Indian J. Plant Physiol., Vol. 16, No. 1, (N.S.) pp. 10-18 (Jan.-Mar., 2011)

GROWTH AND YIELD RESPONSE OF WHEAT GENOTYPES TO RAINFED CONDITION OF ASSAM

PRAKASH KALITA*, RANJAN KALITA, RANJAN DAS AND BIMAL KUMAR RABHA

Department of Crop Physiology, Assam Agricultural University, Jorhat -785013

Received on 12th July, 2010, Revised and Accepted on 15th March, 2011

SUMMARY

Non-availability of well adapted genotypes for rainfed situation of Assam is the major factor contributing to poor productivity of wheat in Assam. This crop is raised with residual moisture left behind by the previous winter rice, because of which the crop faces terminal moisture deficit especially during the pre-anthesis period right from seed germination stage, affecting badly the various physiological processes resulting in lower yield realization. In order to address this crucial production problem, a study was undertaken with seven genotypes of wheat namely Sonalika, HDR-77, PBW-343, PBW-154, Raj-3077, C-306 and K-8027 under rainfed situation during the normal crop season to evaluate their growth and yield performance. The genotypes C-306 followed by PBW-343 were found to be the highest biomass producers at various stages of plant growth. These two genotypes accumulated higher vegetative dry matter, recorded longest root length, higher root surface area and root to shoot ratio at maximum tillering and ear emergence stages, and higher leaf area duration after anthesis, soluble protein content in flag leaf, total plant dry matter, number of effective tillers and grain growth rate.

***Key words*: Dry matter partitioning, grain yield, phenological stage, rainfed, grain growth rate (GGR).**

INTRODUCTION

In Assam wheat is presently being grown in an area of 0.1 million hectares and it is rainfed (Saikia *et al.* 2006). Wheat growing is gradually gaining popularity in Assam since early seventies, especially in view of the frequent failure of winter rice (Sali) owing to flood as well as irregular monsoon rains. The productivity of wheat in Assam is only 1219 kg per hectare (Anonymous 2004) compared to the national average of 2900 kg/ha which mainly appears to be due to lack of irrigation facility and also non-availability of well adapted genotypes for rainfed situation of this region.

Wheat crop in Assam invariably suffers from terminal moisture stress during various stages of crop growth even during the years of normal monsoon. Adequacy in moisture in root zone throughout the life cycle or at least during critical growth stages of wheat plant is essential for higher biological yield. In Assam, mean temperature at sowing time is 20 degree celsius reaching a lowest of 17 degree Celsius at maximum tillering stage, then again the temperature rises gradually and at flowering and grain filling, the mean temperature reaches around 21-22 degree Celsius. During vegetative stage the relative humidity ranges between 82 to 84% then it decreases to around 70%, again it rises and

---

*Corresponding author, E-mail: pkalita2005@yahoo.com reaches around 76% during grain filling stage. Assam receives substantial amount of rainfall during grain filling and maturation (mean around 80 mm per month) because of which pre harvest sprouting occurs in a number of wheat genotypes. Daily average bright Sunshine hours varies between 4 to 6 hours and the highest Sunshine hour of above 7 hours is received during February which corresponds to flowering stage of the crop.

Better expression of inherent potential and efficient utilization of environment and soil resources is dependent on effective development of plant parts, dry matter production and plant dry matter allocation between roots and shoots (Zhao *et al*. 1997). Maintenance of better root length and surface area especially during moisture shortage period is a contributing factor leading to realization of potential yield. Zheng *et al.* (2006) found that better adapted rice varieties exhibited increase in maximum root length, root surface area and grain yield under moisture deficit situation compared to the poorly adapted genotypes.

Wheat plants can respond to nutrient and water stress *via* various mechanisms; *viz*. alternations of root branching and root extension rates (Horst *et al.* 1996), higher root: shoot ratios (Manske, 1989; Hamblin *et al.* 1990), more and longer root hairs (Foehse *et al.* 1991), and by lowering demand for nutrients and water for growth. Grain growth takes place entirely during post – anthesis period and is determined by the rate and duration of grain filling (McMaster 1997). Grain filling is directly related to efficiency of the photosynthesing part of plant (leaf) as well as remobilization of photosynthates from vegetative parts. As the enzyme ribulose-*bis*–phosphate carboxylase and other photosynthetic enzymes constitute a major fraction of the soluble protein in the leaves, a relationship between soluble protein and photosynthetic rate is expected. Consequently biomass production and grain yield may also have a causal relationship with soluble protein content

Keeping in view the above facts, a study was undertaken with seven genotypes of wheat differing in crop duration and adaptability; namely Sonalika, HDR-77, PBW-343, PBW-154, Raj-3077, C-306 and K-8027 to evaluate them for dry matter yield, partitioning pattern, root characters and yield parameters under rainfed situation of Assam.

MATERIALS AND METHODS

The crop was raised for two years during *Rabi* as a normal season crop in the instructional cum research farm, Assam Agricultural University, Jorhat-13. The surface soil of the experimental plot was sandy loam in texture with a pH of 5.16. Geographical location of Jorhat is 26.47^0N latitude and 94^0 12 E longitude with an altitude of 86.6 meters above mean sea level.

Weekly average rainfall received during the crop season was 21.15 mm. During the period between first week of December and third week of January there was no rainfall which corresponded with the tillering and jointing stage of the crop, however the rain fall again resumed from mid of January and it continued till the harvest. Soil moisture content was between 12-13% from sowing to ear emergence, thereafter it was between 14-18%. Rows were made maintaining a gap of 20 cms in between in which three seeds were sown at every 10 cm. After germination, thinning was done and retained only one plant in each spot of sowing. Recommended package of practices were followed with a fertilizer dose of 40:20:20 kg N:P :K/ha. Entire dose of fertilizer N, P, K was applied basally two days before sowing.

The experiment was laid down following randomized block design with four replications. For taking records on dry matter accumulation and partitioning, five plants were uprooted from each plot at every stage, washed thoroughly under running tap water and dried in hot air oven at 70^0C till a constant weight was reached. Before drying the plants, the leaf, stem, root and reproductive parts were separated. The root surface area was measured by following the procedure as suggested by Ansari *et al.* (1995). The yield attributing traits were recorded at harvest in plants from previously marked 0.25 square meter area in each plot. Grain growth rate (GGR) was calculated using the formula GGR= $(W_2-W_1) / (T_2-T_1)$, Where, W_1=Initial grain weight & W_2 = Final grain weight and T_2-T_1 = Duration of grain growth (Days). Soluble protein content in flag leaf was estimated following the method of Lowry *et al*. (1951). Leaf area duration was calculated using the formula suggested by Friend *et al*. (1962). Data on various traits were statistically analyzed by the methods of analysis of variance as described by Panse and Sukhatme (1978).

RESULTS AND DISCUSSION

Growth and growth parameters

Total plant dry matter accumulation: At all the stages of observation significant variation was observed among the genotypes in terms of accumulated plant dry matter and the genotype C-306 recorded the highest value (2.75, 9.0 and 17.87 g plant^{-1} at two leaf, ear emergence and dough stage respectively, Table 1); this genotype was closely followed by PBW-343 (2.07, 8.02 and 15.73 respectively). The genotypes Sonalika and HDR-77 accumulated comparatively lower plant dry matter in all the three stages of observation.

Dry matter accumulation in leaf: Significant variation in accumulated leaf dry matter was observed among the genotypes in all the stages of observations. At two leaf and ear emergence stage, PBW-343 showed highest value of accumulated leaf dry matter (1.01 and 1.49 g plant^{-1}, Table1) followed by C-306 (0.96 and 1.48) and K-8027 (0.77 and 1.43). Genotype Sonalika (0.40) and HDR-77 (1.16) recorded the least leaf dry matter at two leaf and ear emergence stage respectively. At two leaf and ear emergence stage the genotypes C-306 and PBW-343 could maintain higher leaf area (data not shown). At dough stage the genotype C-306 recorded the highest value of leaf dry matter (1.87) followed by Raj-3077 (1.81), Sonalika (1.79) and K-8027 (1.78) and lowest leaf dry weight was found in case of PBW-343 (1.43). During grain filling since only the flag leaves are the primary source of current assimilate and most other leaves get senesced, the reduced share of total plant biomass by leaves at dough stage as observed in the genotype PBW-343 compared to previous stages may be of advantage for higher grain yield. Kumar *et al.* (2000) also has reported changes in leaf dry matter with stages of growth in wheat varieties.

Dry matter accumulation in stem: At two leaf stage and at ear emergence stage the genotype PBW-343 was found to be the highest stem dry matter accumulator (0.75 and 1.39 g plant^{-1}, Table 1) followed by C-306 (0.73and 1.38), however PBW-343 did not show higher values of stem dry matter at dough stage. The lowest value of accumulated stem dry matter was found in Sonalika at two leaf stage but at ear emergence and dough stage HDR-77 recorded the lowest value of stem dry matter. Turner and Begg (1981) and Ehdaie *et al.* (2006) highlighted the important contribution of remobilized stem dry matter during post anthesis period to grain yield in wheat, considering the fact that photosynthesis declines drastically at that period.

Dry matter accumulation in root: At two leaf stage, C-306 registered the highest root dry matter (1.06 g plant^{-1}, Table 1), followed by PBW-154 (0.43). At ear emergence and dough stage also C-306 recorded highest root dry matter (2.59 and 2.85) followed by PBW-343 (1.66 and 1.90). The lowest value of root dry matter at two leaf stage was found in K-8027 but at ear emergence and dough stage HDR-77 showed the lowest values of root dry matter. Maintenance of proper root system at two leaf and ear emergence stages when the soil moisture content was considerably lower was most important factor for acquisition of available soil moisture. From this point of view the genotypes C-306 and PBW-343 were found to be more efficient because they allocated greater amount of dry matter to root compared to other genotypes for development and maintenance of root system. From pot trials also the genotypes PBW-343 and C-306 were found to register higher values of longest root length and root surface area which might have enabled these two genotypes to extract the required amount of moisture from soil, there by contributing to greater plant dry matter accumulation (Table 2). Siddique *et al.* (1990) concluded that in over 100 years all varieties developed in Australia had similar above ground or rooting depth, but they differed in root biomass and root length density in the 0-40 cm soil layer. They also observed that the modern varieties had higher grain yield, harvest index and water use efficiency than the older ones. Kanbar *et al.* (2009) reported that in rain fed rice, root to shoot length and weight ratios and root dry weight had the largest effect on, shoot dry weight and grain yield under well-watered condition; under low moisture stress, maximum root length and root number were also important for improving grain yield and panicle length.

Table 1. Dry matter accumulation and partitioning (g/plant) in wheat genotypes at different stages of growth.

Genotype	Dry matter partitioning pattern													
	Two leaf stage				Ear emergence stage					Dough stage				
	Leaf	Stem	Root	Total	Leaf	Stem	Root	Spike	Total	Leaf	Stem	Root	Spike	Total
Sonalika	0.40	0.27	0.25	0.91	1.32	1.15	0.98	2.65	6.11	1.79	1.47	1.01	7.07	11.34
HDR-77	0.43	0.35	0.31	1.09	1.16	0.56	0.70	2.49	4.92	1.55	1.36	0.73	8.10	11.74
PBW-343	1.01	0.75	0.31	2.07	1.49	1.39	1.66	3.48	8.02	1.43	1.39	1.90	11.01	15.73
PBW-154	0.74	0.35	0.43	1.53	1.35	1.06	0.97	3.09	6.47	1.76	1.52	1.08	10.26	14.62
Raj-3077	0.62	0.48	0.27	1.37	1.31	1.23	1.01	3.09	6.64	1.81	1.57	1.17	8.83	13.38
C-306	0.96	0.73	1.06	2.75	1.48	1.38	2.59	3.54	9.00	1.87	1.66	2.85	11.49	17.87
K-8027	0.77	0.54	0.20	1.51	1.43	1.28	1.03	2.99	6.73	1.78	1.66	1.09	9.34	13.87
SEd	0.04	0.05	0.05	0.08	0.03	0.03	0.15	0.04	0.22	0.03	0.02	0.48	0.06	0.56
CD at 0.05	0.08	0.11	0.11	0.16	0.06	0.06	0.27	0.09	0.40	0.06	0.04	0.87	0.12	0.90

Table 2. Longest root length, root surface area and root to shoot dry weight ratio of wheat genotypes at different stages of growth.

Genotype	Longest root length (cm)			Root surface area (cm^2/plant)			Root: shoot ratio		
	Maximum tillering	Ear emergence	Dough stage	Maximum tillering	Ear emergence	Dough stage	Maximum tillering	Ear emergence	Dough stage
Sonalika	30.58	33.00	54.20	30.67	34.50	36.00	0.56	0.98	1.08
HDR-77	12.79	27.30	47.33	35.50	38.17	39.93	0.93	1.12	1.19
PBW-343	38.07	46.57	62.40	53.50	54.33	55.50	1.25	0.90	1.27
PBW-154	28.70	44.83	59.38	24.50	27.97	29.27	1.03	0.83	0.87
Raj-3077	42.23	45.20	63.97	32.17	39.50	41.50	1.05	0.98	1.00
C-306	53.97	56.33	75.03	48.00	52.17	54.93	0.97	1.32	1.14
K-8027	35.13	36.26	36.73	35.97	46.27	46.33	1.55	1.08	0.90
SEd	0.49	1.08	0.48	1.21	0.93	1.02	0.10	0.23	0.07
CD at 0.05	1.07	2.36	1.05	2.64	2.02	2.22	0.21	0.51	0.16

Genotypic differences in partitioning of assimilates between roots and shoots have been reported in wheat (Sadhu and Bhaduri 1984). In the present study at maximum tillering the genotype K-8027 registered the highest value of root: shoot dry weight ratio (1.55) but at later stages C-306 and PBW-343 recorded the highest values (Table 2).

Dry matter accumulation in reproductive parts: Genotype C-306 recorded the highest reproductive dry matter (3.54 g plant^{-1}, Table 1) at ear emergence followed by PBW-343 (3.48), PBW-154 and Raj-3077 (3.09). The lowest reproductive dry matter was found in genotype HDR-77 (2.49). The genotype C-306 had registered the highest dry matter accumulation in reproductive parts at dough stage (11.49) which was followed by PBW-343 (11.01) and PBW-154 (10.26) and Sonalika had recorded lowest reproductive dry matter (7.07). The genotypes HDR-77 and Sonalika registered the lowest values of spike dry matter accumulation at ear emergence and dough stage respectively. These two genotypes showed lower total plant biomass accumulation which could be the factor responsible for lower values of reproductive dry matter in them. Total plant dry matter along with higher harvest index is one of the important factors for increased grain yield. Tariq *et al.* (2007) reported a significant positive correlation between economic yield and biological yield, harvest index in sorghum. Genotype HDR-77 although showed third highest value of harvest index, due to its lower total dry weight, the grain yield was one of the lowest. In the present investigation reproductive dry matter at ear emergence stage was found to have significant positive correlation with plant dry matter (r=0.89).

Longest root length: The genotype C-306 recorded the highest value of longest root length (53.97,56.33 and 75.03 cm at maximum tillering, ear emergence and dough stage respectively, Table2). The genotypes PBW-343 and Raj-3077 also recorded comparatively higher values of longest root length next to C-306.

Root surface area: At maximum tillering and ear emergence stage highest root surface area was found in PBW-343 (53.50 and 54.33 sq. cm respectively, Table 2) followed by C-306 (48.00 and 52.17, respectively). However, at dough stage the genotype C-306 recorded the highest root surface area (54.93) followed by PBW-343 (55.50).

Root to shoot dry weight ratio: Significant genotypic variation was observed in respect of root: shoot dry weight ratio at all the stages of observation. At maximum tillering the genotype K-8027 showed the highest value

(1.55, Table 2) while Sonalika showed the lowest value (0.56). At ear emergence C-306 registered the highest value of root to shoot dry weight ratio (1.32) however at dough stage PBW-343 recorded the highest (1.27).

Leaf area duration: The genotypes differed widely in terms of leaf area duration measured between anthesis and 15 days after anthesis. The genotype PBW-343 recorded the highest LAD value of 47.3 (Table 3) closely followed by C-306 (45.68) and the lowest value was found in Sonalika (32.40). Maintenance of higher LAD in the genotypes PBW-343 and C-306 may be one of the factors responsible for higher grain yield by way of maintenance of higher current photosynthate supply to developing grains.

Soluble protein content in flag leaf: At 15 days after anthesis the genotype C-306 recorded the highest soluble protein content in flag leaf (5.36 mg g^{-1} fw, Table 3) followed by PBW-343 (4.87). C-306 and PBW-343 also showed higher values of specific leaf weight of flag leaf after anthesis (published elsewhere), supporting higher photosynthetic increment in leaf weight.

Grain growth rate: Significant variation was observed among genotypes in terms of grain growth rate measured between 7 and 15 days after anthesis, with PBW-343 showing the highest value (1.27 mg day^{-1},Table 3) followed by PBW-154 (1.15) and C-306 (1.14). The genotype PBW-343 took comparatively longer duration for anthesis and shorter duration from anthesis to maturity. Genotype PBW-343and C-306 recorded higher number of grains per ear and 1000 grain weight in the present study, however Ehdaie *et al*. (2008) opined that genotypic variation in linear rate of grain growth was not significantly correlated with either the number of grain per spike or grain weight

Yield attributes and yield

Biological yield at harvest: Significant genotypic variation was recorded in terms of this trait. Genotype C-306 showed the highest value (848.0 g m^{-2}, Table 3) followed by PBW-343 (755.6) and the lowest biomass content was found in Raj-3077 (434.8).

Number of ears: Significant variation in the number of ears was observed among the genotypes. Genotype C-306 showed the highest value for this trait (218.10 m $^{-2}$, Table 3) followed by K-8027 and HDR-77 (190.0 and 185.0 respectively). Khumkar *et al.* (2001) reported a significant positive association of grain yield per plot with the final number of tillers per meter length.

Table 3. Physiological traits and yield characters of wheat genotypes

Genotype	Leaf area duration	Soluble protein in flag leaf (mg /g)	Grain growth rate (mg/day)	Biological yield (g/m^2)	No. of ear/m^2	No. of spikelet/ ear	No. of grain/ ear	1000 grain weight	Grain yield (q/ha)	HI (%)
Sonalika	32.40	3.74	1.05	478.4	171.22	18.24	18.60	46.38	14.12	29.51
HDR-77	39.75	4.60	0.96	444.2	185.60	12.93	15.15	48.70	13.20	29.71
PBW-343	47.30	4.87	1.27	755.6	181.0	17.60	23.9	51.79	21.94	29.03
PBW-154	39.80	4.53	1.15	593.8	181.6	15.60	19.41	48.24	16.56	27.88
Raj-3077	39.05	4.27	1.10	434.8	170.80	17.68	19.02	42.60	13.00	29.89
C-306	45.68	5.36	1.14	848.0	218.0	16.37	21.45	56.27	26.12	30.80
K-8027	42.00	4.55	1.06	580.2	190.0	12.65	19.30	44.90	16.24	27.99
SEd	1.36	0.30	0.08	16.29	9.43	0.40	0.90	0.70	0.43	0.02
CD at 0.05	2.95	0.66	0.17	35.50	20.54	0.83	1.96	1.47	0.91	0.04

Number of spikelets per ear: A perusal of the data on number of spikelet per ear at harvest revealed that Sonalika recorded the highest value (18.24, Table 3) and K-8027showed the lowest (12.65). Genotype Raj-3077 registered the second highest value (17.68). The genotype C-306 showed the highest number of ears per square meter but it had moderate number of spikelet per ear. This finding was in contrary to the report of Khawas *et al.* (1999) in which they opined that in wheat the increased number of spikelet per ear was associated with more number of effective tillers per meter length. In the present study the highest grain yielder v*iz.* C-306 and PBW-343 did not show higher number of spikelet per ear.

Number of grains per ear: The genotype PBW-343 registered the highest values of number of grains per ear (23.9, Table 3) followed by C-306 (21.45) and PBW-154 (19.41) and the least value was observed in HDR-77 (15.15). Highest number of grains per ear in PBW-343 and C-306 may be related to the higher number of fertile florets per ear. Entz and Fowler 1990) also reported differential response of wheat genotypes under water deficit condition, resulting in production of variable number of grains per spike. Arduini *et al.* (2006) were of the opinion that an improved partitioning of dry matter to the developing kernels leads to increased number of kernels per unit area and increased kernel weight.

Thousand grain weight: Genotypes showed significant variation in 1000 grain weight. Genotype C-306 recorded the highest value (56.27 g, Table 3) followed by PBW-343 (51.79) and the Raj-3077 registered the lowest value (42.60). Bush and Kofoid (1982) reported that the number of spikelets per ear was negatively correlated to grain test weight. This again appears to be a matter of competition amongst the spikelets of individual ear for photosynthates. In present study, the genotype C-306 and PBW-343 showed higher values of 1000 grain weight but, their values for number of spikelet per ear were only moderate ones. Khan *et.al* (2010) reported positive correlation between grain yield with tillers per unit area and number of grains spike^{-1} and negative correlation of grain yield with 1000 grain weight in rice.

Grain yield: Significant variations were observed among genotypes for this trait; C-306 showing the highest yield (26.12 q/ ha, Table 3) followed by PBW-343 (21.94). Genotype Raj-3077 showed the least value (13.00). Khawas *et al.* (1999) also reported higher grain yield in genotype C-306, compared to a number of other genotypes under rainfed condition. Papakosta (1994) showed the existence of positive correlation between grain yields with number of grains expressed per unit area. In the present study also the higher grain yielder *viz*. C-306 and PBW-343 recorded higher number of grains per ear. Kumar *et al.* (2006) reported higher remobilization of assimilates to fill the grains from stem and leaves in high yielding rice cultivars under drought situation. In wheat, pre-anthesis assimilate reserves from stem and sheath contribute 25-33 % of the final grain weight (Hans, 1993; Gebbing and Schnyder, 1999). Fanny *et al.* (2008) reported that due to breeding efforts contribution of pre-anthesis assimilates to grain yield increased to values of 31 and 27 % in Italian and Spanish modern cultivars of wheat respectively. The recorded higher grain yield in C-306 and PBW-343 also indicates their higher capacity for grain development at a comparatively higher post-anthesis average temperature of around 21 degree Celsius as it has been reported that mean temperature greater than 15-18 degree Celsius following anthesis can result in decrease in grain weight at maturity (Wardlaw 1994).

Harvest Index: Significant genotypic variation was recorded in respect of harvest index. The genotype C-306 recorded the highest value (30.80 %, Table 3) followed by Raj-3077 and HDR-77 (29.89 and 29.71 respectively). PBW-154 showed the lowest value of harvest index.

In the present study, the genotype C-306 showed the highest accumulation of plant dry matter at various stages of crop growth. This genotype also recorded the highest values of longest root length and root surface area (Table 2) at all the stages, indicating the better allocation of dry matter to roots for better acquisition of moisture and nutrients even during moisture deficit periods (up to ear emergence). Zheng *et al.* (2006) also reported that better adapted rice varieties exhibited increase in maximum root length, root surface area and grain yield under moisture deficit situation compared to the poorly adapted genotypes. The genotype PBW-343 closely followed C-306 in terms of root characters and dry matter production. These two genotypes allocated greater amount of dry matter to stem and leaf at two leaf and ear emergence stage. Maintenance of higher total plant dry matter and current photosynthesis through out the crop season may be considered as one of the major contributors towards realization of higher grain yield in these two genotypes.

REFERENCES

Anonymous (2004). Agricultural guide book, Argil. Information Press, Department of Agriculture, Assam, India, pp.37

Ansari, S.A., Kumar, P. and Gupta B.N. (1995). Root surface area measurements based on adsorption and desorption of nitrite. *Plant Soil.* **175:** 133-137.

Arduini, I., Masoni, A., Ercoli, L. and Mariotti, M. (2006). Grain yield and dry matter and nitrogen accumulation and remobilization in durum wheat as affected by variety and seeding rate. *Euro. J. Agron.* **25:** 309- 318.

Bush, L.N. and Kofoid, W.A. (1982). Physiological studies on nitrogen metabolism and grain yield in wheat (*Triticum aestivum* L). *J. Plant Nutr*. **3:** 842-852.

Egle, K., Manske, G.G.B., Romer, W. and V1ek, P.L.G. (1999). Improved phosphorus efficiency of three new wheat genotypes from CIMMYT in comparison with an older Mexican variety. *J. Plant Nutr. Soil Sci.* **162:** 353-358.

Ehdaie, B., Alloush, G.A., Madore, M.A. and Waines, J.G. (2006). Genotypic variation for stem reserves and mobilization in wheat : II. Photosynthesis changes in internode water soluble carbohydrates. *Crop Sci*. **46:** 2093-2103.

Ehdaie, B., Alloush, G.A., Madore, M.A. and Waines, J.G. (2008). Genotypic variation in linear rate of grain growth and contribution of stem reserves to grain yield in wheat. *Field Crops Res.* **106:** 34-43.

Entz, M.H. and Fowler, D.B. (1990). Differential agronomic response of winter wheat cultivars to pre anthesis environmental stress. *Crop Sci.* **30:** 1119- 1123.

Fanny, A., Julio, I., Dolors, V., Luis, F., Garcia del, M. and Conxita, R. (2008). Breeding effects on grain filling, biomass partitioning, and remobilization in Mediterranean Durum wheat. *Agron. J.* **100:** 361-370.

Fohse, D., Claassen, N. and Jungk, A. (1991). Phosphorus efficiency of plants. II. Significance of root radius, root hairs and cation-anion balance for phosphorus influx in seven plant species. *Plant Soil.* **132:** 261-272.

Friend, D.J.C., Helson, V.A. and Eisher, J.E. (1962). Leaf growth in marquis wheat as regulated by temperature, light intensity and day length. *Can. J. Bot*. **40:** 1299-1311.

Gebbing, T. and Schnyder, H. (1999). Pre-anthesis reserve utilization for protein and carbohydrate synthesis in grains of wheat. *Plant Physiol*. **121:** 871-878.

Hans, S. (1993). The role of carbohydrate storage and redistribution in the source –sink relations of wheat and barley during grain filling – a review. *New Phytol*. **123:** 233-245.

Horst, W.J., Abdou, M. and Wiesler, F. (1996). Differences between wheat cultivars in acquisition and utilization of phosphorus. *Z Pflanzenerniihrung Bodenkunde*. **159:** 155.

Kanbar, A., Toorchi, M. and Shashidhar, H.E. (2009). Relationship between root and yield morphological characters in rainfed low land rice (*Oryza sativa* L.). *Cereal Res. Commun.* **37:** 261-268.

Khan, A.J., Azam, F. and Ali, A. (2010). Relationship of morphological traits and grain yield in recombinant inbred wheat lines grown under drought conditions *Pak. J. Bot*. **42:** 259-267.

Khawas, B., Bhattacharjee, I. and Sutradhar, A.K. (1999). Varietal discrimination and variance analysis of wheat (*Triticum aestivum*). *Ann. Agric. Res*. **20**: 43-46.

Khumkar Mahesh, S., Choudhury, H.B. and Deshmukh, P.S. (2001). Genetic variability and association of morpho physiological characters with grain yield in late sown wheat (*Triticum aestivum* L. em Thell). *Ann. Agric. Res.* **22:** 217-220.

Kumar, S., Singh, M. and Verma, R.S. (2000). Pattern of photosynthates partitioning and its remobilization during grain growth period in wheat varieties. *Ann. Agric. Res*. **21:** 267- 270.

Kumar, R., Sarawgi, A.K., Ramos, C., Amarante, S.T. Ismail, A.M. and Wade, L.J. (2006). Partitioning of dry matter during drought stress in rainfed lowland rice. *Field Crops Res.* **98:** 1-11.

Kumar, P., Lakshmi, J., Dube, N. and Mani V.P. (2000). Genotypic differences in photosynthesis and its associated parameters in relation to yield among barnyard millet genotypes under rain fed conditions in hills. *Indian J. Agric. Sci*. **70:** 374-377.

Lowry, O.H., Rosenborough, N.J., Farr, A.L. and Randall, R.J. (1951). Protein measurement with the Folin's phenol reagent. *J. Biol. Chem*. **193:** 265-275.

McMaster, G.S. (1997). Phenology, development and growth of wheat (*Triticum aestivum*) shoot apex : A review. *Advan. Agron*. **59:** 63-118.

Panse, V.G. and Sukhatme, P.V. (1978). Statistical methods for agricultural workers. Pub. ICAR, New Delhi.

Papakosta, D.K. (1994). Analysis of wheat cultivars differences in grain yield, grain nitrogen yield and nitrogen utilization efficiency. *J. Agron. Crop Sci*. **172:** 3015-3016.

Sadhu, D. and Bhaduri, P.N. (1984). Variable traits of roots and shoots of wheat. *Z Acker- Pflanzenbau.* **153**: 216.

Samtsevich, S.A. (1965). Active secretions of plant root and their significance. *Fiziol Rast.* **12**: 837-846.

Saikia, T.P., Barman, B. and Ortiz Ferrara, G. (2006). Participatory evaluation by farmers of on-farm seed priming in wheat in Assam, India in Proceedings of 13th Agronomy conference 2006, 10-14 Sept 2006 Perth, Western Australia Eds. N.C. Turner, Acuna T and Johnson R.C.

Siddique, K.H.M. Belford, R.K. and Tennant, D. (1990). Root/shoot ratio of old and modern tall and semi-dwarf wheat in a Mediterranean environment. *Plant Soil.* **121:** 89-98.

Tariq, M., Awan, S.I. and Irshad-ul-Haq, M. (2007). Genetic Variability and Character Association for Harvest Index in Sorghum under Rainfed Conditions. *Intern. J. Agric. Boil.* **3**: 470–472.

Turner, N.C. and Begg, R.A. (1981). Plant productivity in arid and semi arid zones. *Annu. Rev. Plant Physiol.* **29:** 277-317.

Wardlaw, I.F. (1994). The effect of high temperature on kernel development in wheat: variability related to pre-heading and post anthesis conditions. *Aus. J. Pl. Physiol*. **21:** 731- 739.

Weiner, J. (1990). Plant population ecology in agriculture. In: Ronald, C., Carrol *et al*. (Eds.), Agroecology. McGraw-Hill, New York, pp. 235-261.

Zhao, S.L., Li, F.M. and Zhang, D.Y. (1997). Crop production is a population process. *Acta Ecol. Sin.* **17:** 100-104.

Zheng, B., Jiang, D., Wu, P., Weng, X., Lu, Q. and Wang, N. (2006). Relation of root growth of rice seedling with nutrition and water use efficiency under different water supply conditions. *Rice Sci.* **13:** 291-298.