Rice Genotypes Response to Mid Season Stress on Fertility and Yield at High Altitude

B.B. Bandyopadhyay*

Govind Ballabh Pant University of Agriculture and Technology, Uttarakhand

Abstract

Altitudinal effect of mid season stress which coincided with microspore development stage to anthesis period was examined on 58 rice genotypes. Seeds were planted at the end of March. Mid season growth of plants coincided with high rainfall. An ideal situation of grain production in rice on high hills was determined by significant relation between spikelet fertility and grain yield while stress factors were identified by their significant association with environmental components. Except earliest among early (EEM) and late (LM) maturity group, a reduction in likelihood of these relationships was observed for other rice genotypes. It was presumed that physical separation of pollen grains with stigmas and/or more complex interaction between genotype and environmental factors perhaps constituted this relationship. Variation in soil temperature appeared as major limiting factors for EEM and LM genotypes. The distribution of root in soil, higher capacity of transport system during the period of reduced water uptake, osmotic adjustment of cell for greater water availability and increasing ability of phosphorylation bylight harvesting protein complex of PS II would be considered as effective measures to reduce stress factors on high hills. Regression analysis revealed that pre-fertilization development of carpel, determined grain yield among LM rice genotypes on high altitude.

Key words : Rice, high altitude, cold stress.

Altitudinal effect is an important stress on rice that results in delayed heading and yield reduction due to spikelet sterility, poor fertilization efficiency and impaired seed growth. It is presumed that a combined influence of both air and soil temperature affect the vegetation (Patil and Sinha, 2006) and imposes restriction on stable production of rice (Gunawardena et al., 2003) on high altitude areas of hills. On high hills, atmospheric temperature declines with increase in elevation (Schwerdtfeger, 1976) while heat conduction in soil is governed by the thermal properties (Koorevaar *et al*., 1983) that are strongly dependent on distribution, intensity and volume of rain fall received at growing site. In areas with cool spring, rice seeds are planted in May and only genotypes of medium or short duration can be grown, that results in reduction of grain

*Corresponding author: bbbandyopadhyay@rediffmail.com

yield. On higher altitude, planting of rice seeds in May is not preferred as daily average and minimum temperature fall below 15 and 10^0C, respectively during post-flowering period. This indicates that a coincidence of grain filling stage with the period of potential maximum photosynthesis and suitable temperature regime seems to be important for grain yield (Farrell et al., 2006) on high hills. On the contrary, rice plants are injured due to low temperature at the seedling stage when seeds are planted early spring (Andaya and Mackill, 2003). As the season progresses, rise in temperature and high intensity of sun light encourage pre-flowering growth of plants, while exposing the plant to cool summer damage (Yajima, 1996). The type of cold injury varies depending upon stress level and duration of exposure (Bertin et al., 1996) and becomes difficult to identify factor responsible for stress tolerance because genes contributing to vigour might be different from genes conferring tolerance (Zhang et al., 2005) and the traits that appear important in one environment may not always be important in other environment in determining the phenotype (Tanksley, 1993). High altitude genotypes have not contributed much to the ancestry of cultivated rice; therefore, identification of rice genotypes adapted to altitudinal variations has become important as potential source of genes tailored to confer tolerance to low temperature environments. Field evaluation is the only practical procedure to evaluate high altitude cold tolerance of rice. No attempt to relate these climatic factors to rice production was made for high hill condition in Uttarakhand state. In this investigation, rice genotypes response to mid season cold stress on spikelet fertility and yield was examined under rainfed condition at high altitude.

Materials and Methods

In this investigation a set of 58 temperate rice germplasm was considered for evaluation. This included exotic materials and local collection of land races from high altitude regions. The experiment was conducted for two successive years (2006-2007) at an elevation of 2100 m at Ranichauri ($30^0 18'$ N and $78^0 24'$E) under rain fed condition. Seeds were planted early (March end) in a homogenous field. Experiment was laid out in randomized block design with 3 replications. Each plot consists of 4 rows of 4 m in length. Spacing between rows and plants was maintained at 0.20 and 0.15 m. To facilitate production of uniform plant stand excess plants were removed at seedling stage. Recommended dose of fertilizer were applied and scheduled plant protection measures were adopted to obtain disease free and healthy plants in field. The most vigorous 50 plants were selected at early vegetative growth on field and labeled properly at microspore development stage (MS) that was determined by the distance between the ligule of the flag leaf and that of the penultimate leaf (Yoshida, 1981), considering an interval of -1 cm (flag leaf ligule below the penultimate leaf ligule) as the indicative of beginning of this

stage. In the present study, panicle developed on main shoot was examined. Time required to attain microspore development (MS), panicle emergence (PE) and anthesis (AN) stage on individual plant were recorded by careful observation at 3 days interval from 75 days after date of planting seeds (DP) on field. PE was determined by 25 % visibility of panicle above flag leaf ligule on main shoots while anthesis period (AN) was considered when anther burst in 25% of the visible spikelets present on a panicle. A sample of 30 good and healthy spikelets among 50 selected plants was harvested randomly at maturity for recording observation on grain yield (GY), per cent spikelt fertility (SF), 100 seed weight (SW) and length and breadth ratio of seeds (l:b). Per cent spikelet fertility was obtained by counting the number of filled grain (FG) and empty spikelets on individual spike and express as per cent of filled spikelets in relation to the total number of spiketlets (NS) present on a panicle. Information of environment components on growth and development of plant characters were obtained by collecting meteorological data from respective department of G.B.P.U.A.&T., situated at Hill Campus. Daily maximum and minimum air temperature (Mxt and Mnt respectively) accompanied with volume of rainfall (RF) received and relative variation in maximum and minimum soil temperature at three different depth viz., (ST_1, ST_2, ST_3 at 5, 10, 20 cm, respectively) were recorded. An estimation of average (Avt) and diurnal (Dut) variation of air temperature and average difference in maximum and minimum soil temperature at three different levels of depths (ST_1- ST_2, ST_2 – ST_3 and ST_1 – ST_3) were computed. Cumulative values of thermal time (express in degree days) were calculated for all components of air and soil temperature on individual rice genotypes at two different phenophase of crop growth viz., MS – PE and PE – AN. Total volume of rain fall experienced during respective stage of development was also determined for individual genotype. Six plant traits and 37 environment components (Table 1) at respective phenophase (MS-PE and PE-AN) were subjected to correlation analysis. Significant association between two variables was measured by *t* test. Since the place of origin of a variety is not a sufficient guarantee for possessing high cold tolerance (Ravilla et al., 1998) significant association between SF and GY was considered as major determinant for identifying favourable environment for crop growth on high hills. A reduction in likelihood of relationships between SF and GY was disallowed for consideration of study, while their (SF and GY) non-significant association with environment components had allowed to classify the rice genotypes into shorter range of different maturity groups and were subjected to correlation analysis afresh for second time to observe the significant influence of environment factors controlling the expression of SF and GY to individual sub-groups separately. In this investigation entire rice genotypes (T) were

divided into early (EM, 104-130 days), medium (MM, 131-145 days) and late (LM, 146-165days) maturity groups depending upon time of panicle emergence under field condition. EM was further classified into earliest among early (EEM, 104-110 days), medium among early (MEM, 110-120 days) and late among early maturity (LEM, 120-130 days) groups. Different maturity groups of rice genotypes that exhibited significant correlation of environment components with SF and GY were subjected to combined and separate (with or without association of SF) regression analysis to determine the relation of important environment factors constituting variation in GY on high altitude.

Results and Discussion

The climatic condition remained favourable for normal growth and development of rice plants on hills during experimental period. An appreciable rainfall (1012.2 mm) was experienced during growing season and received 30.4, 48.5, 71.7, 362.3, 370.1, 124.3, 4.9 and 0.0 mm rains respectively from April to November. Maximum and minimum air temperature ranged between 23.9^0 - 11.8^0 in April and 17.5^0 - 5.6^0 C in November, respectively. Sensitivity of rice genotypes to cool environment brought about variation in maturity of reproductive phase transition. The differences in timing of reproductive phase transition had resulted in the rice genotypes exposed to variable climatic condition during mid season growth on high hills. During experimental period high rains coincided with flowering in most of the entries but two extreme maturity groups of rice cultivars, which fell apart of this critical situation. Among different maturity groups, LEM and MM genotypes had failed to establish significant relation between SF and GY (Table 1). The spikelet fertility (SF) and grain yield (GY) however, registered significant positive correlation with Rf_1 (0.688) and significant negative association with the differences in soil minimum temperature of ST_1 and ST_2 (-0.979) for MM and LEM genotypes, respectively at MS and PE stage of growth. Non-significant association of SF and GY with environment components made it difficult to classify MEM rice genotypes further into shorter range of maturity groups, which implied that no single explanation of cultivar events associated with tolerance. It was presumed that a complex photo-thermal interaction with rice genotypes during rainy season at growing site and/or physical separation between pollen grain and stigma at pollination during high rainfall possibly constituted this relation.

Influence of low temperature effect, in this investigation, appeared in two extreme maturity groups (EEM and LM) of rice genotypes at two different stage (MS-PE and PE-AN) of crop growth (Table 1) depending upon climatic condition on high hills. This suggested that sensitivity of rice to cool environment possibly associated with genotypic

differences in maturity among rice plants. EEM experienced rain during grain filling period while LM was exposed to rain at pre-flowering stage. The correlation coefficient values indicated that soil minimum temperature at ST_1 (-0.619, -0.576) and ST_2 (-0.621, -0.578) exerted significant influence on SF and GY among EEM genotypes at PE-AN stage, contrarily differences in soil minimum temperature between ST_1 and ST_3 (0.463, 0.627), and soil maximum temperature at ST_1, and ST_2 (-0.468, -0.566 and -0.499, -0.494, respectively) at MS-PE stage of growth registered significant relationship with SF and GY for LM genotypes. This indicated that variability in soil temperature and moisture availability in soil at critical stage would determine the efficiency of SF and GY potential of crop. Deficiency of moisture results from high soil temperatures and high irradiance of sun light on hills and affected the transport system of water supply by roots to fulfill the atmospheric demand possibly by changing root hydraulic conductivity. Alternatively it could be stated that an alteration in the capacity for phloem loading and long distance export of plants presumed to be a major limiting factor determining SF and GY of rice genotypes on hills. Early transition of reproductive phase before on set of monsoon, in this investigation, induced moisture deficit stress at critical stage of development for EEM genotypes on account of rise in soil temperature. Subsequent development of spikelets for fertilization, therefore, relies on efficient transport system for water and nutrients (Edmeades and Daynard, 1979) during the period of reduced water uptake. It was assumed that the factors which showed the ability to avoid dehydration or maintain metabolic processes despite dehydration (dehydration tolerance) are more likely to improve both SF and GY (Turner, 1979) among rice cultivars.

Correlation study revealed that more complex genotype x environment interaction was involved in grain production among LM genotypes. Earth surface holds good amount of soil moisture and remained cool after an immediate passage of monsoon during MS-PE stage of crop growth for late maturing rice (LM) genotypes. This indicated that despite genotypic differences in timing of reproductive primordial initiation at growing site, lack of development in cultivar- and stress factors- dependent mechanism of plant for efficient utilization of sucrose at an exposure to different levels of light intensity possibly associated with reduction in GY. It was, therefore, apparent that an increase in photosynthesis capacity (Savitha *et al*., 2000) at different levels of light (Allen and Ort, 2001; Sonoike, 1998) with an enrichment of greater light harvesting protein complex of PS II (Gesch and Heilman, 1999) for phosphorylation, permit an ecotype adapted to colder regions tolerated *in situ* condition of hills better than those ecotypes from warmer regions (Anderson and Mc Naughton, 1973). Barring the photosynthesis related physiology to the plants, the distribution of root in soil (Banba and Ohkuba, 1980),

change in Root:Shoot ratio (Equiza *et al.*, 2001) and the capacity of osmotic adjustment (Long, 1974; Turner, 1986; Hsiao et al., 1984) of LM genotypes would be considered as potential measure to control plant water economy at sub-optimal temperature condition of hills because it allowed continuous growth of roots at lower water potential (Sharp and Davies, 1979) to overcome the response of water limitation and can substantially increase the volume of water available to the plant (Jordan *et al.*, 1983), while a consequent increase in fertility of spikelets and grain yield perhaps associated with the development of viable and engorged pollen grains, increasing the efficiency of interception by stigma, pollen germination and fertilization efficiency (Gunawardana *et al*., 2003).

Significant positive correlation of SW with differences in soil minimum temperature between ST_1 and ST_3 at an interval between MS and PE stage (0.570) and GY (0.513) indicated that carpel growth (weight) at pre-anthesis period may be critical for the determination of yield potential (Scott *et al*., 1983). It was presumed that the variation in soil minimum temperature between ST_1 and ST_3 at early floret development (MS-PE stage) possibly induced genotypic differences in size of reproductive organs of plants and the pre-fertilization genetic control of kernel weight, while the effect of ovary volume on kernel growth could operate via limitation imposed on kernel expansion capacity by developing pericarp derived from the ovary wall. This indicated that those environmental factors influencing water and assimilates availability are known to affect kernel weight. These results are in good agreement to that obtained by Yang et al. (2009) who attributed that after initiation of primodia final yield of crops depended upon pre-fertilization development of carpel from meristem. The importance of root distribution and the capacity of transport system of mother plant, to supply these resources into a kernel, appeared as major causal factors to induce significant differences among rice genotypes on hills. It was, therefore, apparent that the genetic and environmental factors that modify fertility and pre-fertilization development of ovary (carpel) possibly set a limit to final grain weight and yield (Calderini *et al*., 1999) of rice cultivars.

The study on regression analysis (Table 2) revealed differences in soil minimum temperature between ST_1 and ST_3 registered significant positive coefficient (b) values on GY in both combined and separate (with or without association of SF) analysis suggesting that on hills, differences in soil minimum temperature (between ST_1 and ST_3) had immense role on governing GY in LM genotypes while a possible alternative mechanism existed for maintaining spikelet fertility. It was, therefore, apparent that the diversity of symptoms of chilling injury at mid season stress in sensitive genotypes operates through intrinsic developmental process of plant

growth. Extensive research showed that genotypic effects on meristem size, ovary volume and kernel weight were all consistent with additive genetic control, suggesting that they were causally related and an effective selection can make improvement of these traits. This study showed that rice genotypes adapted to hills exhibited greatest potential for cold tolerance and could be useful as a source for the improvement of rice genotypes tolerant to cold.

References

Allen, D.J. and Ort, D R. 2001. Impact of chilling temperature on photosynthesis in warm climate plants. *Trends in Plant Science* 6 : 36-42.

Andaya, V.C. and Mackill, D.J. 2003. Mapping of QTLs associated with cold tolerance during the vegetative stage in rice. *Journal of Experimental Botany* 54 (392) : 2579-2585.

Anderson, J.F. and McNaughton, S.I. 1973. Effect of low temperature on transpiration, photosynthesis, leaf relative water content and growth elevationally diverse plant populations. *Ecology* 54: 1220-1233.

Banba, H. and Ohkubo, T. 1980. Relationship between root distribution of upland crops and its yield. II. Influence of mulching methods, seeding times and plant densities on root distribution of upland – cultured paddy rice and upland rice. *Japanese Journal of Crop Science* 49 (2) : 184-190.

Bertin, P., Kinet, J.M. and Bouharmont, J. 1996. Evaluation of chilling sensitivity in different rice varieties. Relationship between screening procedures applied during germination and vegetative growth. *Euphytica* 89 : 201-210.

Calderini, D.F., Abeledo, L.G., Savin, R. and Salfer, G.A. 1999. Effect of temperature and carpel size during pre- anthesis on potential grain weight in wheat. *Journal of Agricultural Sciences, Cambridge* 132 : 453-459.

Edmeades, G.O. and Daynard, T.B. 1979. The relationship between final yield and photosynthesis at flowering in individual maize plant. Canadian *Journal of Plant Science* 59: 585-601.

Equiza, M., Mirave, J.P. and Tognetti, J.A. 2001. Morphological, anatomical and physiological responses related to differential shoots *vs.* root growth inhibition at low temperature in spring and winter wheat. *Annals of Botany* 87: 67-76.

Farrell, T.C., Fukai. S. and Williams, R.L. 2006. Minimising cold damage during reproductive development among temperate rice genotypes. I. Avoiding low temperature with the use of appropriate sowing time and photoperiod sensitive varieties. Australian Journal of Agricultural Research 57 : 75-88.

Gesch, R.W. and Heilman, J.L. 1999. Response of photosynthesis and phosphorylation of the light harvesting complex of photosystem II to chilling temperature in ecologically divergent cultivars of rice. *Environmental and Experimental Botany* 41 : 257-266.

Gunawardena, T.A., Fukai, S. and Blamey, F.P.C. 2003. Low temperature induced spikelet sterility in rice. II. Effect of panicle and root temperatures. *Australian Journal of Agricultural Research* 54: 947-956.

Hsiao, T.C., O'Toole, J.C., Yambao, E.B. and Turner, N.C. 1984. Influence of osmotic adjustment on leaf rolling and tissue death in rice (*Oryza sativa L.*). *Plant Physiology* 75: 338-341.

Jordan, W.R., Dugas, W.A. and Shouse, P.J. 1983. Strategies for crop improvement for drought prone regions. In :J.F. Stone and W.O. Willis (Editors), Plant Production and Management under drought conditions. Elsevier, Amsterdam, pp 281-299.

Koorevaar, P., Menelik, G. and Dirksen, C. 1983. Elements of Soil Physics. Elesevier, Amsterdam, pp. 228.

Long, W.A.E.,1974. Use of physiological studies for the determination of drought tolerance in

corn. M.Sc. Thesis, University of Guelph, Ontario.

Patil, M.M. and Sinha, S. 2006. Soil temperature distribution with vegetation and rainfall over semi- arid regions of western India. *Mousam* 57 (4) : 688-694.

Ravilla, P., Malvear, R.A., Cartea, M.E. and Ordas, A. 1998. Identifying open pollinated population of field corn as source of cold tolerance for improving sweet corn. *Euphytica* 101 : 239-247.

Savitha, L.V., Harney, T. and Huner, N.P.A. 2000. Sucrose metabolism in spring and winter wheat in response to high irradiance, cold stress and cold acclimation. *Physiologia Planterum* 108 : 270-278.

Schwerdtfeger, W. 1976. World Survey of Climatology. Vol. 12. Elsevier, New York.

Scott, R.W., Appleyard, M., Fellows, G. and Kirby, E.M.J. 1983. Effect of genotype and position in the ear on carpel and grain growth and mature grain weight of spring barley. *Journal of Agricultural Science, Cambridge* 100: 383-391.

Sharp, J.E. and Davies, L. 1979. Solute regulation and growth by roots and shoots of water stressed maize plants. *Planta* 147: 43-49.

Sonoike, K.. 1998. Various aspects of inhibition of photosynthesis under light/chilling stress: 'Photoinhibition at chilling temperatures' versus 'chilling damage in light'. *Journal of Plant Research* 111 : 121-129.

Tanksley, S.D. 1993. Mapping polygenes. *Annual Review of Genetics* 27 : 205-233.

Turner, N.C. 1979. Drought resistance and adaptation to water deficits in crop plants. Mussell, H. and Staples. R.C., (eds.) Stress Physiology in Crop Plant. Wiely, New York pp 343-372.

Turner, N.C. 1986. Adaptation to water deficits: A changing prospective. Australian *Journal of Plant Physiology* 13: 175-190.

Yang, Z., Van-Oosterom, E.J., Joordan, D.R. and Hammer, G.L. 2009. Pre-anthesis ovary development determines genotypic differences in potential kernel weight in sorghum. *Journal of Experiomental Botany* 60 (4) : 1399-1408.

Yajima, M. 1996. Monitoring regional rice development and cool summer damage *Japan Agricultural Research Quaterly* 30: 139-143.

Yoshida, S. 1981.Growth and development of rice plants In : Fundamentals of rice crop science. Los Banos : International Rice Research Institute. Pp 1-63.

Zhang, Z.H., Qu, X.S., Wan S, Chen L H and Zhu Y G. 2005. Comparison of QTL controlling seedling vigour under different temperature conditions using recombinant inbred lines in rice (*Oryza sativa*). *Annals of Botany* 95 : 423-429.

Table 1: Correlation coefficient values among important plant traits and environment components (PT & EC) of rice genotypes on high hills under rain fed condition

Geno type	PT & EC	DP-MS	MS-PE	Air temperature and rain fall at MS-PE stage						Air temperature and -	
				Mxt	Mnt	Avt	Dut	RF_1	PE-AN	Mxt	Mnt
		1	2	3	4	5	6	7	8	9	10
T	SF	0.080	0.068	-0.036	-0.185	-0.114	0.032	0.171	0.000	0.169	-0.163
	GY	0.007	0.081	-0.002	-0.182	0.016	0.061	0.066	0.231*	-0.025	-0.105
EM	SF	-0.352*	-0.176	0.359*	-0.146	0.351*	0.307	0.409*	-0.071	0.192	-0.167
	GY	0.093	-0.014	-0.008	0.124	0.089	-0.055	0.106	0.206	-0.230	0.153
MM	SF	-0.334	0.270	-0.325	-0.190	-0.406	-0.193	0.688*	0.320	0.346	0.373
	GY	-0.339	-0.010	-0.358	-0.111	-0.393	-0.251	0.197	0.270	0.369	0.365
LM	SF	0.136	0.117	-0.298	-0.153	-0.132	-0.141	0.308	0.117	0.134	-0.147
	GY	0.574*	0.783**	-0.379	-0.615	-0.086	0.319	-0.141	0.308	0.295	-0.492*
EEM	SF	0.057	-0.347	-0.189	0.180	0.258	-0.208	-0.313	0.234	-0.594*	0.548
	GY	0.040	-0.325	-0.154	-0.067	0.269	-0.193	-0.143	0.255	-0.542	0.475
MEM	SF	-0.349	-0.108	0.622**	-0.117	0.606**	0.582*	0.398	-0.155	0.237	-0.542*
	GY	0.102	0.138	0.089	-0.040	0.057	0.099	0.144	0.237	-0.186	0.022
LEM	SF	-0.025	-0.130	0.114	0.138	0.103	0.135	0.776	-0.032	-0.217	0.866
	GY	-0.218	0.213	0.271	-0.045	0.265	0.301	0.803	0.399	-0.129	0.591
EEM_1	RF_1	-0.443	0.934**	0.678*		-0.766**	0.735**	1.000	0.100	0.710	-0.532
LM		-0.593*	0.278	-0.405	0.439	-0.350	-0.945**	1.000	-0.285	-0.195	0.321
EEM_2	RF_2	-0.449	-0.036	0.333		-0.310	0.328	-0.129	0.877**	-0.628**	0.755**
LM		-0.573*	-0.469	0.892**	0.712**	0.265	0.110	-0.246	-0.607*	-0.149	0.799**
EEM	SW	-0.346	0.138	0.322		-0.292	0.323	0.066	0.059	0.424	-0.132
LM		0.461	0.025	0.193	0.429	0.442	0.711**	-0.527*	0.232	0.425	-0.188

		rain fall at PE-AN stage			Soil minimum temperature at MS-PE stage						Soil
		Avt	Dut	RF_2	ST_1	ST_2	ST_3	ST_1-ST_2	ST_2-ST_3	ST_1-ST_3	ST_1
		11	12	13	14	15	16	17	18	19	20
T	SF	-0.013	0.260*	-0.325*	-0.117	-0.162	-0.211	0.071	-0.149	-0.074	-0.057
	GY	-0.094	0.063	0.008	-0.040	-0.051	-0.020	0.023	-0.007	0.016	-0.096
EM	SF	0.138	0.233	-0.345*	0.042	-0.058	-0.227	0.067	-0.389*	-0.247	0.265
	GY	-0.237	-0.221	0.205	0.087	0.050	0.180	-0.154	-0.012	-0.103	-0.232
MM	SF	0.357	0.287	0.148	0.415	0.367	0.373	-0.515	0.373	0.275	0.328
	GY	0.369	0.354	0.019	0.293	0.276	0.299	-0.266	0.322	0.283	0.319
LM	SF	-0.055	0.185	-0.366	-0.253	-0.222	-0.177	0.298	0.376	0.463*	-0.034
	GY	-0.235	0.549*	-0.512*	-0.698**	-0.645**	-0.606*	0.705**	0.084	0.627**	-0.344
EEM	SF	-0.110	-0.519	0.327	-0.162	0.236	-0.138	-0.217	-0.233	-0.238	-0.619*
	GY	-0.026	-0.429	0.353	0.067	0.135	-0.185	-0.143	-0.239	-0.229	-0.576*
MEM	SF	-0.218	0.258	-0.276	0.237	-0.042	-0.104	0.053	-0.392	-0.395	0.270
	GY	-0.055	-0.177	0.265	0.183	-0.147	0.064	-0.092	0.099	0.092	-0.203
LEM	SF	0.180	-0.177	-0.161	-0.124	-0.058	0.235	-0.880	-0.285	-0.674	-0.599
	GY	-0.012	-0.124	0.079	-0.045	0.050	-0.210	-0.979*	-0.496	-0.870	-0.388
EEM_1	RF_1		0.588	-0.129				0.762**	0.786**	0.797**	0.624*
LM		0.133	0.382	-0.246	0.334	0.320	0.363	-0.484	0.433	-0.116	0.384

EEM_2	RF_2		-0.726*	1.000				0.306	0.283	0.285	-0.786**
LM		0.571*	-0.702**	1.000	0.772**	0.790**	0.768**	-0.448	0.045	-0.263	0.658**
EEM	SW		0.423	-0.182				0.384	0.311	0.302	0.347
LM		0.117	0.385	-0.034	-0.430	-0.400	-0.370	0.658**	0.013	0.570*	-0.074

		Minimum temperature at PE-AN stage					Soil maximum temperature at MS-PE				
		ST_2	ST_3	ST_1-ST_2	ST_2-ST_3	ST_1-ST_3	ST_1	ST_2	ST_3	ST_1-ST_2	ST_2-ST_3
		21	22	23	24	25	26	27	28	29	30
T	SF	-0.026	0.005	0.188	0.171	0.226	-0.171	-0.159	-0.186	-0.134	-0.086
	GY	-0.085	-0.054	0.094	0.142	0.147	0.103	0.099	0.051	0.177	0.187
EM	SF	0.276	0.294	0.114	0.319*	0.306	-0.273	-0.243	-0.274	-0.311*	-0.165
	GY	-0.209	-0.204	-0.237	-0.159	-0.173	0.188	0.200	0.183	0.161	0.229
MM	SF	0.365	0.355	0.081	0.184	0.114	0.382	0.361	0.379	0.409	0.314
	GY	0.357	0.359	0.034	0.290	0.162	0.294	0.266	0.283	0.326	0.229
LM	SF	-0.048	0.000	0.036	0.142	0.090	-0.468*	-0.499*	-0.319	0.194	-0.255
	GY	-0.307	-0.218	0.402	0.480*	0.438	-0.566*	-0.494*	-0.609*	0.175	0.231
EEM	SF	-0.621*	-0.190	-0.001	-0.201	-0.121	0.081	0.235	-0.162	0.160	0.230
	GY	-0.578*	0.138	0.001	-0.249	-0.124	0.055	0.242	0.087	0.143	0.334
MEM	SF	0.282	-0.235	0.131	0.310	0.301	-0.240	-0.225	0.215	-0.247	-0.183
	GY	-0.169	0.016	-0.248	-0.173	-0.193	0.157	0.164	-0.013	0.178	0.176
LEM	SF	-0.433	0.221	-0.238	-0.163	-0.028	0.101	0.063	-0.146	0.248	0.068
	GY	-0.233	-0.032	-0.070	0.006	-0.040	0.223	0.198	-0.094	0.323	0.225

EEM_1	RF_1	0.627*		0.037	-0.189	-0.185	-0.163	-0.600		-0.660*	-0.570
LM		0.289	0.235	-0.538	-0.428	-0.489	-0.319	-0.490	0.016	0.123	-0.870**
EEM_2	RF_2	0.789**		-0.001	-0.656*	-0.606*	-0.204	-0.344		0.081	-0.297
LM		0.645*	0.547*	-0.518*	-0.665**	-0.586*	0.908**	0.865**	0.920**	-0.350	-0.176
EEM	SW	0.348		-0.001	-0.144	-0.235	0.109	-0.441		0.136	-0.303
LM		0.001	0.093	0.339	0.341	0.344	-0.147	-0.046	-0.241	-0.201	0.333

		stage	Soil maximum temperature at PE-AN stage						FG	NS	SW
		ST_1-ST_3	ST_1	ST_2	ST_3	ST_1-ST_2	ST_2-ST_3	ST_1-ST_3			
		31	32	33	34	35	36	37	38	39	40
T	SF	-0.123	0.174	0.179	0.132	0.157	0.280*	0.201	0.826**	0.164	-0.464**
	GY	0.189	0.060	0.041	0.038	0.068	0.093	0.061	0.495**	0.267*	-0.152
EM	SF	-0.268	0.360*	0.353*	0.338*	0.366*	0.376*	0.372*	0.818**	0.281	-0.437*
	GY	0.189	-0.142	-0.172	-0.182	-0.153	-0.152	-0.152	0.580**	0.350*	-0.413*
MM	SF	0.388	0.093	0.099	0.210	0.086	-0.152	-0.031	0.882**	-0.178	-0.619
	GY	0.315	0.134	0.140	0.243	0.126	-0.110	0.015	0.209	-0.539	-0.092
LM	SF	0.036	0.341	0.371	0.417	0.283	0.378	0.295	0.847**	0.554*	0.180
	GY	0.236	0.563*	0.566*	0.592*	0.546*	0.620*	0.535*	0.612*	0.543*	0.513*

EEM	SF	0.257	-0.399	-0.456	-0.483	-0.296	-0.410	-0.334	0.706*	0.509	-0.281
	GY	0.264	-0.412	-0.460	-0.486	-0.324	-0.425	-0.357	0.618*	0.502	-0.240
MEM	SF	-0.242	0.327	0.322	0.312	0.333	0.340	0.337	0.862**	0.109	-0.597**
	GY	0.154	-0.167	-0.168	-0.169	-0.166	-0.165	-0.165	0.604**	0.307	-0.492*
LEM	SF	0.159	0.185	0.121	-0.028	0.483	0.346	0.423	0.882	0.496	-0.964*
	GY	0.279	0.134	0.087	0.001	0.377	0.209	0.290	0.917	0.630	-0.837
EEM_1	RF_1	-0.816	0.088	0.184	0.227	-0.063	0.091	-0.012	-0.141	-0.075	0.066
LM		-0.257	-0.039	0.030	0.112	-0.158	-0.106	-0.115	0.224	0.133	-0.527*
EEM_2	RF_2	-0.262	-0.817**	-0.854**	-0.867**	-0.734*	-0.823**	-0.765**	0.065	-0.011	-0.182
LM		-0.354	-0.930**	-0.948**	-0.954**	-0.875**	-0.875**	-0.898**	-0.395	-0.323	-0.034
EEM	SW	-0.291	-0.005	0.054	0.083	-0.093	0.011	-0.065	-0.157	-0.028	1.000
LM		-0.016	0.203	0.187	0.201	0.234	0.303	0.199	0.136	0.048	1.000

		l;b ratio	SF	GY							
		41	42	43							
T	SF	-0.278	1.000	-							
	GY	-0.189	0.450**	1.000							
EM	SF	-0.288	1.000	-							

	GY	-0.346*	0.515*	1.000							
MM	SF	-0.448	1.000	-							
	GY	0.320	0.513	1.000							
LM	SF	-0.189	1.000	-							
	GY	-0.195	0.497*	1.000							
EEM	SF	-0.555	1.000	-							
	GY	-0.374	0.592*	1.000							
MEM	SF	-0.013	1.000	-							
	GY	-0.244	0.494*	1.000							
LEM	SF	-0.778	1.000	-							
	GY	-0.845	0.904	1.000							
EEM_1	RF_1	0.101	-0.313	-0.143							
LM		0.137	0.308	-0.141							
EEM_2	RF_2	-0.429	0.327	0.353							
LM		-0.077	-0.366	-0.512							
EEM	SW	0.248	-0.281	-0.240							
LM		0.051	0.180	0.513*							

**, * significant at 1 and 5 percent level of probability

t value for testing the significance of correlation between two variables changed with change in number of genotypes represent respective maturity group of rice

T = Entire rice genotypes (combining all maturity groups); EM = Early maturity group; MM = Medium maturity group; LM = Late maturity group; EEM = Earliest among early maturity group; MEM = Medium among early maturity group; LEM = Late among early maturity group; DP-MS = Time interval between date of planting seeds on field to microspore development stage (Days); MS-PE= Time interval between microspore development stage to date of panicle emergenceon plant on main shoot (Days); Mxt = Maximum air temperature, Mnt = Minimum air temperature; Avt = Average air temperature; Dut = Diurnal variation in air temperature; RF_1 = Rain fall experience during the time interval of DP-MS stage; PE-AN =Time interval between panicle emergence to date of anthesis (Days); RF_2 = Rain fall experienced between the time interval of PE-AN stage;

ST_1 = Soil temperature at 5 cm depth; ST_2 = Soil temperature at 10 cm depth; ST_3 = Soil temperature at 20 cm depth; ST_1-ST_2 = Differences in soil temperature between ST_1 and ST_2 depth; ST_2-ST_3 = Differences in soil temperature between ST_2 and ST_3 depth; ST_1-ST_3 = Differences in soil temperature between ST_1 and ST_3 depth. DP = Date of planting the seeds on field, MS = Microspore development stage, PE = Panicle emergence stage, AN = Anthesis stage FG = Percent of filled grain, NS = Total number of spikelet present on a panicle, SW = 100 seed weight, SF = Percent of spikelet fertility, l;b = Length : breadth ratio of seed. GY = Grain yield.

Table 2: Regression equations in separate (soil component on spikelet fertility and grain yield) and combined (soil component in association with spikelet fertility on grain yield) analysis.

Late maturing rice genotypes (LM) :- GY = - 132.6092 + 2.85046 X_1 (R^2 = 0.247294)		
SF = - 98.6874 + 107.7920 X_2	GY = - 1233.00 + 836.5570* X_2	GY = - 1084.05 + 673.8685* X_2 + 1.5092 X_1
(R^2 = 0.2145)	(R^2 = 0.3932)	(R^2 = 0.4477)
SF = 605.3604 - 19.2762 X_3	GY = 3783.834 - 133.5551* X_3	GY = 2754.64 - 100.7828 X_3 + 1.7000 X_1
(R^2 = 0.2200)	(R^2 = 0.3214)	(R^2 = 0.3900)
SF = 37.5135 - 26.1189 *X_4	GY = 3857.981 - 148.1273 X_4	GY = 2446.962 – 98.1579 X_4 + 1.9132 X_1
(R^2 = 0.2493)	(R^2 = 0.2441)	(R^2 = 0.3277)
Earliest among early maturing genotypes (EEM) :- GY = - 106.4013 + 2.581240* X_1 (R^2 = 0.350628)		
SF = 1378.531 - 63.3133* X_5	GY = 5388.635 - 256.7548 X_5	GY = 3086.405 - 151.0177 X_5 + 1.67002 X_1
(R^2 = 0.3817)	(R^2 = 0.3303)	(R^2 = 0.4210)
SF = 1401 - 61.7472* X_6	GY = 5874.274 - 268.5456* X_6	GY = 3718.013 - 173.5408 X_6 + 1.5386 X_1
(R^2 = 0.3707)	(R^2 = 0.3689)	(R^2 = 0.4473)

X_1 = Spikelet of fertility; X_2 = Differences in soil minimum temperature between ST_1 and ST_3 depth at MS-PE stage; X_3 = Soil maximum temperature at ST_1 depth at MS-PE stage; X_4 = Soil maximum temperature at ST_2 depth at MS-PE stage; X_5= Soil maximum temperature at ST_1 depth at PE-AN stage; X_6= Soil maximum temperature at ST_2 depth at PE-AN stage

Abbreviations

T = Entire rice genotypes (combining all maturity groups); EM = Early maturity group; MM = Medium maturity group; LM = Late maturity group; EEM = Earliest among early maturity group; MEM = Medium among early maturity group; LEM = Late among early maturity group; DP-MS = Time interval between date of planting seeds on field to microspore development stage (Days); MS-PE= Time interval between microspore development stage to date of panicle emergence on main shoot plant (Days); Mxt = Maximum air temperature, Mnt = Minimum air temperature; Avt = Average air temperature; Dut = Diurnal variation in air temperature; RF_1 = Rainfall experience during the time interval of DP-MS stage; PE-AN =Time interval between panicle emergence to date of anthesis (Days); RF_2 = Rain fall experienced between the time interval of PE-AN stage; ST_1 = Soil temperature at 5 cm depth; ST_2 = Soil temperature at 10 cm depth; ST_3 = Soil temperature at 20 cm depth; ST_1-ST_2 = Differences in soil temperature between ST_1 and ST_2; ST_2-ST_3 = Differences in soil temperature between ST_2 and ST_3; ST_1-ST_3 = Differences in soil temperature between ST_1 and ST_3. DP = Date of planting the seeds in the field, MS = Microspore development stage, PE = Panicle emergence stage, AN = Anthesis stage, FG = Percent of filled grain, NS = Total number of spikelet present on a panicle, SW = 100 seed weight, SF = Percent of spikelet fertility, 1:b = Length : breadth ratio of seed. GY = Grain yield.