SCREENING WHEAT GENOTYPES FOR DROUGHT TOLERANCE AND CO-RELATION STUDY AMONG MORPHO-PHYSIOLOGICAL TRAITS

Dipendra Pokharel[1], Kiran Baral [2], Bishnu R. Ojha[3], Surya K. Ghimirey[3] and Madhav P. Pandey[3]

ABSTRACT

Wheat crop in developing world including Nepal is grown under rainfed condition and thus face moisture stress at one or more growth stages limiting grain yield. An experiment was conducted at Greenhouse to screen the 60 different genotypes of wheat including Nepalese landraces, commercial cultivars CIMMYT derived advanced lines, NWRP derived advanced lines, and three international drought tolerant check cultivars. The wheat genotypes were grown in pots (single plant) arranged in a replicated split plot design under two contrasting moisture regimes, optimum and moisture stressed. The genotypes were evaluated forwater use, water use efficiency, plant height, number of tillers and biomass production. The analysis revealed significant variance between environments and among the wheat genotypes for most of these traits. A wide range of variability was observed for water use, water use efficiency, days to anthesis, plant height, number of tillers and biomass yield in both moisture stressed and non stressed environments. Gautam showed superiority than Bhrikuti and Vijaya among Nepalese cultivar for drought adaptive physiological traits. Landrace NPGR 7504 showed high level of water use efficiency and other positive traits for drought adaptation.

Keywords: Co-relation, Drought, Morpho-physiological traits, Tolerance, Wheat genotypes

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop of the world providing staple food for 35% of the world population (FAOSTAT, 2011). It is the major staple crop in the Eastern Gangetic Plains (EGP) of South Asia, a region comprising the plains of eastern India, southern Nepal, Bangladesh and Pakistan. This region is regarded as a low-income region with a vast number of small and marginalized farmers. The acreage under wheat cultivation in this region is over 36 million ha which is around 16% of the global wheat area and produces 15% of the global wheat (CIMMYT, 2009).Wheat ranks third important crop in Nepal with the production and productivity of 15, 57,000 Mt and 2.129 t/ha, respectively (MOAC, 2010). It contributes 7.14% to agricultural gross domestic products (MOAC, 2010).

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[1]Crop Development Training Officer, Regional Agricultural Training Center, Pokhara, Nepal. Ph: 9846043660, Email: dgogene@gmail.com

[2] Assistant Professor, Department of Genetics and Plant Breeding, Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal.

[3] Associate Professor, Department of Genetics and Plant Breeding, Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal.

Water is becoming scarce for wheat crop in south Asia as less water recharge from rainfall (Singh, 2000). Moisture stress is one of the major abiotic factors limiting wheat production worldwide (Richards et., 2001). In a survey that covered 102 million hectares of wheat area in the developing countries (47% global wheat area or 89% of the wheat area in developing countries) revealed moisture stress as one of the major constraints to wheat production with and estimated annual yield loss of 19 to 50% (Kosina et al., 2007). Annual wheat yield loss of up to 15% has been reported due to drought stress in the UK (Foulkes et al., 2007).

Drought stress has been recognized as one of the major abiotic factors limiting wheat production in India (Joshi et al., 2007), Pakistan (Kisana et al., 2008) and Nepal (Bhatta et al., 2008). In Nepal, drought majorly winter drought constraints on yields have increased in importance as climate change leads to increasingly hotter and drier days (WFP, 2009). As a result, crop growth rate is reduced and yield is lowered. Despite these risks, there is a large untapped yield potential by screening drought tolerant crop genotypes of different crops in rain-fed agriculture that needs to be explored.

Nepal being the hotspot of biodiversity (Shrestha and Shrestha, 1999) encompasses the existence of four hundred and five local landraces of wheat local landraces from northwestern districts of Jumla and Humla. Genetic resources provide an invaluable gene pool for crop breeding (Reynold et al., 2007), the majority of wheat landraces in Nepal were uncharacterized for drought tolerance and their potential to improve drought adaptation is not quantified.

Information regarding character association is of paramount importance for a plant breeder to ascertain the expected response of other characters when selection is exercised to the character of interest in a breeding program and it is measured by coefficient of correlation (Dabholkar, 1992). Khaliq et al. (2008) reported positive association of flag leaf area and grain yield in bread wheat. Correspondingly, specific flag leaf area also exhibited strong positive relationship with yield, while negative association with specific leaf weight. Relative water content was found positively associated with the relative dry weight (Clarke et al.,1991). Tiwari and Rawat (1993); Sharma et al.,(1995) and Yagdi and Sozen (2009) reported that grain yield per plant in wheat was significantly and positively correlated with plant height, ear length, tillers per plant, biological yield and ears per plant. Biological yield in wheat showed positive and significant correlation with grain yield, tillers per plant, test weight and flag leaf area, while negative association with days to heading and harvest index (Munir et al., 2007). Subhani and Chowdhry (2000) found a positive relationship of grain yield with flag leaf area, plant height , spike length, grains per spike, test weight, biomass per plant and harvest index, while days to booting shows negative correlation with grain yield.

OBJECTIVES

This study was designed to screen different genotypes of wheat in a semi-controlled experimental setup with two contrasting moisture regimes, (1) moisture stressed and (2) optimum moisture, in order to identify important drought adaptive traits and variability in these traits. The objectives of the study were to screen 60 different genotypes of wheat for drought stress tolerance and estimate the range of variability present for these traits and t study the co-relation among the selected morpho-physiological traits of wheat evaluated under two contrasting moisture regimes.

MATERIALS AND METHODS

This study was conducted in a Greenhouse of Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan, Nepal in 2009. In total 60 wheat genotypes were included in the study. This comprised of 24 Nepalese wheat landraces obtained from the Agricultural Botany Division, Nepal Agricultural Research Council (NARC), Khumaltar, Kathmandu; 30 advanced breeding lines from the National Wheat Research Program, NARC, Bhairahawa; three international check cultivars namely, Dharwar Dry (drought tolerant), Hartog (standard high yielding cultivar) and SeriM82 (a high yielding cultivar recommended for water limiting areas). Dharwar Dry is an Indian landrace selected by CIMMYT for dry areas, whereas, Hartog and SeriM82 are Australian cultivars.The seeds of these three wheat cultivars were kindly provided by the Queensland Department of Primary Industries and Fisheries, Leslie Research Centre, Australia. In addition to this, 3 Nepalese commercial cultivars- Gautam, Bhrikuti and Vijaya were also included in the study. The details of the wheat genotypes used in this study are given in Table 1.

DESIGN AND LAYOUT OF THE EXPERIMENT

The experiment was laid out in split plot design with optimum moisture and moisture stressed environments as main plot factors and 60 wheat genotypes as sub-plot factors. Each set of experiment was replicated three times. Plastic bins (n = 360) of 12 cm diameter and 30 cm depth, purchased from the local market were used to raise wheat genotypes in the Greenhouse. Daily temperature and relative humidity of the green house were taken. The minimum, maximum, mean air temperature and relative humidity recorded during the water stress imposed period of the experiment is shown in the Figure 1.

Each pot was filled with 7.5 kg of sandy loam soil (moisture content at 75% field capacity) taken from the wheat-growing field of IAAS research farm. Three seeds of each genotype were sown in each pot in December 06 2009. Thinning was done on January 06 2010 and single seedling of each line was maintained in each pot. All the pots of irrigated set were watered weekly to maintain initial soil moisture content (sandy loam with 75% of field capacity), i.e., 7.5 kg weight throughout the experiment. For moisture stressed experiment, soil moisture content was maintained at 35 % of field capacity (i.e., 6.5 kg soil weight) by withholding watering at tillering (growth stage 20, Zadok scale) until harvested at flowering stage (growth stage 60, Zadok scale). Evapo-transpiration was recorded for each pot regularly and the amount of water transpired by the plants was estimated based on six evaporation control pots randomly placed in the greenhouse.

Table 1. Details of the sixty wheat genotypes and their origin/ source.

S.N.	Genotype	Type[1]	Source	S.N.	Genotype	Type[1]	Source
1	BL 3791	Adv. Line	NWRP	31	BL 3787	Adv. Line	NWRP
2	Dharwar dry	Landrace	QDPIF/India	32	ABL17	Adv. Line	NWRP
3	SeriM82	Adv. Line	QDPIF/ CIMMYT	33	NPGR 5610	Landrace	Nepal
4	Hartog	Cultivar	QDPIF/Australia	34	NPGR 5988	Landrace	Nepal
5	BL 3798	Adv. Line	NWRP	35	NPGR 6001	Landrace	Nepal
6	Bhrikuti	Cultivar	NWRP/Nepal	36	NPGR 6573	Landrace	Nepal
7	BL 3827	Adv. Line	NWRP	37	NPGR 6612	Landrace	Nepal
8	BL 3845	Adv. Line	NWRP	38	NPGR 6696	Landrace	Nepal
9	Gautam	Cultivar	NWRP/Nepal	39	NPGR 7439	Landrace	Nepal
10	BL 3899	Adv. Line	NWRP	40	NPGR 7487	Landrace	Nepal
11	BL 2800	Adv. Line	NWRP	41	NPGR 7504	Landrace	Nepal
12	BL 3924	Adv. Line	NWRP	42	NPGR 7782	Landrace	Nepal
13	BL 3940	Adv. Line	NWRP	43	NPGR 7789	Landrace	Nepal
14	ABL1	Adv. Line	NWRP	44	NPGR 8228	Landrace	Nepal
15	ABL2	Adv. Line	NWRP	45	NPGR 8232	Landrace	Nepal
16	ABL3	Adv. Line	NWRP	46	NPGR 8233	Landrace	Nepal
17	ABL4	Adv. Line	NWRP	47	NPGR 8748	Landrace	Nepal
18	ABL5	Adv. Line	NWRP	48	NPGR 8749	Landrace	Nepal
19	ABL6	Adv. Line	NWRP	49	NPGR 8752	Landrace	Nepal
20	ABL7	Adv. Line	NWRP	50	NPGR 8753	Landrace	Nepal
21	ABL8	Adv. Line	NWRP	51	NPGR 8762	Landrace	Nepal
22	ABL9	Adv. Line	NWRP	52	NPGR 8903	Landrace	Nepal
23	ABL10	Adv. Line	NWRP	53	NPGR 8904	Landrace	Nepal
24	ABL11	Adv. Line	NWRP	54	NPGR 8911	Landrace	Nepal
25	ABL12	Adv. Line	NWRP	55	NPGR 9447	Landrace	Nepal
26	ABL13	Adv. Line	NWRP	56	NPGR 10548	Landrace	Nepal
27	ABL14	Adv. Line	NWRP	57	NL 1042	Adv. Line	NWRP
28	ABL15	Adv. Line	NWRP	58	BL 3625	Adv. Line	NWRP
29	ABL16	Adv. Line	NWRP	59	Vijaya	Cultivar	NWRP/Nepal
30	BL3561	Adv. Line	NWRP	60	BL3555	Adv. Line	NWRP

[1]Adv. lines=Advanced breeding lines. NWRP=National Wheat Research Program, QDPIF=Queensland Department of Primary Industries and Fisheries (Australia).

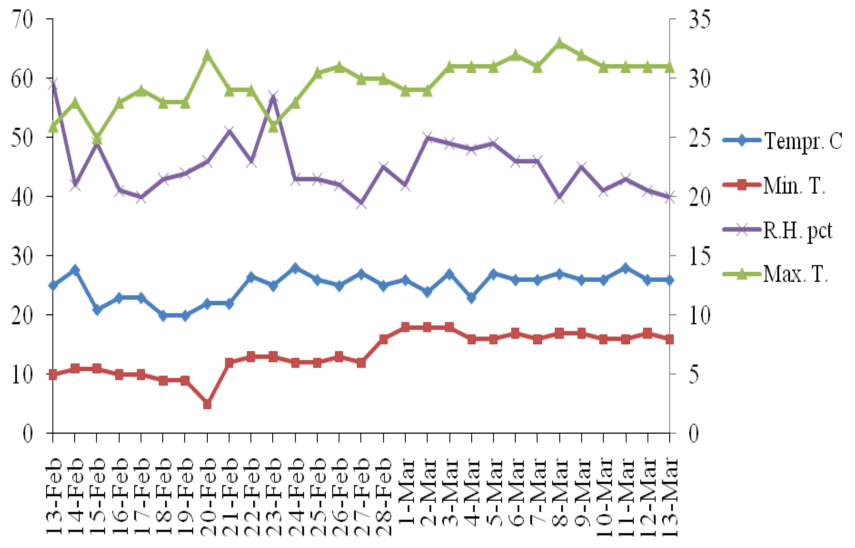

Figure 1. Minimum, maximum and mean temperature and relative humidity of the green house during the research 2009.

DATA RECORDING AND ANALYSIS

The observations were taken for the following morpho-physiological characteristics.

Water Use and Water Use Efficiency

Water use by different wheat lines were estimated by weighing the pot on a weekly interval. In addition, for water use efficiency the biomass weight from each plant was divided by the water use per plant to get the water use efficiency.

Water Use Efficiency = Biomass production /Water use

Number of Tillers per Plant

The number of effective tillers per plant was determined at the flowering stage of wheat (growth stage 60, Zadok scale).

Plant Height

The plant height was measured from the soil surface in cm up to the height of the top of the uppermost spikelet at the time of harvesting.

Phenological Periods

Days to booting, heading and anthesis were recorded.

Biomass Production per Plant

Biomass yield per plant was determined as gram per plant. Above ground biomass yield was taken at the flowering stage for both moisture stressed and irrigated condition.

STATISTICAL ANALYSIS

Data were processed in the Microsoft Office Excel 2007. Analysis of variance and means were computed with GENSTAT software (Discovery Edition package) developed by VSN International. Paired t-test (was used to analyze the difference between the moisture stressed and not stressed condition) and correlation analysis was done with SPSS 16.

RESULTS AND DISCUSSIONS

PHENOLOGICAL PARAMETERS

The days to booting, days to heading and days to anthesis of wheat evaluated under the optimum moisture regime were 73, 81 and 83 respectively whereas it was 69, 77 and 80 under the moisture stressed condition. Analysis of variance reveled that there is a highly significant differences among the genotypes used in this experiment (Table 2). The phenological parameters in the two contrasting moisture regimes were statistically highly significant (Table 3).

Table 2. Mean squares of ANOVA of morpho-physiological traits as influenced by moisture regime and genotypes at Greenhouse, Rampur, Chitwan 2009.

Source	Df	Days to booting	Days to anthesis	Water use	Biomass production	WUE	Plant height	No. of tillers
Replication	2	3.17	17.72	0.1287	0.727	9.493	1161.21	1.433
Moisture regime (A)	1	1472.18	1625.62**	108.1**	3009.67**	306.02**	16889.12	41.344*
Error (a)	2	8.25	16.97	0.1061	12.326	3.361	795.007	2.211
Genotypes (B)	59	65.96**	46.95**	0.1156**	21.573**	17.078**	1056.06**	1.459**
A×B	59	14.41	3.44	0.111**	5.99**	12.498**	1140.11	0.841
Error (b)	236	17.39	16.17	0.0617	3.588	3.755	1026.87	0.926

, * Significant at 0.05 and 0.01 probability levels, respectively. Df: degree of freedon; WUE: Water use efficiency

Olivares-Villegas *et al.* (2007) found reduction in days to booting, heading and anthesis in wheat crop by 10% in moisture stress condition. Reduced growth duration is associated with reduced leaf number (Blum, 2005). Early flowering has been associated with drought escape in spring wheat in environments subjected to severe early season drought stress.

Table 3. Significance test of environment means for the phenological parameters in 60 wheat genotypes.

Treatment	Days to booting	Days to heading	Days to anthesis
Irrigated mean	73.1830	81.3055	83.5556
SEM (irrigated condition)	0.46018	0.38484	0.38316
Drought mean	69.1386	77.055	80.1611
SEM (drought condition)	0.48449	0.36309	0.32845
t- value	10.108**	21.743**	15.884**

, * Significant at 0.05 and 0.01 probability levels, respectively. SEM = Standard error of mean

WATER USE

The amount of water used (WU) by different genotypes of wheat in optimum moisture environments ranged from 1266 to 2390 ml, whereas in moisture stressed environment, WU ranged from 606 to 880 ml which was shown in the Figure 2. The genotype vs. moisture regime interaction for WU was highly significant (Table 2) indicating water use pattern of genotypes changed with water availability. This is in conformity with result of Dodig et al., (2008). BL2800, Gautam, Hartog, and Dharwar dry had higher WU values in non stressed environment in contrast to SeriM82, NPGR6696, Vijaya and Bhrikuti which used minimum water during the test period.

BIOMASS PRODUCTION

he amount of biomass produced by different genotypes of wheat was found highly significant (Table 2) and also for optimum and moisture stressed conditions (Table 4). The average biomass weight was 12.3543 g in optimum moisture condition whereas it was 6.5715 g in stressed condition. The biomass production ranged from 3.52 to 17.82 g in non-stressed environment and 3.26 to 7.43 g in moisture stressed environment. The mean biomass produced by the wheat genotypes in moisture stressed environment was significantly lower than that in the non stressed environment. Reduction in biomass due to moisture stress had been reported by Zhu et al. (2008). Under optimum moisture, NPGR 8762, ABL 17 and Gautam had the highest biomass. Similarly, in moisture stressed condition, NPGR 8753, NL 1042 and Gautam had the highest biomass. The drought tolerant Indian landrace Dharwar dry and Nepalese cv. Vijaya had average biomass, whereas, NPGR 8753, ABL12 and NPGR 8228 had minimum biomass production.

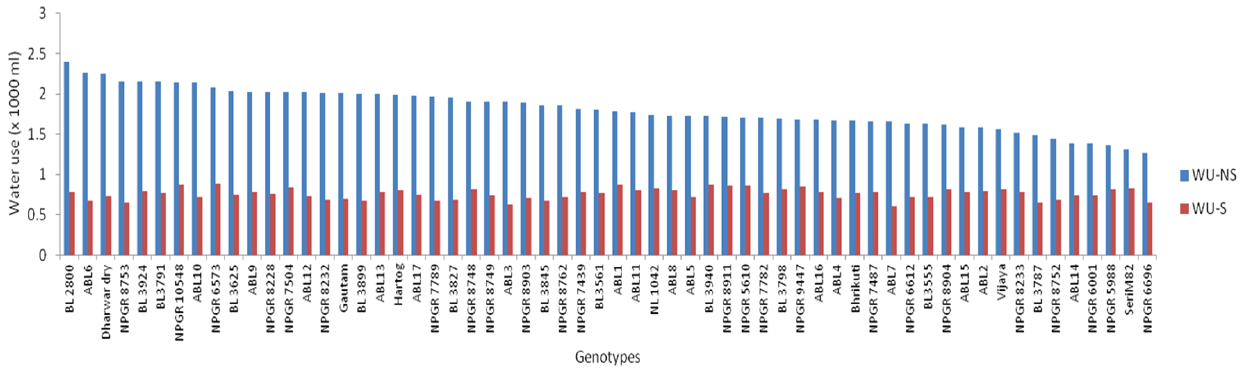

Figure 2. Water use (ml) by the 60 wheat genotypes measured in optimum (WU-NS) and moisture stressed (WU-S) environment. The genotypes are arranged (L to R) in decreasing order of WU values in optimum moisture environment.

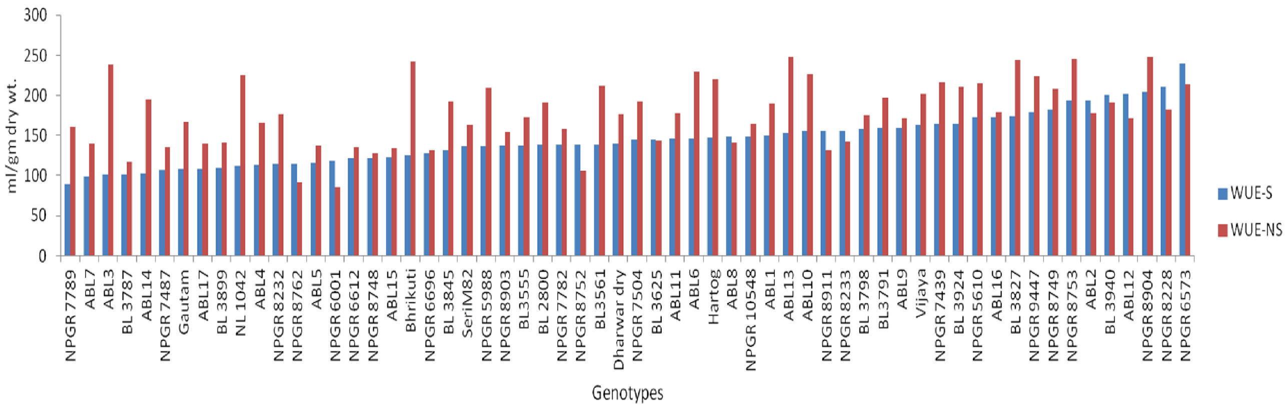

Figure 3. Water use efficiency (ml/gm dry wt.) of the 60 genotypes assessed in optimum WUE-NS) and moisture stressed (WUE-S) environment. The genotypes are arranged (L to R) in increasing order of WUE values in stressed environment.

Table 4. Significance test of environment means for the morpho-physiological traits in 60 wheat genotypes.

Treatments	Water use (l)	Biomass production (g)	Water use efficiency (g/l)	RWC (%)	Plant height (cm)	Number of tillers
Irrigated Mean	1.8565	12.3543	5.5792	73.0629	64.1544	2.3889
SEM (irrigated condition)	0.03437	0.45101	0.23677	1.14634	0.85158	0.9005
Drought Mean	0.7606	6.5715	7.2153	68.4713	57.0961	1.7111
SEM (drought condition)	0.00887	0.18938	0.19906	0.85227	0.66660	0.06837
t- value	31.187**	11.832**	-6.318**	2.957*	6.911**	7.009**

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

WATER USE EFFICIENCY

The water use efficiency (WUE), estimated as total water (ml) transpired per unit dry matter produced (g) varied from 248.12 to 85.83, and 239.20 to 88.67 in optimum and moisture stressed environments, respectively (Figure 3). The expression of WUE was more pronounced in moisture stressed environment. Similar results with improved WUE of winter wheat cultivars grown with limited irrigation has been reported by Zhang et al. (1998) andPoormohammadKiani et al. (2007) in sunflower. In the present study, the most water use efficient wheat genotypes were NPGR 7789, NPGR 6001, ABL7 and ABL3. The popular cv. Gautam was found water use efficient, whereas Bhrikuti, SeriM82 and Dharwar dry were found moderately efficient. The Australian cultivar Hartog, NPGR 6573 and Nepalese cv. Vijaya were characterized poor in WUE. It is worthwhile to mention that ABL3, NL1042 and Bhrikuti were highly water use efficient in moisture stressed condition, however, showed a high level of genotype x environment interaction for WUE. Manschadi et al. (2007) characterized the CIMMYT line SeriM82 and Dharwar dry as drought tolerant and Hartog as a drought sensitive in Australia. The WUE estimated for these genotypes in this experiment also hinted for a similar pattern of drought adaptation (Figure 3).

PLANT HEIGHT

The plant height of 60 wheat genotypes was found highly significant as shown by the analysis of variance (Table 2) and was also highly significant for optimum moisture and stressed conditions as shown by paired t-test (Table 4). The average value of plant height in non stressed condition was 64.15 cm whereas it was 57.09 cm in drought condition. All the genotypes were found taller in non stressed condition. Genotypes namely Gautam, Hartog and Vijaya were found taller; Bhrikuti was average in height; Dhawar dry and SeriM82 were shorter in height. Olivares-Villegas *et al.* (2007) found large difference in the plant height in response to the reduced soil water availability and the range in height reduction under drought condition varied from 10 to 53%, a reduction paralleled by a yield decrease.

NUMBER OF TILLERS

Drought had a pronounced effect on number of tillers per plant. The number of tillers for the 60 wheat genotypes was found highly significant (Table 2) and also between optimum and moisture stressed condition as shown by paired t-test (Table 3). The average number of tillers in irrigated condition was 2.38 whereas 1.71 in stressed condition.Early water stress in barley was found to damage the number of tillers which strongly reduced yield potential (Sahnoune *et al.,* 2004). Genotypes, SeriM82, and Vijaya had less number of tillers, Gautam average and Bhrikuti, Hartog and Dhawardry has larger number of tillers for both the moisture regimes. However, there was a reduction of tillers by 13% on an average under moisture stressed condition.

CORRELATION STUDY

Pearson's correlation coefficients among the selected physiological traits under moisture stressed and non stressed condition are presented in Table 5. In case of moisture non stressed condition, water use was positively correlated and highly significant with relative water content (RWC) (0.392), flag leaf area (0.273), plant height (0.455), leaves number (0.335), flag leaf length (0.442) and tiller number (0.413). However, water use was negatively correlated with days to anthesis (-0.018) and highly significant negative correlation water use efficiency (-0.381).

Biomass production was found to be highly significantly positive correlation with water use efficiency (0.607) and negative correlation with RWC. Days to booting were highly significant and positively correlated with flag leaf area (0.377). Whereas, days to heading and anthesis had highly significant and positive correlation with leaves number. Days to anthesis were found to be positively related and highly significant with days to heading (0.676) and days to booting (0.674). Days to anthesis was found to be significant and positively correlated with the number of tillers (0.296).

In case of moisture stressed condition, water use was positively correlated with RWC, days to booting and days to anthesis. However, it was highly significant and negatively correlated with WUE (-0.518) and negative correlation with days to heading and biomass production. Water use is highly significant and positively correlated with flag leaf area (0.505), plant height (0.523), leaves number (0.354) and positively significant correlation with flag leaf length (0.279) and number of tillers (0.262). Biomass production was highly significant and positively correlated with WUE (0.578). WUE is highly significant and negatively correlated with flag leaf area (-0.364) and plant height (-0.354). Flag leaf area was highly significant and positively correlated with flag leaf length (0.760). Leaf number was highly significant and positively correlated with days to booting (0.367) and number of tillers (0.893), whereas significant and positive correlation with days to heading and anthesis. Similar findings were also reported by Munir *et al.,* (2007).

Table No 5. Correlation coefficients among morpho-physiological traits based on 60 wheat genotypes evaluated for drought tolerance in Rampur, Chitwan.

	WU S	BM S	WUE S	RWC S	FLA S	PHT S	LFNO S	FLL S	Bootday S	Headday S	Anthday S
	WU NS	BM NS	WUE NS	RWC NS	FLA NS	PHT NS	LFNO NS	FLL NS	Bootday N	Headday N	Anthday NS
BM S	-0.198										
BM NS	0.133										
WUE S	-0.518**	0.578**									
WUE NS	-0.381**	0.607**									
RWC S	0.039	0.054	0.250								
RWC NS	0.392**	-0.78	-0.219								
FLA S	0.505**	-0.209	-0.364**	-0.247							
FLA NS	0.273**	0.212	0.009	0.113							
PHT S	0.523**	0.023	-0.354**	-0.062	0.289*						
PHT NS	0.455**	0.119	-0.119	0.143	0.182						
LFNO S	0.354**	-0.093	0.035	0.166	0.016	0.201					
LFNO NS	0.355**	0.118	-0.065	0.117	0.130	0.184					
FLL S	0.279*	-0.129	-0.161	-0.312*	0.760**	0.199	0.070				
FLL NS	0.442**	0.167	-0.087	0.119	0.707**	0.342**	0.187				
Bootday S	0.077	0.027	0.139	0.097	0.099	0.175	0.367**	0.142			
Bootday NS	0.93	-0.24	0.002	0.094	-0.052	0.377**	0.210	0.053			
Headday S	-0.035	-0.063	0.103	0.003	0.180	-0.030	0.308*	0.221	0.513**		
Headday NS	0.018	-0.44	0.043	0.098	-0.014	0.245	0.349**	0.132	0.676**		
Anthday S	0.041	-0.019	0.027	0.037	0.197	0.149	0.310*	0.188	0.589**	0.905**	
Anthday NS	0.018	-0.034	0.013	0.070	0.028	0.240	0.369**	0.099	0.674**	0.933**	
tillerno S	0.262*	-0.175	0.023	0.177	-0.019	0.166	0.893**	0.071	0.250	0.182	0.160
tillerno NS	0.413**	0.144	-0.075	0.111	-0.076	0.263*	0.662**	0.100	0.295*	0.322*	0.296*

*, ** Significant at 0.05 and 0.01 probability levels, respectively. (NS: non stressed condition and S: moisture stressed condition). WU: Water use; BM: Biomass weight; WUE: Water use efficiency; RWC: Relative water content; FLA: Flag leaf area, PHT: Plant height; LFNO: Leaf numbers; FLL: Flag leaf length; Bootday: Booting days; Headday: Heading days; Anthday: Anthesis days; tillerno: Tiller number.

Days to booting were highly significant and positively correlated with days to heading (0.513) and days to anthesis (0.589). Days to heading were highly significant and positively correlated with anthesis days (0.905). Tillers per plant were positively correlated with almost all the traits in both the crosses but negatively associated with days to heading. The interrelationship between these traits showed that they are under the control of certain common genes, which can be exploited as selection criteria in breeding programs. The positive selections for one trait would also improve the other coorelated traits. This study suggested that drought tolerance showed genotypic correlations, which could lead to predictable correlated responses that can be usefully exploited for selection of drought tolerant of wheat from the breeding programs.

CONCLUSIONS

Water use, water use efficiency, biomass yield and flag leaf relative water content are the important drought tolerance traits in wheat (Richards et al., 2002; Rampino et al., 2006). This study revealed a wide range of variability for these traits in Nepalese wheat germplasm, particularly, in landraces and advanced breeding lines. This information can be utilized for wheat improvement for drought stressed environments. Among Nepalese cultivars, Gautam was found superior; Bhrikuti was found average in terms of drought adaptability, whereas Vijay was characterized as drought sensitive. A number of landraces and advanced breeding lines possessed drought tolerance attributes. Landrace NPGR 7504 is a perspective source of favorable alleles for drought adaptation breeding. As a matter of fact that the present study was based on single plant performance and did not include a full crop cycle as well as grain yield, results are indicative and further experimentation is required to verify the findings.

REFERENCES

Blum, A., 2005. Drought resistance, water-use efficiency, and yield potential- are they compatible, dissonant, or mutually exclusive? Australian Journal of Agricultural Research, 56: 1159-1168.

CIMMYT, 2009. CIMMYT Homepage; URL: www.cimmyt.org

Clarke, J.M., R.A. Richards, and A. G. Condon, 1991. Effect of drought on residual transpiration and its relationship with water use of wheat. Canadian Journal of Plant Sciences, 71:695-702.

Dabholkar, A. R. 1992. Elements of Biometrical Genetics. Concept Publication Camp., New Delhi, India.

Dodig, D., M. Zoric, D. Knezevic, S. R. King and G. Surlan-Momirovic, 2008. Genotype x environment interaction for wheat yield in different drought stress conditions and agronomic traits suitable for selection. Australian Journal of Agricultural Research, 59: 536-545.

FAOSTAT, 2011. FAOSTAT Homepage; URL : faostat.fao.org

Khaliq,I., A. Irshad, and M. Ahsan, 2008. Awns and flag leaf contribution towards grain yield in spring wheat (Triticum aestivum L.). Cereal Research Communication, 36:65-76.

Manschadi, A.M., G.L. Hammer, J.T. Christopher and P. deVoil, 2007. Genotypic variation in seedling root architectural traits and implications for drought adaptation in wheat (*Triticum aestivum* L.). Plant and Soil, 303: 115-129.

MOAC, 2010. Statistical information on Nepalese agriculture. Nepal Government, MOAC, Agri-Business Promotion and Statistics Division, Singh Durbar, Kathmandu, Nepal.

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

Olivares-Villegas, J. J., M. P. Reynolds, and G. K. McDonald, 2007. Drought-adaptive attributes in the Seri/Babax hexaploid wheat population. Functional Plant Biology, 34: 189-203.

Poormohammad Kiani, S., P. Grieu, P. Maury, T. Hewezi, L. Gentzbittel and A. Sarrafi, 2007. Genetic variability for physiological traits under drought conditions and differential expression of water stress-associated genes in sunflower (*Helianthus annuus* L.). Theoretical and Applied Genetics, 114 (2):193-207.

Rampino, P., S. Pataleo, C. Gerardi, G. Mita and C. Perrotta, 2006. Drought stress response in wheat: physiological and molecular analysis of resistant and sensitive genotypes. Plant Cell Environment, 29: 2143-2152.

Reynolds, M. P., A. Mujeeb-Kazi, and M. Sawkins, 2005. Prospects for utilizing plant-adaptive mechanisms to improve wheat and other crops in drought and salinity-prone environments. Annals of Applied Biology, 146: 239–259.

Reynolds, M.P., C. Saint Piere, Abu S. I. Saad, M. Vargas and G. Condon, 2007. Evaluating potential genetic gains in wheat associated with stress-adaptive traits expression in elite genetic resources under drought and heat stress, Crop Science, 47(S3): S172-S189.

Richards, R. A., G. J. Rebetzke, A. G. Condon, A. F. Herwaarden, 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. Crop Science, 42:111-121.

Sahnoune, M., A. Adda, S. Soualem, M. K. Harch, and O. Merah, 2004. Early water-deficit effects on seminal roots morphology in barley. Agronomy, 327: 389-398.

Sharma, D. J., R. K. Yadav, and R. K. Sharma, 1995. Genetic variability and association for some yield components in winter×spring nursery of wheat. Advances of Plant Sciences in India. 8:95-99.

Shrestha, G. L., and B. Shrestha, 1999. An overview of wild relatives of cultivated plants in Nepal. In: G. L. Shrestha and B. Shrestha (eds.) Proceedings of National Conference on wild relatives of cultivated plants in Nepal. Green Energy Mission, Nepal. pp 19-23.

Singh, R. B. 2000. Environmental consequences of agricultural development: a case study from the green revolution state of Haryana. Agriculture, Ecosystem and Environment, 82:97-103.

Subhani, G. M., and M. A. Chowdhry, 2000. Correlation and path coefficient analysis in bread wheat under drought stress and normal conditions. Pakistan Journal of Biological Sciences. 3:72-77.

WFP, 2009. Food Security Bulletin-23. May 2009. Nepal Food security Monitoring system of WFP, Nepal. 6 p.

Zhang, J., X. Suib, B. Lib, B. Sub, J. Lib and D. Zhoub, 1998. An improved water-use efficiency for winter wheat grown under reduced irrigation. Field Crops Research, 59 (2): 91-98.

Zhu, L., Z.S. Liang, X. Xu, S.H. Li, J.H. Jing, and P. Monneveux, 2008. Relationships between carbon isotope discrimination and leaf morphophysiological traits in spring-planted spring wheat under drought and salinity stress in Northern China. Australian Journal of Agricultural Research, 59:941-949.