

**PHOSPHORUS UPTAKE, YIELD AND
QUALITY PARAMETERS IN WHEAT
(*TRITICUM AESTIVUM* L)**

BY

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2010

CERTIFICATE – I

This is to certify that this dissertation entitled, “**Phosphorus uptake, yield and quality parameters in wheat (*Triticum aestivum* L)**” submitted for the degree of **Master of Science** in the subject of **Plant Physiology** of the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Mrs. Renu Bala** 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.

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CERTIFICATE – II

This is to certify that this thesis, entitled “**Phosphorus uptake, yield and quality parameters in wheat (*Triticum aestivum* L)**”, submitted by **Ms. Renu Bala** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfilment of the requirement for the degree of **Master of Science** in the subject of **Plant physiology**, has been approved by the Student’s Advisory Committee, after an oral examination on the same.

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ABBREVIATIONS

CD	-	Critical difference
CRD	-	Complete randomized design
DAS	-	Days after sowing
DMSO-		Dimethyl sulphoxide
S	-	Susceptible
WUE	-	Water use efficiency
A	-	Assimilation rate
E	-	Transpiration rate
O.D	-	Optical Density
EDTA -		Ethylene diamine tera acetic acid
PVP	-	Polyvinyl pyrrolidone
Pi	-	Ortho-Phosphate
PPDK	-	Pyruvate Phosphate Dikinase
PEPC	-	Phosphoenol pyruvate carboxylase
NPQ	-	Non-photo chemical quenching-
AWRC	-	Alkaline Water Retention Capacity

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CHAPTER-I

INTRODUCTION

Wheat is the oldest of man's crop and is cultivated extensively in north western and central zone of India. On the global scale it provides nourishment to more number of people than any other food crop. After the advent of green revolution the production of wheat has shown a gigantic increase from 10.4 million tons in 1965 to 80.58 million tons in 2008-09. Haryana is one of the important wheat growing state in the country occupying an area of 24.62 lakh ha and annual production of 113.60 lakh tons (Anonymous, 2009).

Wheat consumes 45% of total fertilizer used in the country. Wheat is frequently supplied with inorganic Phosphorus to maintain yield and quality with crop production. P fertilizer is an expensive input and its use efficiency in wheat may range from 10-25%. Projection for the year 2020 predicts a 50% increase in demand for phosphatic fertilizers (Bumb and Banante, 1996), because of increasing demand for food by growing world populations. The annual consumption of phosphatic fertilizer was more than 39 million tons (Hoffer, 2008) ranking second after Nitrogen (N)

Phosphorus is the second major element whose deficiency has become wide spread in Indian soils. P is one of the least available mineral elements in the soils and frequently limit plant growth because P made complexes with calcium in alkaline, aluminium and iron in acidic soils. Due to its chemical fixation in soil and low solubility, 10-25% of applied Phosphate is used by the crops during the season. It is estimated that P availability to plant is limited up to nearly 67% of total cultivated soil causing an important constraint to crop production (Batjes, 1997).

Phosphorus deficiency in soil is caused by general low total P content of the soil or low bioavailability of P in the soil. The amount of available soluble P depends on pH, its availability is reduced at both higher and lower levels of pH than normal soil. Phosphorus has many roles in plant growth and metabolism. One of the key functions of phosphorus is in energy transfer, through the action of adenosine triphosphate (ATP). ATP and its derivatives, ADP and AMP are involved in all aspect of energy transfer in every part of plant growth. Aside from this global function, phosphorus is also needed for manufacture of nucleic acids (DNA & RNA), proteins, enzymes and carbohydrates. It plays an essential role in photosynthesis and is involved in the formation of sugar and starch. It is important in the formation of seeds and the development of roots (Ramaekers *et al* .2010).

Plants respond adaptively to ortho-phosphate (Pi) deprivation through the induction of alternative pathway of glycolysis and mitochondrial electron transport. These respiratory by passes allow respiration to proceed in Pi deficient plant cell because they negate the necessity for adenylate and Pi, both pools of which are severely depressed following nutritional Pi starvation. Phosphorus is taken by plants primarily in the form of primary ortho-phosphate ion (H_2PO_4) (Vance *et al.* 2003, Hammond *et al.* 2004 and White and Hammond, 2008). Wheat roots absorb P from the soils up to physiological maturity (Miller *et al.* 1994).

Phosphorus is critical for reaching the attainable yield potential of wheat. Although only small amount of P (15% of the total P uptake) is taken up by wheat early in the season, but this P uptake plays a major role in early plant development and determination of attainable yield potential. Early season P nutrition (First 5 to 6 weeks) is critical for wheat. An insufficient supply of P early in season creates recoverable losses. Phosphorus shortages at later stages of plant growth in the season have less impact than these encountered earlier (Goos and Johnson, 1996).

Genotypic variation and tolerance to P deficiency in wheat have been reported (Manske *et al.* 1995, Gahoonia and Nielsen 1996). Considering differential behaviour of varieties of a species in nutrient, particularly P, wheat genotypes were screened at deficient and adequate phosphorus level for growth and utilization. The difference in P uptake among varieties will help in reducing cost of P fertilization and enhancing productivity with more P efficient cultivars. P use efficiency is defined as the ability of plant genotypes to acquire P from rhizosphere zone and incorporate or utilize in the production of total plant biomass, seed, grain and fruit etc. (Blair, 1993).

To distinguish efficiency of genotypes from their genetic P uptake efficiency, their response to P under normal and P stress should be studied. Genotypes having the same yield potential may behave differently with respect to their P uptake efficiency. Identifying efficient genotypes in low input production system would reduce the production costs associated with P fertilizer application, minimize under ground water pollution and contribute to maintenance of world P resource globally (Cakmak 2002, Vance *et al.* 2003, Raghothama and Karthikaeyan 2005). Any species which maintains metabolic activities at low tissue concentration and produce more dry matter per unit of P absorbed is considered efficient in P utilization (Sepehr *et al.* 2009). Under optimal conditions, the sufficient P level in plants is approx. about 4.0 mg g^{-1} dry weight (Reuters and Robinson, 1997).

Many soils have large reserves of total phosphorus, but level of available phosphorus is generally low. Al-Abbas and Barber (1964) reported that the total soil P is often 100 times

higher than the fraction of soil P available to crop plants. There is little information about contribution of uptake and utilization of total P use efficiency in wheat. Evaluating genotypes under both low and high P conditions allows the identification of P uptake efficient genotypes. Therefore, the present study was conducted with the following objectives:

1. To identify the genotypes efficient in phosphorus uptake and utilization.
2. To study the effect of phosphorus doses on quality parameters of wheat grains.
3. To identify the root morpho-physiological traits associated with efficient phosphorus uptake.

CHAPTER-II

REVIEW LITERATURE

Phosphorus (P) is an essential plant nutrient ranking second after nitrogen. Its peculiar behaviour, both in calcareous soils (high Ca^{2+}) and in acidic soils (high Al^{3+} and Fe^{3+}), requires regular annual application of this element to maintain optimum crop yield. The annual P fertilizer consumption is about 8, 00,000 tons (Malakouti *et al.* 2008). Because of the complexity of P chemistry in soil, only about 20% of the total amount of P fertilizer is utilized by the first crop and the remaining 80% is fixed in soil as unavailable form (Grotz and Gverinot, 2002). Various approaches that can increase utilization of P fertilizer in the soil plant system have been considered, including selection of genotypes with increased P acquisition and utilization efficiency (Marschmer, 1995). The relevant literature pertaining to “Phosphorus uptake, yield and quality parameters in wheat (*Triticum aestivum* L.)” has been reviewed in this chapter under following subhead:

1. Genotypic variation and phosphorus use efficiency
2. Growth and phenology
3. Physiological and biochemical attributes
4. Yield and quality parameters

Genotypic variation and phosphorus use efficiency

Phosphorus efficiency in plants is the capacity of plants to acquire P and convert it into harvestable product such as biomass or grain. Phosphorus efficiency has two components:

- (i) The efficiency of absorbing P from the soil (P uptake efficiency).
- (ii) The efficiency with which P in the plant is utilized to produce yield (Sattelmacher *et al.* 1994).

Schenk and Barber (1979) reported that root acidification was an important character in P uptake and utilization efficiency. Brassica is considered to be P-efficient compared to other crops (Fohse *et al.* 1988).

Genotypic variation in phosphorus (P) uptake by cereals is known from early studies (Gahoonia and Nielsen, 1996). Genotypic differences in general nutrient acquisition arise primarily through differences in root characteristics, Root characteristics result in exploration of larger soil volume or alter the release of phosphate ion from soil particles and are of great importance in P-uptake because of the low mobility of P in soils. Root exudation of organic

acid anions or phosphatase are important determinates of P-uptake efficiency (Raghothama, 1999, Manske *et al.* 2000). There are genotypic differences in root phosphatases excreted or bound at the root surface (Mclachlan, 1980). Following approach can be used to enhance P uptake (Polle and Konzak, 1990, Johansen *et al.* 1995).

- **Increasing the root surface / soil content area:** This can be achieved by modifying root morphology. For a certain level of root biomass, roots with higher specific root length can cover a larger surface area. A second approach for achieving the same objective is through increased root hair development. Root fineness or branching is an important determinant for P-uptake efficiency in wheat.
- **Increasing the effective root area:** Root symbiosis with arbuscular mycorrhizal fungi (AMF) has been shown to enhance P absorption by increasing the effective root area (Hayman and Mosse, 1971). AMF infection improves P influx (P uptake per unit root length). On the other hand the information available discussing the genetic diversity present among wheat cultivars to associate with vesicular arbuscular mycorrhiza (VAM) is not consistent (Vlek *et al.* 1996). In contrast, extensive screening of CIMMYT's spring wheat cultivars for mycorrhizal association found very small differences among genotypes, the difference were not strongly associated with higher P absorption (Manske *et al.* 2000).
- **Increasing nutrient availability:** Through rhizosphere modification root exudates, ranging from protons to complex organic molecules can influence nutrient availability and uptake. Phosphatases have been reported to transform poorly available organic phosphorus, which usually accounts for 40-50% of plants, total P supply into inorganic forms available to plant (Randall, 1995).

Wheat genotypes responded differentially to P application in term of plant height, tillers and shoot/root ratio, plant height at low, medium and high P level is varied. Similarly tillers numbers varied at three concentration of P (Fageria and Baligar, 1999). Plant species and genotypes of a given species develop adaptive responses when they suffer from P deficiency stress. Some plant responses to P-deprivation appears to be regulated at genetic level (Foyer and Spencer, 1986) and not all species respond in same way to the lack of Pi and low P inputs, plants may suffer from P deficiency. However, crop plants are able to adapt to low P conditions by increased nutrient efficiency, for instance by increased root growth, root exudation and increased utilization efficiency (Marschner, 1995).

P deficiency can significantly alter the composition of root exudates in a way that is at least in some plant species, related to an increased ability for the mobilization of sparingly soluble P source (Jones, 1998). Gilbert *et al.* (1999) describe the development of proteoid roots when grown in phosphorus deficient condition and these roots were adapted to

increased P availability. Under low P condition, differences among genotypes were very similar to these under high Pi. The stimulation of root growth relative to shoot growth in young deficient plants should enhance the plants ability to acquire soil P (Longergan, 1978).

Phosphate uptake by wheat is greatest during the early growth stages (until the end of shooting). The P requirement at a later stage is markedly lower (Romer and Schilling 1986). The difference in P uptake between the barley cultivars, especially in low P soil, were closely related to their root hair formation. The variation in P-uptake and root hairs become gradually less when 10 and 20 kg P ha⁻¹ was applied because increasing P level had negative effect on root hair formation and at higher P levels the variation in root hairs decreased.

Growth and Phenology

P deficiency in wheat plants results in stunted, spindly growth, poor tiller production, necrosis and death of the oldest leaf blade (Bolland, 1979, Snowball and Robson, 1983, Grundon, 1987). During P deficiency plant yield were reduced by up to 41% (Ball, 1979). Plant colour was also affected by P-deficiency in glass house experiment. In glass house experiment, actually P-deficient wheat was noticeably green than P-adequate (Elliott *et al.* 1997). Acute P-deficiency reduced shoot and root growth and delayed phasic development in roots.

The response of wheat to low rates of starter P is often referred to as the “pop up effect” and marked by improved leaf and root growth, tiller formation and yield. P is one of the least available mineral elements in the soil and frequently limits plant growth (Vance *et al.* 2003 and Tiessen, 2008). Wheat like other cereals crops requires 16 essential elements to complete the metabolic processes necessary for growth and reproduction (Andrew *et al.* 1969 and Graham *et al.* 1996).

Genotypic variation in P-efficiency of cereals is reported (Batten and Khan, 1987, Jones *et al.* 1989, Gahoonia and Nielsen, 1996, Manske *et al.* 2000, Wang *et al.* 2005 and Liao *et al.* 2008). In P efficient crop genotypes lower proportional total P are retained in roots and stems and higher proportion translocated to leaves compared to the efficient genotypes.

Root profile and nutrient use efficiency

Root system geometry is essential to improve NUE and maximizing the roots per unit soil volume in areas where nutrient and water are available root length is major determinant of the absolute surface area. Wheat genotypes with higher root length density are able to take up more phosphorus. Root fineness or branching is also important determinant of P uptake efficiency in wheat. Under low phosphorus conditions, the correlation between root length density and P-uptake or grain yield is usually 0.5-0.6 but decrease with P supply (Manske *et al.* 2000).

Root growth

Roots are the most important organ for absorption of various nutrients from the soil. The various parameters root hairs, root length, root/ shoot ratio and secondary lateral roots are most important contributing characters which help in absorption.

If the phosphorus uptake efficiency is high and root system is small, then genotypes have superior root physiology (i.e. large capacity to take up per unit of root) where as if phosphorus uptake efficiency is high and root system larger then root system size is more important. At low level of available P, total root length was found to be an important trait for improved P absorption and it was positively & genetically correlated with P use efficiency in wheat (Manske *et al.* 2000).

Laboratory (Bates and Lynch, 1996, Fohse and Junk, 1983) and field studies (Gahoonia *et al.* 1999) have shown that plants adapt to low P supply by extending the length of root hairs. Such plasticity helps to explore large volume of soil for P acquisition, especially in low P soils. The role of root hairs in P uptake was studied in many plant species and root hair mutants (Fohse *et al.* 1991, Yan *et al.*, 1995 Bates and Lynch, 2000, Gahoonia and Nielsen, 2003,). Root hair was clearly related to grain stability. Root hair length is regulated by P-supply and increase in root surface area through root hairs proliferation in low-P environment is an efficient strategy for P acquisition (Bates and Lynch, 2000). Barley genotypes with long root hairs may not substitute for P fertilization entirely, but will be of added advantage for enhancing the efficiency for P fertilization and for sustaining high yield in low P soils. In a study with *Arabidopsis thaliana*, Bates and Lynch (2001) conclude that root hair confer a competitive advantage to plants in low P environment. Root hairs alter the release of phosphate ion from soil particles and are of great importance in P uptake because of the low mobility of P in soils.

Root dry weight

More or less all the wheat genotypes produced higher root dry matter at deficient P level. Increase in root dry matter was possibly due to stimulation effect of P-deficiency on root growth under P stress condition.

Increase in root biomass production under P was also reported by many workers (Haynes *et al.* 1991, Gill *et al.* 1994 and Yassen *et al.* 1998 & 2004). They reported increase in root biomass due to more translocation of photosynthates from shoot to root under P-stress which probably can help plant to absorb more P under limited supply in the growth medium.

Dry weight of shoot

Among the growth parameters, shoot dry weight was most sensitive to P-deficiency, followed by shoot-root ratio. Shoot dry matter production and total amount of P per shoot at

low P treatments are most reliable parameters in assessing wheat genotypes for their P-efficiency at the vegetative stage. It is interesting to note that P-uptake in shoots at deficient P level differed significantly. This indicates that wheat genotypes which accumulated more P in their shoot from a deficient growth medium were more tolerant to P-deficiency stress (Haynes *et al.* 1991).

Shoot dry matter production was also used successfully by Fageria and Baligar 1999 and Osborne and Rengel 2002, for ranking wheat genotypes for P-efficiency. Similarly also in other crop species such as tomato and rice shoot dry weight at low P supply was considered as a screening parameters for P efficiency (Coltman *et al.* 1986 and Fageria *et al.* 1998). Shoot dry weight were reduced by 19% and 50% respectively when rice genotypes grown in P-deficiency and P-sufficient condition.

Root hair length was clearly related to grain yield stability. Root hair length was regulated by P-supply and increase in root surface area through root hair proliferation in low-P-environment and efficient strategy for P-acquisition (Bates and Lynch, 2000). Root hairs not only provide extra-root surface area acids especially citrate (Narang *et al.* 2000). If phosphorus uptake efficiency is high and the root system is small, then genotypes have superior root physiology (i.e. larger capacity to take up P per unit of root). Whereas if phosphorus uptake efficiency is high and root system larger than root system size is more important.

Manske *et al.* (2000) suggested to select wheat genotypes for P-efficiency in advertently by applying less P than the crop requirement of the under normal soils, or deliberately selection for high P absorption capacity under acid soils.

Physiological and Biochemical attributes

Phosphorus is one of the key components in ATP, phospholipids & nucleic acid. P is an essential element and involved in energy transfer through ATP. It is also involved in root development and in metabolic activities especially in synthesis of protein. Limitation of phosphate leads to both molecular and development adaptations (Raghothama, 1995, Schachtman *et al.* 1998 and Lopez bucio *et al.* 2002).

Photosynthesis rate

Higher photosynthetic rate is very important to sustain normal growth of plants when suffering from low P stress. Fu *et al.* (2006). Reduction in leaf photosynthetic rate of rice plants induced by P deficiency. However, photosynthesis in rice plants induced by P-deficiency was not due to stomatal limitation. Under P deficiency, cell expansion is restricted more than chlorophyll synthesis resulting in more chlorophyll per unit leaf area (Marschner, 1995). Phosphorus starvation affects various cellular metabolic pathways in

plants such as decrease in rate of photosynthesis, respiration, soluble protein content and chlorophyll content. Activities of enzymes such as PPDK, PEPC, Rubisco, and Fructose 1, 6-BPase decrease on Pi deprivation (Poirier and Bucher, 2002). Phosphorus deficiency limits photosynthesis through a reduced regeneration of ribulose 1, 5-biphosphate (RUBP) (Brooks, 1986, Brooks *et al.* 1988, Rao and Terry, 1995). RUBP regeneration capacity of leaves can be reduced if the availability of fixed carbon, the initial activity of the Calvin cycle enzymes and /or the supply of ATP and NADPH are limited. Under moderate P deficient condition Rao and Terry (1995) proposed that RUBP regeneration is most probably limited by the supply of RU5P and /or the initial activity of the RU5P Kinase. The lower content of Photosynthetic pigments and weaker capacity of photosynthesis in the P-deficient rice plants inevitably results in the accumulation of excess photon energy under high irradiance. Excess photons may cause an increased production of reactive oxygen species (ROS) as byproducts of photosynthesis, including superoxide (O_2^-) hydrogen peroxide (H_2O_2), hydroxyl radical (OH) and single oxygen (O) (Xu *et al.* 2007)

Stomatal conductance

In wheat, stomatal conductance correlates with canopy temperature depletion in wide range of climatic condition (Lu *et al.* 1998). Lower stomatal conductance affects transpiration which in turn reduces leaf cooling. low P treatment decreased stomatal conductance, in rice genotypes, but had no significant influence on leaf internal CO_2 concentration suggesting that the decrease in stomatal conductance did not restrict the diffusion rate of CO_2 (Fu *et al.* 2006).

Water use efficiency (WUE)

Traits that can be selected to improve the water use efficiency of wheat are long coleoptiles, phonological growth at low temperature, deeper roots, late flowering, root to shoot partitioning, specific leaf area, stomatal conductance, canopy temperature, glaucousness, pubescence, residual transpiration, leaf size and habit, assimilate re-translocation, stay green / leaf rolling and osmotic adjustment. (Richardson *et al.* 2009).

Higher WUE is associated with higher grain yield, particularly in more stressful condition. Fertilizer use has a remarkable effect on crops yield and WUE. There are several studies reporting increase of cereal WUE with N and P application. Nitrogen and phosphorus nutrition have been shown to increase the early growth. In wheat, N and P fertilizer input reduced soil evaporation, increasing the WUE (Turner, 2004).

Chlorophyll Fluorescence

In recent years, techniques of chlorophyll fluorescence have become ubiquitous in plant eco-physiological studies. It has become a non-invasive powerful and reliable method to

assess the changes in the function of PS II (Schreiber *et al.* 1994). Chlorophyll fluorescence indirectly measures photosynthesis efficiency. It indicates thylakoid membrane integrity and relative efficiency of transport from PS II to PS I and is a useful tool in evaluation for thermo tolerance in plants (Mofitt *et al.* 1990a). It was reported that there was liner relationship between CO₂ assimilation efficiency and actual PS-II efficiency derived from chlorophyll fluorescence (Lu and Lu, 2004).

Widely used parameter F_v/F_m (ratio of variable to maximum fluorescence) was shown to be directly proportional to the quantum yield of photochemistry and net photosynthesis (Demming-Admas *et al.* 1989). Changes in photo chemical efficiency of PS II has been shown not only to affect plant growth but also population biology via affect on seedling establishment and survival (Asseng *et al.* 2001).

During evolutionary process, plants have developed many endogenous adaptive response systems to protect their photosynthetic apparatus against photo inhibition (Krause, 1988). It was observed that a decreased F_v/F_m was accompanied by a constant F_v/F_m , which suggested that the plants initiated the pro- active, photo protection by virtue of reducing the efficiency of the excitation capture in PS-II before it reached the PS-II centers (Demming Adams *et al.* 1996). The Non-photo chemical quenching (NPQ) rose dramatically in P-deficient rice plants in comparison with the control, indicating the excitation energy can be dissipated harmlessly as heat before reaching the photosynthetic reaction centers.

Acid / alkaline phosphatases

Soil phosphatases play a major role in the mineralization processes of organic P-substrates. There are several confounding factors that may effect the capacity of plant phosphatases to improve the P – uptake efficiency in soil (George *et al.* 2008), in many plant species. P deficiency or low P condition develops a range of mechanisms which enhance their ability to acquire P from soils (Marschner 1995 and Vance *et al.* 2005). The P deficient condition modifies the root structure (Liu *et al.* 2001) and production of root exudates such as organic anion (Ryan *et al.* 2001) and phosphatase enzymes (Tadano *et al.* 1993, George *et al.* 2002b). Phosphatase catalyze the hydrolysis of organic P to release free ortho-phosphatase and provide available form of P per plant. Hydrolyzing and mobilizing inorganic P from monoester organic phosphorus (Duff *et al.* 1994) are estimated to account for about 30-80% of total P in agricultural soils. (Gilbert *et al.* 1999).

Phosphatases have been classified as being alkaline or acid phosphatase according to whether their optimal pH for catalysis is above or below pH 7.0 (Vincent *et al.* 1992) Acid phosphatases differs from alkaline phosphatases by displaying optimum activity below pH 7.0 and generally having low substrate specificity Plant alkaline phosphatase generally display

absolute substrate specificity, while acid phosphatases do not normally exhibit an absolute substrate specificity. Role of phosphatases in nutrition is evidenced by the fact that P-stressed lupin plants secrete about 20 fold more acid phosphatases from roots compared to P-sufficient control plants (Tadano and Saki 1991 and Gilbert *et al.* 1999).

Yield and grain quality:

Grain yield

Both grain yield and quality get adversely affected by P-deficiency. Crop yield on 30-40% of world arable land is limited by P availability. Grain yield is a complex trait and potential of a given genotypes to produce grains in given environment may differ due to the yield components, like number of kernels per spike, thousand kernel weight and tillering capacity (Egle *et al.* 1999, Radriguez *et al.* 1998). Grain yield under Pi deficiency appear to be most reliable parameter for screening genotypes for P efficiency.

With increase in P level from 40 kg to 120 kg P/ha there was corresponding increase in grain yield. Cultivars with short root hair reduced grain yield in P limited soils and they produced high grain yield only when P fertilizers were applied (Gahoonia and Nielson, 2004). In wheat 70%-80% of total P in wheat is usually found in grains at harvest, the possibilities to raise P translocation from vegetative biomass into grain is limited (Gill *et al.* 2004).

The application of phosphorus to mungbean has been reported to increase dry matter at harvest, no. of pods / plants, seed / plant, 1000-grain weight, seed yield and total biomass (Mitra *et al.* 1999). Horst *et al.* (1993) found an increase in number of tillers from 15 to 37 in response to P application at a rate of 60 mg Kg⁻¹ soil (100% P level). So in addition to N, phosphorus can be used to increase tillering and increase crop density.

Therefore, screening of crop species / varieties that can grow at low P level can be a promising approach for sustainable crop production (Horst *et al.* 2001).

Grain quality:

Protein

Proteins are important components of wheat grain governing their quality (Weigels *et al.* 1996). Protein is the only quality trait improving penalty on grain yield. Higher protein level were achieved at low P condition as a result of the lower yield associated with low P-levels. The native Indian wheat had been globally recognized for its quality and was always in demand by overseas clients. The quality requirement of wheat for various products like chapatti, bread, biscuit and pasta are different like hard wheat with strong gluten, > 12.0% and protein, 5-10%. High molecular weight glutenin subunit with 9 or 10 Glu-1 score are

required for making good bread. For biscuit the quality requirement are weak and soft wheat with <10.0% protein, < 30 ml sedimentation value and approximately 50% alkaline water retention capacity (AWRC). For chapatti the quality requirement are in between to those required for bread and biscuit.

Genetic improvement of quality traits in bread wheat is becoming a new thrust area in the Indian wheat programme. For most traditional uses, wheat quality derives mainly from two inter related characteristics grain hardness and protein content. Grain hardness is a heritable trait but it can be strongly affected by abnormal weather condition such as excessive rainfall during the harvest period. Protein content is weakly heritable and strongly dependent on environmental factors such as available soils nitrogen and moisture during the growing season (Gupta R.K. 2008).

Starch

Starch is predominant carbohydrates reserve in many plants. It constitutes more than 78% of wheat grain and its amount in grain directly affects the wheat productivity. However, in rice, low level of phosphorus treatment did not increase the content of starch in shoot and root. Enhancement of starch synthesis is induced when plants are starved of P because an increase in Triose-P/pi ratio in chloroplast caused by P-deficiency. Phosphate deficiency induced a large accumulation of starch, glucose and fructose in leaf of bean (Bernal *et al.* 2005).

CHAPTER-III

MATERIAL AND METHODS

Experimental materials

Investigation were carried on ten genotypes of bread wheat (*Triticum aestivum* L.) viz. WH-147 Raj-4083, WH-1022 LOK-1, WH-1021, NW-2030, C-306, WH-1025, PBW-343 and PBW-550 in the green house of Department of Botany and Plant Physiology in college of Basic Sciences & Humanities, CCS Haryana Agricultural University, Hisar. Genotypes were selected on their comparative P uptake efficiency and other desirable traits e.g. grain yield and physiological parameters.

Seed of wheat genotypes used in the experiment were obtained from Wheat Section, Department of Plant Breeding, College of Agriculture, CCS HAU, Hisar.

Experimental Details

EXP 1: To identify the genotypes efficient in phosphorus uptake and utilization.

Plants of ten varieties of wheat were raised in earthen pots (20 x 16 cm) with 5 kg dune sand in natural condition. Seeds were sterilized with alcohol, washed 3-4 times with distilled water and dried on filter paper. Six seeds were sown in each pot at uniform depth. Thinning was done one week after germination to leave four plants of comparable growth in each pot. The plants were supplied with nutrient solution (Hoagland and Arnon 1950) at 10 days intervals.

CHEMICAL COMPOSITION OF HOAGLAND NUTRIENT SOLUTION

Major Salt

Stock solution I	Ca (NO ₃) ₂	364.0 g/L
Stock solution II	MgSO ₄	217.6 g/L
Stock solution III	KH ₂ SO ₄	62.1 (100%), 31.05 g/l (50%) 12.4 (20%)
Stock solution IV	KNO ₃	221.3/l (100%), 276 g/l (50%), 331 g/l (20%)

Minor Salt

Stock Solution V

ZnSO ₄	0.097 g/l
H ₃ BO ₃	1.269 g/l
Na ₂ HPO ₄	0.400 g/l
CuSO ₄ .5H ₂ O	0.035 g/l
MnSO ₄	0.60 g/l

Volume with 1 liter of water.

Iron source

Stock solution VI	Tartaric acid	4 g l ⁻¹
	FeSO ₄ .7H ₂ O	5 g l ⁻¹

Nutrient solution 25 L was prepared by mixing 62.5 ml of each of stock solution 1 to 5 and 15 ml at stock solution and diluted to 25 L .

Treatments

Plants were supplied with following modified nutrient solution for giving varying doses of phosphorus.

T_{100%} (control) (100% P as in Nutrient solution, 60 mg P/kg soil)

T_{50%} (50% P as in Nutrient solution, 30 mg P/kg soil)

T_{20%} (20% P as in Nutrient solution, 12 mg P/kg soil)

Sampling : Sampling was done at 3 stages

1. Vegetative stage (55 days after sowing)
2. Anthesis stage (100 days after sowing)
3. Harvest stage

Statistical Analysis

The data collected were analyzed statistically by the method of ‘Analysis of Variance’ developed by Fisher (1950) the significance was judged from the critical difference (CD) at 5% level of significance by using factorial Completely Randomized Design (CRD).

Observation

- A. Dry weight of different plant parts i.e. roots stem, leaf (at all three sampling stages)
- B. The following observation was taken after anthesis and sampling was done at the interval of 10 days.
 - a. Chlorophyll fluorescence
 - b. Assimilation rate
 - c. Transpiration rate
 - d. Stomatal conductance
 - e. Water use efficiency
- C. Observation recorded from heading to harvest Stage
 - a. Days to Heading
 - b. Days to Anthesis
 - c. Days to Maturity
 - d. Grain Filling duration
 - e. Plant Height

- f. No. of productive tillers/plant
 - g. Biomass/plant
 - h. Spike length
 - i. Grain yield/plant
 - j. Test weight
- D. Phosphorus content: P content of different plant parts (leaf, stem, roots) was recorded at vegetative and harvest Stage.
- E. Quality parameter in grain: Data of quality parameter viz. protein, ash content, moisture content was recorded by using Grain Analyser.

Methods

- A. **Dry weight:** The plants were up-rooted from the soil and their components i.e. leaves, stem, roots and ear heads were separated and wrapped in a piece of paper and allowed to dry in laboratory condition for a day and then placed in oven at 60°C to dry till constant weight and dry weight was recorded.
- B. **Chlorophyll fluorescence:** The chlorophyll fluorescence was measured by using chlorophyll fluoremeter (Model 0S30 p USA). Data was recorded between 10:00 to 12:00 a.m.
- C. **Gas exchange studies:** Assimilation rate ($\text{mole m}^{-2} \text{sec}^{-1}$), transpiration rate ($\text{m mole m}^{-2} \text{sec}^{-1}$) and stomatal conductance were measured by using portable Infra Red Gas Analyser between 10.00 to 11.00 a.m. Water use efficiency (WUE) was determined by method of Rosenberg and Kriiger (1993) and it is ratio of A (assimilation rate) and E (transpiration rate).

Phenological observation

- a) **Days to heading:** It was calculated as days taken from sowing to appearance of first earhead.
- b) **Days to antehsis:** It was calculated as days taken from sowing to appearance of yellow pollen on ear heads.
- c) **Days to maturity:** It was calculated as days taken from sowing upto 75% of ear heads losses green colour.
- d) **Grain filling duration:** It was calculated by subtracting days to heading from days to maturity.

Estimation of phosphorus

Total P in plant sample was determined by Vanadomolybdophosphoric yellow colour method as described by Jackson (1973).

Reagents:

Vanadate – Molybdate reagent:

Solution 'A' was prepared by dissolving 25g ammonium molybdate in about 400 ml warm water.

Solution 'B' was separately prepared by dissolving 1.25 g of ammonium metavanadate in 300 ml of warm water (70°C), cooled at room temperature and added 250 ml of concentrated HNO₃ and cooled again at room temperature. Then added solution 'A' to solution 'B' slowly with continuous stirring and diluted to one liter with distilled water.

6N HCl solution: Diluted 517 ml of conc. HCl to one litre.

2, 4 di-nitrophenol indicator (2.5%): Dissolved 2.5g of 2, 4 di-nitro phenol in 100 ml of 95% ethanol.

Ammonia solution:

Standard curve –Dissolved 0.2195 g of dried KH₂PO₄ in water acidified with 25 ml of 7N H₂SO₄ and diluted to 1 litre. This solution contains 50 ppm P. Different conc.of standard solution 0.05, 0.1, 0.2, 0.3, 0.4, 0.8 and 1.0 ppm. were prepared from above solution.

Procedure

200 mg of weight material was taken in a 50 or 100 ml conical flask. 10 ml of di-acid mixture of HNO₃ and HClO₄ in ratio of 9:1 was added. Kept it for overnight. Next day keep on hot plate and heated gently at first, then heated more vigorously until a clear colorless solution resulted or till white fumes ceased to come out. Discontinue heating, when the volume is reduced to 3-4 ml. Cooled it and transferred to other flask. Distilled water was added in to the flask and total volume was made 25 ml in vials.

(II) Colour development

1. 5 ml of aliquot (digested plant material) in 50 ml of volumetric flask.
2. Add 2-3 drops of 2, 4 di-nitro phenol indicator.
3. Added ammonia solution till yellow colour appeared and NH₄Cl was added (dropwise) till it become colorless.
4. 5 ml of Vanadate molybdate solution was added and diluted to 25 ml with distilled water.
5. Mixed well and read the intensity of yellow colour on spectrophotometer by using blue filter at 440 nm wavelength.
6. Run a blank without P solution simultaneously.
7. Calculate P content of sample using the standard curve

Starch**Extraction**

100 mg of dry grain (flour) was grinded and refluxed in 10 ml distilled water for 2-3 h. It was cooled and centrifuged at $10,000 \times g$ for 30 min. The supernatant was kept aside and pellet was refluxed and then centrifuged. The supernatants were pooled and pellet was refluxed again with 5 ml distilled water for 30 min. and centrifuged. The total volume was made to 25 ml with distilled water. This constituent the soluble carbohydrate fraction.

Estimation

The pellet was treated with 3.0 ml. mix. of 6.5 ml of 52% perchloric acid plus 5 ml of distilled water and centrifuged at $10,000 \times g$ for 30 minute .The supernatant was kept aside and pellet again treated two times with the same reagent. The supernatant were pooled and total volume was made to 12.0 ml with distilled water and constitutes starch fraction. Starch was estimated using phenol-sulphuric acid method (Dubois *et al.* 1956). To 0.5ml aliquote of starch extract, 1.0 ml of 1% phenol and 2.0 ml conc. H_2SO_4 was add. Allowed to stand for 30 minutes and after cooling absorbance was measured at 475 nm against the reagent blank. Standard curve was prepared using glucose (10-50 μ g). Concentration of starch was calculated by multiplying glucose standard values by 0.9 (0.9g of starch on hydrolysis, yields one gram of glucose).

D. Quality parameters in grain

Protein, ash content and moisture all these parameters were recorded by using instrument 'Grain Analyzer, USA.

Experiment 2

To identify root morpho-physiological traits associated with efficient phosphorus uptake

Plan of work:

Ten genotypes were germinated in petriplates and then transferred to germination paper and kept in beakers containing nutrient solution with different concentrations of phosphorus.

Observation

Following observations were recorded seven days after germination.

1. Root length
2. No of roots
3. Root/shoot ratio
4. Alkaline phosphatase activity
5. Acid phosphatase activity

Enzyme Assay :

Preparation of crude extract for enzyme studies:

Roots were homogenized in a chilled glass mortar with a pestle using acid washed sand as abrasive. The extraction medium (pH 7.4) used was having composition: 0.05 M tris-HCl buffer (pH 7.4); 0.4 M sucrose; 0.1 M KCL; 10 mM MgCl₂; 0.01 M EDTA (Ethylene diamine tera acetic acid); 0.01 M Mercepto ethanol and 2.5% PVP (Polyvinyl pyrrolidone) (Copper and Beever, 1969). The homogenate was centrifuged at 16000 rpm for 30 minutes at 0-4°C. The supernatant was used for estimating the activities of alkaline phosphatase.

Alkaline phosphatase activity

Assay by method of Jones (1969) for alkaline P-ase activity, p-nitrophenyl phosphate as substrate and the pH optima for alkaline phosphatase was determined and found to be 7.8 for alkaline phosphatase.

Compostion of substrate solution

P – nitrophenyl phosphate	(5 mg /10 mg)	10 ml
	0.1 M MgCl ₂	1 ml
0.1 M tris HCl buffer	(pH 7.8)	30 ml
	Total	41 ml.

Procedure

The incubation mixture consisting of 1 ml of enzyme extract and 1 ml of substrate solution was incubated at 37°C for 20 minute. Reaction was stopped with 5 ml of 0.1 N NaOH and the p-nitrophenol liberated was determined by measuring colour intensity at 405 nm. A standard curve (0.05 K mole-0.25 p moles) was also prepared by using pure p-nitrophenol. The activity of enzyme was expressed as moles of p-nitrophenol / hour under specific experimental conditions.

Acid phosphatase

Assay of acid phosphatasse was carried out by method of Jones (1969) using p-nitrophenyl phosphate as a substrate.

Reagents

- (a) p-nitrophenyl phosphate – 0.5 mg/ml
- (b) 0.1 M MgCl₂
- (c) 0.1 M acetate buffer (pH 4.8)
- (d) Substrate solution – Reagents a, b and c was mixed in the ratio of 10: 1: 30
- (e) 0.1 N NaOH

Procedure

Mixture of 50 μ l of enzyme extract and 1 ml of substrate solution was incubated at 37°C for 20 min. The solution was then made alkaline with 5 ml of 0.1 N NaOH to stop the reaction and O.D. of yellow coloured product i.e. p-nitrophenol was recorded at 410 nm. A standard curve was prepared using graded concentrations of p-nitrophenol. Enzyme activity was expressed as n mol of p-nitrophenol.

CHAPTER-IV

EXPERIMENTAL RESULTS

The present investigation was aimed to study the phosphorus uptake, yield and quality parameters in wheat (*Triticum aestivum* L.). Ten wheat genotypes with WH-147, Raj-4083, WH-1022, LOK-1, WH-1021, NW-2030, C-306, WH-1025, PBW-343 and PBW-550 were screened for their response to 20% P, 50% P and 100% P levels. The present investigation was carried out under two experiments and results obtained experiment wise are as below:

Experiment –I

Days to Heading

Overall days to heading in different genotypes of wheat was delayed at 20% and 50% phosphorus level as compared to 100% P level (Table 1). Maximum days to heading was observed in NW-2030 (120 days). Minimum days to heading were observed LOK-1 (83 days). Genotypes Raj-4083, WH-1022, NW-2030, WH-1025 and PBW-343 were found significantly better than other genotypes at different level of Phosphorus in terms of days to heading.

Days to Anthesis

Overall days to anthesis in different wheat genotypes was delayed at 20% and 50% P level as compared to 100% P level. Genotypes Raj-4083, WH-1022, NW-2030, WH-1025 and PBW-343 were significantly, different than other genotypes for days to anthesis (Table 2).

Maximum days to anthesis was taken by PBW-343 (103 days) Raj-4083 (102 days), WH-1022 (102 days), WH-1025 (101 days) at 20% P level. Minimum days to anthesis was observed in LOK-1 (90 days) at 20% P level as compared to 100% P level.

Days to Maturity

Days to maturity in different genotypes of wheat was delayed at 20% and 50% P level as compared to 100% P level (Table 3). Overall WH-147, WH-1022, C-306, WH-1025 and PBW-343 were found significantly different than other in days to maturity at different level of phosphorous. Maximum days to maturity were taken by C-306 (134 days) at 20% P level and minimum was taken by LOK-1 (122 days).

Grain filling duration

Grain filling duration was calculated by difference between days to maturity and days to anthesis. Overall WH-147, LOK-1 and C-306 were found significantly different than other genotypes for grain filling at different levels of phosphorus (Table 4). Maximum days to grain filling duration was observed in C-306 (41 days) at 20% P level. Minimum was observed in Raj-4083 (25 days) at 20% P level.

Table 1: Effect of different levels of phosphorus application on days to heading in wheat varieties

Varieties	Days to Heading			
	Level of Phosphorus			
	100%	50%	20%	Mean
WH-147	85.00	90.33	91.00	88.78
RAJ-4083	95.33	96.67	99.00	97.00
WH-1022	94.33	91.33	99.67	95.11
LOK-1	76.67	77.67	83.67	79.34
WH-1021	86.33	92.67	94.00	91.00
NW-2030	87.33	93.00	102.67	94.33
C-306	84.67	90.33	88.67	87.89
WH-1025	94.00	92.67	97.00	94.56
PBW-343	90.33	94.00	97.67	94.00
PBW-550	86.00	84.67	94.00	88.22
MEAN	88.00	90.33	94.73	91.02

CD at 5%

Variety 0.47

Phosphorus Treatment 0.26

Variety X Phosphorus Treatment 0.82

Table 2: Effect of different levels of phosphorus application on days to anthesis in wheat varieties.

Varieties	Days to anthesis			
	Level of Phosphorus			
	100%	50%	20%	Mean
WH-147	89.0	96.3	97.7	94.33
RAJ-4083	99.7	100.7	102.7	101.03
WH-1022	97.0	93.7	102.7	97.80 *
LOK-1	81.7	83.0	90.3	85.00
WH-1021	90.0	97.3	97.3	94.87
NW-2030	90.0	96.3	100.3	95.53 *
C-306	89.3	93.7	92.7	91.90
WH-1025	97.7	99.0	101.7	99.47 *
PBW-343	94.0	96.7	103.0	97.90 *
PBW-550	90.0	89.3	98.0	92.43
MEAN	91.84	94.60	98.64	95.03

CD at 5%

Variety 0.44

Phosphorus Treatment 0.24

Variety X Phosphorus Treatment 0.77

Table 3: Effect of different levels of phosphorus application on days to maturity in wheat varieties

Varieties	Days to maturity			
	Level of Phosphorus			
	100%	50%	20%	Mean
WH-147	124.7	129.0	132.3	128.67 *
RAJ-4083	127.7	128.0	128.7	128.13
WH-1022	130.0	128.3	133.7	130.67 *
LOK-1	126.7	125.0	128.3	126.67
WH-1021	123.0	127.7	122.7	124.47
NW-2030	121.3	125.0	126.7	124.33
C-306	131.0	132.7	134.7	132.80 *
WH-1025	126.7	128.7	133.0	129.47 *
PBW-343	125.7	128.7	132.3	128.90 *
PBW-550	121.7	125.0	127.0	124.57
MEAN	125.85	127.81	129.94	127.87

CD at 5%

Variety 0.44

Phosphorus Treatment 0.24

Variety X Phosphorus Treatment 0.77

Table 4: Effect of different levels of phosphorus application on grain filling duration in wheat varieties

Varieties	Grain filling duration			
	Level of Phosphorus			
	100%	50%	20%	Mean
WH-147	35.67	33.00	33.67	34.11*
RAJ-4083	27.67	27.00	25.67	26.78
WH-1022	33.33	33.67	31.00	32.67
LOK-1	44.33	41.67	38.00	41.33*
WH-1021	32.67	31.33	26.33	30.11
NW-2030	32.00	28.33	27.00	29.11
C-306	41.33	39.33	41.00	40.55*
WH-1025	29.33	30.33	31.00	30.22
PBW-343	31.67	31.33	30.00	31.00
PBW-550	32.33	35.67	29.33	32.44
MEAN	34.03	33.17	31.30	32.83

CD at 5%

Variety 0.48

Phosphorus Treatment 0.26

Chlorophyll fluorescence (Fv/Fm)

Chlorophyll fluorescence of flag leaf of wheat was observed at different days after sowing (100, 110 and 120 DAS). Overall chlorophyll fluorescence of flag leaf in different wheat genotypes decreased with decreasing level of phosphorus (20%) as compared to 100% P level (Table 5).

However no significant genotypes difference was observed at different level of phosphorus application. Highest per cent of reduction was noted in NW-2030 (21.02) and lowest per cent of reduction was observed in C-306 (14.27) at 100 DAS. Overall there is no significant difference in all genotypes at 110 DAS at different level of P. Similarly on 120 days after sowing – chlorophyll fluorescence of flag leaf decreased with decreasing level of phosphorus (20% P) as compared to 100% P level. Lowest per cent of reduction was observed in WH-1022 (13.21) and highest per cent of reduction was noted in WH-147 and PBW-550 (18.47).

Transpiration rate (μ moles $m^{-2} sec^{-1}$)

The transpiration rate decreased with decreasing levels of P at all three sampling stage (100, 110 and 120 DAS) in all genotypes (Table 6).

NW-2030, C-306 has shown significantly increase in transpiration rate at different P levels as compared to other genotypes at 100 DAS. Highest per cent reduction of transpiration was noted in WH-1022 (50.71) and lowest was in NW-2030 (6.52) at different P levels.

Genotypes WH-1022 has showed significant difference in transpiration rate at different level of P at 110 DAS. Highest per cent reduction in transpiration rate was in LOK-1 (32.23) and WH-147 (32.36) and lowest was noted in WH-1021 (4.63).

PBW-343 showed significant difference in transpiration rate at different level of P as compared to other genotypes at 120 DAS. Highest per cent reduction was in PBW-550 (25.70) and lowest per cent reduction was observed in WH-147 (6.68).

Water use efficiency (WUE)

Overall there was decrease in water use efficiency with decreasing level of P (20% P) application at all three sampling stages (100, 110 and 120 DAS) (Table 7). WH-147 and Raj-4083 showed significant difference in water use efficiency at different level of P application. Highest per cent of reduction in water use efficiency was in WH-1025 (48.74) and lowest was noted in observed in Raj-4083 (3.07) at different P level at 100 DAS.

WH-147 and Raj-4083 showed significant in water use efficiency as compared to other genotypes at 110 DAS. Highest per cent of reduction of WUE was in WH-1025 (40.40) and lowest was observed in WH-147 (6.74) at different P levels.

Table 5: Effect of different levels of phosphorus application on chlorophyll florescence (F_v/F_m) of flag leaf at different days after sowing in wheat varieties

Sampling															
100 DAS						110 DAS					120 DAS				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	0.770	0.738	0.635	0.714	17.53	0.785	0.722	0.640	0.716	18.47	0.795	0.774	0.645	0.738	18.47
RAJ-4083	0.757	0.726	0.632	0.705	16.51	0.780	0.759	0.639	0.726	18.08	0.785	0.770	0.640	0.732	15.74
WH-1022	0.750	0.746	0.623	0.706	16.93	0.778	0.709	0.629	0.705	19.15	0.788	0.725	0.664	0.726	13.21
LOK-1	0.739	0.722	0.632	0.698	14.48	0.790	0.745	0.697	0.744	11.77	0.795	0.750	0.690	0.745	15.27
WH-1021	0.748	0.724	0.629	0.700	15.91	0.796	0.725	0.639	0.720	19.72	0.799	0.738	0.677	0.738	14.61
NW-2030	0.785	0.775	0.620	0.727	21.02	0.757	0.754	0.695	0.735	8.19	0.787	0.760	0.672	0.740	16.35
C-306	0.729	0.705	0.625	0.686	14.27	0.778	0.740	0.655	0.724	15.81	0.789	0.788	0.660	0.746	17.20
WH-1025	0.748	0.721	0.607	0.692	18.85	0.763	0.744	0.640	0.716	16.12	0.779	0.776	0.645	0.733	15.88
PBW-343	0.752	0.725	0.623	0.700	17.15	0.798	0.792	0.634	0.741	20.55	0.80	0.778	0.673	0.750	18.29
PBW-550	0.778	0.736	0.636	0.717	18.25	0.796	0.748	0.663	0.736	16.71	0.82	0.727	0.670	0.739	18.47
MEAN	0.756	0.732	0.626	0.705		0.782	0.744	0.653	0.726		0.794	0.759	0.664	0.739	

CD at 5%

Variety N.S
Phosphorus Treatment N.S
Variety X Phosphorus Treatment N.S

CD at 5%

Variety N.S
Phosphorus Treatment N.S
Variety X Phosphorus Treatment N.S

CD at 5%

Variety 0.04
Phosphorus Treatment N.S
Variety X Phosphorus Treatment N.S

Table 6: Effect of different levels of phosphorus application on transpiration rate (m mol m⁻² s⁻¹) of flag leaf at different days after sowing in wheat varieties

Sampling															
100 DAS						110 DAS					120 DAS				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	3.33	3.05	2.38	2.92	28.53	5.46	4.63	3.70	4.60	32.23	7.33	7.33	6.84	7.17	6.68
RAJ-4083	4.23	3.68	3.10	3.67	26.71	6.21	5.12	4.37	5.23	29.63	7.13	7.05	6.26	6.81	12.20
WH-1022	4.93	4.60	2.43	3.99	50.71	7.91	7.56	7.27	7.58	8.09	8.11	8.09	7.45	7.88	8.14
LOK-1	4.70	4.40	3.87	4.32	17.66	7.91	6.37	5.35	6.54	32.36	8.46	8.31	7.13	7.97	15.72
WH-1021	4.11	3.99	3.60	3.90	12.41	7.13	7.07	6.80	7.00	4.63	7.46	7.13	5.74	6.78	23.06
NW-2030	4.91	4.80	4.59	4.77	6.52	7.25	6.30	6.13	6.56	15.45	6.97	7.95	6.27	7.06	10.04
C-306	4.58	5.18	4.12	4.63	10.04	7.21	6.30	5.46	6.32	24.27	8.31	8.19	7.16	7.89	13.84
WH-1025	4.80	4.31	3.30	4.14	31.25	6.87	6.30	6.22	6.46	9.46	8.91	8.25	7.79	8.32	12.57
PBW-343	4.46	4.09	3.73	4.09	16.37	6.79	6.67	5.62	6.36	17.23	8.91	8.67	7.98	8.52	10.44
PBW-550	4.25	3.81	2.89	3.65	32.00	7.23	5.75	5.46	6.15	24.48	9.22	7.43	6.85	7.83	25.70
MEAN	4.43	4.19	3.40	4.01		7.00	6.21	5.64	6.28		8.08	7.84	6.95	7.62	

CD at 5%

Variety 0.70
Phosphorus Treatment 0.38
Variety X Phosphorus Treatment N.S

CD at 5%

Variety 0.88
Phosphorus Treatment N.S
Variety X Phosphorus Treatment 1.52

CD at 5%

Variety 1.05
Phosphorus Treatment N.S
Variety X Phosphorus Treatment N.S

Table 7: Effect of different levels of phosphorus application on stomatal conductance (mol m⁻² s⁻¹) of flag leaf at different days after sowing in wheat varieties

Sampling															
100 DAS						110 DAS					120 DAS				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	0.97	0.97	0.78	0.91	19.6	0.46	0.44	0.35	0.42	23.9	0.73	0.61	0.42	0.59	42.5
RAJ-4083	0.94	0.92	0.68	0.85	27.7	0.5	0.27	0.24	0.34	52.0	0.83	0.79	0.45	0.69	45.8
WH-1022	0.86	0.52	0.26	0.55	69.8	0.8	0.79	0.73	0.77*	8.8	0.88	0.86	0.82	0.85	6.8
LOK-1	0.89	0.8	0.56	0.75	37.1	0.6	0.45	0.31	0.45	48.3	0.94	0.9	0.55	0.80	41.5
WH-1021	0.77	0.69	0.62	0.69	19.5	0.53	0.46	0.45	0.48	15.1	0.76	0.54	0.3	0.53	60.5
NW-2030	0.93	0.92	0.88	0.91	5.4	0.48	0.36	0.33	0.39	31.3	0.97	0.54	0.44	0.65	54.6
C-306	0.81	0.56	0.45	0.61	44.4	0.63	0.49	0.33	0.48	47.6	0.92	0.59	0.56	0.69	39.1
WH-1025	0.75	0.43	0.39	0.52	48.0	0.76	0.45	0.43	0.55	43.4	0.78	0.6	0.52	0.63	33.3
PBW-343	0.63	0.38	0.26	0.42	58.7	0.5	0.45	0.42	0.46	16.0	0.76	0.63	0.54	0.64	28.9
PBW-550	0.54	0.43	0.2	0.39	63.0	0.57	0.4	0.33	0.43	42.1	0.92	0.79	0.56	0.76	39.1
MEAN	0.81	0.66	0.51	0.66		0.58	0.46	0.39	0.48		0.85	0.69	0.52	0.68	

CD at 5%

Variety	0.28	
Phosphorus Treatment	0.15	
Variety X Phosphorus Treatment		N.S

CD at 5%

Variety	0.176	
Phosphorus Treatment	N.S	
Variety X Phosphorus Treatment		N.S

CD at 5%

Variety		N.S
Phosphorus Treatment		N.S
Variety X Phosphorus Treatment		N.S

At 120 DAS – water use efficiency was lowest at 20% P as compared to 100% P in all ten wheat genotypes. WH-147 and Raj-4083 performed better at different level of phosphorus in maintaining WUE. Highest % of reduction in WUE was observed in WH-1021 (38.75) and lowest was in WH-1025 (00.00) at different P application.

Stomatal conductance ($\text{mol m}^{-2} \text{s}^{-1}$)

The stomatal conductance decreased with decreasing level of P (20% P) at all 3 sampling stages (100, 110 and 120 DAS) (Table 8). At 100 DAS, WH-147 and NW-2030 has shown significant in stomatal conductance at different level of P as compared to other genotypes. Highest per cent reduction of stomatal conductance was observed in WH-1022 (69.8) and lowest stomatal conductance was in NW-2030 (5.4).

Minimum stomatal conductance was observed at 20% P level as compared to 100% P level. WH-1022 showed significant difference in stomatal conductance at different level of P application at 110 DAS. Highest per cent of reduction was in Raj-4083 (52.0) and lowest per cent of reduction was observed in WH-1022 (8.8).

There was no significant difference in all wheat genotypes at different level of P application. Highest per cent reduction of stomatal conductance was noted in WH-1021 (60.5) and lowest per cent of reduction was observed in WH-1022 (6.8).

Photosynthetic rate ($\mu \text{mole m}^{-2} \text{s}^{-1}$)

Photosynthetic rate of different wheat genotypes (20%, 50% and 100% P) at different days after sowing (DAS) decreased with decreasing level of P application at all three sampling stages (100, 110 and 120 DAS) (Table 9). Mean photosynthetic rate was found 13.71 (20%), 15.47 (50% P) and 18.08 (100%) at 100 DAS. WH-147 and WH-1022 showed better performance in photosynthetic rate at different level of P as compared to other genotypes. Highest per cent reduction in photosynthetic rate was observed in C-306 (42.22) and lowest was observed in WH-147 (11.87).

Overall at 110 DAS, WH-1022 performed better and could maintain photosynthetic rate at different levels of phosphorus. Highest per cent reduction of photosynthetic rate was noted in PBW-343 (41.63) and lowest was observed in LOK-1 (7.54).

At 120 DAS gradual decrease in photosynthetic rate was observed with decreasing levels of phosphorus application in different wheat genotypes. Overall at 120 DAS none varieties showed significant results in maintaining photosynthetic rate at different P levels. Highest per cent reduction of photosynthetic rate was noted in PBW-550 (24.04) and WH-147 (23.49) while lowest was observed in PBW-343 (6.18) and WH-1025 (7.76).

Table 8: Effect of different levels of phosphorus application on water use efficiency (A/E) of flag leaf at different days after sowing in wheat varieties

Sampling															
100 DAS						110 DAS					120 DAS				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	7.89	6.73	4.12	6.25*	47.78	3.86	3.64	3.60	3.70*	6.74	2.60	2.53	2.34	2.49*	10.00
RAJ-4083	5.28	4.66	4.59	4.84	13.07	3.11	2.89	2.30	2.77*	26.05	2.59	2.57	2.33	*2.50	10.04
WH-1022	4.81	4.08	4.01	4.30	16.63	2.56	2.40	2.17	2.38	15.23	2.37	2.31	2.16	2.28	8.86
LOK-1	3.44	3.35	2.73	3.17	20.64	2.85	2.61	2.31	2.59	18.95	1.94	1.93	1.77	1.88	8.76
WH-1021	4.45	4.21	3.10	3.92	30.34	2.47	2.01	1.76	2.12	28.74	2.40	1.93	1.47	1.93	38.75
NW-2030	4.06	3.57	3.28	3.64	19.21	2.47	2.26	2.22	2.32	10.12	2.43	2.09	1.86	2.13	23.46
C-306	3.62	2.69	2.64	2.98	27.07	2.53	2.29	1.98	2.27	21.74	2.03	1.98	1.56	1.86	23.15
WH-1025	4.76	4.12	2.44	3.77	48.74	3.02	2.49	1.80	2.44	40.40	2.06	1.90	1.90	1.95	7.7
PBW-343	3.27	3.23	2.48	2.99	24.16	2.77	2.10	1.92	2.26	30.69	1.94	1.82	1.80	1.85	7.22
PBW-550	3.48	2.76	2.49	2.91	28.45	2.46	2.28	2.20	2.31	10.57	1.89	1.85	1.84	1.86	2.65
MEAN	4.51	3.94	3.19	3.88		2.81	2.55	2.23	2.51		2.49	2.49	2.49	2.08	

CD at 5%

Variety	1.06
Phosphorus Treatment	0.58
Variety X Phosphorus Treatment	1.84

CD at 5%

Variety	0.28
Phosphorus Treatment	
Variety X Phosphorus Treatment	

CD at 5%

Variety	0.33
Phosphorus Treatment	N.S
Variety X Phosphorus Treatment	N.S

Table 9: Effect of different levels of phosphorus application on photosynthetic rate (μ mol m⁻² s⁻¹) of flag leaf at different days after sowing in wheat varieties

Sampling															
100 DAS						110 DAS					120 DAS				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	22.49	22.49	19.82	21.60	11.87	19.9	16.65	14.36	16.97	27.84	18.73	17.75	14.33	16.94	23.49
RAJ-4083	19.26	17.23	16.23	17.57	15.73	17.8	15.93	10.09	14.61	43.31	18.41	16.61	16.12	17.05	12.44
WH-1022	23.70	18.38	19.87	20.65	16.16	18.63	18.18	17.15	17.99	7.94	19.08	17.55	17.25	17.96	9.59
LOK-1	15.21	12.79	12.79	13.60	15.91	16.7	16.2	15.44	16.11	7.54	16.19	15.05	13.76	15.00	15.01
WH-1021	17.58	17.34	10.45	15.12	40.56	17.52	12.24	11.75	13.84	32.93	17.85	13.72	8.93	13.50	49.97
NW-2030	19.44	16.37	16.12	17.31	17.08	16.12	15.09	14.11	15.11	12.47	16.66	15.45	13.00	15.04	21.97
C-306	18.83	12.35	10.88	14.02	42.22	18.09	13.57	12.5	14.72	30.90	14.91	14.18	13.10	14.06	12.14
WH-1025	16.43	15.3	10.79	14.17	34.33	18.84	17.13	11.6	15.86	38.43	17.13	16.64	15.80	16.52	7.76
PBW-343	14.59	10.89	10.09	11.86	30.84	18.52	13.99	10.81	14.44	41.63	16.51	15.83	15.49	15.94	6.18
PBW-550	13.25	11.59	10.02	11.62	24.38	16.51	14.15	11.97	14.21	27.50	17.14	13.84	13.02	14.67	24.04
MEAN	18.08	15.47	13.71	15.75		17.86	15.31	12.98	15.38		17.26	15.66	14.08	15.67	

CD at 5%

Variety 3.37
Phosphorus Treatment 1.84
Variety X Phosphorus Treatment 5.83

CD at 5%

Variety 2.04
Phosphorus Treatment 1.11
Variety X Phosphorus Treatment 3.53

CD at 5%

Variety N . S
Phosphorus Treatment N.S
Variety X Phosphorus Treatment N.S

Dry weight of root, stem and leaf at vegetative stage

Dry weight of leaf (g)

Dry weight of leaf of wheat genotypes decreased with decreasing levels of P. Minimum dry weight was observed with 20% P application (0.410 g/plant) as compared to 100% P (1.137 g/plant) in all ten wheat genotypes (Table 10). Overall no significant difference in leaf dry weight was observed in all ten genotypes at different phosphorus levels (20% P, 50% P and 100% P). Minimum per cent reduction of leaf dry weight was noted in WH-1022 (13.16) and maximum was observed in WH-1025 (75.58).

Dry weight of stem (g/plant)

Dry weight of stem dry matter in different wheat genotypes at vegetative stages decreased with decreasing levels of phosphorus application. Genotypic variation was also found in different wheat genotypes for stem dry weight at different P level. Overall LOK-1, WH-1021, NW-2030 and C-306 showed significant difference in retaining shoot dry weight at different level of phosphorus. Minimum % reduction of stem dry weight was noted in WH-1022 (32.26) and highest was observed in WH-1025 (84.41).

Root dry weight (g/plant)

Root dry weight also decreased with decreasing level of P application. Minimum dry weight of root was noted in 20% P (0.549) as compared to 100% P (1.164 g/plant) in all ten wheat genotypes. Overall LOK-1, WH-1021 and NW-2030 showed significant difference in retaining root dry weight at different phosphorus levels. Minimum per cent of reduction in root dry weight was noted in PBW-343 (5.52) and maximum was in LOK-1 (74.93).

Dry weight of root, stem and root at anthesis stage:

Dry weight leaf: Overall dry weight of leaf decreased with decreasing level of phosphorus in all ten wheat genotypes (Table 11).

Overall Raj-4083, WH-1022, NW-2030 and WH-1025 were found to be significantly superior in retaining leaf dry weight at different P levels (100% P, 50% P and 20% P). There was less per cent reduction of leaf dry weight in WH-1022 (12.25) and highest was observed in PBW-550 (67.06).

Stem dry weight (g/plant)

Dry weight of stem decreased with decreasing levels of phosphorus in the ten wheat genotypes. In shoot dry matter genotypes Raj-4083, WH-1022, LOK-1, NW-2030, C-306 and WH-1025 was to be found to be significantly superior in retaining shoot dry weight at different P level. Less per cent of reduction of shoot dry weight was noted in WH-1022 (17.44) and highest was observed in PBW-343 (75.38).

Table 10: Effect of different levels of phosphorus application on dry weight (g) in different plant parts of wheat at vegetative stage

Sampling															
Leaf						Stem					Root				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	1.070	0.545	0.345	0.653	67.76	0.840	0.280	0.180	0.433	78.6	0.915	0.880	0.425	0.740	53.55
RAJ-4083	1.170	0.780	0.460	0.803	60.68	0.775	0.515	0.190	0.493	75.48	0.875	0.665	0.535	0.692	38.86
WH-1022	0.760	0.685	0.660	0.702	13.16	0.465	0.320	0.315	0.367	32.26	0.750	0.650	0.605	0.668	19.33
LOK-1	1.365	0.541	0.435	0.780	68.13	1.005	0.640	0.250	0.632	75.12	1.895	1.230	0.475	1.200	74.93
WH-1021	0.950	0.865	0.365	0.727	61.58	0.865	0.595	0.170	0.543	80.35	2.150	1.075	0.730	1.318	66.05
NW-2030	1.165	0.880	0.300	0.782	74.25	0.850	0.635	0.150	0.545	82.35	1.255	1.245	0.445	0.982	64.54
C-306	1.385	0.870	0.340	0.865	75.45	0.780	0.615	0.135	0.510	82.69	1.155	1.115	0.625	0.965	45.89
WH-1025	1.290	0.690	0.315	0.765	75.58	0.930	0.405	0.145	0.493	84.41	0.885	0.590	0.345	0.607	61.02
PBW-343	1.215	0.615	0.410	0.747	66.26	0.655	0.380	0.165	0.400	74.81	0.905	0.890	0.855	0.883	5.52
PBW-550	1.000	0.475	0.470	0.648	53.00	0.640	0.350	0.145	0.378	77.34	0.855	0.445	0.445	0.582	47.95
MEAN	1.137	0.695	0.410	0.747		0.781	0.474	0.184	0.479		1.164	0.879	0.549	0.864	

CD at 5%

Variety

Phosphorus Treatment

Variety X Phosphorus Treatment

N.S

0.080

0.251

CD at 5%

Variety

Phosphorus Treatment

Variety X Phosphorus Treatment

0.025

CD at 5%

Variety

0.014 Phosphorus Treatment

0.043 Variety X Phosphorus Treatment

0.022

0.040

0.069

Table11: Effect of different levels of phosphorus application on dry weight (g) in different plant parts of wheat varieties at anthesis stage

Sampling															
Leaf						Stem					Root				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	2.155	1.175	1.095	1.475	49.19	9.755	3.905	3.500	5.720	64.12	1.600	1.360	0.820	1.260	48.75
RAJ-4083	2.245	2.075	1.660	1.993*	26.06	7.430	6.405	5.135	6.323*	30.89	2.275	2.130	0.720	1.708*	68.35
WH-1022	2.530	2.405	2.220	2.385*	12.25	7.195	6.425	5.940	6.520*	17.44	2.235	1.315	0.715	1.422	68.01
LOK-1	2.095	1.900	1.170	1.722	44.15	7.780	7.210	4.190	6.393*	46.14	1.875	1.390	1.120	1.462	40.27
WH-1021	2.350	1.325	0.785	1.487	66.60	5.640	4.330	1.675	3.882	70.30	1.270	1.190	0.835	1.098	34.25
NW-2030	2.055	1.980	1.600	1.878*	22.14	8.650	6.895	4.610	6.718*	46.71	1.895	1.660	0.970	1.508	48.81
C-306	1.620	1.450	1.090	1.387	32.72	10.39	8.24	3.225	7.285*	68.96	1.805	0.900	0.705	1.137	60.94
WH-1025	3.065	2.240	1.495	2.267*	51.22	10.700	6.690	3.405	6.932*	68.18	1.585	1.565	1.235	1.462	22.08
PBW-343	2.070	1.480	0.860	1.470	58.45	7.615	4.945	1.875	4.812	75.38	3.440	1.990	0.840	2.090*	75.58
PBW-550	1.715	0.680	0.565	0.987	67.06	5.375	2.680	1.835	3.297	65.86	2.450	1.780	0.340	1.523*	86.12
MEAN	2.190	1.671	1.254	1.705		8.053	5.773	3.539	5.788		2.043	1.528	0.830	1.467	

CD at 5%

Variety 0.040
Phosphorus Treatment 0.022
Variety X Phosphorus Treatment 0.069

CD at 5%

Variety 0.053
Phosphorus Treatment
Variety X Phosphorus Treatment

CD at 5%

Variety 0.047
Phosphorus Treatment 0.029
Variety X Phosphorus Treatment 0.082

Dry weight of root (g/plant)

Dry weight of root of ten wheat genotypes decreased with levels of P 20% as compared to 100% P level. Maximum mean dry weight of root was observed at 100 % P (2.155 g/plant) and minimum was noted in 20% P (1.095 g/plant). Overall Raj-4083, PBW-343 and PBW-550 were found to be significantly superior in retaining root dry weight at different P levels. Less per cent reduction of root dry weight was found in WH-1025 (22.08) and highest was in PBW-550 (86.12).

Dry weight of root, shoot, and leaf at maturity

Dry weight of leaf (g/plant) Overall leaf dry weight of ten wheat genotypes decreased with decreasing level of P application (Table 12). Maximum mean leaf dry weight was observed at 100% P level (2.315 g/plant) and minimum was noted in 20% P level (1.150 g/plant). WH-1025 and PBW-343 were significantly superior in retaining leaf dry weight at different P levels. Lowest % reduction in leaf dry weight found in C-306 (18.26) and highest was noted in WH-1021 (62.64).

Dry weight of stem (g/plant): Dry weight of stem in different genotypes of wheat at harvest stage decreased with decreasing level of P (20%). Maximum mean dry weight was found at 100% P level (7.465 g) and minimum was noted in 20% P (3.20 g). Overall WH-1025 and PBW-343 were significantly superior in retaining stem dry weight at different P level. Less per cent reduction of shoot dry weight was observed in Raj-4083 (10.54) and highest was noted in PBW-550 (63.43).

Dry weight of root (g/plant): Dry weight of root of ten wheat genotypes decreased with decreasing level of P application. Minimum mean dry weight was found at 20% P (0.495 g/plant) and maximum was noted in 100% P (1.789 g/plant) Overall WH-1025, PBW-343 and PBW-550 were significantly superiority in retaining root dry weight at different levels of phosphorus application Less per cent reduction was observed in PBW-343 (14.81) and highest was noted in WH-1025 (74.03).

Plant height (cm)

Plant height of ten wheat genotypes decreased with decreasing level of P (20% P) (Table 14). Overall maximum plant height was found at 100% P (72.3 cm) as compared to 20% P (62.3 cm) in ten genotypes. C-306 was found significantly superior in retaining plant height at different P level. Minimum per cent reduction of plant height was found in WH-1022 (2.8 cm) and highest was noted in WH-1021 (28.8 cm).

Table12: Effect of different levels of phosphorus application on dry weight (g) in different plant parts of wheat varieties at maturity

Sampling															
Leaf						Stem					Root				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	2.315	1.465	1.150	1.643	50.32	7.465	5.250	3.200	5.305	57.13	1.345	0.675	0.495	0.838	63.20
RAJ-4083	2.650	2.155	1.835	2.213	30.75	5.170	4.945	4.625	4.913	10.54	1.630	1.230	0.800	1.220	50.92
WH-1022	2.520	1.840	1.595	1.985	36.71	5.685	5.180	4.345	5.070	23.57	0.950	0.770	0.650	0.790	31.58
LOK-1	2.280	2.210	1.340	1.943	41.23	7.830	5.185	3.330	5.448	57.47	1.515	1.010	0.640	1.055	57.76
WH-1021	3.065	1.715	1.145	1.975	62.64	7.830	5.275	3.490	5.532	55.43	1.995	0.945	0.930	1.290	53.38
NW-2030	2.360	1.840	1.145	1.782	51.48	7.665	4.870	3.150	5.228	58.90	1.645	1.305	0.700	1.217	57.45
C-306	2.300	2.000	1.880	2.060	18.26	6.030	5.490	5.285	5.602	12.35	1.380	0.865	0.445	0.897	67.75
WH-1025	4.260	3.565	1.825	3.217*	57.16	10.765	9.125	4.255	8.048*	60.47	2.830	1.880	0.735	1.815	74.03
PBW-343	3.330	2.540	1.980	2.617*	40.54	8.690	5.945	4.300	6.312*	50.52	2.735	2.585	2.330	2.550	14.81
PBW-550	3.045	1.730	1.670	2.148	45.16	8.750	4.375	3.200	5.442	63.43	1.860	1.220	1.080	1.387	41.94
MEAN	2.813	2.106	1.557	2.158		7.588	5.564	3.918	5.690		1.789	1.249	0.881	1.306	

CD at 5%

Variety 0.070
Phosphorus Treatment 0.038
Variety X Phosphorus Treatment 0.122

CD at 5%

Variety 0.067
Phosphorus Treatment
Variety X Phosphorus Treatment

CD at 5%

Variety 0.044
Phosphorus Treatment 0.037
Variety X Phosphorus Treatment 0.024
0.177 0.076

Table13: Effect of different levels of phosphorus application on spike dry weight(g) in wheat varieties

Spike dry weight (gm)					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	4.09	2.00	1.90	2.66	53.55
RAJ-4083	3.45	3.26	2.14	2.95*	37.97
WH-1022	3.26	2.76	2.31	2.78	29.14
LOK-1	3.81	3.79	1.72	3.11*	54.86
WH-1021	4.10	2.62	1.93	2.88	52.93
NW-2030	3.62	3.06	2.01	2.90	44.48
C-306	3.98	3.08	1.27	2.78	68.09
WH-1025	4.09	2.46	1.22	2.59	70.17
PBW-343	3.67	2.10	1.06	2.28	71.12
PBW-550	2.96	1.23	1.11	1.77	62.50
MEAN	3.71	2.63	1.67	2.67	

CD at 5%

Variety 0.29

Phosphorus Treatment 0.16

Variety X Phosphorus Treatment 0.50

Productive tiller/plant

Data related to productive tillers/plant presented in Table 15 revealed that: Productive tiller of different genotypes decreased with decreasing level of P application. Maximum no. of productive tillers was observed at 100% P level (3.5) followed by 50% P and 20% P application respectively 2.0 and 1.5. LOK-1 and WH-1025 were found to be significantly superior in retaining productive tiller at different levels of phosphorus.

Minimum % of reduction of productive tiller was noted in WH-147 (22.7) and maximum % of reduction was observed in WH-1021 (50.0), C-306 (50.6), PBW-550 (50.0), PBW-343 (50.0) at different levels of phosphorus application.

Plant Biomass (g/plant)

Total plant biomass of different wheat genotypes decreased with decreasing phosphorus level (Table 16). Lowest plant biomass was observed at 20% P and highest was noted at 100% P levels in all different wheat varieties.

Raj-4083, WH-1025, WH-1022 and NW-2030 were found significantly superior in retaining plant biomass at different phosphorus levels. There was less % of reduction in plant biomass in Raj-4083 (33.1%) and highest was noted in WH-1021 (72.1%) at different P application.

Table 14: Effect of different levels of phosphorus application on plant height (cm) in wheat varieties at maturity

Plant height					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	67.2	57.2	56.2	60.2	16.4
RAJ-4083	70.2	64.5	64.1	66.3	8.7
WH-1022	71.2	70.7	69.2	70.4	2.8
LOK-1	66.7	61.0	53.7	60.5	19.5
WH-1021	81.5	66.0	58.0	68.5	28.8
NW-2030	71.5	70.5	69.0	70.3	3.5
C-306	94.7	84.5	70.5	83.2*	16.6
WH-1025	78.2	68.5	65.5	70.7	16.2
PBW-343	73.5	64.5	62.2	66.7	15.4
PBW-550	58.5	57.5	54.2	56.7	7.4
MEAN	72.3	67.5	62.3	67.4	

CD at 5%

Variety 6.6

Phosphorus Treatment 3.6

Variety X Phosphorus Treatment 11.5

Table15: Effect of different levels of phosphorus application on productive tiller in wheat varieties at maturity

Productive tiller					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	2.2	2.0	1.7	2.0	22.7
RAJ-4083	2.2	2.0	1.5	1.9	31.8
WH-1022	2.5	2.0	1.5	2.0	40.0
LOK-1	3.5	2.7	2.2	2.8*	37.1
WH-1021	2.0	1.2	1.0	1.4	50.0
NW-2030	2.0	1.7	1.5	1.7	25.0
C-306	3.0	2.7	1.5	2.4	50.0
WH-1025	3.2	2.5	2.2	2.6*	31.3
PBW-343	2.0	1.5	1.0	1.5	50.0
PBW-550	2.0	1.5	1.0	1.5	50.0
MEAN	2.5	2.0	1.5	2.0	

CD at 5%

Variety 0.4

Phosphorus Treatment 0.2

Variety X Phosphorus Treatment 0.8

Spike length (cm)

Result presented in Table 17 show that spike length of different wheat genotypes was maximum at 100% P (9.07 cm) and minimum was noted in 20% P level (6.6 cm). Different wheat varieties showed differential behaviour at different level of P. WH-1022 and WH-1025 was found significantly superior in retaining spike length at different phosphorus levels. Less % of reduction of spike length was observed in NW-2030 (9.4 cm) and highest was noted PBW-550 (35.0 cm) at different levels of phosphorus.

Dry weight of spike (g/plant)

Dry weight of spikes of wheat varieties decreased with decreasing level of phosphorus application. Spike dry weight of different wheat genotypes was minimum at 20% P level. Maximum mean dry weight was observed at 100% P level. RAJ-4083, LOK-1 was found significantly superior in retaining spike dry matter as compared to other varieties at different P level. Less per cent of reduction was observed in WH-1022 (29.14) and highest was in PBW-343 (71.12).

Total grain yield

Total grain yield of different wheat genotypes at different level of phosphorus decreased with decreasing level of P application (Table 18). Overall maximum total grain yield was observed at 100% P (10.28 g/plant), followed by 50% P (7.43 g/plant) and 20% P (5.28 g/plant) P levels. Raj-4083, WH-1022, NW-2030 and PBW-550 was found significantly superior in retaining total grain yield at different P level. Less % of reduction in total grain yield was observed in WH-147 (14.83 g/plant) and highest was in WH-1025 (74.27 g/plant) and PBW-343 (74.40 g/plant).

Test weight (g/plant)

Test weight of different wheat genotypes decreased with decreasing level of P. LOK-1 was found to be significantly superior in retaining test weight at 100%, 50% and 20% P level respectively as compared to other genotypes (Table 19). There was less % reduction in Raj-4083 (3.19 g/plant) and highest % reduction was in WH-1025 (40.60 g/plant).

Grain protein content

A decrease in grain protein content was observed at 20% P and 50% P as compared to 100% P level in all ten wheat genotypes (Fig. 1). However less decrease in protein content was observed WH-1021 and WH-1022 at in 20% and 50% P level. Highest protein content was found in PBW-550 at 100% P level.

Table 16: Effect of different levels of phosphorus application on total plant biomass in wheat varieties

Plant biomass					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	31.2	15.2	14.7	20.4	53.0
RAJ-4083	25.8	23.9	17.3	22.3*	33.1
WH-1022	28.8	24.4	18.6	23.9*	35.4
LOK-1	27.3	22.6	15.0	21.7	45.1
WH-1021	29.9	14.1	8.3	17.4	72.1
NW-2030	29.4	26.9	15.3	23.9*	48.0
C-306	23.7	22.8	12.6	19.7	46.7
WH-1025	34.2	23.4	11.6	23.0*	66.2
PBW-343	28.9	18.4	8.8	18.7	69.5
PBW-550	24.1	10.7	8.4	14.4	65.0
MEAN	28.3	20.2	13.1	20.5	

CD at 5%

Variety

2.17

Phosphorus Treatment

1.19

Variety X Phosphorus Treatment

3.77

Table17: Effect of different levels of phosphorus application on spike length (cm) in wheat varieties at maturity

Spike length					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	8.3	6.8	6.0	7.0	27.7
RAJ-4083	8.7	8.0	7.8	8.2	10.3
WH-1022	10.2	9.2	8.7	9.4*	14.7
LOK-1	8.0	7.7	5.8	7.2	27.5
WH-1021	11.1	6.7	6.0	7.9	45.9
NW-2030	8.5	8.3	7.7	8.2	9.4
C-306	8.7	8.2	6.0	7.6	31.0
WH-1025	10.1	9.2	6.8	8.7*	32.7
PBW-343	9.1	7.8	6.0	7.6	34.1
PBW-550	8.0	7.3	5.2	6.8	35.0
MEAN	9.07	7.92	6.6	7.9	

CD at 5%

Variety

0.7

Phosphorus Treatment

0.4

Variety X Phosphorus Treatment

1.2

Table18: Effect of different levels of phosphorus application on total grain yield in wheat varieties

Total grain yield					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	6.00	5.75	5.11	5.62	14.83
RAJ-4083	10.78	9.83	6.80	9.13*	36.92
WH-1022	9.20	8.62	7.36	8.39*	20.00
LOK-1	8.05	7.23	5.35	6.87	33.54
WH-1021	13.04	5.38	3.52	7.31	73.01
NW-2030	11.55	7.48	6.69	8.57*	42.08
C-306	9.34	6.01	3.36	6.23	64.03
WH-1025	12.98	8.60	3.34	8.31*	74.27
PBW-343	12.58	7.30	3.22	7.70	74.40
PBW-550	9.28	8.75	7.42	8.48*	20.04
MEAN	10.28	7.43	5.28	7.66	

CD at 5%

Variety 0.69

Phosphorus Treatment 0.38

Variety X Phosphorus Treatment 1.20

Table19: Effect of different levels of phosphorus application on test weight in wheat varieties

Test weight					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	3.90	3.50	3.25	3.55	16.67
RAJ-4083	3.45	3.43	3.34	3.41	3.19
WH-1022	4.48	4.04	3.69	4.07	17.63
LOK-1	5.05	4.51	4.46	4.67*	11.68
WH-1021	3.95	3.90	3.45	3.77	12.66
NW-2030	4.01	3.69	3.52	3.74	12.22
C-306	3.90	3.39	2.76	3.35	29.23
WH-1025	4.36	3.56	2.59	3.50	40.60
PBW-343	4.00	3.80	3.40	3.73	15.00
PBW-550	3.95	3.99	3.54	3.83	10.38
MEAN	4.11	3.78	3.40	3.76	

CD at 5%

Variety 0.55

Phosphorus Treatment 0.30

Variety X Phosphorus Treatment N.S.

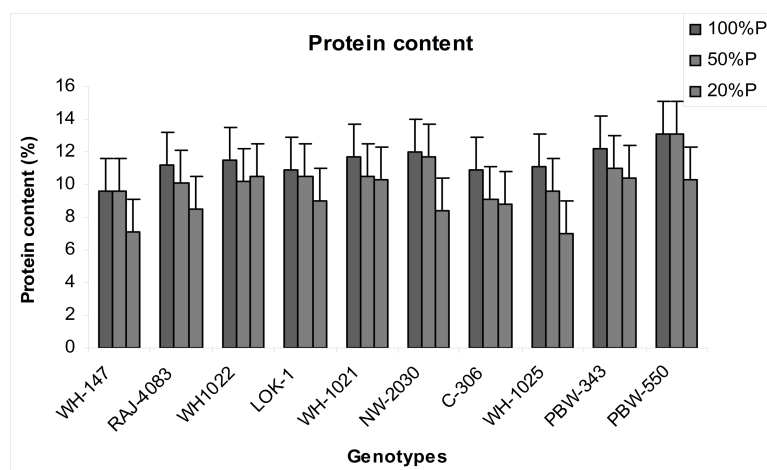


Fig. 1: Effect of different levels of phosphorus application on grain protein content in wheat varieties

Starch

Starch content decreased with decreasing level of Phosphorus (20% P) application as compared to 100% P (Fig. 2). Maximum reduction of starch content was in found WH-147, WH-1022 and WH-1021 at 20% P level. Among the ten wheat genotypes, highest starch content was noted in Raj-4083.

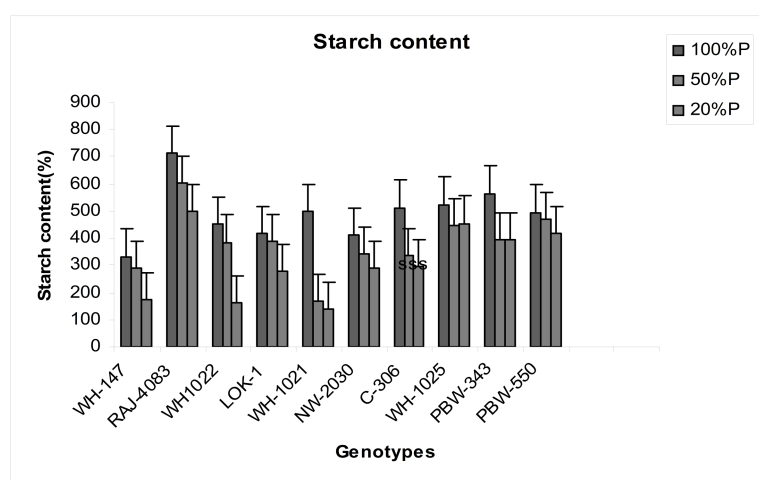


Fig. 2: Effect of different levels of phosphorus application on grain starch content in wheat varieties .

Ash content

Equal reduction was observed at 20% and 50% P level as compared to 100% P level in wheat genotypes WH-1022 (Fig. 3). Among ten wheat genotypes NW-2030 showed the highest ash content.

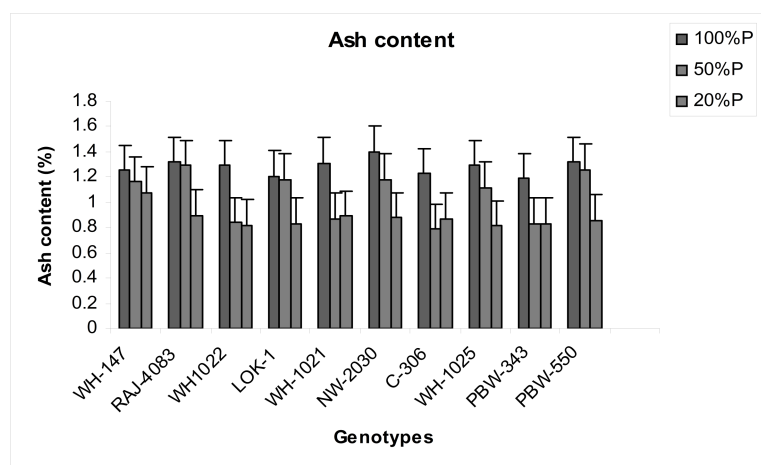


Fig. 3: Effect of different levels of phosphorus application on grain ash content in wheat varieties .

Moisture content

Overall equal reduction in moisture content at 20% P and 50% P level as compared to 100% P in all ten wheat genotypes was observed (Fig. 4). No change in moisture content was observed in WH 147 at three levels of P (20%, 50% and 100%).

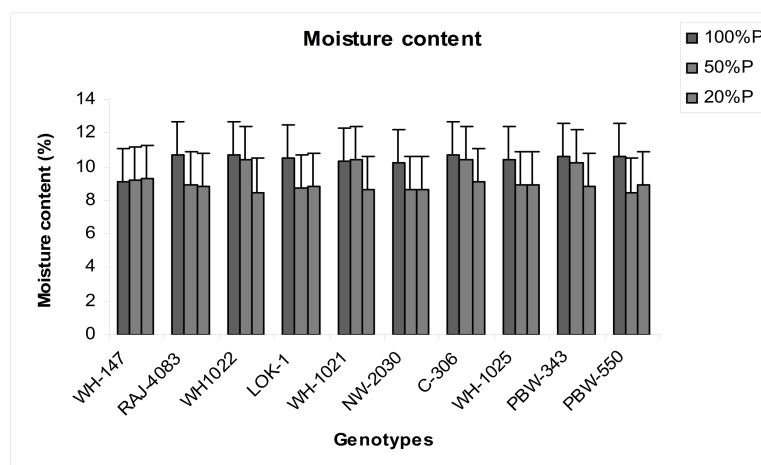


Fig. 4: Effect of different levels of phosphorus application on grain moisture content in wheat varieties.

Total phosphorus content of leaf (mg/g)

Total phosphorus content of leaf of different wheat varieties decreased with decreasing levels of phosphorus application (Table 20). Overall wheat varieties showed

maximum P content at 100% P (0.037 mg/g) levels as compared to 20% P (0.028 mg/g) level. Among varieties no significant difference was observed in P content at leaf. However, WH-1025 (11.4 mg/g) minimum reduction in total P uptake content was observed and maximum was noted in PBW-343 (48.1 mg/g) at different level of phosphorus.

Table20: Effect of different levels of phosphorus application on phosphorus content (mg/g) in different plant parts of wheat varieties at maturity

Sampling															
Leaf						Shoot					root				
Level of phosphorus															
Varieties	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction	100%	50%	20%	Mean	% reduction
WH-147	0.033	0.026	0.029	0.029	12.1	0.011	0.01	0.01	0.010	9.1	0.016	0.014	0.012	0.014	25.0
RAJ-4083	0.029	0.028	0.021	0.026	27.6	0.012	0.01	0.008	0.010	33.3	0.024	0.027	0.017	0.023	29.2
WH-1022	0.042	0.031	0.033	0.035	21.4	0.012	0.01	0.006	0.009	50.0	0.014	0.014	0.009	0.012	35.7
LOK-1	0.04	0.035	0.035	0.037	12.5	0.013	0.01	0.01	0.011	23.1	0.006	0.008	0.005	0.006	16.7
WH-1021	0.037	0.036	0.03	0.034	18.9	0.011	0.009	0.009	0.010	18.2	0.023	0.013	0.012	0.016	47.8
NW-2030	0.039	0.033	0.024	0.032	38.5	0.011	0.01	0.007	0.009	36.4	0.034	0.024	0.026	0.028	23.5
C-306	0.034	0.029	0.027	0.030	20.6	0.013	0.009	0.011	0.011	15.4	0.038	0.035	0.029	0.034*	23.7
WH-1025	0.035	0.033	0.031	0.033	11.4	0.016	0.013	0.012	0.013	0.25	0.061	0.036	0.024	0.040*	60.7
PBW-343	0.052	0.039	0.027	0.039	48.1	0.012	0.014	0.01	0.012	16.7	0.034	0.017	0.012	0.021	64.7
PBW-550	0.03	0.029	0.024	0.028	20.0	0.012	0.012	0.011	0.012	8.3	0.038	0.029	0.027	0.031	28.9
MEAN	0.037	0.032	0.028	0.032		0.012	0.011	0.009	0.011		0.029	0.022	0.017	0.023	

CD at 5%

Variety

Phosphorus Treatment

Variety X Phosphorus Treatment

N.S

N.S

N.S

CD at 5%

Variety

Phosphorus Treatment

Variety X Phosphorus Treatment

N.S

N.S

N.S

CD at 5%

Variety

Phosphorus Treatment

Variety X Phosphorus Treatment

0.015

N.S

N.S

Total phosphorus content of stem (mg/g)

Phosphorus content in shoot decreased with decreasing levels of phosphorus in all genotypes (Table 21). No significant difference in phosphorus in stem was observed in all genotypes at different level of phosphorus. Minimum % of reduction was found in WH-1025 (0.0 mg/g) and maximum was noted in WH-1022 (50.0 mg/g).

Phosphorus content of root (mg/g)

Total phosphorus content of root of different wheat varieties decreased with decreasing levels of phosphorus application (Table 20).

Maximum phosphorus content was observed at 100% P level (0.02 g mg/g) followed by 50% and 20% P application. C-306 and WH-1025 showed significant difference in root P content as compared to other wheat varieties. Minimum reduction in phosphorus content was found in LOK-1 (16.7 mg/g) and maximum was noted in PBW-343 (64.7 mg/g).

Experiment II**Root length (cm)**

Root length of ten wheat seedlings increased with decreasing level of phosphorus application (Table 21). Mean maximum root length was found at 20%P (20.3 cm) followed by 50% P (19.0 cm) and 100% P (17.1 cm). Overall Raj-4083, NW-2030 and C-306 were found significantly superior in retaining root length at different level of phosphorus. Minimum % increase in root length was in WH-1025 (4.4 cm) and maximum % increase was noted in Raj.-4083 (285 cm).

Shoot length (cm)

Shoot length of ten wheat seedling decrease with decreasing level of phosphorus (Table 22). Mean maximum shoot length was observed with 100% P (16.0 cm) followed by 50% P (15.2 cm) and 20% P (14.8 cm) overall WH-147, LOK-1 and C-306 was found significantly superior in retaining shoot length at 7 days after germination at different level of P. Minimum % of reduction in shoot length was observed in WH-147 (2.4 cm) followed by PBW-556 (2.7 cm) and maximum was noted in Raj-4083 (17.9 cm).

Table 21: Effect of different levels of phosphorus application on root length (cm) in wheat varieties 7 days after germination

Root length					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% increase
WH-147	15.8	18.9	21.1	18.6	25.1
RAJ-4083	17.3	22.2	24.2	21.2	28.5
WH-1022	19.2	19.8	21.4	20.1	10.3
LOK-1	13.8	14.7	14.8	14.4	6.8
WH-1021	14.4	16.9	17.3	16.2	16.8
NW-2030	20.2	23.2	23.9	22.4	15.5
C-306	19.9	23.1	24.4	22.5	18.4
WH-1025	15.1	15.6	15.8	15.5	4.4
PBW-343	16.8	18.9	20.5	18.7	18.0
PBW-550	18.4	19.7	19.9	19.3	7.5
MEAN	17.1	19.0	20.3	20.3	

CD at 5%

Variety

1.6

Phosphorus Treatment

N.S.

Variety X Phosphorus Treatment

2.9

Table22: Effect of different levels of phosphorus application on shoot length (cm) in wheat varieties 7 days after germination

Shoot length					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% reduction
WH-147	16.4	16.0	16.0	16.1	2.4
RAJ-4083	16.8	14.6	13.8	15.1	17.9
WH-1022	15.3	14.9	14.4	14.9	5.9
LOK-1	18.5	17.5	17.5	17.8*	5.4
WH-1021	16.6	15.7	14.6	15.6	12.0
NW-2030	14.4	13.5	13.5	13.8	6.3
C-306	17.5	16.2	15.8	16.5*	9.7
WH-1025	13.8	13.2	13.1	13.4	5.1
PBW-343	16.0	15.4	14.6	15.3	8.8
PBW-550	14.6	14.5	14.2	14.4	2.7
MEAN	16.0	15.2	14.8	15.3	

CD at 5%

Variety

0.9

Phosphorus Treatment

N.S.

Variety X Phosphorus Treatment

N.S.

Root/shoot dry weight ratio

Root-shoot dry weight ratio of ten wheat varieties increased with decreasing levels of phosphorus (Table 23). Mean root/shoot dry weight ratio was found maximum at 20% P level (0.97) followed by 50% P (0.84) and 100% P level (0.68) respectively. Different wheat varieties showed differential behaviour for root/shoot dry weight ratio. Overall WH-1022 was found significant at different level of phosphorus. Minimum % increase in root/shoot dry weight ratio was observed in WH-1022 (9.6) and maximum was noted in PBW-343 (57.3).

Table 23: Effect of different levels of phosphorus application on root/shoot dry weight ratio of different varieties of wheat 7 days after germination

Root/ shoot dry weight ratio (g)					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% increase
WH-147	0.58	0.62	0.70	0.63	17.1
RAJ-4083	0.77	0.88	0.91	0.85	15.4
WH-1022	1.03	1.05	1.14	1.07*	9.6
LOK-1	0.54	0.65	1.00	0.73	46.0
WH-1021	0.63	0.79	0.89	0.77	29.2
NW-2030	0.67	0.77	1.03	0.82	35.0
C-306	0.90	1.01	1.03	0.98	12.6
WH-1025	0.65	0.80	0.89	0.78	27.0
PBW-343	0.50	0.93	1.17	0.87	57.3
PBW-550	0.56	0.92	0.97	0.82	42.3
MEAN	0.68	0.84	0.97	0.83	

CD at 5%

Variety 0.18

Phosphorus Treatment N.S.

Variety X Phosphorus Treatment 0.31

No. of secondary lateral roots

Number of secondary lateral roots of ten wheat genotypes increased with decreasing level of phosphorus application (Table 24). Maximum no. of secondary lateral root hairs were recorded at 20% P (26.9) which decreased to 18.9 with 100% P application. Overall WH-1022 and PBW-550 was found to be significantly superior in retaining sec. lateral roots at different levels of phosphorus. Minimum % increase in secondary lateral roots was observed in PBW-343 (9.7) and maximum was noted in NW-2030 (57.7).

Table 24: Effect of different levels of phosphorus application on secondary lateral roots in wheat varieties 7 days after germination

Secondary lateral roots					
Level of Phosphorus					
Varieties	100%	50%	20%	Mean	% increase
WH-147	9.7	14.8	14.9	13.1	34.9
RAJ-4083	15.9	18.8	24.3	19.7	34.6
WH-1022	28.5	31.0	33.5	31.0*	14.9
LOK-1	13.5	28.6	31.3	24.5	56.8
WH-1021	12.9	14.3	18.9	15.3	31.8
NW-2030	12.9	20.5	30.5	21.3	57.7
C-306	22.0	24.4	28.3	24.9	22.1
WH-1025	22.4	23.1	28.2	24.6	20.7
PBW-343	24.5	26.2	27.1	25.9	9.7
PBW-550	26.8	28.5	32.0	29.1*	16.3
MEAN	18.9	23.0	26.9	22.9	

CD at 5%

Variety

6.3

Phosphorus Treatment

N.S.

Variety X Phosphorus Treatment

N.S.

Acid phosphatase activity

Acid phosphatase activity increased with decreasing levels of phosphorus (Fig. 5) in different wheat genotypes. 20% P treatment had the highest acid phosphatase activity followed by 50% P and 100% P application.

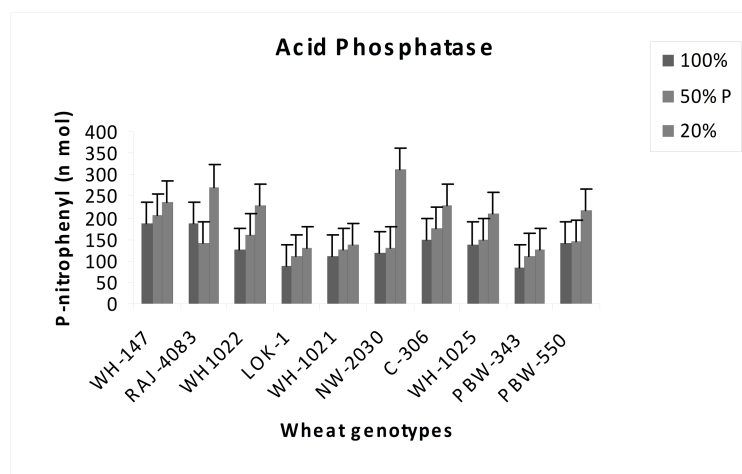


Fig. 5: Effect of different levels of phosphorus application on acid phosphatase activity in wheat genotypes at 7 days after germination

Among the ten genotypes, NW-2030 had maximum acid phosphatase activity at 20% P level and minimum activity was observed in LOK-1, WH-1021, NW-2030 and PBW-343 at 100% P level.

Alkaline phosphatase activity

Alkaline Phosphatase activity increased with decreasing level of P in different wheat genotypes (Fig 6). NW-2030 showed the highest activity of alkaline phosphatase at 20% P level as compared to other genotypes. Lowest activity of alkaline phosphatase was observed in LOK-1 and PBW-343 at 100% P level.

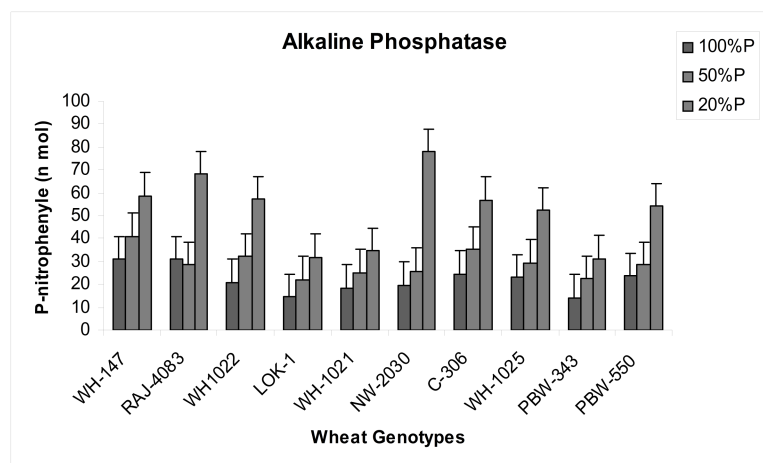


Fig. 6: Effect of different levels of phosphorus application on alkaline phosphatase activity in wheat genotypes at 7 days after germination

CHAPTER-V

DISCUSSIONS

Phosphorus (P) is an essential inorganic nutrient for plant growth and often limits primary productivity in natural system as well as cropping system, unless supplied as fertilizer (Vance *et al.* 2003). P is one of the least available mineral elements in the soils and frequently limits plant growth because P made complexes with calcium in alkaline, aluminum and iron in acidic soils. Due to its chemical fixation in soil and low solubility only 10-25% of applied Phosphate is used by the crops during the season.

Winter wheat is one of the cereals which have the highest requirement of P. Significant differences were observed in wheat varieties with respect to P uptake and use efficiency (Gill *et al.* 2004). Sheokand *et al.* (2009) reviewed the genotypic variation in legumes for nutrient stress and also reported genotypic differences in nutrient use efficiency are linked with root nutrient acquisition capacity or with utilization by plant or both. Pi acquisition efficient genotypes of beans possess highly branched root system (Lynch and Beebe, 1995). Larger root systems provide greater root soil contact which is particularly important for less mobile ion like P. A considerable intraspecific variation in root hair formation has been found among genotypes of white clover (Caradus, 1979), common bean (Yan *et al.* 2001) and cowpea (Krasilnikott *et al.* 2001).

Wheat exhibits a remarkable plasticity in root growth, adjusting to the soil nutrient and water status (Vlek *et al.* 1996). Under P deficiency, P efficient wheat varieties tend to enhance their root growth (Romer *et al.* 1988). With more root length per unit above ground biomass, the wheat plants are able to access more P resources in the soil and improve P uptake. Improved P- uptake efficiency is particularly important for farmers with limited resources, such as those in developing countries, where manufactured P fertilizer is prohibitively expensive and supply restricted (Lajtha and Harrison 1995, Sanchez *et al.* 1997). Wheat genotypes with higher root length density are able to take up more phosphorus. The difference in P uptake among species or cultivars will hopefully help to reduce costs of P fertilization and enhance plant productivity with more P efficient plant. The main strategy for P acquisition used by plants consists of maximal and continued soil exploration through proliferation and extension of all root types with preference for those roots that are metabolically efficient and acquire P avidly (Lynch and Ho, 2005).

Therefore, the present investigations was undertaken with the view; To identify the wheat genotypes efficient in phosphorus uptake and utilization, the effect of phosphorus doses

on quality parameters of wheat grains and identify the root morpho-physiological traits associated with efficient phosphorus uptake. Studies were carried out on wheat genotypes WH-147, Raj 4083 WH-1022, LOK-1, WH-1021, NW-2030, C-306, WH-1025, PBW-343 and PBW-550. Phosphorus was applied as 20% P, 50%P and 100% P of the recommended dose. The observations recorded are discussed under the following sections.

EXP 1

1. Growth and Phenology

In P efficient crop genotypes lower proportion of total P are retained in roots and stems and higher proportion translocated to leaves compared to the non efficient genotypes.

Root dry weight

Increase in root dry matter was possibly due to stimulation effect of P deficiency on root growth under P stress condition. Dry weight of root (Table 10,11 and 12) decreased with decreasing levels of P application in ten wheat genotypes at all the sampling stage i.e. 100 DAS, 110 and 120 days after sowing. Highest % reduction of root dry weight at vegetative stage was observed in LOK-1 and lowest was in PBW -343, the highest % reduction was noted in PBW-550 and lowest was in WH-1025 at anthesis. Similarly highest % of reduction was in WH-1025 and lowest was in PBW-343 at maturity. Root dry matter increased at 100% P level because P increased various metabolic activities inside the plant and thus more dry matter was produced. These results are in conformation with the results of Oshan *et al.* (2002) reported that in native texas legume shoot dry matter yield and root dry matter weight with increase P application level up to 80 kg P ha⁻¹. Dry weight of wheat genotypes LOK-1, WH-1021 and NW-2030 was maximum at different level of phosphorus.

Dry weight of stem

Shoot dry matter production and total amount of P per shoot at low P treatment are the most reliable parameters in assessing wheat genotypes for their P efficiency at vegetative stage. P taken up by plants is used efficiently at the cellular level to contribute to better shoot growth at low supply (Ozturk *et al.* 2005) Genotypes that produce a lot of dry matter in a soil at a low P level and respond well to added P are generally the most desirable because they are able to express their high yield potential in a wide range of environment (Fageria and Da costa, 2000). Shoot dry weight were reduced by 19% and 50% respectively when rice genotypes grown in P deficiency and P sufficient condition (Manske *et al.* (2000). In the present investigation data on shoot dry weight of ten wheat genotypes (Table 10, 11 and 12) indicated a reduction of shoot dry weight with decreasing level of phosphorus application at all sampling stage i.e. 100 DAS, 110 and 120 days after sowing. LOK-1, WH-1021, NW-2030 and C-306 showed better performance at different levels of P. The shoot P content

in Pigeon pea genotypes is significantly correlated with shoot dry weight at low and medium P levels, but not at high P level in soil. Some of the genotypes efficient in P acquisition invested more in root development so that they could have better absorptive surface.

Physiological and Biochemical attributes

Phosphorus is one of key component in ATP, phospholipids and nucleic acids. P is involved in root development and in metabolic activities especially in synthesis of proteins (Tanwar & Shaktawat 2003).

Chlorophyll fluorescence: Chlorophyll fluorescence indirectly measures photosynthetic efficiency. It was reported that there was linear relationship between CO₂ assimilation efficiency and actual PS-II efficiency derived from chlorophyll fluorescence (Lu and Lu, 2004). Similarly, data presented in the present study indicates that the chlorophyll fluorescence of flag leaf of wheat decreased with decreasing level of phosphorus at 100, 110 and 120 DAS in all ten wheat genotypes at different level of phosphorus (Table 5). As far as chlorophyll fluorescence is concerned, on 100 and 110 day after sowing there is no significant difference in chlorophyll fluorescence at different level of P. whereas at later stage i.e. 120 days after sowing WH-1022 showed lowest % of reduction and highest was noted in WH-147.

Photosynthetic rate

Higher photosynthetic rate is very important to sustain normal growth of plants when suffering from low P stress (Fu *et al.* 2006). A plant must possess an efficient photosynthetic mechanism to be highly productive biologically. Under P deficiency cell expansion is restricted more than chlorophyll synthesis resulting in more chlorophyll per unit leaf area (Marschner 1995). In the present investigation also the photosynthetic rate decreased with decreasing levels of P application in all ten wheat genotypes at all sampling stages i.e. 100, 110 and 120 DAS (Table 9). As far as photosynthetic rate is concerned on 100 days after sowing, WH -147 and WH-1022 genotypes performed better to maintain photosynthetic rate at different levels of phosphorus. Where at later stage i.e. 110 and 120 days after sowing WH-1020 performed better at different level of P. Genotypic variability in photosynthetic rate has been identified within several crop species (Babu *et al.* 1985 and Mohan, 1990).

Stomatal conductance

Low P content decreased stomatal conductance in rice genotypes, but has no significant influence on leaf internal CO₂ concentration suggesting that the decrease in stomatal conductance did not restrict the diffusion rate of CO₂ (Fu *et al.* 2006). The results presented in (Table 8) also showed the decrease in stomatal conductance with decreasing

level of P at all three sampling stages (i.e. 100, 110 and 120 days after sowing). WH-147, NW-2030 and WH-1022 show significant results at different level of P.

Water use efficiency (WUE)

The results presented in (Table 7) also showed the decrease in water use efficiency with decreasing level of phosphorus (20% P levels) as compared to their respective control (100%). In all 3 samplings (100, 110 and 120 DAS) WH-147 and Raj-4083 showed better water use efficiency at different levels of phosphorus application.

Yield and grain quality

Total grain yield

Grain yield is a complex trait and potential of a given genotypes to produce grains in given environment (Egle *et al.*1999).With increase in P level from 40 kg to 120 kg / ha there was corresponding increase in grain yield but under P- deficient condition markedly reduced grain yield primarily by depressing the number of fertile tillers (Shah *et al.*2006) Similarly, data presented in the present study indicate that the total grain yield of wheat is minimum at 20% P level as compared to 100% P. Grain yield increased with increasing levels of phosphorus (Table 18). Varieties Raj-4083, WH-1022, NW-2030 and PBW-550 were found to be significantly superior for attaining total grain yield at different P levels in term of grain yield.

The application of phosphorus to mungbean has been reported to increase dry matter at harvest, no. of pods/ plants, seed / plant, 1000-grain weight, seed yield and total biomass (Horst *et al.* 1993 and Mitra *et al.* 1999). An increase in number of productive tillers was observed in response to P application at a rate of 60 mg Kg⁻¹ soil (100% P level).Similarly the data presented in Table 14 showed increase in productive tillers from 20% to 100% P. There was a relative decrease in spike length (Table 17), 100 seed weight (Table 19), total plant biomass (table 16) with decreasing levels of phosphorus (20%P) as compared to 100% P level in all the ten wheat genotypes. P deficiency during the first 4-6 weeks of growth causes large reduction in tiller development and head formation of wheat, which can not be recovered even if sufficient P is supplied at a later stage (Gericke 1924, 1925 and Brenchley, 1929).

Protein

Protein constitutes important component of wheat grain governing their quality (Weigels *et al.* 1996). Higher protein levels were achieved at low P condition as a result of the lower yield associated with low P levels (Ortiz-monasterio *et al.* 2002). Phosphorus nutrition directly and indirectly influences wheat grain protein, under controlled condition, P favorably affected plant growth, tillering, kernel number, all of which are important factors in

grain yield and synergistically interacted with grain protein (Porter and Paulsen, 1983). On the contrary, the present investigation indicated the decrease in protein content with decreasing level of phosphorus (fig 1). Less decrease in protein content was observed in WH-1021 and WH-1022 at 20% and 50% P levels. Highest protein content was found in PBW-343 at different levels of phosphorus.

Starch

Starch accumulation in leaves is one of the more consistently observed bio chemical responses. Starch is the predominant carbohydrate reserve in many plants. In rice, low level of phosphorus treatment did not increase the content of starch in shoot and root (Cieszko and Barbachowska, 2000).

The results presented in (fig- 2) also showed the minimum % of starch at low P level (20% P) with respect to 100% P level (60 kg P/ha⁻¹) in ten wheat genotypes. Maximum reduction of starch content was observed in WH-147, WH-1022 and WH-1021 at 20% P level. Overall Raj-4083 shows the maximum starch content at different phosphorus level.

In this study days to heading, anthesis, maturity and grain filling duration got delayed at low P level (20%) as compared to 100% P.

Raj-4083, WH-1022, NW-2030, WH-1025, C-306, PBW-343 and PBW-550 showed significant difference for root, shoot and leaf dry weight at different level of phosphorus during anthesis stage. WH-147 and Raj-4083 was better in maintaining WUE at different P level. Acid and alkaline phosphate activity increased with decrease in the P. Activity of both enzymes was highest in NW-2030. For majority of the yield components the genotypes Raj-4083, WH-147, LOK-1, NW-2030 and PBW-550 performed better at different P levels. Among all these seedling characteristics root length root / shoot dry weight and no. of secondary lateral roots increased at 20% P, but shoot length decreased at 20% P.

Experiment-II

Root length

Root acidification is an important character in P uptake and utilization efficiency (Schenk and Barber, 1979). For certain level of root biomass, root with higher specific root length can cover a larger surface area. Data in (Table 21) revealed that Root length of ten wheat seedling increased with decrease level of phosphorus. Overall genotypes Raj-4083, NW-2030 and C-306 were found significantly superior in maintaining root length at different level of phosphorus application. Highest % increase in root length was observed in Raj-4083 and lowest was noted in WH-1025.

Secondary lateral roots hairs

Secondary lateral roots would be a suitable plant parameter for selecting P-efficient cultivars. The difference in P uptake between the barley cultivars especially in low P soil was due to secondary lateral roots hairs. The variation in P uptake and secondary lateral roots hairs become gradually less when 10 and 20 kg P ha⁻¹ was applied because increasing P level had negative effect on secondary lateral roots hairs formation and at higher P levels the variation in secondary lateral roots hairs decreased (Gahoonia *et al.* 1999). Data in (Table 24) revealed the number of sec. lateral roots of ten wheat genotypes increased with decreasing level of phosphorus. Maximum number of sec. lateral roots was observed at 20% P level as compared to control (100%P) in all wheat genotypes. WH-1022 and PBW-550 performed better to attain more secondary lateral roots hairs at different levels of P. % increase of secondary lateral roots hairs was the highest in NW-2030 and lowest was noted in PBW- 343. Secondary root development by wheat and secondary root development by intermediate wheat grass followed similar patterns to that of tiller development by wheat (Boatwright *et al.* 1966).

Root / Shoot dry weight ratio

At P deficiency condition increase to root / shoot dry weight ratio due to greater stimulation of root growth at the expense of shoot growth (Mollier and Pellerin, 1999, Hermans *et al.* 2006). In common bean also P-efficient genotypes maintained a higher root / shoot dry weight ratio during their growth under P-deficient conditions as compared to P-inefficient genotypes (Nielsen *et al.* 2001) An increase in root to shoot ratio is considered important for tolerance to low nutrient stress (Fujita *et al.* 2004). Similarly data presented in (Table 23) showed root /shoot dry weight ratio of ten wheat varieties increased with decreasing levels of phosphorus. A higher root/ shoot dry weight ratio was observed at 20 % P level as compared to 100% (control). Variety WH-1022 performed better for retaining root/shoot dry weight ratio at different levels of phosphorus. In P efficient pigeon pea genotypes higher root/ shoot ratio was observed (Sheokand *et al.* 2007).

Acid/ Alkaline Phosphates

Soil phosphatases play major role in the mineralization processes of organic P substrates. Under P- deficient condition, plants shows various morphological and biochemical adaptive responses. Phosphatases are adaptive enzyme and their activity increase with hydrolysis of organic P compound which is presented to the plants (Yadav and Tarafdar, 2001). Phosphates catalyze the hydrolysis of organic P to release free ortho- phosphates and provide available form of P per plant. Hydrolyzing and mobilization inorganic P form monoester organic phosphorus (Duff *et al.* 1994). Phosphatase activity increased in P-deficient conditions. Similarly, data presented in the present study indicated that the

activity of acid / alkaline phosphatase increase with decrease level of phosphorus (Fig. 5 and 6) NW-2030 had the highest acid / phosphatase activity at low P (20%). Acid phosphatase differs from alkaline phosphatase by displaying optimum activity below /pH 7.0 and generally having low substrate specificity. It has been frequently reported that the activity of acid phosphatase in plant tissues increased under P-deficient condition (Yadav *et al.* 2001). Increased intracellular and secreted APases can contribute to enhancing P uptake and utilization under P –limited condition (Yan *et al.* 2001). The activity of acid phosphatase could be a useful selection criterion for determining the P-release efficiency of organic P compounds, as proposed by Thung (1990) and Vose (1990).

CHAPTER-VI

SUMMARY AND CONCLUSION

The present investigation was aimed to study “Phosphorus uptake, yield and quality parameters in wheat (*Triticum aestivum* L.)”. The wheat genotypes WH-147, Raj-4083, WH-1022, LOK-1, WH-1021, NW-2030, C-306, WH-1025, PBW-343 PBW-550 were used to evaluate wheat genotypes for phosphorus uptake efficiency. The plants were raised in screen house at three levels of P treatment (20%, 50%, 100%).

The observation were recorded on dry weight of different plant parts i.e. root, shoot and leaf, days to heading, anthesis, day to maturity and grain filling duration. In addition the data was recorded for grain yield, its components and quality traits, namely protein, starch, moisture and ash content in grain.

Physiological observations included chlorophyll fluorescence transpiration rate, stomatal conductance, water use efficiency and photosynthetic rate. Biochemical observations included estimation of acid and alkaline phosphatases. Observation on root length, shoot length and number of secondary roots were also recorded from 7 days old grown seedlings. Salient findings of this experimentation are given below:.

Growth and phenology

- All growth and phenological parameters showed decreasing trend with decreasing levels of phosphorus in all wheat genotypes.
- Days to heading, anthesis, maturity and grain filling duration got delayed at low P level (20%) as compared to 100% P.
- Dry weight of root, shoot and leaf was lowest at 20% P level at all the three stages i.e. vegetative, anthesis and maturity.
- At vegetative stage, LOK-1, WH-1021, NW-2030 and C-306 performed better in retaining dry weight at different levels of phosphorus.
- Raj-4083, WH-1022, NW-2030, WH-1025, C-306, PBW-343 and PBW-550 showed significant difference for root, shoot and leaf dry weight at different level of phosphorus during anthesis stage.
- Genotypes WH-1025 and PBW-343 were better for dry weight of root, shoot and leaf at maturity stage at all the three levels of P.

Physiological parameters

- All physiological and biochemical parameters showed decreasing trends with decreasing levels of phosphorus. At 100 DAS the highest per cent reduction in chlorophyll fluorescence was observed in NW-2030 and the lowest was in C-306 at different levels of phosphorus. Similarly at 110 DAS, PBW-343 showed highest per cent of reduction and the lowest was noted in NW-2030 but at 120 DAS the lowest percent reduction was in WH-1022 and highest was noticed in WH-147.
- Photosynthetic rate, stomatal conductance and water use efficiency (WUE) decreased with decrease in level of phosphorus at all stages. WH-147 and Raj-4083 was better in maintaining WUE at different P level. The highest per cent of reduction for WUE was noticed in WH-1025.
- All sampling stages (100, 110 and 120 DAS) WH-147 NW-2030 and WH-1022 performed well for stomatal conductance at different P level. The highest per cent reduction in stomatal conductance was in WH-1022 and followed by WH-1021 and Raj-4083 and the lowest per cent of reduction was noted in WH-1022.
- The varieties WH-147 and WH-1022 showed better performance in maintaining photosynthetic rate at different levels of P. The highest per cent reduction in photosynthetic rate was noted in C-306 followed by PBW-343 and PBW-550 and the lowest was in WH-1025.

Biochemical attributes

- Acid and alkaline phosphatase activity increased with decrease in the P. Activity of both enzymes was highest in NW-2030.

Yield and quality parameters

- Total grain yield decreased at low P level (20%) as compared to control (100% P). The highest per cent of reduction for grain yield was observed in WH-1025 followed by PBW-343 and the lowest was noted in WH-147.
- Plant biomass was low at 20% P and high at 100% P in different wheat genotypes. Percentage of reduction of plant biomass was highest in WH-1021 and the lowest was noted in WH-147.
- Highest percent reduction in test weight was observed in WH-1025 and the lowest percentage of reduction was noted in Raj-4083.
- Productive tillers/plant and spike length decreased at 20% P level as compared to 100% P level.
- For majority of the yield components the genotypes Raj-4083, WH-147, LOK-1, NW-2030 and PBW-550 performed better at different P levels.

Grain quality characters

- Starch content decreased at 20% P level. The lowest percentage of reduction was noted in WH-147 and WH-1021 and highest was observed in Raj -4083 at different P level.
- Protein content decreased at low P level in all wheat genotypes as compared to control. The highest protein content was observed in PBW-550 and the lowest was noted in WH-147 at all different levels of phosphorus.
- Moisture and ash content decreased at 20% P as compared to 100% P level in all wheat genotypes.
- Reduction in quality characteristics was observed at 20% P level in all the genotypes. In general Raj-4083, NW-2030 and PBW-343 showed high protein, starch and ash content at different P levels. However, there was no difference in moisture content in these varieties irrespective of P levels.

Seedling characteristics

- Root length was more at 20% P level in all ten wheat genotypes, however, the genotypes Raj-4083 and C-306 had higher root length than other genotypes.
- Shoot length decreased with decrease P level. The highest per cent reduction was noted in Raj-4083 and the lowest was in WH-147.
- Root/shoot dry weight ratio increased at 20% P level, but less increase was noted in PBW-343 and more increase was observed in WH-1022 at different P levels.
- Number of secondary lateral roots increased with decreasing level of phosphorus application. NW-2030 showed the highest percentage of increase in secondary lateral roots and the lowest was noted in PBW-343.
- Among all these seedling characteristics root length root / shoot dry weight and no. of secondary lateral roots increased at 20% P, but shoot length decreased at 20% P.

On the basis of above experiments, the varieties WH-1025, NW-2030, PBW-550 and Raj-4083 were identified as P uptake efficient genotypes .

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ABSTRACT

Title of thesis : **“Phosphorus uptake, yield and quality parameters in Wheat (*Triticum aestivum* L.)”**

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Key words: Wheat, Phosphorus uptake, efficiency, shoot-root morphophysiological traits, quality traits, yield, acid/alkaline phosphates activity.

The present experimentation was carried out on ten wheat genotypes namely WH-147, Raj-4083, WH-1021, WH-1022, WH-1025, LOK-1, NW-2030, C-306, PBW-343 and PBW-550 with three level of phosphorus i.e. 20%, 50% and 100% in order to identify the genotypes efficient in phosphorus uptake and utilization, the effect of phosphorus doses on quality parameters of wheat grains and the root morpho-physiological traits associated with efficient phosphorus uptake. The investigation involved pot studies under screen house conditions during the year 2008-09. Data was recorded for dry weight of root, stem and leaves, physiological parameters (Chlorophyll fluorescence, Assimilation rate, Transpiration rate, Stomatal conductance, Water use efficiency), days to heading, days to Anthesis, days to Maturity, Grain Filling duration, Plant Height, No. of productive tillers/plant, biomass/plant, Spike length, Grain yield/plant Test weight, Phosphorus content Quality parameter in grain. In this study day to heading, anthesis, maturity and grain filling duration got delayed at low P level (20%) as compared to 100% P. Raj-4083, WH-1022, NW-2030, WH-1025, C-306, PBW-343 and PBW-550 showed significant difference for root, shoot and leaf dry weight at different level of phosphorus during anthesis stage. WH-147 and Raj-4083 was better in maintaining WUE at different P level. Acid and alkaline phosphate activity increased with decrease in the P. Activity of both enzymes was highest in NW-2030. For majority of the yield components the genotypes Raj-4083, WH-147, LOK-1, NW-2030 and PBW-550 performed better at different P levels. Among all these seedling characteristics root length root/shoot dry weight and no. of secondary lateral roots increased at 20% P, but shoot length decreased at 20% P. No. of secondary lateral roots was found as major determinant of P deficiency.

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