ASSESSMENT OF GENETIC VARIABILITY AND GENOTYPE X ENVIRONMENT INTERACTION FOR SOME QUANTITATIVE TRAITS AND LEAF AREA IN BREAD WHEAT (*Triticum aestivum* L.)

THESIS

Submitted to the
Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur
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By

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1989

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CERTIFICATE-I

This is to certify that the thesis entitled, "ASSESSMENT OF GENETIC VARIABILITY AND GENOTYPE x ENVIRONMENT INTERACTION FOR SOME QUANTITATIVE TRAITS AND LEAF AREA IN BREAD WHEAT (<u>Triticum aestivum</u> L.)", submitted in partial fulfilment of the requirements for the Degree of "MASTER OF SCIENCE IN AGRICULTURE" of the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, is a record of the bonafide research work carried out by Shri **VINAY KUMAR UPADHYAYA** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

YMishra 18/9/89

(Y. Mishra)
Chairman of the Advisory Committee

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CERTIFICATE-II

This is to certify that the thesis entitled, "ASSESSMENT OF GENETIC VARIABILITY AND GENOTYPE X ENVIRONMENT INTERACTION FOR SOME QUANTITATIVE TRAITS AND LEAF AREA IN BREAD WHEAT (*Triticum aestivum* L.)", submitted by Shri **VINAY KUMAR UPADHYAYA** to the J.N. Krishi Vishwa Vidyalaya, Jabalpur, in partial fulfilment of the requirements for the degree of M.Sc.(Ag.), in the Department of **PLANT BREEDING AND GENETICS**, has after evaluation, been approved by the External Examiner and by the Student's Advisory Committee after an oral examination on the same.

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V. K. Upadhyaya
(V.K. Upadhyaya)

Jabalpur
Sept. 18, 1989

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INTRODUCTION

1. INTRODUCTION

Wheat (Triticum aestivum L.) is the most important food grain crop of India and is now cultivated in nearly 23 million hectares. In prehistoric times, it was grown in ancient Persia, Egypt, Greece and Europe as early as 10,000 to 15,000 B.C. The late dwellers of Switzerland grew wheat and there are indications of its cultivation in China about 300 B.C. Extensive references have been made to wheat grain in ancient Indian scriptures "Atharva Veda" which is supposed to have been written between 1500 and 500 B.C. The man, thus depended upon the wheat plants for the last thousands of years and hundreds of generations.

India has made rapid progress in wheat production during the past two decades which has enabled the country to self-sufficiency in food grains. Wheat production has increased by nearly four times from 12.26 million tonnes in 1964-65 to 46.89 million tonnes in 1985-86. During this period, area under wheat has gone up from 13.4 million hectares to more than 23 million hectares and productivity has increased from 913 kg/ha to 2032 kg/ha (Table 1(a) and Fig.1(a)[1]. Among the

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[1] Technology for increasing wheat production in India. Wheat Project Directorate (All-India Coordinated Wheat Improvement Project), ICAR, New Delhi, 1988, pp 19.

Table 1(a) : Area, production and productivity of wheat in India

Year	Area (million hectares)	Production (million tons)	Yield (kg/ha)
1949-50	9.76	6.39	655
1950-51	9.75	6.46	663
1951-52	9.47	6.18	653
1952-53	9.83	7.50	763
1953-54	10.68	8.02	750
1954-55	11.26	9.04	803
1955-56	12.37	8.76	708
1956-57	13.52	9.40	695
1957-58	11.73	7.99	682
1958-59	12.62	9.96	789
1959-60	13.38	10.32	772
1960-61	12.93	11.00	851
1961-62	13.57	12.07	890
1962-63	13.59	10.78	793
1963-64	13.50	9.85	730
1964-65	13.42	12.26	913
1965-66	12.57	10.40	827
1966-67	12.84	11.39	887
1967-68	14.99	16.54	1103
1968-69	15.96	18.65	1169
1969-70	16.63	20.09	1209
1970-71	18.24	23.83	1307
1971-72	19.14	26.41	1380
1972-73	19.46	24.74	1271
1973-74	18.58	21.78	1172
1974-75	18.01	24.10	1338
1975-76	20.45	28.84	1410
1976-77	20.92	29.01	1387
1977-78	21.46	31.75	1480
1978-79	22.64	35.51	1568
1979-80	22.17	31.83	1436
1980-81	22.28	36.31	1630
1981-82	22.14	37.45	1691
1982-83	23.57	42.79	1816
1983-84	24.67	45.48	1843
1984-85	23.56	44.07	1970
1985-86	23.07	46.89	2032

food grain crops, wheat has recorded the highest compound growth rate of 5.64 per cent in production and 3.15 per cent in yield per hectare between 1967-68 to 1985-86. Area of wheat has shown

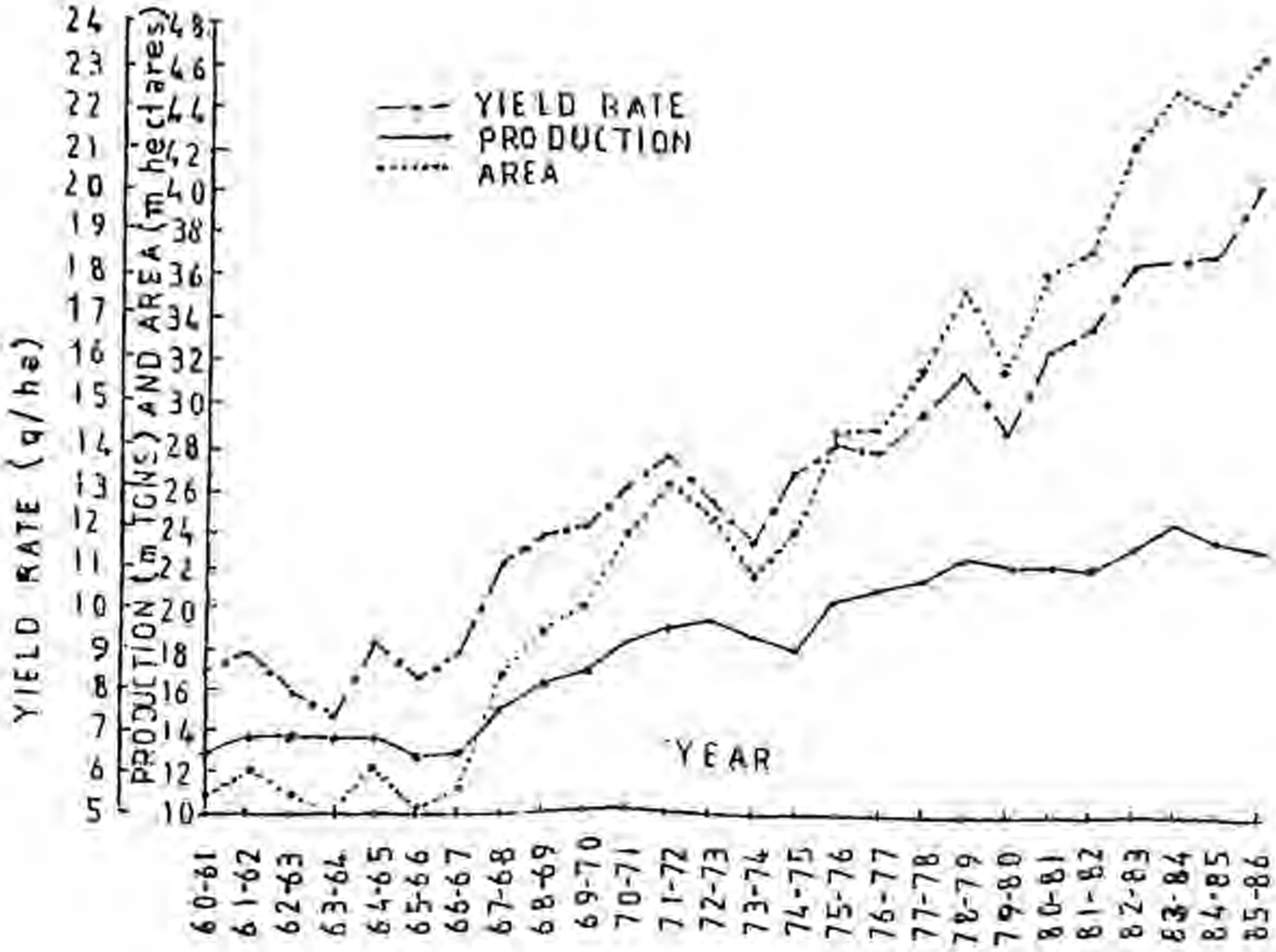

FIG-1a : PROGRESS IN AREA, PRODUCTION AND YIELD RATE OF WHEAT IN INDIA the highest growth rate which comes to 2.41 per cent. The figure of the growth rate of cereals in the country for the same period has been 2.97 per cent for production, 2.21 per cent for productivity and 0.31 per cent for area (Table 1(b)).

Table 1(b) : Compound growth rate (per cent per annum) for selected food crops from 1967-68 to 1985-86

Crop	Area	Production	Yield
Rice	0.65	2.54	1.92
Wheat	2.41	5.64	3.15
Small millets	-2.18	-1.84	0.35
Total cereals	0.31	2.97	2.21
Pulses	0.44	0.65	0.29
Total foodgrains	0.34	2.74	2.30

These changes further increased the importance of wheat in the country because of increasing total food production from about 13 to 30 per cent. The per capita availability of wheat has also increased from 49.1 g in 1961 to 147.1 g in 1986[1].

Major wheat growing States with their area, production and productivity have been given in Table 1(c).

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[1] Survey of Indian Agriculture. The Hindu, 1988.

Table 1(c) : Statewise area, production and yield rate of wheat

State	Area ('000 ha)		Production ('000 tons)		Productivity (kg/ha)	
	1985-86	1984-85	1985-86	1984-85	1985-86	1984-85
Bihar	1909.2	1917.1	3143.2	3099.1	1646	1616
Gujarat	431.4	636.9	782.8	1329.3	1815	2087
Haryana	1699.0	1704.0	5257.0	4418.0	3094	2593
M.P.	3602.3	3536.5	4269.0	3729.1	1185	1055
Maharashtra	881.5	988.6	664.4	856.5	754	866
Punjab	3113.0	3096.0	10992.0	10133.0	3531	3289
Rajasthan	1773.5	1719.0	3918.0	2794.5	2209	1626
U.P.	8275.2	8554.1	16842.7	15974.0	1992	1867
W.Bengal	305.1	335.9	578.0	812.2	1894	2418
Other States	1073.4	1116.1	935.5	1018.2	871	912
All-India	23074	23614	46885	44229	2032	1972

Madhya Pradesh is one of the major wheat growing States and it is grown in almost all the districts of M.P., but the major wheat growing districts are Chhatarpur, Guna, Hoshangabad, Jabalpur, Morena, Raisen, Sagar, Shajapur, Surguja, Tikamgarh, Ujjain and Vidisha (Fig.1(b)). During the past two decades in Madhya Pradesh, wheat production has passed through a virtual revolution. In this period, from 1965 to 1986, the area under wheat has increased from 3197.6

FIG.1b: MAP SHOWING WHEAT GROWING DISTRICTS IN MADHYA PRADESH

S.No	District
1.	Raipur
2.	Durg
3.	Rajnandgaon
4.	Bastar
5.	Bilaspur
6.	Surguja
7.	Raigarh
8.	Sidhi
9.	Shabdol
10.	Mandla
11.	Balaghat
12.	Rewa
13.	Satna
14.	Panna
15.	Jabalpur
16.	Seoni
17.	Chhattarpur
18.	Tikamgarh
19.	Damoh
20.	Narsinghpur
21.	Chhindwara
22.	Sagar
23.	Raisen
24.	Hoshangabad
25.	Betul
26.	Khandwa
27.	Dewas
28.	Sehore
29.	Bhopal
30.	Vidisha
31.	Guna
32.	Shivpuri
33.	Gwalior
34.	Datia
35.	Bhind
36.	Morena
37.	Rajgarh
38.	Shajapur
39.	Mandsaur
40.	Ratlam
41.	Ujjain
42.	Indore
43.	Khargone
44.	Dhar
45.	Jhabua

thousand hectares to 3549.0 thousand hectares, while production went up from 2035.4 thousand tonnes to 4329 thousand tonnes. Correspondingly yield per hectare increased from 636 kg/ha to 1220 kg/ha. Madhya Pradesh has got 16 per cent (35.49 thousand hectares) of country's wheat area and contributes to 9.1 per cent (43.29 thousand tonnes) wheat production. The productivity of M.P. is lesser (1220 kg/ha) in comparison to national average productivity (2032 kg/ha)[1]. The Wheat Project Directorate has set up a production target of 5.30 million tonnes for M.P., while for whole nation, it is 52.32 million tonnes for the year 1989-90[2].

Wheat is a crop having wider adaptability and can be grown under a wide range of soils and climatic conditions. The wheat crop is grown most successfully between the latitudes of 30° and 60° north and between 27° and 40° south. In India, wheat is grown mostly in plains, whereas in the hills, it is cultivated in mountaneous region of north India and Nilgiris and Pali hills in south India. Wheat is grown in the world in rainfall ranges from 30 to 113 cm. More than 50 per cent of the area under wheat in the world is in the 36 to 63 cm rainfall range, 15 per cent in area where rainfall is 88 cm and 10 per cent area with less than 38 cm rainfall.

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1. Hand Book of Agricultural Statistics, 1987-88.

2. Technology for increasing wheat production in India. Wheat Project Directorate (All-India Coordinated Wheat Improvement Project), ICAR, New Delhi, 1988.

A member of Gramineae family, wheat comprises widely cultivated species like bread wheat (Triticum aestivum L., 2n=42), durum wheat (Triticum durum, 2n=28), and their wild and cultivated hexaploid, tetraploid and diploid relatives. It is a self-pollinated crop having extent of natural out crossing being lesser than 1 per cent in most of the varieties, but it may exceed in some varieties at some locations.

The factors which have major contribution in productivity of wheat over the past two decades are adoption of high yielding varieties and improved technologies, increase in area under irrigated wheat (increased from 36.8% in 1965 to 72.4% in 1986), increase in fertilizer consumption (increased from 4.9 kg/ha in 1965 to 50.1% in 1986), increase in wheat area in traditional regions, extension of wheat cultivation to non-traditional regions and the like[1].

Climatic limitations, soil problem, socio-economic constraints, organizational issue and disease and insect problems have been the major constraints in wheat production.

To overcome these, following are the few technological components which may bring further increase in production and productivity of wheat[2].

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[1] Data of irrigation percentage and fertilizer consumption - Survey of Indian Agriculture. The Hindu, 1988.

[2] Technology for increasing wheat production in India. Wheat Project Directorate (All-India Coordinated Wheat Improvement Project), ICAR, New Delhi, 1988.

(1) Change over to latest improved varieties.

(2) Increase in use of balanced fertilizers.

(3) Increase in area under timely sown wheat.

(4) Adoption of improved wheat management technology.

(5) Popularization of the use of weedicides.

These may further be strengthened by -

1. Breeding still more efficient plant types adaptable to wider range of ecological conditions for broad spectrum of disease and pest resistance, better nutritive quality and responsiveness to inputs.

2. Standardizing the breeding procedures for the exploitation of heterosis to economic advantage in this crop.

3. Increasing yield per unit area with adoption of suitable transfer of technology.

4. Bringing more area under wheat cultivation.

5. Bringing breakthrough in the yield levels through improvement in harvest index and physiological traits.

6. Attempting multiple crosses, spring x winter crosses and adopting recurrent selection for multiple resistance and developing multilines etc.

The measurement, evaluation and manipulation of genetic variability in desired direction becomes extremely important in any yield improvement programme. Such programmes stress to upgrade the yield potential by improving yield components. Yield is a complex character controlled by a large number of genes and highly influenced by environment, whereas yield components are governed by relatively fewer genes and are less sensitive to environmental conditions. Thus, selection based on yield components, has better chances of improvement.

Improvement of a crop depends upon the magnitude of genetic variability and heritability of economic characters. Genetic variability can be measured with the help of suitable genetic parameters such as genetic coefficient of variation, heritability estimates and genetic advance.

The correlation coefficient gives an idea about the various associations existing between yield and yield components and amongst themselves. The path coefficient analysis explores the relative contribution of both direct and indirect effects of yield components on yield. Correlation and path analysis have been very useful in making direct selections in purelines and non-segregating population with the help of selection indices.

Differential response of genotypes under varying environments reflects g x e interaction for quantitatively inherited traits. The traits with minimum or no genotype x environment interaction gives an idea of phenotypic stability which may be useful in developing cultivars with wider adaptability.

Keeping these investigations in view, 44 diverse genotypes of bread wheat were evaluated in two environments viz., high fertility ($N_{100}P_{50}K_{25}$) and low fertility ($N_{40}P_{40}K_{0}$) with the following objectives :-

(1) To estimate the relative extent of genetic variability of yield and its components along with leaf area index.

(2) To estimate heritability and expected genetic advance for grain yield and other characters.

(3) To assess the phenotypic, genotypic and environmental correlation coefficients in order to know the extent of association of grain yield with its components and leaf area index.

(4) To estimate the direct and indirect effects of yield and its components and leaf area index through path coefficient analysis.

(5) To study genotype x environment interaction for yield and its components.

Chapter - II

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

To strengthen the findings of the present investigation, an attempt has been made to review the literature available in wheat under the following headings :-

2.1 Genetic parameters

2.2 Correlation coefficients

2.3 Path coefficient analysis

2.4 Genotype x environment interaction

2.1 Genetic Parameters

2.1.1 Genotypic and phenotypic variabilities

The genotypic variability in relation to environment was first studied by Fisher (1918). Later, Fisher and several other workers devised techniques for the estimation of components of variance (Wright, 1921; Lush, 1940; Robinson et al., 1949 and Warner, 1952). Findings of the previous workers have been summarised below :-

Parameters 1.	Traits 2.	Result 3.	Workers 4.	Year 5.
G.V.	1000-grain weight, No. of tillers/plant Yield/plant	H	Anand et al.	1970
C.V.	No. of tillers/plant, 1000-grain weight, No. of grains/spike	H	Mishra	1971
	No. of spikelets/spike	L		

1.	2.	3.	4.	5.
G.C.V.	No. of tillers/plant	H	Phul *et al.*	1972
G.C.V. & P.C.V.	Spikes/plant, plant height, yield/plant, 1000-grain weight	H	Sethi and Singh	1972
G.C.V.	Yield/plant Days to 50% flowering	H L	Tikka *et al.*	1973
G.C.V.	1000-grain weight, plant height	H	Randhawa *et al.*	1975
G.C.V. & P.C.V.	Plant height, 1000-grain weight, grain yield/plant	H	Mustafeav *et al.*	1978
G.C.V.	Plant height, No. of grains/spike, spikelets/spike, 1000-kernel weight	H	Gupta and Ahmed	1982
G.C.V. & P.C.V.	LAI-I, LAI-II in *Setaria italica*	H	Kharche	1986
G.C.V. P.C.V.	LAI-I, LAI-II LAI-I, LAI-II (in kodo millet)	M H	Sharma	1988

Note : G.V. : Genotypic variability
C.V. : Coefficient of variation
G.C.V. : Genotypic coefficient of variation
P.C.V. : Phenotypic coefficient of variation
No. : Number
H : High
M : Medium or moderate
L : Low

2.1.2 Heritability

The importance of heritability of metric traits in plant population had been emphasised by Frankel (1947).

Warner (1952) first developed the detailed method of estimating the degree of heritability in plant.

Johnson et al. (1955a) defined heritability as a ratio of genotypic to phenotypic variances and stressed its importance in selection programmes. According to them, broad sense heritability estimates may vary greatly, depending upon the unit for which the variance is considered. It indicates the effectiveness with which selection of genotypes can be based on phenotypic performance. Review of work done on this aspect has been summarised below :-

S. No.	Traits	Result	Workers	Year
1.	2.	3.	4.	5.
1.	Grain yield/plant	L	Paroda and Joshi	1970a
2.	1000-grain weight, No. of spikelets/spike, spike length, plant height	H	Mishra	1971
3.	Plant height, ear length	H	Khan et al.	1972
4.	Plant height, ear length, grain yield/plant	H	Reddy et al.	1972
5.	Ear length, plant height	H	Rana et al.	1973
6.	Effective tillers/plant, 1000-grain weight	M to H	Tikka et al.	1973
7.	Plant height, 1000-grain weight, No. of grains/spike	H	Randhawa et al.	1975
8.	Harvest index	M	Bhatt	1976
9.	Plant height, ear length, spikelets/spike, grain yield/plant, 1000-grain weight	H	Islam	1976

1.	2.	3.	4.	5.
10.	No. of days to heading	H	Singh *et al.*	1977
11.	Plant height, No. of days to heading, ear length, harvest index	H	Sharma	1981
12.	Grain yield/plant, biological yield/plant, harvest index	H	Shrivastava *et al.*	1981
13.	Plant height, spikelets/spike, spike length, 1000-grain weight	H	Gupta and Ahmed	1982
14.	Heading date, plant height, No. of tillers/plant, grain weight/plant	H	Joarder *et al.*	1982
15.	1000-grain weight, grain yield/plant	L	Pacucci *et al.* (experiment conducted at different N_2 levels)	1982
16.	Grain weight/plant, 1000-grain weight, grains/spike, spikelets/plant	L	Shrivastava *et al.* (in *durum* wheat)	1982
17.	Plant height, 1000-grain weight	H	Camargo and Oliveira	1983
	Grain yield/plant	L		
18.	Grains/spike, plant height, days to maturity	H	Das and Rahman	1984
	1000-grain weight, spike length	L		
19.	1000-grain weight, heading date, plant height	H	Martynov *et al.*	1984
20.	Plant height, spike length, No. of grains/spike, 1000-kernel weight	H	Sharma *et al.*	1984
	No. of tillers/plant	M		
	Grain yield/plant	L		
21.	Harvest index	H	Kralijevic *et al.*	1985
22.	1000-grain weight	H	Pathak and Nema	1985
23.	Plant height	H	Choudhary *et al.*	1986

1.	2.	3.	4.	5.
24.	LAI-I LAI-II (in *Setaria italica*)	H M	Kharche	1986
25.	LAI-I and LAI-II (in kodo millet)	L	Sharma	1988

H - High; M - Moderate; L - Low; No. - Number

2.1.3 Genetic advance

Johnson *et al.* (1955a) indicated that heritability estimates when studied in conjuction with genetic advance would provide more appropriate information than the study of heritability alone. The brief review of the work done on wheat, on this aspect has been given below :-

S. No. 1.	Traits 2.	Result 3.	Workers 4.	Year 5.
1.	1000-grain weight, ear length, No. of spikelets/ spike	H	Mishra	1971
2.	No. of effective tillers/ plant, No. of grains/ear	M	Khan *et al.*	1972
3.	Effective tillers/plant, 1000-grain weight	H	Tikka *et al.*	1973
4.	Plant height, 1000-grain weight, No. of grains/ear	H	Randhawa *et al.*	1975
5.	Plant height, spikelets/ spike	H	Islam	1976

1.	2.	3.	4.	5.
6.	Biological yield/plant, harvest index, grain yield per plant	H	Shrivastava *et al.*	1981
7.	LAI-I, LAI-II (in *Setaria italica*)	H	Kharche	1986
8.	LAI-I LAI-II	M L	Sharma	1988

No. - Number; H - High; M - Medium; L - Low,
LAI-I - Leaf area index (preflowering)
LAI-II - Leaf area index (postflowering)

2.2 Correlation Coefficients

Yield is an important economic character and is the ultimate outcome of interaction of several metric traits. Among various yield and yield contributing characters, some may be directly and positively associated with yield, which are useful in selection programme.

In general, genotypic correlations are higher than phenotypic correlations as confirmed by Weber and Murthy (1952) and later by Johnson *et al.* (1955b). Mathematical implications of correlations at phenotypic, genotypic and environmental levels have been discussed by Searle (1961). Findings of previous workers have been summarised below :-

S. No.	Character combination	Result	Workers	Year
1.	2.	3.	4.	5.
1.	Tiller No./plant - Grains/spike	-ve	Choudhary *et al.*	1970
	Ear length - No. of grains/spike	+ve		
2.	Grain yield - Days to 50% flowering	+ve	Paroda and Joshi	1970b
	- Plant height			
	- Ear length			
	- Grains/ear			
	- Spikelets/ear			
	- 1000-grain weight			
3.	Grain yield - Grains/ear	+ve	Singh and Anand	1971a
4.	Grain yield - Spikelets/spike	+ve	Singh and Anand	1971b
5.	Grain yield - No. of tillers/plant	+ve	Singh and Randhawa	1971
	- No. of spikelets/spike			
	- No. of ears/plant			
6.	Biological yield - No. of ears/plant	+ve	Barrath *et al.*	1972
	- Grain weight/plant			
	No. of ears/plant - Grain weight/plant			
7.	Grain yield - Ears/plant	+ve	Sethi and Singh	1972
	- Days to maturity	-ve		
	- 1000-grain weight			
	1000-grain weight - Plant height	+ve		
	- Ear length			
8.	Grain yield - Plant height	+ve	Randhawa *et al.*	1975
	- Ears/plant			
	Ear length - 1000-grain weight			
9.	Grain yield - Days to maturity	+ve	Maya	1975

1.	2.		3.	4.	5.
10.	Plant height	- Ear length	+ve	Raut *et al.*	1977
		- 1000-grain weight			
	No. of spikelets/ spike	- Grains/ear			
11.	No. of tillers/plant	- Yield components	-ve	Abakumenko	1979
12.	Grain yield	- Leaf area	+ve	Dhiman *et al.*	1980
13.	Grain yield	- Plant height	+ve	Lu and Chen	1980
		- Test weight			
14.	Grain yield	- Spikelets/spike	+ve	Kumbhar *et al.*	1981
		- Grains/ear			
		- 1000-grain weight			
	Ears/plant	- Spikelets/spike			
		- Grains/ear			
		- 1000-grain weight			
	Spikelets/spike	- Grains/ear			
		- 1000-grain weight			
	Grains/ear	- 1000-grain weight			
15.	Grain yield	- Leaf area	+ve	Lyfenko *et al.*	1981
	Note : The semi-dwarf variety exceeded moderately tall varieties in leaf area during the grain filling, although reverse was true at the beginning of tillering.				
16.	Grain yield	- 1000-grain weight	+ve	Sambhu	1982
		- No. of tillers/plant			
17.	Grain yield	- Spikes/plant	+ve	Bhullar and Nijjar (in *durum* wheat)	1984
		- 1000-grain weight			
		- Plant height			
		- Spikelets/spike			
		- Spike length			
		- Days to maturity			

1.	2.		3.	4.	5.
18.	Grain yield	- 100-grain weight	+ve	Bhutta *et al.*	1984
19.	Grain yield	- 1000-kernel weight - Grains/spike - No. of tillers/plant - Plant height	+ve	Sandhu and Managat (in *T. aestivum*, *T. durum*, *T. sphaerococcum*)	1985
20.	Grain yield	- No. of tillers/plant - No. of ears/plant - Grains/ear	+ve	Anderson	1986
21.	LAI-I	- Plant height - Ear length	+ve	Kharche	1986
	LAI-II	- Plant height			
22.	Grain yield/plant	- Plant height - Grains/spike	+ve	Kumar *et al.*	1986
	1000-grain weight	- Grains/spike	-ve		
23.	Grain yield	- Biological yield - No. of tillers/plant - Harvest index	+ve	Kumar and Chowdhary (in *durum* wheat, in 3 environments on irrigation and fertility basis)	1986
	Biological yield	- No. of tillers/plant			
24.	Grain yield	- Spike length - Grains/spike - Plant height - Flag leaf area	+ve	Sheoran *et al.*	1986
25.	Grain yield	- plant height, ear length	+ve	Pathak *et al.*	1986
26.	Grain yield	- No. of tillers/plant - Biological yield	+ve	Balyan and Singh	1987
27.	Grain yield	- Harvest index, grains/ear - No. of ears/plant	+ve	Shamsuddin	1987

+ve : Significant positive correlation; -ve : Significant negative correlation

2.3 Path Coefficient Analysis

Path coefficient analysis is a standardized partial regression coefficient analysis which helps in examining the relative contribution of both direct and indirect effects of independent variables on dependent variable.

Concept of path coefficient was originally developed by Wright (1921). This method was utilized by many workers viz., Dewey and Lu (1959) in crested wheat grass. In wheat, many workers have used path coefficient technique to gain deeper insight into the nature of inter-relationship of various yield components and yield *per-se*.

In path coefficient analysis of metric traits in common wheat, Paroda and Joshi (1970b) observed that all the yield components viz., ears per plant, grain weight per ear and 1000-grain weight had high positive direct effects on yield. Negative direct effect of grains per ear on grain yield was also noticed by them.

Ears per plant had the highest positive direct effects on grain yield and 1000-grain weight (Jaimini *et al.*, 1974). Spikes per plant, grains per ear, plant height and grain weight in wheat had positive direct effects on grain yield. Indirect effects of ears per plant via plant height and 1000-grain weight were also important (Sethi and Singh, 1974). In spring wheat, positive direct effects of 1000-grain weight and number of grains/spike on grain yield were noted, while grain weight per spike was found to have indirect effects (Martynov, 1978).

Path coefficient analysis in *durum* and bread wheat revealed that harvest index exerted maximum direct effect on yield per square metre (Kumbhar *et al*., 1982). Plant height was an important component in wheat which contributed directly and indirectly in positive direction on grain yield. Negative direct effects of plant height and ears per plant on grain yield were also observed (Jatasra and Paroda, 1983c).

Path analysis conducted in *durum* wheat (Bhullar and Nijjar, 1984) revealed that spike number, 1000-grain weight and plant height were the most important in selection for high yield. Path coefficient study in eight varieties grown under various conditions showed that weight of grains from the main ear was the main character determining grain yield (Kozlovskaya and Metnik, 1985). Kumar and Choudhary (1986) estimated path coefficient for grain yield in three environments and found that tiller number had significant indirect effect on grain yield via biological yield. In a study on wheat by Kumar *et al*. (1986) under normal and saline conditions, it was revealed that in normal environment, plant height had maximum direct positive effect on grain yield (1.62), whereas grains per spike and 1000-grain weight had strong negative direct effects (-0.12 and -1.379, respectively) on grain yield.

Path analysis (Sheoran *et al*., 1986) in rainfed wheat revealed that selection of rainfed wheat might be based on

1000-grain weight and grains/spike. Greatest direct effect of biological yield on grain yield was reported by Balyan and Singh (1987). Boyadzhieva (1987) in his path coefficient analysis in wheat revealed that the greatest direct effect on grain weight per plant was shown by grain weight per ear and number of productive tillers per plant. Correlation and path coefficient analysis (Shamsuddin, 1987) in 30 genotypes of bread wheat (*Triticum aestivum* L.) indicated that spikes per plant, grains per spike, 1000-grain weight, biological yield and harvest index were related to yield and had direct effects.

2.4 Genotype x Environment Interaction

Differential response of genotypes under varying environments is termed as g x e interaction. Significant g x e interaction was observed for grain yield and spikes per plant (Purohit *et al.*, 1981).

For all the characters under investigation, significant cultivar x locality interaction was reported by Doss *et al.* (1983), while for harvest index, grain yield, biological yield and plant height on 10 hard red wheat (*Triticum aestivum* L.) cultivars grown at 5 locations.

In a study of 24 wheat cultivars sown on 3 different dates at 2 locations, significant genotype x environment interaction was observed by Rasal *et al.* (1983).

Significant genotype x environment interaction was also observed for almost all the characters except number of tillers per plant, number of ears per plant and harvest index by Singh (1989) in a study of 54 diverse wheat lines sown in two different environments.

Chapter - III

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was conducted at the Livestock Farm of the Department of Plant Breeding and Genetics, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, during rabi 1987-88.

Jabalpur is situated at 79°57'E longitude, 23°12'N latitude and at an altitude of 393.2 metres above the mean sea level. The climate of Jabalpur is semi-humid and sub-tropical with extreme rainy, winter and summer seasons. The summer temperature seldom goes beyond 118°F and in winter it occasionally falls down below 32°F. In general, rabi season starts from mid-October and extends upto mid-March. The soil of the experimental site is heavy black clay with uniform topography and free from waterlogged condition. It is medium in available nitrogen and phosphorus, but rich in potassium.

The monthly minimum and maximum temperatures, relative humidity, rainfall, number of rainy days and sunshine hours (meteorological data) during the crop season have been presented in Table 2.

Table 2 : Meteorological data for the crop season (rabi 1987-88)

Month	Av. temperature(°C) Max.	Av. temperature(°C) Min.	Relative humidity (%)	Rainfall (mm)	No. of rainy days	Sunshine hours/ day
1987						
Nov.	28.2	13.3	66.5	16.5	1	7.8
Dec.	25.2	8.4	68.3	4.3	1	8.5
Jan.'88	25.4	9.2	68.0	7.9	1	8.4
Feb.	28.9	11.7	58.5	-	0	9.2
March	33.8	15.4	49.0	19.3	1	9.1
April	39.5	22.5	31.0	2.8	0	8.0

3.1 Experimental Material

The experimental material comprised 44 diverse genotypes of bread wheat (*Triticum aestivum* L.). out of which 4 genotypes were well developed high yielding varieties used as check varieties and other 40 genotypes were the advanced lines (F_6 generation) of bread wheat (*T. aestivum* L.) obtained from CIMMYT (International Centre of Maize and Wheat Improvement), Mexico during March-April, 1987. The list of the genotypes with their source and pedigree is given in Table 3.

Table 3 : List of genotypes with their source and pedigree

S. No.	CIMMYT Entry No.	Variety or Cross	Pedigree
1.	2.	3.	4.
1.	30016	CM83304	Glew/4/KVZ/IBB/CHA/3/TRM
2.	30052	CM83347	VEE ≠ S'S'/THB'S'
3.	30072	CM83352	VEE ≠ S'S'//BUC'S'/PVN'S'
4.	30166	CM85518	Ures/3/Ald'S'/Cep75630//Cep75234/PAT7219
5.	30228	CM85591	BUC'S'//Ald'S/AZ
6.	30305	CM85645	Vee 5^{s}'S^{s}/5/IAS58/4/KAL/VV//CJ'S/3/Ald'S'
7.	30311	-do-	-do-
8.	30472	CM85776	NGS/CNTB//ALDKN'S'/IAS58/3/CNR'S'
9.	30482	-do-	-do-
10.	30515	CM85795	PFAU'S/Vee ≠ S'S'
11.	30564	CM85817	Papagos 86/Seri
12.	30579	CM85819	Papagos 86/S/Fury/SLM/Aldar'S'
13.	30596	-do-	-do-
14.	30616	-do-	-do-
15.	30647	CM85836	ND/VO9144//Kal/BB/3/Yaco's'/4/Vee ≠ S'S'
16.	30683	-do-	-do-
17.	30747	CM85839	Kea'S'/BVC'S'//FCT'S'
18.	30792	CM87368	F_9'70/Maxa's//Lira's/3/Ures
19.	30803	CM87398	NGNG7840//ALD'S/PVN'S/3/Lira's'
20.	30835	CM87559	WH283/3/GOB/A2//MUC'S'/4/Lira's'
21.	30934	CM83693	CI14227/TRM//Mad's'/3/THB'S'
22.	30951	-do-	-do-
23.	30977	CM83715	Bow's'//Jup/BHy's

Table 3 contd...

1.	2.	3.	4.
24.	31053	CM85940	KVZ//BB/CHA/3/TRM/4/THB'S'
25.	31268	CM86106	CAR853/COC/Vee's'/3/Bow's'
26.	31402	CM86108	CAR853/COC/Vee's'/3/Saral
27.	31431	CM86115	ALD'S/PVN'S'//THB'S'
28.	31498	CM86171	PAR ≠ 2/H567.71//THB'S'
29.	31504	CM86205	MRNG/AIDAN'S'//SARA
30.	31507	-do-	-do-
31.	31539	CM86210	Ald's'/COC//THB'S'
32.	31551	CM86211	Ald's'/COC//SARA
33.	31654	CM8770	IAS20/H567.71//Vee ≠ S'S'/3/
34.	31663	-do-	-do-
35.	31789	CM86726	IAS58/4/KAL/BBI/CJ'S'/3/ALD'S'/3/ Bow's'
36.	31831	CM87414	Kezaol/Glenn/3/Aldan's'/Cep7563// Cep75234/PAT7219
37.	31834	-do-	-do-
38.	31843	CM87493	BVC'S/Vee ≠ s's'/3/Ald's/Cep75630/ Cep75630//Cep75234/PAT7219
39.	32041	CM84758	ANB'S'/BVC'S'
40.	32177	CM78363	SNBS/3/GOB/AZ//MUS'S'
41.	Lok-1		S308 x S331
42.	WH147		(E4870 x C303) x (S339 x V18)
43.	Sonalika		(53-388-An) x (Yt54 x N10B) LR64
44.	J405		Cno x Ilnia x Bb/Cno"S"-Pj62 x Gallo

Note : Sr. No. 41,42,43 and 44 are the check varieties, i.e., well adopted high yielding varieties of India.

3.2 Methods

3.2.1 Sowing and application of fertilizers

The crop was sown on 2nd December, 1987 under two different fertility levels (two environments) :-

E_1 (High fertility level) : Fertilizers like N (urea), P_2O_5 (single superphosphate) and K_2O (muriate of potash) were applied @ 100, 50 and 25 kg/ha, respectively.

E_2 (Low fertility level) : Fertilizers like N (urea), P_2O_5 (single superphosphate) both were applied @ 40 kg/ha. K_2O was not applied.

3.2.2 Experimental design

The experiment was laid out in a randomized complete block design under two different environments viz., high fertility environment (E_1) and low fertility environment (E_2) each with three replications. In each replication of both the environments, genotypes were randomly allotted to the plots of two rows of 2.5 metre length. The spacings between rows and plants were maintained at 23 cm and 7.5 cm, respectively.

3.2.3 Observations recorded

There was separate sampling for morphological characters. Border rows were discarded to avoid border effect.

Observations were recorded from each entry in each replication under two environments separately.

3.2.4 Plant sampling for morphological characters

Ten competitive plants were randomly selected and tagged to record the following observations from each entry in each replication of both the environments separately :-

(1) Days to 50% flowering

The period from the date of sowing to date of 50% flowering was recorded and expressed in days (average number of days). Date of 50% flowering was recorded when 50% of the florets of the ears of the selected plants had bloomed.

(2) Days to maturity

The period from the date of sowing to date of maturity (ripening of every selected plant) was recorded and expressed in days (average number of days).

(3) Duration from flowering to maturity

It has been denoted by 'D'. Days to 50% flowering (F) was substituted from the days to maturity (M) and the value of 'D' was calculated as under :-

$$'D' = M - F$$

(4) Plant height

Height of the plants from ground level to top of the earhead excluding awns was recorded in centimeter at maturity.

(5) Tillers per plant

Total number of tillers for each tagged plant were counted at maturity and expressed in number.

(6) Ears per plant

Ears were counted from each tagged plant just before harvest and expressed in number.

(7) Ear length

Length of all ears per plant was measured from the base to the tip of the ear. Average ear length was computed and expressed in centimeter.

(8) Spikelets per spike

Number of spikelets was calculated on the basis of average of spikelets of all the spikes from each tagged plant.

(9) Grains per spike

Two spikes from each tagged plant were threshed separately and seeds were counted from these spikes directly.

(10) 1000-grain weight

1000 grains were drawn randomly from total grain yield of selected ten plants and weighed in grams.

(11) Grain yield per plant

Grains of each tagged plant were threshed separately and sun-dried and weighed in grams.

(12) Biological yield per plant

It is taken as total sun-dried plant weight (including ears with grains and excluding roots) and weighed in grams.

(13) Harvest index (%)

Harvest index was calculated as follows :-

$$\text{HI (\%)} = \frac{\text{Grain yield per plant}}{\text{Biological yield per plant}} \times 100$$

3.2.5 Plant sampling for leaf area index

In both E_1 and E_2 environments, investigations on some of the physiological aspects were taken up at two stages; first at 45 days after sowing and second at 65 days after sowing. At 45-day stage, none of the genotypes had ear emergence. Therefore, this stage was taken as pre-flowering stage and at 65-day stage nearly all the genotypes had bloomed.

Therefore, this stage was taken as post-flowering stage. Observations were based on two competitive plants which were uprooted for this purpose. Leaves were detached from the plants and then total leaf area for two plants was measured by leaf area meter known as LI-COR Model LI-3000 Portable Area Meter. This instrument utilizes an electronic method of rectangular approximation to measure leaf area on intact plant.

Calculation of leaf area index

Leaf area index (LAI) is the ratio of leaf area (LA) to the ground occupied by a plant and is worked out by the formula -

$$\text{LAI} = \frac{\text{Leaf area (LA)}}{\text{Ground area occupied by a plant (P), i.e., spacing } 23 \times 7.5 \text{ cm}^2}$$

3.3 Statistical Analysis

The data recorded on various plant characters were subjected to statistical analysis for each environment separately. In addition, pooled analysis was also carried out.

3.3.1 Analysis of variance

The data of both the environments were subjected to analysis of variance for all the characters separately. The skeleton of the analysis of variance was as given below :-

Skeleton of ANOVA Table

Source of variation	Degree of freedom	Sum of squares	Observed mean square	Expected mean square	F ratio
Replications	$(r-1)=2$	SS_R	MS_R		
Genotypes	$(g-1)=43$	SS_G	MS_G	$\sigma^2 e + r\sigma^2 g$	$\frac{MS_G}{MS_E}$
Error	$(r-1)(g-1)=86$	SS_E	MS_E	$\sigma^2 e$	
Total	$(rg-1)=131$				

where,

r = number of replications

g = number of genotypes

$\sigma^2 e$ = error variance = $\frac{MS_E}{r}$

$\sigma^2 g$ = genotypic variance = $\frac{MS_G - MS_E}{r}$

$\sigma^2 p$ = phenotypic variance = $\sigma^2 g + \sigma^2 e$

3.3.2 Pooled analysis of variance

Data on both the experiments were subjected to pooled analysis of variance after testing the two environments for the homogeneity by Bartelett's test. The skeleton of pooled analysis of variance was as follows :-

ANOVA Table for pooled analysis

Source of variation	Degree of freedom	Observed mean square	Expected mean square
Environments	1		
Replications within environment	4		
Genotypes	43	M_3	$\sigma^2_e + r\sigma^2_{ge} + r_e\sigma^2_g$
Environment x Genotype	43	M_2	$\sigma^2_e + r\sigma^2_{ge}$
Error	172	M_1	σ^2_e

3.3.3 Estimation of genetic parameters

Mean, range, components of variance (σ^2_g, σ^2_p and σ^2_e), genotypic and phenotypic coefficients of variation, heritability, genetic advance and genetic advance as percentage of mean were calculated for both the environments separately for all the traits studied.

(1) Mean and range :- Means and ranges were calculated as per conventional methods.

(2) Genotypic and phenotypic coefficients of variation:- These were computed using the formulae given by Burton (1952) :-

$$\text{G.C.V.} = \frac{\sigma g}{\bar{X}} \times 100$$

$$\text{P.C.V.} = \frac{\sigma p}{\bar{X}} \times 100$$

(3) Heritability in broad sense :- Heritability in broad sense (h^2_B) was calculated by the method proposed by Hanson *et al.* (1956). It is the ratio of total genotypic variance to the total phenotypic variance and expressed in percentage.

$$h^2_B = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

(4) Expected genetic advance :- Expected genetic advance was calculated by using the method of Johnson *et al.* (1955a).

$$\text{Expected Genetic Advance} = k.\sigma_p.h^2_B$$

where,

k = Constant value. The value of k is fixed at a particular level of intensity, i.e., at 5%, $k = 2.06$

σ_p = phenotypic standard deviation

h^2_B = heritability in broad sense

(5) Genetic advance as percentage of mean :- It is the ratio of genetic advance to the general mean of the character and expressed in percentage.

$$\text{G.A. as percentage of mean} = \frac{\text{G.A.}}{\bar{\bar{X}}} \times 100$$

3.3.4 Analysis of covariance

The analysis of covariance was carried out in order to find out the covariance components and to estimate correlation coefficient. Its skeleton was as given below :-

Skeleton of ANACOVA Table

Source of variation	Degree of freedom	Observed mean sum of product	Expected mean sum of product
Replications	(r-1)		
Genotypes	(g-1)	M_{ij}	$\sigma^2 e_{ij} + \sigma^2 g_{ij}$
Error	(r-1)(g-1)	E_{ij}	$\sigma^2 e_{ij}$

where,

$\sigma^2 e_{ij}$ = error covariance between i th and j th characters

$$= \frac{E_{ij}}{r}$$

$\sigma^2 g_{ij}$ = genotypic covariance between i th and j th characters

$$= \frac{M_{ij} - E_{ij}}{r}$$

$\sigma^2 p_{ij}$ = phenotypic covariance between i th and j th characters

$$= \sigma^2 g_{ij} + \sigma^2 e_{ij}$$

3.3.5 Estimation of correlation coefficients

Correlation coefficients were calculated for all the character combinations at genotypic, phenotypic and environmental levels with the help of formula suggested by Miller *et al.* (1958).

$$r_{xixj} = \frac{\text{Cov.}(x_i, x_j)}{\sqrt{\text{Var}(x_i).\text{Var}(x_j)}}$$

where,

r_{xixj} = correlation coefficient between characters x_i and x_j

Cov.(x_i, x_j) = covariance between characters x_i and x_j

Var(x_i) = variance of i^{th} character

Var(x_j) = variance of j^{th} character

Genotypic, phenotypic and environmental correlations were calculated by substituting genotypic, phenotypic and environmental covariances and variances in the formula.

Correlation coefficient was tested by 't' test.

$$'t_c' = \frac{|r|}{\sqrt{1 - r^2}} \cdot \sqrt{n-2} \quad \text{at (n-2) degree of freedom}$$

where,

$'t_c'$ = calculated 't' value at (n-2) degree of freedom

r = estimated value of correlation coefficient

n = number of observations

3.3.6 Path coefficient analysis

Path coefficient is simply a standardized partial regression coefficient which measures the direct and indirect effects of the independent variables on dependent variable. Path coefficient analysis was carried out by partitioning the correlation coefficients between grain yield, biological yield and harvest index and its components into direct and indirect effects.

Wright (1921) has evolved the method for the path coefficient analysis which was further modified by Dewey and Lu (1959).

Residual effect (R) was calculated by the formula given below :-

$$R = \sqrt{1 - \Sigma d_i r_{ij}}$$

where,

d_i = direct effect of i th character

r_{ij} = correlation coefficient of i th character with j th dependent character

Chapter - IV

RESULTS

4. RESULTS

Genetic analysis of 13 traits including yield and its components along with leaf area index (LAI) at two stages of crop growth and development was carried out in 44 diverse genotypes of wheat at two levels of fertility viz., high fertility (environment E_1) and low fertility (environment E_2). Pooled analysis of data for both the environments was also carried out. The results of E_1, E_2 and pooled analysis have been presented under the following heads :-

- 4.1 Parameters of genetic variability
  - 4.1.1 Analysis of variance, mean performance and estimates of genotypic and phenotypic coefficients of variation, i.e., GCV and PCV, respectively
  - 4.1.2 Heritability and genetic advance expressed as percentage of mean
- 4.2 Correlation coefficient analysis
- 4.3 Path coefficient analysis
- 4.4 Genotype x environment interaction

4.1 Genetic Parameters of Variability

4.1.1 Analysis of variance and mean performance and estimates of genotypic and phenotypic coefficients of variation

The analysis of variance revealed highly significant differences due to genotypes for all the characters in both the environments (Tables 4 & 5).

Table 4 : Analysis of variance for yield and its components (E_1 - high fertility)

Characters / Source of variation	d.f.	Days to 50% flowering	Days to maturity	'D'	Plant height (cm)	No. of tillers per plant	No. of ears per plant	Ear length (cm)	No. of spikelets per spike
Replications	2	0.0000	0.0500	0.1900	18.8500	4.7203	0.3457	10.4843	19.7950
Genotypes	43	58.5616**	21.2604**	32.5251**	193.0232**	7.1277**	6.1454**	1.5225**	5.2516**
Error	86	0.0543	0.0092	0.1196	9.7744	0.9813	0.2759	0.5750	1.4776

Characters / Source of variation	df	No. of grains per spike	1000-grain weight (g)	LAI-I	LAI-II	Grain yield/ plant (g)	Biological yield/ plant(g)	Harvest index (%)
Replications	2	1.9100	9.9650	0.0198	0.0131	37.3820	11.1200	0.7100
Genotypes	43	202.5579**	106.5679**	3.1363**	3.5076**	80.7597**	226.5504**	43.3372**
Error	86	13.6739	5.4689	0.0463	0.0713	33.2461	6.3046	2.4083

* Significant at 5% level
** Significant at 1% level

Table 5 : Analysis of variance for yield and its components (E_2 - low fertility)

Characters Source of variation	df	Days to 50% flowering	Days to maturity	'D'	Plant height (cm)	No. of tillers per plant	No. of ears per plant	Ear length (cm)	No. of spikelets per spike
Replications	2	0.0300	0.4000	0.2350	2.4950	0.7260	0.2912	8.5410	9.4160
Genotypes	43	46.4160**	19.2720**	34.8448**	119.6518**	4.0323**	3.0028**	2.0020**	5.4016**
Error	86	0.1620	0.1151	0.2581	5.8993	0.4317	0.1454	0.9132	0.5419

Characters Source of variation	df	No. of grains per spike	1000-grain weight (g)	LAI-I	LAI-II	Grain yield/plant (g)	Biological yield per/plant (g)	Harvest index (%)
Replications	2	53.2200	2.3250	0.0063	0.0131	1.6400	1.0390	4.8050
Genotypes	43	140.1832**	84.2686**	2.1271**	2.4493**	16.9309**	168.1177**	31.9960**
Error	86	11.6427	1.8448	0.0253	0.0424	1.9212	77.3063	1.7208

* Significant at 5% level
** Significant at 1% level

In order to see genetic variability at a glance, mean performance and ranges of variations for each character in E_1, E_2 and pooled analysis have been presented in Tables 6,7 and 8, respectively.

Genetic variations present in the experimental material for the traits taken into consideration were studied in E_1, E_2 and in pooled analysis which have been presented in Tables 6,7 and 8, respectively.

Variances were calculated at genotypic, phenotypic and environmental levels. Phenotypic variances were found higher than the genotypic and environmental ones for all the characters in both the environments (E_1 and E_2) and also in the pooled analysis.

In general, the estimates of PCV were higher than GCV. In E_1, the highest value of PCV was recorded for grain yield per plant (32.70), followed by LAI-I (28.83), biological yield per plant (24.13), LAI-II (22.72), number of tillers per plant (19.34), number of ears per plant (18.81), number of grains per spike (18.25), 1000-grain weight (13.42), plant height (9.09), harvest index (8.89), ear length (8.33), days from flowering to maturity, i.e., 'D' = M-f (7.94), number of spikelets per spike (6.84), days to 50% flowering (6.12) and days to maturity (2.35). Similarly, the highest value of GCV was obtained for LAI-I (28.83), followed by grain yield per plant (25.08), biological yield per plant (23.79), LAI-II

Table 6 : Parameters of genetic variability (E_1 - high fertility)

Parameters / Characters	Mean	Range Min.	Range Max.	$\sigma^2 p$	$\sigma^2 g$	$\sigma^2 e$	PCV	GCV	$h^2 B$ (%)	G.A.	GA as percentage of mean
Days to 50% flowering	72.12	64.00	85.00	19.52	19.50	0.01	6.12	6.12	99.94	9.09	12.61
Days to maturity	112.80	107.00	121.00	7.09	6.88	0.20	2.35	2.32	97.17	5.32	4.72
Days from flowering to maturity	40.74	32.00	47.00	10.48	10.44	0.03	7.94	7.93	99.61	6.64	16.30
Plant height (cm)	88.18	70.90	102.42	64.45	61.08	3.25	9.09	8.86	94.93	15.68	17.78
No. of tillers per plant	7.96	5.26	13.20	2.37	2.04	0.32	19.34	17.94	86.07	2.72	34.29
No. of ears/plant	7.59	5.26	12.86	2.04	1.95	0.09	18.81	18.39	95.58	2.81	37.05
Ear length (cm)	8.48	6.93	9.60	0.50	0.31	0.19	8.33	6.56	62.00	0.90	10.64
No. of spikelets per spike	19.33	14.83	21.40	1.75	1.25	0.49	6.84	5.78	71.42	1.94	10.06
No. of grains per spike	45.00	26.81	61.51	67.51	62.96	4,55	18.25	17.63	93.26	15.78	35.07
1000-grain weight (g)	44.99	35.23	54.66	35.52	33.69	1.82	13.24	12.90	94.84	11.64	25.88
LAI-I	3.52	1.82	5.92	1.04	1.03	0.01	28.83	28.83	99.03	2.08	59.10
LAI-II	4.78	3.21	7.18	1.16	1.14	0.02	22.72	22.33	98.27	2.18	45.61
Grain yield per plant (g)	15.86	9.26	28.25	26.91	15.83	11.08	32.70	25.08	58.82	6.28	39.63
biological yield per plant (g)	36.00	21.19	58.10	75.51	73.41	2.10	24.13	23.79	97.21	17.40	48.34
Harvest index (%)	42.73	35.40	48.733	14.44	13.64	0.80	8.89	8.64	94.45	7.39	17.30

Table 7 : Parameters of genetic variability (E_2 - low fertility)

Parameters / Characters	Mean	Range Min.	Range Max.	$\sigma^2 p$	$\sigma^2 g$	$\sigma^2 e$	PCV	GCV	$h^2 B$ (%)	G.A.	G.A. as percentage of Mean
Days to 50% flowering	74.69	66.00	86.00	15.47	15.41	0.05	5.26	5.25	99.61	8.07	10.80
Days to maturity	113.38	110.00	122.66	6.42	6.38	0.03	2.23	2.22	99.37	5.16	4.57
Days from flowering to maturity	38.67	28.00	45.66	11.61	11.52	0.08	8.81	8.77	99.22	6.96	18.01
Plant height (cm)	84.22	4.73	9.06	39.88	37.91	1.96	7.49	7.31	95.06	12.36	14.68
No. of tillers/plant	6.00	3.66	8.13	1.34	1.20	0.14	19.29	18.25	89.55	2.13	35.50
No. of ears/plant	5.69	6.13	9.63	1.00	0.95	0.04	17.57	17.12	95.00	1.95	34.39
Ear length	8.36	15.26	22.46	0.66	0.36	0.30	9.71	7.17	54.54	0.91	10.91
No. of spikelets per spike	18.88	27.59	58.40	1.80	1.61	0.18	7.10	6.72	89.44	2.47	13.09
No. of grains per spike	41.49	31.40	56.56	46.72	42.84	3.88	16.47	15.77	91.69	12.91	31.11
1000-grain weight (g)	39.46	31.40	56.56	28.09	27.47	0.61	13.42	13.28	98.32	10.67	27.06
LAI-I	2.44	1.10	4.74	0.71	0.70	0.01	34.53	34.28	98.60	1.71	70.13
LAI-II	3.20	1.84	5.97	0.81	0.80	0.01	28.12	27.95	98.76	1.83	57.22
Grain yield per plant (g)	9.22	4.32	14.25	5.64	5.00	0.64	25.75	24.25	88.65	4.33	47.03
Biological yield per plant (g)	24.42	16.40	48.36	56.03	30.27	25.76	30.65	22.52	54.02	8.33	34.11
Harvest index (%)	40.34	35.16	48.60	10.66	10.09	0.57	8.09	7.87	94.65	6.36	15.78

Table 8 : Parameters of genetic variability (pooled analysis)

Parameters / Characters	Mean	Range		σ^2p	σ^2g	σ^2e	PCV	GCV	h^2B (%)	G.A.	GA as percentage of Mean
		Min.	Max.								
Days to 50% flowering	73.41	65.00	85.50	32.60	32.56	0.03	7.77	7.76	99.87	11.74	16.00
Days to maturity	113.09	109.33	121.83	10.01	9.99	0.02	2.79	2.79	99.80	6.50	5.75
Days from flowering to maturity	39.70	31.00	44.33	16.88	16.82	0.06	10.89	10.33	99.64	8.43	21.24
Plant height	86.20	69.81	97.86	94.28	91.58	2.60	11.26	11.10	97.13	19.42	22.53
No. of tillers/plant	6.98	5.30	10.66	2.65	2.42	0.23	23.32	22.19	91.32	3.06	43.87
No. of ears/plant	6.64	5.10	10.13	2.15	2.08	0.07	22.08	21.72	96.74	2.92	44.00
Ear length (cm)	8.42	6.70	9.56	0.96	0.71	0.24	11.63	10.00	73.95	1.49	17.72
No. of spikelets per spike	19.11	16.88	20.90	2.75	2.41	0.33	8.67	8.12	87.63	2.99	15.66
No. of grains per spike	43.25	29.62	55.29	80.67	76.45	4.22	20.76	20.21	94.76	17.53	40.54
1000-grain weight (g)	42.23	34.43	59.86	48.92	47.70	1.22	16.56	16.35	97.50	14.04	33.26
LAI-I	2.98	1.46	5.33	1.49	1.48	0.01	40.96	40.82	99.32	2.47	83.55
LAI-II	3.99	2.49	6.07	1.67	1.66	0.01	32.38	32.29	99.40	2.69	66.31
Grain yield/plant(g)	12.54	7.18	23.07	19.48	13.62	5.86	35.19	29.43	69.91	6.35	50.63
Biological yield per plant (g)	30.21	16.93	44.82	80.98	67.05	13.93	29.78	27.10	82.79	15.34	50.80
Harvest index (%)	41.53	34.43	48.81	18.28	17.59	0.68	10.29	10.09	96.22	8.47	20.40

(22.33), number of ears per plant (18.39), number of tillers per plant (17.94), number of grains per spike (17.63), 1000-grain weight (12.90), plant height (8.86), harvest index (8.64), 'D' (7.93), ear length (6.56), days to 50% flowering (6.12), number of spikelets per spike (5.78) and days to maturity (2.32).

In E_2, the highest value of PCV was recorded for LAI-I (34.53), followed by biological yield (30.65), LAI-II (28.12), grain yield per plant (25.75), number of tillers per plant (19.29), number of ears per plant (17.57), number of grains per spike (16.47), 1000-grain weight (13.42), ear length (9.71), 'D' (8.81), harvest index (8.09), plant height (7.49), number of spikelets per spike (7.10), days to 50% flowering (5.26) and days to maturity (2.23). Estimates of GCV was highest for LAI-I (34.28), followed by LAI-II (27.95), grain yield per plant (24.25), biological yield per plant (22.52), number of tillers per plant (18.25), number of ears per plant (17.12), number of grains per spike (15.77), 1000-grain weight (13.28), 'D' (8.77), harvest index (7.87), plant height (7.31), ear length (7.17), number of spikelets per spike (6.72), days to 50% flowering (5.25) and days to maturity (2.22).

Phenotypic coefficients of variation estimates for pooled analysis was found highest for LAI-I (40.96), followed by grain yield per plant (35.19), LAI-II (32.38), biological yield (29.78), number of tillers per plant (23.32), number of ears per plant (22.08), number of grains per spike (20.76), 1000-grain weight (16.56), ear length (11.63), plant height (11.26), 'D' (10.89), harvest index (10.09), number of spikelets per spike (8.67), days to 50% flowering (7.77) and days to maturity (2.79). Similarly, the highest value of GCV was recorded for LAI-I (40.82), followed by LAI-II (32.29), grain yield per plant (29.43), biological yield (27.10), number of tillers per plant (22.19), number of ears per plant (21.72), number of grains per spike (20.21), 1000-grain weight (16.35), plant height (11.10), 'D' (10.33), ear length (10.00), harvest index (10.09), number of spikelets per spike (8.12), days to 50% flowering (7.76) and days to maturity (2.79).

4.1.2 Heritability and genetic advance (GA) expressed as percentage of mean

Heritability estimates varied from character to character. Heritability estimates were also found different for the same character under different environments (Tables 6,7 & 8).

In E_1, days to 50% flowering had the highest heritability estimates (99.94%), followed by 'D' (99.61%), LAI-I (99.03%), LAI-II (98.27%), biological yield (97.21%), days to maturity (97.17%), number of ears/plant (95.58%), plant height (94.93%), 1000-grain weight (94.84%), harvest index (94.45%), number of grains per spike (93.26%), number of tillers per plant (86.07%), number of spikelets per spike (71.42%) and ear length (62.00). Estimates of heritability was found lowest for grain yield per plant (58.82%).

In E_2, highest heritability value was recorded for days to 50% flowering (99.61%), followed by days to maturity (99.37%), 'D' (99.22%), LAI-II (98.76%), LAI-I (98.59%), 1000-grain weight (97.82%), plant height (95.06%), number of ears per plant (95.00%), harvest index (94.65%), number of grains per spike (91.69%), number of tillers per plant (89.55%), number of spikelets per spike (89.44%), grain yield per plant (88.65%), ear length (54.54%) and biological yield (54.02%).

Pooled analysis revealed that days to 50% flowering had the highest heritability value (99.87%), followed by days to maturity (99.80%), 'D' (99.64%), LAI-II (99.40%), LAI-I (99.32%), 1000-grain weight (97.50%), plant height (97.13%), number of ears per plant (96.74%), harvest index (96.22%), number of grains per spike (94.76%), number of tillers per plant (91.23%), number of spikelets per spike (87.63%), biological yield per plant (82.79%), ear length (73.95%) and grain yield per plant (69.91%).

Expected GA expressed as percentage of mean was calculated using heritability in broad sense for each character for both the environments and pooled analysis (Tables 6,7 & 8). A good deal of fluctuations had been noticed for the characters. Estimates of genetic advance are influenced by the unit of measurement, therefore, GA was calculated as percentage of mean in order to make relative comparison of different characters. In E_1, LAI-I (59.10%) had the highest GA as percentage of mean, followed by biological yield per plant (48.34%), LAI-II (45.61%), grain yield per plant (39.63%), number of ears per plant (37.05%), number of grains per spike (35.07%), number of tillers per plant (34.29%), 1000-grain weight (25.88%), plant height (17.78%), harvest index (17.30%), 'D' (16.30%), days to 50% flowering (12.61%), ear length (10.64%) and number of spikelets per spike (10.06%). The lowest GA as percentage of mean was recorded for days to maturity (4.72%).

In E_2, LAI-I had the highest GA as percentage of mean (70.13%), followed by LAI-II (57.22%), grain yield per plant (47.03%), number of tillers per plant (35.50%), number of ears per plant (34.39%), biological yield per plant (34.11%), number of grains per spike (31.11%), 1000-grain weight (27.06%), days from flowering to maturity, i.e., 'D' (18.01%), harvest index (15.78%), plant height (14.68%), number of spikelets per spike (13.09%), ear length (10.91%) and days to 50% flowering (10.80%). Days to maturity exhibited the lowest GA as percentage of mean (4.57%).

The highest GA as percentage of mean under pooled analysis was exhibited by LAI-I (83.55%), followed by LAI-II (66.31%), biological yield (50.80%), grain yield per plant (50.63%), number of ears per plant (44.00%), number of tillers per plant (43.87%), number of grains per spike (40.54%), 1000-grain weight (33.26%), plant height (22.56%), 'D' (21.24%), harvest index (20.40%), ear length (17.72%) and days to 50% flowering (16.00%). The lowest GA as percentage of mean was recorded for days to maturity.

4.2 Correlation Coefficient Analysis

To estimate the correlation between two characters, correlation coefficients at phenotypic, genotypic and environmental levels have been worked out separately for E_1 and E_2. Pooled analysis was also carried out (Tables 9,10 & 11).

In both E_1 and E_2 environments and pooled analysis as well, the results of phenotypic correlation coefficients indicated that days to 50% flowering had highly significant positive correlations with days to maturity (0.668, 0.644 and 0.993). However, highly significant and negative correlations of this trait were found with 'D' (-0.787, -0.751 and -0.947) and 1000-grain weight (-0.409, -0.406 and -0.573), respectively.

Days to maturity had highly significant positive correlations with days to 50% flowering in both E_1 and E_2 environments and also in pooled analysis (0.668, 0.644 and 0.993). This trait also had significant positive correlation with number of ears per plant (0.325) in E_2 and highly significant negative correlations with 'D' (-0.870) and 1000-grain weight (-0.425) in pooled analysis.

Table 9 : Phenotypic (P), genotypic (G) and environmental (E) correlation coefficients of yield with its components (F_1 - High fertility)

Characters		Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/spike 8	No. of grains per spike 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant(g) 13	Biological yield/plant(g) 14	Harvest index (%) 15
1	P	0.6661**	-0.7974**	0.0392	0.0612	0.0887	0.0821	0.1311	0.1065	-0.4090**	0.0173	0.0032	-0.0027	-0.0804	0.0051
	G	0.6693	-0.7335	0.0422	0.0750	0.0959	0.1396	0.1891	0.1163	-0.4419	0.0189	0.0040	-0.0064	-0.0870	0.0095
	E	0.2069	-0.0613	0.0021	-0.0111	-0.0505	-0.0218	0.0961	0.0488	0.0179	-0.1078	-0.0574	0.0213	0.1987	-0.1756
2	P		-0.0375	-0.0359	0.2092	0.2302	0.0162	0.2300	0.1867	-0.2871	0.0713	0.1240	0.1687	0.1952	-0.1256
	G		-0.0345	-0.0397	0.2510	0.2455	0.0304	0.3420	0.2061	-0.3102	0.0739	0.1287	0.2978	0.2024	-0.1351
	E		0.0376	0.2000	0.0595	0.0436	-0.0652	-0.0655	0.0010	0.0330	-0.1350	-0.0343	-0.0121	0.1004	-0.0339
3	P			-0.0907	0.0859	0.0640	-0.0729	0.0184	0.0046	0.3151*	0.0171	0.0317	0.1389	0.2597	-0.1131
	G			-0.0836	0.1044	0.0649	-0.1298	0.0394	0.0074	0.3438	0.0163	0.0835	0.2419	0.2751	-0.1294
	E			-0.0987	0.0193	0.0977	0.0473	-0.1052	-0.0474	-0.0529	0.0373	0.0525	-0.0149	-0.1522	0.1360
4	P				0.0723	0.0503	0.2760	0.1605	0.2279	0.0773	0.1076	0.1675	0.1751	0.2790	0.0865
	G				0.0858	0.0606	0.4016	0.1607	0.2763	0.0896	0.1177	0.1770	0.3837	0.2982	0.0740
	E				0.0368	0.0585	0.1811	0.2172	-0.0295	0.0011	0.0100	0.0899	-0.0786	0.1278	0.1614
5	P					0.9258**	-0.1265	-0.1385	0.0767	-0.1038	0.2292	0.2381*	0.5003**	0.6009**	0.1203
	G					1.0052	-0.0587	-0.2140	0.1176	-0.1119	0.3035	0.3751	0.8570	0.6706	0.1714
	E					0.7598	-0.2137	-0.0483	-0.0455	-0.0864	-0.1265	-0.0071	0.2136	0.4481	-0.0439
6	P						-0.1276	-0.1523	0.0794	-0.1512	0.2854	0.3457	0.5110**	0.6268**	0.1686
	G						-0.1160	-0.1554	0.1509	-0.1724	0.3161	0.3768	0.8911	0.5675	0.1770
	E						-0.2228	-0.2074	-0.3275	-0.0874	-0.0361	0.0409	0.1234	0.3199	0.1102
7	P							0.1616	0.1061	0.0114	-0.0410	-0.0295	-0.0430	0.0275	-0.0605
	G							0.3165	0.1213	0.0410	-0.1070	-0.0727	-0.0229	0.0867	-0.1235
	E							0.0573	0.1197	-0.0374	0.1279	0.0642	-0.0534	-0.0977	0.0234
8	P								0.3699*	-0.1342	0.0023	0.0250	-0.0656	0.1530	-0.0373
	G								0.4709	-0.2672	0.0045	0.0403	0.0861	0.1515	0.0987
	E								0.2593	0.1234	-0.0043	-0.0092	-0.1533	-0.2631	0.0856
9	P									-0.3775*	0.0873	0.2499	0.3184*	0.5669**	0.0747
	G									-0.4370	0.1068	0.3024	0.4697	0.5891	0.0843
	E									-0.0784	-0.0938	-0.1564	0.2202	0.4659	0.0259
10	P										0.0172	-0.0327	-0.0126	0.0125	0.1711
	G										0.0271	-0.0159	0.0099	0.0167	0.1769
	E										-0.0952	-0.2030	-0.0580	-0.0217	0.1368
11	P											0.9385**	0.2047	0.3690*	-0.0261
	G											0.9481	0.3989	0.4034	-0.0398
	E											0.7678	-0.0993	-0.1670	0.1220
12	P												0.3061*	0.5230**	-0.0308
	G												0.5913	0.5692	0.0403
	E												-0.0995	-0.1030	0.0559
13	P													0.5692**	0.1463
	G													0.9178	0.2650
	E													0.2976	0.0235
14	P														-0.1189
	G														-0.1099
	E														-0.1992

* Significant at 5%
** Significant at 1%

Table 10 : Phenotypic (P), genotypic (G) and environmental (E) correlation coefficients of yield with its components (E_2 - Low fertility)

Character		Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per 6	Ear length (cm) 7	No. of spikelets/ spike 8	No. of grains per spike 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant(g) 13	Biological yield/ plant(g) 14	Harvest index (%) 15
1	P	0.6445**	-0.7516**	0.0083	0.0063	0.0377	0.0195	0.0891	0.0745	-0.4068**	0.0847	0.0533	0.1897	-0.0378	-0.1266
	G	0.6526	-0.7553	0.0108	0.0112	0.0438	0.0426	0.1023	0.0852	-0.4236	0.0679	0.0564	-0.2219	-0.0776	-0.1416
	E	0.0766	-0.5582	-0.0432	-0.0606	-0.0774	-0.0361	0.0200	-0.0135	0.0423	-0.0633	-0.0590	-0.0388	0.0365	0.0387
2	P		-0.0461	-0.0957	0.2882	0.3253*	-0.1542	0.0897	-0.0232	-0.1239	-0.0960	-0.0585	-0.0015	0.0331	-0.0031
	G		-0.0601	-0.1199	-0.3304	0.3447	0.2814	0.0960	0.0305	-0.1266	-0.0972	-0.0616	-0.0153	0.0856	-0.0229
	E		0.6536	0.3048	0.1081	0.1471	0.0484	0.1094	0.0594	-0.0734	-0.0534	0.0306	0.1637	-0.1056	0.3509
3	P			-0.0857	0.1810	0.1520	0.0643	-0.0081	-0.0843	0.4537**	-0.0646	-0.0045	0.2400	0.1113	0.1686
	G			-0.1030	0.2088	0.1589	0.0969	-0.0132	-0.1028	0.4799	-0.0661	-0.0063	0.2758	0.2107	0.1671
	E			0.1676	0.0522	0.0890	0.0971	0.0432	0.0652	-0.1528	-0.2249	0.0472	0.1049	0.0060	0.2816
4	P				0.1317	0.1608	0.1419	0.1790	0.2646	-0.0183	0.0720	0.1365	0.2676	0.1660	0.0497
	G				0.1000	0.1388	0.2716	0.1722	0.3157	0.0197	0.0823	0.1501	0.3155	0.3891	0.0652
	E				0.2749	0.3034	0.0231	0.2238	0.0250	-0.0043	-0.0477	0.0056	0.0817	-0.0194	-0.0454
5	P					0.9554**	0.1302	-0.1103	-0.0149	0.2237	0.1979	0.2671	0.6517**	0.3466*	0.2188
	G					0.9910	0.2814	-0.2446	0.0188	0.3195	0.2277	0.3134	0.7664	0.7599	0.2636
	E					0.8754	0.0036	0.2770	-0.1200	-0.2438	0.0634	0.0446	0.4469	0.0021	0.0498
6	P						0.1789	-0.1101	0.0327	0.1985	0.2045	0.2863	0.5940**	0.3856**	0.2556
	g						0.3199	-0.1621	0.0818	0.2317	0.2232	0.2051	0.7761	0.6994	0.2979
	E						0.0649	0.2012	-0.0274	-0.1105	0.1388	0.1153	0.4149	0.1266	-0.0264
7	P							0.1452	0.2555	0.0707	-0.0958	-0.0189	0.2697*	0.2109	0.0057
	G							0.3927	0.5204	0.0831	-0.1669	-0.0227	0.5414	0.5772	0.0069
	E							-0.0381	0.0242	0.1309	-0.0454	-0.0375	-0.0994	0.0663	0.0072
8	P								0.5547**	-0.4235**	0.0581	0.1261	0.0821	0.0761	-0.0430
	G								0.7160	-0.4812	0.0698	0.1480	0.0404	0.2324	-0.0553
	E								0.0223	-0.1619	-0.0139	0.0113	0.1989	-0.0721	0.0068
9	P									-0.3953**	0.3340*	0.4154**	0.4088**	0.2458	0.0962
	G									-0.4459	0.3930	0.4859	0.4480	0.4688	0.1102
	E									-0.1092	-0.0964	-0.0434	0.2920	0.0646	0.0332
10	P										-0.0142	0.0110	0.3611*	0.1786	0.0898
	G										-0.0201	0.0051	0.4325	0.3179	0.1163
	E										0.1054	0.1095	0.0394	0.0273	-0.1486
11	P											0.9613**	0.3547*	0.1970	-0.0041
	G											0.9729	0.4148	0.3265	0.0037
	E											0.7110	0.0846	0.1695	0.1053
12	P												0.4547**	0.2626	0.0085
	G												0.5408	0.4183	0.0195
	E												0.0571	0.2442	-0.1065
13	P													0.4641**	0.2719
	G													0.9440	0.3531
	E													0.0861	-0.0274
14	P														-0.0629
	G														-0.0900
	E														-0.0579

* Significant at 5%
** Significant at 1%

Table 11 : Phenotypic (P), genotypic (G) and environmental (E) correlation coefficients of yield with its components (Pooled analysis)

Character		Days to maturity	'D'	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per 6	Ear length (cm) 7	No. of spikelets/ spike 8	No. of grains per spike 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant (g) 13	Biological yield/ plant (g) 14	Harvest index (%) 15
1	P	0.9930**	-0.9472**	0.0390	0.0302	0.0750	0.0523	0.1270	0.0676	-0.5730**	0.0757	0.0414	-0.0724	-0.1191	-0.1158
	G	1.0049	-0.9575	0.0434	0.0443	0.0898	0.0941	0.1773	0.1083	-0.6346	0.0797	0.0445	-0.1855	-0.2397	-0.1330
	E	0.0919	-0.5700	-0.0221	-0.0334	-0.0592	-0.0313	0.0502	0.0122	0.0262	-0.0758	-0.0538	0.0025	0.0589	-0.0543
2	P		-0.8701**	-0.0584	-0.0385	-0.0234	0.0435	0.2841	0.0784	-0.4250**	0.0644	-0.0062	-0.2682	-0.2579	-0.0109
	G		-0.9065	-0.0749	-0.0627	-0.0347	0.0706	0.4030	-0.1006	-0.4730	0.0689	-0.0065	-0.7006	-0.4839	-0.0294
	E		0.5363	-0.1810	0.0713	0.0934	0.0251	0.0401	0.0236	-0.0256	-0.0603	-0.0010	0.0348	-0.0861	0.1994
3	P			-0.1055	-0.1078	-0.1798	-0.0309	0.0734	-0.1417	0.6436**	-0.0449	-0.0367	-0.0652	0.0368	0.1878
	G			-0.1203	-0.1561	-0.2203	-0.0744	0.1123	-0.1826	0.7264	-0.0477	-0.0414	-0.1684	0.0781	0.1995
	E			0.0457	0.0329	0.0877	0.0794	-0.0326	0.0294	0.0892	0.0186	0.0463	-0.0010	-0.0159	0.2087
4	P				0.1397	0.1728	0.2163	0.2131	0.2643	0.0423	0.0932	0.1775	0.2456	0.2787	0.0802
	G				0.1611	0.1807	0.3451	0.2349	0.3659	0.0508	0.1055	0.1539	0.7301	0.5758	0.0612
	E				0.1177	0.1470	0.1002	0.2187	-0.0065	-0.0001	-0.0105	0.0566	-0.0469	0.0364	0.0830
5	P					0.8975**	-0.1575	-0.0655	-0.0685	0.1763	0.2516	0.2343	0.3511*	0.2303	0.4070**
	G					0.9903	-0.2284	-0.2101	-0.0665	0.3233	0.3698	0.3301	0.7183	0.4503	0.6574
	E					0.7967	-0.1091	0.0449	-0.0727	-0.1299	-0.0639	0.0104	0.2310	0.1036	-0.0101
6	P						-0.1475	-0.1049	-0.0630	0.1570	0.2761*	0.3030*	0.3225*	0.2757	[illegible]**
	G						-0.2267	-0.1244	0.0270	0.2246	0.3856	0.3528	0.7340	0.4751	0.7343
	E						-0.0822	-0.0823	-0.2772	-0.0937	0.0120	0.0676	0.1550	0.3444	0.0686
7	P							0.1475	0.3158	0.0459	-0.0819	-0.0757	-0.0920	0.0924	[illegible]
	G							0.3402	0.3978	0.0630	-0.1701	-0.3405	-0.2597	0.2306	[illegible]
	E							0.0150	0.0676	0.0314	0.0427	0.0138	0.0142	0.0334	0.0147
8	P								0.6096**	-0.4605**	0.0313	0.0929	-0.0293	0.0982	0.1876
	G								0.9465	-0.7452	0.0476	0.1363	0.1590	0.2279	0.2766
	E								0.1703	0.0492	-0.0072	-0.0020	-0.1116	0.0256	0.0581
9	P									-0.3562	0.4146**	0.4767**	0.2630	0.3594*	0.1268
	G									-0.4572	0.5404	0.6355	0.4810	0.6975	0.1706
	E									-0.0568	-0.0885	-0.1066	0.2034	0.1360	0.0293
10	P										-0.0829	-0.0859	0.1001	0.1086	0.2157
	G										-0.0901	-0.0846	0.3267	0.2089	0.2653
	E										-0.0346	-0.1047	-0.0444	0.0296	0.0428
11	P											0.9560**	0.2514	0.3840**	0.1014
	G											0.9737	0.6954	0.7408	0.1167
	E											0.7469	-0.0659	0.0598	0.0344
12	P												0.2535	0.4306**	0.0815
	G												0.7177	0.8099	0.1002
	E												-0.0666	0.1209	-0.0076
13	P													0.2350	0.3088*
	G													0.7752	0.8987
	E													0.0986	0.0130
14	P														0.0843
	G														0.2680
	E														-0.0779

* Significant at 5% level; ** Significant at 1% level

'D' had highly significant positive correlations with 1000-grain weight in E_2 and pooled analysis (0.453 & 0.643), while only significant positive in E_1 (0.315). This trait had highly significant negative correlations with days to 50% flowering in E_1, E_2 and pooled analysis (-0.787, -0.751 and -0.947), while it was negatively correlated with days to maturity (-0.870) in pooled analysis only.

Number of tillers per plant had highly significant positive correlations with number of ears per plant (0.925, 0.955 and 0.897) in E_1, E_2 and pooled analysis, respectively. This trait had significant positive correlations with LAI-II (0.298) only in E_1. It also exhibited highly significant positive correlations with grain yield in E_1 and E_2 (0.5003 & 0.681) and significant but positive (0.351) in pooled analysis. This trait also had highly significant positive correlations with biological yield in E_1 (0.600) and significant positive in E_2 (0.346). In pooled analysis, this trait had highly significant positive correlation with harvest index (0.407).

In E_1 and E_2, number of ears per plant had highly significant positive correlations with number of tillers per plant (0.925 & 0.955), grain yield per plant (0.511 & 0.694) and biological yield (0.626 & 0.385), respectively. In pooled analysis, this trait was found to have highly significant positive correlations with number of tillers per plant (0.897) and harvest index (0.562) and significant positive with LAI-I (0.320), LAI-II (0.303) and grain yield (0.322).

In E_1, number of spikelets per spike had significant positive correlation with number of grains per spike (0.369). However, in E_2 and pooled analysis, this trait exhibited highly significant positive correlations with number of grains per spike (0.554 & 0.608) but highly significant negative correlations with 1000-grain weight (-0.423 & 0.460).

Number of grains per spike in E_1 had highly significant positive correlation with biological yield (0.566), significant positive with number of spikelets per spike (0.369) and grain yield per plant (0.318), while significant negative with 1000-grain weight (-0.377). In E_2, number of grains per spike had highly significant positive correlations with spikelets per spike (0.554), LAI-II (0.415) and grain yield (0.408) and significant positive with LAI-I (0.334). However, it had highly significant negative correlation with 1000-grain weight (0.395). In pooled analysis, this trait exhibited highly significant correlations with number of spikelets per spike (0.698), LAI-I (0.414) and LAI-II (0.474), while it was significant and positive with biological yield (0.359) and significant negative with 1000-grain weight (-0.356).

1000-grain weight had highly significant positive correlations with 'D' in E_2 and pooled analysis (0.4537 & 0.643) but significant positive correlation in E_1 (0.315).

Significant positive correlation of this trait was also found with grain yield (0.361) in E_2. However, this trait was also observed to have highly significant negative correlations with days to 50% flowering (-0.409, -0.406 and -0.573) in E_1, E_2 and pooled analysis, respectively, but only with days to maturity (-0.425) in pooled analysis and with number of spikelets per spike (-0.423 and -0.460) in E_2 and pooled analysis. 1000-grain weight also had significant negative correlation with number of grains per spike (-0.356).

LAI-I had highly significant positive correlations with LAI-II (0.938, 0.961 and 0.958) in E_1, E_2 and pooled analysis, respectively. LAI-I exhibited significant positive correlation with biological yield in E_1 (0.369) and highly significant positive correlation in pooled analysis (0.384). Only in E_2, this trait was found to have positive and significant correlation with grain yield (0.354).

LAI-II had highly significant positive correlations with LAI-I (0.938, 0.961 and 0.958) in E_1, E_2 and pooled analysis, respectively and with biological yield in E_1 and pooled analysis (0.523 and 0.430). This trait also had significant positive correlation with grain yield (0.306) in E_1 and highly significant positive in E_2 (0.454).

Correlation coefficients of grain yield with number of tillers per plant and number of ears per plant were found positive and highly significant in E_1 (0.5003 and 0.511) and

E_2 (0.681 and 0.694) and significant positive in pooled analysis (0.351 and 0.322), respectively. This character also exhibited highly significant positive correlations with biological yield in E_1 and E_2 (0.569 and 0.464), while positive but significant with harvest index (0.308) in pooled analysis.

Biological yield in E_1 had positive and highly significant correlations with number of tillers per plant, number of ears per plant, number of grains per spike, LAI-II and grain yield (0.600, 0.628, 0.5669, 0.523 and 0.569, respectively) and had significant positive correlation with LAI-I (0.369). In E_2, biological yield had significant positive correlations with number of tillers per plant and grain yield (0.385 and 0.464). In pooled analysis, this character was found to have positive and highly significant correlations with LAI-I and LAI-II (0.384 and 0.430), while positive and significant with number of grains per spike (0.359).

Harvest index exhibited no significant correlation coefficient with any of the traits in E_1 and E_2. However, under pooled analysis, it was found to have highly significant positive correlations with number of tillers per plant and number of ears per plant (0.407 and 0.562) and only significant but positive with grain yield (0.308).

4.3 Path Coefficient Analysis

In the present study, grain yield, biological yield and harvest index were considered as dependent variables.

4.3.1 Grain yield as dependent variable

4.3.1.1 Environment E_1

Direct and indirect effects of different yield contributing characters on grain yield at genotypic level have been presented in Table 12.

(i) Direct effects :- Number of tillers per plant had the highest positive direct effect (1.7559) on grain yield, followed by LAI-II (1.1009), biological yield (0.6746), number of spikelets per spike (0.3602), harvest index (0.3372), days to maturity (0.2698) and plant height (0.1865). Highest negative direct effect on grain yield was observed for number of ears per plant (-1.4195), followed by LAI-I (-0.9918), days to 50% flowering (-0.5038), number of grains per spike (-0.4277), 'D' (-0.4193), ear length (-0.2503) and 1000-grain weight (-0.1567).

(ii) Indirect effects :- Days to 50% flowering had positive indirect effects on grain yield via 'D' (0.3331), days to maturity (0.1806) and number of tillers per plant (0.1317), while negative indirect effect was observed via number of ears per plant (-0.1362).

Days to maturity had positive indirect effects via number of tillers per plant (0.4443), LAI-II (0.1417), biological yield per plant (0.1365) and number of spikelets per spike (0.1232), while negative indirect effects were observed

Table 12 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters towards grain yield (Z_1 - High fertility)

Character / Character	Days to 50% flowering 1	Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/spike 8	No. of grains per spike 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Biological yield/plant (g) 14	Harvest index (%) 15
1	-0.5038	0.1506	0.3311	0.0079	0.1317	-0.1364	-0.0349	0.0678	-0.0493	0.0692	-0.0189	0.0044	-0.0587	0.0031
2	-0.3376	0.2645	0.0443	-0.0074	0.4443	-0.3484	-0.0076	0.1232	-0.0791	0.0485	-0.0733	0.1417	0.1359	[illegible]
3	0.397	-0.0766	-0.4193	-0.0156	0.1903	-0.0920	0.0325	0.0142	-0.0032	-0.0539	-0.0161	0.0317	0.1366	-0.0433
4	-0.0213	-0.0107	0.0351	0.1865	0.1507	-0.0860	-0.1093	0.0579	-0.1181	-0.0140	-0.1167	0.1949	0.2011	0.0260
5	-0.0378	0.0693	-0.0455	0.0160	1.7559	-1.4269	0.0147	-0.0771	-0.0503	0.0175	-0.3010	0.4129	0.4524	0.0378
6	-0.0833	0.0662	-0.0272	0.0113	1.7650	-1.4195	0.0290	-0.0560	-0.0645	0.0270	-0.3135	0.4148	0.4469	0.0600
7	-0.0703	0.0032	0.0544	0.0749	-0.1032	0.1645	-0.2503	0.1140	-0.0519	-0.0064	0.1061	-0.0800	0.0585	-0.0416
8	-0.0948	0.923	-0.0165	0.0300	-0.3759	0.2207	-0.0792	0.3602	-0.2014	0.0419	-0.0045	0.0443	0.1022	-0.0333
9	-0.0587	0.0555	-0.0031	0.0515	0.2064	-0.2142	-0.0304	0.1696	-0.4277	0.0665	-0.1059	0.3329	0.3967	0.0284
10	0.2226	-0.0837	-0.1442	0.0167	-0.1966	0.2447	-0.0103	-0.0963	0.1869	-0.1567	-0.0268	-0.0175	0.0112	0.0596
11	-0.0035	0.0199	-0.0069	0.0219	0.5330	-0.4488	0.0268	0.0016	-0.0457	-0.0042	-0.9918	1.0438	0.2721	-0.0124
12	-0.0020	0.0347	-0.0349	0.0330	0.6586	-0.5349	0.0182	0.0145	-0.1293	0.0025	-0.9403	1.1009	0.3840	-0.0136
14	0.0439	0.0346	-0.1161	0.0556	1.1775	-0.9405	-0.0217	0.0546	-0.2515	-0.0026	-0.4001	0.6266	0.6746	-0.0370
15	-0.0048	-0.0364	0.0542	0.0138	0.3010	-0.2526	0.0309	-0.0355	-0.0361	-0.0277	0.0395	-0.0444	-0.0741	0.3372

Residual effect : -0.0912

via number of ears per plant (-0.3484) and days to 50% flowering (-0.3372).

'D' had positive indirect effects via days to 50% flowering, number of tillers per plant and biological yield per plant (0.3977, 0.1903 and 0.1868), respectively. This trait had negligible negative indirect effects on grain yield via several other traits.

Plant height had positive indirect effects via biological yield (0.2011), LAI-II (0.1948) and number of tillers per plant (0.1507), while negative via number of grains per spike (-0.1181), LAI-I (-0.1167) and ear length (-0.1005).

Number of tillers per plant had positive indirect effects via biological yield (0.4524) and LAI-II (0.4129), while negative via number of ears per plant (-1.4249) and LAI-I (-0.3010).

Number of ears per plant had positive indirect effects via number of tillers per plant (1.7650), biological yield (0.4469) and LAI-II (0.4148), while negligible negative indirect effects were observed via several characters.

Ear length had positive indirect effects via number of ears per plant (0.1645), number of spikelets per spike (0.1140) and LAI-I (0.1061) but negative via number of tillers per plant (-0.1032).

Number of spikelets per spike had positive indirect effects via number of ears per plant (0.2207) and biological yield (0.1022), while negative via number of tillers per plant (-0.3758) and number of grains per spike (-0.2014).

Number of grains per spike had positive indirect effects via biological yield (0.3967), LAI-II (0.3329), number of tillers per plant (0.2064) and number of spikelets per spike (0.1696), while negative via number of ears per plant (-0.2142) and LAI-I (-0.1059).

1000-grain weight had positive indirect effects via number of ears per plant (0.2447), days to 50% flowering (0.2226) and number of grains per spike (0.1869), while negative via number of tillers per plant (-0.1966) and 'D' (-0.1442).

LAI-I had positive indirect effects via LAI-II (1.0438), number of tillers per plant (0.5330) and biological yield (0.2721) but negative via number of ears per plant (-0.4488).

LAI-II had positive indirect effects via number of tillers per plant (0.6586) and biological yield (0.3840), while negative via LAI-I (0.9403), number of ears per plant (-0.5349) and number of grains per spike (-0.1293).

Biological yield had positive indirect effects via number of tillers per plant (1.1775) and LAI-II (0.6266), while negative via number of ears per plant (-0.9405).

LAI-I (-0.4001), number of grains per spike (-0.2515) and 'D' (-0.1161).

Harvest index had positive indirect effects via number of tillers per plant (0.3010) and negative via number of ears per plant (-0.2526).

4.3.1.2 Environment E_2 (Table 13)

(i) Direct effects :- Number of grains per spike had the highest positive direct effect (0.7508) on grain yield, followed by 1000-grain weight (0.6556), number of ears per plant (0.5447), LAI-I (0.3317), number of tillers per plant (0.2980), days to 50% flowering (0.1164), plant height (0.0602), number of spikelets per spike (0.0547), ear length (0.0432) and 'D' (0.0430). The highest negative direct effect on grain yield was observed for LAI-II (-0.3497), followed by days to maturity (-0.2501), biological yield (-0.2310) and harvest index (-0.0595).

(ii) Indirect effects :- Positive indirect effects of days to 50% flowering on grain yield via other traits were negligible. This trait had negative indirect effect on grain yield via 1000-grain weight (-0.2777).

Days to maturity had positive indirect effect via number of ears per plant (0.1878), while negative via other traits were negligible.

Table 13 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters towards grain yield (E_2 - Low fertility)

Character / Character	Days to 50% Flowering 1	Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/spike 8	No. of grains per spike 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Biological yield/plant (g) 14	Harvest index (%) 15
1	0.1164	-0.1632	-0.0325	0.0006	0.0033	0.0239	0.0018	0.0056	0.0540	-0.2777	0.0392	-0.0197	0.0179	0.0084
2	0.0760	-0.2501	-0.0026	-0.0072	0.0985	0.1878	0.0122	0.0053	-0.0239	-0.0830	-0.0323	0.0215	-0.0198	0.0014
3	-0.0879	0.0150	0.0430	-0.0062	0.0632	0.0870	0.0043	-0.0007	-0.0771	0.3146	-0.0219	0.0022	-0.2497	-0.0093
4	0.0013	0.0300	-0.0044	0.0602	0.0398	0.0756	0.0117	0.0394	0.2371	-0.0131	0.0271	-0.0525	-0.0999	-0.0039
5	0.0013	-0.0826	0.0090	0.0060	0.3380	0.5398	0.0122	-0.0134	0.0145	0.2094	0.0755	-0.1096	-0.1735	-0.0137
6	0.0051	-0.0862	0.0069	0.0084	0.2954	0.5447	0.0138	-0.0100	0.0614	0.1519	0.0707	-0.1067	-0.1616	-0.0177
7	0.0050	-0.0304	0.0043	0.0163	0.0839	0.1742	0.0432	0.0215	0.3907	0.0545	-0.0380	0.0079	-0.1333	-0.0064
8	0.0119	-0.0340	-0.0006	0.0103	-0.0729	-0.0992	0.0170	0.0547	0.5376	-0.3154	0.0232	-0.0517	-0.0537	0.0033
9	0.0099	0.0076	-0.0044	0.0190	0.0056	0.0445	0.0225	0.0392	0.7508	-0.2923	0.1303	-0.1699	-0.1083	-0.0066
10	-0.0493	0.0317	0.0206	-0.0012	0.0952	0.1262	0.0036	-0.0263	-0.3347	0.5555	-0.0067	-0.0018	-0.0734	-0.0069
11	0.0102	0.0243	-0.0029	0.0050	0.0679	0.1161	-0.0073	0.0038	0.2950	-0.0133	0.3317	-0.3403	-0.0754	-0.0002
12	0.0066	0.0154	-0.0003	0.0090	0.0334	0.1662	-0.0010	0.0081	0.3649	0.0033	0.3227	-0.3497	-0.0966	-0.0012
14	-0.0090	-0.0214	0.0091	0.0234	0.2265	0.3810	0.0249	0.0127	0.3520	0.2084	0.1083	-0.1463	-0.2310	0.0054
15	-0.0165	0.0057	0.0072	0.0039	0.0786	0.1623	0.0003	-0.0030	0.0827	0.0752	0.0012	-0.0068	0.0208	-0.0595

Residual effect : -0.0157

'D' had positive indirect effect via 1000-grain weight. Indirect effects of the remaining traits, however, were negligible.

Plant height had positive indirect effect on grain yield via number of grains per spike (0.2371). The remaining indirect effects were of negligible magnitudes.

Number of tillers per plant had positive indirect effects via number of ears per plant (0.5398) and 1000-grain weight (0.2094), while negative via biological yield (-0.1755) and LAI-II (-0.1095).

Number of ears per plant had positive indirect effects via number of tillers per plant (0.2954) and 1000-grain weight, while negative via biological yield (-0.1616) and LAI-II (-0.1067).

Ear length had positive indirect effects via number of grains per spike (0.3907) and number of ears per plant (0.1742), while negative via biological yield (-0.1333).

Number of spikelets per spike had positive indirect effect via number of grains per spike, while negative via 1000-grain weight (-0.3154).

Number of grains per spike had positive indirect effect via LAI-I (0.1303), while negative via 1000-grain weight (-0.2923), LAI-II (-0.1699) and biological yield (-0.1083).

1000-grain weight had positive indirect effect via number of ears per plant (0.1262), while negative via number of grains per spike (-0.3347).

LAI-I had positive indirect effects via number of grains per spike (0.2952) and number of ears per plant (0.1161), while negative via LAI-II (-0.3403).

LAI-II had positive indirect effects via number of grains per spike (0.3648), LAI-I (0.3227) and number of ears per plant (0.1662). The indirect effects of other traits were of negligible importance.

Biological yield had positive indirect effects via number of ears per plant (0.3810), number of grains per spike (0.3520), number of tillers per plant (0.2268), 1000-grain weight (0.2084) and LAI-I (0.1083), while negative via LAI-II (-0.1463).

Harvest index had positive indirect effect via number of ears per plant (0.1623). Indirect effects of other traits were of negligible importance.

4.3.1.3 Pooled Analysis (Table 14)

(i) Direct effects :- LAI-II had highest positive direct effect (47.7995) on grain yield, followed by days to maturity (25.7358), ear length (15.8368), number of ears per plant (12.1095), plant height (4.4454), harvest index (2.9287)

Table 14 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters towards grain yield (Pooled analysis)

Character / Character	Days to 50% flowering 1	Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/ spike 8	No. of grains per spike 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Biological yield/ plant(g) 14	Harvest index(%) 15
1	-63.1832	25.8523	23.4943	0.1928	-0.2883	1.0870	1.4907	0.2088	-2.2572	10.7243	-2.0431	1.1274	2.8083	-0.3995
2	-63.4938	25.7358	22.2437	-0.3331	0.4081	3.4205	1.1207	0.4748	2.1053	7.9609	-1.7666	-0.3097	5.6702	-0.6862
3.	60.4953	-23.3703	-24.5362	-0.5350	1.0161	-2.6675	-1.1792	0.1324	3.8222	-12.3104	1.2234	-1.9772	-0.9153	0.5843
4.	-2.7403	-1.9375	2.9531	4.4454	-1.0459	2.1884	5.4658	0.2768	-8.0786	-0.8383	-2.7049	9.2576	-3.7463	0.2377
5.	-2.7985	-1.6128	3.8309	0.7163	-5.5100	11.9920	-3.6175	-0.2475	1.3916	-5.4638	-9.4799	15.9685	-5.2767	1.9258
6.	-5.6716	-0.8936	5.4054	0.8034	-6.4469	12.1095	-3.5909	-0.1465	-0.5655	-3.7984	-9.9841	16.8542	-5.8016	2.1506
7.	-5.9473	1.8305	1.8256	1.5343	1.4871	-2.7457	15.9368	0.4010	-8.3260	-1.0643	4.3617	-6.7148	-2.7022	-0.1265
8.	-11.1994	10.3766	-2.7566	1.0443	1.3679	-1.5050	5.3901	1.1782	-19.8535	12.5942	-1.2206	6.6125	-3.6706	0.8107
9.	-6.8334	-2.5874	4.4806	1.7157	0.4328	0.3271	5.2992	1.1175	20.9323	7.7263	-13.9565	30.3746	-8.1727	0.4995
10.	40.0935	-12.1180	-17.8738	0.2258	-2.1046	2.7214	0.9973	-0.8780	9.5695	-16.9004	2.3095	-4.0425	-2.4481	0.7759
11.	-5.0358	1.7729	1.1740	0.4691	-2.4074	4.6691	-2.6946	0.0561	-11.3962	1.5225	-25.6351	46.5417	-8.6798	0.3418
12.	-2.8120	-0.1667	1.0150	0.8619	-2.1612	4.2724	-2.2247	0.1630	-13.3016	1.4293	-24.9505	47.7335	-9.4901	0.0935
14.	15.1427	12.4489	-1.9168	2.5595	-2.9316	5.7890	3.6522	0.2685	-14.5998	-3.5309	-18.9395	38.7134	-11.7175	0.7849
15.	8.4033	-0.7572	-4.8952	0.3608	-4.2808	8.8923	-0.6838	0.3261	-3.5701	-4.4832	-2.9916	4.7396	-3.1402	2.9287

Residual effect : 6.8149

and number of spikelets per spike (1.1782). Highest negative direct effect was observed for days to 50% flowering (-63.1832), followed by LAI-I (-25.6351), 'D' (-24.5362), number of grains per spike (-20.9323), 1000-grain weight (-16.9004), biological yield (-11.7175) and number of tillers per plant (-6.5100).

(ii) Indirect effects :- Days to 50% flowering had positive indirect effects on grain yield via days to maturity (25.8523), 'D' (23.5943), 1000-grain weight (10.7243), LAI-II (2.1274), biological yield (2.8083), ear length (1.4907), number of ears per plant (1.0870), number of spikelets per spike (0.2088) and plant height (0.1928), while negative via number of grains per spike (-2.2672), LAI-I (-2.0431), harvest index (-0.3895) and number of tillers per plant (-0.2883).

Days to maturity had positive indirect effects via 'D' (22.2437), 1000-grain weight (7.9609), biological yield (5.6702), number of grains per spike (2.1053), ear length (1.1207), number of spikelets per spike (0.4748) and number of tillers per plant (0.4081), while negative via days to 50% flowering (-63.4938), LAI-I (-1.7666), number of ears per plant (-0.4206), plant height (-0.3331) and LAI-II (-0.3097).

'D' had positive indirect effects via days to 50% flowering (60.4953), number of grains per spike (3.8222), LAI-I (1.2234), number of tillers per plant (1.0163), harvest index (0.5843) and number of spikelets per spike (0.1324), while negative via days to maturity (-23.3703), 1000-grain weight (-12.3104), number of ears per plant (-2.6675), LAI-II (-1.9772), biological yield (-1.9153), ear length (-1.1782) and plant height (-0.5350).

Plant height had positive indirect effects via LAI-II (9.2676), ear length (5.4658), 'D' (2.9531), number of ears per plant (2.1884), number of spikelets per spike (0.2768) and harvest index (0.2377), while negative via number of grains per spike (-8.0786), biological yield (-6.7463), days to 50% flowering (-2.7403), LAI-I (-2.7049), days to maturity (-1.9375), number of ears per plant (-1.0489) and 1000-grain weight (-0.8583).

Number of tillers per plant had positive indirect effects via LAI-II (15.8685), number of ears per plant (11.9920), 'D' (3.8309), harvest index (1.9258), number of grains per spike (1.3916) and plant height (0.7163), while negative via LAI-I (-9.4799), 1000-grain weight (-5.4638), biological yield (-5.2667), ear length (-3.6176), days to 50% flowering (-2.7985), days to maturity (-1.6128) and number of spikelets per spike (-0.2745).

Number of ears per plant had positive indirect effects via LAI-II (16.8542), 'D' (5.4054), harvest index (2.1506) and plant height (0.8034), while negative via LAI-I (-9.8841), number of tillers per plant (-6.4469), days to 50% flowering (-5.6716), biological yield (-5.6016), 1000-grain weight

(-3.7984), ear length (-3.5908), days to maturity (-0.8936), number of grains per spike (-0.5655) and number of spikelets per spike (-0.1465).

Ear length had positive indirect effects via LAI-I (4.3617), days to maturity (1.8305), 'D' (1.8256), plant height (1.5343), number of tillers per plant (1.4871) and number of spikelets per spike (0.4010, while negative via number of grains per spike (-8.3260), LAI-II (-6.7148), days to 50% flowering (-5.9473), number of ears per plant (-2.7457), biological yield (-2.7022), 1000-grain weight (-1.0643) and harvest index (-0.1265).

Number of spikelets per spike had positive indirect effects via 1000-grain weight (12.5942), days to maturity (10.3766), LAI-II (6.6125), ear length (5.3901), number of tillers per plant (1.3679), plant height (1.0443) and harvest index (0.8107), while negative via number of grains per spike (-19.8535), days to 50% flowering (-11.1994), 'D' (-2.7566), biological yield (-2.6706), number of ears per plant (-1.5060) and LAI-I (-1.2206).

Number of grains per spike had positive indirect effects via LAI-II (30.3746), 1000-grain weight (7.7263), ear length (6.2992), days to maturity (4.4806), plant height (1.7157), number of spikelets per spike (1.1175), number of tillers per plant (0.4328), harvest index (0.4995) and number of ears per plant (0.3271), while negative via LAI-I (-13.9565), biological yield (-8.1727), days to 50% flowering (-6.8434) and days to maturity (-2.5874).

1000-grain weight had positive indirect effects via days to 50% flowering (40.0935), number of grains per spike (9.5695), number of ears per plant (2.7214), LAI-I (2.3095), ear length (0.9973), harvest index (0.7769) and plant height (0.2258), while negative via 'D' (-17.8738), days to maturity (-12.1180), LAI-II (-4.0425), biological yield (-2.4481), number of tillers per plant (-2.1046) and number of spikelets per spike (-0.8780).

LAI-I had positive indirect effects via LAI-II (46.5417), number of ears per plant (4.6691), days to maturity (1.7729), 1000-grain weight (1.5226), 'D' (1.1740), plant height (0.4691) and harvest index (0.3518), while negative via number of grains per spike (-11.3762), biological yield (-8.6798), days to 50% flowering (-5.0358), ear length (-2.6946) and number of tillers per plant (-2.4094).

LAI-II had positive indirect effects via number of ears per plant (4.2724), 1000-grain weight (1.4293), 'D' (1.0150), plant height (0.8019) and number of spikelets per spike (0.1630), while negative via LAI-I (-24.9605), number of grains per spike (-13.3016), biological yield (-9.4901), days to 50% flowering (-2.8102), ear length (-2.2247), number of tillers per plant (-2.1612) and days to maturity (-0.1667).

Biological yield had positive indirect effects via LAI-II (38.7134), days to maturity (12.4489), number of ears per plant (5.7890), ear length (3.6522), plant height (2.5591), harvest index (0.7849) and number of spikelets per spike (0.2685), while negative via LAI-I (-18.9825), number of grains per spike (-14.5998), 1000-grain weight (-3.5309), number of tillers per plant (-2.9316), and 'D' (-1.9168).

Harvest index had positive indirect effects via number of ears per plant (8.8923), days to 50% flowering (8.4033), LAI-II (4.7896), plant height (0.3608) and number of spikelets per spike (0.3261), while negative via 'D' (-4.8952), 1000-grain weight (-4.4832), number of tillers per plant (-4.2808), number of grains per spike (-3.5701), biological yield (-3.1402), LAI-I (-2.9716) and ear length (-0.6838).

4.3.2 Biological yield as dependent variable

4.3.2.1 Environment E_1 (Table 15)

(i) Direct effects :- Number of grains per spike had the highest positive direct effect on biological yield (0.6822), followed by number of tillers per plant (0.5935), 1000-grain weight (0.5451), LAI-II (0.4591), number of ears per plant (0.2932), number of spikelets per spike (0.1511), days to maturity (0.0765) and plant height (0.0713). Highest negative direct effect was observed for harvest index (-0.3591); LAI-I (-0.3245), grain yield per plant (-0.2446), days to 50% flowering (-0.2150), 'D' (-0.1908) and ear length (-0.0744) followed.

Table 15 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters towards biological yield per plant (E_1 - High fertility)

Character / Character	Days to 50% flowering 1	Days to maturity 2	'D' 3	Plant height (cm) 4	No.of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No.of spikelets/spike 8	No. of grains per plant 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant(g) 13	Harvest index (%) 15
1	-0.2150	0.0512	0.1506	0.0030	0.0445	0.0281	-0.0104	0.0284	0.0795	-0.2409	-0.0061	0.0018	0.0016	-0.0034
2	-0.1439	0.0765	0.0188	-0.0028	0.1502	0.0720	-0.0023	0.0517	0.1406	-0.1691	-0.0240	0.0591	-0.0728	0.0485
3	0.1697	-0.0075	-0.1908	-0.0060	0.0643	0.0190	0.0097	0.0050	0.0051	0.1974	-0.0053	0.0382	-0.0594	0.0165
4	-0.0091	-0.0030	0.0160	0.0713	0.0509	0.0178	-0.0299	0.0243	0.1885	-0.0489	-0.0382	0.0812	-0.0939	-0.0266
5	-0.0161	0.0194	-0.0207	0.0061	0.5935	0.2947	0.0044	-0.0323	0.0802	-0.0610	-0.0985	0.1722	-0.2096	-0.0616
6	-0.0206	0.0188	-0.0124	0.0043	0.5965	0.2932	0.0085	-0.0235	0.1029	-0.0940	-0.1026	0.1730	-0.2160	-0.0639
7	-0.0300	0.0023	0.0248	0.0286	-0.0349	-0.0340	-0.0744	0.0478	0.0828	0.0224	0.0347	-0.0334	0.0056	0.0443
8	-0.0404	0.0282	-0.0075	0.0115	-0.1270	-0.0456	-0.0235	0.1511	0.3212	-0.1457	-0.0015	0.0185	-0.0211	0.0354
9	-0.0250	0.0158	-0.0014	0.0197	0.0598	0.0442	0.0090	0.0711	0.6822	-0.2382	-0.0346	0.1388	-0.1149	-0.0303
10	0.0950	-0.0237	-0.0656	0.0064	-0.0564	-0.0505	-0.0031	-0.0404	-0.2981	0.5451	-0.0088	-0.0073	-0.0024	-0.0635
11	-0.0041	0.0057	-0.0031	0.0084	0.1301	0.0927	0.0080	0.0007	0.0728	0.0148	-0.3245	0.4352	-0.0976	0.0143
12	-0.0009	0.0099	-0.0159	0.0126	0.2226	0.1105	0.0054	0.0061	0.2063	-0.0097	-0.3076	0.4592	-0.1446	0.0145
13	0.0014	0.0228	-0.0463	0.0273	0.5086	0.2613	0.0017	0.0130	0.3204	0.0054	-0.1294	0.2714	-0.2446	-0.0952
15	-0.0020	-0.0103	0.0247	0.0053	0.1017	0.0522	0.0092	-0.0149	0.0575	0.0964	0.0129	-0.0185	-0.0648	-0.3591

Residual effect : 0.0331

(ii) Indirect effects :- Days to 50% flowering had positive indirect effect on biological yield via 'D' (0.1506), while negative via 1000-grain weight (-0.2409).

Days to maturity had positive indirect effects via number of tillers per plant (0.1502) and number of grains per spike (0.1406), while negative via 1000-grain weight (-0.1691) and days to 50% flowering (-0.1439).

'D' had positive indirect effects via 1000-grain weight (0.1874) and days to 50% flowering (0.1697). Remaining traits had indirect effects of negligible magnitudes.

Plant height had positive indirect effect via number of grains per spike (0.1406). Indirect effects of other characters were smaller in magnitude and thus of little importance.

Number of tillers per plant had positive indirect effects via number of ears per plant (0.2947) and LAI-II (0.1722), while negative via grain yield (-0.2096).

Number of ears per plant had positive indirect effects via number of tillers per plant (0.5965), LAI-II (0.1730) and number of grains per spike (0.1029), while negative via grain yield per plant (-0.2180) and LAI-I (-0.1026).

All the indirect effects of ear length of either sign were very small in magnitude.

Number of spikelets per spike had positive indirect effect via number of grains per spike (0.3212), while negative via 1000-grain weight (-0.1457) and number of tillers per plant (-0.1270).

Number of grains per spike had positive indirect effect via LAI-II (0.1388), while negative via 1000-grain weight (-0.2382) and grain yield per plant (-0.1149).

1000-grain weight had negative indirect effect via number of grains per spike. Remaining indirect effects were of little importance because of having smaller magnitudes.

LAI-I had positive indirect effects via LAI-II (0.4352) and number of tillers per plant (0.1801). Indirect effects of other traits were negligible.

LAI-II had positive indirect effects via number of tillers per plant (0.2226), number of grains per spike (0.2063) and number of tillers per plant (0.1105), while negative via LAI-I (-0.3075) and grain yield per plant.

Grain yield per plant had positive indirect effects via number of tillers per plant (0.5086), number of grains per spike (0.3204), LAI-II (0.2714) and number of ears per plant (0.2613), while negative via LAI-I (-0.1294).

Harvest index had lpositive indirect effect via number of tillers per plant (0.1017). Indirect effects of other traits were of no importance because of much lower magnitudes.

4.3.2.2 Environment E_2 (Table 16)

(i) Direct effects :- Number of tillers per plant had the highest positive direct effect (4.5209) on biological yield, followed by number of grains per spike (2.4373), 1000-grain weight (1.9332), LAI-I (1.4586), number of spikelets per spike (0.3869), plant height (0.3204) and ear length (0.2597). The highest negative direct effect was observed for grain yield per plant (-3.1574), LAI-II (-1.5569), days to maturity (-0.6138), number of ears per plant (-0.5774), 'D' (-0.2268), harvest index (-0.1476) and days to 50% flowering (-0.0344).

(ii) Indirect effects :- Days to 50% flowering had positive indirect effects on biological yield via grain yield per plant (0.7007), number of grains per spike (0.2076), 'D' (0.1714) and LAI-I (0.1282), while negative via 1000-grain weight and days to maturity (-0.4006).

Days to maturity had positive indirect effect via number of tillers per plant (1.4935), while negative via number of ears per plant (-0.5437), 1000-grain weight (-0.2448) and LAI-I (-0.1418).

'D' had positive indirect effects via number of tillers per plant (0.9438) and 1000-grain weight, while negative via grain yield per plant (-0.8708), number of ears

Table 16 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters towards biological yield per plant (E_2 - Low fertility)

Character Character	Days to 50% flowering 1	Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/spike 8	No. of grains per plant 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant (g) 13	Harvest index (%) 15
1	-0.0341	-0.4073	0.1714	0.0034	0.0504	-0.0691	0.0111	0.0396	0.2076	-0.8189	0.1282	-0.0878	0.7007	0.0209
2	-0.0224	-0.2138	0.0125	-0.0384	1.4435	-0.6437	0.0731	0.0371	-0.0744	-0.2448	-0.1418	0.0958	0.0485	0.0034
3	0.0280	0.1369	-0.3388	-0.0330	0.9438	-0.1520	0.0257	-0.0051	-0.2504	0.9277	-0.0964	0.0099	-0.8708	-0.0047
4	-0.0009	0.0736	0.0234	0.3204	0.4523	-0.2181	0.0705	0.0662	0.7693	-0.0388	0.1201	-0.2337	-1.0057	-0.0096
5	-0.0084	-0.2028	-0.0474	0.0321	4.5209	-1.3632	0.0731	-0.0946	0.0454	0.6176	0.3321	-0.4879	-2.4261	-0.0389
6	-0.0013	-0.2116	-0.0362	0.0445	4.4301	-0.5774	0.0831	-0.0704	0.1994	0.4479	0.3110	-0.4758	-2.4604	-0.0440
7	-0.0015	-0.1727	-0.0224	0.0870	0.2720	-0.5043	0.2597	0.1519	1.2684	0.1607	-0.2463	0.0354	-1.7025	-0.0010
8	-0.0035	-0.0589	0.0030	0.0549	-0.1059	0.2872	0.1020	0.3869	1.7450	-0.9302	0.1018	-0.2304	-0.1274	0.0068
9	-0.0029	0.0187	0.0233	0.1011	0.0843	-0.1291	0.1352	0.2770	2.4373	-0.8618	0.5732	-0.7565	-1.4146	-0.0163
10	0.0146	0.0777	-0.1089	0.0064	0.4442	-0.3655	0.0216	-0.1861	-1.0865	1.9332	-0.0293	-0.0079	-1.3656	-0.0172
11	-0.0030	0.0507	0.0150	0.0264	1.0293	-0.3364	-0.0439	0.0270	0.9578	.0.0380	1.4586	-1.5148	-1.3098	-0.0005
12	-0.0019	0.0378	0.0014	0.0481	1.4168	-0.4913	-0.0059	0.0372	1.1843	0.0098	1.4191	-1.5569	-1.7074	-0.0029
13	0.0076	0.0094	-0.0626	0.1020	3.4738	-0.2242	0.1406	0.0155	1.0919	0.8361	0.6051	-0.8420	-3.1374	-0.0521
15	0.0049	0.0140	-0.0379	0.0209	1.1918	-0.4700	0.0018	-0.0214	0.2685	0.2248	0.0054	-0.0304	-1.1149	-0.1476

Residula effect : -0.2140

per plant (-0.2520) and number of grains per spike (-0.2504).

Plant height had positive indirect effects via number of grains per spike (0.7693), number of tillers per plant (0.4523), number of ears per plant (0.2181) and LAI-I (0.1201), while negative via grain yield per plant (-1.0057) and LAI-II (-0.2337).

Number of tillers per plant had positive indirect effects via 1000-grain weight (0.6176) and LAI-I (0.3321), while negative via number of ears per plant (-1.5632), LAI-II (-0.4879) and days to maturity (-0.2028).

Number of ears per plant had positive indirect effects via number of tillers per plant (4.4801), 1000-grain weight (0.4479), LAI-I (0.3110) and number of grains per spike (0.1994), while negative via grain yield per plant (-2.4504), LAI-II (-0.4750) and days to maturity (-0.2116).

Ear length had positive indirect effect via number of grains per spike (1.2684), number of tillers per plant (0.2720), 1000-grain weight (0.1607) and number of spikelets per spike (0.1519), while negative via grain yield per plant (-1.7095), number of ears per plant (-0.5045), LAI-I (-0.2463) and days to maturity (-0.1727).

Number of spikelets per spike had positive indirect effects via number of grains per spike (1.7450), number of ears per spike (0.2872), LAI-I (0.1080) and ear length (0.1020), while negative via 1000-grain weight (-0.9302), LAI-II (-0.2304), grain yield per plant (-0.1274) and number of tillers per plant (-0.1059).

Number of grains per spike had positive indirect effects via LAI-I (0.5732), number of spikelets per spike (0.2770), ear length (0.1352) and plant height (0.1011), while negative via grain yield per plant (-1.4166), LAI-II (-0.7565), 1000-grain weight (-0.6618) and number of ears per plant (-0.1291).

1000-grain weight had positive indirect effects via grain yield per plant (-1.3656), number of tillers per plant (0.4442), while negative via number of grains per spike (-1.0865), number of tillers per plant (-0.3655), number of spikelets per spike (-0.1861) and 'D' (-0.1089).

LAI-I had positive indirect effects via number of tillers per plant (1.0293) and number of grains per spike (0.9578), while negative via LAI-II (-1.5148), grain yield per plant (-1.3098) and number of ears per plant (-0.3364).

LAI-II had positive indirect effects via LAI-I (1.4191), number of tillers per plant (1.4168) and number of grains per spike (1.1843), while negative via grain yield per plant (-1.7074) and number of ears per plant (-0.4813).

Grain yield per plant had positive indirect effects via number of tillers per plant (3.4738), 1000-grain weight

(0.8361), LAI-I (0.6051), ear length (0.1406) and plant height (0.1020), while negative via LAI-II (-0.8420), number of ears per plant (-0.2242).

Harvest index had positive indirect effects via number of tillers per plant (1.1918), number of grains per spike (0.2685) and 1000-grain weight (0.2248), while negative via grain yield per plant (-1.1149) and number of ears per plant (-0.4700).

4.3.2.3 Pooled analysis (Table 17)

(i) Direct effects :- LAI-II had the highest positive direct effect (1.6195) on biological yield, followed by number of tillers per plant (0.8509), days to maturity (0.6220), ear length (0.5739), plant height (0.2421), harvest index (0.1834) and grain yield per plant (0.0452). The highest negative direct effect was observed for days to maturity (-1.9946), 'D' (-0.8690), LAI-I (-0.7199), 1000-grain weight (-0.4969), number of grains per spike (-0.2492), number of spikelets per spike (-0.1044), number of ears per plant (-0.6252).

(ii) Indirect effects :- Days to 50% flowering had positive indirect effects on biological yield via 'D' (0.8320), days to maturity (0.6251) and 1000-grain weight (0.3153). Indirect effects of other traits were negligible.

Table 17 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters towards biological yield per plant (Pooled analysis)

Character / Character	Days to 50% flowering 1	Days to maturity 2	'D' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/spike 8	No. of grains per plant 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant(g) 13	Harvest index (%) 15
1	-1.8743	0.5251	0.8120	0.0105	0.0377	-0.0561	0.0540	-0.0185	-0.0270	0.3153	-0.0574	0.0721	-0.0084	-0.0346
2	-2.0044	0.6220	0.7878	-0.0181	-0.0533	0.0217	0.0406	-0.0421	0.0251	0.2341	-0.0496	-0.0105	-0.0317	-0.0051
3	1.9097	-0.5638	-0.8590	-0.0291	-0.1328	0.1377	-0.0427	-0.0117	0.0435	-0.3619	0.0344	-0.0576	-0.0076	0.0365
4	-0.0365	-0.0465	0.1946	0.3421	0.1371	-0.1130	0.1981	-0.0245	-0.0362	-0.0252	-0.3760	0.3140	0.0030	0.0147
5	-0.0393	-0.0190	0.1357	0.0390	0.8509	-0.6192	-0.1311	0.0219	0.0166	-0.1506	-0.2662	0.5376	0.0325	0.1206
6	-0.1790	-0.0216	0.1915	0.0438	0.8427	-0.6252	-0.1301	0.0130	-0.0057	-0.1117	-0.2776	0.5714	0.0332	0.1347
7	-0.1877	0.0440	0.0647	0.0316	-0.1944	0.1418	0.5739	-0.0355	-0.0991	-0.0313	0.1225	-0.2275	-0.0163	-0.0079
8	-0.1335	0.2507	-0.0976	0.0569	-0.1728	0.0779	0.1953	-0.1044	-0.2364	0.3703	-0.0343	0.2240	0.0072	0.0508
9	-0.2160	-0.0626	0.1587	0.0934	-0.0566	-0.0169	0.2281	-0.0390	-0.2492	0.2272	-0.3919	1.0291	0.0218	0.0313
10	1.2657	-0.2930	-0.5330	0.0123	0.2751	-0.1405	0.0361	0.0778	0.1139	-0.4969	0.0549	-0.1370	0.0149	0.0487
11	-0.1590	0.0429	0.0415	0.0265	0.3147	-0.2411	-0.0976	-0.0050	-0.1357	0.0448	-0.7199	1.5763	0.0315	0.0214
12	-0.0938	-0.0040	0.0359	0.0469	0.2825	-0.2205	-0.0806	-0.0144	-0.1584	0.0420	-0.7010	1.6195	0.0325	0.0184
13	0.3700	0.4357	0.1463	0.1768	0.6112	-0.4589	-0.2054	-0.0166	-0.1199	-0.1633	-0.5006	1.1624	0.0452	0.1648
15	0.2653	-0.0183	-0.1734	0.0197	0.5595	-0.4591	-0.0248	-0.0239	-0.0425	-0.1318	-0.0840	0.1623	0.0406	0.1934

Residual effect : -0.0263

Days to maturity had positive indirect effects via 'D' (0.7878) and 1000-grain weight (0.2341), while negative via days to 50% flowering (-2.0044).

'D' had positive indirect effects via days to 50% flowering (1.9097) and number of ears per plant (0.1377), while negative via days to maturity (-0.5638), 1000-grain weight (-0.3619) and number of tillers per plant.

Plant height had positive indirect effects via LAI-II (0.3140), ear length (0.1981), number of tillers per plant (0.1371) and 'D' (0.1046), while negative via number of ears per plant.

Number of tillers per plant had positive indirect effects via LAI-II (0.5376), 'D' (0.1357) and harvest index (0.1206), while negative via number of ears per plant (-0.6192), LAI-I (-0.2662), 1000-grain weight (-0.1606) and ear length (-0.1311).

Number of ears per plant had positive indirect effects via number of tillers per plant (0.8427), LAI-II (0.5714), 'D' (0.1915) and harvest index (0.1347), while negative via LAI-I (-0.2776), days to 50% flowering (-0.1790), ear length (-0.1301) and 1000-grain weight (-0.1117).

Ear length had positive indirect effects via number of ears per plant (0.1418) and LAI-I (0.1225), while negative via LAI-II (-0.2275), number of tillers per plant (-0.1944) and days to 50% flowering (-0.1877).

Number of spikelets per spike had positive indirect effects via 1000-grain weight (0.3703), days to maturity (0.2507), LAI-II (0.2240) and ear length (0.1953), while negative via days to 50% flowering (-0.3535), number of grains per spike (-0.2304) and number of tillers per plant (-0.1788).

Number of grains per spike had positive indirect effects via LAI-II (1.0291), ear length (0.2283), 1000-grain weight (0.2272) and 'D' (0.1587), while negative via LAI-I (-0.3919) and days to 50% flowering (-0.2160).

1000-grain weight had positive indirect effects via days to 50% flowering (1.2657), number of tillers per plant (0.2751) and number of grains per spike (0.1139), while negative via 'D' (-0.6930), days to maturity (-0.2930), number of tillers per plant (-0.1405) and LAI-II (-0.1370).

LAI-I had positive indirect effects via LAI-II (1.5768) and number of tillers per plant (0.3147), while negative via number of ears per plant (-0.2411), days to 50% flowering (-0.1590) and number of grains per spike (-0.1357).

LAI-II had positive indirect effects via number of tillers per plant (0.2825), while negative via LAI-I (-0.7010), number of ears per plant (-0.2206) and number of spikes per plant (-0.1584).

Grain yield per plant had positive indirect effects via LAI-II (1.1624), number of tillers per plant (0.6112), days to maturity (0.4357), days to 50% flowering (0.3700), plant height (0.1768), harvest index (0.1648) and 'D' (0.1463), while negative via LAI-I (-0.5006), number of ears per plant (-0.4589), ear length (-0.2064), 1000-grain weight (-0.1633) and number of grains per spike (-0.1199).

Harvest index had positive indirect effects via number of tillers per plant (0.5595), days to 50% flowering (0.2653) and LAI-II (0.1623), while negative via number of ears per plant (-0.4591), 'D' (-0.1734) and 1000-grain weight (-0.1318).

4.3.3 Harvest index as dependent variable

None of the yield contributing traits and yield per-se showed significant correlation with harvest index in E_1 and E_2 environments. Therefore, the results of path coefficient analyses in E_1 and E_2 for harvest index as dependent variable have not been described. However, in pooled analysis, since harvest index had shown significant correlations with some of the yield contributing traits, therefore, the results of path analysis for harvest index as dependent variable have been described (Table 18).

(i) Direct effects :- Number of ears per plant had the highest positive direct effect on harvest index (5.9327), followed by days to 50% flowering (5.4110), LAI-I (2.6696),

Table 18 : Path analysis showing direct (underlined) and indirect effects of yield contributing characters on harvest index
(Pooled analysis)

Character Parameter	Days to 50% flowering 1	Days to maturity 2	'U' 3	Plant height (cm) 4	No. of tillers per plant 5	No. of ears per plant 6	Ear length (cm) 7	No. of spikelets/ spike 8	No. of grains per plant 9	1000-grain weight (g) 10	LAI-I 11	LAI-II 12	Grain yield per plant(g) 13	Biological yield/ plant(g) 14
1	5.4110	-1.5198	-2.3384	-0.0257	-0.0751	1.5125	-0.1692	0.0490	0.1688	-1.4400	0.2138	-0.2341	0.0246	-0.5155
2	5.4376	-1.3124	-2.2026	0.0443	0.3879	-0.1061	-0.1264	0.1114	-0.1493	-1.0338	-0.1940	0.0341	0.0929	-1.0410
3	-5.1808	1.3710	3.4298	0.0712	0.9660	-1.3069	0.1339	0.0311	-0.2711	1.5760	-0.1274	0.2175	0.0223	0.1690
4	0.2347	0.1133	-0.2924	-0.5917	-0.9969	1.0731	-0.6166	0.0849	0.5731	0.1169	0.2317	-1.0196	-0.0968	1.2386
5	0.2397	0.0948	-0.3793	-0.0959	-6.1575	5.8751	0.4091	-0.0381	-0.0987	0.7439	0.9872	-1.7459	-0.0982	0.9688
6	0.4857	0.0525	-0.5352	-0.1069	-6.1274	5.9327	0.4051	-0.0344	0.0401	0.5171	1.0293	-1.8554	-0.0973	1.0234
7	0.5093	-0.1070	-0.1808	-0.2042	1.4124	-1.3452	-1.7856	0.0941	0.5906	0.1449	-0.4542	0.7388	0.0477	0.4961
8	0.9591	-0.6095	0.2730	-0.1390	1.3002	-0.7373	-0.6081	0.2764	1.4084	-1.7146	0.1271	-0.7275	-0.0211	0.4903
9	0.5861	0.1521	-0.4437	-0.2254	0.4114	0.1603	-0.7107	0.2622	1.4849	-1.0519	1.4534	-1.3418	-0.0639	1.5004
10	-3.4336	0.7124	1.7699	-0.0301	-2.0004	1.3334	-0.1125	-0.2050	-0.6789	2.3009	-0.2405	0.4448	-0.0436	0.4494
11	0.4313	-0.1042	-0.1160	-0.0624	-2.2881	2.2875	0.3040	0.0132	0.8084	-0.2073	2.6696	-5.1205	-0.0222	1.5936
12	0.2408	0.0098	-0.1005	-0.1147	-2.0541	2.0931	0.2510	0.0382	0.9436	-0.1946	2.5994	-5.2589	-0.0953	1.7423
13	-1.0038	1.0595	-0.4091	-0.4320	-4.4444	4.3544	0.0427	0.0439	0.7142	0.7586	1.8564	-1.7746	-0.1326	1.6677
14	-1.2968	0.7319	0.1898	-0.3407	-2.7864	2.8361	-0.4120	0.0630	1.0357	0.4807	1.9776	-4.2593	-0.1028	2.1612

Residual effect : -0.3086

'D' (2.4298), 1000-grain weight (2.3009), biological yield (2.1512), number of grains per spike (1.4849), and number of spikelets per spike (0.2764). Highest negative direct effect on harvest index was observed for number of tillers per plant (-6.1875), followed by LAI-II (-5.2589), ear length (-1.7866), days to maturity (-1.5124), plant height (-0.5917) and grain yield (-0.1326).

(ii) Indirect effects :- Days to 50% flowering had positive indirect effects on harvest index via number of ears per plant, LAI-I and number of grains per spike (0.1608), while this trait had negative indirect effects on harvest index via 'D' (-2.3264), days to maturity (-1.5198), 1000-grain weight (-1.4600), biological yield (-0.5156), LAI-II (-0.2341) and ear length (-0.1682).

Days to maturity had positive indirect effects via days to 50% flowering (5.4376), number of tillers per plant (0.3879), LAI-I (0.1840) and number of spikelets per spike, while negative via 'D' (-2.2026), 1000-grain weight (-1.0838), biological yield (-1.0410), number of ears per plant (-0.2061), number of spikelets per spike (-0.1493) and ear length (-0.1264).

'D' had positive indirect effects via 1000-grain weight (1.6760), days to maturity (1.3710), number of tillers per plant (0.9660), LAI-II (0.2175), biological yield (0.1680) and ear length (0.1329), while negative via days to

50% flowering (-5.1808), number of ears per plant (-1.3069), number of grains per spike (-0.2711) and LAI-I (-0.1274).

Plant height had positive indirect effects via biological yield (1.2386), number of ears per plant (1.0721), number of grains per spike (0.5731), LAI-I (0.2817), days to 50% flowering (0.2347), 1000-grain weight (0.1169) and days to maturity (0.1133), while negative via LAI-II (-1.0196), number of tillers per plant (-0.9969), ear length (-0.6166) and 'D' (-0.2924).

Number of tillers per plant had positive indirect effects via number of ears per plant (5.8751), LAI-I (0.9872), biological yield (0.9688), 1000-grain weight (0.7439), ear length (0.4081) and days to 50% flowering, while negative via LAI-II (-1.7459) and 'D' (-0.3793).

Number of ears per plant had positive indirect effects via LAI-I (1.0293), biological yield (1.0284), 1000-grain weight (0.5171), days to 50% flowering (0.4851) and ear length (0.4051), while negative via number of tillers per plant (-6.1474), LAI-II (-1.8554), 'D' (-0.5352) and plant height (-0.1069).

Ear length had positive indirect effects via number of grains per spike (1.4134), LAI-II (0.7388), number of grains per spike (0.5906), days to 50% flowering (0.5093), biological yield (0.4961) and 1000-grain weight (0.1449).

while negative via number of ears per plant (-1.3452), LAI-I (-0.4542), plant height (-0.2040), 'D' (-0.1808) and days to maturity (-0.1070).

Number of spikelets per spike had positive indirect effects via number of grains per spike (1.4084), number of tillers per plant (1.3002), days to 50% flowering (0.9591), biological yield (0.4903), 'D' (0.2730) and LAI-I (0.1271), while negative via 1000-grain weight (-1.7146), number of ears per plant (-0.7378), LAI-II (-0.7275), days to maturity (-0.6095), ear length (-0.6081) and plant height (-0.1390).

Number of grains per spike had positive indirect effects via biological yield (1.5004), LAI-I (1.4534), days to 50% flowering (0.5861), number of tillers per plant (0.4114), number of spikelets per spike (0.2622), number of ears per plant (0.1603) and days to maturity (0.1521), while negative via LAI-II (-3.3418), 1000-grain weight (-1.0519), ear length (-0.7107), 'D' (-0.4437) and plant height (-0.2284).

1000-grain weight had positive indirect effects via 'D' (1.7699), number of ears per plant (1.3334), days to maturity (0.7124), biological yield (0.4494) and LAI-II (0.4448), while negative via days to 50% flowering (-3.4336), number of tillers per plant (-2.0004), number of grains per spike (-0.6788), LAI-I (-0.2405), number of spikelets per spike (-0.2060) and ear length (-0.1125).

LAI-I had positive indirect effects via number of ears per plant (2.2875), biological yield (1.5936), number of grains per spike (0.8084), days to 50% flowering (0.4313) and ear length (0.3040), while negative via LAI-II (-5.1206), number of tillers per plant (-2.2881), 1000-grain weight (-0.2073), 'D' (-0.1160) and days to maturity (-0.1042).

LAI-II had positive indirect effects via LAI-I (2.5994), number of ears per plant (2.0931), biological yield (1.7423), ear length (0.2510) and days to 50% flowering (0.2408), while negative via number of ears per plant (-2.0541), 1000-grain weight (-0.1946), plant height (-0.1147) and 'D' (-0.1005).

Grain yield per plant had positive indirect effects via number of ears per plant (4.3544), LAI-I (1.8564), biological yield (1.6677), days to maturity (1.0595), 1000-grain weight (0.7566) and number of grains per spike (0.7142), while negative via number of tillers per plant (-4.4444), LAI-II (-3.7746), days to 50% flowering (-1.0038), plant height (-0.4320) and 'D' (-0.4091).

Biological yield had positive indirect effects via number of ears per plant (2.8361), LAI-I (1.9776), number of grains per spike (1.0357), days to maturity (0.7319), 1000-grain weight (0.4807) and 'D' (0.1898), while negative via LAI-II (-4.2593), number of tillers per plant (-2.7864), days to 50% flowering (-1.2960), ear length (-0.4120), plant height (-0.3407) and 'D' (-0.1028).

Table 19 : Pooled analysis of variance for yield and its components

Characters Source of variation	df	Days to 50% flowering	Days to maturity	'D'	Plant height (cm)	No. of tillers/plant	No. of ears/plant	Ear length (cm)	No. of spikelets per spike
Environment(E)	1	435.4000	22.6000	282.3000	1037.1000	253.3100	239.4020	0.9510	12.9380
Within Envi.	4	0.0000	0.3500	0.4250	21.3500	5.4460	0.6360	19.0100	29.2000
Genotypes(G)	43	97.8116**	30.0395**	50.6523**	282.5465**	7.9743**	6.4731**	2.8984**	8.2677**
E x G	43	7.1651**	10.4930**	16.7176**	30.1279**	3.1858**	2.6750**	0.6261**	2.3853**
Error	172	0.1087	0.0622	0.1888	7.8063	0.7065	0.2107	0.7441	1.0098

Characters Source of variation		No. of grains per spike	1000-grain weight (g)	LAI-I	LAI-II	Grain yield/plant (g)	Biological yield per plant (g)	Harvest index (%)
Environment(E)	1	812.5600	2016.3400	77.2308	166.1556	2905.4010	8839.5800	377.8000
Within Envi.	4	55.1300	12.2900	0.0250	0.0260	39.0210	12.1600	5.5150
Genotypes(G)	43	242.0225**	146.7606**	4.4876**	5.0377**	58.4630**	242.9583**	54.8437**
E x G	43	100.7074**	44.0630**	0.7758**	0.9190**	39.2204**	151.7095**	20.4806**
Error	172	12.6601	3.6601	0.0358	0.0569	17.5837	41.8030	2.0668

* Significant at 5% level; ** Significant at 1% level

4.4 Genotype x Environment Interaction

It is commonly observed that relative performance of different genotypes alter in different environments, i.e., there exists a genotype x environment interaction.

Pooled analysis of variance for E_1 and E_2 have been carried out to get genotype x environment interaction for different characters (Table 19).

Mean squares due to genotype as well as genotype x environment interaction showed highly significant differences for all the characters.

Chapter - V

DISCUSSION

5. DISCUSSION

The present day wheat varieties have a potential to yield better than the varieties available during the early sixties. This increase in productivity has been possible through the hard and strenuous work of the plant breeders.

In Madhya Pradesh, wheat is generally grown as a sole crop and in some places as mixture with gram, oats, barley etc. Areawise, this State stands second but on total production basis, it stands fourth and on productivity basis, eighth in the country. It is, therefore, imperative to go into further details of researches in increasing the yielding ability of wheat genotypes.

Yield is the ultimate outcome of the whole life cycle of a crop plant depending upon rates, duration and interlinkings of many processes at all the stages of development. Thus, it is a function of total dry matter production and harvest index. Dry matter production involves leaf area development, leaf area index, rate of photosynthesis, respiration and photorespiration, nutrient uptake, nitrate assimilation and water use efficiency. Substantial gains in productivity have been realized by laying emphasis on greater genetic yield potential coupled with greater varietal adaptation and better agronomy.

Therefore, the present investigation involves to assess the phenotypic and genotypic variabilities for metric traits of economic importance along with leaf area indices in two environments viz., high (E_1) and low (E_2) fertility levels. Pooled analysis was also carried out to judge the g x e effects of various traits because the identification of genotypes with stable yield performance over a wide range of environments is an important consideration in any crop improvement programme.

Heritability in broad sense coupled with the knowledge of genetic advance expresses the reliability of phenotypic value as a guide to breeding value and also measures the degree of correspondence between these two. The phenotypic and genotypic correlation coefficients of paired traits were also estimated for their likely response to selection. Path analysis was carried out to get the direct and indirect effects of different traits taking grain yield, biological yield and harvest index as dependent variables, separately. The results of the present experiment have been discussed as follows :-

5.1 Parameters of Genetic Variability

5.1.1 Analysis of variance, mean performance and estimates of genotypic and phenotypic coefficients of variation

The mean squares due to genotypes were found to be highly significant for all the traits in both the environments and pooled analysis, indicating a wide range of variation. This is supplemented with the findings of highly significant differences due to genotypes found for all the characters in both the environments and in the pooled analysis to confirm further the existence of sufficient amount of variability for different characters in the material. Genotypic variability cannot be measured directly. It is deduced from total phenotypic variation which results from the interplay of genotypes and the environment. Maximum amount of PCV was exhibited by grain yield per plant in E_1. LAI-II showed maximum PCV in E_2 and pooled. The lowest PCV estimates were found for days to maturity in E_1, E_2 and pooled. LAI-I had the highest GCV, while days to maturity had the lowest GCV in E_1, E_2 and pooled.

Number of tillers per plant, number of ears per plant, number of grains per spike, 1000-grain weight, LAI-I, LAI-II, grain yield and biological yield exhibited high GCV and PCV in E_1, E_2 and pooled. This partitioning of variabilities revealed that observed variations were largely influenced by the genetic variation. Similar results of GCV and PCV were also obtained by Sethi and Singh (1972) for spikes (ears) per plant, yield per plant and 1000-grain weight; Mustafeav <u>et al</u>. (1978) for 1000-grain weight and yield per plant, and by Kharche in <u>Setaria italica</u> for LAI-I and LAI-II. High CV for number of tillers per plant, 1000-grain weight and number of grains per spike was estimated by Mishra (1971). High GCV was estimated for number of tillers per plant by Phul <u>et al</u>. (1972); for grain yield per plant by Tikka <u>et al</u>. (1973); for 1000-grain weight by Randhawa <u>et al</u>. (1975) and for number of grains per spike and 1000-grain weight by Gupta and Ahmed (1982). Sharma (1988) in kodo millet obtained high GCV and moderate PCV for LAI-I and LAI-II. High estimates of PCV and GCV have been reported by Sethi and Singh (1972) and Mustafa et al. (1978) for plant height. Similarly, Randhawa et al. (1975) and Gupta and Ahmed (1982) also reported high GCV for this trait. Results of the present investigation conform well with the above workers' findings wherein plant height had high PCV in pooled analysis. Plant height along with ear length and harvest index had moderate estimates of PCV in E_1 and E_2.

Mishra (1971) estimated low CV for number of spikelets per spike and Tikka et al. (1973) estimated low GCV for days to 50% flowering, but in the present investigation, moderate values of PCV and GCV for these traits have been observed which are in sharp contrast to the findings of the above workers. Days to maturity had practically no interaction for PCV and GCV estimates.

There has been close relationship between coefficient of genetic variability and GA as % of $\overline{X}$, i.e., these two parameters possessed more or less similar values and hence, occupied approximately similar rank (Tables 19-21)viz., grain yield per plant, harvest index, biological yield, LAI-I, and tillers per plant had higher GCV with higher GA as % $\overline{X}$ and vice-versa. This indicated that selection in the base population for these traits would bring improvement, i.e., there would be an improvement in the traits due to increase in the genotypic value. Kharche (1986) in Setaria italica Beauv. has also emphasised on this aspect.

5.1.2 Heritability and genetic advance

It is known that total phenotypic variation in a population is the result of genotypic and environmental effects. The amount of genetic variation is critical in achieving genetic gains and it is also known that only this component is transmitted to the next generation. The proportion of total variation caused by the genotype is called heritability and its estimates are the ratio of genotypic variance to the total variance, i.e., phenotypic variance. Thus, heritability denotes the proportion of phenotypic variance that is due to genotype, i.e., heritable.

In the present study, broad sense heritability has been computed which indicates the degree of genetic determination, i.e., extent to which individual's phenotypes are determined by their genotypes. This object of estimation of heritability is to predict the genetic advance in the population through selection programme.

The estimates of broad sense heritability have been broadly classified into low (below 50%), medium (50-70%) and high (above 70%).

Days to 50% flowering had the highest heritability in both the environments and pooled analysis as well. Grain yield had the lowest heritability values in E_1 and pooled analysis, whereas biological yield in E_2.

All the traits except ear length, grain yield and biological yield exhibited high h^2B in E_1, E_2 and pooled, indicating these traits to possess large proportion of total variance that may be attributed to additive gene effects. It also reflects high degree of correspondence between phenotypic value and breeding value. High heritability estimates have also been reported for plant height, 1000-grain weight, number of spikelets per spike, days to heading, number of tillers per plant, number of grains per spike and days to maturity by many workers namely, Mishra (1971), Khan et al. (1972), Reddy et al. (1972), Rana et al. (1972), Tikka et al. (1973), Randhawa et al. (1975), Islam (1976), Sharma (1981), Gupta and Ahmed (1982), Joarder et al. (1982), Camargo and Oliveira (1983), Sharma et al. (1984), Das and Rahman (1984), Martynov (1984), Choudhary et al. (1985) and Pathak and Nema (1985). High heritability for harvest index was estimated by Shrivastava et al. (1981) and Kraljevic et al. (1985).

Contrary to the results of the present investigation, moderate heritability was reported for harvest index (Bhatt, 1976), 100-grain weight (Camargo and Oliveira, 1983) and number of tillers per plant (Sharma et al., 1984). Low heritability for 1000-grain weight, grains per spike and spikelets per spike was recorded by Shrivastava et al. (1982) in durum wheat. Low heritability was also estimated by Pacucci et al. (1982) for 1000-grain weight at different N_2 levels.

Ear length had moderate heritability values in E_1 and E_2 but high in pooled. Grain yield had moderate heritability values in E_1 and pooled, but high in E_2. Biological yield exhibited high heritability in E_1 and pooled but moderate in E_2. None of the characters had low heritability. Several workers viz., Khan *et al.* (1972), Reddy *et al.* (1972), Islam (1976) and Gupta and Ahmed (1982) recorded high heritability for ear length and grain yield per plant. High heritability for grain yield per plant and biological yield per plant was estimated by Shrivastava *et al.* (1981).

Contrary to the present findings, low heritability for grain yield per plant was estimated by Pacucci *et al.* (1982) at different N_2 levels by Shrivastava *et al.* (1982) in *durum* wheat and by Camargo and Oliveira (1983). Low heritability for spike length (ear length) was estimated by Das and Rahman (1984).

The genetic advance as percentage of mean (GA as % of $\overline{X}$) based on heritability estimates was also computed. The genetic advance depends on the unit of measurement, therefore, it is expressed as percentage of mean. This provides a relative comparison of expected genetic gain realized after one generation of selection in a hypothetical selection programme.

In both E_1 and E_2 environments and pooled analysis, LAI-I had the highest GA as % of $\overline{X}$. This indicates that selection based on LAI-I would have better selection advantage.

Number of tillers per plant, number of ears per plant, number of grains per spike, 1000-grain weight, LAI-I, LAI-II, grain yield and biological yield had high GA as % of $\bar{\bar{X}}$ in E_1, E_2 and pooled, while 'D', plant height and harvest index had moderate GA as % of $\bar{X}$ in E_1 and E_2 but high in pooled. Similar to the findings of the present investigation, high estimates of GA % for 1000-grain weight, effective tillers per plant, number of grains per ear, biological yield, grain yield, plant height and harvest index have been reported by Mishra (1971), Tikka <u>et al</u>. (1973), Randhawa <u>et al</u>. (1975), Islam (1976) and Shrivastava <u>et al</u>. (1981). Contrary to the results obtained in the present investigation, Khan <u>et al</u>. (1972) recorded moderate GA for number of tillers per plant and number of grains per ear.

Estimates of GA as % of $\bar{X}$ for days to 50% flowering, ear length and number of spikelets per spike were moderate. Contrary to this, high GA as % of $\bar{X}$ for ear length was recorded by Mishra (1971).

Days to maturity was the only trait which had low GA as % of $\bar{X}$ in this investigation.

Characters studied in the present investigation were ranked to examine the relationship between PCV, GCV, h^2_B and GA %. It was observed that rank values of PCV, GCV and GA % were closer to each other for most of the characters except ear length in both the environments and pooled analysis. However, no consistent trend could be established among PCV, GCV, h^2_B and GA % (Tables 19,20 & 21).

Table 19 : Relationship between different parameters in E_1 environment - ranking procedure

Parameter	PCV	GCV	h^2B	GA %	Total
Days to 50% flowering	14	13	1	12	40
Days to maturity	15	15	6	15	51
'D'	12	11	2	11	36
Plant height	9	9	9	9	36
No. of tillers/plant	5	6	12	7	30
No. of ears/plant	6	5	7	5	23
Ear length	11	12	14	13	49
Spikelets per spike	13	14	13	14	54
Grains per spike	7	7	11	6	31
1000-grain weight	8	8	8	8	32
LAI-I	2	1	3	1	7
LAI-II	4	4	4	3	15
Grain yield/plant	1	2	15	4	22
Biological yield/plant	3	3	5	2	13
Harvest index	10	10	10	10	40

Table 20 : Relationship between different parameters in E_2 environment - ranking procedure

Parameter	PCV	GCV	h^2B	GA %	Total
Days to 50% flowering	14	14	1	14	43
Days to maturity	15	15	2	15	47
'D'	10	9	3	9	31
Plant height	12	11	7	11	41
No. of tillers/plant	5	5	11	4	25
No. of ears/plant	6	6	8	5	25
Ear length	9	12	14	13	48
Spikelets per spike	13	13	12	12	50
Grains per spike	7	7	10	7	31
1000-grain weight	8	8	6	8	30
LAI-I	1	1	5	1	8
LAI-II	3	2	4	2	11
Grain yield/plant	4	3	13	3	23
Biological yield/plant	2	4	15	6	27
Harvest index	11	10	9	10	40

Table 21 : Relationship between different parameters under pooled analysis - ranking procedure

Parameter	PCV	GCV	$h^{2}B$	GA %	Total
Days to 50% flowering	14	14	1	13	42
Days to maturity	15	15	2	15	47
'D'	11	10	3	10	34
Plant height	10	9	7	9	35
No. of tillers/plant	5	5	11	6	27
No. of ears/plant	6	6	8	5	25
Ear length	9	11	14	12	46
Spikelets per spike	13	13	12	14	52
Grains per spike	7	7	10	7	31
1000-grain weight	8	8	6	8	30
LAI-I	1	1	5	1	8
LAI-II	3	2	4	2	11
Grain yield/plant	2	3	15	4	24
Biological yield/plant	4	4	13	3	24
Harvest index	12	12	9	11	44

In all the three analyses viz., E_1, E_2 and pooled, values of different genetic parameters of selection were more or less similar. Hence, the discussion could be generalized. In general, higher values of PCV were associated with higher values of GCV and GA % in E_1, E_2 and pooled analysis. This situation was observed for grain yield, biological yield, LAI-I, LAI-II and number of tillers per plant. This indicated the probability of selection advantage based on PCV estimates. It has further been observed that when h^2B and GA % are compared, no consistent trend could be observed.

It is known that heritability alone is no reliable estimate of any genetic gain realized in selection unless it is associated with GA % estimates. From the tables of rank procedure, high heritability with high genetic advance is found for the traits LAI-I and LAI-II. According to Panse (1957), it may be due to additive gene effects and higher genetic gain can be obtained through straight selections. Plant height, number of ears/plant and 1000-grain weight had moderate heritability with moderate estimates of GA %. Such a situation is indicative of predominance of additive gene effects and therefore, selection gains could be anticipated. Days to 50% flowering, maturity and 'D' (duration from flowering to maturity) had high heritability with low genetic advance. This is suggestive of predominance of non-additive gene effects. Hence, the population will have lack of fixable components of genetic variance and thus selection advantage may not be realized for these traits in direct selections based on phenotypes. Similar observations have also been made by Kharche (1986) in Setaria italica and Sharma (1988) in kodo millet.

5.2 Correlation Coefficient Analysis

Galton (1980) considered application of correlation coefficient as an asset to indicate degree of association in variables. The utility of estimates of correlation gets considerable spread by partitioning into phenotypic, genotypic and environmental components. Application of correlation was determined by Searle (1961) at genotypic, phenotypic and environmental levels.

Correlations among characters are of much interest because the changes brought about by selection for one trait may bring simultaneous changes in other characters also.

For both the environments and pooled analysis, correlation coefficients among yield, yield components and leaf area indices were estimated separately at phenotypic, genotypic and environmental levels. If two characters show high magnitude of positive correlation coefficient at genotypic level, it will indicate strong linkage at genic level but if the correlation values are high at phenotypic level only, it may show weak association and may be broken up with changes in environment. If the correlation coefficient value for a pair of characters is high at environmental level, it would reflect that such associations are found in that particular environment only and such associations may not exist if there is change in that environment. The same principle is applicable to negative correlations also.

Correlations may be true or false. True correlations arise mostly due to linkage, pleiotropy and physiological functions of metabolic pathways. The genetic cause of correlation is pleiotropy chiefly. Linkage is the cause of transient correlation, particularly in a population derived from crosses between divergent strains. Pleiotropy is simply a property of gene(s) affecting two or more characters simultaneously. Correlation coefficient between any two traits may be attributed to genetic and environmental causes.

In the present investigation, correlations at phenotypic, genotypic and environmental levels in all possible character combinations were estimated separately for E_1, E_2 and pooled analyses in 44 genotypes of bread wheat. Correlations at genotypic level can be estimated but they cannot be tested for their significance, hence, phenotypic correlations significant at 5% or 1% probability levels have been discussed here.

In general, genotypic correlation coefficients were higher than phenotypic and environmental correlation coefficients in E_1, E_2 and pooled analyses. Positive and significant correlations among most of the characters are useful and selection based on these characters would likely to improve the desired traits.

Experimental findings revealed that grain yield was positively correlated with number of tillers per plant and number of ears per plant in E_1, E_2 and pooled analysis as well. Grain yield also had positive significant correlations with number of grains per spike, LAI-II and biological yield in E_1 and E_2, while 1000-grain weight in E_2 and harvest index in pooled analysis/ Presence of positive correlations of grain yield with number of tillers per plant and number of ears in all the three analyses indicated negligible role of environments for these traits/ However, number of grains per spike, LAI-II and biological yield which possess positive correlations with grain yield in E_1 and E_2 is further suggestive of non-significant role of environments on these traits. Harvest index has shown positive correlation with grain yield in pooled analysis. This suggested that g x e interaction is operating. Therefore, it would be inferred that selection for these traits would likely to improve grain yield in bread wheat. Similar results have also been reported by several workers namely, Singh and Randhawa (1971) who reported positive correlations of grain yield with number of tillers per plant, number of ears per plant and grains per ear; Kumar and Chowdhary (1986) who reported positive correlations of grain yield with biological yield, number of tillers per plant and harvest index in an experiment conducted in three environments in durum wheat; Balyan and Singh (1987) who reported positive correlations of grain yield with number of tillers per plant and biological yield and Shamsuddin (1987) who reported positive correlations of grain yield with harvest index, number of ears per plant and grains per ear.

In E_1 and E_2 environments, number of tillers per plant had positive correlations with number of ears per plant, grain yield and biological yield but with LAI-II it was only in E_1. In pooled analysis also, number of tillers per plant had positive correlations with number of ears per plant, grain yield and harvest index. Similar results have also been reported by Kumar and Chowdhary (1986), Singh and Randhawa (1971), Sambhu (1982), Anderson (1986) and Balyan and Singh (1987).

Number of ears per plant had positive association with number of tillers per plant, grain yield and biological yield in E_1 and E_2 but with LAI-II, it was only in E_1, while with days to maturity, it was in E_2. In pooled analysis, this trait had positive association with number of tillers per plant, LAI-I, LAI-II, grain yield and harvest index. Similar correlations of number of tillers per plant with grain yield have also been reported by Singh and Randhawa (1971), Sethi and Singh (1972), Anderson (1986) and Shamsuddin (1987).

Correlation coefficients of number of tillers per plant and number of ears per plant were positive and significant.

Although the associations of these two traits with other traits were of varying magnitudes in all the three analyses, yet they had positive and significant correlations with grain yield and between themselves also. These traits also had positive associations with biological yield in E_1 and E_2. Thus, straight selection over these traits may improve grain yield together with biomass. In pooled analysis, number of ears per plant had positive associations with LAI-I and LAI-II (also in E_1) which indicated that the selection for higher leaf area may be conducive to better grain yield but selection for higher leaf area in post-flowering stage will be more effective in improving grain yield.

Number of grains per spike exhibited positive association with grain yield in E_1 and E_2; with biological yield in E_2 and pooled. This trait also had positive association with number of spikelets per spike and negative with 1000-grain weight in all the three analyses viz., E_1, E_2 and pooled. Here also correlated response to selection could be realized for grain yield, biological yield, LAI-I, LAI-II and spikelets per spike. Number of grains per spike had negative correlation with 1000-grain weight. This result is as per general expectation, i.e., number of grains per ear would be reduced if 1000-grain weight would increase and vice-versa.

Positive association of biological yield was found with grain yield and yield contributing traits like number of tillers per plant, number of ears per plant in both the environments, i.e., E_1 and E_2 and with LAI-I, LAI-II and number of grains per spike in E_1 and pooled analysis. Presence of positive correlations of biological yield with grain yield, number of tillers and ears in both the environments, i.e., E_1 and E_2 is indicative of true relationship of these traits which would be further confirmed by path coefficient analysis and thus, the environmental influences on these associations are negligible.

Positive correlations of biological yield with LAI-I, LAI-II and number of grains per spike have been found in E_1 (i.e., better environment) and pooled analysis. This is suggestive of g x e interaction and therefore, these traits may have better performance under better environments. It may be inferred that improvement due to selection for grain yield and yield components will be associated in increasing biomass (biological yield). This increase would be more pronounced in high fertility conditions (E_1).

A critical examination regarding studies on leaf area indices in relation to yield and other attributes has given the following inferences :-

(1) LAI-I had positive significant correlation with LAI-II in both the environments and under pooled analysis. This suggested that leaf area at pref-flowering stage has a direct bearing on leaf area at post-flowering stage, i.e., initial

supply of photosynthates is necessary to maintain the plant growth which may continue to support leaves at post-flowering stage. This process would continue till the grain formation, irrespective of the varying environments, although the quantum of photosynthates and their mobilization to the sink may vary depending upon the source capacity and the sink strength.

(2) LAI-I as well as LAI-II had significant positive associations with biological yield in E_1 and pooled analysis. This indicated interplay of g x e interaction and suggested that better environment may produce high biological yield.

(3) LAI-II had significant association with grain yield in both the environments. Significant positive associations of LAI-II with grain yield in E_1 and E_2 are suggestive of the activeness of leaf surface after post-flowering which also contribute a major portion of photosynthates to the developing grains. It is immaterial whether the environment is good or bad, but the process of photosynthesis and photosynthate formation and its mobilization would continue. This relationship would not be altered by environmental changes, although the quantum of carbohydrate synthesis and supply may vary.

(4) Biological yield had significant positive association with grain yield in both the environments.

Thus, the breeders should aim at evolving genotypes with better foliage development so as to achieve higher [illegible] development.

[illegible] (19??), grain yield [illegible] number of tillers per plant [illegible] number of tillers [illegible] yield [illegible] grain yield [illegible].

4.3 Path coefficient analysis

The correlation coefficients obtained in correlation analysis simply indicate the degree of association among the [illegible] towards economic yield. [illegible] yield *per se* [illegible] components of yield and their relative contribution. The path coefficient analysis helps in understanding the [illegible] because it partitions the total correlation of a [illegible] into direct and indirect effects [illegible] components of yield. Path coefficient studies are useful in several ways [illegible].

In the present investigation, path coefficient analysis was carried out at genotypic level taking grain yield, biological yield and harvest index as dependent variables separately for E_1, E_2 and pooled analyses. One dependent variable was considered once at a time taking independent variables common to each. The purpose of taking aforesaid three factors as dependent variables is to derive valid conclusion of independent variables regarding their cause and effect relationship.

Harvest index, except under pooled analysis, had no significant correlation coefficients with any of the traits so the direct and indirect effects of other traits on harvest index in E_1 and E_2 have not been discussed. Only pooled analysis has been discussed. Grain yield and biological yield have been discussed for E_1 and E_2 environments and pooled analysis as well.

5.3.1 Grain yield as dependent variable

5.3.1.1 Under E_1

Number of tillers per plant, LAI-II and biological yield showed positive correlations and positive direct effects on grain yield. Such a situation showed true relationship. Number of ears per plant and number of grains per spike had positive correlations and negative direct effects on grain yield. In such condition, indirect effects seem to be the cause of correlations. Under such a situation, the indirect causal factors are to be considered. Number of ears per plant and number of grains per spike had indirect effects on grain yield via number of tillers per plant, biological yield and LAI-II.

It is concluded that selection based on number of tillers per plant, LAI-II, and biological yield may be useful in better environment viz., high fertility conditions.

Several workers have carried out path analysis taking grain yield as dependent variable. Similar findings have been reported by Paroda and Joshi (1970b), Jatasra and Paroda (1983c), Balyan and Singh (1987) and Boyadzhieva (1987).

5.3.1.2 Under E_2

Number of grains per spike, 1000-grain weight, number of ears per plant, LAI-I and number of tillers per plant showed positive correlation and positive direct effects on grain yield per plant, showing true relationship.

LAI-II and biological yield had positive correlations and negative direct effects on grain yield, indicating importance of indirect effects on grain yield via number of ears per plant, number of tillers per plant, number of grains per spike and LAI-I.

Under low fertility conditions, selection based on number of tillers per plant, number of ears per plant, number of grains per spike, 1000-grain weight and grain-protein [illegible] direction.

Similar findings have been reported by [illegible] and [illegible], Ahmad et al. (1978) and [illegible] (1977).

5.2.1.4 Grain protein content

Number of ears per plant and harvest index exhibited significant positive correlations and positive direct effects on grain yield per plant with a [illegible] influence [illegible] independently.

Number of tillers per plant had positive correlation and negative direct effects on grain yield. In the condition, indirect effects seem to be the cause of correlation. Here number of tillers per plant had positive indirect effects via number of ears per plant, [illegible], harvest index, number of grains per spike and plant height. Besides other traits, number of ears per plant and harvest index should also be given weightage in selection programme.

Similar findings have also been reported by [illegible] and [illegible] (1970b), Jaimini (1974) and [illegible] (1982).

5.3.1 Biological yield as dependent variable

5.3.1.1 [illegible] F_1

Number of grains per spike, number of tillers per plant, [illegible] and number of ears per plant showed significant positive correlations and positive effects on biological yield. Therefore direct selection based on these traits would be effective to improve biological yield in better environments.

LAI-I and grain yield showed significant positive correlations and negative direct effects on biological yield. In such conditions, indirect effects seem to be the cause of correlations. Under such situations, indirect causal factors are to be considered. Here, aforesaid traits had positive indirect effects via LAI-II, number of tillers per plant and grain yield, and also via number of ears per plant and number of grains per spike.

It is concluded that selection based on number of tillers per plant, number of ears per plant, number of grains per spike and LAI-II may be useful in the better environment.

Similar results have also been reported by Sharma (1988) in kodo millet.

5.3.2.2 Under E_2

Number of tillers per plant showed significant positive correlation and positive direct effect on biological yield. Direct selection for this trait would improve biological yield under low fertility conditions.

Number of ears per plant and grain yield showed significant positive correlations and negative direct effects on biological yield. In such conditions, indirect effect seems to be the cause of correlations. Aforesaid traits had positive indirect effects via number of tillers per plant, 1000-grain weight and LAI-I.

Selection based on number of tillers per plant, 1000-grain weight and LAI-I would be useful.

Similar results have also been obtained by Sharma (1988) in kodo millet.

5.3.2.3 Under pooled analysis

LAI-II is the only trait showing positive correlation and positive direct effect on biological yield, in the present investigation. Therefore, direct selection for LAI-II would be effective.

LAI-I and number of grains per spike had significant positive correlations but negative direct effects on biological yield. Here, these traits had positive indirect effects mainly via LAI-II. Therefore, indirect selection for this trait would improve biological yield.

Similar results were obtained by Sharma (1988) in kodo millet.

5.3.3 Harvest index as dependent variable (Pooled Analysis)

Number of ears per plant showed positive correlation and positive direct effect on harvest index. Such situation shows true relationship and direct selection based on number of ears per plant would be effective to increase harvest index and ultimately to the grain yield.

Number of tillers per plant and grain yield had positive correlations but negative direct effects on harvest index. In such conditions, indirect effects seem to be the cause of correlation. Here, aforesaid traits had positive indirect effects via LAI-I, biological yield and 1000-grain weight. Therefore, indirect selection for these traits would be effective.

Results of the present investigation are more or less similar to the findings of Singh (1989) who observed significant positive association of harvest index only with grain yield in E_1 (high fertility) and only with biological yield in pooled, but none of the traits in E_2 (low fertility).

Concluding discussion on path coefficient analysis, the following observations have been made :-

Under E_1 environment

Days to maturity, plant height, number of tillers per plant, number of spikelets per spike and LAI-II had in common, positive direct effects on grain yield and biological yield, while days to 50% flowering, 'D', ear length and LAI-II had in common, negative indirect effects on grain yield and biological yield.

Here, out of 13 independent variables, nine had common effects on both the dependent variables viz., grain yield and biological yield, where 5 had positive and 4 had negative direct effects.

Under E_2 environment

Plant height, number of tillers per plant, ear length, number of spikelets per spike, number of grains per spike, 1000-grain weight and LAI-I had in common, positive direct effects on grain yield and biological yield, while 'D', LAI-II, and harvest index had in common, negative direct effects on grain yield and biological yield.

Here, out of 13 independent variables, ten had common direct effects on grain yield and biological yield, where 7 had positive and 3 had negative direct effects.

Under pooled analysis

Direct effects of either sign, with few exceptions, were similar on grain yield and biological yield, but were totally different for harvest index.

Days to maturity, plant height, ear length, harvest index and LAI-II had in common, positive direct effects on grain yield and biological yield, while days to 50% flowering, 'D', number of grains per spike, 1000-grain weight and LAI-I had in common, negative direct effects on grain yield and biological yield.

Chapter - VI

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

V. SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

SUMMARY

The present investigation entitled "[illegible] of genetic variability and [illegible] components for some quantitative traits and [illegible] wheat (*Triticum aestivum* L.)", was conducted at the [illegible] Farm, [illegible] [illegible] [illegible] during [illegible]. The experimental material comprised [illegible] genotypes of wheat laid out in a randomized complete block design with three replications in two environments [illegible] on [illegible] [illegible], [illegible].

Phenotypic and genotypic variabilities, broad sense heritability, genetic advance as percentage of mean and correlation coefficients at genotypic, phenotypic and environmental levels were calculated. Path analysis treated grain yield, biological yield and harvest index as dependent variables alternatively was also carried out under both the environments and pooled analysis for yield and its contributing traits.

The analysis of variance indicated considerable amount of variability for the characters studied in both the environments. The pooled analysis of variance exhibited highly significant variances due to genotype x environment interaction

[illegible]

[illegible]

[illegible]

number of ears per plant, LAI-I, days to 50% flowering, number of grains per spike, 'D', ear length and 1000-grain weight had negative direct effects on grain yield. In E_2, number of ears per plant, number of tillers per plant, days to 50% flowering, plant height, 'D', number of grains per spike, 1000-grain weight, LAI-I, number of spikelets per spike and ear length had positive direct effects, while LAI-II, days to maturity, biological yield and harvest index had negative direct effects on grain yield. In pooled analysis, LAI-II, days to maturity, ear length, number of ears per plant, plant height, harvest index and spikelets per spike had positive direct effects, while days to 50% flowering, LAI-I, 'D', number of grains per spike, 1000-grain weight, biological yield and number of tillers per plant had negative direct effects on grain yield.

In E_1, number of tillers per plant, LAI-II and biological yield had significant positive correlations with positive direct effects, while number of ears per plant and number of grains per spike had significant positive correlations with negative direct effects on grain yield. In E_2, number of ears per plant, number of tillers per plant, days to 50% flowering, number of grains per spike, 1000-grain weight and LAI-I had significant positive correlations with positive direct effects, while LAI-II and biological yield had significant positive correlations with negative direct effects on grain yield. In pooled analysis, number of ears per plant and harvest index had significant positive correlations with positive direct effects, while number of tillers per plant had significant positive correlation with negative direct effect on grain yield.

CONCLUSION :

On the basis of heritability estimates, genetic advance as percentage of mean, correlation coefficient analysis and path coefficient analysis, it may be inferred that selection based on number of tillers per plant, number of ears per plant, LAI-II and biological yield would help in increasing yield potential of the crop.

SUGGESTIONS FOR FURTHER WORK ;

(1) This experiment should be conducted over years and locations to assess stability performance.

(2) An ideotype of bread wheat may be constructed on the basis of number of tillers per plant, number of ears per plant, LAI-II and biological yield.

(3) D^2 analysis should be carried out to get genetic divergence of the materials for their further use in recombination breeding.

(4) The study should also be carried on various physiological traits like CGR, NAR, RGR etc. so as to derive valid conclusions underlying the mechanism of production potential of the crop.

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* Original not seen.

APPENDICES

APPENDIX-I

Mean values of yield and yield contributing characters (E_1 - High fertility)

Genotype	No.	Days to 50% flowering	Days to maturity	'D'	Plant height (cm)	No. of tillers/plant	No. of ears per plant	Ear length (cm)	No. of spikelets per plant	No. of grains per spike	1000-grain wt. (g)	LAI-I	LAI-II	Grain yield per plant (g)	Biological yield/plant (g)	Harvest Index (%)
30016	1	76.33	114.00	37.66	92.98	13.20	12.86	7.20	19.66	56.50	38.96	5.93	6.89	29.25	58.10	48.73
30052	2	71.33	113.00	41.66	95.00	10.66	10.33	8.25	19.13	55.75	38.73	5.05	6.80	22.13	50.94	43.34
30072	3	70.00	113.00	43.00	95.83	10.06	9.73	8.96	19.33	55.60	47.10	5.38	6.81	25.48	53.89	48.16
30166	4	75.66	112.00	36.33	101.00	6.53	6.13	8.66	20.60	55.28	43.93	3.12	4.87	14.89	25.79	57.73
30228	5	76.00	112.00	36.00	84.96	6.26	6.26	8.20	18.20	53.85	41.90	1.31	3.39	14.41	32.98	43.10
30305	6	68.66	112.00	43.33	81.96	7.93	7.66	8.55	14.83	43.51	42.81	2.41	1.93	14.65	32.78	44.84
30311	7	70.00	114.00	44.00	95.60	7.46	7.13	8.90	19.50	52.69	49.10	3.95	5.21	20.54	58.02	35.40
30472	8	69.00	114.00	45.00	89.16	6.93	6.46	8.60	21.76	51.51	49.00	2.59	4.52	19.43	44.41	43.80
30482	9	70.00	114.00	44.00	81.25	6.86	6.26	7.60	20.86	52.06	40.73	3.84	3.65	13.01	30.73	42.40
30515	10	71.00	111.00	40.00	98.55	7.86	7.20	9.06	19.93	51.49	45.23	3.54	5.32	17.06	44.79	37.96
30564	11	69.00	113.00	44.00	84.37	9.26	8.66	7.20	19.30	50.07	50.60	5.07	6.87	21.95	50.47	43.50
30579	12	69.33	113.00	43.66	80.95	8.43	7.45	8.05	19.65	49.67	46.83	5.43	7.18	17.83	41.49	38.95
30596	13	72.00	113.00	42.00	74.09	9.40	9.33	7.46	18.53	44.70	41.30	4.20	5.87	15.37	35.47	43.33
30616	14	69.00	113.00	44.00	82.66	7.26	7.20	8.00	18.33	36.63	54.65	3.88	4.70	14.29	32.63	43.75
30647	15	70.00	113.00	43.00	76.08	7.46	7.20	8.10	16.66	37.06	42.70	3.63	4.54	12.01	26.12	45.96
30683	16	70.00	111.00	41.00	73.46	7.13	6.73	7.20	17.66	32.91	42.00	2.47	3.14	9.26	21.19	43.66
30747	17	69.00	116.00	47.00	85.66	8.93	8.26	9.46	20.80	39.47	44.43	2.52	3.57	14.71	35.20	42.16
30792	18	61.66	115.33	33.66	90.13	9.06	8.60	8.66	17.73	44.26	38.50	2.38	4.47	14.65	35.61	41.30
30803	19	78.00	115.33	37.00	81.61	9.93	9.46	9.66	20.53	45.84	35.23	3.00	4.06	15.29	34.75	40.86
30835	20	71.00	107.00	36.00	79.16	6.86	6.53	7.83	17.56	40.06	40.90	3.64	4.62	10.79	26.93	40.10
30934	21	70.66	111.00	40.33	100.53	6.80	6.53	9.36	19.00	43.46	39.73	4.48	5.54	11.25	26.63	42.23
30951	22	76.00	115.00	39.00	98.36	8.25	8.05	9.05	19.93	41.80	41.10	2.73	5.25	13.93	33.13	42.03
30977	23	71.00	114.00	43.00	81.65	10.06	9.73	8.40	20.06	47.70	41.53	3.07	5.59	19.22	45.42	42.06
31053	24	71.00	113.00	42.00	92.67	7.93	7.86	9.60	21.00	44.32	41.96	2.64	6.20	14.62	36.99	39.53
31258	25	71.00	114.00	43.00	91.53	6.93	6.73	7.93	20.60	40.70	48.20	3.37	3.79	13.22	31.63	41.80
31402	26	78.00	117.00	39.00	90.15	7.00	6.66	8.46	19.83	46.38	42.73	4.05	3.93	13.20	32.78	40.26
31431	27	74.00	114.00	40.00	90.58	7.33	6.73	8.66	18.73	35.28	54.96	3.41	6.26	13.00	32.35	40.40
31498	28	73.00	112.00	43.00	95.33	7.33	6.73	8.66	20.20	42.55	47.83	2.51	3.35	13.69	32.80	41.59
31504	29	70.00	113.00	41.00	93.61	7.00	6.66	6.93	19.53	41.72	48.63	3.13	3.77	13.52	32.06	42.50
31507	30	71.00	110.00	39.00	82.26	6.00	6.06	7.80	21.40	41.84	41.33	2.16	3.21	12.11	29.86	40.56
31539	31	72.00	115.00	34.00	98.75	9.20	8.40	8.36	20.00	48.18	42.66	3.82	5.58	18.42	49.70	37.06
31551	32	74.00	116.00	42.00	93.67	10.00	9.60	8.13	18.13	41.17	42.60	3.57	5.25	38.53	39.17	43.45
31654	33	74.00	114.00	40.00	94.44	5.26	5.26	8.60	19.80	49.13	47.16	4.57	5.59	12.28	29.67	41.36
31663	34	76.00	111.00	35.00	86.40	6.00	6.00	9.86	19.93	25.82	54.50	5.60	6.20	11.39	26.14	43.53
31789	35	66.00	111.00	45.00	78.92	7.20	6.60	9.20	19.20	41.08	51.16	3.74	3.79	13.87	32.07	43.23
31831	36.	72.00	110.00	38.00	79.40	7.13	7.13	9.06	20.36	52.63	42.26	2.87	3.93	15.83	37.11	42.66
31834	37	71.00	111.00	40.00	86.50	6.60	6.60	9.40	18.46	40.23	39.36	5.23	6.26	10.45	30.17	34.66
31843	38	72.00	112.00	40.00	86.46	6.33	6.00	9.33	20.80	59.61	35.46	2.34	3.35	12.62	29.74	42.53
32041	39	85.00	117.00	32.00	93.33	8.13	7.46	9.33	19.53	49.13	46.26	2.70	3.77	16.85	35.50	47.16
32177	40	84.00	121.00	37.00	70.90	8.66	8.46	7.46	19.40	63.10	39.96	3.58	4.58	12.02	29.91	40.20
Lok-1	41	66.00	109.00	43.00	84.73	9.33	8.13	8.33	16.86	31.96	53.16	3.26	4.14	15.52	32.92	46.90
WH-147	42	66.00	109.00	43.00	83.28	6.93	7.93	7.53	19.53	41.78	52.33	3.48	4.58	17.19	35.53	48.46
Sonalika	43	64.00	107.00	43.00	96.52	9.36	8.66	8.33	17.13	28.81	57.80	2.38	3.49	15.25	34.95	43.73
J-405	44	69.00	109.00	40.00	102.42	7.93	7.53	8.30	18.60	43.90	42.16	3.45	4.53	14.60	33.65	43.43

APPENDIX-II

Mean values of yield and yield contributing characters (E_2 - Low fertility)

Genotype	No.	Days to 50% flowering	Days to maturity	'D'	Plant height (cm)	No.of tillers per plant	No.of ears per plant	Ear length (cm)	No. of spikelets per plant	No. of grains per spike	1000-grain Wt. (g)	LAI-I	LAI-II	Grain yield per plant (g)	Biological yield/plant (g)	Harvest index (%)
30016	1	76.00	111.00	35.00	90.40	5.13	7.40	7.90	19.10	54.09	33.90	4.74	5.36	13.60	31.54	46.16
30052	2	72.66	111.00	38.33	91.36	7.13	6.70	8.20	19.65	37.45	40.96	4.10	4.89	10.57	25.91	40.95
30072	3	74.00	111.00	37.00	85.93	4.66	4.40	8.46	18.66	41.66	42.33	2.28	2.64	7.66	16.40	46.76
30166	4	76.00	114.00	38.00	94.46	5.93	5.93	8.53	21.70	58.40	31.40	3.39	3.56	10.86	27.22	39.90
30228	5	72.00	112.00	39.00	81.13	6.06	5.86	8.06	17.46	31.26	38.73	1.10	1.35	7.23	20.24	35.73
30305	6	74.00	111.00	37.00	78.36	5.06	4.93	8.60	18.93	36.31	39.40	2.08	2.34	7.40	21.34	34.66
30311	7	72.66	110.00	37.00	91.60	5.73	5.73	9.30	18.66	47.83	35.55	3.01	3.68	9.32	27.16	33.46
30472	8	72.33	113.00	42.00	84.50	5.20	5.00	8.33	10.85	39.59	42.63	2.17	2.88	8.28	44.43	40.33
30482	9	73.00	112.00	41.00	73.73	5.40	5.13	7.46	19.60	40.26	36.86	3.36	4.25	7.72	18.75	41.20
30515	10	73.00	113.00	42.00	91.76	6.06	5.13	6.80	19.20	48.45	49.06	3.18	4.31	12.16	32.97	36.90
30564	11	73.00	113.00	42.00	83.53	6.33	6.20	8.93	18.00	47.79	43.80	3.38	4.43	12.93	30.27	42.93
30579	12	74.00	111.00	37.00	81.65	6.53	6.26	9.00	19.45	51.72	39.40	4.64	5.37	13.02	33.57	39.93
30596	13	72.00	112.00	40.00	81.33	5.66	5.66	8.06	19.40	45.66	38.46	3.52	4.38	10.01	24.57	40.76
30616	14	74.00	111.00	37.00	81.20	5.40	5.20	7.80	17.93	46.10	39.63	2.95	3.48	9.45	23.74	39.80
30647	15	78.00	116.00	36.00	77.46	6.40	6.06	8.80	18.66	38.22	51.36	2.90	3.36	11.96	32.52	36.80
30683	16	61.66	111.00	39.33	73.66	6.00	5.06	7.23	16.86	27.59	36.56	1.49	1.84	5.10	12.68	40.26
30747	17	71.33	113.00	41.66	72.86	4.80	4.66	8.53	20.73	43.39	41.13	1.65	2.10	8.30	20.11	42.26
30792	18	81.33	116.00	28.33	83.43	6.60	6.53	9.13	16.43	42.90	34.20	1.50	3.24	9.59	24.00	40.04
30803	19	78.00	117.00	39.00	76.03	7.33	6.66	8.40	21.25	45.41	33.63	2.25	2.99	10.14	26.29	38.56
30835	20	75.00	112.00	37.00	79.00	3.73	3.66	6.43	17.60	29.86	33.23	2.45	2.54	4.32	11.17	38.73
30934	21	77.66	115.00	37.33	89.93	5.60	5.46	9.63	19.10	44.03	35.80	1.32	2.06	8.64	20.90	40.93
30951	22	78.00	115.00	37.00	95.45	7.86	7.23	9.23	19.93	47.34	36.26	1.75	2.74	12.67	49.35	40.13
30977	23	72.00	112.00	40.00	84.80	5.73	6.00	8.13	18.33	42.83	35.53	1.40	2.20	8.70	17.94	48.60
31053	24	72.66	113.00	40.33	91.70	4.66	4.53	8.53	20.26	42.68	39.73	2.18	3.12	7.66	20.07	38.26
31268	25	73.66	116.00	42.33	87.73	6.00	5.60	8.30	20.30	53.25	34.16	2.81	3.72	10.24	24.66	41.60
31402	26	83.00	116.00	33.00	81.73	5.33	5.20	8.50	17.86	40.20	34.40	3.07	3.73	7.37	18.90	43.00
31431	27	71.00	116.00	39.33	88.46	5.73	5.73	8.33	19.00	43.17	35.76	2.08	2.72	6.26	22.10	39.20
31498	28	76.66	114.00	37.33	89.26	5.26	5.06	8.46	18.70	36.52	39.66	1.66	2.44	7.28	19.06	38.13
31504	29	72.00	112.00	40.00	83.53	5.30	4.93	6.46	18.06	30.77	41.70	2.23	2.76	7.07	18.09	37.75
31507	30	73.66	112.66	39.00	81.23	5.20	5.06	7.26	17.53	36.95	40.83	1.80	2.41	7.97	18.08	43.76
31539	31	75.66	113.00	37.33	86.00	5.73	5.20	7.93	19.26	40.46	33.73	3.14	3.85	7.19	20.16	35.16
31551	32	78.00	112.00	34.00	94.70	5.73	5.33	6.13	19.00	37.80	38.93	2.26	3.03	7.78	19.06	40.38
31654	33	78.00	115.00	37.00	87.20	6.46	6.20	8.46	18.46	44.18	38.43	3.10	3.95	10.54	26.15	40.30
31663	34	74.00	115.0	40.00	87.66	4.90	4.66	9.26	18.13	40.34	38.43	2.45	3.01	7.27	18.52	39.30
31769	35	70.00	113.00	43.00	72.76	5.66	5.20	8.73	17.93	44.13	39.03	1.81	2.53	8.96	20.71	41.26
31831	36	75.00	110.00	35.00	82.06	4.53	4.46	9.30	19.40	40.82	38.73	2.07	2.58	8.20	20.66	39.66
31834	37	74.00	110.00	36.00	83.13	5.20	4.86	8.06	18.33	41.90	35.90	2.42	2.78	7.31	37.24	35.96
31843	38	73.00	111.33	38.33	84.20	4.73	4.46	9.73	22.46	50.82	38.90	1.31	3.38	8.83	20.99	41.80
32041	39	86.00	118.00	33.00	87.53	6.73	6.33	8.93	17.80	32.89	41.96	2.25	3.88	8.72	20.67	42.33
32177	40	85.00	122.66	37.66	86.73	7.53	6.93	8.20	18.93	38.21	34.70	2.90	3.70	6.74	24.89	36.86
Lok-1	41	70.00	113.33	43.33	83.93	9.06	8.13	8.26	15.26	30.97	56.56	2.53	3.53	14.25	31.61	45.10
WH-147	42	70.00	114.33	44.33	84.03	8.46	7.93	8.73	19.85	41.50	41.75	2.16	3.00	13.74	29.33	46.83
Sonalika	43	66.00	111.36	45.66	85.93	8.40	7.46	9.20	16.13	30.43	55.10	1.65	2.58	12.51	31.19	40.13
J-405	44	70.66	116.33	45.65	90.33	6.46	6.26	9.13	19.80	37.98	44.36	2.23	2.98	9.85	23.53	41.90

APPENDIX-III

Mean values of yield and yield contributing characters (pooled analysis)

Genotype	No.	Days 50% flowering	Days to maturity	'D'	Plant height (cm)	No. of tillers/ plant	No. of ears/ plant	Ear length (cm)	No.of spikelets/ spike	No.of grains/ spike	1000-grain wt. (g)	LAI-I	LAI-II	Grain yield per plant (g)	Biological yiled/ plant (g)	Harvest index (%)
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
30016	1	76.16	112.50	36.33	91.69	10.66	10.33	7.55	19.38	55.29	36.43	5.33	6.07	20.92	44.28	47.45
30052	2	72.00	112.00	40.00	93.22	9.90	8.51	8.23	19.40	46.60	39.85	4.58	5.85	16.37	38.43	42.15
30072	3	72.00	112.00	40.00	90.88	7.36	7.06	8.71	19.00	48.63	44.71	3.83	4.72	16.57	34.65	47.46
30166	4	75.83	113.00	37.16	97.86	6.23	6.03	8.60	21.15	56.84	37.66	2.75	4.21	12.87	26.51	48.81
30228	5	74.00	112.00	37.50	83.05	6.16	6.06	8.13	17.83	42.56	40.31	1.46	2.72	10.72	26.61	39.41
30305	6	71.33	111.50	40.16	80.15	6.50	6.40	8.57	16.88	40.91	41.11	2.25	3.38	11.03	27.06	39.75
30311	7	71.33	112.00	40.50	93.60	6.60	6.43	9.10	19.08	53.26	42.33	3.41	4.44	15.18	42.59	34.43
30472	8	70.66	113.50	43.50	86.83	6.06	5.73	8.46	20.87	50.05	45.81	2.38	3.75	13.87	44.41	42.06
30482	9	71.50	113.00	42.50	77.49	6.13	5.70	7.53	20.23	46.46	38.80	3.61	4.65	10.37	24.72	41.80
30515	10	72.00	112.00	41.00	95.15	6.96	6.16	8.93	19.56	49.97	47.30	3.36	4.76	14.61	38.88	37.43
30564	11	71.00	113.00	43.00	83.95	7.80	7.43	9.06	18.60	48.93	47.20	4.22	5.65	17.44	40.37	43.21
30579	12	71.66	112.00	40.33	81.47	7.33	6.86	8.53	19.56	51.16	43.07	5.04	6.57	15.20	38.53	39.45
30596	13	72.00	112.50	41.00	78.16	7.53	7.00	7.76	18.96	45.18	39.88	3.86	5.12	12.69	30.02	42.05
30616	14	71.50	112.00	40.50	81.93	6.33	6.20	7.50	18.13	41.36	47.15	3.32	4.09	11.87	28.18	41.78
30647	15	74.00	114.50	40.50	76.77	6.93	6.63	8.35	18.66	37.65	47.13	3.27	3.95	11.98	29.32	41.38
30683	16	70.83	111.00	40.16	73.56	6.56	5.90	7.21	17.26	30.25	39.28	1.98	2.49	7.18	16.93	41.96
30747	17	70.16	114.50	44.33	79.26	6.86	6.46	9.00	20.76	41.38	42.78	2.08	2.88	11.50	27.56	42.21
30792	18	81.50	115.66	31.00	86.78	7.83	7.56	8.90	18.07	43.58	36.35	2.09	3.35	12.12	29.80	40.61
30803	19	78.00	116.00	38.00	78.82	8.63	8.06	9.03	20.90	45.62	34.43	2.63	3.52	12.71	30.52	39.71
30835	20	73.00	109.50	36.50	89.09	5.30	5.10	7.13	17.58	34.96	40.36	3.04	3.73	7.59	19.05	39.41
30934	21	74.16	113.00	38.83	95.23	6.20	6.00	9.45	19.05	43.74	37.76	2.90	3.75	9.94	23.37	41.58
30951	22	77.00	115.00	38.00	96.90	8.06	7.65	9.15	19.93	44.57	38.68	2.24	3.25	13.30	40.74	41.07
30977	23	71.50	113.00	41.50	83.22	7.90	7.86	8.26	19.20	45.25	38.53	2.23	3.50	13.69	31.68	45.33
31053	24	71.83	113.00	41.16	92.18	6.30	6.20	9.06	20.63	43.50	40.85	2.41	3.73	11.14	28.53	38.90
31268	25	72.33	115.00	42.66	89.63	6.46	6.16	8.11	20.45	46.47	41.18	3.09	4.04	11.73	28.14	41.70
31402	26	80.50	116.50	36.00	85.94	6.15	5.93	8.48	18.85	43.29	38.56	3.56	4.41	10.28	24.84	41.63
31431	27	75.50	115.16	39.66	89.52	6.53	6.23	8.50	18.86	39.22	45.36	2.75	3.65	9.63	27.22	39.80
31498	28	74.83	113.00	40.16	92.29	6.30	5.90	8.56	19.45	39.54	43.75	2.08	3.04	10.48	25.93	39.86

Contd...

appendix-III contd...

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
31504	29	71.00	112.50	40.50	88.57	6.10	5.80	6.70	18.80	36.25	45.16	2.68	3.48	10.29	25.08	40.13
31507	30	72.33	111.33	39.00	81.75	5.60	5.56	7.53	19.46	39.40	41.08	1.98	2.81	10.04	23.97	42.16
31539	31	73.83	114.00	40.16	92.37	7.46	6.80	8.15	1963	44.23	38.20	3.48	4.71	12.80	34.93	36.11
31551	32	76.00	114.00	38.00	94.15	7.86	7.45	7.13	18.56	39.48	40.76	2.91	4.14	23.07	29.17	42.15
31654	33	76.00	114.50	38.50	90.82	5.86	5.73	8.53	19.13	46.65	42.80	3.84	4.77	11.41	27.91	40.83
31663	34	75.16	113.00	37.50	88.03	5.40	5.33	9.56	19.03	33.08	46.46	4.02	4.60	9.33	22.33	41.41
31789	35	68.00	112.00	44.00	75.84	6.43	5.90	8.96	18.56	42.61	45.10	2.27	3.16	11.42	26.39	42.25
31831	36	73.50	110.00	36.50	80.73	5.83	5.80	9.18	19.88	46.73	40.50	2.47	3.25	12.01	28.88	41.16
31834	37	72.83	110.00	38.00	84.81	5.90	5.73	8.23	18.40	41.06	37.63	3.83	4.52	8.88	33.70	35.31
31843	38	72.50	111.66	39.16	85.33	5.53	5.23	9.53	21.63	55.21	37.18	1.82	2.86	20.72	25.37	42.15
32041	39	86.50	117.83	32.50	90.43	7.43	6.90	9.13	18.66	41.01	44.11	2.47	3.32	12.79	28.09	44.75
32177	40	84.50	121.83	37.33	69.81	8.10	7.70	7.83	19.16	37.16	37.33	3.24	4.14	9.38	27.40	38.53
Lok-1	41	68.00	111.16	43.16	84.33	9.20	8.13	8.30	16.06	31.45	59.86	2.90	3.84	14.88	32.26	45.95
WH-147	42	68.00	111.66	43.66	83.65	7.70	7.73	8.13	19.70	41.64	47.05	2.82	3.83	15.47	32.43	47.65
Sonalika	43	65.00	109.33	44.33	91.22	9.13	8.06	8.76	16.63	29.62	56.45	2.02	3.03	13.88	33.07	41.93
J-405	44	69.83	112.66	42.83	96.37	7.20	6.90	8.96	19.20	40.94	41.76	2.84	3.75	12.22	28.59	42.66

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[illegible] successfully completed the [illegible] from the College of Agriculture, [illegible] in 19[illegible], [illegible] and continued his study for the [illegible] in the Department of Plant Breeding [illegible] the same College [illegible]