genetic advance as percentage of mean was low (2.08%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was low (25.90 %) and genetic advance was also on lower side (0.98 %) (Table 22).

4.3.10 Grains per spike

Under optimum input conditions the estimates of gcv (6.77%) and pcv (7.84%) were low in 2012-13 for grains per spike, similarly in 2013-14 gcv (5.66 %) and pcv (6.75 %) came out to be in lower range, while under low input conditions estimates of gcv (6.03 %) and pcv (7.43%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (7.32 %) and pcv (8.20%) were also in lower side. The heritability in broad sense was moderate (74.75%) and genetic advance as percentage of mean was low (12.07%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (70.17 %) and genetic advance was on low range side (4.46 %). While under low input conditions the heritability in broad sense was moderate (65.89%) and genetic advance as percentage of mean was low (3.89%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was high (79.71 %) and genetic advance was also on lower side (5.17 %) (Table 22).

4.3.11 Days to heading

Under optimum input conditions the estimates of gcv (0.56%) and pcv (1.06%) were low in 2012-13 for days to heading, similarly in 2013-14 gcv (3.29 %) and pcv (3.63 %) came out to be in lower range, while under low input conditions estimates of gcv (0.41 %) and pcv (1.10%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (2.36 %) and pcv (2.74%) were also in lower side. The heritability in broad sense was low (28.50%) and genetic advance as percentage of mean was low (0.62%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (82.23 %) and genetic advance was on low range side (5.45 %). While under low input conditions the heritability in broad sense was low (14.02%) and genetic advance as percentage of mean was low (0.27%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was high (73.87 %) and genetic advance was also on lower side (3.68 %) (Table 22).

4.3.12 Days to maturity

Under optimum input conditions the estimates of gcv (3.27%) and pcv (3.63%) were low in 2012-13 for days to maturity, similarly in 2013-14 gcv (2.96 %) and pcv (3.42 %) came out to be in lower range, while under low input conditions estimates of gcv (1.70 %) and pcv (2.06%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (1.35 %) and pcv (2.38%) were also in lower side. The heritability in broad sense was high (81.68%) and genetic advance as percentage of mean was low (6.10%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (74.80 %) and genetic advance was on low range side (6.55 %). While under low input conditions the heritability in broad sense was moderate (68.00%) and genetic advance as percentage of mean was low (3.38%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was low (31.79 %) and genetic advance was also on lower side (1.90 %) (Table 22).

4.3.13 Nitrogen content in grains

Under optimum input conditions the estimates of gcv (7.36%) and pcv (8.21%) were low in 2012-13 for N content, similarly in 2013-14 gcv (7.09 %) and pcv (8.54 %) came out to be in lower range, while under low input conditions estimates of gcv (6.12 %) and pcv (8.61%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (6.86 %) and pcv (9.19%) were also in lower side. The heritability in broad sense was high (80.49%) and genetic advance as percentage of mean was low (13.61%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was moderate (68.78 %) and genetic advance was on low range side (0.24%). While under low input conditions the heritability in broad sense was moderate (50.54%) and genetic advance as percentage of mean was low (0.15%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was low (55.75 %) and genetic advance was also on lower side (0.17 %) (Table 22).

4.3.14 P content in grains

Under optimum input conditions the estimates of gcv (13.27%) and pcv (13.7%) were moderate in 2012-13 for P content, similarly in 2013-14 gcv (12.61 %) and pcv (13.10 %) came out to be in medium range, while under low input conditions estimates of gcv (15.37 %) and pcv (15.99%) in 2012-13 were medium, similarly in 2013-14, estimates of gcv (14.81 %) and pcv (15.35%) were also in moderate side. The heritability in broad sense was high (93.94%) and genetic advance as percentage of mean was moderate (26.51%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (92.72 %) and genetic advance was on low range side (1.51%). While under low input conditions the heritability in broad sense was high (92.38%) and genetic advance as percentage of mean was low (1.50%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was high (93.11 %) and genetic advance was on lower side (1.43 %) (Table 22).

4.3.15 Zinc content in grains

Under optimum input conditions the estimates of gcv (14.02%) and pcv (14.65%) were moderate in 2012-13 for Zn content, similarly in 2013-14 gcv (14.12 %) and pcv (14.80 %) came out to be in medium range, while under low input conditions estimates of gcv (13.41 %) and pcv (14.15%) in 2012-13 were medium, similarly in 2013-14, estimates of gcv (11.52 %) and pcv (12.46%) were also in moderate side. The heritability in broad sense was high (91.65%) and genetic advance as percentage of mean was moderate (27.66%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (90.96 %) and genetic advance was on moderate range side (16.10%). While under low input conditions the heritability in broad sense was high (89.85%) and genetic advance as percentage of mean was moderate (12.35%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was high (85.36 %) and genetic advance was on moderate side (10.21 %) (Table 22).

4.3.16 Root biomass

Under optimum input conditions the estimates of gcv (6.45%) and pcv (7.44%) were low in 2012-13 for root biomass, similarly in 2013-14 gcv (6.60 %) and pcv (7.43 %) came out to be in lower range, while under low input conditions estimates of gcv (5.54 %) and pcv (6.96%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (6.28 %) and pcv (7.66%) were also in lower side. The heritability in broad sense was high (75.18%) and genetic advance as percentage of mean was moderate (11.53%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (78.96 %) and genetic advance was on lower range side (0.66%). While under low input conditions the heritability in broad sense was moderate (63.40%) and genetic advance as percentage of mean was low (0.40%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was moderate (67.13 %) and genetic advance was on low side (0.46%) (Table 22).

4.3.17 Root length

Under optimum input conditions the estimates of gcv (6.16%) and pcv (6.87%) were low in 2012-13 for root length, similarly in 2013-14 gcv (6.22 %) and pcv (7.11 %) came out to be in lower range, while under low input conditions estimates of gcv (5.43 %) and pcv (6.54%) in 2012-13 were low, similarly in 2013-14, estimates of gcv (6.22 %) and pcv (7.36%) were also in lower side. The heritability in broad sense was high (80.44%) and genetic advance as percentage of mean was moderate (11.38%) in 2012-13under optimum input conditions. In 2013-14, under optimum input conditions heritability in broad sense was high (76.27 %) and genetic advance was on lower range side (5.42%). While under low input conditions the heritability in broad sense was moderate (68.99%) and genetic advance as percentage of mean was low (3.64%) in 2012-13. In 2013-14, under low input conditions heritability in broad sense was moderate (71.37 %) and genetic advance was on low side (4.16%) (Table 22).

4.4 Correlation coefficients

Genotypic and phenotypic correlation coefficients among various characters are shown in Table 23,24,25 and Table26. The magnitude of the genotypic correlations was higher than their corresponding phenotypic correlations for almost all of the characters under both conditions. This indicated the association at genotypic level and control of sampling error.

4.4.1 Grain yield and its components

Under optimum input conditions grain yield per plant was significantly positively correlated with biomass per plant (r=0.892**), harvest index (r= 0.450**) and spikelets per spike (r= 0.278**) and significantly negatively correlated with plant height (r= -0.265*), root biomass (r= -0.239**) and root length (r=-0.225*) in 2012-13, while in 2013-14, grain yield per plant was significantly positively correlated with harvest index (r=0.678**), biomass per plant (r= 0.651**), 1000- grain weight (0.413 **), days to maturity (r=0.242**) and P content (r=0.181*) and significantly negatively correlated with root biomass (r=-0.183*).In 2012-13 under low input conditions grain yield showed significant positive correlations with harvest index (r=0.830**), biomass per plant (r= 0.796**) and significantly negatively correlated with root length (r=-0.254 **), while in 2013-14 grain yield showed significantly positive correlation with harvest index (r= 0.757**), biomass per plant (r=0.723**), chlorophyll fluorescence (r= 0.227*) and spikelets per spike (r =0.283**). Root biomass was significantly positively correlated with root length (r=0.911**).biomass per plant was significantly negatively correlated with root length (r= -0.267**). Days to heading was significantly correlated P content (r=0.187*) and root biomass (r=0.198*) under low input conditions in 2012-13.

4.5 Path coefficient

The direct and indirect effects of various characters along with their genotypic correlation under optimum and low input conditions are presented in (Table27 and Table 28). The residual effects under optimum and low input conditions were 0.00306 and 0.00444 respectively in 2012-13, while the corresponding figures in 2013-14 were 0.00619 and 0.00444 respectively. This indicated that a considerable magnitude of variation was present for association of grain yield with the dependent traits under both conditions. The direct effects revealed that biomass per plant under optimum input conditions had (0.886) and (0.741) in 2012-13 and 2013-14 respectively, while under low input conditions had (0.584) and (0.657) in 2012-13 and 2013-14 respectively, was the most important trait indicating association with grain yield followed by harvest index (0.450 and 0.785 under optimum, 0.644 and 0.687 under low in 2012-13 and 2013-14 respectively). Under optimum input conditions spikelets per spike had high indirect contribution towards yield via biomass per plant (0.271) in 2012-13. Under low input conditions spikelets per spike also had high indirect effect (0.104) via biomass per plant followed by harvest index (0.0.193) in 2012-13, while in 2013-14 spikelets per spike under low input conditions had high indirect effect (0.162) via harvest index followed by plant height (0.104). In 2013-14, under optimum input conditions 1000- grain weight had highest indirect effect (0.412) through harvest index towards grain yield followed by spikelets per spike (0.222) via biomass per plant.

Implications of nutrient use efficiency

The experimental results summarized in Table 30 revealed some promising genotypes in common for grain yield and its components, nutrient use characters and root traits under both low and optimum input conditions in both seasons viz. WH 1105 for grain yield per plant, Sonalika and HD 2967 for 1000-grain weight, WH 1105, WH 1127 and DPW 621-50 for number of tillers per plant, WH 147 for spikelets per spike, HD 2851 for grains per spike. Similarly, for nutrient use characters, LOK 54 for N content in grains, WH 1105, Sonalika and PBW 373 for P content in grains, DBW 17, PBW 175, WH 711 and WH 1100 for Zn content in grains, HD 2967 and PBW 644 for Nitrogen use efficiency as well as Phosphorous use efficiency both, WH 1105 for Zinc use efficiency. Similarly, for root traits, DBW 17 and PBW 373 for root biomass and DBW 17 for root length. These results show considerable variability among genotypes for the characters under study, which further indicate the scope of developing promising genotypes through magic breeding programme (crossing among better genotypes for most of the traits) like WH 1105, HD 2967, DBW 17 followed by selection in segregating generations may lead to identification of physiologically efficient and high yielding genotypes coupled with better nutrient use under low as well as optimum input conditions. Also, genotypes resistant to both low and optimum input conditions may be identified.

Table23: Phenotypic (Above diagonal) and Genotypic (Below diagonal) Correlation coefficiencts of various characters under optimum input conditions in year 2012-13.

	PH	BPP	HI	Ch. Flu	C.C	GY	1000-gr-wt	NTPP	SPS	GPS	DTH	DTM	Ncontent	Pcontent	Zn content	R. Biomass	Root Lth
PH		-0.295^{**}	-0.012^{NS}	-0.072^{NS}	-0.213^{*}	-0.265^{**}	0.145^{NS}	-0.001^{NS}	-0.136^{NS}	-0.021^{NS}	-0.026^{NS}	0.169^{NS}	0.030^{NS}	-0.374^{**}	-0.101^{NS}	-0.038^{NS}	-0.072^{NS}
BPP	-0.362^{**}		0.003^{NS}	0.108^{NS}	-0.008^{NS}	0.892^{**}	0.149^{NS}	-0.048^{NS}	0.306^{**}	-0.040^{NS}	0.096^{NS}	-0.014^{NS}	0.066^{NS}	0.188^{*}	0.066^{NS}	-0.204^{*}	-0.204^{*}
HI	-0.029^{NS}	0.281^{**}		0.107^{NS}	-0.075^{NS}	0.450^{**}	0.057^{NS}	0.233^{*}	-0.010^{NS}	0.046^{NS}	-0.058^{NS}	-0.134^{NS}	-0.056^{NS}	-0.105^{NS}	-0.175^{NS}	-0.135^{NS}	-0.105^{NS}
Ch. Flu	-0.066^{NS}	0.197^{*}	0.119^{NS}		0.040^{NS}	0.141^{NS}	0.121^{NS}	0.082^{NS}	0.086^{NS}	0.155^{NS}	0.041^{NS}	0.232^{*}	-0.059^{NS}	0.012^{NS}	0.099^{NS}	-0.083^{NS}	-0.166^{NS}
C.C	-0.300^{**}	-0.017^{NS}	-0.289^{**}	0.073^{NS}		-0.032^{NS}	-0.068^{NS}	-0.117^{NS}	-0.147^{NS}	-0.066^{NS}	0.163^{NS}	0.008^{NS}	-0.182^{*}	-0.078^{NS}	-0.041^{NS}	0.196^{*}	0.153^{NS}
GY	-0.338^{**}	0.984^{**}	0.444^{**}	0.211^{*}	-0.055^{NS}		0.162^{NS}	0.064^{NS}	0.278^{**}	-0.024^{NS}	0.061^{NS}	-0.064^{NS}	0.030^{NS}	0.120^{NS}	-0.018^{NS}	-0.239^{**}	-0.225^{*}
1000-gr-wt	0.148^{NS}	0.128^{NS}	0.087^{NS}	0.227^{*}	-0.093^{NS}	0.138^{NS}		-0.090^{NS}	0.015^{NS}	-0.002^{NS}	-0.100^{NS}	0.124^{NS}	0.116^{NS}	0.031^{NS}	-0.069^{NS}	0.167^{NS}	0.087^{NS}
NTPP	0.026^{NS}	-0.058^{NS}	0.842^{**}	-0.031^{NS}	-0.127^{NS}	0.099^{NS}	-0.152^{NS}		0.084^{NS}	0.258^{**}	0.018^{NS}	-0.223^{*}	-0.183^{*}	-0.100^{NS}	-0.111^{NS}	0.046^{NS}	0.029^{NS}
SPS	-0.222^{*}	0.422^{**}	0.111^{NS}	0.119^{NS}	-0.208^{*}	0.422^{**}	0.044^{NS}	0.134^{NS}		0.292^{**}	0.057^{NS}	-0.112^{NS}	0.063^{NS}	0.044^{NS}	-0.069^{NS}	-0.048^{NS}	-0.107^{NS}
GPS	-0.066^{NS}	-0.043^{NS}	0.171^{NS}	0.339^{**}	-0.098^{NS}	-0.015^{NS}	-0.002^{NS}	0.393^{**}	0.378^{**}		0.195^{*}	-0.039^{NS}	-0.088^{NS}	-0.258^{**}	0.015^{NS}	0.003^{NS}	-0.060^{NS}
DTH	-0.087^{NS}	0.090^{NS}	0.117^{NS}	0.326^{**}	0.296^{**}	0.107^{NS}	-0.387^{**}	0.063^{NS}	0.464^{**}	0.344^{**}		0.069^{NS}	-0.286^{**}	-0.244^{**}	0.118^{NS}	0.041^{NS}	-0.005^{NS}
DTM	0.218^{*}	-0.006^{NS}	-0.334^{**}	0.463^{**}	0.024^{NS}	-0.059^{NS}	0.192^{*}	-0.327^{**}	-0.049^{NS}	-0.051^{NS}	0.099^{NS}		0.178^{NS}	0.002^{NS}	0.128^{NS}	0.014^{NS}	-0.020^{NS}
Ncontent	0.050^{NS}	0.063^{NS}	-0.136^{NS}	0.069^{NS}	-0.240^{**}	0.029^{NS}	0.173^{NS}	-0.225^{*}	0.073^{NS}	-0.085^{NS}	-0.635^{**}	0.205^{*}		0.245^{**}	0.131^{NS}	0.119^{NS}	0.027^{NS}
Pcontent	-0.419^{**}	0.205^{*}	-0.223^{*}	-0.022^{NS}	-0.082^{NS}	0.151^{NS}	0.057^{NS}	-0.147^{NS}	0.035^{NS}	-0.301^{**}	-0.443^{**}	0.011^{NS}	0.304^{**}		0.143^{NS}	0.049^{NS}	0.091^{NS}
Zn content	-0.129^{NS}	0.063^{NS}	-0.440^{**}	0.176^{NS}	-0.059^{NS}	-0.018^{NS}	-0.099^{NS}	-0.106^{NS}	-0.065^{NS}	-0.001^{NS}	0.137^{NS}	0.155^{NS}	0.151^{NS}	0.147^{NS}		0.119^{NS}	0.187^{*}
R. Biomass	0.000^{NS}	-0.258^{**}	-0.276^{**}	-0.171^{NS}	0.238^{**}	-0.297^{**}	0.179^{NS}	0.099^{NS}	-0.106^{NS}	0.036^{NS}	0.235^{**}	0.028^{NS}	0.129^{NS}	0.037^{NS}	0.126^{NS}		0.911^{**}
Root Lth	-0.040^{NS}	-0.251^{**}	-0.143^{NS}	-0.224^{*}	0.185^{*}	-0.265^{**}	0.108^{NS}	0.112^{NS}	-0.146^{NS}	-0.046^{NS}	0.130^{NS}	-0.030^{NS}	0.027^{NS}	0.108^{NS}	0.189^{*}	0.973^{**}	

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

Table 24: Phenotypic (Above diagonal) and Genotypic (Below diagonal) Correlation coefficiencts of various characters under Low input conditions in year 2012-13.

	PH	BPP	HI	Ch. Flu	C.C	GY	1000-gr-wt	NTPP	SPS	GPS	DTH	DTM	Ncontent	Pcontent	Zn content	R. Biomass	Root Lth
PH		-0.188^{*}	-0.032^{NS}	-0.138^{NS}	-0.198^{*}	-0.134^{NS}	0.017^{NS}	0.070^{NS}	-0.029^{NS}	-0.041^{NS}	-0.027^{NS}	-0.074^{NS}	0.236^{**}	-0.256^{**}	-0.026^{NS}	-0.158^{NS}	-0.150^{NS}
BPP	-0.282^{**}		0.332^{**}	-0.100^{NS}	0.090^{NS}	0.796^{**}	-0.000^{NS}	-0.029^{NS}	0.178^{NS}	0.156^{NS}	0.063^{NS}	0.060^{NS}	-0.053^{NS}	0.114^{NS}	-0.031^{NS}	-0.127^{NS}	-0.267^{**}
HI	-0.016^{NS}	0.633^{**}		-0.105^{NS}	-0.087^{NS}	0.830^{**}	-0.156^{NS}	0.112^{NS}	-0.098^{NS}	0.073^{NS}	-0.063^{NS}	0.075^{NS}	0.128^{NS}	-0.156^{NS}	-0.061^{NS}	-0.063^{NS}	-0.177^{NS}
Ch. Flu	-0.331^{**}	-0.300^{**}	-0.201^{*}		0.073^{NS}	-0.126^{NS}	-0.216^{*}	-0.004^{NS}	-0.125^{NS}	0.048^{NS}	-0.017^{NS}	-0.030^{NS}	-0.062^{NS}	0.065^{NS}	0.145^{NS}	0.053^{NS}	-0.122^{NS}
C.C	-0.277^{**}	0.113^{NS}	-0.118^{NS}	-0.072^{NS}		0.008^{NS}	0.155^{NS}	-0.065^{NS}	0.229^{*}	0.031^{NS}	-0.120^{NS}	0.079^{NS}	-0.177^{NS}	-0.024^{NS}	-0.049^{NS}	-0.034^{NS}	0.020^{NS}
GY	-0.202^{*}	0.956^{**}	0.833^{**}	-0.266^{**}	0.037^{NS}		-0.099^{NS}	0.053^{NS}	0.053^{NS}	0.138^{NS}	-0.017^{NS}	0.093^{NS}	0.040^{NS}	-0.023^{NS}	-0.061^{NS}	-0.112^{NS}	-0.254^{**}
1000-gr-wt	-0.013^{NS}	0.014^{NS}	-0.254^{**}	-0.332^{**}	0.172^{NS}	-0.099^{NS}		-0.245^{**}	0.003^{NS}	-0.080^{NS}	-0.023^{NS}	-0.101^{NS}	-0.030^{NS}	0.154^{NS}	-0.282^{**}	0.081^{NS}	0.039^{NS}
NTPP	-0.059^{NS}	-0.055^{NS}	0.181^{*}	0.002^{NS}	-0.104^{NS}	0.036^{NS}	-0.446^{**}		0.185^{*}	0.177^{NS}	-0.006^{NS}	0.030^{NS}	-0.071^{NS}	-0.056^{NS}	-0.074^{NS}	-0.024^{NS}	-0.038^{NS}
SPS	-0.139^{NS}	0.283^{**}	-0.150^{NS}	-0.209^{*}	0.434^{**}	0.150^{NS}	-0.050^{NS}	0.299^{**}		0.458^{**}	-0.069^{NS}	-0.043^{NS}	-0.007^{NS}	-0.100^{NS}	-0.029^{NS}	-0.143^{NS}	-0.090^{NS}
GPS	-0.096^{NS}	0.215^{*}	-0.018^{NS}	0.018^{NS}	0.075^{NS}	0.142^{NS}	-0.154^{NS}	0.270^{**}	0.582^{**}		0.085^{NS}	-0.085^{NS}	-0.007^{NS}	-0.073^{NS}	0.027^{NS}	-0.126^{NS}	-0.113^{NS}
DTH	-0.245^{**}	0.118^{NS}	0.161^{NS}	0.038^{NS}	-0.242^{**}	0.121^{NS}	-0.053^{NS}	-0.058^{NS}	-0.267^{**}	-0.037^{NS}		-0.153^{NS}	0.133^{NS}	0.187^{*}	0.059^{NS}	0.198^{*}	0.114^{NS}
DTM	-0.036^{NS}	0.052^{NS}	0.105^{NS}	-0.333^{**}	0.086^{NS}	0.090^{NS}	-0.138^{NS}	0.042^{NS}	-0.047^{NS}	-0.077^{NS}	-0.264^{**}		-0.019^{NS}	-0.164^{NS}	-0.215^{*}	0.151^{NS}	0.125^{NS}
Ncontent	0.423^{**}	-0.075^{NS}	-0.009^{NS}	-0.261^{**}	-0.380^{**}	-0.081^{NS}	-0.020^{NS}	-0.055^{NS}	0.077^{NS}	-0.050^{NS}	0.575^{**}	-0.056^{NS}		-0.053^{NS}	0.106^{NS}	-0.041^{NS}	-0.174^{NS}
Pcontent	-0.346^{**}	0.119^{NS}	-0.230^{*}	0.285^{**}	-0.048^{NS}	-0.008^{NS}	0.173^{NS}	-0.044^{NS}	-0.087^{NS}	-0.050^{NS}	0.451^{**}	-0.256^{**}	-0.031^{NS}		0.041^{NS}	0.050^{NS}	0.139^{NS}
Zn content	-0.045^{NS}	-0.029^{NS}	-0.038^{NS}	0.472^{**}	-0.060^{NS}	-0.038^{NS}	-0.341^{**}	-0.025^{NS}	0.014^{NS}	0.070^{NS}	0.474^{**}	-0.262^{**}	0.116^{NS}	0.043^{NS}		0.105^{NS}	0.077^{NS}
R. Biomass	-0.192^{*}	-0.181^{*}	-0.215^{*}	0.031^{NS}	-0.032^{NS}	-0.219^{*}	0.231^{*}	-0.104^{NS}	-0.181^{*}	-0.283^{**}	0.403^{**}	0.116^{NS}	-0.082^{NS}	0.078^{NS}	0.173^{NS}		0.608^{**}
Root Lth	-0.178^{NS}	-0.337^{**}	-0.499^{**}	0.156^{NS}	0.052^{NS}	-0.433^{**}	0.064^{NS}	-0.146^{NS}	-0.135^{NS}	-0.186^{*}	0.250^{**}	0.149^{NS}	-0.309^{**}	0.193^{*}	0.126^{NS}	0.785^{**}	

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

Table 25: Phenotypic (Above diagonal) and Genotypic (Below diagonal) Correlation coefficiencts of various characters under Optimum input conditions in year 2013-14.

	PH	BPP	HI	Ch. Flu	C.C	GY	1000-gr-wt	NTPP	SPS	GPS	DTH	DTM	Ncontent	Pcontent	Zn content	R. Biomass	Root Lth
PH		-0.084^{NS}	0.095^{NS}	0.101^{NS}	-0.024^{NS}	0.007^{NS}	0.029^{NS}	-0.059^{NS}	0.007^{NS}	-0.057^{NS}	0.118^{NS}	0.167^{NS}	0.043^{NS}	-0.312^{**}	-0.149^{NS}	-0.058^{NS}	-0.212^{*}
BPP	-0.139^{NS}		-0.109^{NS}	-0.045^{NS}	0.221^{*}	0.651^{**}	0.055^{NS}	0.107^{NS}	0.300^{**}	-0.112^{NS}	-0.119^{NS}	0.029^{NS}	0.087^{NS}	0.008^{NS}	0.166^{NS}	-0.039^{NS}	-0.040^{NS}
HI	0.078^{NS}	-0.159^{NS}		-0.157^{NS}	-0.005^{NS}	0.678^{**}	0.525^{**}	-0.057^{NS}	-0.241^{**}	-0.215^{*}	0.197^{*}	0.311^{**}	0.127^{NS}	0.223^{*}	-0.047^{NS}	-0.195^{*}	-0.122^{NS}
Ch. Flu	0.206^{*}	-0.027^{NS}	-0.249^{**}		0.131^{NS}	-0.138^{NS}	-0.146^{NS}	0.269^{**}	0.001^{NS}	-0.080^{NS}	-0.209^{*}	-0.210^{*}	-0.162^{NS}	-0.122^{NS}	-0.006^{NS}	0.150^{NS}	0.150^{NS}
C.C	-0.206^{*}	0.396^{**}	-0.013^{NS}	0.232^{*}		0.148^{NS}	-0.051^{NS}	-0.001^{NS}	0.050^{NS}	-0.181^{*}	-0.045^{NS}	0.118^{NS}	-0.112^{NS}	0.037^{NS}	0.080^{NS}	0.037^{NS}	0.034^{NS}
GY	-0.054^{NS}	0.677^{**}	0.615^{**}	-0.184^{*}	0.298^{**}		0.413^{**}	0.061^{NS}	0.042^{NS}	-0.225^{*}	0.049^{NS}	0.242^{**}	0.159^{NS}	0.181^{*}	0.104^{NS}	-0.183^{*}	-0.118^{NS}
1000-gr-wt	0.090^{NS}	0.063^{NS}	0.693^{**}	-0.230^{*}	0.013^{NS}	0.527^{**}		-0.105^{NS}	-0.147^{NS}	-0.009^{NS}	0.095^{NS}	0.139^{NS}	0.053^{NS}	0.182^{*}	-0.156^{NS}	-0.094^{NS}	-0.146^{NS}
NTPP	-0.060^{NS}	0.127^{NS}	-0.151^{NS}	0.447^{**}	-0.173^{NS}	0.033^{NS}	-0.127^{NS}		0.192^{*}	0.242^{**}	-0.112^{NS}	-0.146^{NS}	-0.097^{NS}	0.002^{NS}	0.035^{NS}	0.200^{*}	0.237^{**}
SPS	-0.004^{NS}	0.408^{**}	-0.318^{**}	0.108^{NS}	0.018^{NS}	0.102^{NS}	-0.322^{**}	0.311^{**}		0.266^{**}	-0.068^{NS}	0.093^{NS}	0.211^{*}	-0.155^{NS}	0.033^{NS}	0.213^{*}	0.193^{*}
GPS	-0.173^{NS}	-0.122^{NS}	-0.245^{**}	-0.037^{NS}	-0.301^{**}	-0.257^{**}	0.008^{NS}	0.469^{**}	0.333^{**}		0.040^{NS}	-0.022^{NS}	-0.185^{*}	-0.227^{*}	0.072^{NS}	0.024^{NS}	0.036^{NS}
DTH	0.165^{NS}	-0.142^{NS}	0.220^{*}	-0.304^{**}	-0.095^{NS}	0.039^{NS}	0.120^{NS}	-0.233^{*}	-0.070^{NS}	0.001^{NS}		0.406^{**}	0.047^{NS}	0.094^{NS}	0.087^{NS}	0.078^{NS}	0.001^{NS}
DTM	0.220^{*}	0.019^{NS}	0.426^{**}	-0.254^{**}	0.312^{**}	0.307^{**}	0.197^{*}	-0.225^{*}	0.141^{NS}	-0.052^{NS}	0.507^{**}		0.127^{NS}	-0.021^{NS}	0.057^{NS}	-0.086^{NS}	-0.128^{NS}
Ncontent	-0.015^{NS}	0.101^{NS}	0.181^{*}	-0.256^{**}	-0.206^{*}	0.213^{*}	0.087^{NS}	-0.114^{NS}	0.295^{**}	-0.318^{**}	0.008^{NS}	0.161^{NS}		0.102^{NS}	0.011^{NS}	-0.010^{NS}	-0.036^{NS}
Pcontent	-0.410^{**}	0.016^{NS}	0.297^{**}	-0.142^{NS}	0.060^{NS}	0.235^{**}	0.264^{**}	-0.039^{NS}	-0.210^{*}	-0.316^{**}	0.083^{NS}	-0.024^{NS}	0.135^{NS}		0.179^{NS}	0.126^{NS}	0.224^{*}
Zn content	-0.203^{*}	0.175^{NS}	-0.085^{NS}	-0.015^{NS}	0.203^{*}	0.093^{NS}	-0.168^{NS}	0.042^{NS}	0.059^{NS}	0.075^{NS}	0.117^{NS}	0.070^{NS}	0.039^{NS}	0.181^{*}		0.002^{NS}	0.024^{NS}
R. Biomass	-0.063^{NS}	-0.052^{NS}	-0.254^{**}	0.216^{*}	-0.052^{NS}	-0.234^{**}	-0.044^{NS}	0.233^{*}	0.293^{**}	0.029^{NS}	0.037^{NS}	-0.084^{NS}	-0.017^{NS}	0.119^{NS}	-0.001^{NS}		0.843^{**}
Root Lth	-0.280^{**}	-0.029^{NS}	-0.184^{*}	0.187^{*}	0.041^{NS}	-0.156^{NS}	-0.171^{NS}	0.360^{**}	0.269^{**}	-0.007^{NS}	-0.042^{NS}	-0.139^{NS}	-0.068^{NS}	0.243^{**}	0.017^{NS}	0.887^{**}	

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

Table 26: Phenotypic (Above diagonal) and Genotypic (Below diagonal) Correlation coefficiencts of various characters under Low input conditions in year 2013-14.

	PH	BPP	HI	Ch. Flu	C.C	GY	1000-gr-wt	NTPP	SPS	GPS	DTH	DTM	Ncontent	Pcontent	Zn content	R. Biomass	Root Lth
PH		-0.142^{NS}	0.153^{NS}	-0.197^{*}	-0.105^{NS}	0.025^{NS}	-0.061^{NS}	-0.058^{NS}	-0.018^{NS}	0.100^{NS}	-0.092^{NS}	-0.073^{NS}	0.194^{*}	-0.203^{*}	-0.031^{NS}	-0.014^{NS}	-0.044^{NS}
BPP	-0.224^{*}		0.101^{NS}	0.077^{NS}	0.020^{NS}	0.723^{**}	0.079^{NS}	-0.144^{NS}	0.190^{*}	-0.237^{**}	-0.048^{NS}	0.014^{NS}	0.129^{NS}	0.119^{NS}	-0.005^{NS}	-0.064^{NS}	-0.113^{NS}
HI	0.190^{*}	0.095^{NS}		0.253^{**}	-0.044^{NS}	0.757^{**}	0.061^{NS}	-0.128^{NS}	0.236^{**}	-0.060^{NS}	-0.155^{NS}	-0.186^{*}	0.040^{NS}	-0.004^{NS}	0.233^{*}	-0.112^{NS}	-0.139^{NS}
Ch. Flu	-0.349^{**}	0.099^{NS}	0.545^{**}		-0.066^{NS}	0.227^{*}	-0.003^{NS}	-0.135^{NS}	0.133^{NS}	-0.060^{NS}	0.052^{NS}	-0.121^{NS}	-0.074^{NS}	0.130^{NS}	0.138^{NS}	-0.108^{NS}	-0.049^{NS}
C.C	-0.272^{**}	0.095^{NS}	-0.299^{**}	-0.303^{**}		-0.016^{NS}	0.091^{NS}	-0.018^{NS}	-0.092^{NS}	-0.020^{NS}	0.005^{NS}	0.076^{NS}	-0.222^{*}	-0.033^{NS}	-0.031^{NS}	-0.045^{NS}	-0.101^{NS}
GY	-0.055^{NS}	0.834^{**}	0.627^{**}	0.374^{**}	-0.097^{NS}		0.085^{NS}	-0.182^{*}	0.283^{**}	-0.186^{*}	-0.147^{NS}	-0.114^{NS}	0.122^{NS}	0.064^{NS}	0.162^{NS}	-0.126^{NS}	-0.175^{NS}
1000-gr-wt	0.020^{NS}	0.089^{NS}	0.048^{NS}	0.021^{NS}	0.428^{**}	0.082^{NS}		-0.221^{*}	-0.034^{NS}	-0.217^{*}	-0.039^{NS}	-0.029^{NS}	-0.100^{NS}	0.184^{*}	-0.166^{NS}	0.130^{NS}	0.135^{NS}
NTPP	-0.004^{NS}	-0.218^{*}	-0.299^{**}	-0.329^{**}	0.005^{NS}	-0.354^{**}	-0.338^{**}		0.016^{NS}	0.290^{**}	0.033^{NS}	0.183^{*}	-0.118^{NS}	-0.037^{NS}	-0.053^{NS}	0.007^{NS}	0.018^{NS}
SPS	-0.290^{**}	0.431^{**}	0.843^{**}	0.611^{**}	-0.344^{**}	0.772^{**}	-0.269^{**}	0.090^{NS}		0.120^{NS}	-0.051^{NS}	-0.020^{NS}	0.005^{NS}	0.153^{NS}	-0.110^{NS}	0.013^{NS}	0.077^{NS}
GPS	0.227^{*}	-0.246^{**}	0.012^{NS}	-0.082^{NS}	-0.198^{*}	-0.177^{NS}	-0.305^{**}	0.342^{**}	0.166^{NS}		0.079^{NS}	0.077^{NS}	-0.043^{NS}	-0.090^{NS}	-0.044^{NS}	-0.008^{NS}	0.024^{NS}
DTH	0.085^{NS}	-0.079^{NS}	-0.203^{*}	0.127^{NS}	0.191^{*}	-0.180^{*}	-0.027^{NS}	0.035^{NS}	-0.057^{NS}	0.127^{NS}		0.190^{*}	-0.029^{NS}	0.026^{NS}	0.035^{NS}	0.005^{NS}	0.123^{NS}
DTM	0.141^{NS}	-0.019^{NS}	-0.592^{**}	-0.418^{**}	0.381^{**}	-0.327^{**}	-0.151^{NS}	0.316^{**}	-0.187^{*}	0.166^{NS}	0.340^{**}		-0.126^{NS}	-0.116^{NS}	-0.109^{NS}	-0.102^{NS}	0.005^{NS}
Ncontent	0.125^{NS}	0.199^{*}	0.271^{**}	-0.165^{NS}	-0.354^{**}	0.324^{**}	-0.147^{NS}	-0.171^{NS}	0.007^{NS}	0.037^{NS}	-0.040^{NS}	-0.141^{NS}		-0.096^{NS}	0.152^{NS}	0.058^{NS}	-0.006^{NS}
Pcontent	-0.407^{**}	0.119^{NS}	-0.072^{NS}	0.157^{NS}	-0.195^{*}	0.039^{NS}	0.230^{*}	-0.085^{NS}	0.220^{*}	-0.099^{NS}	0.039^{NS}	-0.367^{**}	-0.111^{NS}		0.001^{NS}	0.312^{**}	0.307^{**}
Zn content	-0.064^{NS}	0.005^{NS}	0.447^{**}	0.178^{NS}	-0.071^{NS}	0.251^{**}	-0.204^{*}	-0.103^{NS}	-0.189^{*}	-0.024^{NS}	0.067^{NS}	-0.241^{**}	0.231^{*}	-0.002^{NS}		0.101^{NS}	-0.022^{NS}
R. Biomass	-0.145^{NS}	-0.055^{NS}	-0.303^{**}	-0.073^{NS}	-0.180^{*}	-0.218^{*}	0.148^{NS}	0.030^{NS}	-0.009^{NS}	0.004^{NS}	0.030^{NS}	-0.162^{NS}	0.070^{NS}	0.385^{**}	0.154^{NS}		0.722^{**}
Root Lth	-0.191^{*}	-0.152^{NS}	-0.341^{**}	-0.011^{NS}	-0.104^{NS}	-0.318^{**}	0.097^{NS}	0.019^{NS}	0.188^{*}	0.012^{NS}	0.181^{*}	-0.039^{NS}	0.022^{NS}	0.367^{**}	-0.034^{NS}	0.767^{**}	

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

Table 27: Direct and Indirect effects of various characters on grain yield of year 2012-13

		PH	**BPP**	**HI**	**Ch. Flu**	**C.C**	**1000-gr-wt**	**NTPP**	**SPS**	**GPS**	**DTH**	**DTM**	**Ncontent**	**Pcontent**	**Zn content**	**R. Biomass**	**Root Lth**	**r (g)**
PH	**O**	**0.0057**	-0.26185	-0.0055	0.00049	-0.00282	0.00082	-0.00001	-0.00286	0.00031	0.00002	0.00217	-0.00018	-0.00031	-0.00064	0.00012	-0.00025	**-0.26479**
	L	**0.00588**	-0.1096	-0.02048	-0.00041	-0.00121	-0.00007	-0.00036	-0.00044	0.00009	0.00035	-0.00052	-0.00131	-0.00389	0.0001	0.0007	-0.00286	**-0.13403**
BPP	**O**	-0.00168	**0.88619**	0.00114	-0.00073	-0.0001	0.00084	-0.00044	0.00643	0.00059	-0.00008	-0.00018	-0.00039	0.00015	0.00042	0.00066	-0.00071	**0.89211**
	L	-0.0011	**0.58408**	0.21345	-0.0003	0.00055	0	0.00015	0.00275	-0.00035	-0.00084	0.00042	0.0003	0.00174	0.00011	0.00056	-0.00508	**0.79644**
HI	**O**	-0.00007	0.00224	**0.45037**	-0.00073	-0.00099	0.00032	0.00213	-0.00021	-0.00068	0.00005	-0.00172	0.00033	-0.00009	-0.00111	0.00044	-0.00036	**0.44992**
	L	-0.00019	0.19363	**0.64389**	-0.00031	-0.00053	0.00068	-0.00058	-0.00152	-0.00016	0.00084	0.00053	-0.00071	-0.00237	0.00023	0.00028	-0.00338	**0.83033**
Ch. Flu	**O**	-0.00041	0.09549	0.04799	**-0.00681**	0.00053	0.00069	0.00075	0.0018	-0.0023	-0.00003	0.00298	0.00035	0.00001	0.00063	0.00027	-0.00057	**0.14137**
	L	-0.00081	-0.05858	-0.06737	**0.003**	0.00044	0.00095	0.00002	-0.00193	-0.00011	0.00022	-0.00021	0.00035	0.00099	-0.00054	-0.00023	-0.00233	**-0.12614**
C.C	**O**	-0.00122	-0.0069	-0.03365	-0.00027	**0.01324**	-0.00039	-0.00107	-0.0031	0.00097	-0.00013	0.0001	0.00108	-0.00006	-0.00026	-0.00063	0.00053	**-0.03176**
	L	-0.00117	0.05244	-0.05614	0.00022	**0.00607**	-0.00068	0.00034	0.00354	-0.00007	0.00159	0.00056	0.00099	-0.00036	0.00018	0.00015	0.00039	**0.00805**
1000-gr-wt	**O**	0.00082	0.1318	0.02557	-0.00083	-0.00091	**0.00567**	-0.00082	0.00032	0.00003	0.00008	0.0016	-0.00069	0.00003	-0.00044	-0.00054	0.0003	**0.16199**
	L	0.0001	-0.00029	-0.10017	-0.00065	0.00094	**-0.00439**	0.00126	0.00005	0.00018	0.00031	-0.00071	0.00017	0.00234	0.00105	-0.00036	0.00074	**-0.09943**
NTPP	**O**	-0.00001	-0.04242	0.10487	-0.00056	-0.00154	-0.00051	**0.00914**	0.00176	-0.00382	-0.00002	-0.00286	0.00108	-0.00008	-0.00071	-0.00015	0.0001	**0.06427**
	L	0.00041	-0.01688	0.07183	-0.00001	-0.0004	0.00107	**-0.00516**	0.00286	-0.00039	0.00008	0.00021	0.00039	-0.00086	0.00028	0.0001	-0.00072	**0.05281**
SPS	**O**	-0.00078	0.27113	-0.0046	-0.00058	-0.00195	0.00009	0.00076	**0.02101**	-0.00433	-0.00005	-0.00144	-0.00037	0.00004	-0.00044	0.00015	-0.00037	**0.27827**
	L	-0.00017	0.1038	-0.06321	-0.00037	0.00139	-0.00001	-0.00096	**0.01546**	-0.00102	0.00092	-0.0003	0.00004	-0.00152	0.00011	0.00063	-0.00171	**0.05308**
GPS	**O**	-0.00012	-0.03558	0.02066	-0.00106	-0.00087	-0.00001	0.00236	0.00614	**-0.01481**	-0.00016	-0.0005	0.00052	-0.00021	0.0001	-0.00001	-0.00021	**-0.02376**
	L	-0.00024	0.09104	0.04727	0.00014	0.00019	0.00035	-0.00091	0.00709	**-0.00223**	-0.00113	-0.0006	0.00004	-0.00111	-0.0001	0.00056	-0.00215	**0.13821**
DTH	**O**	-0.00015	0.08476	-0.02606	-0.00028	0.00216	-0.00057	0.00017	0.00121	-0.00289	**-0.00082**	0.00089	0.0017	-0.0002	0.00075	-0.00013	-0.00002	**0.06052**
	L	-0.00016	0.03703	-0.04044	-0.00005	-0.00073	0.0001	0.00003	-0.00107	-0.00019	**-0.01331**	-0.00108	-0.00074	0.00283	-0.00022	-0.00087	0.00217	**-0.0167**
DTM	**O**	0.00096	-0.01247	-0.06035	-0.00158	0.0001	0.00071	-0.00204	-0.00235	0.00058	-0.00006	**0.01284**	-0.00105	0	0.00081	-0.00004	-0.00007	**-0.06401**
	L	-0.00043	0.035	0.04857	-0.00009	0.00048	0.00044	-0.00016	-0.00066	0.00019	0.00203	**0.00707**	0.00011	-0.00248	0.0008	-0.00066	0.00238	**0.09259**
Ncontent	**O**	0.00017	0.05808	-0.02515	0.0004	-0.00242	0.00066	-0.00167	0.00132	0.0013	0.00023	0.00228	**-0.00593**	0.0002	0.00083	-0.00038	0.00009	**0.03001**
	L	0.00139	-0.03094	0.08242	-0.00019	-0.00108	0.00013	0.00037	-0.00011	0.00002	-0.00178	-0.00014	**-0.00557**	-0.00081	-0.0004	0.00018	-0.00331	**0.04018**
Pcontent	**O**	-0.00213	0.16653	-0.0475	-0.00008	-0.00103	0.00017	-0.00091	0.00093	0.00383	0.0002	0.00003	-0.00145	**0.00082**	0.00091	-0.00016	0.00031	**0.12047**
	L	-0.00151	0.06684	-0.10047	0.0002	-0.00014	-0.00068	0.00029	-0.00154	0.00016	-0.00248	-0.00116	0.0003	**0.01518**	-0.00015	-0.00022	0.00264	**-0.02274**
Zn content	**O**	-0.00058	0.05877	-0.0789	-0.00067	-0.00054	-0.00039	-0.00102	-0.00145	-0.00023	-0.0001	0.00164	-0.00078	0.00012	**0.00636**	-0.00038	0.00065	**-0.0175**
	L	-0.00016	-0.0179	-0.03937	0.00044	-0.0003	0.00124	0.00038	-0.00044	-0.00006	-0.00079	-0.00152	-0.00059	0.00062	**-0.00373**	-0.00046	0.00148	**-0.06116**
R. Biomass	**O**	-0.00022	-0.18097	-0.06102	0.00057	0.0026	0.00094	0.00042	-0.00101	-0.00004	-0.00003	0.00018	-0.0007	0.00004	0.00076	**-0.00321**	0.00315	**-0.23854**
	L	-0.00093	-0.07444	-0.04056	0.00016	-0.0002	-0.00036	0.00012	-0.00222	0.00028	-0.00264	0.00106	0.00023	0.00076	-0.00039	**-0.0044**	0.01158	**-0.11195**
Root Lth	**O**	-0.00041	-0.18112	-0.04751	0.00113	0.00202	0.00049	0.00027	-0.00224	0.00089	0	-0.00025	-0.00016	0.00007	0.00119	-0.00293	**0.00346**	**-0.2251**
	L	-0.00088	-0.1557	-0.11425	-0.00037	0.00012	-0.00017	0.0002	-0.00139	0.00025	-0.00152	0.00088	0.00097	0.0021	-0.00029	-0.00267	**0.01906**	**-0.25366**

*, **: significant at 5% and 1% level of significance respectively**.** C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

Residual effect of low input conditions is : 0.00306

Residual effect of optimum input conditions is : 0.00444

Table 28: Direct and Indirect effects of various characters on grain yield of year 2013-14

		PH	BPP	HI	Ch. Flu	C.C	1000-gr-wt	NTPP	SPS	GPS	DTH	DTM	Ncontent	Pcontent	Zn content	R. Biomass	Root Lth	r (g)
PH	**O**	**0.00672**	-0.06199	0.07423	0.00136	0.00023	-0.00109	-0.00067	-0.00002	-0.00162	-0.00108	-0.00173	0.00019	-0.00486	-0.0014	0.00105	-0.00196	**0.00736**
	L	**0.01114**	-0.09302	0.10496	-0.00164	-0.00049	0.0003	0.00014	0.00012	0.00113	0.00106	-0.00058	0.00172	0.00083	-0.00012	0.00008	-0.00016	**0.02547**
BPP	**O**	-0.00056	**0.74099**	-0.08522	-0.00061	-0.00215	-0.0021	0.00123	-0.00083	-0.00321	0.00109	-0.0003	0.00038	0.00013	0.00156	0.00071	-0.00037	**0.65074**
	L	-0.00158	**0.6566**	0.06968	0.00064	0.00009	-0.00039	0.00036	-0.00125	-0.0027	0.00055	0.00011	0.00114	-0.00048	-0.00002	0.00039	-0.00041	**0.72273**
HI	**O**	0.00064	-0.08042	**0.78521**	-0.00211	0.00005	-0.01991	-0.00065	0.00066	-0.00614	-0.0018	-0.00321	0.00055	0.00347	-0.00044	0.00352	-0.00113	**0.67829**
	L	0.0017	0.06659	**0.68709**	0.00211	-0.00021	-0.0003	0.00032	-0.00155	-0.00069	0.0018	-0.00149	0.00035	0.00002	0.00088	0.00069	-0.00051	**0.7568**
Ch. Flu	**O**	0.00068	-0.0337	-0.12339	**0.01343**	-0.00128	0.00552	0.00308	0	-0.00227	0.00192	0.00217	-0.0007	-0.00191	-0.00005	-0.00271	0.00139	**-0.13782**
	L	-0.00219	0.05039	0.17362	**0.00834**	-0.00031	0.00001	0.00034	-0.00087	-0.00068	-0.0006	-0.00097	-0.00065	-0.00053	0.00052	0.00066	-0.00018	**0.2269**
C.C	**O**	-0.00016	0.16358	-0.00374	0.00176	**-0.00975**	0.00192	-0.00001	-0.00014	-0.00516	0.00041	-0.00122	-0.00049	0.00057	0.00075	-0.00067	0.00032	**0.14797**
	L	-0.00117	0.01322	-0.03056	-0.00055	**0.00469**	-0.00045	0.00004	0.0006	-0.00023	-0.00006	0.00061	-0.00197	0.00014	-0.00012	0.00028	-0.00037	**-0.0159**
1000-gr-wt	**O**	0.00019	0.04105	0.41236	-0.00195	0.00049	**-0.0379**	-0.0012	0.00041	-0.00026	-0.00087	-0.00143	0.00023	0.00283	-0.00146	0.0017	-0.00135	**0.41284**
	L	-0.00068	0.05183	0.04225	-0.00002	0.00043	**-0.00488**	0.00055	0.00022	-0.00247	0.00046	-0.00023	-0.00088	-0.00075	-0.00063	-0.00079	0.00049	**0.0849**
NTPP	**O**	-0.0004	0.07952	-0.04471	0.00362	0.00001	0.00397	**0.01145**	-0.00053	0.00691	0.00103	0.00151	-0.00042	0.00003	0.00033	-0.00361	0.0022	**0.06091**
	L	-0.00064	-0.09466	-0.08772	-0.00113	-0.00008	0.00108	**-0.00249**	-0.0001	0.0033	-0.00039	0.00146	-0.00104	0.00015	-0.0002	-0.00004	0.00007	**-0.18243**
SPS	**O**	0.00004	0.22243	-0.18888	0.00002	-0.00048	0.00558	0.0022	**-0.00275**	0.0076	0.00063	-0.00096	0.00091	-0.00241	0.00031	-0.00385	0.00178	**0.04217**
	L	-0.0002	0.12504	0.16241	0.00111	-0.00043	0.00016	-0.00004	**-0.00654**	0.00136	0.00059	-0.00016	0.00004	-0.00062	-0.00042	-0.00008	0.00028	**0.2825**
GPS	**O**	-0.00038	-0.08332	-0.16899	-0.00107	0.00176	0.00035	0.00277	-0.00073	**0.02854**	-0.00037	0.00023	-0.0008	-0.00354	0.00067	-0.00043	0.00033	**-0.22498**
	L	0.00111	-0.1559	-0.04146	-0.0005	-0.00009	0.00106	-0.00072	-0.00078	**0.01137**	-0.00092	0.00062	-0.00038	0.00036	-0.00017	0.00005	0.00009	**-0.18626**
DTH	**O**	0.0008	-0.08855	0.1548	-0.00281	0.00043	-0.0036	-0.00129	0.00019	0.00114	**-0.00914**	-0.00419	0.0002	0.00147	0.00081	-0.00142	0.00001	**0.04885**
	L	-0.00102	-0.0313	-0.10651	0.00043	0.00002	0.00019	-0.00008	0.00033	0.0009	**-0.0116**	0.00152	-0.00026	-0.0001	0.00013	-0.00003	0.00045	**-0.14693**
DTM	**O**	0.00113	0.02171	0.24423	-0.00282	-0.00116	-0.00526	-0.00167	-0.00025	-0.00064	-0.00371	**-0.01033**	0.00055	-0.00033	0.00054	0.00156	-0.00119	**0.24236**
	L	-0.00081	0.00929	-0.12791	-0.00101	0.00036	0.00014	-0.00045	0.00013	0.00088	-0.00221	**0.00801**	-0.00112	0.00047	-0.00041	0.00062	0.00002	**-0.114**
Ncontent	**O**	0.00029	0.06472	0.09987	-0.00217	0.00109	-0.00201	-0.00111	-0.00058	-0.00527	-0.00043	-0.00131	**0.00432**	0.00158	0.0001	0.00019	-0.00033	**0.15895**
	L	0.00216	0.08472	0.02744	-0.00062	-0.00104	0.00049	0.00029	-0.00003	-0.00048	0.00034	-0.00101	**0.00885**	0.00039	0.00058	-0.00035	-0.00002	**0.12171**
Pcontent	**O**	-0.0021	0.0062	0.17484	-0.00164	-0.00036	-0.0069	0.00002	0.00043	-0.00648	-0.00086	0.00022	0.00044	**0.01558**	0.00168	-0.00228	0.00207	**0.18086**
	L	-0.00226	0.07814	-0.00262	0.00109	-0.00016	-0.0009	0.00009	-0.001	-0.00102	-0.0003	-0.00093	-0.00085	**-0.00406**	0.00001	-0.00191	0.00112	**0.06444**
Zn content	**O**	-0.001	0.12292	-0.03677	-0.00008	-0.00078	0.0059	0.0004	-0.00009	0.00205	-0.00079	-0.00059	0.00005	0.00278	**0.0094**	-0.00003	0.00023	**0.1036**
	L	-0.00035	-0.00317	0.15982	0.00115	-0.00014	0.00081	0.00013	0.00072	-0.0005	-0.00041	-0.00087	0.00134	-0.00001	**0.00379**	-0.00062	-0.00008	**0.16161**
R. Biomass	**O**	-0.00039	-0.02892	-0.15278	0.00201	-0.00036	0.00355	0.00229	-0.00059	0.00067	-0.00072	0.00089	-0.00004	0.00196	0.00002	**-0.0181**	0.0078	**-0.18271**
	L	-0.00015	-0.04195	-0.0769	-0.0009	-0.00021	-0.00063	-0.00002	-0.00009	-0.00009	-0.00006	-0.00081	0.00051	-0.00127	0.00038	**-0.00613**	0.00263	**-0.12569**
Root Lth	**O**	-0.00142	-0.02941	-0.09599	0.00201	-0.00034	0.00554	0.00272	-0.00053	0.00103	-0.00001	0.00132	-0.00016	0.00348	0.00023	-0.01525	**0.00925**	**-0.11753**
	L	-0.00049	-0.07393	-0.09568	-0.00041	-0.00047	-0.00066	-0.00004	-0.0005	0.00027	-0.00142	0.00004	-0.00006	-0.00125	-0.00008	-0.00442	**0.00364**	**-0.17546**

*, **: significant at 5% and 1% level of significance respectively. C.D : denote critical difference for main effects at 5 % level of significance S.E (d): denotes standard error of difference, C.V : denotes coefficient of variation

PH : Plant height, BPP: Biomass per plant, HI: Harvest index, CF: Chlorophyll fluorescence, CC: Chlorophyll content , GY: Grain yield, NTPP: Number of tillers per plant, SPS: Spikelets per spike, GPS: Grains per spike, DTH: Days to heading, DTM: Days to maturity, O: optimum input conditions, L: low input conditions

Residual effect of Low input conditions is : 0.00619

Residual effect of optimum input conditions is : 0.00444

Table 29: List of promising genotypes found per character under study

Grain yield	Low	2012-13	PBW 533, WH 1105. WH 1061, WH 542, HD 2967, DBW 17, PBW 644
		2013-14	LOK 54, HD 2967, PBW 475, PBW 644, SONALIKA, PBW 527
	optimum	2012-13	WH 1105, DPW 621-50, PBW 590, PBW 503, PBW 533, PBW 475, HD 2687, WH 542, HD 2967, WH 1138, PBW 644, WH 1061, WH 1160, PBW 527
		2013-14	WH 1105, HD 2967, DPW 621-50, HD 2687, WH 1140, PBW 644
1000- gr-wt	Low	2012-13	WH 1140, SONALIKA, WH 1105, PBW 503, WH 711, C 518, WH 730, HD 2687, WH 1160, C 306, HD 2967, RAJ 3765, PBW 373 WH 416, WH 147, WH 1142
		2013-14	SONALIKA, HD 2687,PBW 503, WH 1105, HD 2285, C 518
	optimum	2012-13	SONALIKA, WH 1160, LOK 54, WH 1140, HD 2967
		2013-14	SONALIKA, WH 1140, PBW 373, WH 1160
NTPP	Low	2012-13	WH 1105, WH 1127, WH 1098, PBW 175, HD 2285
		2013-14	WH 1081, WH 1127, RAJ 3765, WH 1098, DPW 621-50, WH 1105, HD 2285
	optimum	2012-13	HD 2285, WH 1105, WH 1127, WH 1098, PBW 533, DPW 621-50, PBW 175
		2013-14	WH 1127, DPW 621-50, WH 1081, WH 1105
SPS	Low	2012-13	WH 730, WH 542, WH 1081
		2013-14	WH 147
	optimum	2012-13	WH 542, WH 711, WH 147, PBW 475
		2013-14	WH 147
GPS	Low	2012-13	RAJ 3765, WH 1080, HD 2851, WH 1061, WH 1081, HD 2967
		2013-14	WH 1081, HD 2851, RAJ 3765, WH 730, WH 1098, WH 1080, PBW 644, SONALIKA
	optimum	2012-13	HD 2851, RAJ 3765, WH 730, WH 1080, WH 1127, WH 542
		2013-14	HD 2851, WH 1081, WH 730, PBW 175 ,WH 542
DH	Low	2012-13	N/S
		2013-14	PBW 590, WH 1123, PBW 527, WH 542, HD 2285, LOK 54, SONALIKA
	optimum	2012-13	C 306, SONALIKA
		2013-14	WH 1081, WH 542, WH 1098, WH 416, WH 1123, PBW 590, C 306, WH 1063, DPW 621-50, HD 2851, PBW 373

DM	Low	2012-13	SONALIKA, WH 1140, PBW 527, HD 2285, WH 730
		2013-14	WH 730
	optimum	2012-13	WH 416, PBW 533, WH 1080, WH 1021, RAJ 3765, WH 1081, PBW 373, DPW 621-50, PBW 590, C 306, WH 1061, WH 730, HD 2285, WH 1098
		2013-14	WH 1081, RAJ 3765, WH 1021, PBW 373, PBW 590, WH 730, WH 1061, C 306, HD 2285, WH 1098,
N content	Low	2012-13	WH 1123, C 306, LOK 54
		2013-14	LOK 54
	optimum	2012-13	LOK 54, WH 1025, WH 711, WH 147, SONALIKA, WH 1127, WH 1063
		2013-14	LOK 54, WH 147, SONALIKA, WH 1025
P content	Low	2012-13	WH 1105, PBW 373, SONALIKA, PBW 644, DPW 621-50, WH 416, WH 1061, WH 711, WH 1025, WH 1139, WH 147, WH 1100, WH 1081, WH 1160
		2013-14	PBW 373, SONALIKA, WH 416, WH 1105,DBW 17,WH 1100, WH 711, WH 1081,DPW 621-50, WH 1025, WH 1061, WH 147, PBW 644, WH 1139,WH 1098
	optimum	2012-13	WH 1105, SONALIKA, PBW 644, PBW 373, WH 711, DBW 17, HD 2687, WH 1025, WH 416, DPW 621-50, PBW 590
		2013-14	WH 1105,PBW 644, SONALIKA, PBW 373, DBW 17, WH 711, WH 1025, HD 2687, WH 416, WH 1081, WH 1142, WH 1160, WH 1139, PBW 503
Zn content	Low	2012-13	DBW 17, PBW 175, HD 2851, LOK 54, WH 1100, WH 1127, WH 1063, WH 1021, PBW 527, PBW 644
		2013-14	DBW 17, PBW 175, WH 1100, LOK 54, HD 2851, PBW 527, PBW 644, WH 1021, WH 1127, PBW 503, WH 1063, WH 711
	optimum	2012-13	WH 1100, DBW 17, WH 1021, HD 2851, WH 1127, WH 1063, PBW 644, LOK 54, PBW 503, PBW 175, PBW 475, WH 711, PBW 527
		2013-14	DBW 17, HD 2851, WH 1100, PBW 175, PBW 503, PBW 644, WH 1127, LOK 54, PBW 475, PBW 527, WH 1063, WH 711, WH 1105
NUE	Low	2012-13	PBW 533, WH 1105, WH 1061, WH 542, HD 2967, DBW 17, PBW 644
		2013-14	LOK 54, HD 2967, PBW 475, PBW 644, SONALIKA
	optimum	2012-13	WH 1105, DPW 621-50, PBW 590, PBW 503, PBW 533, PBW 475, HD 2687, WH 542, HD 2967, WH 1138, PBW 644, WH 1061, WH 1160, PBW 527
		2013-14	WH 1105, HD 2967, DPW 621-50, WH 1160, HD 2687, WH 1140, WH 147
PUE	Low	2012-13	PBW 533, WH 1105, WH 1061, WH 542, HD 2967, DBW 17, PBW 644
		2013-14	LOK 54, HD 2967, PBW 475, PBW 644, SONALIKA

	optimum	2012-13	WH 1105, DPW 621-50, PBW 590, PBW 503, PBW 533, PBW 475, HD 2687, WH 542, HD 2967, WH 1138, PBW 644, WH 1061, WH 1160, PBW 527
		2013-14	WH 1105, HD 2967, DPW 621-50, WH 1160, HD 2687, WH 1140, WH 147
ZnUE	Low	2012-13	PBW 533, WH 1105, WH 1061, WH 542, HD 2967, DBW 17, PBW 644
		2013-14	LOK 54, HD 2967, PBW 475, PBW 644, SONALIKA
	optimum	2012-13	WH 1105, DPW 621-50, PBW 590, PBW 503, PBW 533, PBW 475, HD 2687, WH 542, HD 2967, WH 1138, PBW 644, WH 1061, WH 1160, PBW 527
		2013-14	WH 1105, HD 2967, DPW 621-50, WH 1160, HD 2687, WH 1140, WH 147
Root Biomass	Low	2012-13	DBW 17, SONALIKA, PBW 373, WH 1142
		2013-14	DBW 17, WH 1105, WH 416, PBW 373, SONALIKA
	optimum	2012-13	WH 1100, WH 1142, WH 1138, PBW 373, DBW 17, WH 542
		2013-14	WH 147, DBW 17, PBW 373, WH 1138, WH 1142, WH 1098, WH 416, WH 1100, HD 2285, WH 1021
Root Length	Low	2012-13	DBW 17, WH 1100, WH 1081, PBW 373, SONALIKA, WH 711
		2013-14	DBW 17, WH 1140, WH 416, WH 1105, PBW 373
	optimum	2012-13	WH 1100, WH 1138, PBW 373, WH 1142, DBW 17, HD 2851, WH 1021, WH 711, PBW 644
		2013-14	WH 147, DBW 17, WH 1138, PBW 373, WH 1142, WH 1100, WH 1098, WH 416

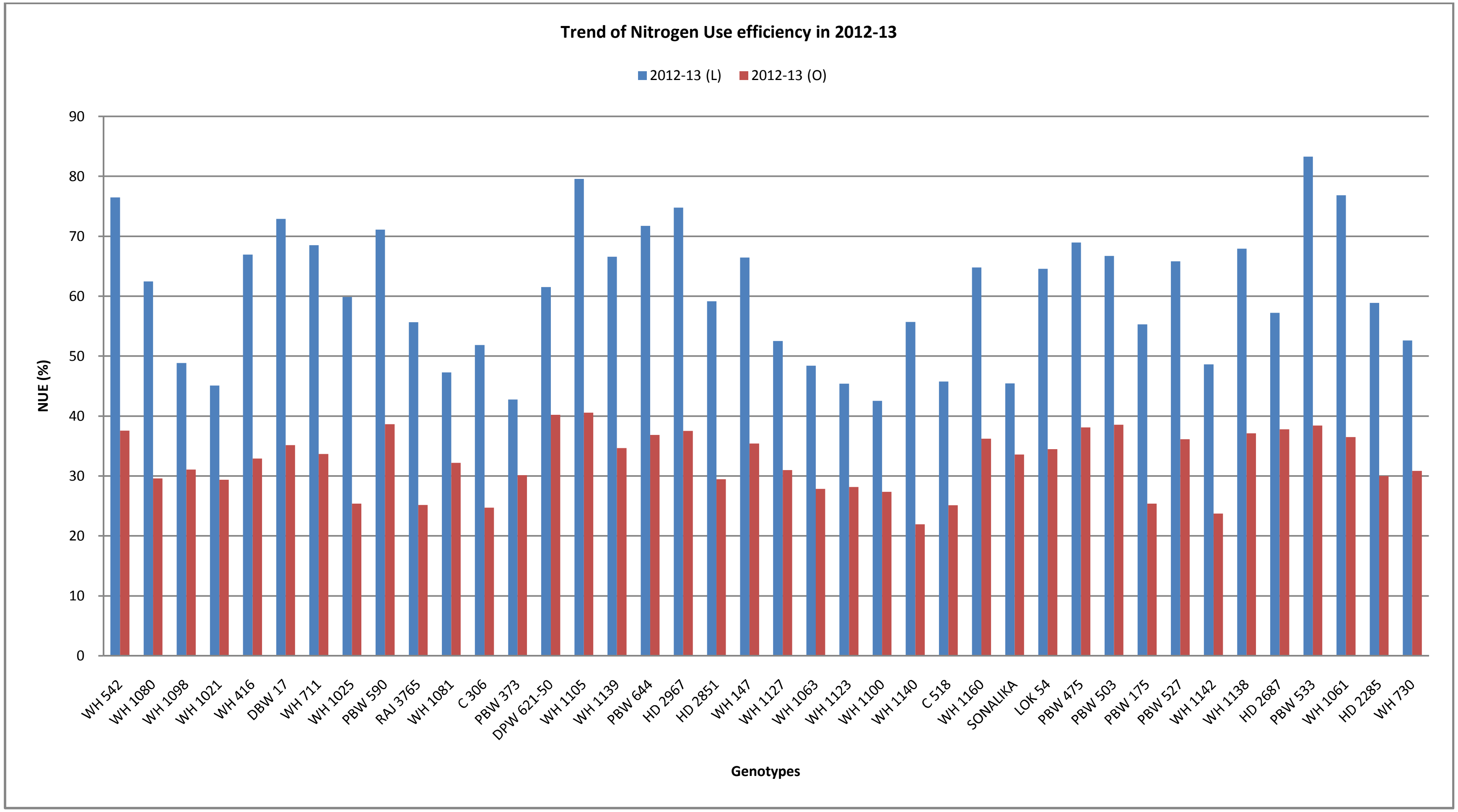

Figure 1: Trend of Nitrogen Use Efficiency in 2012-13 in Low (i.e L with blue bars) as well as Optimum (O with red bars) input conditions

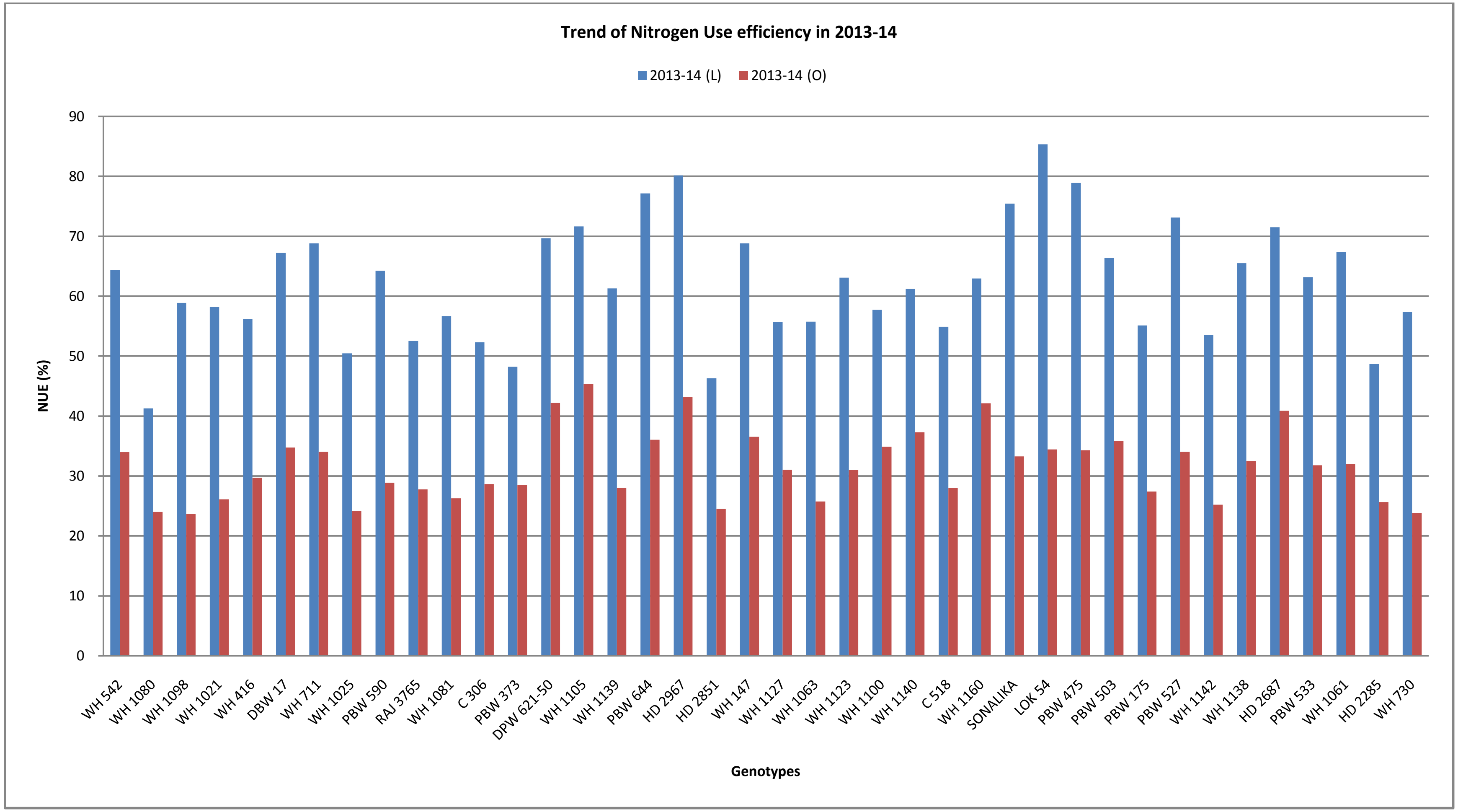

Figure 2: Trend of Nitrogen Use Efficiency in 2013-14 in Low (i.e L with blue bars) as well as Optimum (O with red bars) input conditions

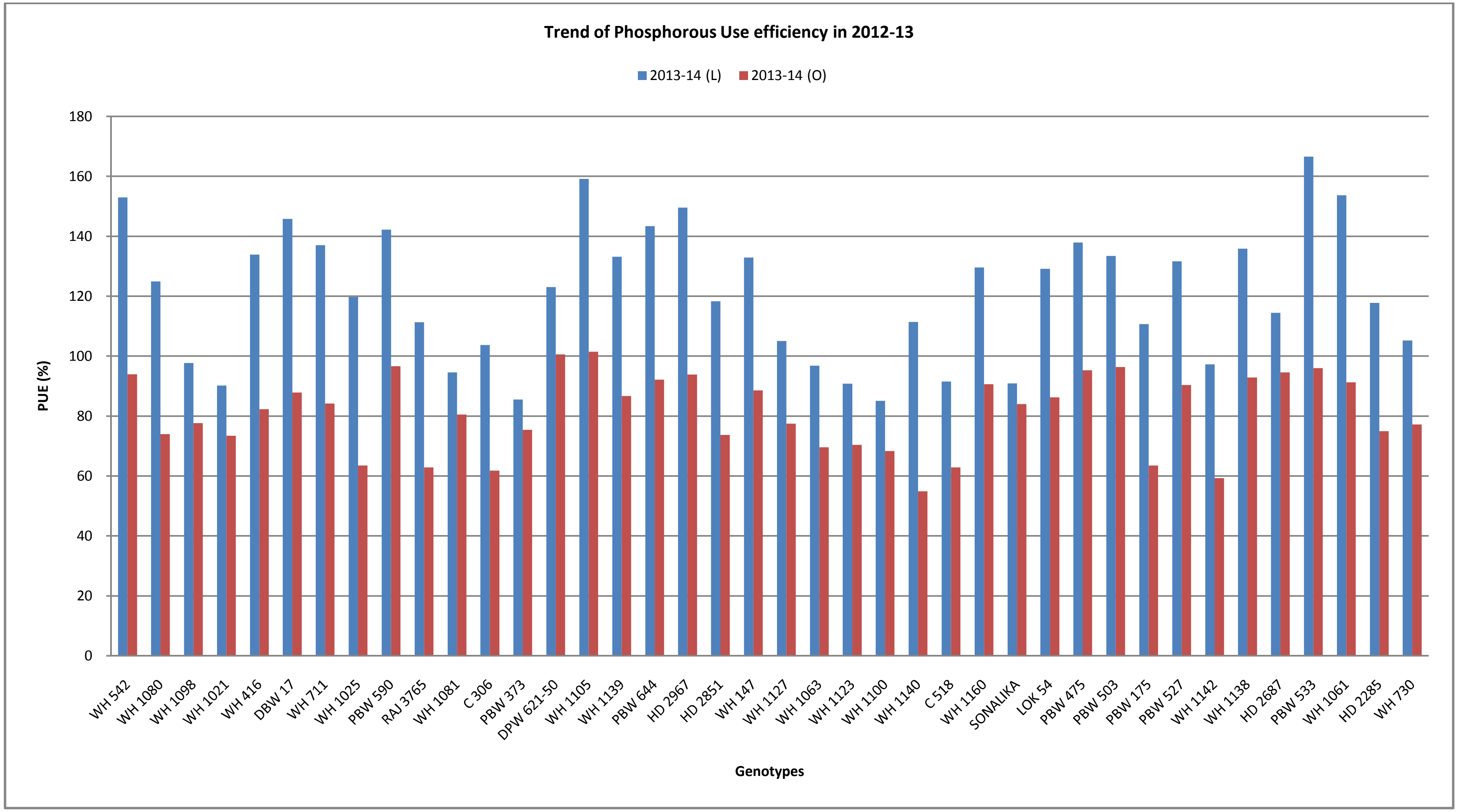

Figure 3: Trend of Phosphorous Use Efficiency in 2012-13 in Low (i.e L with blue bars) as well as Optimum (O with red bars) input conditions

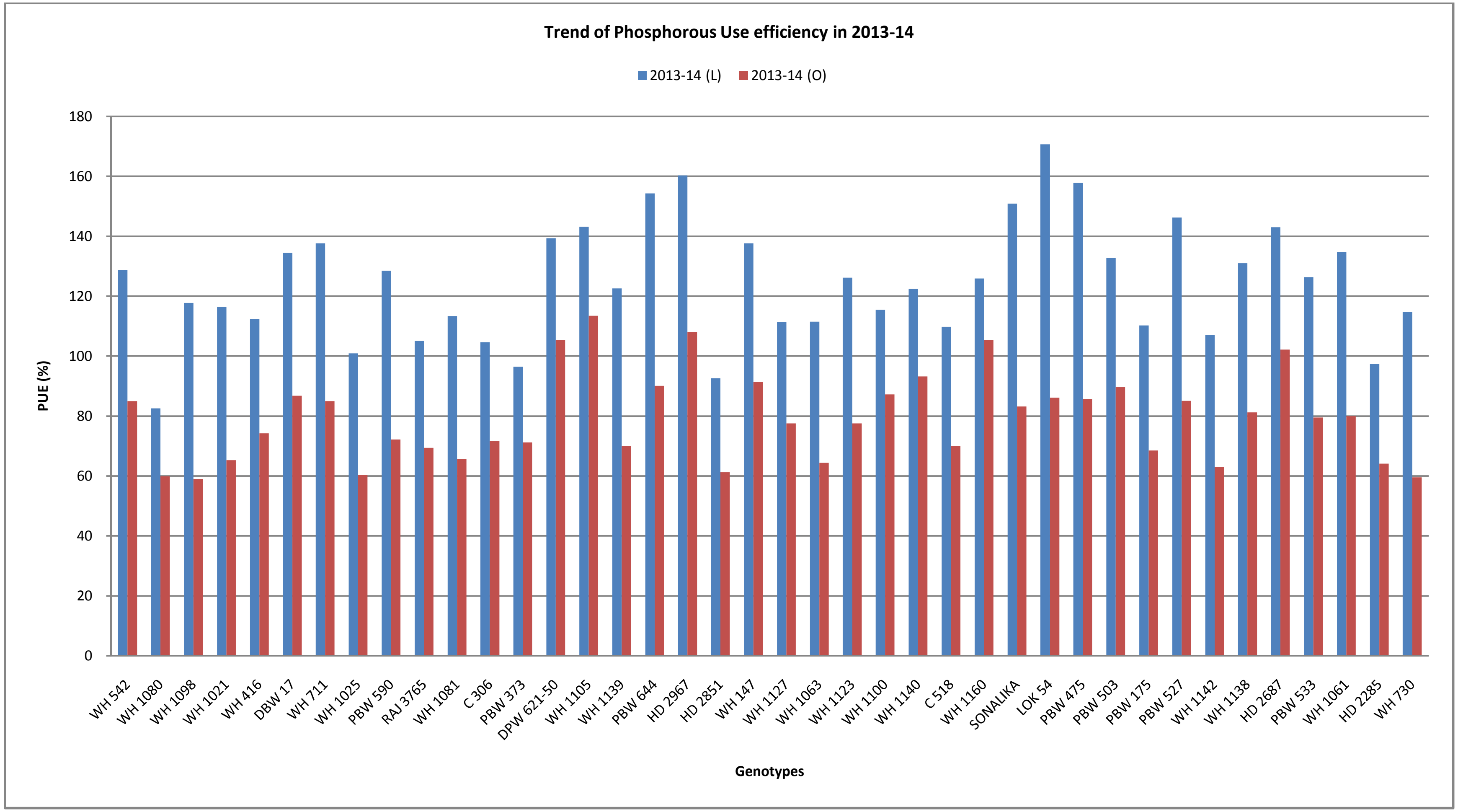

Figure 4: Trend of Phosphorous Use Efficiency in 2013-14 in Low (i.e L with blue bars) as well as Optimum (O with red bars) input conditions

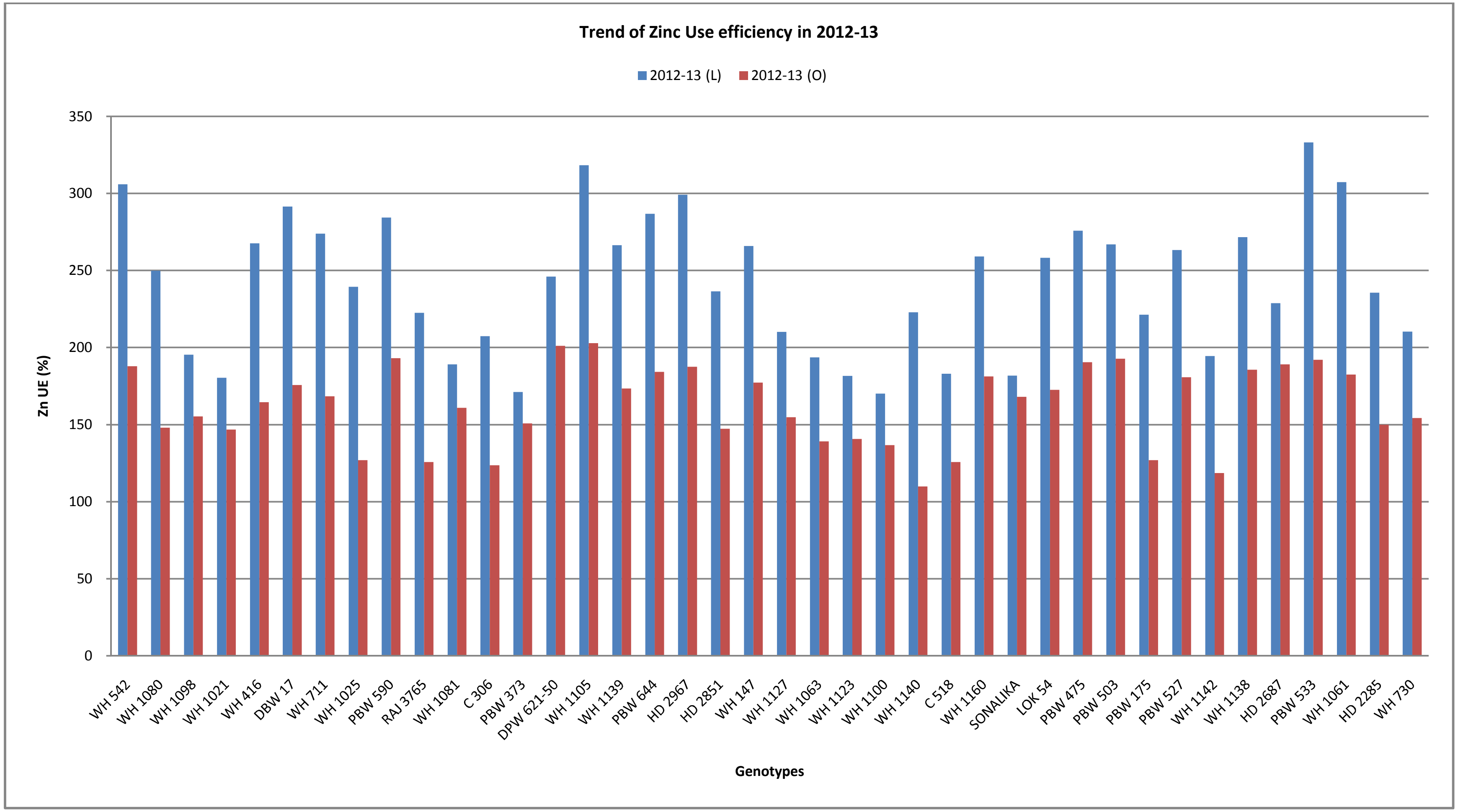

Figure 5: Trend of Zinc Use Efficiency in 2012-13 in Low (i.e L with blue bars) as well as Optimum (O with red bars) input conditions

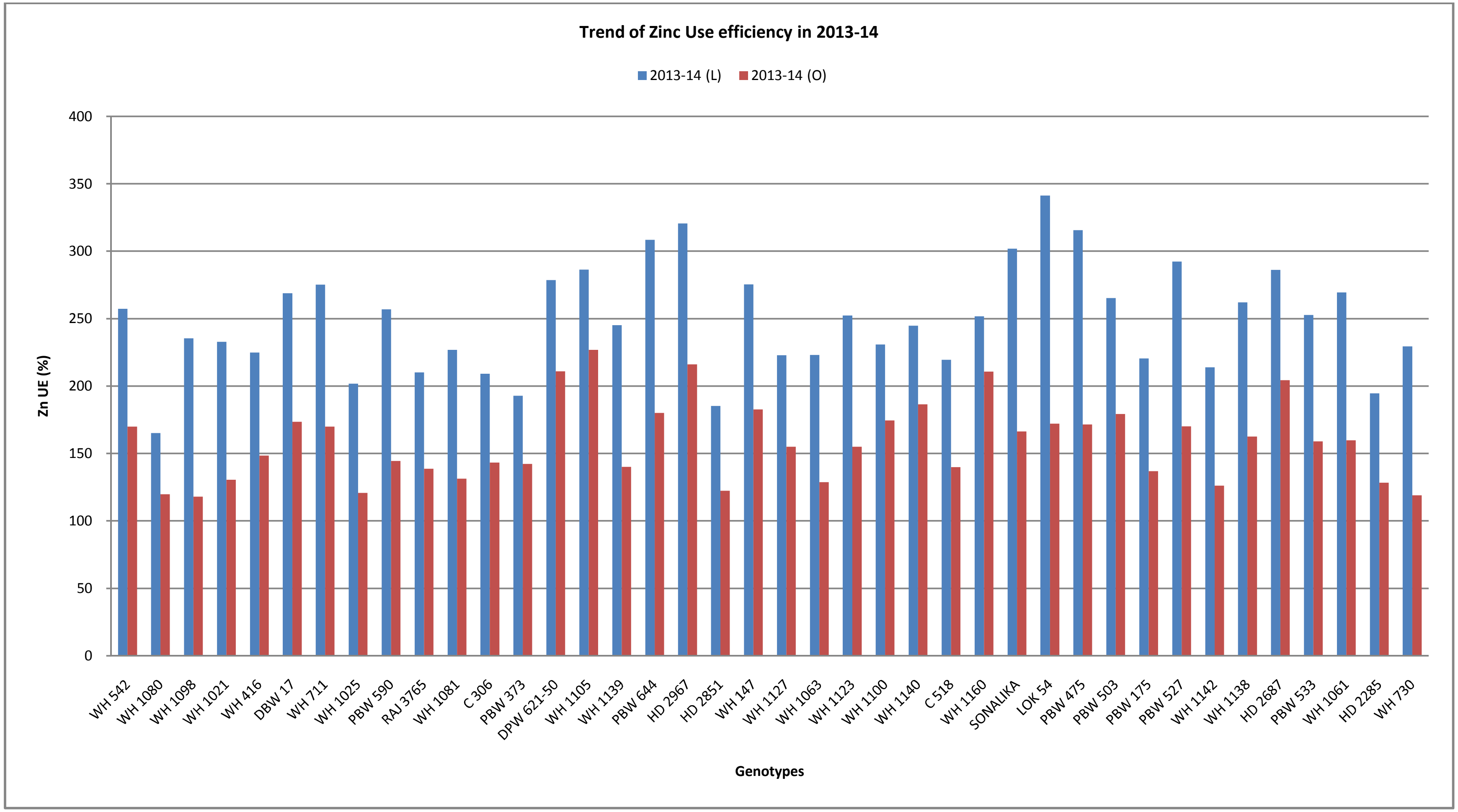

Figure 6: Trend of Zinc Use Efficiency in 2013-14 in Low (i.e L with blue bars) as well as Optimum (O with red bars) input conditions

Table 30: List of promising genotypes in common for both seasons under both low and optimum conditions

Grain yield and its components		
Sr. no.	**Traits**	**Genotypes**
Grain yield and its components		
1	Grain yield	**WH 1105**
2	1000-grain weight	**SONALIKA, HD 2967**
3	Number of tillers per plant	**WH 1105, WH 1127, DPW-621-50**
4	Spikelets per spike	**WH 147**
5	Grains per spike	**HD2851**
Nutrient use characters		
1	N content	**LOK 54**
2	P content	**WH 1105, SONALIKA, PBW 373**
3	Zn content	**DBW 17,PBW 175, WH 711, WH 1100**
4	Nitrogen use efficiency	**HD 2967, PBW 644**
5	Phosphorous use efficiency	**HD 2967, PBW 644**
6	Zinc use efficiency	**WH 1105**
Root traits		
1	Root biomass	**DBW 17, PBW 373**
2	Root length	**DBW 17**

CHAPTER - V

DISCUSSION

Cereal figure prominently in food production strategies for the future because it is the main diet for the majority of global population. Among cereals wheat is the widely cultivated food plant and its production is directly related with the world food supply. The high yielding semi-dwarf wheat varieties developed through exploitation of major reduced plant height genes (Rht 1, Rht 2 and Rht 3) made India and other developing countries under the era of green revolution during 1960’s and 1970’s. However, potential of these genotypes could be realized under high input conditions.

Worldwide, single-season recovery of N in harvested crops is estimated at 33% of applied fertilizer N (Raun and Johnson, 1999). Poor N recovery is a function of N flows to competing pathways such as gaseous N losses, leaching and biological immobilization and inefficiencies in crop N uptake and utilization (Moll et al., 1982).Continuous use of high doses of chemical fertilizers has adversely affected soil health which led to decline in productivity in many wheat grown areas in India and elsewhere (Manske, 1998). In these areas soils are low in mineral nutrients, organic carbon and rhizospheric activities. Wheat varieties differ with regard to nutrient use efficiency (Manske, 1998), therefore, the emphasis now a days is laid on selection of high and low input use efficient wheat genotypes for different agro-climatic areas to maximize production. Integrated nutrient management strategies involving chemical fertilizers and bio-fertilizers have been suggested to enhance the sustainability of crop production (Manske *et al*., 2000).

Important characteristics of low input genotypes are; a high efficiency of nutrient and water use, a high assimilation, a proper assimilate transport and distribution, less loses of assimilates through respiration and adequate nutrient acquisition by the root system. In rhizosphere, microorganisms fix nitrogen and make phosphorus available under low input conditions. When the applied nutrients are available in excess they show parasitism. So efforts have to be made to select such genotypes which can use efficiently these nutrients present in the soil. For bringing effective improvement in crop plants, the first and foremost pre-requisite is the presence of adequate and promising genetic variability and thus ensure better chances of producing new desired forms of crop plants. It is further necessary to have proper quantitative estimate of the nature and extent of genetic variability for the character under study so as to exploit existing variability.

Bread wheat (*Triticum aestivum* L. em. Thell) possesses a fibrous root system comprising 6 to 7 seminal (primary) axile roots and about 20 nodal (adventitious) roots (axiles) per stem. Seminal roots initiate from the coleorhiza, are thinner, grow deeper into the soil and are important for seedling moisture absorption and establishment, as well as tolerance to drought stress (Gregory et al., 1978; Percival, 1921; Watt et al., 2008). Nodal roots are thicker and emerge horizontally from the coleoptile and stem nodes at the tillering stage (Grando et al., 1995; Kirby, 2002). They represent younger, newly emerged roots, thus are more reflective of root growth vigor and soil nutrient status (Sullivan et al., 2000; Tennant., 1976). Agronomic improvements and genetic variation in bread wheat have been achieved by means of alien genome transfers such as chromosome substitutions and translocations from species of related *genera* like rye (*Secale cereale*) (Merker, 1984). The root system is rapidly emerging as central to environmentally sound, sustainable approaches to address wheat crop productivity challenges including declining soil fertility that threaten to raise prices by 2050 (Rosegrant and Agcaoili, 2010; Gewin, 2010; CIMMYT, 2011). The plant root system's roles as the suppliers of water and minerals, provision of anchorage, competitiveness, adaptation to abiotic and biotic stress are well documented (Russell, 1971; Barraclough, 1986). Plant roots are also critical to crop improvement efforts due to their role in belowground carbon sequestration, soil structure improvement and maintenance of soil fertility through regulation of microbial processes (White et al., 2013). Longer and thinner roots had higher uptake rates of zinc and phosphorus in durum (*Triticum turgidum*) and bread wheat (Dong et al., 1995; Gregory, 2006; Rengel and Graham, 1995).

Roots could therefore substantially influence the plant's N economy. Roots also play a key role in post anthesis N uptake especially under non limiting N and soil moisture conditions and are credited with post anthesis N contributions as high as 24.3% to grain N at maturity (Smith et al., 1983; Banziger et al.,1994; Andersson et al., 2005). Daigger et al. (1976) documented a larger demand for N by wheat grains post anthesis than could be met solely by N translocation from shoots. Root architecture, biomass morphology and physiology are especially influential in the plant's NUE (Dawson et al., 2008). Higher N uptake efficiency has been associated with early vigorous root growth, larger root densities and more extensive root systems in wheat and perennial grasses (Liao et al., 2004; Noulas et al., 2010; Jiang et al., 2000; Zemenchik and Albrecht, 2002). Higher wheat root biomass has also been associated with reduced leachate nitrate concentrations and more efficient N acquisition (Ehdaie et al., 2010).

The results of present investigation may be discussed under following heads

Analysis of variance

Mean squares due to genotypes were significant for all the characters. Significant differences due to genotypes for various traits indicated that there was considerable variation among the genotypes. Genotype × fertilizer (G × F) interaction was significant for majority of the characters except in Plant height, Chlorophyll content and Number of tillers per plant. This indicated that genotypes differed in their response from low to optimum input conditions for the characters under study (Table1).

Mean performance of genotypes under low and optimum input conditions

1. Grain yield and Biological yield

The genotype PBW 533 (5.00 g) was found with highest grain yield per plant among all the forty genotypes followed by WH 1105 (4.77 g) under low input conditions in year 2012-13, while in year 2013-14, LOK 54 (5.12 g) was found highest among means of various genotypes for the trait grain yield per plant followed by HD 2967 (4.81 g). Under Optimum input conditions in year 2012-13the genotype WH 1105 (6.09 g) was found possessing highest grain yield per plant followed by DPW 621-50 (6.03 g), while in 2013-14 under optimum input conditions genotype WH 1105 (6.81 g) was having highest grain yield per plant among all the genotypes. Highest response over low input conditions in 2012-13 was observed in Sonalika (84.85 %) followed by PBW 373 (76.18 %), WH 1081 (70.21 %) and HD 2687 (65.24 %) while lowest response over low input conditions was observed in genotype WH 1025 (6.02 %). Negative response over low input conditions was also observed in genotype WH 1140 (-1.46 %). In year 2013-14, highest response over low input conditions was found in genotype WH 1160 (67.36 %) followed by WH 1105 (58.40 %), WH 1140 (52.29 %) and DPW 621-50 (51.34 %), however, WH 1098 (0.27 %) was found lowest responding genotype. The genotype WH 1105 (12.33 g) was found with highest biological yield among all the forty genotypes under low input conditions in year 2012-13, while in year 2013-14, WH 1105 (12.93 g) was found highest among means of various genotypes for the trait biomass per plant. Under optimum input conditions in year 2012-13the genotype WH 1105 (14.4 g) was found possessing highest biomass per plant followed by WH 416 (14.07 g), while in 2013-14 under optimum input conditions genotype WH 1105 (14.87 g) was having highest biomass per plant among all the genotypes followed by DPW 621-50 (14.80 g). Highest response over low input conditions in 2012-13 was observed in Sonalika (48.12 %) followed by WH 416 (30.25 %) and WH 1100 (29.92 %), while lowest response over low input conditions was observed in genotype PBW 175 (1.49 %). Negative response over low input conditions was also observed in genotypes WH 1025 (-2.78 %) followed by RAJ 3765 (-9.59 %) and WH 1140 (-9.79 %). In year 2013-14, highest response over low input conditions was found in genotype WH 1080 (41.92 %) followed by PBW 503 (36.54 %), HD 2851 (32.54 %) and DPW 621-50 (31.36 %). These results were in accordance with Sen and Swain (1994) which concluded that plant height, number of tillers, leaves per plant and chlorophyll content increased with rate of NPK from 40 kg N + 20 kg P2O5 + 20 kg K2O to double or triple of this dose. Significant increase in plant height of wheat with increasing N levels from 60 to 120 kg/ha has also been reported by Yadav et al. (1995) and Patel et al. (1995). Singh et al. (1996) found that the application of 60 kg P_2O_5 per ha significantly increased the plant height, dry matter accumulation and plant tillers over 40 kg P_2O_5 per ha in control. Singh and Prasad (1998) indicated that N application (0-80 kg N /ha) significantly increased the grain yield of wheat. Azad *et al.* (1998) found significant increase in yield of wheat due to increase in rate of fertilizer application from recommended dose of NPK to 150 percent.

2. Number of tillers per plant, Spikelets per spike, Grains per spike and Harvest index

In 2012-13WH 1105 (4.33) had highest number of tillers per plant under low input conditions, while in 2013-14, WH 1081 (4.44) was having highest number of tillers per plant under low input conditions. Under optimum input conditions in 2012-13, HD 2285 (5.33) was having highest number of tillers per plant and in 2013-14, WH 1127 (5.44) exhibited highest number. PBW 533 (35.29 %) responded higher followed by WH 1061 (33.33 %) in 2012-13. In 2013-14, Highest response was observed in genotype DBW 17 (39.29 %). For number of spikelets per spike under low input conditions WH 730 (22.33) was found highest among all the forty genotypes. Under optimum input conditions WH 542 (27.33) was having highest number of spikelets per spike, while in 2013-14, WH 147 (28.67) came out to be sole genotype which differed significantly over mean of all the forty genotypes under optimum input conditions. In 2012-13, PBW 590 (38.78 %) responded highest over low input conditions while WH 1100 (5.36 %) was found lowest. In 2013-14, WH 1080 (67.39 %) was highly responding genotype. For grains per spike under low input conditions in 2012-13 RAJ 3765 (43.33) was having highest number , while in 2013-14 genotype WH 1081 (45.00) was found highest in number of grains per spike. Under optimum input conditions HD 2851 (53.67) was having highest number of grains per spike in 2012-13, while in 2013-14, HD 2851(51.00) was found highest in number of grains per spike under optimum input conditions. DPW 621-50 (8.85 %) responded lowest among all the forty genotypes. In 2013-14, WH 1138 (33.03 %) was highly responding genotype. For harvest index per plant, under low input conditions genotype PBW 533 (40.73) performed significantly highest among all the genotypes followed by WH 542 (39.61) in 2012-13, while genotype HD 2967 (43.99) was having highest harvest index followed by PBW 644 (43.39) in 2013-14. Under optimum in put conditions genotype WH 1160 (53.25) was possessing highest harvest index followed by WH 1140 (52.42) in 2013-14. As per percent of increase over low input conditions PBW 373 (47.66) was found highest in response in 2012-13 followed by WH 1081 (42.70 %). while HD 2851 (5.09 %) was found lowest in response to low input conditions. Genotype WH 416 (-5.67 %) was negatively responding over low input conditions in 2012-13. In 2013-14, percentage of increase over low input conditions was found highest in WH 1160 (60.64 %) followed by WH 1105 (37.66 %). In accordance to the results, Tanaka (1994) indicated that harvest index in wheat is closely related to the percentage of productive tillers and generally decreased with increase N application. An increase of N application favors huge vegetative growth and thereby results in the lower percent productive tiller, panicle number and finally lower harvest index (Tanaka, 1994). Decreasing trend of harvest index with increased rate of N application has been confirmed by several studies (Kumar and Rao, 1992; Hari et al., 1997). Ewert and Honermier (1999) observed spikelet initiation in response to two levels of nitrogen fertilization on the main stem and the first initiated tiller of winter triticale and winter wheat. The duration of spikelet initiation was not affected by nitrogen application in both cereals. Similarly Torabi and Malakuti (1997) found that the application of N (0-80 kg N/ha) increased grain yield but decreased harvest index of wheat.

3. Days to Heading, Days to maturity and Plant height in correlation to Chlorophyll fluorescence and Chlorophyll content

Under low input conditions Sonalika (83.67) genotype was found earliest in days to heading among all the genotypes while in 2012-13 for optimum input conditions trend was, Sonalika (81.67) was found earliest Similarly in 2013-14 for optimum input conditions PBW 373 (82.67) was found among earliest genotypes, While for days to maturity, Under low input conditions WH 730 (113.67) genotype was found earliest in days to maturity among all the genotypes, Similarly for optimum input conditions in 2012-13 WH 1098 (115) was found earliest genotypes with regard to days to maturity, While in 2013-14, WH 1098 (119) was found earliest regarding days to maturity. For plant height, The genotype DBW 17 (68.51 cm) was found most dwarf among all the forty genotypes, under low input conditions in year 2012-13, while in year 2013-14, DBW 17 (68.67 cm) was found most dwarf among all the *Triticum aestivum* L.. *em.* Thell. genotypes under low input conditions. Under Optimum input conditions the genotype DBW 17 (84.52 cm) was found most dwarf, while in 2013-14 under optimum input conditions genotype HD 2687 (82.30 cm) was found dwarfest among all the genotypes, Highest response over low input conditions in 2012-13 was observed in WH 711 (29.09 %), while lowest response over low input conditions was observed in genotype WH 1080 (2.18 %). In year 2013-14, highest response over low input conditions was found in genotype WH 711 (28.07 %). Genotype WH 1081 (0.58 %) was found to be almost negligibly responding to low input conditions in year 2013-14. For chlorophyll fluorescence genotype PBW 475 (0.79) was significantly highest among all the genotypes While, under optimum input conditions WH 1100 (0.86) was found highest, In 2013-14, PBW 533 (0.94) was found highest among all the genotypes under optimum input conditions. As per response of genotypes over low input conditions, genotype WH 542 (35.81 %) responded better. While WH 1081 (0.91 %) responded lowest. However, in 2013-14, genotypes C306 (48.96 %), WH 1080(32.34 %), WH 1021 (31.28 %) and WH 542 (27.80%) responded better. Lowest response was found in PBW 475 (1.52 %). In 2012-13 for chlorophyll content under low input conditions, genotype WH 1140 (41.33) was having highest while genotype C 518 (60.40) was found highest in chlorophyll content among all the genotypes under optimum input conditions. C 306 (89.43 %) responded best over low input conditions. Lowest response was found in WH 1127 (0.39 %). In 2013-14 WH 1140 (49.17 %) was found highly responding, while lowest response was found in WH 1123 (2.40 %).. In contrast to the results indicating different genotypes for different characters, Sen and Swain (1994) concluded that plant height, number of tillers, leaves per plant and chlorophyll content increased with rate of NPK from 40Kg P_2O_5 + 20 kgK_2O to double or triple of this dose. Qiang *et al.* (2006) revealed that under the field fertility conditions rates of NPK had obvious effect on canopy photosynthetic rate, chlorophyll content and nitrate reductase activity and all the photosynthetic characters indices increased with NPK and S supply, but the most powerful fertilizer factor at different date after anthesis was different. Nevena Djukic (2008) indicated that chlorophyll content depended on the presence and ratio of mineral elements in the substrate. The content of chlorophyll a, chlorophyll b, and total chlorophyll (a+b) was measured for each variant. Mauromical *et al.* (2010) reported positive linear relationship was established between nitrogen supply and chlorophyll content, Fo (initial chlorophyll fluoresence) in potato crop. Nitrogen supply upto 10g/m^2 also had positive effect on Fm and Fv, but above this rate it reduced Fv/Fm. Chlorophyll content decreased with increasing percentage, whereas Fo, Fm and Fv increased until complete canopy depression and thereafter declined until crop maturity. Rosyara *et al.* (2010) reported that the physiological traits chlorophyll content, chlorophyll fluoresence showed higher correlations with grain yield and thousand kernel weight.

4. N, P and Zn content in Plant

Under low input conditions in 2012-13, genotype WH 1123 (1.93 %) was having maximum N content per plant, while in 2013-14, LOK 54 (1.98 %) was found highest in N content per plant. In 2012-13, under optimum input conditions, maximum N content was found in LOK 54 (2.46 %) while in 2013-14, LOK 54 (2.46 %) was having highest N content per plant. As per response over low input conditions WH 1025 (35.63 %) was found highly responding genotype, while lowest responding genotype was found to be WH 1123 (14.9 %) in 2012-13, while in 2013-14 WH 1100 (32.88 %) was found highly responding genotype. while lowest response was of PBW 503 (6.76 %). WH 1105 (6.59 %) was found significantly highest in mean performance on overall mean under low input conditions for P content in grains while in 2013-14, PBW 373 (6.22 %) was found highest. Under optimum input conditions WH 1105 (7.54 %) was found highest in P content in grains. while in 2013-14 WH 1105 (7.26 %) was significantly highest in P content. In 2012-13 WH 730 (36.73 %) was highest responding genotype for P content in grains. In 2013-14, WH 1142 (45.99 %) was found to be highest responding genotype. while lowest responding genotype was found to be

WH 1100 (10.66 %). DBW 17 (60.09 %) was found significantly highest in mean performance on overall mean under low input conditions for Zn content in grains while in 2013-14 also, DBW 17 (58.96 %) was found highest in Zn content in grains. Under optimum input conditions WH 1100 (77.10 %) was found highest in Zn content in grains, while in 2013-14 DBW 17 (81.63 %) was significantly highest in Zn content. In 2012-13 PBW 503 (38.52 %) was highest responding genotype for Zn content in grains, while lowest response was observed in C 306 (3.5 %). And drastic change in response over the years was indicated from the result that in 2013-14, C 306 (42.48 %) was found to be highest responding genotype, while lowest responding genotype was found to be WH 1142 (14.87 %). Variability in results is attributed to the results shown by Semenov et.al (2007) who reported that decrease in leaf N increased NUE by 10-15%. When N was limiting, but For high N supply the effect on NUE was negligible. Korkmaz et.al (2009) reported that shoot dry matter was the most sensitive indicator of genetic variability under P deficient conditions. Svecnjak *et al.* (2007) reported that despite an associated increase in 1000-grain weight, the use of low N-fertilization brought about a significant decrease in grain yield and grain N content. In contrast grain P content was not affected by N- fertilization or growing season. Kandera (1975) revealed that fertilization with Zn increased the N content of the grain, but had no effect on P and K contents. N fertilization had the greatest influence in raising grain yields, while fertilization with trace elements slightly increased the grain yield. Ryakhovskaya *et al*. (1975) observed that the application of Mn, B and Zn increased the wheat grain yield by 220, 140 and 210 kg/ha, respectively. This increase in grain yield was attributed to increased leaf area dry matter accumulation and grain protein content. Yield and quality was significantly improved when NPK was applied in combination with trace elements (Mn, B and Zn).Rengel and Graham (1995) observed that zinc may be important for an early establishment of crops on low fertility soil and also for high grain yield. At maturity, plants derived from the high Zn seed had bigger grains and produced more grains than plants grown from the low zinc seed. They also observed that Zn deficient plant produced seed with higher concentration of all inorganic nutrients determined except Zn and concluded that crops grown from seed containing higher Zn content have distinct advantages which culminate in greater yield when grown in soil of low Zn status.

5. Nutrient use efficiency

Under low input conditions in 2012-13, PBW 533 (83.28 %) was found highly efficient for nitrogen use among all the forty genotypes followed by, WH 1105 (79.57 %), while in 2013-14 LOK 54 (85.33 %) was found highest in nitrogen use efficiency followed by HD 2967 (80.13%), Similarly, under optimum input conditions WH 1105 (40.58 %) was found most efficient genotype in nitrogen use followed by DPW 621-50 (40.23 %) in 2012-13, while in 2013-14 also WH 1105 (45.37 %) was found most efficient. In response to low input conditions WH 1140 (-60.58 %) was found most responding genotype, Similarly, WH 1098 (-59.89 %) was found to be the highest responding genotype in 2013-14, while lowest response was observed in WH 1160 (-33.06 %). in 2012-13, PBW 533 (166.56 %) was found highly efficient for phosphorous use among all the forty genotypes under low input conditions. while in 2013-14 LOK 54 (170.65 %) was found highest in phosphorous use efficiency. Similarly, under optimum input conditions WH 1105 (101.45 %) was found most efficient genotype. while in 2013-14 WH 1105 (113.44 %) was found most efficient. In response to low input conditions WH 1140 (-50.73%) was found most responding genotype. while lowest responding genotype was found to be Sonalika (-7.58 %). Similarly, WH 1098 (-49.86 %) was found to be the highest responding genotype in 2013-14. Under low input conditions in 2012-13, PBW 533 (333.13 %) was found highly efficient for Zinc use among all the forty genotypes. while in 2013-14 LOK 54 (341.30 %) was found highest in zinc use efficiency. Similarly, under optimum input conditions WH 1105 (202.90 %) was found most efficient genotype in zinc use. while in 2013-14 WH 1105 (226.87%) was found most efficient. WH 1140 (-50.73%) was found most responding genotype in 2012-13, while lowest responding genotype was found to be Sonalika (-7.58 %). Similarly, WH 1098 (-49.86 %) was found to be the highest responding genotype in 2013-14. Trend above seems to be directly reflected by grain yield. Grain yield influences the nutrient use efficiency of any genotype more. Also , In wheat, grain N content rather than yield components is largely influenced by the amount of N taken up after anthesis and by the amount of N remobilized originated from pre anthesis N uptake since these two sources of N are used for storage protein synthesis (Dupont and Altenbach , 2003) . In developed economies N use efficiency (NUE: defined as grain dry matter per unit of N available from the soil, fertilizer included) (Raun and johanson, 1999). Baresel *et al.* (2008) reported that significant differences for N uptake in three periods (tillering, stem elongation/heading and grain filling) and the quantity of mineralized N during the same sub periods traits and significant interactions among varieties and environments could be detected for nitrogen efficiency and its components. Limiting N availability during grain filling was typical for the more extensive organic environments. Under these conditions, differences became more evident and were mainly due to direct uptake during grain filling. This confirms, that different varieties are necessary in different environments and that breeding may contribute to improve baking quality to a certain extent. However, utilization of mineralized N is still unsatisfactory in organic farming systems in Germany. More N efficient varieties alone will help only little to resolve this problem; this can be achieved only by also improving the cropping systems. Korkmaz *et al.* (2009) reported that dry matter yield and P content were significantly increased by increasing P rates, with significant differences between soils. Some genotypes performed better under P stress because of better P utilization efficiency. Shoot DM was the most sensitive indicator of genetic variability under P- deficient conditions. Fageria *et al.* (2008) reported that zinc concentration had a quadratic increase. Zinc uptake followed an exponential quadratic response in four crops. Zinc use efficiency in shoot dry weight production had significant quadratic responses in upland rice and soyabean with increasing plant age. Zinc use efficiency for shoot dry weight production was linear as a function of plant age. Cereals had higher Zn use efficiency than legumes.

6. Root studies: root biomass and Root length

For root biomass in 2012-13 under low input conditions DBW 17 (5.13 g) was having highest root biomass among all the genotypes while genotype DBW 17 (5.1 g) was having highest mean in 2013-14. Under optimum input conditions trend was WH 1100 (6.17 g) possessed highest root biomass, while in 2013-14, WH 147 (6.09 g) was having highest root biomass followed by DBW 17 (6.07 g). WH 1100 (39.46 %) was found most responding genotype in 2012-13. In 2013-14 WH 1127 (38.17 %) was found most responding genotype. Similarly for root length in 2012-13 under low input conditions DBW 17 (44.33 cm) and genotype DBW 17 (45.33 cm) in 2013-14. Under optimum input conditions trend was WH 1100 (56.73 cm) possessed highest root length. In 2013-14, WH 147 (53.87 cm) was having highest root length. WH 147 (37.37 %) was found most responding genotype in 2012-13, while lowest response was observed in WH 1123 (10.41 %). Lowest response was observed in Sonalika (9.02 %) over low input conditions in 2013-14. In accordance to the experimental results, Zhang *et al.* (1998) reported that reduced irrigation promoted root expansion deep in the soil profile (80±180 cm). I0 and I1 had 9.9% and 6.3%, respectively, of their total dry root mass below 80 cm soil depth, compared to only 2.4% in I4. In the 40±80 cm layer, I1 also had more root mass than I4 crop. As expected, roots of I4 wheat were mainly in the shallow soil (0±40 cm). Non-irrigated plots showed the most yield reduction because kernel numbers were also substantially reduced. Yield of I1 plots was reduced by about 10±15%, mainly due to the reduced kernel weight, but harvest index was greater than both I0 and I4. Leaf water potential of I1 was similar to that of well-watered plots at both predawn and mid day. The maintenance of predawn leaf water potential is probably a consequence of the deep root system and the absence of serious midday leaf water deficit a result of the reduced stomatal opening and transpiration. Roots could therefore substantially influence the plant’s N economy. Roots also play a key role in post anthesis N uptake especially under non limiting N and soil moisture conditions and are credited with post anthesis N contributions as high as 24.3% to grain N at maturity (Smith et al., 1983; Banziger et al.,1994; Andersson et al., 2005).

Variability Parameters

The estimates of gcv and pcv fell in medium range for the characters like Grain yield per plant under both optimum as well as low input conditions in both the seasons, for plant height in 2012-13 under low input conditions, for biomass per plant in 2013-14 under low input conditions, for harvest index in 2013-14 under optimum input conditions, for chlorophyll content under optimum input conditions in 2012-13, for number of tillers per plant, P content and Zn content under both optimum as well as low input conditions in both the seasons. While for most of the characters genotypic and phenotypic coefficient of variability fell out in low range category like plant height in both years under optimum input conditions and low input conditions in 2013-14, biomass per plant in 2012-13 and 2013-14 under optimum input conditions, harvest index in 2012-13 under both optimum as well as under low input conditions. Similarly, for chlorophyll fluorescence, chlorophyll content, 1000- grain weight , spikelets per spike, grains per spike, days to heading and days to maturity, N content in grains, root biomass and root length under both optimum as well as low input conditions in both the seasons gcv and pcv were on lower side indicating less variability per character. In contrast, Dharmendra and Singh (2010) reported that phenotypic and genotypic coefficient of variation (PCV and GCV), heritability, genetic advance (GA), correlation and path analysis for 10 characters were estimated in 20 genotypes of bread wheat. High estimates of PCV, GCV, heritability and GA indicated scope for improvement through simple selection for grain yield components namely, grain per spike, grain yield per plant, plant height followed by 1000-grain weight. However for days to heading and maturity results were somewhat supported by Dharmendra and Singh (2010) who reported that there was little variability and scope for selection in the materials for days to 50 % heading, days to maturity and germination percent. Jalata *et al*. (2011) observed significant variation among materials tested for important quantitative traits across locations indicating the presence of variability. In addition, genotypic coefficient of variability (GCV) and phenotypic coefficient of variability (PCV) was relatively higher for grain yield per plot, number of kernels per spike and spike weight respectively, across locations, and relatively high heritability was obtained for spike length followed by thousand kernel weight, number of kernels per spike, grain yield per plot across locations showing better condition for effective selection in these characters. Longer and thinner roots had higher uptake rates of zinc and phosphorus in durum (*Triticum turgidum durum*) and bread wheat (Dong et al., 1995; Gregory, 2006; Rengel and Graham, 1995). Positive correlations between total root length and grain yield have also been reported for winter wheat, oats and barley (Barraclough, 1984; Leon and Schwang, 1992). Additionally, root biomass investments at depth have been associated with adaptation to drought in wheat as they improve the plant's ability to mine a larger soil profile for water and nutrients (Evans, 1977; King et al., 2003; Waines et al., 2007; Lopes and Reynolds, 2010).

Correlation coefficients

Genotypes having high grain yield per plant were also having high biomass per plant, harvest index and spikelets per spike. While genotypes having high grain yield were having lesser plant height, root biomass and root length in 2012-13, while in 2013-14, trend was that plant with high grain yield per plant was having higher harvest index, biomass per plant, 1000-grain weight, days to maturity and P content. However, high yielding plant was having root biomass on lower side. In 2012-13, also under low input conditions grain yield showed significant positive correlations with harvest index, biomass per plant and significantly negatively correlated with root length, while in 2013-14 grain yield showed significantly positive correlation with harvest index, biomass per plant, chlorophyll fluorescence and spikelets per spike indicating biomass per plant and harvest index having strong association with grain yield and characters for further scope of selection . Moreover harvest index also exhibited a significant positive association with grain yield which indicated efficient translocation of photosynthesis from source to sink. Due to that some genotypes might have more responded to fertilizer dose by increasing the vegetative phase and decreasing the productive phase under optimum input conditions leading to non-significant correlations with physiological traits and most of the phenological traits. Paul and Ganguli (1996) revealed that number of spikes per plant, grain weight per spike and number of grains per spike were positively and significantly correlated with grain yield. The tillers per plant appear to be important trait among yield components as it showed significant association with more number of yield components. The genotypes having high tillers per plant also had high number of grains per spike, high biological yield and harvest index under optimum input conditions, but under low input conditions the trend was not same, the genotypes having more tillers had high grain weight but few grains per spike. Thus grains per spike and harvest index were important trait for determining tillers per plant under optimum input conditions, while 1000-grain weight was more important under low input conditions.. Khan and Mohammed (1999) reported that phenotypic correlations between plant height and grain yield per plant were significant and negative with 1000-grain weight. Singh *et al.*(2003) revealed positive and significant correlation between effective tillers per plant, biological yield per plant and harvest index with grain yield per plant. 1000-grain weight was the next important character indicating that the genotypes having high grain weight also had high harvest index under both input conditions, while high grains per spike also had high harvest index under optimum input conditions. This may be probably due to large number of grains under low input conditions were under weight because of low input conditions, therefore they did not contributed much to harvest index. Root biomass was significantly positively correlated with root length and biomass per plant was significantly negatively correlated with root length. Days to heading was significantly correlated P content and root biomass under low input conditions in 2012-13.

Path coefficient analysis

The direct and indirect effects of various characters along with their genotypic correlation under optimum and low input conditions are presented in (Table27 and Table 28). The residual effects under optimum and low input conditions were 0.00306 and 0.00444 respectively in 2012-13, while the corresponding figures in 2013-14 were 0.00619 and 0.00444 respectively. This indicated that a considerable magnitude of variation was present for association of grain yield with the dependent traits under both conditions. The residual effects considerably low under both input conditions indicating a high contribution of dependent traits to the grain yield. Biomass per plant had the highest direct effect under both conditions, but the indirect contribution of 1000 grain weight, grains per spike and plant height, spikelets per spike and harvest index was changed in both degree and direction from low to optimum input conditions. This may be probably due to changes in the expression of genotypes over the environments. The spikelets per spike and plant height were contributed more towards biomass per plant under optimum input conditions, while biomass per plant was more important under low input conditions. Khan and Mohammed (1999) reported that the path coefficient analysis showed that the harvest index, plant height and grains per spike were the important character in order of magnitude. Mondal and Khajuria (2001) and Sudesh *et al.* (2002) reported that path analysis showed highest direct effect of grains per spike, biomass ratio towards grain yield followed by spike length and spikelets per spike. The indirect effect of grains per spike, biomass ratio through spike length and number of spikelets per spike being negative towards grain yield resulted in lowering the correlation coefficients. Singh *et al.* (2003) revealed that biological yield per plant, grains per ear, 1000 grain weight and effective tillers per plant had positive and high direct effect on grain yield per plant.

Implications of nutrient use efficiency

The experimental results summarized in Table 30 revealed some promising genotypes in common for grain yield and its components, nutrient use characters and root traits under both low and optimum input conditions in both seasons viz. WH 1105 for grain yield per plant, Sonalika and HD 2967 for 1000-grain weight, WH 1105, WH 1127 and DPW 621-50 for number of tillers per plant, WH 147 for spikelets per spike, HD 2851 for grains per spike. Similarly, for nutrient use characters, LOK 54 for N content in grains, WH 1105, Sonalika and PBW 373 for P content in grains, DBW 17, PBW 175, WH 711 and WH 1100 for Zn content in grains, HD 2967 and PBW 644 for Nitrogen use efficiency as well as Phosphorous use efficiency both, WH 1105 for Zinc use efficiency. Similarly, for root traits, DBW 17 and PBW 373 for root biomass and DBW 17 for root length. These results show considerable variability among genotypes for the characters under study, which further indicate the scope of developing promising genotypes through magic breeding programme (crossing among better genotypes for most of the traits) like WH 1105, HD 2967, DBW 17 followed by selection in segregating generations may lead to identification of physiologically efficient and high yielding genotypes coupled with better nutrient use under low as well as optimum input conditions. Also, genotypes resistant to both low and optimum input conditions may be identified.

CHAPTER - VI

SUMMARY AND CONCLUSION

The objectives of present investigation were:

1) To evaluate the various genotypes of bread wheat for various characters under low and optimum input conditions.
2) To determine the genotypic and phenotypic variability for the grain yield, its components and morpho- physiological traits under low and optimum input conditions.
3) To determine the various indices of yield, its components and other morpho-physiological traits for the traits for nutrient use efficiency.
4) To determine the promising genotypes for nutrient uptake and use efficiency

Experimental material comprised forty genotypes of bread wheat (*Triticum aestivum em.* Thell.). The experiment was conducted under low and optimum input conditions. The observations recorded were estimation of N, P and Zn content from straw and grain, grain yield and its components, root traits (root biomass and root length) and physiological parameters (chlorophyll content, chlorophyll fluorescence). The findings of this experiment are summarised in following heads.

Analysis of variance

Mean squares due to genotypes were significant for all the characters. Significant differences due to genotypes for various traits indicated that there was considerable variation among the genotypes. Genotype × fertilizer (G × F) interaction was significant for majority of the characters except in Plant height, Chlorophyll content and Number of tillers per plant. This indicated that genotypes differed in their response from low to optimum input conditions for the characters under study (Table1).

Mean performance of genotypes for various traits under low and optimum input conditions

Under Optimum input conditions in year 2012-13the genotype WH 1105 (6.09 g) was found possessing highest grain yield per plant, while highest response over low input conditions in 2012-13 was observed in Sonalika. Lowest response over low input conditions was observed in genotype WH 1025, while in year 2013-14, highest response over low input conditions was found in genotype WH 1160**.** The genotype WH 1105 was found having highest biological yield among all the forty genotypes under low input conditions in year 2012-13, highest response over low input conditions in 2012-13 was observed in Sonalika. The higher increase under optimum input conditions indicated the potential for fertilizer responsiveness of the genotypes which can be used in breeding programme for improvement of the trait under consideration. For number of tillers per plant PBW 533 and DBW 17 were highest responding genotypes under optimum input conditions. Similarly, for spikelets per spike PBW 590 and WH 1080. DPW 621-50 for grains per spike responded lowest The numbers of spikelets per spike of both main stem tillers were significantly increased due to nitrogenous fertilizer at anthesis of wheat.

Physiological parameters

The genotypes WH 542 was better in response over low input conditions alongwith C 306 in both the seasons for chlorophyll fluorescence and chlorophyll content. C 306 performed better per increase in nutrient dose from low to optimum input conditions.

Nutrient uptake parameters

Trend remained same for the increase in mean performance of genotypes for N, P and Zn use efficiency from low to optimum input conditions as PBW 533 and WH 1105 under both low and optimum input conditions were better in mean performance over the years for nitrogen, phosphorous as well as zinc use efficiency. This may be due to the reason that all the efficiencies depend on the grain yield performance. WH 1140 and WH 1098 came out to be better responding genotypes over both the seasons from low to optimum input conditions.

Root traits

DBW 17, WH147 and WH 1100 were found promising for root length as well as root biomass. WH 1100 was better responding genotype came out from low to optimum input conditions.

Correlation coefficients

Correlation coefficients revealed that the biomass per plant and harvest index were significant components of grain yield under low and optimum input conditions. Trend deflected the path for grains per spike, plant height, spikelets per spike, root traits and days to heading and maturity. This may be due to that some genotypes might have more responded fertilizer dose by increasing the vegetative phase and decreasing the productive phase under optimum input conditions leading to non-significant correlations with biomass per plant yield. However, biomass per plant was affected greatly by spikelets per spike and plant height. Similar results were recorded for root traits as grain yield was found negatively correlated with root length and root biomass.

Path coefficient

Considerable magnitude of variation was present for association of grain yield with the dependent traits under both conditions. The residual effects considerably low under both input conditions indicating a high contribution of dependent traits to the grain yield. Biomass per plant had the highest direct effect under both conditions, but the indirect contribution of 1000 grain weight, grains per spike and plant height, spikelets per spike and harvest index was changed in both degree and direction from low to optimum input conditions. This may be probably due to changes in the expression of genotypes over the environments. The spikelets per spike and plant height contributed more towards biomass per plant under optimum input conditions, while biomass per plant was more important under low input conditions.

Conclusions

- For grain yield and biomass per plant, WH 1105 genotype showed highest mean in both the seasons. WH 1160 and Sonalika were better responding genotypes for grain yield and biological yield.
- For number of tillers per plant PBW 533 and DBW 17 were highest responding genotypes under optimum input conditions. Similarly, for spikelets per spike PBW 590 and WH 1080. DPW 621-50 for grains per spike responded lowest The numbers of spikelets per spike of both main stem tillers were significantly increased due to nitrogen fertilization at anthesis of wheat.
- The genotypes WH 542 was better in response over low input conditions alongwith C 306 in both the seasons for chlorophyll fluorescence and chlorophyll content. C 306 performed better per increase in nutrient dose from low to optimum input conditions.
- Correlation coefficients revealed that the biomass per plant and harvest index were significant component of grain yield under low and optimum input conditions. Trend deflected the path for grains per spike, plant height, spikelets per spike, root traits and days to heading and maturity.
- Trend remained same for the increase in mean performance of genotypes for N, P and Zn use efficiency from low to optimum input conditions as PBW 533 and WH 1105 under both low and optimum input conditions were better in mean performance over the years for nitrogen, phosphorous as well as zinc use efficiency.
- DBW 17, WH147 and WH 1100 were found promising for root length as well as root biomass. WH 1100 was better responsive genotype from low to optimum input conditions.
- Biomass per plant had the highest direct effect under both conditions, but the indirect contribution of 1000 grain weight, grains per spike and plant height, spikelets per spike and harvest index was changed in both degree and direction from low to optimum input conditions.
- For most of the characters genotypic and phenotypic coefficient of variability was in low range category like plant height in both years under optimum input conditions and low input conditions in 2013-14, biomass per plant in 2012-13 and 2013-14 under optimum input conditions, harvest index in 2012-13 under both optimum as well as under low input conditions. Similarly, under both optimum as well as low input conditions in both the seasons gcv and pcv for chlorophyll fluorescence, chlorophyll content, 1000- grain

weight, spikelets per spike, grains per spike, days to heading and days to maturity, N content in grains, root biomass and root length were on lower side indicating less variability per character.

- Experimental results show considerable variability among genotypes for the characters under study, which further indicate the scope of developing promising genotypes through MAGIC (Multi parent advanced generation inter-cross) breeding programme (crossing among better genotypes for most of the traits) like WH 1105, HD 2967, DBW 17 followed by selection in segregating generations among. This may lead to identification of physiologically efficient and high yielding genotypes coupled with better nutrient use under low as well as optimum input conditions. More emphasis will be given to genotypes performing best (most NUE) in low input conditions.

REFERENCES

Afzaal, M., Farooq, S., Akram, M., Naz, F., Arshad, R. and Bano, A. 2006. Differences in agronomic are physiological performance of various wheat genotypes grown under saline conditions. *Pakistan Journal of Botany.* **38** (5): 1745-1750.

Akbari, K.N., Karan, F., Quresh, F.M., Pandya, H.R., 1999. Effect of micronutrient, sulphur and gypsum on yield of wheat and post harvest fertility in red loam soil of Mewar (Rajasthan). *Indian Journal of Agricultural Resea*rch. **33** (2): 80-86.

Al-Jibouri, H.A., Miller, P.A. and Robinson, H.P. 1958. Genotypic and Phenotypic covariance in an upland cotton cross of interspecific origin. *Agronomy Journal.* **50**: 633-636.

Alloway, B.J. 2008. Micronutrient deficiencies in global production. Department of soil science, White Knights Reading RG 66DW:UK).

Andarab, S.S. 2013. Study of correlation among yield and yield components affecting traits of bread wheat under drought stress and non stress conditions. *Annals of biological research*. **4**(5):286-289.

Andersson, A., and Johansson, E., 2006. Nitrogen partitioning in entire plants of different spring wheat cultivars. *Journal of agronomy and crop science*.**192**, 121-131.

Andersson, A., Johansson, E., Oscarson, P., 2005. Nitrogen redistribution from the roots in post-anthesis plants of spring Wheat. *Plant and Soil.* **269**: 321-332.

Andrascik, W. and Kqaribinora, M. 1986. Response of spring wheat to varying fertility level. *Current Agricultural Research.* **1** (2): 18-21.

Anonymous. 2014. Progress report of the All India Coordinated Wheat & Barley improvement Project 2014-15 – Crop Improvement. (Eds.) Shoran J, Tiwari, V, Chatrath, R, Verma, A, Singh, G, Tiwari R, Kumar R, Tyagi, BS, Sareen S, Singh SK and Singh SS Vol I, DWR, Karnal (Haryana), India.

Arnall, D.B., Tubana, Brenda, S., Holtz, S.L., Girma, K. and Rawn, W.R. 2009. Relationship between nitrogen use efficiency and response index in winter wheat. *Journal of Plant Nutrition.* **32** (3): 502-515.

Austin, R.B., Ford, M.A., Morgan, C.L. and Yeoman, D. 1993. Old and modern wheat cultivars compared to broad balk wheat experiment. *European Journal of Agronomy.* **2** (2): 141-147.

Azad, B.S., Gupta, S.C. and Peer, A.C. 1998. Influence of organic and inorganic fertilizers in maximizing wheat yield at irrigated conditions. *Environment & Ecology.* **16** (1): 71-73.

Bahar, B., Yildirim, M., Celaleddin, B. 2009. Relationships between stomatal condtuance and yield compnetns in spring durum wheat under mediterancean conditions. *Notulae Botanicae Horti. Agrobtanici Cluj-Napoca*. **37** (2): 45-48.

Baresel, J. P., Zimmermann, G., Reents H. J. 2008. Effects of genotype and environment on N uptake and N partition in organically grown winter wheat (*Triticum aestivum* L.) in Germany. *Euphytica*.**163**(3): 347-354.

Barraclough, P. B., and Leigh, R. A., 1984. The growth and activity of winter wheat roots in the field: the effect of sowing date and soil type on root growth of high yielding crops. *Journal of Agricultural Science, Cambridge***.103**: 59-74.

Batten, G.D. 1986. The uptake and utilization of phosphorus and nitrogen by diploid, tetraploid and hexaploid wheats (*Triticum* spp.). *Annals of Botany*. **58** (1): 49-59.

Behera, A.K.. 1998. Response of crops to nitrogen under transplanted condition. *Indian journal of Agronomy*. **43**(1):64-67.

Behl, R.K., Gupta, S.P., Gupta, V.K., Singh, K.P. 1998. Response of disomic chromosome substitution lines of wheat to zinc application. *Sustainable Agriculture for Food, Energy and Industry*. **35** : 658-661.

Behl, R.K., Osaki, M., Wasaki, J., Watanabe, T., shinano, T. 2003. Breeding wheat for zinc efficiency improvement in semi arid climate: A review. *Tropics*. **12**(4): 295-312.

Bieleski, R.L. 1973. Phosphate pools, phosphate transport, and phosphate availability. *Annual Review of Plant Physiology*. **24**: 225-252.

Bosquet, C.L., Rossella, A., Joscb-Luis, A. and Salvador, N. 2009. Photosynthetic capacity of field grown durum wheat under different N availabilities : A comparative study from leaf so canopy. *Environmental and experimental botany*. **67** (1): 145-152.

Brancourt, H.H., Heumez, E., Pluchard, P., Begnin, D., Departure, C. Girard, A., Le-Gousi, J. 2005. Indirect versus direct selection of winter wheat for low-input or high input levels. *Crop Science*. **45** (4): 1427-1431.

Bumb B.L., baanante, A.C. 1996. The Role of fertilizer in sustaining Food Security and protecting the environment. Food, Agriculture and the environment discussion paper 17. International Food policy research institute, Washington, D.C.

Cakmak, I., Derici, R., Torun, B., Tolay, I., Braun, H.J., Schlegel, R. 1997. Role of rye chromosomes in improvement of zinc efficiency in wheat and triticale. *Plant and Soil*. **196**: 249-253.

Cakmak, I., Tolay, I., Ozdemir, A., Ozkan, H., Ozturk L., Kling C. I.1999. Differences in Zinc Efficiency among and within Diploid, Tetraploid and Hexaploid Wheats. *Annals of Botany*. **84**: 163-171.

Campbell, C.A., Cameron, D.R., Nicholaichuk, W., Davidson, H. R., 1977. Effects of fertilizer N and soil moisture on growth, N content, and moisture use by spring wheat. *Canadian Journal; of Soil Science*.**57**: 289-310.

Cao, H.J., Gao, J., Zhang, Shu, X., Xu, Ming, G., Huang, S.M. and Yang, X.Y. 2009. Posphours use efficiency of wheat on three typical farmers soils under long term fertilization. *Ying yong shengati Xue Bao*. **20** (9): 2142-2148.

Cassman, K. G., Dobermann, A., Walters, D.T., 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. *Journal of the Human Environment*. **31**(2):132-140.

Chandra, S., Varshney, M.L., Singh, J. and Singh, S.K. 1992. Response of wheat varieties to different levels of nitrogen. *Narendra Deva. Journal of Agriculture Research*. 7 (1): 169-171.

Chaudhary, N.R., Vyas, A.K. and Singh, A.K. 1997. Growth and nutrient uptake in wheat as influenced by nitrogen, phosphorus and zinc fertilization. *Annals of Agriculture Research*. **18** (3): 365-366.

CIMMYT, 2011. Wheat - Global alliance for improving food security and the livelihoods of the resource-poor in the developing world: proposal submitted by CIMMYT and ICARDA to the CGIAR Consortium Board. 2011, Mexico.)

Cormier, F., Faure, S., Dubreuil, P., Heumez, E., Beauchêne, K., Lafarge, S., Praud, S. and Le Gouis, J.A. (2013) multi-environmental study of recent breeding progress on nitrogen use efficiency in wheat (*Triticum aestivum* L.). *Theoretical and Applied Genetics*. **126**: 3035-3048.

Da silva, Cristiano, L.Benin, G., Bornhofen, E.,Beche, E.,Henrique, Todeschini, M. and Minioli, Anderson, S. 2014. Nitrogen use efficiency is associated with chlorophyll content in Brazilian spring wheat. *Australian journal of crop science*.**8**(6):957-964.

Daigger, L.A., Sander, D.H., and Peterson, G.A., 1978. Nitrogen content of winter wheat during growth and maturation. *Agronomy Journal.* **68:** September - October 1978.

Dawson, J.C., Huggins, D.R., Jones. S.S., 2008. Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. *Field Crops Research.* **107**: 89-101.

Dewey, D.R. and Lu, K.H.1959. Correlation and path analysis of components of crested wheatgrass seed production. *Agronomy Journal*. **51**: 515-518.

Dharmendra, S. and Singh, K.N. 2010. Variability analysis for yield and yield attributes of bread wheat under salt affected conditions. Division of crop improvement, Central Soil Salinity Research Institute, Karnal 132001, Haryana India.

Dong, B., Rengel, Z., Graham, R.D., 1995. Root morphology of wheat genotypes differing in zinc efficiency. *Journal of Plant Nutrition*. **18**(12): 2761-2773.

Dupont, F.M., Altenbach, S.B., 2003. Molecular and biochemical impacts of environmental factors on wheat grain development and protein synthesis. *Journal of cereal sciences.* **38**: 133–146.

Ehdaie, B., Merhaut, D.J., Ahmadian, S., Hoops, A.C., Khuong, T., Layne, A.P., and Waines, J. G., 2010. Root system size influences water-nutrient uptake and nitrate leaching potential in *Wheat journal of agriculture and crop science*. ISSN 0931-2250.

Eilrich, G.L., Hageman, R.H. 1973. Nitrate reductase activity and its regulation to accumulation of vegetative and grain nitrogen in wheat (*Triticum aestivum* L.). Crop science. **13**: 59-66.

Erenglu, B., Nicolic, M., Romeheld, V. and Cakmak, I. 2002. Uptake and Transport of foliar applied Zinc(65 Zn) in bread and durum wheat cultivars differing in Zinc efficiency. *Plant and Soil* **241**(2): 251-257.

Evans, P.S., 1977. Comparative root morphology of some pasture grasses and clovers. *New Zealand Journal of Agricultural Research.* **20**(3): 331-335.

Ewert, F. and Honermeier, B. 1999. Spikelet initiation of winter triticale and winter wheat in response to nitrogen fertilization. *European Journal of Agronomy*. **11** (2): 107-113.

Fageria, N.K., Filhobarbosa, M.P. and Santos, A.B. 2008. Growth and zinc uptake and use efficiency in food crops. *Communications in soil science and plant analysis.* **39** (15-16): 2258-2269.

Fischer, R.A. 1981. Optimizing the use of water and ntiorgen through breeding of crops. *Plant and Soil.* **58**: 249-278.

Fitzgerald, G.A., Rodriguez, D.B. and Leary, G.O. (2010) Measuring and predicting canopy nitrogen nutrition in wheat using a spectral index - The canopy chlorophyll content index (CCCI). *Field Crop Res*earch. **116**: 318–324.

Fraser, J., Doughests, C.T. and Langer, R.H.M. 1982. Dynamics of tiller populations of standard height and standard height and semi-dwarf wheat. *New Zealand Journal of Agriculture Research*. **25**: 321-328.

Gaju, O, Allard, Martre, P., Snape, J.W., Heumez, E., Le Gouis, J., Moreau, D., Bogard, M., Griffiths, S., Orford, S., Hubbart, S. and Foulkes, M.J. (2011) Identification of traits to improve the nitrogen-use efficiency of wheat genotypes. *Field Crop Research*. **123**: 139–152.

Gallagher, J.N., and Biscoe, P.V., 1978. Radiation absorption, growth and yield of cereals. *Journal of agriculture science, Cambridge.* **91:** 47-60.

Garnett, T., Conn, V., Kaiser, B.N., 2009. Root based approaches to improving nitrogen use efficiency in plants. Plant, Cell and Environment. 32, 1272–1283.

Geron, C.A., Danneberger, T.K., Traina, S.J., Logan, T.J., Street, J.R., 1993. The effects of establishment methods and fertilization practices on nitrate leaching from turfgrass. *Journal of environment and quality*. **22**:119–125.

Gewin, V., 2010. An underground revolution. *Nature*. **466**: 552 - 553.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for agricultural research. 2nd ed. John wiley & sons, New York.

Gorny, A.G. and Garczynski, S. 2008. Nitrogen and phosphorus efficiency in wild and cultivated species of wheat. *Journal of Plant Nutrition.* **31** (1-3): 263-279.

Gouis, J. L. , Beghin D., Heumez E.and Pluchard, P. 2002. Diallel Analysis of Winter Wheat at Two Nitrogen Levels. *Crop Science.* **42**:1129-1134.

Gouis, J.L. and Pluchard,P. 2000. Genetic variation for nitrogen use efficiency in winter wheat (*Triticum aestuivum* L.) *European Journal of Agronomy.* **12** (3-4): 163-173.

Grahham, P.H. and Vance, C.P. 2000. Nitrogen fixation in perspective: an overview of research and extension needs. *Fields Crop Research*. **65**: 93-106.

Grando, S., Ceccarelli, S., 1995. Seminal root morphology and coleoptile length in wild barley (*Hordeum vulgare ssp. spontaneum*) and cultivated (*Hordeum vulgate ssp. vulgare*). *Euphytica.* **86:** 73-80.

Gregory, P. J., McGowan, M., Biscoe, P. V., Hunter, B., 1978. Water relations of winter wheat: Growth of the root system. *Journal of Agricultural Science, Cambridge.* **91**: 91-102.

Gregory, P.J., 2006. Plant Roots: Their Growth, Activity and Interactions with Soil. Blackwell Scientific Publications, Oxford, U.K. pp. 318.

Hari, O. M., Katyal, S. K. and Dhiman, S. D. 1997. Effect of nitrogen and seed rate in nursery on growth and yield of hybrid rice (Oryza sativa). *Indian journal of Agronomy*. **42**(2):275–277.

Hirel, B., Le- Gouis, J., Ney B.and Gallais, A. 2007. The challenge of improving nitrogen use efficiency in crop plants: towards a more central role for genetic variability and quantitative genetics within integrated approaches. *Journal of Experimental Botany*. **58**(9):2369-2387.

Jain, N.K., Krantz, B.A.; Bains, K.B., Bhardwaj, R.B.L. Bhattacharya, S., Giel, G.S., Gupta, K.P., Moolani, M.K., Morabad, I.R., Patee, V.J., Reddy, M.K., Sandhu, K.S., Sharma, A.K., Sharma, K.C., Shekhawat, M. Singh, R.R., Srivastava, M.P. and Wright, B.C. 1975. Response of dwarf wheat varieties to nitrogen. pp: 11-23. In: A.M. Wadhwani & Rajinder Singh (Ed.). Agronomy of Dwarf Wheats – Summary of investigations of the All-India Co-ordinated wheat improvement project. Indian Council of Agricultural Research New Delhi.

Jalata, Z., Ayana, A. and Zeleke, H. 2011. Variability, heritability and genetic advance for some yield and yield related traits in Ethiopian Barley (*Hordeum Vulgare* L.). Landraces and crosses. *International Jornal of Plant Breeding and Genetics.* **5**: 44-52.

Jamaati-e-Somarin, S., Hassanzadeh, M., Peyghami, F. and Zabihi-e-Mahmoodabad, R. 2009. Response of durum wheat growth and chlorophyll content to nitrogen rates and plant populations. *Research Journal of Biological Sciences*. **4** (11): 1135-1141.

Jiang, Z., Sullivan, W.M., Hull, R.J., 2000. Nitrate uptake and nitrogen use efficiency by Kentucky Blue grass cultivars. *Horticulture Science*. **35(**7): 1350–1354.

Kandera, J. 1975. Reaction of winter wheat to fertilization with trace elements. *Rosttinna-vyroba*. **21**(11): 1183-1190.

Kanungo and Rout, 1994.Responses of trans planted summer rice genotypes to varying level of fertility and plant density. *Indian journal of Agronomy*.**39** (2): 216 - 219.

Karanan, M.R., Kandemir, N., Sachin, S. and Coban, S. 2010. Strategies to select genetic variations of barley (Hordeum vulgare L.) cultivars for agronomic zinc utilization characters. *Journal of food, agriculture and environment.* **8** (2): 395-399.

Kaur, A., Pannu, R.K. and Buttar, G.S. 2010. Impact of nitrogen application on the performance of wheat (*Tirticum aestivum*) and nitrogen use efficiency under different dates of sowing. *Indian Journal of Agronomy*. **55** (1): 40-45.

Kaushik, J. and Sharma, H.S. 1997. Effect of nitrogen and sulphur levels on concentration and uptake of nitrogen in wheat. *Annals of Biology.* **13** (1): 85-86.

Kaushik, S.K., Sharma, S.C., Sharma, G.R. 1996. Studies on correlation and path coefficient analysis in sibmated vis-à-vis selfed population in wheat. *Haryana Agricultural University Journal of Research.* **26** (4): 235-241.

Khalh, A.M.; Hussain, Z. and Malik, M. 1994. Growth of wheat as influenced by fertilizer levels. *Thailand Journal of Agriculture Sciences*. **24** (2): 199-201.

Khalilzadeh, G.H., Mozaffari, J., Azizov, E. 2011. Genetic differences for nitrogen uptake and nitrogen use efficiency in bread wheat landraces (*Triticum aestivum* L.). *International journal of agricultural sciences* **1**: 232-243.

Khan, H.A. and Mohammad, S. 1999. Characters association and path coefficient analysis of grain yield and yield components in wheat. Deptt. Genetics of Pl. Br. Agri. College Rajendranagar, Hyderabad 500030, AP India. *Crop Research.* **17**: 229-233.

Khan, M.H. and Dar, A.N. 2010. Correlation and path coefficient analysis of some quantitative traits in wheat. *African Crop Science Journal.* **18** (1): 9-14.

Kiche, T., Heumez, E., Pocholle, D., Pageau, K., Vanacher, H., Dubois, F., Le-Gouis, J., and Hirel, B. 2006. Combined agronomic and Physiolosicaal aspects of nitrogen management in wheat highlight a central role of glutamine synthetase. *New Phytologist*. **169**(2): 265-278.

Kichey,T., Hirel, B., Heumez, E., Dubois, F. and Le Gouis, J. (2007). In winter wheat (*Triticum aestivum L.*), post-anthesis nitrogen uptake and remobilisation to the grain correlates with agronomic traits and nitrogen physiological markers. *Fields crops research*. **102**:22-32.

King, J., Gay, A., Sylvester-Bradley, R., Bingham, I., Foulkes, J., Gregory, P., 2003. Modelling cereal root systems for water and nitrogen capture: towards an economic optimum. *Annals of Botany*. **91**,383–390.

Kirby, E.J.M., 2002. Botany of the wheat plant. In. FAO Plant Production and Protection Series. Bread wheat: Improvement and Production Eds. B.C. Curtis, S. Rajaram, H. Gómez Macpherson.FAO.

Korkmaz K.,Ibrikei H., Karnez E., Buyuk G., Ryan J., Ulger A.C. and Oguz H. 2009. Phosphorus Use Efficiency of Wheat genotypes Grown in Calcareous Soils. *Journal of Plant Nutrition*. **32**:2094-2106.

Kumar and Rao,1992. Nitrogen and phosphorus requirement of upland rice in Manipur. *Oryza*. **29**: 306 - 309.

Kumar, B.N.A. and Hunshal, C.S. 1998. Correlation and path coefficient analysis is durum wheats (*Triticum durum* Desf.) under different planting dates. *Crop Research.***16** (3): 358-361.

Kumar, H., Khosla, G., Sharma, P.K. 2010. Utilization of genetic variability, correlation and path analysis for seed yield improvement in bread wheat (*Triticum aestivum*). Genotypes. *Environment & Ecology*. **28** (1): 91-94.

Lack, S., Dadnia, M.R. and Shirvani, I. 2009. Nitrogen use efficiency of wheat (*Triticum aestivum* L.) in climatical conditions of Ahwaz, Iran. *Research on Crops*. **10** (1): 1-4.

Leon, J., and Schwang, K. U., 1992. Description and application of a screening method to determine root morphology traits of cereals cultivars. *Z. Acker. Pflanzenbau*. **169**: 128–134.

Liao, M.T., Fillery, I.R.P., Palta, J.A., 2004. Early vigorous growth is a major factor influencing nitrogen uptake in wheat. *Functional Plant Biology*. **31**: 121-129.

Lopes, M.S., and Reynolds, M.P., 2010. Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat. *Functional Plant Biology*. **37**: 147–156.

Manske, G.G.B. 1990. Utilization of the genotypic variability of VAM-symbiosis and root length density in breeding phosphorus efficient wheat cultivars at CIMMYT. Final Report of Special Project No. 1-60127166, funded by BMZ, Germany.

Manske, G.G.B., J.I. Ortiz-Monasterio R., M. van Ginkel, R.M. Gonzalez, R.A. Fischer, S. Rajaram, and P. Vlek. 2000. Importance of P-uptake efficiency vs. P-utilization for wheat yield in acid and calcareous soils in Mexico. *European Jornal of Agronomy*. **14**(4):261-274.

Mauromicale, G., Lerna, A. and Marchese, M. 2010. Chlorophyll fluorescence and chlorophyll content in field grown potato as affected by nitrogen supply, genotype and plant age. *Photosynthetica*. **44** (1): 76-82.

Merker.A.,1984. The rye genome in wheat breeding. *Hereditas*. **100:** 183-191.

Moll R.H., Kamprath E.J., Jackson W.A.1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronomy Journal*. **74**:562–564.

Mondal, S.K. and Khajuria, M.R. 2001. Correlation and path analysis in bread wheat (*Triticum aestivum* L.) under rainfed conditions. *Environment & Ecology*. **18** (2): 405-408.

Motzo, R., Attene, G., and Deidda, M., 1993. Genotypic variation in durum wheat root systems at different stages of development in a Mediterranean environment. *Euphytica*. **66**: 197-206.

Munik, M., Aslam, R., Chowhdary, M. and Malik, T.A. 2007. Correlation studies among yield and its components in bread wheat under drought conditions. *International Journal of Agriculture and Biology*. **9** (2): 287-290.

Nevena, D. 2008. Effect of ntiorgen nutrition to chlorophyll content in wheat (*Triticum aesivum*). *Cereals research communications* **36** (2): 1267-1270.

Nofouzi, F., Rashidi, V. and Tarinezad, A.R. 2008. Path analysis of grain yield with its components in durum wheat under drought stress. International meeting on soil fertility land management and agro-climatology. *Turkey Journal of Agriculture Sciences*. **32**: 681-686.

Noulas, C., Liedgens, M., Stamp, P., Alexiou, I., Herrera, J. M., 2010. Subsoil root growth of field grown spring wheat genotypes (*Triticum aestivum* l.) differing in nitrogen use efficiency parameters. *Journal of Plant Nutrition.* **33**(13): 1887-1903.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, I.A. 1954. Estimation of available phosphorous in soils by extraction with sodium bicarbonate. *United State Department of Agriculture Circular*. 939.

Olson, R. V., Swallow, C. W., 1984. Fate of labeled nitrogen fertilizer applied to winter wheat for five years. *Soil Science Society Of American Journal*. **48**: 583-586.

Ortiz, Monasterio, J.I., Pena, R.J., Pfeifer, W.H. and Hede, A.H. 2002. Phosphorus use efficiency in Triticale and durum wheat yield and quality under irrigated conditions. Proceedings of 5th International Triticale symposium, supplement, June 30 – July 5, Rad Zikow, Poland : 53-58.

Ortiz-Monasterio, J.I., Sayre K. D. and Rajaram, S. 1997. Genetic Progress in Wheat Yield and Nitrogen Use Efficiency under Four Nitrogen Rates. *Crop Science.* **37**:898-904

Ottman, M., Thompson, T. 2006. Fertilizing small grains in Arizona. The University of Arizona cooperative extension. cals.arizona.edu/pubs/crops/az1346.pdf.

Ozturk, L., Eker, S., Torun, B. and Cakmak, I. 2005. Variation in phosphorus efficiency among 73 bread and durum wheat genotypes grown in a phosphorus deficient calcareous soil. *Plant and soil* **269**: 69-80.

Paknejad-Nasri, M. and Tohidi-Moghadam, H.R. 2007. Effects of Drought stress on chlorophyll fluorescence parameters. Chlorophyll content and grain yield of wheat cultivars. *Journal of Biological Sciences.* **7** (6): 841-847.

Panse, V.G. and Sukhatme, R.V. 1967. Statistical methods for agricultural workers. 2nd Ed. ICAR, New Delhi.

Parmar, D.K. and Sharma, P.K. 1996. Phosphorus and mulching effects on nutrient uptake and grain yield of wheat at different growth stages. *Tropical Agriculture.* **73** (3): 196-200.

Parry Martin, A.J., Reynolds, M., Salvucci, M.E., Raines, C., Andralose, P.J., Xin-Guang, Z., Dean Prince, G., Condon, A.G. and Furbunk, R.T. 2010. Raising yield potential of wheat II. Increasing photosynthetic capacity and efficiency. *Journal of Experimental Botany.* **10**: 1093.

Patel, D.M., Patel, S.K. and Karella, G.N. 1995. Integrated nutrient management in pearlmillet (*Pennisetum glaucum*)-Wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy.* **40** (2): 266-268.

Paul, A. and Ganguli, D.K. 1996. Association analysis under normal and saline enviorments in bread wheat. *BAU Journal of Agriculture Research.* **8** (2): 127-129.

Peng, Yu., Philip, J. W., Frank, H. and Chunjian, L. 2014. Phenotypic plasticity of the maize root system in response to heterogeneous nitrogen availability. Planta. *DOI 10.1007/s00425-014-2150-y*.

Percival, J., 1921. The Wheat Plant: A Monograph. London: Duckwork and Co. pp. 35-43.

Pinstrup-Anderson, P., Pandy-Lorchr, R. and Rosegrant, M.W. 1997. The world food situation : recent developments, emerging issues and long-term prospects. Vision 2020: Food policy report. International Food Policy Research Institute, Washington, D.C. 36 pp.

Pokhrel, P.R., Burdun, A.M. and D. Raghavtsev, V.A. (1993). Harvest index and grain sink size in wheat. *Indian Journal of Genetics*. **53** (4): 361-365.

Quing, Guo, L., Yun, Ji, Z., Tian, Cai, G. and WenZhong, T. 2006. Effect of N, P, K and S fertilization on photosynthetic characteristics and grain yield of winter wheat. *Journal of Soil and Water Conservation.* **96** : 206.

Raun, W.R., and Johnson, G.V., 1999. Improving nitrogen use efficiency for cereal production. *Agronomy journal.* **91**: 357–363.

Rengal, Z. and Graham, R.D. 1995. Importance of seed Zn content for wheat growth on Zn-deficient soil. *Plant and Soil.* **173**: 259-274.

Rosegrant, M.W., and Agcaoili, M., 2010. Global food demand, supply and price prospects to 2010. International Food Policy Research Institute, Washington, D.C.USA.

Rosyare Umesh, R., Subedi, S., Duveiller, E. and Sharma R. 2010. The effect of spot blotch and heat stress on variation of canopy temperature depression, chlorophyll fluorescence and chlorophyll content of hexaploid wheat genotypes. *Euphytica.* **174** (3): 377-390.

Ruiz, M., Aguiriano, E. and Carrillo, M. 2007. Effects of N fertilization on yield for low input production in spanich wheat landrances. *Plant Breeding.* **127**: 20-23.

Ryakhovskaya, N.N., Girfanov, V.K., Radtseva, G.E.and Sakaerk, K.B. 1975. Effect of trace elements on morphogenesis productivity and grain quality of spring Wheat. *Regulyatsiya Otlozheriya. Zapasnytch. Veshcepv-I-produktivnost-rastetill.* 122-130.

Schactman, D.P., Reid, R.J. and Ayeing, S.M.C. (1998). Phosphorus uptake by plants : from soil to cell. *Plant Physiology*. **116**: 447-453.

Sedri, M.H. and Malakouti, M. J. 1998. A study on the effects of iron, Zinc and copper on the quality and quantity of wheat. *Soil and water Journal*. **12(6)**: 19-31.

Semenov, M.A., Jamieson, P.D. and Martre, P. 2007. Deconvoluting nitrogen use efficiency in wheat : Asimuation study. *European Journal of Agronomy*. **26** (3): 283-294.

Sen, A. and Swain, D. 1994. Effect of Biozyme- a seaweed extract and NPK on the expression of agro-morphological traits in wheat. *Orissa Journal of Agriculture Research.* **7** (1/2): 46-48.

Serret, M.D., Ortiz, Monasterio, J.I., Pardo, A. and Arans, J.L. 2008. The effects of urea fertilization and genotype on yield, nitrogen use efficiency, delta N-15 and delta C-13 in wheat. *Annals of Applied Biology.* **153** (2): 243-257.

Shahryari, R. and Molasadeghi, V. 2011. Grouping bread wheat genotypes under terminal drought in the presence of humic fertilizer by use of multivariate statistical analysis. *Advances in Environmental Biology.* **5**(3): 510-515.

Sharma, K.D. and Kumar, A. 2001. Physiological processes associated with grain yield of wheat under restricted soil moisture. *Indian Journal of Plant Physiology*. **14** (1): 55-59.

Sharma, S. and Agarwal, A. 2007. Differential action of zinc, nickel and cadmium on total chlorophyll content, total nitrogen content and grain yield of wheat (*Triticum aestivum* Cv. 2425). *Vegetos.* **20** (2): 27-30.

Singh, A.K. 1991. Response of irrigated wheat (*Triticum aestivum*) to nitrogen and phosphorus on farmers field in Ganga dhara of Bihar. *Indian Journal of Agronomy*. **36**: 46-49.

Singh, M., Swarnkar, G.B., Lallu, L.P., Singh, M. and Prasad, L. 2003. Genetic variability and path coefficient analysis in advanced generations of bread wheat under rainfed condition. *Plant Archives.* **3**: 89-92.

Singh, R., Meena, N.L. and Godara, A.S. 1996. Growth and yield attributes of wheat (*Tirticum aestivum*) as influenced by phosphorus, zinc sulphate and plant growth regulator. *Annals of Agriculture of Biological Research*. **1** (1/2): 133-135.

Singh, R.P. and Anderson, R.G. 1978. Dry matter accumulation in plants as influenced by nitrogen fertilization. *Indian Journal of Agriculture Sciences*. **48**: 696-710.

Singh, V.P. and Prasad, A. 1998. Effect of nitrogen levels and weed control methods on wheat under rainfed and irrigated conditions of low roll and valley situation. *Annals of Agriculture Research.* **19** (1): 72-76.

Smil, V. 1999. Nitrogen in crop production. *Global Biological Cycle.* **13**: 647-662.

Sobkowicz, P. and Snaidy, R. 2004. Nitrogen uptake and its efficiency in tricale (*Triticozecale* witt). Field beans (*Vicia faba* var. Minor L.) *Inter crop plant soil environment.* **50** (11): 500-506.

Socolow, R.H. 1999. Nitrogen management and the future of food : lessons from the management of energy and carbon. *Proceedings of national academy of sciences.* USA **96**: 6001-6008.

Sokoto, M.B., Abubakar, I.U. and Dikko, A.U. 2012. Correlation analysis of growth yield, yield components and grain quality of wheat (*T. aestivum. L.*). Nigerian journal of basic and applied science. **20**(4):349-356.

Srinivas, A. and Satyanarayana, V. 1997. Nutrient utilization efficiency of wheat varieties as influence by nitrogen levels and methods of zinc application. *Annals of Agriculture Research*. **18** (4): 427-431.

Sudesh, R., Yadava, K. and Rana, O.P.S. 2002. Association and path analysis in homogeneous glenerations for ‘gigas’ spike of wheat (*Triticum aestivum* (L.) em. Thell). *Crop Research.* **24** (1): 67-71.

Sullivan, W., Jiang, M. Z., Hull, R.J., 2000. Root morphology and its relationship with nitrate uptake in Kentucky bluegrass. *Crop science.* **40**,765–772.

Sun, Y., Havlon, J.L. and Paulsen, G.M. 1989. Evaluation of nutrient deficiencies in wheat seedlings by chlorophyll fluorescence. *Journal of Plant Nutrition.* **12** (6): 769-782.

Svecnjak, Z., Bujan, M., Vedrina dragoJevic, I., Vitali, D., Cebuskin, A. and Jenel, M. 2007. Nitrogen and phosphorus content, Hectoliter weight and yield variations of wheat grown as affected by cropping intensity. *Agricultural conspectus scientificus.* (ACS) **72** (3): 251-255.

Svecnjak, Z., Jenel, M., Drago Jevic Irena, V., Bujan, M. and Varga, B. 2008. Effect of nitrogen fertilization and cultivars on Mineral composition of wheat grain. *Cereal Research Communications.* **36** (3): 1695-1698.

Tanaka, A. 1994. Plant characters related to Nitrogen response in rice pp 334 - 439. In: The mineral nutrition of the rice plant, Proceedings of the rice plant.Vol. 2. Food and Agriculture Policy Research Center, Tokyo.

Tennant, D., 1976. Root growth of wheat. I. Early patterns of multiplication and extension of wheat roots including effects of levels of nitrogen, phosphorus and potassium. *Australian Journal of Agricultural Research.* **27:** 183-196.

Thakur, D.R., Prakash, O., Kher, Wara, P.C. and Bhalla, S.K. 1998. Effect of nitrogen and plant spacing on yield, nitrogen uptake and economics in baby corn (*Zea mays*). *Indian Journal of Agronomy.* **43**: 668-671.

Thakur, R. B. 1993. Performance of summer rice (*Oryza sativa*) to varying levels of nitrogen. *Indian journal of Agronomy.***38** (2): 187 - 190.

TIlman, D., Fargone, J., Wolff, B. D'Antonio, C.. Dobson, A., Howarth, R., Schinder, D., Schlesinger, W.H., Simberloff, D. and Swackhamer, D. 2001. Forecasting agroculturally driven global environmental change. *Science.* **292**: 281-284.

Torabi, M. and Malakuti, M.J. 1997. Evaluation of sources and rates of nitrogen on rainfed wheat and determining its DRIS indices. *Soil and water journal.* **10** (1): 21-28.

Uprety, D.C., Dwivedi, N., Raj, A., Jaiswal, S., Paswan, G., Jain, V. and Maini, H.K. 2009. Study on the response of diploid, tetraploid and hexaploid species of wheat to the elevated CO_2. *Physiology and Molecular Biology of Plants.* **15** (2): 161-168.

Van Oosterom, E.J., Borrell, A.K., Chapman, S.C., Broad, I.J. and Hammer, G.L. (2010) Functional dynamics of the nitrogen balance of sorghum: I. N demand of vegetative plant parts. *Field Crop Research* **115**:19-28**.**

Vukovic, I., Mesic, M., Zgorclec, Z., Jurisic, A. and Sajko, K. 2008. Nitrogen use efficiency in winter what. *Cereal Research Communications.* **36** (2): 1199-1202.

Waines, J. G., Ehdaie, B., 2007. Domestication and crop physiology: Roots of green-revolution wheat. *Annals of Botany*. **100:** 991–998.

Wang, Zheng, H., Wu-Xian, S., Xiao Ping, C., Runzni, L. and Ruilian, J. 2010. Chlrophyll content and chlorophyll fluorescence kinetics parameters of flag leaf and their gray relation to grade with yield in wheat. *Acta Agronomica Sinica.* **36** (2): 217-227.

Watt, M., Magee, L. J., McCully, M. E., 2008. Types, structure and potential for axial water flow in the deepest roots of field-grown cereals. *New Phytologist.***178:** 135-146.

White, E.M. and Wilson, F.E.A. 2006. Responses of grain yield, biomass and Harvest index and their rates of genetic progress to nitrogen availability in ten winter wheat varieties. *Irish Journal of Agricultural and Food Research.* **45**: 85-101.

Wiesler, F. and Horst, W. J. 1994. Root growth and nitrate utilization of maize cultivars under field conditions. Plant soil **163**: 267-277.

Yadav, P.K.; Kurchania, S.P. and Tiwari, J.P. 1995. Herbicides and fertilizer compatibility under normal and stalebed sowing of wheat (*Tritium aestivum*) at different levels of nitrogen. *Indian Journal of Agriculture Sciences.* **65** (4): 265-270.

Yildirim, M., Bahar, B., Genc, I., Korkmaz, K. and Karnez, E. 2007. Diallel Analysis of wheat parents and their F2 progenies under medium and low level of available N in soil. *Journal of Plant Nutrition*. **30** (4-6): 937-945.

Yilmaz, A., Ekiz, H. , Gltekin, I., Torun, B., Barut, H. and Karanlik, S. 1998. Effect of seed zinc content on grain yield and zinc concentration of wheat grown in zinc-deficient calcareous soils. *Journal of Plant Nutrition*. **21**(10): 2257 - 2264.

Zemenchik, R., Albrecht, K.A., 2002. Nitrogen use efficiency and apparent nitrogen recovery of Kentucky Blue grass, Smooth Brome grass and Orchard grass. *Agronomy Journal*. **94:** 421-428.

Zhang, F., Zhang, J. and Zhang, R. 2004. Nitrogen fertilization on uptake of inorganic phosphorus fractions in wheat root zone. *Soil Science Society of America Journal.* **68**(6):1890-95.

Zhang, J., Sui, X.,Li, B., Su. B., Li, J. and Zhou, D. 1998. An improved water use efficiency for winter wheat grown under reduced irrigation. *Fields crops research*. **59**: 91-98.

Zhang, K., Zhang, Y., Chon, G. and Tian, J. 2009. Genetic analysis of grain yield and leaf chlorophyll contents in common wheat. *Cereals Research Communications.* **37** (4): 499-511.

ABSTRACT

Title of thesis	:	Nutrient use efficiency of various genotypes of bread wheat under low and optimum input conditions.
Full Name of degree holder	:	AKSHAY KUMAR VATS 2011A21D
Title of Degree	:	Doctor of Philosophy in Genetics and Plant Breeding
Name and address of Major Advisor	:	**Dr. R.P. Saharan** Project Director Directorate of research CCS Haryana Agricultural University, Hisar-125004, INDIA
Degree awarding University	:	CCS Haryana Agricultural University, Hisar-125004, Haryana, India
Year of award of degree	:	2015
Major subject	:	Plant Breeding
Total number of pages in the thesis	:	101 + x
Number of words in the abstract	:	369

Key words: Nutrient use efficiency, Bread wheat, low input wheat, Root studies, Physiological traits, Low and Optimum input conditions.

The objectives of present two years investigation were to evaluate the various genotypes of bread wheat for various characters under low and optimum input conditions, to determine the genotypic and phenotypic variability for the grain yield, its components and morpho- physiological traits under low and optimum input conditions and to determine the various indices of yield, its components and other morpho-physiological traits for the traits for nutrient use efficiency, to determine the promising genotypes for nutrient uptake and use efficiency. Results revealed Mean squares due to genotypes were significant for all the characters. Significant differences due to genotypes for various traits indicated that there was considerable variation among the genotypes. Genotype × fertilizer (G × F) interaction was significant for majority of the characters except in Plant height, Chlorophyll content and Number of tillers per plant. This indicated that genotypes differed in their response from low to optimum input conditions for the characters under study. Correlation coefficients revealed that the biomass per plant and harvest index was significant component of grain yield under low and optimum input conditions. Trend deflected the path for grains per spike, plant height, spikelets per spike, root traits and days to heading and maturity Trend remained same for the increase in mean performance of genotypes for N, P and Zn use efficiency from low to optimum input conditions as PBW 533 and WH 1105 under both low and optimum input conditions were better in mean performance over the years for nitrogen, phosphorous as well as zinc use efficiency. For most of the characters genotypic and phenotypic coefficient of variability fell out in low range category like plant height in both years under optimum input conditions and low input conditions in 2013-14, biomass per plant in 2012-13 and 2013-14 under optimum input conditions, harvest index in 2012-13 under both optimum as well as under low input conditions. Similarly, under both optimum as well as low input conditions in both the seasons gcv and pcv for chlorophyll fluorescence, chlorophyll content, 1000- grain weight , spikelets per spike, grains per spike, days to heading and days to maturity, N content in grains, root biomass and root length were on lower side indicating less variability per character.

MAJOR ADVISOR **SIGNATURE OF STUDENT**

HEAD OF THE DEPARTMENT

CURRICULUM VITAE

(a) Name : Akshay Kumar Vats

(b) Date of Birth : 16th March, 1986

(c) Place of Birth : Naraingarh (Ambala)

(d) Mother's Name : Smt. Poonam Vats

(e) Father's Name : Shri. Naresh Kumar Vats

(f) Permanent Address : Akshay Kumar Vats
S/o Naresh Kumar Vats,
Durga Colony, Naraingarh, District
Ambala, Pin: 134203

(g) Telephone : +919416421341

(h) E-mail : akshayvts@gmail.com

(i) Academic Qualification :

Degree	**University/Board**	**Year of Passing**	**Percentage of marks**	**Subjects**
Ph.D	CCS Haryana Agricultural University, Hisar, Haryana -125004	2015	73.40	Major: Genetics and Plant Breeding Minor: Biotechnology and Molecular Biology
M.Sc (Plant Breeding)	CCS Haryana Agricultural University, Hisar, Haryana -125004	2011	72.80	Major: Plant Breeding Minor: Genetics
B.Sc. (Hons.) Agri.	CCS Haryana Agricultural University, Hisar, Haryana -125004	2008	68.70	All Agriculture subjects
Intermediate (Class XII)	Govt. Sr. Sec. school (Boys), Naraingarh	2003	59.60	Hindi, English, Physics, Chemistry, and Biology
Matriculation (Class X)	Arya High School, Naraingarh	2001	66.00	English, Hindi, Maths, Science and Social science, Sanskrit

(j) Co-Curricular Activties : Participated in Interagril. uni. Sports (Badminton), Participated in Reverie (All India Talent Search Competition (2009)

(k) Publications from Ph.D: Genetic variability and path analysis for nutrient use efficiency traits in bread wheat (*Triticum aestivum* L. em Thell.) under low and optimum input conditions

Akshay Kumar Vats

UNDERTAKING OF THE COPY RIGHT

"I, **Akshay Kumar Vats,** Admission No. **2011A21D** undertake that I give copy right to the CCS HAU, Hisar of my thesis entitled **"Nutrient Use efficiency of various genotypes of bread wheat under low and optimum input conditions".** I also undertake that, patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCSHAU, Hisar.

Akshay Kumar Vats
2011A21D