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Genetic Trend of Maize (*Zea mays* L.) under Normal and Water Stress Conditions

Muhammad Ijaz Tabassum and Muhammad Saleem
Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan

Abstract: A diallel cross comprising eight inbred lines of maize was evaluated to determine the genetic trend of maize inbred lines across two different planting conditions (normal and water stress). Grain yield and its related traits revealed highly significant differences among inbred lines under both plantings. Graphical analysis revealed that additive gene action for plant height under normal condition remained unchanged under water stress while over-dominance type of gene action for leaf area per plant, 1000-grain weight and grain yield per plant under normal experiment also remained unchanged under water stress. It was revealed that over-dominance type of gene action for biological yield under normal changed to additive with partial type of gene action under moisture stress condition whereas, additive type of gene action for harvest index under normal changed to over-dominance type of gene action under water stress.

Key words: Maize, genetic trend, water stress, diallel cross, gene action

INTRODUCTION

Maize (*Zea mays* L.) is one of the three important cereals of the world after wheat and rice. Average yield of maize in Pakistan is low as compared to the world average. One of the important factors affecting maize yield is the shortage of water resulting in drought. The extent of yield reduction depends upon the degree, duration and timing of drought occurrence. An understanding of morphological basis of drought tolerance is a prerequisite for the efficient selection of inbred lines and breeding for moisture stress. Thus, it is essential to know the genetic architecture of traits related to drought tolerance and their mode of inheritance. A lot of information is documented in the literature; however, such information with respect to water stress is scanty. Tabassum[1] found that plant height, 1000-grain weight and yield per plant were conditioned by additive type of gene action. Sharma and Bhalla[2] observed that dominance gene action was predominant for leaf area under rainfed conditions.

Mahajan and Khera[3] evaluated eight maize inbred lines under eight environments and observed that additive gene action was involved for plant height. Yang and Hsiang[4] reported that water stress reduced plant height and leaf length in a maize cultivar. They also found that increasing water stress also decreased root weights. Yousaf[5] found that plant height, leaf area, 100-grain weight and grain yield per plant were controlled by over-dominance type of gene action. Damborsky *et al.*[6] reported that grain yield was mainly conditioned by additive type of gene action. Perez *et al.*[7] reported that plant height was controlled by additive type of gene action. Dutu[8] indicated that additive gene action was predominant in the inheritance of grain yield. Shabbir and Saleem[9] reported that grain yield per plant was under the control of over-dominance type of gene action.

The present study was conducted to ascertain the effects of water stress on the genetic architecture of some plant traits reflecting yield and its components by making a comparative assessment of their genetic trend under normal and water stress conditions. This information would be useful for developing new inbred lines and hybrids of maize for moisture deficit areas.

MATERIALS AND METHODS

The study was conducted in the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad during 2001 and 2002. One hundred inbred lines with diverse origin were collected from various national (Maize and Millet Research Institute, Sahiwal and Ayub Agricultural Research Institute, Faisalabad)and international (Maize and Wheat Improvement Center, CIMMYT, Maxico) sources and were screened on the basis of seedling traits for drought tolerance in glasshouse, both under normal and moisture stress to select parental inbred lines. The selected inbred lines were further subdivided into drought tolerant (F-133, F-141 and F-128), moderately drought tolerant (F-131, F-135 and SR-402) and drought susceptible (F-149 and SEL-8).

Corresponding Author: Muhammad Ijaz Tabassum, Wheat Research Institute, Ayub Agricultural Research Institute, Jhang Road, Faisalabad, Pakistan E-mail: ijazrabassum2003@yahoo.com

The eight inbred lines were crossed in all possible combinations in a diallel fashion during April/May, 2002. During the following season (August/September, 2002), the 28 F_1,s along with their reciprocals and eight parents were sown in the field using a randomized complete block design with three replications. Two seeds per hill were planted with the help of a dibble keeping plant to plant and line to line distance of 20 and 75 cm, respectively. The experimental plot was a single row of five meter length. After germination, thinning was done to have a single healthy seedling per site. Non-experimental lines were also raised at the start and end of each replication to eliminate border effects. Minimum and maximum temperature recorded in the research area ranged from 20.5 to 33.1°C. The same experiment was also planted under water stress condition. All other agronomic and cultural practices except irrigation were kept uniform. To ensure water stress, only three irrigations were applied to the water stress experiment at critical stages of the crop growth. Data for plant height, leaf area, 1000-grain weight, biological yield, grain yield per plant and harvest index were collected and subjected to analysis of variance[10]. Graphical analysis for gene action and determination of genetic components of variation was also conducted following Hayman[11] and Jinks[12].

RESULTS AND DISCUSSION

An analysis of variance revealed highly significant differences among the genotypes for all the characters both under normal and water stress which allowed to proceed for further genetic analysis (Table 1).

Under normal experiment, the maximum plant height (129.8 cm) was recorded for the parental genotype F-133 closely followed by F-135 (125.0 cm), F-149 (124.0 cm) and F-141 (122.2 cm) while F-131 and SEL-8 displayed the least plant height (68.9 and 87.0 cm, respectively). Under water stress, the parental line F-135 was the tallest (119.4 cm) while minimum plant height (47.3 cm) was shown by F-131. Among crosses, plant height ranged from 82.5 (F-131 x SEL-8) to 136.5 cm (F-131 x F-135) under normal condition while under water stress, it ranged from 61.6 (F-131 x SEL-8) to 124.6 cm (F-149 x F-135). An overall average reduction of 13.9% was recorded for genotypes under water stress. Reduction in plant height under water stress has also been reported by Gu *et al.*[13], Yang and Hsiang[4], Vicente *et al.*[14] and Dass *et al.*[15].

For leaf area per plant, the highest value (287.3 cm^2) was recorded for the parental line F-149 followed by F-133 (178.5 cm^2) under normal environment. F-149 had the maximum leaf area (170.2 cm^2) under water stress sowing. Among the crosses F-149 x F-135 showed

Table 1: Analysis of variance for studied traits in 8 x 8 diallel crosses of maize

		Mean squares		
Traits	Conditions	Replication	Genotypes	Error
Plant height	Normal	1.96	6.99.45**	1.06
	Water stress	153.13	818.12**	61.95
Leaf area	Normal	8.33	5730.87**	10.46
per plant	Water stress	2.03	6081.33**	22.00
Number of	Normal	35.41	6925.58**	17.61
kernels per ear	Water stress	3.13	86.80**	1.47
1000-grain	Normal	40.14	3362.47**	13.87
weight	Water stress	14.31	857.35**	5.97
Biological	Normal	38.02	8547.44**	31.97
yield	Water stress	43.07	2356.76**	47.83
Grain yield	Normal	11.76	2803.02**	9.56
per plant	Water stress	45.57	1409.35**	27.35
Harvest	Normal	0.0000022	0.02268**	0.00000083
Index	Water stress	0.0002450	0.005116**	0.00041

** $p \leq 0.01$, degree of freedom for replication, genotypes and error mean squares is 2, 63 and 126, respectively.

maximum (286.4 cm^2) leaf area closely followed by F-141 x F-133 (280.2 cm^2) under normal planting. Under water stress, the cross F-149 x F-131 had maximum (232.4 cm^2) leaf area followed by F-141 x F-133 (230.6 cm^2). On combined mean basis, the leaf area per plant depicted a reduction of about 26.9% under water stress (Table 2). Reduction in this trait has also been reported in maize under moisture stress by Yang and Hsiang[4].

Thousand grain weight ranged from 173 (F-133) to 327.0 g (F-135) in the parental genotypes under normal, whereas under water stress this range was from 156.7 (F-133) to 256.7 g (F-135). Among crosses, 1000-grain weight ranged from 220.0 to 357.0 g for the crosses SEL-8 x F-141 and F-131 x F-149, respectively, under normal conditions. While under water stress, this range was 211.3 to 251.0 for the cross SEL-8 x F-141 and three other crosses viz., F-149 x F-135, SR-402 x F-149 and F-133 x F-141. It was observed that over all reduction of all genotypes showed a loss of 16.23% in 1000-grain weight under water stress. These results are similar with those of Bolanos and Edmeades[16] who also reported considerable reduction in 1000-grain weight under water stress condition (Table 2).

As regards biological yield per plant (Table 3), it was the highest (369.7 g) in the parental line F-133 followed by the inbred line F-135 (337.3 g) under normal conditions. Under water stress, F-133 had the highest value of 303.2 g for biological yield per plant, closely followed by genotype F-135 (291.3 g). Among crosses, F-149 x F-133 hybrid showed the highest biological yield (441.0 g) under normal whereas the cross F-149 x F-135 showed the highest value (282.3 g) under water stress. On overall average basis, a reduction of 30.27% was recorded for biological yield under water stress. These results are similar with those of Ouattar *et al.*[17],

Table 2: Means, LSD value and CV% of plant height, leaf area per plant and 1000-grain weight of maize in an 8x8 diallel cross under normal and water stress conditions

	Plant height (cm)		Leaf area per plant (cm^2)		1000-grain weight (g)	
Parental lines/crosess	Normal	Water stress	Normal	Water stress	Normal	Water stress
F.133	129.80	110.10	178.50	140.40	173.00	156.70
F.141	122.20	100.70	148.60	123.10	230.00	224.70
F.128	91.00	71.60	155.30	72.30	250.00	197.30
F.131	68.90	47.30	80.70	66.70	240.00	191.70
F.135	125.00	119.40	160.30	122.50	327.00	256.70
SR.402	113.80	93.60	154.80	118.40	240.00	220.70
F.149	124.00	110.20	287.30	170.20	260.00	252.30
SEL.8	87.00	69.30	127.90	92.10	223.00	189.00
F.133 x F.141	130.50	113.40	271.30	204.30	260.00	251.00
F.133 x F.128	125.20	106.00	249.80	188.20	284.00	245.70
F.133 x F.131	126.30	103.80	231.60	161.30	297.00	242.30
F.133 x F.135	123.80	110.80	207.50	195.20	313.00	238.00
F.133 x SR.402	134.50	116.30	202.40	151.50	277.00	245.30
F.133 x F.149	123.00	111.20	245.40	172.20	277.00	243.00
F.133 x SEL.8	134.00	117.20	240.50	218.80	280.00	247.70
F.141 x F.133	132.20	108.50	280.20	230.60	250.00	248.30
F.141 x F.128	97.30	79.20	208.10	155.00	300.00	220.70
F.141 x F.131	118.00	100.30	252.20	190.00	260.00	233.00
F.141 x F.135	114.80	94.50	221.40	191.50	337.00	233.00
F.141 x SR.402	117.00	95.20	217.50	162.00	280.00	230.70
F.141 x F.149	133.70	120.20	276.80	202.90	303.00	249.00
F.141 x SEL.8	127.50	114.30	219.40	218.40	230.00	224.30
F.128 x F.133	131.80	104.80	246.50	185.90	290.00	245.70
F.128 x F.141	121.50	102.30	224.60	161.20	293.00	223.70
F.128 x F.131	100.30	96.40	168.10	124.40	257.00	234.30
F.128 x F.135	120.80	103.00	166.70	138.30	307.00	237.00
F.128 x SR.402	116.00	104.10	189.60	181.10	283.00	239.70
F.128 x F.149	124.00	104.90	237.60	220.90	280.00	239.00
F.128 x SEL.8	103.20	89.10	201.10	84.90	267.00	229.30
F.131 x F.133	119.20	107.80	246.10	168.60	280.00	240.70
F.131 x F.141	104.00	96.70	258.20	225.60	270.00	232.70
F.131 x F.128	96.20	73.70	179.40	156.40	260.00	228.70
F.131 x F.135	136.50	115.80	256.70	223.20	223.00	217.30
F.131 x SR.402	108.50	87.90	215.30	150.80	250.00	227.00
F.131 x F.149	122.60	96.00	220.40	163.50	357.00	243.00
F.131 x SEL.8	82.50	61.60	124.60	49.70	260.00	216.70
F.135 x F.133	130.00	118.90	196.40	141.90	300.00	238.70
F.135 x F.141	121.30	108.60	236.40	143.60	330.00	241.30
F.135 x F.128	117.70	111.30	162.70	124.70	307.00	241.30
F.135 x F.131	127.70	112.70	212.10	161.00	330.00	244.70
F.135 x SR.402	118.50	97.50	174.30	99.30	300.00	233.70
F.135 x F.149	123.30	120.80	272.40	136.70	293.00	238.70
F.135 x SEL.8	109.50	91.20	228.10	115.50	280.00	228.00
SR.402 x F.133	131.70	114.00	221.70	198.20	297.00	244.00
SR.402 x F.141	116.50	100.20	226.60	137.60	280.00	235.70
SR.402 x F.128	122.20	109.40	175.30	140.10	300.00	244.00
SR.402 x F.131	109.50	93.30	206.60	147.60	247.00	229.70
SR.402 x F.135	104.80	85.00	189.50	111.70	310.00	225.30
SR.402 x F.149	133.40	123.70	259.40	210.90	283.00	251.00
SR.402 x SEL.8	91.50	80.70	206.30	124.60	240.00	237.30
F.149 x F.133	131.30	107.60	244.50	177.30	273.00	238.70
F.149 x F.141	111.70	102.70	260.30	209.30	313.00	236.30
F.149 x F.128	114.80	101.80	223.60	166.70	277.00	236.00
F.149 x F.131	130.50	117.60	234.50	232.40	356.00	247.00
F.149 x F.135	133.00	124.60	286.40	165.90	300.00	251.00
F.149 x SR.402	130.00	117.90	248.40	204.40	270.00	247.70
F.149 x SEL.8	97.30	81.90	139.70	85.70	275.00	221.70
SEL.8 x F.133	131.70	117.70	234.90	167.70	303.00	246.70
SEL.8 x F.141	123.60	107.90	181.50	106.20	220.00	211.30
SEL.8 x F.128	102.50	85.80	209.70	143.80	270.00	227.00
SEL.8 x F.131	83.00	64.20	155.40	86.50	265.00	212.00
SEL.8 x F.135	110.00	95.50	233.80	182.40	283.00	232.70
SEL.8 x SR.402	113.00	83.50	203.70	126.80	240.00	238.00
SEL.8 x F.149	89.80	78.70	157.40	68.70	280.00	221.70
Grand mean	116.35	100.18 (-13.9)	211.50	154.68 (-26.9)	277.90	232.80 (-16.23)
CV%	0.89	7.86	7.53	3.03	1.34	1.05
LSD	1.40	10.67	4.38	4.36	5.05	3.31

Table 3: Means, LSD value and CV% of biological yield, grain yield per plant and harvest index of maize in an 8x8 diallel cross under normal and water stress conditions

	Biological yield (g)		Grain yield per plant (g)		Harvest index (%)	
Parental lines/crosses	Normal	Water stress	Normal	Water stress	Normal	Water stress
F.133	369.70	303.20	183.00	148.00	49.50	48.80
F.141	313.30	290.70	139.30	123.00	44.46	42.31
F.128	322.30	195.00	168.00	86.00	52.12	44.13
F.131	235.00	156.00	142.30	69.30	60.57	44.51
F.135	337.30	291.30	226.00	147.70	67.00	54.42
SR.402	277.30	255.00	145.70	134.70	52.52	50.70
F.149	266.70	259.70	163.00	138.30	61.13	53.26
SEL.8	237.70	175.30	144.70	70.00	60.87	39.92
F.133 x F.141	411.30	282.00	232.70	156.30	56.56	55.43
F.133 x F.128	398.30	259.00	225.70	146.00	56.65	56.41
F.133 x F.131	374.00	260.30	212.30	139.00	56.77	53.40
F.133 x F.135	415.30	249.30	235.30	129.70	56.66	52.09
F.133 x SR.402	430.00	267.70	243.00	144.70	56.51	54.05
F.133 x F.149	432.70	261.70	244.70	140.00	56.55	53.49
F.133 x SEL.8	416.30	274.70	235.70	150.30	56.60	54.74
F.141 x F.133	426.30	294.00	241.30	151.70	56.61	51.60
F.141 x F.128	354.70	205.00	201.70	94.30	56.86	46.13
F.141 x F.131	430.70	237.00	243.30	119.70	56.50	50.57
F.141 x F.135	407.00	236.00	230.70	119.30	56.68	50.51
F.141 x SR.402	328.70	229.70	187.30	114.00	57.00	49.67
F.141 x F.149	310.70	277.30	177.30	152.70	57.08	55.05
F.141 x SEL.8	315.00	265.00	180.00	142.70	57.14	53.84
F.128 x F.133	417.30	269.30	236.30	146.30	56.63	54.33
F.128 x F.141	348.30	245.30	198.00	99.70	56.84	40.65
F.128 x F.131	316.70	240.00	181.00	122.30	57.16	50.97
F.128 x F.135	319.70	246.70	182.70	127.70	57.14	51.76
F.128 x SR.402	352.30	252.70	200.30	132.70	56.86	52.52
F.128 x F.149	426.30	251.70	241.00	131.70	56.53	52.33
F.128 x SEL.8	308.30	226.30	176.00	111.30	57.08	49.26
F.131 x F.133	360.30	255.30	205.00	135.00	56.89	52.88
F.131 x F.141	439.00	235.00	248.30	118.30	56.57	50.35
F.131 x F.128	324.70	200.00	185.00	110.00	56.98	54.98
F.131 x F.135	349.30	271.00	198.70	147.30	56.87	54.34
F.131 x SR.402	294.30	220.00	168.70	106.30	57.30	48.37
F.131 x F.149	358.70	286.70	203.70	139.70	56.79	48.73
F.131 x SEL.8	281.00	194.70	161.00	85.70	57.30	44.04
F.135 x F.133	423.70	274.70	240.00	130.30	56.65	47.52
F.135 x F.141	423.00	257.70	239.00	136.70	56.50	53.03
F.135 x F.128	315.00	256.70	180.00	136.00	57.14	52.99
F.135 x F.131	343.00	267.00	195.30	144.30	56.95	54.11
F.135 x SR.402	361.70	238.30	205.70	121.00	56.87	50.77
F.135 x F.149	331.30	251.00	188.70	131.00	56.94	52.29
F.135 x SEL.8	298.70	222.70	171.00	108.70	57.25	48.80
SR.402 x F.133	421.70	265.00	238.70	142.70	56.60	53.81
SR.402 x F.141	340.00	242.70	194.00	124.70	57.06	51.46
SR.402 x F.128	369.30	264.30	209.70	142.00	56.77	47.71
SR.402 x F.131	305.70	227.00	174.70	112.00	57.15	49.34
SR.402 x F.135	360.30	216.30	205.00	103.30	56.89	47.77
SR.402 x F.149	318.30	281.70	181.70	156.30	57.07	55.50
SR.402 x SEL.8	295.00	270.00	169.00	128.00	57.29	47.41
F.149 x F.133	441.00	251.00	249.30	131.00	56.54	52.18
F.149 x F.141	317.30	245.30	181.00	126.70	57.04	51.68
F.149 x F.128	421.30	244.00	238.30	125.70	56.57	51.46
F.149 x F.131	362.70	272.30	206.00	148.30	56.80	54.48
F.149 x F.135	327.70	282.30	187.00	156.70	57.07	55.49
F.149 x SR.402	321.70	274.30	183.70	150.30	57.10	54.80
F.149 x SEL.8	317.00	206.70	181.00	95.30	57.10	46.10
SEL.8 x F.133	415.00	270.30	234.70	147.00	56.55	54.35
SEL.8 x F.141	296.70	257.00	170.00	136.30	57.30	53.05
SEL.8 x F.128	316.70	220.30	180.70	106.70	57.05	48.37
SEL.8 x F.131	291.30	182.30	167.00	75.70	57.32	41.46
SEL.8 x F.135	296.70	235.00	169.30	118.70	57.08	50.51
SEL.8 x SR.402	300.00	249.00	171.70	129.70	57.22	52.06
SEL.8 x F.149	316.70	207.70	181.00	96.30	57.16	46.44
Grand mean	349.80	243.90 (-30.27)	198.10	126.50 (-36.1)	56.70	51.53 (-9.11)
CV%	1.62	2.84	1.56	4.14	0.16	3.94
LSD	7.66	9.37	4.19	7.09	0.0012	0.0275

Rahman and Hassaneinn[18]. Gu *et al.*[13] also reported considerable reduction in biological yield under water stress.

In case of grain yield per plant (Table 3), parental line F-135 produced the highest yield (226.0 g) under normal and F-133 gave the highest yield (148.0 g) under water stress condition closely followed by the parent F-135 (147.7 g). Among crosses, the cross F-149 x F-133 showed highest value of 249.3 g under normal closely followed by F-131 x F-141 (248.3 g). Whereas the cross F-149 x F-135 showed the highest value (156.7 g) under water stress experiment closely followed by hybrids F-133 x F-141 and SR-402 x F-149 with a value of 156.3 g. Over all performance of genotypes showed a mean reduction of 36.1% for grain yield per plant. The results are in accordance with Bolanos and Edmeades[16] and Vicente *et al.*[14], who also reported reduction in grain yield per plant under water stress.

In case of harvest index (Table 3), the parent F-135 had the maximum values 67.0% under normal and 54.42% under water stress, the maximum values of 57.32 and 64.41% were obtained in the crosses of SEL-8 x F-131 and F-133 x F-128 under normal and water stress conditions, respectively. All genotypes had greater harvest index under normal planting and showed a mean reduction of 9.11% under water stress.

The exposure of the breeding material to the water stress significantly affected the growth of the maize plant as expressed in terms value of altered morphological traits studied. The significant differences obtained in the genotypes allowed proceeding for further genetic analysis for all traits.

Scaling Test: To test the adequacy of the data for additive-dominance model, two types of scaling tests (regression analysis and analysis of variance of Wr+Vr and Wr-Vr) were employed separately for the data under normal and water stress (Table 4). Results of the scaling tests displayed partial adequacy of the data for all the traits due to the failure of one of the two tests. Similarly, under water stress, data regarding leaf area per plant, 1000-grain weight, biological yield, grain yield per plant and harvest index showed partial adequacy whereas data for plant height displayed complete adequacy. Thus, whole of the data under normal and water stress were analysed further for the determination of genetic information.

Plant height: Estimation of genetic components of variation (Table 5) for plant height revealed significant value of D under both normal and water stress conditions indicating the importance of additive genetic effects. Importance of dominant variation was also indicated by significant H components H_1 and H_2 under both plantings. Unequal value of H_1 and H_2 under both environments displayed the different distribution of dominant genes. A positive and significant value of F indicated that positive genes were more frequent under both plantings. Environmental variation E was significant under water stress however; it was non-significant in case of normal planting.

Heritability estimates under both plantings displayed that more than 50% of the genetic variation transferred from the parents, was of additive nature. Degree of dominance (0.972 and 0.944, respectively) under both environments indicated the involvement of additive gene action for the inheritance of plant height. Graphical representation of the data (Fig.1a and b) also displayed the additive gene action for plant height under normal as well as water stress. These results are in accordance with those of Tabassum[1], Mahajan and Khera[3] and Perez *et al.*[7] who also reported additive gene action for this trait. Distribution of array points in the graphs (Fig.1) depicted that under normal experiment, the parent F-135 possessed the most dominant genes for plant height followed by F-131 and F-149, while the parent SR-402 contained the most recessive genes for this trait. The remaining genotypes were of intermediate constitution. In case of water stress, the array points showed that the parent F-133 had the most dominant genes being in close vicinity to the origin followed by F-141, while the parent

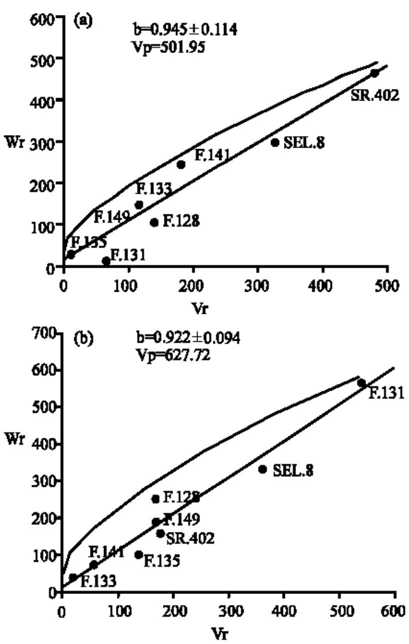

Fig. 1: Vr/Wr graph for plant height under a) normal and b) water stress conditions

Table: 4: Test of adequacy of additive-dominance model for the traits with significant variation

		Regression analysis		Analysis of array variances		
Traits	Conditions	b = 0	b = 1	Wr+Vr	Wr-Vr	Model
Plant height	Normal	8.28**	0.48	812.80**	280.01**	Analysis of Array made partial adequate
	Water stress	10.59**	0.09	11.81**	1.39	-------Adequate-------
Leaf area per plant	Normal	2.86*	1.84	124.69**	90.78**	Analysis of Array made partial adequate
	Water stress	3.00*	2.37	185.71**	108.95**	"
1000-grain weight	Normal	2.73*	0.94	264.49**	56.53**	Analysis of Array made partial adequate
	Water stress	3.88**	2.36	190.74**	50.98**	"
Biological yield	Normal	2.86*	1.41	84.71**	62.84**	Analysis of Array made partial adequate
	Water stress	9.52 **	-0.93	32.49 **	8.33 **	"
Grain yield per plant	Normal	2.72*	1.94	108.37**	57.77**	Analysis of Array made partial adequate
	Water stress	12.39**	1.44	67.34**	6.56**	"
Harvest index	Normal	19.56*	-0.688	10652.6**	153.56**	Analysis of Array made partial adequate
	Water stress	6.61 **	0.50	11.98 **	3.81 *	"

* = P ≤ 0.05, ** = P ≤ 0.01, b = Regression coefficient, Wr = Covariance of array and parental values, Vr = Array variance

Table 5: Genetic components of variation for studied traits in an 8 x 8 diallel cross of maize

	Plant height		Leaf area per plant		1000-grain weight	
Component	Normal	Water stress	Normal	Water stress	Normal	Water stress
D	501.5±33.5*	606.6±28.9*	3429.6±417.5*	1204.29±383.1*	1835.37±275.9*	1150.9±120.9*
H_1	474.2±77.1*	540.9±66.5*	6593.4±959.9*	5343.35±880.5*	3627.15±634.3*	1669.1±278.0*
H_2	391.4±67.1*	452.4±57.9*	5234.3±835.1*	4517.42±766.1*	2971.23±551.9*	939.5±241.9*
F	303.1±79.3*	381.2±68.4*	3252.9±986.5*	635.60±905.0	1712.59±651.9*	1738.3±285.7*
E	0.359±11.4	21.1±9.8*	3.4±141.9	07.23±130.2	4.76±98.8	2.0±41.1
$(H_1/D)^{0.5}$	0.972	0.944	1.387	02.10	1.41	1.2
h^2 (NS)	58.9%	53.9%	36.90%	38.0%	34.25%	23.09%
h^2 (BS)	99.85%	92.75%	99.83%	99.61%	99.58%	99.34%

Table 5: (Continued)

	Biological yield		Grain yield per plant		Harvest index	
Component	Normal	Water stress	Normal	Water stress	Normal	Water stress
D	2610.01±463.49*	2087.44±106.99*	893.70±153.30*	1148.17±51.96*	0.00775±0.00013*	0.00303±0.00027
H_1	6782.93±1065.50*	1800.59±245.97*	3236.40±352.41*	1294.55±119.45*	0.00716±0.0003*	0.00531±0.00063
H_2	6008.50±926.98*	1395.23±213.99*	2452.69±306.60*	1064.32±103.92*	0.00294±0.00026*	0.00455±0.00055
F	39.22±1095.08	1643.19±252.8*	820.07±362.20*	918.43±122.77*	0.0114±0.00031*	0.00282±0.00065
E	10.69±157.56	15.92±36.37	3.20±52.11	9.21±17.66	0.0000003±0.00004*	0.000136±0.00009
$(H_1/D)^{0.5}$	1.61	0.929	1.90	1.06	0.962	1.323
h^2 (NS)	52.51%	53.80%	41.0%	46.0%	26.75%	27.59%
h^2 (BS)	99.66%	97.99%	99.69%	98.18%	99.97%	92.25%

* The value of variance is significant when the value exceeds 1.96 after dividing it with its standard error

F-131 possessed the most recessive genes for plant height having farthest position from the origin.

Leaf area per plant: The genetic components D and H were significant under both plantings suggesting that leaf area per plant was under the control of both additive and dominant genetic effects (Table 5). Unequal values of H_1 and H_2 revealed different distribution of dominant and recessive genes. The value of F was found to be positive and significant under normal planting, suggesting that positive and dominant genes were more frequent, while under water stress, positive or dominant genes were less important for this trait. Component (E) was found non-significant under normal as well as water stress.

Degree of dominance revealed that this character was governed by over-dominance gene action under both plantings. Broad sense heritability estimates were quite high but lower estimates of narrow sense heritability estimates (36.9 and 38.0%, respectively) under both experiments were observed which also indicated that greater amount of genetic variation inherited was of dominance nature. This was also supported by graphical representation of the data where the intercept of the regression line was negative under both experiments displaying an over dominance gene action (Fig. 2a and b). These findings are in accordance those of Yousaf[5] and Shabbir and Saleem[9] who also reported over-dominance type of gene action for this trait. Distribution of array points in the graphs displayed that most dominant genes were contained in F-133 while F-131 had the most recessive genes in both of the planting conditions. Rest of the parental lines hold intermediary gene constitution.

1000-grain weight: Both D and H components were significant under both plantings, displaying importance of additive a s well as dominance effects for the control of

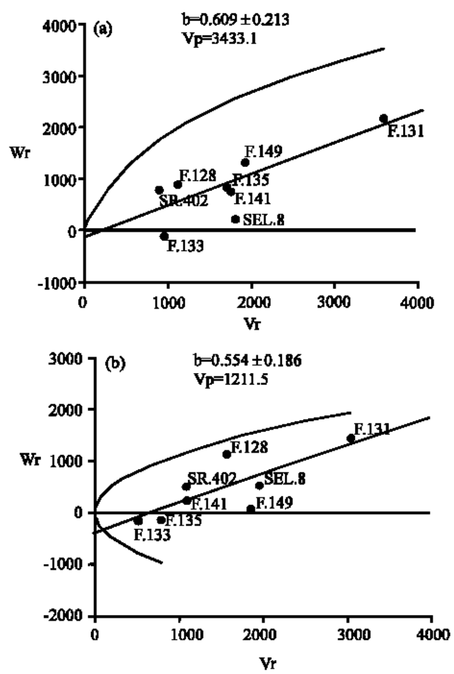

Fig. 2: Vr/Wr graph for leaf area under a) normal and b) water stress conditions

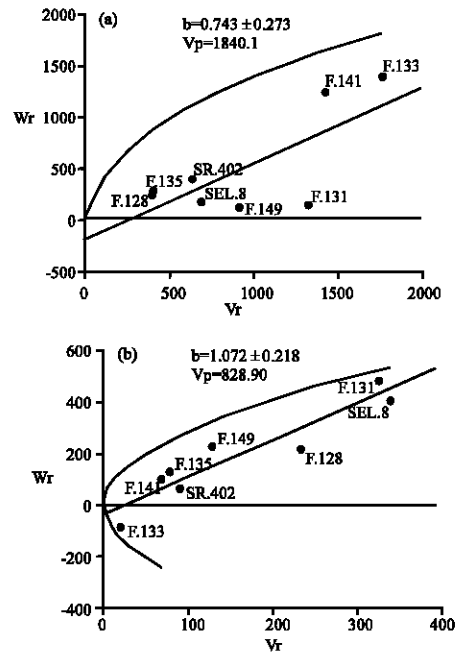

Fig. 3: Vr/Wr graph for 1000-grain weight under a) normal and b) water stress conditions

1000-grain weight. Dominance effects were, however, more pronounced. Unequal values of H_1 and H_2 indicated the dissimilar distribution of positive and negative genes. Positive and significant values of F, displayed the greater frequency of dominant genes under both environments. The environmental component (E) was found non-significant under both sowings.

Mean degree of dominance under normal and water stress was more than 1 (1.41 and 1.20, respectively) indicating the over-dominance type of gene action. Low narrow sense heritability values of 34.25 and 23.09% for 1000-grain weight under normal and water stress, respectively, also displayed the inheritance of dominance variation in great amount. Similarly, the regression line intercepted the Wr-axis below the point of origin, showing the presence of over dominance in the expression of 1000-grain weight under both environments (Fig. 3a and b). Results are similar with those of Yousaf[5] and Perez *et al.*[7].

The Vr/Wr graph (Fig. 4a and b) disclosed that under normal planting, inbred line F-128 possessed maximum dominant genes for 1000-grain weight closely followed by F-135 and the maximum recessive genes were exhibited by F-133. In case of water stress, the genotype F-133 kept the maximum dominant genes for 1000-grain weight whereas maximum numbers of recessive genes were present in the inbred line F-131.

Biological yield: Estimation of genetic components of variation (Table 5) for biological yield revealed significant variation due to both additive and dominance gene effects under both sowing situations. Unequal values of H_1 and H_2 components indicated different distribution of positive and negative genes under normal and water stress conditions. Value of F was non-significant under normal, whereas it was positive and significant under water stress, signifying the preponderance of dominant genes for the control of this trait. Environmental (E) variation was found to be non-significant under both plantings indicating insignificant role of environment for the expression of this trait. High estimates of broad sense heritability (99.66 and 97.99%, respectively) were recorded for biological yield under normal and water stress conditions. However, the narrow sense heritability estimates (52.51 and 53.80%, respectively) indicated a medium proportion of additive genetic variation of the total genetic variation inherited.

The value of the degree of dominance was found to be more than one under normal planting and less than one under water stress condition, indicating over-dominance and additive with partial type of gene action under normal and water stress, respectively. The graphical presentation of the data (Fig. 4a and b) also revealed the same situation. The results are in accord with those of Shakil[19], Shabbir and Saleem[9] who reported over-dominance type of gene action for biological yield.

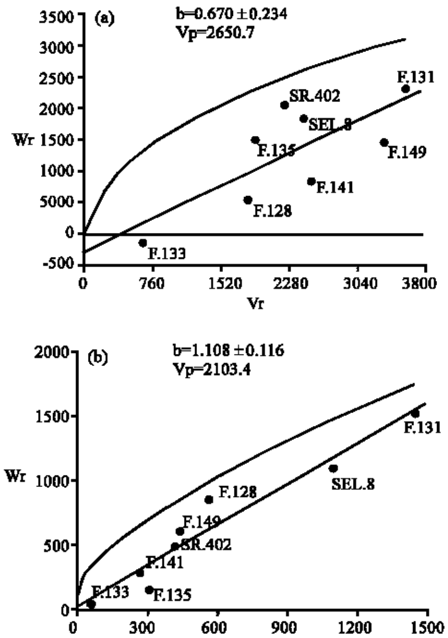

Fig. 4: Vr/Wr graph for biological yield under a) normal and b) water stress conditions

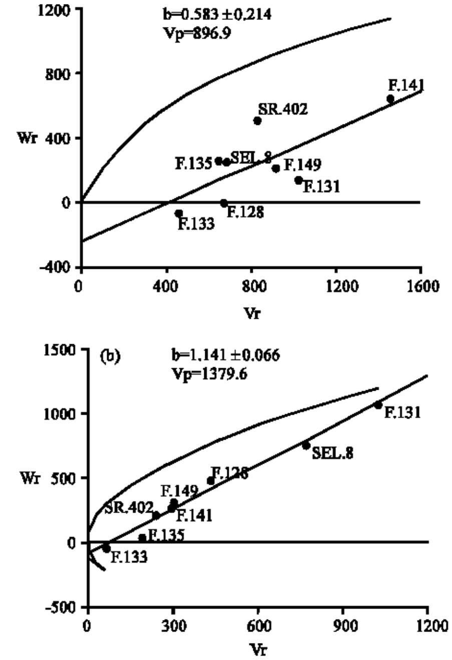

Fig. 5: Vr/Wr graph for grain yield per plant under a) normal and b) water stress conditions

Distribution of the array points indicated that the inbred line F-133 contained maximum dominant genes and F-131 maximum recessive genes under both sowings.

Grain yield per plant: The significant values of D and H (Table 5) components under both plantings displayed the importance of additive as well dominance effects for the control of grain yield per plant. Dissimilar values of H_1 and H_2 indicated the dissimilar distribution of dominant genes. Values of F were positive and significant displaying the greater frequency of dominant or positive genes under both environments. Environmental variation (E) was also found non-significant under both cases. Narrow sense heritability was recorded as 41 and 46.0%, respectively. The average degree of dominance under both experiments was more than one (1.90 and 1.06, respectively), indicating an over-dominance type of gene action for the control of this trait. Graphical presentation of the data (Fig. 5a and b) also depicted a similar gene action for this trait under normal as well as water stress. Results are similar with those of Yousaf[5], Shabbir and Saleem[9], who also reported over-dominance type of gene action while Tabassum[1], Damborsky *et al.*[6], Dutu[8] and Mani[20] who reported additive gene action for this trait.

Distribution of array points indicated that the inbred line F-133 contained maximum dominant genes for grain yield per plant under both environments. F-141 and F-131 had the least dominant genes under normal and water stress, respectively. The remaining inbred lines were of intermediate constitution.

Harvest index: Estimates of genetic components of variation (Table 5) displayed almost similar outcome in both the experimental conditions. Both additive and dominant components of variation were significant, with unequal distribution of negative and positive genes among the parents for harvest index. Values of F were positive and significant displaying greater frequency of dominant genes for the trait under study. Overall dominance effects due to environmental components of variation (E) were non-significant under normal but significant under water stress.

Involvement of dominance reduced the heritability of the trait in narrow-sense under normal as well as water stress (26.75 and 27.59%, respectively) indicating a very small amount of additive heritable variation in the total genetic variation inherited. Average degree of dominance under each planting (0.962 and 1.323) indicated additive and over-dominant type of gene action, respectively for harvest index. Figure 6a and b) also depicted an additive and over-dominance type of gene action for normal and water stress, respectively. These results are in corroborating with those of Shakil[19], Shabbir and Saleem[9] who reported over-dominance type of gene action for this trait. It was noted that under normal, maximum dominant genes were contained in the inbred

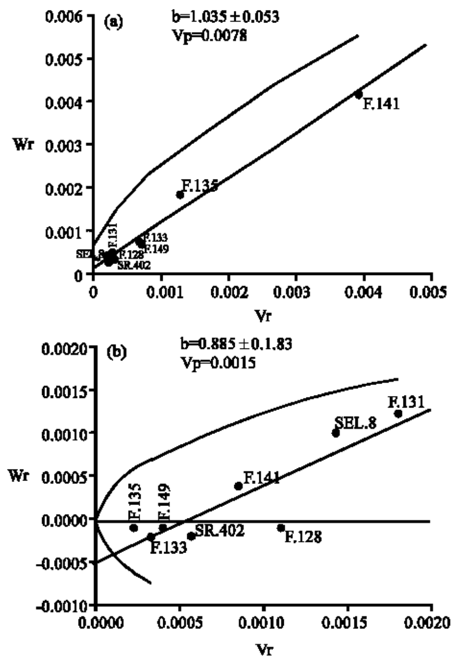

Fig. 6: Vr/Wr graph for harvest index under a) normal and b) water stress conditions

lines SR-402 and F-128 while F-141 contained the minimum dominant genes. In case of water stress, F-135 was indicated as having the most dominant genes while SEL-8 contained the least dominant genes.

Estimation of genetic components analysis revealed that under normal, components of both additive D and dominant H genetic variations were significant for plant height, leaf area per plant, 1000-grain weight, biological yield, grain yield per plant and harvest index.

Average degree of dominance under normal condition indicated that additive gene action for plant height remained unchanged under water stress while over-dominance type of gene action for leaf area per plant, 1000-grain weight and grain yield per plant under normal planting also remained unchanged under water stress. On the other hand over-dominance type of gene action for biological yield under normal condition changed to additive with partial type of gene action under water stress whereas for harvest index, additive with partial type of gene action under normal changed to over-dominance type of gene action for this trait under water stress. It was also observed that parental genotypes shifted their position in the graph from dominant to recessive or the midway or vice versa, showing different genetic constitution for the same trait in response to environmental change.

On the basis of overall results of this study and performance of the genotypes, inbred lines F-133 and F-135 were the best for plant height, 1000-grain weight, biological yield, grain yield and harvest index on the basis of mean performance under both normal and water stress. Additive gene action for plant height predominated under each planting. Over dominance type of gene action for leaf area per plant, 1000-grain weight and grain yield per plant under normal remained unchanged under water stress condition. Additive gene action for harvest index under normal planting changed to over dominance under water stress condition. Thus, the above mentioned inbred lines are suggested to be used in future breeding strategies for the production of drought tolerant maize genotypes.

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