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Short Research Article

Selection Indices Studies in Maize (*Zea mays* L.) under Multiple Abiotic Stress Conditions

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Abstract

The present investigation was undertaken on maize (*Zea mays* L.) under two abiotic stress conditions viz. low-nitrogen (low soil fertility) and excess soil moisture conditions (waterlogging) during *kharif* 2010. Studies were carried out for developing suitable selection indices in relation to multiple abiotic stress tolerance. The experimental material consisted of twelve lines and four testers and their 48 single crosses planted in Randomized Block Design. Analysis of variance revealed significance for all the traits studied in both the conditions, indicating there by the existence of high genetic variability in the genotypes. In low-N conditions, the best performing line was L_5 followed by and among testers T_3 ranked highest. Among the crosses, $L_{11}\times T_4$ ranked highest followed by $L_8\times T_1$ and $L_{11}\times T_3$. In waterlogging conditions, L_6 performed better followed by L_5. Among the crosses $L_6\times T_4$ ranked highest. Economic weights were assigned to various traits under low-nitrogen and excess soil moisture (ESM) conditions. Among the crosses, aggregate score were higher in most of the cases but general trend was that ESM traits had the lower score values. Crosses $L_{11}\times T_4$, $L_8\times T_1$, $L_{11}\times T_3$, $L_7\times T_2$ and $L_6\times T_2$ performed well in low-nitrogen conditions for the assigned selection criteria. In waterlogging trials, $L_6\times T_4$, $L_7\times T_2$ and $L_4\times T_1$ performed excellent while crosses $L_5\times T_1$, $L_{12}\times T_2$, $L_5\times T_4$, and $L_3\times T_3$ ranked very low in ESM trials. Thus for ESM tolerance, the crosses $L_6\times T_4$ and $L_7\times T_2$ are the best available crosses according to the given selection criteria and for low-nitrogen tolerance, $L_{11}\times T_4$ and $L_8\times T_1$ were the best crosses.

1. Introduction

Crowned with the rhetoric phrase the queen of cereal maize (*Zea mays* L.) is the world's most important cereal and occupies the apex position in terms of production at the world level. It is an economically important cereal crop for human food, animal feed, fiber and a range of industrial uses. Maize crop grown in tropics during summer-rainy season occasionally face extreme climatic conditions and various biotic or abiotic stresses that severely limit crop growth and development and eventually yield potential. Among the abiotic stresses, low nitrogen and Excess Soil Moisture (ESM) are the most important constraints for maize production and productivity in the world and Asian region. Indian soils have been characterized as being low in organic matter and N. Tropical rain fed soils in semi-arid regions are typically low in organic matter, often containing less than 1% organic matter, with a total N generally not exceeding 0.1%. About 77% of these rain fed soils are classified as low to very low in available N (Katyal et al., 1994). Recent statistics on N fertilizer consumption pattern showed that average application of N in developed countries is 250 kg ha^{-1}, while in developing countries it is 82 kg ha^{-1}, and in Sub-Saharan African countries it is as low as 5.0 kg ha^{-1} (SAA, 2002). The trend of low N application contributes to low maize yield of about 1−2 t ha^{-1} in developing countries (CIMMYT, 1994), which is in stark contrasts to yields reported from research stations in the same countries ranging from 4−12 t ha^{-1} (CIMMYT, 1995, 1996). Yields in Africa are considerably lower than the world average because the cultivation of maize is often prone to low soil fertility (primarily N but also P and other nutrient deficiencies) in addition to biotic stresses (FAO, 2010). Additional reasons for low-N fertility in the tropics include poor soil types with low N mineralization, high run off or leaching of applied fertilizer with heavy rainfall due to light textured soils, and poor uptake of applied N due to problems of water stress.

In India, excess soil moisture caused by flooding, waterlogging, high water table or heavy soil texture is also one of the most important constraints for crop production where about 8.5 mha of arable land is in the grip of this problem. In case of June planting it may coincide with flowering which may interfere with the normal pollination behavior and seed setting (Savita et al., 2004). In India out of total 6.6 mha area of maize over 2.5 mha is prone to face excessive soil moisture/ waterlogging conditions, which causes on average 25−30% loss of national maize production almost every year (DMR, 2001). The maize crop suffers badly whenever it encounters temporary excess soil moisture (ESM) conditions during the monsoon season or grown in poorly drained converted paddy fields after a rainy season rice crop, a practice more common in Thailand, Japan and Eastern China (Shimizu, 1992). Maize plants are injured more and greater yield losses occur when flooded at early stages. Therefore, it would be desirable to develop maize cultivars with increased resistance to low N and ESM conditions which is desirable for sustainable production systems with improved yield, without any threat on environment and ecosystems.

Population improvement of a crop is the primary objective of a plant-breeding program. However, the progress in any breeding program depends primarily upon the genetic diversity and the effectiveness of the selection procedure involved. Besides other selection method used for the Population improvement, selection indices are considered as an aid to the breeder for simultaneous selection of multiple traits (Smith, 1936). This tool can help the breeder in spotting the desirable genotype/family of a crop species in a population improvement program. Smith (1936) and Hazel (1943) illustrated the procedure for constructing a selection index that gives maximum advance from selection. Selection indices provide useful information about which traits to be combined (Banziger and Lafitte, 1997). Selection indices have been an effective selection criterion to increase grain yield in corn (Modaressi et al., 2004). Many other Researchers have used selection indices as an effective selection criterion in their breeding programs on different crops (Vikram and Roy, 2003; Xie et al., 1998; Dolan et al., 1996). Keeping this in mind, the proposed study was carried out with the objective to construct selection indices with regard to low N and ESM tolerance.

2. Materials and Methods

The present investigation was undertaken with twelve inbred lines and four testers which were initially screened for their performance in low-N and ESM tolerance and normal conditions at the Crop Research Center of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. These inbred lines were then crossed in line×tester fashion at Pantnagar to generate $F_{1's}$. The experimental material thus consisted of twelve lines, four testers and 48$F_{1's}$. Field trials were laid down in low-N, excess soil moisture and normal conditions during *kharif* 2010 at Pantnagar. The details of the parental lines have been indicated in the Table 1 (Table 1: Details of the parental lines).

Table 1: Details of the parental lines

Parents	Pedigree	Coded pedigree
1.	POB. 33 C_3-12-2-1-1-2-2	L_1
2.	POB. 33 C_3-12-2-1-2-2-5	L_2
3.	POB. 33 C_3-142-1-6-1-1-4	L_3
4.	POB. 45 C_8-86-1-3-7-6-4	L_4
5.	POB. 45 C_8-45-2-6-1-2-7	L_5
6.	POB. 45 C_8-269-2-4-6-3-3	L_6
7.	POB. 45 C_8-86-1-1-7-5-1	L_7
8.	CLG 1708-1-1-9	L_8
9.	POB. 45 C_8-45-2-6-1-1-1	L_9
10.	POB. 45 C_8-86-1-3-4-5-2	L_{10}
11.	POB. 45 C_8-86-1-3-2-2-5	L_{11}
12.	POB. 45 C_8-269-2-4-6-6-1	L_{12}
13.	POB. 445 ⊗ 58-6-3-B-B-B	T_1
14.	POB. 446-74-2-B-B-B	T_2
15.	CML-421	T_3
16.	CML-423	T_4

For the present study, parents along with all the developed generations were grown in Randomized Block Design in one row plot of 5 m length with 3 replications following spacing of 75 cm between rows and 25 cm between plants. The crop management practices were applied in the three environments as per the recommendations. In low N condition, 40 kg N ha^{-1} was applied. In ESM trials, waterlogging treatment was given at knee high growth stage for 6 days, by keeping continuous submergence with an average depth of ponding of about 5 cm. After 6 days of ponding, water was drained out of the plots. The data were recorded on days to 50% tasseling, days to 50% silking, anthesis, silking interval, plant height, ear height, cob length, cob diameter, 100-kernel weight, grain yield, nodes bearing adventitious roots, leaf senescence and number of ears per plant. Appropriate statistical and biometrical analysis for selection index (Smith-Hazel) was carried out. A selection index with many traits is likely to have low heritability (Bernardo and Yu, 2007). Genotypic and phenotypic variance-covariance matrices were developed to aid calculation of index coefficients. Estimated indices were calculated by the method described by Smith (1936).

Application of discriminate function as a basis for making selection on several characters simultaneously is aimed at discriminating the desirable genotypes from undesirable genotypes on the basis of their phenotypic performance.

Later on, Hazel (1943) developed a simultaneous selection model following path analysis approach.

Smith (1936) defined the genetic worth of an individual (H) as:

$$H=a_1G+a_2G_2+ \ldots\ldots +a_nG_n=\sum_{i=1}^{n} a_iG_i$$

Where, G_1, G_2, G_n are the genotypic (breeding) values of individual characters and a_1, a_2, ….., an signify their relative economic importance. Another function (I) based on the phenotypic performance of various characters, is defined as:

$$I=b_1p_1+ b_2p_2+ \ldots\ldots\ldots\ldots +b_np_n$$

Where, b_1, b_2, ….., b_n are to be estimated such that the correlation between H and I, i.e. r(H, I), becomes maximum. Once such function is obtained, discrimination of good genotypes from the undesirable ones will be possible on the basis of phenotypic performance, *i.e.* p_1, p_2, …. p_n directly.

The maximization of r(H, I) leads to a set of simultaneous equation which upon solving give the desired estimate of b_i values.

Considering 4 characters, the simultaneous equations look like as follows:

$$b_1\times 11+b_2\times 12+b_3\times 13+b_4\times 14=a_1G_{11}+a_2G_{12}+a_3G_{13}+a_4G_{14}$$

$$b_1\times 21+b_2\times 22+b_3\times 33+b_4\times 24=a_1G_{21}+a_2G_{22}+a_3G_{23}+a_4G_{24}$$

$$b_1\times 31+b_2\times 32+b_3\times 33+b_4\times 34=a_1G_{31}+a_2G_{32}+a_3G_{33}+a_4G_{34}$$

$$b_1\times 41+b_2\times 42+b_3\times 43+b_4\times 44=a_1G_{41}+ a_2G_{42}+a_3G_{43}+a_4G_{44}$$

Which in matrix form become :

$$\begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{23} \\ x_{31} & x_{32} & x_{33} & x_{33} \\ x_{41} & x_{42} & x_{43} & x_{43} \end{bmatrix} . \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} & G_{13} & G_{14} \\ G_{21} & G_{22} & G_{23} & G_{24} \\ G_{31} & G_{32} & G_{33} & G_{34} \\ G_{41} & G_{42} & G_{43} & G_{44} \end{bmatrix} . \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}$$

The solution of these equations gives the estimates of b_i values in the following manner :

$b=X^{-1}Ga$

Where, *b* is the column vector, X^{-1} is the inverse of phenotypic variance and covariance matrix and *a* is the column vector for economic weights.

The various steps involved in the construction of selection indices are described below:

(i) Estimation of variance and covariance matrix

Genotypic and phenotypic variances and covariance's were determined using Randomized Complete Block Design with analysis of variance for each trait and covariance between every pairs of traits.

The expected mean sums of squares are as follows:

$$E\ (MS_g) = \sigma_2^2 + r\sigma_g^2$$

$$E\ (MS_e) = \sigma_e^2$$

And, therefore, $\sigma_g^2 = \dfrac{MS_g - MS_e}{r}$, where r is number of replications.

Thus, the estimated genotypic variance is σ_g^2 and the environmental variance is σ_e^2 . The phenotypic variance, σ_p^2, is calculated as $\sigma_g^2 + \sigma_e^2$.

Similarly, expectations of mean sum of products are calculated as follows:

$$E\ (MSP_g) = \sigma e_1e_2 + r\sigma g_1g_2$$

$$E\ (MSP_e) = \sigma e_1e_2\ ,$$

And hence, $\sigma g_1g_2 = \dfrac{MSP_g - MSP_e}{r}$

Thus, the estimated genotypic covariance is σg_1g_2, and the environmental covariance is σe_1e_2. The phenotypic covariance, σp_1p_2 is calculated as $\sigma g_1g_2+ \sigma e_1e_2$. The genotypic variance and covariance matrix is constructed as follows:

$$\begin{bmatrix} \sigma^2_{g1} & \sigma_{g1g2} & \sigma_{g1g3} & \sigma_{g1g4} \\ \sigma_{g1g2} & \sigma^2_{g2} & \sigma_{g2g3} & \sigma_{g2g4} \\ \sigma_{g1g3} & \sigma_{g2g3} & \sigma^2_{g3} & \sigma_{g3g4} \\ \sigma_{g1g4} & \sigma_{g2g4} & \sigma_{g3g4} & \sigma^2_{g4} \end{bmatrix}$$

And genotypic variance and covariance matrix is constructed as follows:

$$\begin{bmatrix} \sigma^2_{p1} & \sigma_{p1p2} & \sigma_{p1p3} & \sigma_{p1p4} \\ \sigma_{p1p2} & \sigma^2_{p2} & \sigma_{p2p3} & \sigma_{p2p4} \\ \sigma_{p1p3} & \sigma_{p2p3} & \sigma^2_{p3} & \sigma_{p3p4} \\ \sigma_{p1p4} & \sigma_{p2p4} & \sigma_{p3p4} & \sigma^2_{p4} \end{bmatrix}$$

(ii) Setting of simultaneous equations

Assuming that all characters are economically equally important, $a_1=a_2=a_3=a_4=1$, we can write down the simultaneous equation (in a matrix form) by using the values given in above two matrices.

$$\begin{bmatrix} \sigma^2_{p1} & \sigma_{p1p2} & \sigma_{p1p3} & \sigma_{p1p4} \\ \sigma_{p1p2} & \sigma^2_{p2} & \sigma_{p2p3} & \sigma_{p2p4} \\ \sigma_{p1p3} & \sigma_{p2p3} & \sigma^2_{p3} & \sigma_{p3p4} \\ \sigma_{p1p4} & \sigma_{p2p4} & \sigma_{p3p4} & \sigma^2_{p4} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} \sigma^2_{g1} & \sigma_{g1g2} & \sigma_{g1g3} & \sigma_{g1g4} \\ \sigma_{g1g2} & \sigma^2_{g2} & \sigma_{g2g3} & \sigma_{g2g4} \\ \sigma_{g1g3} & \sigma_{g2g3} & \sigma^2_{g3} & \sigma_{g3g4} \\ \sigma_{g1g4} & \sigma_{g2g4} & \sigma_{g3g4} & \sigma^2_{g4} \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

(iii) The solution of the equation for b_i values

As we know: $b=X^{-1}Ga$

We first require to inverse the phenotypic variance-covariance matrix. Now the inverse (X^{-1}) is multiplied with the genotypic variance and covariance matrix, i.e. G. The resultant matrix i.e. $X^{-1} G$ is multiplied by a vector a_i to get b_i values.

(iv) The selection index and selection criterion

The mathematical description of the function (I) is known as selection index.

$I=b_1p_1+b_2p_2+\ldots, +b_np_n$

Using this function, the selection criterion or index value for each individual is determined as follows:

Genotype Characters b Selection criterion

$$\begin{bmatrix} p1 \\ p2 \\ p3 \\ p4 \\ \ldots \\ pn \end{bmatrix} \quad \begin{matrix} X1 & X2 & X3 & X4 \end{matrix} \begin{bmatrix} X11 & X21 & X31 & X41 \\ X12 & X22 & X32 & X42 \\ X13 & X23 & X33 & X43 \\ X14 & X24 & X34 & X44 \\ \ldots & \ldots & \ldots & \ldots \\ X1n & X2n & X3n & X4n \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} SC1 \\ SC2 \\ SC3 \\ SC4 \\ \ldots \\ SCn \end{bmatrix}$$

3. Results and Discussion

Analysis of variance for all the characters were carried out and it was found that mean squares for all the genotypes studied were highly significant under normal, low-N and ESM conditions, clearly indicating the existence of genetic variability in the genotypes. In normal conditions, among parents, L_5 ranked first and L_9 ranked last among lines and in case of testers T_1 ranked first and T_4 ranked last. In low-N conditions, L_5 performed better followed by L_2 and the least rank was shown by L_9 in case of lines and in testers T_3 ranked highest while T_4 ranked last as indicated in Table 2 (Table 2: Selection criterion and ranking of parents and crosses in maize for four traits under normal, high N and low-N conditions). Among the crosses, $L_{11}\times T_4$ ranked highest followed by $L_8\times T_1$ and $L_{11}\times T_3$ and the least performing cross for this particular selection index was $L_5\times T_4$. In ESM conditions, L_6 performed better followed by L_5 and the least rank was shown by L_9 in case of lines as indicated in Table 3 (Table 3: Selection

Table 2 : Selection criterion and ranking of parents and crosses in maize for four traits under normal (high N) and low-N conditions

Variable / character	βi value				Variable / character	βi value			
	normal		low-N			normal		low-N	
	score	rank	score	rank		score	rank	score	rank
L_1	8849.18	62	6622.45	61	L_5T_1	20494.14	40	20491.50	27
L_2	11902.97	59	16698.69	47	L_5T_2	24227.27	15	24200.58	6
L_3	7327.56	63	7102.92	60	L_5T_3	25050.14	10	23955.92	10
L_4	13421.64	56	8809.45	57	L_5T_4	14619.18	55	10470.03	55
L_5	20932.03	36	16728.90	46	L_6T_1	19114.48	46	16503.29	48
L_6	16314.75	52	15150.55	51	L_6T_2	26356.79	6	24581.19	5
L_7	12749.13	57	6551.71	62	L_6T_3	24695.18	12	24184.04	7
L_8	9338.65	60	6062.84	63	L_6T_4	23211.62	24	22421.66	17
L_9	5047.73	64	1275.16	64	L_7T_1	20532.68	39	13517.20	52
L_{10}	15869.99	53	12327.51	53	L_7T_2	26785.70	4	26442.40	4
L_{11}	16702.96	51	7832.50	59	L_7T_3	22729.83	26	18789.70	35
L_{12}	12087.18	58	8505.43	58	L_7T_4	25187.81	9	21260.09	23
T_1	22535.39	27	19543.95	32	L_8T_1	26564.27	5	26868.71	2
T_2	18819.55	47	17558.67	42	L_8T_2	20884.16	37	17813.30	40
T_3	21065.57	33	20886.25	26	L_8T_3	22244.48	29	19923.14	45
T_4	9147.12	61	8899.67	56	L_8T_4	23030.11	25	22386.47	18
L_1T_1	21696.24	30	20309.81	28	L_9T_1	24492.03	13	18147.27	38
L_1T_2	24417	14	21888.40	20	L_9T_2	23692.94	20	23333.35	14
L_1T_3	28386.52	3	24063.96	9	L_9T_3	20991.55	35	19993.80	30
L_1T_4	19472.11	44	19912.76	31	L_9T_4	19815.38	43	18561.58	37
L_2T_1	18017.78	50	17340.87	43	$L_{10}T_1$	23503.16	22	23416.53	13
L_2T_2	20142.32	42	15982.90	49	$L_{10}T_2$	21366.22	31	20931.92	25

Continue...

Variable / character	βi value				Variable / character	βi value			
	normal		low-N			normal		low-N	
	score	rank	score	rank		score	rank	score	rank
L_2T_3	20353.96	41	19242.79	33	$L_{10}T_3$	24699.01	11	24130.03	8
L_2T_4	24191.44	16	23647.40	12	$L_{10}T_4$	25357.74	8	21583.88	21
L_3T_1	22523.35	28	21503.89	22	$L_{11}T_1$	23300.98	23	18919.04	34
L_3T_2	19214.70	45	18767.49	36	$L_{11}T_2$	21270.54	32	17976.47	39
L_3T_3	18447.71	48	15158.63	50	$L_{11}T_3$	28683.45	2	26610.25	3
L_3T_4	23682.85	21	22918.61	15	$L_{11}T_4$	32176.19	1	27387.26	1
L_4T_1	25470.92	7	22797.26	16	$L_{12}T_1$	18179.58	49	17696.19	41
L_4T_2	20737.84	38	21213.44	24	$L_{12}T_2$	14797.99	54	11219.38	54
L_4T_3	21034.69	34	17170.95	44	$L_{12}T_3$	24028.84	19	20309.17	29
L_4T_4	24088.85	17	23797.00	11	$L_{12}T_4$	24057.94	18	22213.98	19

Table 3: Selection criterion and ranking of parents and crosses in maize for ten traits under normal and ESM conditions

Variable / character	βi value				Variable / character	βi value			
	normal		low-N*			normal		low-N*	
	score	rank	score	rank		score	rank	score	rank
L_1	3346.19	62	1367.91	60	L_5T_1	7141.33	40	829.601	63
L_2	3983.94	59	3389.20	52	L_5T_2	8583.03	16	5853.49	19
L_3	2543.73	63	1342.96	61	L_5T_3	8698.80	9	6110.88	12
L_4	4763.65	56	3924.67	42	L_5T_4	5255.76	55	1757.92	59
L_5	7126.36	41	4229.90	40	L_6T_1	6754.48	46	4772.63	31
L_6	5922.43	51	4469.16	35	L_6T_2	9009.48	6	6742.36	5
L_7	4699.29	57	2627.95	55	L_6T_3	8291.04	17	6480.97	9
L_8	3513.99	60	2173.47	56	L_6T_4	8157.46	22	7763.04	1
L_9	2108.32	64	540.42	64	L_7T_1	7856.38	29	3614.23	49
L_{10}	5713.92	53	3965.73	41	L_7T_2	9074.43	4	7248.57	2
L_{11}	5835.42	52	2112.85	57	L_7T_3	7875.79	28	4370.82	37
L_{12}	4282.29	58	1903.35	58	L_7T_4	8526.91	10	6060.50	13
T_1	8086.28	26	6546.67	8	L_8T_1	9021.61	5	6026.82	16
T_2	6403.47	50	5236.52	27	L_8T_2	7315.56	38	5799.06	20
T_3	7321.12	37	6971.58	4	L_8T_3	7749.57	30	3731.47	46
T_4	3489.73	61	6117.76	11	L_8T_4	8093.24	24	5241.24	26
L_1T_1	7570.80	31	5331.36	25	L_9T_1	8417.63	13	6038.15	15
L_1T_2	8477.53	12	5402.93	22	L_9T_2	8164.11	21	6203.02	10
L_1T_3	9710.50	3	5396.58	23	L_9T_3	7416.92	35	4270.82	39
L_1T_4	6894.50	43	4976.63	29	L_9T_4	6876.76	44	4283.38	38
L_2T_1	6447.36	49	3472.04	51	$L_{10}T_1$	8213.88	19	6614.17	7
L_2T_2	7462.63	33	3327.55	53	$L_{10}T_2$	7337.47	36	3702.33	47
L_2T_3	7091.92	42	3478.18	50	$L_{10}T_3$	8512.62	11	5031.58	28
L_2T_4	8415.32	14	4475	34	$L_{10}T_4$	8791.91	7	6005.61	17
L_3T_1	7934.82	27	4613.34	32	$L_{11}T_1$	8176.15	20	6052.27	13
L_3T_2	6816.85	45	5357.07	24	$L_{11}T_2$	7485.62	32	3828.57	44

continue...

Variable / character	βi value				Variable / character	βi value			
	normal		low-N*			normal		low-N*	
	score	rank	score	rank		score	rank	score	rank
L_3T_3	6598.16	47	2992.24	54	$L_{11}T_3$	9834.54	2	5720.87	21
L_3T_4	8153.21	23	4475.00	33	$L_{11}T_4$	10735.98	1	6005.60	18
L_4T_1	8706.99	8	7071.64	3	$L_{12}T_1$	6498.81	48	3911.99	43
L_4T_2	7289.06	39	3688.21	48	$L_{12}T_2$	5444.21	54	1042.60	62
L_4T_3	7430.32	34	378.79	45	$L_{12}T_3$	8247.38	18	4461.88	36
L_4T_4	8389.48	15	4885.98	30	$L_{12}T_4$	8091.42	25	6632.28	6

* This is low nitrogen application trial. In this trial, no nitrogen was applied to provide the abiotic stress of low soil fertility

criterion and ranking of parents and crosses in maize for ten traits under normal and ESM conditions). Among the crosses $L_6×T_4$ ranked highest and the least performing cross for this particular selection index was $L_5×T_1$.

Economic weights assigned to various traits under low-N and ESM conditions in the present study have been presented in as indicated in Table 4 (Table 4: Simultaneous selection indices for normal and low-N trials in maize) and Table 5 (Table 5: Simultaneous selection indices for normal and ESM trials in maize), respectively.

Among the parents, none of the parents ranked high among all genotypes according to the assigned selection criteria in normal low-N and ESM conditions. Among the crosses aggregate score were higher in most of the cases but general trend was that ESM traits had the lower score values. Crosses $L_{11}×T_4$, $L_8×T_1$, $L_{11}×T_3$, $L_7×T_2$, and $L_6×T_2$ performed well in both normal and low-N conditions for the assigned selection criteria while crosses $L_5×T_4$, and $L_{12}×T_2$ performed poorly in low-N conditions. In ESM trials, $L_6×T_4$, $L_7×T_2$, and $L_4×T_1$ performed excellent while crosses $L_5×T_1$, $L_{12}×T_2$, $L_5×T_4$, and $L_3×T_3$ ranked very low in ESM trials. Now for ESM tolerance we can deduce from the results that crosses $L_6×T_4$ and $L_7×T_2$ are the best available crosses according to the given selection criteria. For low-N tolerance, $L_{11}×T_4$ and $L_8×T_1$ were the best crosses. Similar studies with different objectives were conducted by Brim et al. (1959), Mulamba and Mock (1978), Kauffmann and Dudley (1979), Nawar et al. (1991) Banziger and Lafitte (1997), Edmeades et al. (1999); Modaressi et al. (2004); Kebede (2007); Lone (2006) in different stress conditions.

Table 4: Simultaneous selection indices for normal and low-N trials in maize

Variable/character	Economic weight	βi value	
		Normal	ESM*
ASI	2	-21.83	34.04
Yield (kg ha^{-1})	5	4.87	4.90
Leaf senescence	1	-56.02	14.47
Number of ears plant^{-1}	1	190.13	175.18

* This is excess soil moisture trials. In this trial, waterlogging treatment was given at knee high growth stage for 6 days by keeping continues submergence with an average depth of ponding of about 5 cm. After 6 days of ponding, water was drained out of the plots.

Table 5: Simultaneous selection indices for normal and ESM trials in maize

Variable/character	Economic weight	βi value	
		Normal	ESM
Days to 50% tasseling	1	4.331	49.222
Days to 50% silking	1	-13.752	-48.945
ASI	0.7	-23.832	50.842
Plant height	1	2.325	0.897
Ear height	1	4.011	2.782
Cob length	1	29.787	-3.385
Cob diameter	1	-91.623	11.315
100 kernel weight	1	22.626	1.437
Yield (kg ha^{-1})	1.6	1.512	1.556
Nodes bearing adventitious roots	1.3	-36.061	14.192

4. Conclusion

It is desirable to develop maize cultivars with increased resistance to abiotic stress for sustainable production. For this, selection indices are considered as an aid for simultaneous selection of multiple traits which can help the breeder in spotting the desirable genotype/family of a crop species in a population improvement program. The study carried out illustrates how to construct selection indices with regard to low N and ESM tolerance. Thus, it has been recognized that most rapid improvement in the economic value is expected from selection applied simultaneously to all the characters which determine the economic value of a plant, provided appropriate weights are assigned to each character.

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