CHARACTER ASSOCIATION OF ROOT ATTRIBUTES WITH YIELD UNDER DIFFERENT GROWING CONDITION IN COWPEA [*Vigna unguiculata* (L.) Walp.]

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..............*Raj*

ABSTRACT

CHARACTER ASSOCIATION OF ROOT ATTRIBUTES WITH YIELD UNDER DIFFERENT GROWING CONDITION IN COWPEA

[*Vigna unguiculata* (L.) Walp.]

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ABSTRACT

Three sets of thirty genotypes were grown in randomized block design with three replications in root structure and protected structures filled with uniform soil. All the three sets were raised under normal irrigated conditions till flower initiation, after which, the roots were excavated in the set grown in root structure by gently washing the soil with the pressure of water and observations on root length, fresh root weight, dry root weight, root volume, root density and root : shoot ratio were recorded. One of the two sets in protected structure was exposed to water stress after flower initiation. The other set was maintained as normal and irrigation was applied whenever required. These two sets were used to study the biological yield, harvest index and grain yield under post flowering stress and normal conditions, respectively. The analysis of variability revealed significant genotypic differences for all the characters. Further, there was little difference in the magnitude of genotypic and phenotypic correlation coefficients.

Grain yield per plant evinced highly significant and positive correlation with biological yield and harvest index under both normal and post flowering water stress condition. However, it exhibited positive though non-significant correlation with root: shoot ratio indicating the importance of root: shoot ratio

along with biological yield and harvest index in realizing higher yield under normal growing condition. On the other hand, yield per plant under post flowering water stress condition showed positive though non-significant correlation with fresh root weight, dry root weight and root volume indicating importance of biological yield and harvest index in realizing higher yield under post flowering water stress condition too, though significance of fresh root weight, dry root weight and root volume can not be overlooked. Further, the percent injury in yield due to post flowering water stress showed negative and non-significant correlation with root length, fresh root weight, dry root weight, root volume and root density that further substantiated that the plants with long roots, more root volume, root density, fresh weight and dry weight are desirable for yield enhancement under post flowering water stress condition.

Fresh root weight and harvest index evinced high positive direct effect on grain yield under normal growing condition. Harvest index also exhibited high positive direct effects and indirect effects via root volume, dry root weight, root density, root length and root: shoot ratio on grain yield evincing importance of fresh root weight and harvest index for aiming higher yield under normal growing conditions. Contrarily, the importance of root attributes like root volume, root density, dry root weight, root length and root: shoot ratio besides harvest index and biological yield was palpable as indicated by high positive and direct effect of on grain yield under post flowering water stress condition. Harvest index and biological yield also exhibited highly significant and positive correlation with grain yield due to its positive direct effect and positive indirect effect via other characters. Thus, harvest index and biological yield seem to be the most important traits for yield enhancement under post flowering water stress condition.

Only two characters viz. fresh root weight and root: shoot ratio exhibited the negative direct effect on the percent injury in yield due to post flowering water stress condition. This was attributed to positive indirect effect via each other except, via fresh root weight and root: shoot ratio that contributed negatively to percent injury to yield via other characters. This indicated that increase in fresh root weight and root: shoot ratio is desired for breeding least percent injury due to post flowering water stress.

Thus, biological yield and harvest index, that are indicators of photosynthesis and effective carriage of carbohydrates synthesized to developed sink, respectively, appeared most important attributed under both normal and post flowering water stress condition. However, these two characters needs complementation with root: shoot ratio under normal condition and larger, heavier and more voluminous roots under post flowering water stress condition.

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Place: Sardarkrushinagar

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INTRODUCTION

I. INTRODUCTION

Pulses are economically cheaper and vital source of protein in Indian diet. India has a distinction of growing over a dozen of pulses and ranks first in acreage, production and consumption. Despite per capita availability of pulses is dismally as low as 28g /capita/ day as against the optimum and minimum stipulations of 104 g and 60 g / capita/ day, respectively, as per World Health Organization standards. The situation is dicey and often leads to malnutrition. The predicament still assumes volume as the predominant Indians are vegetarian. Therefore, pulses may simply be termed as health line of the country and needs all out concerted efforts for enhancing their production.

Among all the pulses, cowpea [*Vigna unguiculata* (L.) Walp.] locally known as lobiya, chowla, southern pea, black eye pea belongs to family *Fabaceae*. *Vigna* is pan-tropical genus comprising of 170 species (Faris, 1965). It is an important crop that can further play a significant role in enhancement of production of pulses as the crop is short duration that can be grown over different seasons. The crop can be raised as major crop during main season or can also be squeezed in between two major crops. Cowpea is also suitable as good intercrop under both intensive and limited resources growing conditions inclusive drought or rainfed conditions. The crop can yield as high as 20-25 quintals in about two months under favourable growing conditions. The crop has still more potential for yield enhancement through innovative breeding interventions.

Cowpea is a multi-purpose crop and may be grown both for its pods as well as for using the leaves (fodder and salad). The traditional varieties are long and creeping types that produce abundant leaves and set a moderate number of pods late in the season. Newly introduced varieties are predominantly bushy and determinate type producing very little leaves but more number of pods with more seeds per pod.

Cowpea includes four culti-groups (Baudin and Mirechal, 1985) namely, (1) *Unguiculata* - major group; (2) *Biflora* or *Catjang* - differentiated mainly by its small erect pods and grown in Southeast Asia; (3) *Sesquipedalis* - yard long bean differentiated mainly by very long pods and climbing growth habit. It is grown for its fresh pod in Asia and (4) *Textilis* - grown in West Africa for the textile fibers obtained from its long peduncles. *Unguiculata* is the most diverse of the culti-groups and exhibits substantial diversity in West Africa. It is diploid with 2n = 22 chromosomes. It is strictly an autogamous annual herb in which out crossing is negligible. Cowpea originated in Central Africa. However, it is regarded as indigenous to North-West in Central Asia (Faris, 1965).

The major production region for cowpea in the world is West Africa. It is also grown in Asia, North and South America, Australia, Central and Southern part of Europe. Gujarat, West Bengal, Tamil Nadu, Kerala, Orissa and Andhra Pradesh are the major cowpea cultivating states in India.

The yield is a complex character and is dependent on yield components that have been adequately exploited in breeding programmes. Almost all breeding strategies for restructuring plant type in cowpea have hovered around above ground parts encompassing growth habit, branching habit, pod and seed characters. The under ground parts in general and root in particular have not been considered attributable to complexities in its measurement. Consequently, it has been virtually ignored in planning breeding strategies for yield and quality enhancement in cowpea. This is despite all growth and development activities of the plant are largely dependent upon root and its attributes (Acharya *et al.*, 2007). The significance of roots assumes still more importance as the crop is specially adapted to less endowed arid and semi arid conditions, where water is the limiting factor. Consequent upon rainfed growing conditions and restricted least growth period, the crop often experiences water stress during the post flowering phase. This defines a situation where the crop grows normal up to flower initiation stage producing good vegetative growth but the same is restricted thereafter due to water stress putting a limit on biological yield. The root growth too is normal till flower initiation and plays an important role in extracting moisture from soil that is so important to alleviate the impact of water stress. The nagging global warming and consequent capricious fluctuations in weather conditions in general and rainfall pattern in particular make it pertinent to give due importance to till day neglected root and its attributes in yield enhancement. This is important as the root functions as suction for the moisture and nutrients from the soil. Further, the biological yield indicates the potential of photosynthetic activity, while the harvest index evinces the translocational efficiency of synthesized carbohydrates to the sink.

Thus, holistically and precisely appropriate situation specific collaboration of root attributes with biological yield and harvest index are desired for higher productivity. Considering the importance of this factual information, the present study entitled **"Character Association of Root Attributes with Yield under Different Growing Condition in Cowpea [*Vigna unguiculata* (L.) Walp]"** was undertaken to unravel the character association of root attributes at flower initiation stage with yield under intensive and post flower water stress conditions with following objectives:

1. To ascertain the magnitude of phenotypic and genotypic correlation of yield under intensive and post flower water stress conditions in relation to root attributes.
2. To unravel the direct and indirect effect of root attributes on yield under intensive and post flowering water stress conditions through path coefficient analysis.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

The available literature pertaining to present study is reviewed under following sub-heads:

2.1 Correlation Studies

2.2 Path Analysis

2.1 Correlation Studies

Before attempting to improve any character, it is necessary to understand its association with other characters. Knowledge of the inter-relationship among various characters helps in proper planning of breeding programme, so as not to jeopardize one character while trying to improve another. With this view both genotypic as well as phenotypic association among various characters are important for penultimate improvement in yield. The concept of correlation was first set forth by Galton (1889) and later elaborated by Fisher (1918). It is an index of the proportion of causes common in the genesis of two variables of the total and not to the causes themselves (Bowley, 1920). The study of correlation is very useful to plant breeder for selecting suitable plant type.

Sinha *et al.* (1977) studied genotypic and phenotypic correlation in yam bean (*Pachyrhizus erosus*) where genotypic correlation coefficients were greater than phenotypic correlation coefficients for most of the yield characters. Yield was negatively correlated with number of days to first flowering, days to pod maturity, length of main stem, number of leaves per plant, number of pods per plant, root length, root volume and root density and positively correlated with 100-seed weight and root diameter.

Rangasamy and Shanmugam (1984) studied correlation among nine characters in 10-day-old seedlings of 27 *Vigna radiata* cultivars. At genotypic level, 100-seed weight and the seedling characters *viz*., number of rootlets, length of rooting zone, fresh root weight and dry root weight were negatively correlated with seed yield and positively correlated with root: shoot ratio and root volume.

Kolotilov and Kolotilova (1985) studied root system in *Lathyrus sativus* and its effect on yield by growing seven varieties. Root weight and root length were greater in high-yielding varieties than low-yielding ones, but the former reacted more (in terms of yield) to insufficiency of moisture in the soil. In favourable years, yield was positively correlated with root weight in the ploughed soil horizon ($r = 0.67$). In drought years, the correlation was negative ($r = -0.23$).

Bertholdsson (1989) studied root development and crop reliability in pot trials with 11 normal and 30 leafless pea genotypes. The shoot dry matter, root dry matter and shoot: root ratio (S: R) were measured at the beginning of flowering and three weeks later. he reported a significant negative correlation between percentage yield decrease and total root length both before and after flowering under drought. In field trials, however, final yield was positively correlated with total root length in 10-day-old seedlings.

Brindza *et al.* (1989) tested local and foreign pea collections for the formation of above-ground organs and the root system. A total of 204 varieties were studied in hydroponic culture using 46-day-old plants. Root length was not correlated with the other parameters studied. The correlation coefficients between root dry weight and 1000-seed weight, biological yield, stem length, root volume and stem dry weight were 0.33, 0.59, 0.37, 0.41 and 0.56, respectively.

Das and Chatterjee (1992) reported the effect of seed size on the growth, yield and root attributes of kidney bean (*Phaseolus vulgaris* L.) cv. PDR 14. They observed that large (545 mg), bold (470 mg), medium (414 mg) and small (291 mg) seeds gave seed yields of 11.1, 12.0, 9.3 and 5.8 g / plant, respectively. Root dry weight and volume were highest with the large seeds.

In a study on drought tolerance complex in French bean to evaluate 19 traits in 12 trials, Velich (1993) found out a good correlation between yield and the 18 other traits tested, with root weight in irrigation trials. Of the total 19 traits, seven were closely correlated with actual drought tolerance.

Rao and Nanda (1994) conducted an experiment on 18 genotypes of horsegram for seed yield. The traits *viz*., days to maturity, plant height, number of pod bearing nodes per plant, number of pods per plant and harvest index were positively correlated with seed yield but only harvest index was found significant.

Singh *et al.* (1998b) evaluated a set of 45 exotic and indigenous collections of cowpea [*Vigna unguiculata* (L.) Walp.] for 10 morphological traits. Correlation study revealed that, in general, genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients. Grain yield per plant was positively and significantly associated with biological yield.

Oko and Amalu (1999) studied influence of root perimeter on the growth and yield characteristics of cowpea (*Vigna unguiculata* (L) Walp.) cv. Lemon 25 and IT-820-716. Root length, root dry weight, root volume and root perimeter were generally positively correlated with total and effective pod numbers, pod weight and seed yield.

Aleem *et al.* (2000) studied the effects of soil type on the yield, yield components, root characteristics, plant height, harvest index and root: shoot ratio of 27 wheat genotypes and the correlation between root characteristics and grain yield were studied under greenhouse conditions. Results of simple linear regression indicated that grain yield was positively correlated with root characteristics and root: shoot ratio. The correlation coefficient was highly significant between grain yield and dry root weight and root volume.

Singh *et al.* (2002) analyzed correlation in 21 genotypes of carrots to determine the effects of leaf length, leaf width, fresh root weight and root length and diameter. They revealed that the genotypic correlation was higher than phenotypic correlation and analysis of variance showed highly significant differences for all the characters examined. Highly positive and significant correlation coefficient was recorded between root length and fresh root weight both at the genotypic and phenotypic level.

Tamboli and Daftardar (2002) studied the effect of different P sources on the root characteristics and yield in 4 legumes, i.e. groundnut, pigeonpea, chickpea and pea. Root weight and volume expressed significant positive correlation with yield in all legumes, whereas root length and phosphate activity were negatively correlated with yield.

Arora and Jatasara (2003) evaluated ten diverse genotypes of cowpea for eight morphological characters *viz*., hypocotyl length, epicotyl length, seedling height, length and width of first pair of true leaves, petiole length of first trifoliate leaf and fresh and dry weight of seedlings at seedling stage. The magnitude of genotypic correlation, in general, was higher than the phenotypic correlation. Selection for high fresh seedling weight might be very helpful in bringing genetic improvement for several component traits of seedling dry weight in cowpea.

Chakrabarty and Parimal (2003) assessed nine mungbean cultivars (A-20, A-89, A-93, A-151, A-119, A-130, Tgl, A-33 and A-160) to study the correlation among different traits. Results showed that pod length, micropylar length, seed coat thickness and root length and showed the desired correlation and can be used to increase the yield per plant.

Makhan *et al*. (2003) studied genetic variability and selection response for root and other characters in groundnut (*Arachis hypogaea* L.). On the bases of correlation root length was positively correlated with number of nodules per plant.

Kanbar *et al*. (2004) studied correlation analysis for root morphological traits on 127 doubled haploid lines of rice (*Oryza sativa* L.) to determine the effects of plant height, number of tillers per plant, maximum root length, total root number, root volume, shoot dry weight and dry root weight. They observed the positive and significant correlation between dry root weight and all the other traits measured.

Nigude *et al*. (2004) studied correlation in 45 cowpea genotypes. Grain yield per plant was significantly and positively associated with all the characters except pod length and test weight at both levels.

Patil *et al*. (2004) studied correlation of biomass partitioned for ten yield contributing characters in 47 genotypes of cowpea. They observed that the seed yield per plant had highly positive and significant correlation with biological yield at the phenotypic and genotypic levels.

Kumawat *et al*. (2005) studied association analysis in fifty genotypes of cowpea [*Vigna unguiculata* (L.) Walp.]. Seed yield per plant had significant positive correlations with branches per plant, clusters per plant, pods per plant, biological yield per plant and harvest index. These characters also had positive correlation among themselves, except correlation of harvest index with biological yield per plant.

Dahiya *et al*. (2007) studied correlation analysis in cowpea (*Vigna unguiculata* (L.) Walp.). They revealed that the seed yield per plant showed significant and positive association with No. of clusters per plant, No. of pods per plant, pod length, No. of seeds per pod, 100-seed weight and harvest index.

Eswaran *et al.* (2007) evaluated a set of thirty genotypes of cowpea [*Vigna unguiculata* (L.) Walp.] for association of component characters. They reported that seed yield per plant had high significant positive correlation with total dry matter production (biological yield) and harvest index both at phenotypic and genotypic levels.

2.2 Path Analysis

The concept of path analysis was developed by Wright (1921). This technique is capable of providing a measure of direct and indirect effects of the traits influencing yield and permits the separation of the correlation coefficients into two components of direct and indirect effects towards the yield. The utilization of path coefficient analysis in plant selection was demonstrated by Deway and Lu (1959) in the crested wheat progenies.

Sasmal (1987) studied relationship of root and shoot characters in parent, F_1 and F_2 populations of rice. Path analysis showed that fresh root weight had a positive direct effect on grain yield in all 3 generations, and in the F_2, roots/plant had a positive direct effect on grain yield. Root length and dry root weight had negative direct effects on grain yield in the F_2.

Topare (1994) studied path analysis in 32 strains of *lablab* bean and found that days to maturity, number of seeds per pod, number of pods per plant, number of branches per plant, days to first flowering, harvest index and 100-seed weight have positive direct effects on yield, while days to first pod maturity, pod length, plant height, number of inflorescence per plant had direct negative effects on yield. Generally indirect effects involving pod length and 100-seed weight were negative.

Mehetre *et al.* (1997) studied path analysis in root growth and yield characters in 41 soybean [*Glycine max* (L.) Merrill] genotypes. Path coefficient analysis indicated that the number of branches / plant exerted the highest positive direct effect followed by contribution of total dry matter / plant, root dry matter / plant, 100-seed weight, number of pods / plant, root length / plant and leaf area. The highest indirect positive effects were found from root length, number of pods / plant and leaf area.

Singh *et al.* (1998a) studied path analysis in early generation of hullless barley (*Hordeum vulgare* L.). Path analysis revealed that root weight and shoot: root ratio though had direct negative contributions towards grain yield, yet indirect contribution via main shoot weight was significantly positive.

While studying path analysis of seedling traits and yield components in six accessions of *Brassica napus* including a standard variety, Zia *et al.* (1998) reported that the grain yield per plant followed by total seedling length, fresh root weight and plant height had the highest direct and positive effect on the grain yield per plot. The shoot length followed by number of grains per pod showed highest indirect effect.

Alam *et al.* (1999) analyzed path coefficient in sesame (*Sesamum indicum* L.). The highest direct and positive contribution at genotypic level was made by maturity followed by root length at 40 days after seeding, harvest index and root weight at 20 days after seeding.

Chakrabarty and Parimal (2003) evaluated nine mungbean cultivars (A-20, A-89, A-93, A-151, A-119, A-130, Tgl, A,33 and A-160) to estimate path coefficient analysis. They reported that the number of seeds per pod, seed weight, micropylar length, seed coat thickness, seedling root length (ambient seed), seedling shoot length (ambient seed), fresh weight of seedlings (controlled and ambient seed) and dry weight of seedlings (controlled seed) may be selected for better yield.

Makhan *et al.* (2003) studied Genetic variability and selection response for root and other characters in groundnut (*Arachis hypogaea* L.). The root length had high and positive direct effect on yield per plant based on path analysis.

Tikka *et al*. (2003) studied path coefficient analysis based on genetic correlation and reported that pods per plant, pod length, branches per plant, plant height and harvest index were the main yield contributing characters in Indianbean.

Nigude *et al*. (2004) analyzed path coefficients in 45 cowpea genotypes. They observed that biomass (dry weight) at harvest and harvest index had the highest direct effect on grain yield. Association of biomass with grain yield was significantly positive.

Golparvar and Ghasemi (2006) studied indirect selection for genetic improvement of seed yield and biological nitrogen fixation in Iranian common bean genotypes (*Phaseolus vulgaris* L.). Path analysis indicated that harvest index and biological yield have considerable and positive direct effect on seed yield. Therefore, these traits are recommended as the best indirect selection criteria for improvement of seed yield especially in early generations.

MATERIALS AND METHODS

III. MATERIALS AND METHODS

The present investigation entitled "**Character Association of Root Attributes with Yield under Different Growing Conditions in Cowpea [*Vigna unguiculata* (L.) Walp.]**" was carried out during summer 2007-08 at the Main Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar.

3.1 Geographic and Edaphic Details

Geographically, Sardarkrushinagar is situated at 24^0-19' North latitude and 72^0-19' East longitude with an attitude of 154.52 meters above mean sea level. The soil of the experimental field was sandy loam and poor in organic matter content with pH of 7.5 to 8.0. The weather condition during the growing season was favorable for the crop and are summarized in Appendix-I.

3.2 Experimental Material

The experimental material for the present investigation comprised 30 genotypes of cowpea obtained from the germplasm maintained at the Main Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The summary of the genotypes used in the experiment are listed in Table 3.1

3.3 Experimental Details

The experiment comprised three sets of thirty genotypes. The first set was conducted in root structure filled with uniform soil. The other two sets were sown in protected structures filled with the same uniform soil as in root

Table 3.1: Summary of 30 genotypes of cowpea [*Vigna unguiculata* (L.) Walp.] used for conducting present study

Sr. No.	Genotypic Designation	Selection/ Pedigree	Source
1	GC-3	Selection from GC-3	MPRS[@]
2	GC-4	Selection from GC-4	MPRS[@]
3	GC-5	Selection from GC-5	MPRS[@]
4	GC-0502	Selection from GC-0502	MPRS[@]
5	GC-0503	Selection from GC-0503	MPRS[@]
6	GC-0504	Selection from GC-0504	MPRS[@]
7	GC-0505	Selection from GC-0505	MPRS[@]
8	GC-0405	Selection from GC-0405	MPRS[@]
9	GC-0408	Selection from GC-0408	MPRS[@]
10	GC-0410	Selection from GC-0410	MPRS[@]
11	GC-0311	Selection from GC-0311	MPRS[@]
12	CP-5	Selection from CP-5	CAZRI[$]
13	CP-6	Selection from CP-6	CAZRI[$]
14	CP-7	Selection from CP-7	CAZRI[$]
15	CP-8	Selection from CP-8	CAZRI[$]
16	CP-9	Selection from CP-9	CAZRI[$]
17	CP-12	Selection from CP-12	CAZRI[$]
18	CP-16	Selection from CP-16	CAZRI[$]
19	CP-18	Selection from CP-18	CAZRI[$]
20	IC-402099	Selection from IC-402099	NBPGR[&]
21	IC-402101	Selection from IC-402101	NBPGR[&]
22	IC-402159	Selection from IC-402159	NBPGR[&]
23	IC-402161	Selection from IC-402161	NBPGR[&]
24	IC-402174	Selection from IC-402174	NBPGR[&]

25	IC-402182	Selection from IC-402182	NBPGR[&]
26	EC-17574-6	Selection from EC-17574-6	NBPGR[&]
27	EC-1758413-9	Selection from EC-1758413-9	NBPGR[&]
28	EC-394708	Selection from EC-394708	NBPGR[&]
29	EC-458402	Selection from EC-458402	NBPGR[&]
30	EC-472250	Selection from EC-472250	NBPGR[&]

[@], [$] and [&] stands for Main Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar; Central Arid Zone Research Institute, Jodhpur (Rajasthan) and National Bureau of Plant Genetic Resources, New Delhi, respectively.

structure. Each set was laid out in randomized block design with three replications. Each plot comprised two row plot of two meter length with row-to- row and plant-to-plant spacing of 45 cm and 10 cm, respectively. The seeds were sown on 30th March, 2007. The recommended packages of practices were followed to raise the good crop. All the three sets were raised under normal irrigated conditions till flower initiation. After flower initiation, the set in root structure was used for root studies. The roots were excavated by gently washing the soil with the pressure of water till the entire mass of root is exhumed. One of the sets in protected structure was exposed to water stress after flower initiation by discontinuing water application after flower initiation. The other set was maintained as normal and irrigation was applied whenever required. These two sets were used to study the biological yield, harvest index and grain yield under post flowering stress and normal conditions, respectively.

3.4 Characters Studied

Five competitive plants were selected randomly in each plot and observations were recorded from those plants. Mean values were subjected to statistical analysis. The root attributes were recorded in the first set of experiment, while the quantitative yield was recorded in second and third set. In all the observations were recorded on the following traits.

3.4.1 Seed Yield per Plant (g)

The average weight of grains harvested from the selected plants and was recorded in grams.

3.4.2 Biological Yield (g)

The average weight of the selected dry plant with pods and was recorded in grams.

3.4.3 Harvest Index (%)

Harvest index is measured as proportion of economic yield to the biological yield expressed in percentage.

3.4.4 Root Length (cm)

Root length was measured in centimeters from ground level to the tip of the root.

3.4.5 Fresh Root Weight (g)

The average root weight of the selected plant recorded in grams.

3.4.6 Dry Root Weight (g)

The average weight of the roots after overnight drying in oven at 70^0 C and was recorded in grams.

3.4.7 Root Volume (ml)

Volume of root measured in milliliter after immersing the root in measuring cylinder filled with water.

3.4.8 Root Density (g/ml)

Root density was measured as proportion of dry root weight to the root volume.

3.4.9 Root: Shoot Ratio

The proportion of dry root weight to shoot biomass weight was recorded as root: shoot ratio.

3.4.10 Percent Injury Due to Post Flowering Water Stress (%)

3.4.10.1 Percent Injury in Yield

The seed yield per plant was recorded in both normal and post flowering water stress conditions. Percent injury in yield was recorded as proportion of difference between seed yield per plant under normal and post flowering water stress condition expressed as percentage to normal.

3.4.10.2 Percent Injury in Biological Yield (%)

The seed biological yield was recorded in both normal and post flowering water stress conditions. Percent injury in biological yield was recorded as proportion of difference between biological yield under normal and post flowering water stress condition expressed as percentage to normal.

3.4.10.3 Percent Injury in Harvest Index (%)

The harvest index was calculated in both normal and post flowering water stress conditions. Percent injury in harvest index was recorded as proportion of difference between harvest index under normal and post flowering water stress condition expressed as percentage to normal.

3.5 Statistical Analysis

3.5.1 Analysis of Variance

The mean data obtained for each character were analyzed by the usual standard statistical procedure as suggested by Panse and Sukhatme (1978). The statistical model and ANOVA (Table 3.2) for the same is presented here as under:

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

Where,

Y_{ij} = Mean performance of the i^{th} genotype in the j^{th} replication

$i = 1, 2, 3, \text{-----------}, g$

$j = 1, 2, 3, \text{-----------}, r$

μ = General mean,

g_i = Effect of i^{th} genotype,

r_j = Effect of j^{th} replication, and

e_{ij} =Uncontrolled error variation associated with i^{th} genotype in j^{th} replication.

3.2 Analysis of Variance

Source of variation	d.f.	Mean square	Expected mean square
Replications	(r-1)	M_1	$\sigma^2_e + g\,\sigma^2_r$
Genotypes	(g-1)	M_2	$\sigma^2_e + r\,\sigma^2_g$
Error	(r-1) (g-1)	M_3	σ^2_e
Total	(rg-1)	TSS	

Where,

r = Number of replication,

g = Number of genotypes,

σ^2_e = Variance due to error,

σ^2_r = Variance due to replication, and

σ^2_g = Variance due to genotype.

M_1, M_2, M_3 = Mean squares for replication, genotype and error, respectively.

The standard error of differences between treatment means was calculated by using the following formula:

$$S.Em. = \left(\frac{2M_3}{r} \right)^{0.5}$$

Where,

M_3 = Error mean square, and

r = Number of replications.

The critical differences to compare the means of various genotypes were calculated by using the following formula:

$$C.\ D. = S.Em. \times (2)^{0.5} \times t$$

Where,

S.Em. = Standard error of the difference of treatment means.

t = Table value of 't' at 1 percent or 5 percent levels of significance.

The coefficient of variation (C.V. %) was calculated by using following formula:

$$C.V.\,\% = \frac{(M_3)^{0.5}}{\overline{X}} \times 100$$

Where,

M_3 = Error mean square, and

$\overline{X}$ = Population mean.

3.5.2 Correlation Coefficient Analysis

The phenotypic and genotypic correlation coefficients for all the characters were worked out with yield. The data were subjected to covariance analysis from which different components of mean sum of products were estimated (Table 3.3).

Table 3.3: Analysis of Covariance

Source of variation	d.f.	M.S.P.	Expected M.S.P.
Replications	(r-1)	-	-
Genotypes	(g-1)	Mg	$Co\,\sigma^2_e + rCo\,^2_{g1.2}$
Error	(r-1) (g-1)	Me	$\sigma^2_{e1.2}$

Where,

M_g = Mean sum of products due to genotypes between character first and character second,

M_e = Mean sum of products due to error between character first and character second, and

r = Number of replications.

The genotypic, phenotypic and error variances and covariances were used for calculating the genotypic and phenotypic correlation coefficient.

(a) Genotypic correlation coefficient ($r_{g1.2}$) :

$$r_{g1.2} = \frac{Co\,\sigma^2_{g1.2}}{\sqrt{\sigma^2_{g1} \times \sigma^2_{g2}}}$$

(b) Phenotypic correlation coefficient ($r_{p1.2}$):

$$r_{p1.2} = \frac{Co\,\sigma^2_{p1.2}}{\sqrt{\sigma^2_{p1} \times \sigma^2_{p2}}}$$

Where,

$Co\,\sigma^2_{g1.2}$ = Genotypic covariance for a pair of trait first and second,

$Co\,\sigma^2_{p1.2}$ = Phenotypic covariance for the pair of trait first and second,

$\sigma^2_{g1}, \sigma^2_{p1}$ = Genotypic and phenotypic variance for trait first, respectively, and

$\sigma^2_{g2}, \sigma^2_{p2}$ = Genotypic and phenotypic variance for trait second, respectively.

The phenotypic correlation was tested by 't' for their significance which was suggested by Fisher and Yates (1963).

$$t = \frac{r}{\sqrt{1-r^2}} \times \sqrt{n-2}$$

Where,

t = Calculated value of 't'

r = Correlation coefficients, and

n = Total number of observations

The genotypic correlation was tested by transforming 'r' to a quantity 'z' according to the formula given below:

$$Z = 1/2 \log_e (1+r) - \log_e (1-r)$$

$$= 1/2 \log_e [(1+r) / (1-r)]$$

This sample value of z is distributed approximately normally with mean zero and variance (n – 3). It follows that z (n - 3) is a standard normal deviate corresponding to α degree of freedom. Therefore, if z (n – 3) exceeds 1.96 and 2.576, z is said to be significant at 5 and 1 per cent, respectively. In other words correlation coefficient (r) is significant if z is significant.

3.5.3 Path Coefficient Analysis:

The genotypic correlation coefficient data were subjected to path coefficient analysis. The path analysis was carried out by the method suggested by Wright (1921) and elaborated by Dewey and Lu (1959). The genotypic correlations among nine characters were partitioned into their direct and indirect effects on yield. Causal variable and their direct and indirect effects on yield were estimated as under:

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the present investigation conducted on "Character Association of Root Attributes with Yield under Different Growing Conditions in Cowpea (*Vigna unguiculata* [L.] Walp.)" are presented under the following heads:

4.1 Analysis of Variance

4.2 Correlation Coefficient

4.3 Path Coefficient

4.1 Analysis of Variance

Analysis of variance for different characters was done and is summarized in Table 4.1. It evinced significant differences among the genotypes for all the characters studied. This indicated sufficient phenotypic variability among the experimental material. The mean values of genotypes for different characters under study are presented in Appendix II.

4.2 Correlation Coefficient

The seed yield is a complex polygenic character that depends on number of component characters. The relationship between the yield and yield components like pods / plant, seeds / pod and seed weight has been extensively studied (Mittal *et al.*, 2005). The relationship among root attributes and their association with seed yield is of enormous significance for exercising selection pressure in relation to root attributes for genetic improvement of seed yield. The correlation coefficient between grain yield under different growing

Table 4.1: Analysis of variance for different characters in cowpea [*Vigna unguiculata* (L.) Walp]

		Flower initiation stage						Post flowering water stress condition			Normal growing condition			Percent injury due to post flowering water stress as expressed through		
Source of variation	d. f.	Root length (cm)	Fresh root weight (g)	Dry root weight (g)	Root volume (ml)	Root density (g/ml)	Root: Shoot ratio	Yield per plant (g)	Biological yield (g)	Harvest index (%)	Yield per plant (g)	Biological yield (g)	Harves t index (%)	Yield per plant (%)	Biological yield (%)	Harvest index (%)
Replication	2	22.411	0.886	0.801*	0.092	0.008*	0.001	2.169*	21.797	7.242	26.163**	90.827	6.627	26.292	3.713*	115.408
Treatment	29	75.846**	10.427**	5.256**	5.635**	0.034**	0.031**	5.295**	62.927**	18.812*	15.702*	193.538**	7.612*	105.886**	90.221*	294.358**
Error	58	21.334	0.502	0.378	0.228	0.003	0.003	0.817	22.284	3.676	9.037	57.896	3.676	22.459	37.525	119.939

*and **significant at 5 and 1 per cent level of significance, respectively.

conditions and root component characters were estimated at phenotypic and genotypic levels. The phenotypic (r_p) and genotypic (r_g) correlation coefficients between different characters are presented in Table 4.2. The correlation at genotypic and phenotypic levels exhibited the same trend. In majority of the cases, the value of genotypic correlation was greater than corresponding values of phenotypic correlation coefficient.

4.2.1 Relationship of Grain Yield with Root Attributes under Normal Condition. (Table 4.2)

Grain yield per plant under normal condition exhibited significantly high and positive correlation with biological yield at both genotypic and phenotypic levels (r_g = 0.748 and r_p = 0.751) and with harvest index at genotypic level (r_g = 0.619). It showed significant and negative correlations at genotypic level with root length (r_g = -0.378), fresh root weight (r_g = -0.496), dry root weight (r_g = -0.510), root volume (r_g = -0.522) and root density (r_g = -0.370).

Grain yield per plant under normal condition also manifested non-significant negative phenotypic correlation with root length (r_p = -0.137), fresh root weight (r_p = -0.265), dry root weight (r_p = -0.260), root volume (r_p = -0.270) and root density (r_p = -0.206). The correlations were non-significant positive with root: shoot ratio at both the levels (r_p = 0.047 and r_g = 0.321) and with harvest index at phenotypic level (r_p = 0.176).

The values of genotypic correlation were higher than the corresponding values of phenotypic correlation coefficient in all the cases, except for biological yield.

Table 4.2: Phenotypic and genotypic correlation coefficients among different characters in cowpea [*Vigna unguiculata* (L.) Walp.]

Stages	Characters	r	Flower initiation stage					Post flowering water stress condition			Normal growing condition			Percent injury due to post flowering water stress		
			Fresh root weight (g)	Dry root weight (g)	Root volume (ml)	Root density (g/ml)	Root: shoot ratio	Biological yield (g)	Harvest index (%)	Yield per plant (g)	Biological yield (g)	Harvest index (%)	Yield per plant (g)	Biological yield (%)	Harvest index (%)	Yield per plant (%)
FIS	Root length (cm)	rp	0.728**	0.697**	0.727**	0.598**	0.238	0.171	-0.143	-0.028	0.029	-0.240	-0.137	-0.108	0.029	-0.043
		rg	0.975**	0.950**	0.945**	0.884**	0.282	0.401*	-0.375*	-0.050	0.043	-0.596**	-0.378*	-0.305	0.111	-0.095
	Fresh root Weight (g)	rp		0.925**	0.911**	0.902**	0.353	0.266	-0.135	0.045	-0.075	-0.306	-0.265	-0.247	-0.004	-0.178
		rg		0.988**	0.944**	0.922**	0.371*	0.376*	-0.236	0.038	-0.073	-0.545**	-0.496**	-0.367*	0.005	-0.214
	Dry root Weight (g)	rp			0.883**	0.799**	0.427*	0.196	-0.106	0.027	-0.059	-0.318	-0.260	-0.184	-0.033	-0.159
		rg			0.917**	0.926**	0.395*	0.390*	-0.278	0.019	-0.044	-0.604**	-0.510**	-0.365*	-0.025	-0.198
	Root volume (ml)	rp				0.650**	0.392*	0.293	-0.105	0.089	-0.003	-0.401*	-0.270	-0.238	-0.068	-0.216
		rg				0.746**	0.402*	0.467**	-0.187	0.106	0.025	-0.728**	-0.522**	-0.397*	-0.104	-0.279
	Root density (g/ml)	rp					0.242	0.167	-0.173	-0.050	-0.118	-0.166	-0.206	-0.184	0.090	-0.064
		rg					0.266	0.185	-0.329	-0.107	-0.136	-0.284	-0.370*	-0.228	0.193	-0.039
	Root : shoot ratio	rp						0.100	-0.084	-0.004	0.305	-0.262	0.047	0.107	-0.022	0.003
		rg						0.197	-0.133	0.038	0.557**	-0.377*	0.321	0.210	-0.046	0.011
PFWSC	Biological yield (g)	rp							-0.158	0.477**	-	-	-	-	-	-
		rg							0.547**	0.863**	-	-	-	-	-	-
	Harvest index (%)	rp								0.783**	-	-	-	-	-	-
		rg								0.897**	-	-	-	-	-	-
	Yield per plant (g)	rp									-	-	-	-	-	
		rg									-	-	-	-	-	-
NC	Biological yield (g)	rp										-0.047	0.751**	-		-
		rg										-0.520**	0.748**	-		-
	Harvest index (%)	rp											0.176	-	-	-
		rg											0.619**	-	-	-
	Yield per plant (g)	rp												-	-	-
		rg												-	-	-
PIPFWS	Biological yield (%)	rp													0.628**	0.579**
		rg													-0.061	0.892**
	Harvest index (%)	rp														0.762**
		rg														0.903**

*and **significant at 5 and 1 per cent level of significance, respectively.

FIS Flower initiation stage
PFWSC Post flower water stress condition
NC Normal Growing Condition
PIPFWS Percent injury due to post flowering water stress

4.2.2 Relationship of Grain Yield under Post Flowering Water Stress Condition with Root Attributes (Table 4.2)

Grain yield per plant under post flowering water stress condition exhibited significantly high and positive correlation with biological yield (r_p = 0.477 and r_g = 0.863) and harvest index (r_p = 0.783 and r_g = 0.897) at both genotypic and phenotypic levels.

Grain yield per plant under post flowering water stress condition also showed non-significant negative correlation with root length (r_p = -0.028 and r_g = -0.050) and root density (r_p = -0.050 and r_g = -0.107) at both the levels. It also exhibited negative and non-significant correlation at phenotypic level with root: shoot ratio (r_p = -0.004). The correlation were non-significantly positive with fresh root weight (r_p = 0.045 and r_g = 0.038), dry root weight (r_p = 0.027 and r_g = 0.019) and root volume (r_p = 0.089 and r_g = 0.106) at both the levels, and with root: shoot ratio (r_g = 0.038) at genotypic level.

The value of genotypic correlation was higher than the corresponding phenotypic correlation coefficient in all the cases, except fresh root weight and dry root weight.

4.2.3 Relationship of Percent Injury in Yield Due to Post Flowering Water Stress with Different Characters. (Table 4.2)

It was observed that percent injury in yield per plant due to post flowering water stress exhibited non-significant and negative correlation with root length (r_p = -0.043 and r_g = -0.095), fresh root weight (r_p = -0.178 and r_g = -0.214), dry root weight (r_p = -0.159 and r_g = -0.198), root volume (r_p = -0.216

and r_g = -0.279) and root density (r_p = -0.064 and r_g = -0.039) and non-significant positive correlation with root: shoot ratio (r_p = 0.003 and r_g = 0.011) at both the levels. Similarly the correlations of percent injury due to post flowering water stress in yield per plant were significantly high and positive with percent injury due to post flowering water stress as measured through biological yield (r_p = 0.579 and r_g = 0.892) and harvest index (r_p = 0.762 and r_g = 0.903) at both phenotypic and genotypic levels.

The value of genotypic correlation was higher than the corresponding phenotypic correlation coefficient in all the cases except root density.

4.2.4 Root Length (cm) (Table 4.2)

This root length exhibited positive and highly significant correlation with fresh root weight (r_p = 0.728 and r_g = 0.975), dry root weight (r_p = 0.697 and r_g = 0.950), root volume (r_p = 0.727 and r_g = 0.945) and root density (r_p = 0.598 and r_g = 0.884) at both phenotypic and genotypic levels. It evinced significant and positive genotypic correlation with biological yield under post flowering water stress condition (r_g = 0.401). It also showed negative and highly significant correlation with harvest index under normal condition (r_g = -0.596) and negative significantly correlation with harvest index under post flowering water stress condition (r_g = -0.375) at genotypic level.

Root length exhibited positive and non-significant correlation with root: shoot ratio (r_p = 0.238 and r_g = 0.282), biological yield (r_p = 0.029 and r_g = 0.043) under normal condition and percent injury due to post flowering water stress as measured through harvest index (r_p = 0.029 and r_g = 0.111) at both the levels and with biological yield under post flowering water stress condition (r_p

Variability for Root Attributes in Cowpea

[*Vigna unguiculata* (L.) Walp.]

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= 0.171) at phenotypic level. It had negative and non-significant correlation with percent injury due to post flowering water stress as measured through biological yield (r_p = -0.108 and r_g = -0.305) at both the levels and with harvest index at post flowering water stress condition (r_p = -0.143) and harvest index under normal condition (r_p = -0.240) at phenotypic level.

4.2.5 Fresh Root Weight (g) (Table 4.2)

Positive and highly significant association was exhibited by fresh root weight with dry root weight (r_p = 0.925 and r_g = 0.988), root volume (r_p = 0.911 and r_g = 0.944) and root density (r_p = 0.902 and r_g = 0.922) at both phenotypic and genotypic levels and at genotypic level with root: shoot ratio (r_g = 0.371) and biological yield under post flowering water stress condition (r_g = 0.376). It showed negative and highly significant correlation with harvest index under normal condition (r_g = -0.545) and negative and significant association with percent injury in biological yield due to post flowering water stress (r_g = -0.367) at genotypic level.

The biological yield under normal condition (r_p = -0.075 and r_g = -0.073) and harvest index under post flowering water stress condition (r_p = -0.135 and r_g = -0.236) had negative and non-significant association with fresh root weight at both the levels, while at phenotypic level with harvest index under normal condition (r_p = -0.306), percent injury due to post flowering water stress in biological yield (r_p = -0.247) and harvest index (r_p = -0.004). It had positive and non-significant association with root: shoot ratio (r_p = 0.353) and biological yield under post flowering water stress condition (r_p = 0.266) at phenotypic level and percent injury due to post flowering water stress as measured through harvest index at genotypic level (r_g = 0.005).

4.2.6 Dry Root Weight (g) (Table 4.2)

Dry root weight exhibited positive and significant association with root volume (r_p = 0.883 and r_g = 0.917), root density (r_p = 0.799 and r_g = 0.926) and root: shoot ratio (r_p = 0.427 and r_g = 0.395) at both phenotypic and genotypic levels, while at genotypic level with biological yield under post flowering water stress condition (r_g = 0.390). It showed negative and highly significant association with harvest index under normal condition (r_g = -0.604) and significant with percent injury due to post flowering water stress as measured through biological yield (r_g = -0.365) at genotypic level.

Biological yield under normal condition (r_p = -0.059 and r_g = -0.044), harvest index at post flowering water stress condition (r_p = -0.106 and r_g = -0.278) and percent injury due to post flowering water stress as measured through harvest index (r_p = -0.033 and r_g = -0.025) exhibited negative and non-significant association with dry root weight at both the levels. At phenotypic level, biological yield under post flowering water stress condition (r_p = 0.196), harvest index under normal condition (r_p = -0.318) and percent injury due to post flowering water stress as measured through biological yield (r_p = -0.184) had non-significant association with dry root weight.

4.2.7 Root Volume (ml) (Table 4.2)

Root volume evinced positive and significant correlation with both root density (r_p = 0.650 and r_g = 0.746) and root: shoot ratio (r_p = 0.392 and r_g = 0.402) at both phenotypic and genotypic levels. It also showed positive and highly significant correlation with biological yield under post flowering water stress condition (r_g = 0.467) at genotypic level. It showed highly significant negative association with harvest index under normal condition (r_g = -0.728) at genotypic level and negatively significant correlation at phenotypic level (r_p = -0.401). It also showed negatively significant association with percent injury due to post flowering water stress as measured through biological yield (r_g = -0.397) at genotypic level.

Biological yield under normal condition (r_p = -0.003 and r_g = 0.025), harvest index under post flowering water stress condition (r_p = -0.105 and r_g = -0.187) and percent injury in harvest index due to post flowering water stress (r_p = -0.068 and r_g = -0.104) showed non significant association at both the levels, while biological yield under post flowering water stress condition (r_p = 0.293) and percent injury in biological yield due to post flowering water stress (r_p = -0.238) exhibited non-significant phenotypic association with root volume.

4.2.8 Root Density (g/ml) (Table 4.2)

Root density exhibited positive and non-significant association with root: shoot ratio (r_p = 0.242 and r_g = 0.266), biological yield under post flowering water stress condition (r_p = 0.167 and r_g = 0.185) and percent injury due to post flowering water stress as measured through harvest index (r_p = 0.090 and r_g = 0.193). It exhibited negative and non-significant association with harvest index (r_p = -0.173 and r_g = -0.329) under post flowering water stress condition; biological yield (r_p = -0.118 and r_g = -0.136] and harvest index (r_p = -0.166 and r_g = -0.284) under normal condition and percent injury due to post flowering water stress as measured through biological yield (r_p = -0.184 and r_g = -0.228) at both phenotypic and genotypic levels.

4.2.9 Root: Shoot Ratio (Table 4.2)

Root: shoot ratio had highly significant and positive association at genotypic level with biological yield (r_g = 0.557) and significant negative association with harvest index under normal condition (r_g = -0.377).

The biological yield (r_p = 0.100 and r_g = 0.197) and harvest index (r_p = -0.084 and r_g = -0.133) under post flowering water stress condition; percent injury due to post flowering water stress as measured through biological yield (r_p = 0.107 and r_g = 0.210) and harvest index (r_p = -0.022 and r_g = -0.046) evinced non-significant association with root: shoot ratio at both the levels. At phenotypic level it did so with biological yield (r_p = 0.305) and harvest index (r_p = -0.262) under normal condition.

4.2.10 Biological Yield under Normal Condition (g) (Table 4.2)

Biological yield under normal condition exhibited highly significant negative association (r_g = -0.520) with harvest index under normal condition at genotypic level. It showed non-significant negative correlation with harvest index (r_p = -0.047) at phenotypic level under normal condition.

4.2.11 Biological Yield under Post Flowering Water Stress Condition (g) (Table 4.2)

Biological yield under post flowering water stress condition revealed highly significant positive genotypic correlation with harvest index under post flowering water stress condition (r_g = 0.547), while the association was negative and non-significant (r_p = -0.158) at phenotypic level.

4.2.12 Percent Injury Due to Post Flowering Water Stress in Biological Yield (%) (Table 4.2)

Percent injury due to post flowering water stress as measured through biological yield had positive and highly significant association with percent injury due to post flowering water stress as measured through harvest index (r_p = 0.628) at phenotypic level and negative non-significant association (r_g = - 0.061) at genotypic level.

4.3 Path Coefficient

Grain yield is a complex character that is dependent upon many component characters. The above ground yield components have been extensively studied. However, the underground parts like roots that play an important role in ascertaining yield limit under different growing conditions have not been studied in consonance to their importance. The cumbersome exhuming process of roots deters the breeders to undertake the root studies. However, roots are very important particularly under water stress condition and can not be ignored in any crop improvement programme for long. Therefore, association of root attributes as also their direct and indirect effect on yield under different growing conditions *viz*., normal and post flowering water stress, was studied. The estimates of direct and indirect effects of different independent traits on grain yield under normal and post flowering water stress condition is presented as under:

4.3.1 Grain Yield under Normal Condition as Dependent Trait (Table 4.3.1)

4.3.1.1 Root Length (cm)

Negative and significant association (-0.378) was depicted by this trait on grain yield per plant under normal condition. Its direct effect on grain yield was negative (-0.638). It exhibited negative association due to its negative indirect effect via root volume (-1.614) followed by root density (-1.219), dry root weight (-0.740), harvest index (-0.447) and root: shoot ratio (-0.092) and positive indirect effect via fresh root weight (4.308) and biological yield (0.064).

4.3.1.2 Fresh Root Weight (g)

Fresh root weight exhibited negative and highly significant correlation with grain yield (-0.496). It manifested the highest positive direct effect (4.417) among all the traits on grain yield under normal condition. It showed high negative indirect effect via root volume (-1.612), root density (-1.271), dry root weight (-0.770), root length (-0.622) and harvest index (-0.408) and low negative indirect effect via root: shoot ratio (-0.121) and biological yield (-0.109).

4.3.1.3 Dry Root Weight (g)

A highly significant negative correlation was observed for this trait with grain yield (-0.510). It showed high negative direct effect (-0.779) with grain yield under normal condition. Only fresh root weight (4.364) showed positive indirect effect via this trait. Dry root weight evinced negative indirect effect via

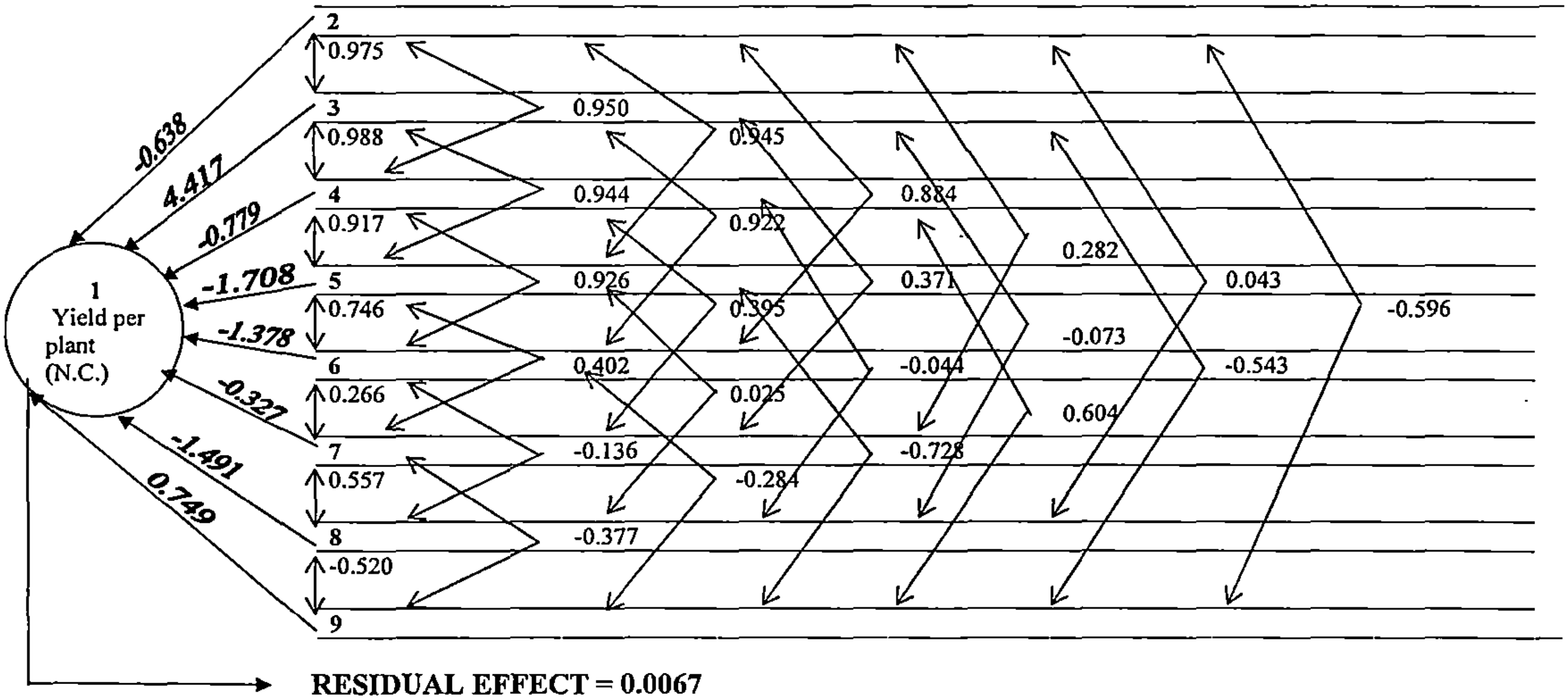
Table 4.3.1: Path coefficient analysis showing direct and indirect effect of different root attributes on yield under normal condition in cowpea [*Vigna unguiculata* (L.) Walp.]

Characters	Flower initiation stage						Normal growing condition		
	Root length (cm)	Fresh root weight (g)	Dry root weight (g)	Root volume (ml)	Root density (g/ml)	Root: shoot ratio	Biological yield (g)	Harvest index (%)	Genotypic correlation with grain yield
Root length (cm)	**-0.638**	4.308	-0.740	-1.614	-1.219	-0.092	0.064	-0.447	-0.378*
Fresh root weight (g)	-0.622	**4.417**	-0.770	-1.612	-1.271	-0.121	-0.109	-0.408	-0.496**
Dry root weight (g)	-0.606	4.364	**-0.779**	-1.566	-1.276	-0.129	-0.065	-0.453	-0.510**
Root volume (ml)	0.603	4.170	-0.714	**-1.708**	-1.028	-0.131	0.038	-0.545	-0.522**
Root density (g/ml)	-0.564	4.072	-0.722	-1.274	**-1.378**	-0.087	-0.203	-0.213	-0.370*
Root : shoot ratio	-0.180	1.640	0.308	-0.686	-0.367	**-0.327**	0.831	-0.282	0.321
Biological yield (g)	-0.027	-0.323	0.304	-0.043	0.188	-0.182	**-1.491**	-0.390	0.748**
Harvest index (%)	0.380	-2.407	0.471	1.243	0.392	0.123	-0.776	**0.749**	0.619**

Residual effect = 0.0067

*and **significant at 5 and 1 per cent level of significance, respectively.

Fig. 1: Genotypic path diagram for association study of cowpea under normal condition



RESIDUAL EFFECT = 0.0067

2-Root length, **3**-Fresh root weight, **4**-Dry root weight, **5**- Root volum,e, **6**- Root density, **7**-Root: shoot ratio, **8**-Biological yield, **9**-Harvest index.

↔ Correlation coefficient, ⟶ Direct effect root volume (-1.566), root density (-1.276), root length (-0.606), harvest index (-0.453), root: shoot ratio (-0.129) and biological yield (-0.065).

4.3.1.4 Root Volume (ml)

Root volume exhibited highly significant negative correlation with grain yield under normal condition (-0.522). The direct effect on grain yield was negative and highest (-1.708). Indirect effect via root density (-1.028), dry root weight (-0.714), harvest index (-0.545) and root: shoot ratio (-0.131) was negative. The positive indirect effects were recorded via fresh root weight (4.170), root length (0.603) and biological yield (0.038).

4.3.1.5 Root Density (g/ml)

Root density exhibited the high negative direct effect (-1.378) on grain yield under normal condition. Its negative significant association with grain yield (-0.370) was attributable to the negative indirect effect via root volume (-1.274), dry root weight (-0.722), root length (-0.564), harvest index (-0.213), biological yield (-0.203) and root: shoot ratio (-0.087). It evinced positive indirect effect via fresh root weight (4.072).

4.3.1.6 Root: Shoot Ratio

Root: shoot ratio showed negative direct effect on grain yield under normal condition (-0.327). It revealed positive association with grain yield (0.321) that was attributed to its positive indirect effect via fresh root weight (1.640), biological yield (0.831) and dry root weight (0.308). However, it showed negative indirect effect via root volume (-0.686), root density (-0.367), harvest index (-0.282) and root length (-0.180).

4.3.1.7 Biological Yield (g)

Biological yield exhibited highly significant positive correlation with grain yield under normal condition (0.748), though its direct effect on grain yield was high and negative (-1.491). It exerted negative indirect effect on grain yield via harvest index (-0.390), fresh root weight (-0.323), root: shoot ratio (-0.182), root volume (-0.043) and root length (-0.027), while indirect effect were positive via dry root weight (0.304) and root density (0.188).

4.3.1.8 Harvest Index (%)

This trait exhibited positive and highly significant association with grain yield under normal condition (0.619). It evinced a positive direct effect (0.749) on grain yield. Similarly, the indirect effects were also positive via root volume (1.243), dry root weight (0.471), root density (0.392), root length (0.380) and root: shoot ratio (0.123). However, it exhibited negative indirect effect on grain yield via fresh root weight (-2.407) and biological yield (-0.776).

4.3.2 Grain Yield under Post Flowering Water Stress Condition as Dependent Trait (Table 4.3.2)

4.3.2.1 Root Length (cm)

Negative and non-significant association (-0.050) was depicted by root length on grain yield under post flowering water stress condition. Its direct effect on grain yield was low and positive (0.093). However, its association with grain yield under post flowering water stress condition was negative due to its negative indirect effect via fresh root weight (-1.900) followed by harvest index (-0.277). It revealed positive indirect effect via root volume (0.804), root

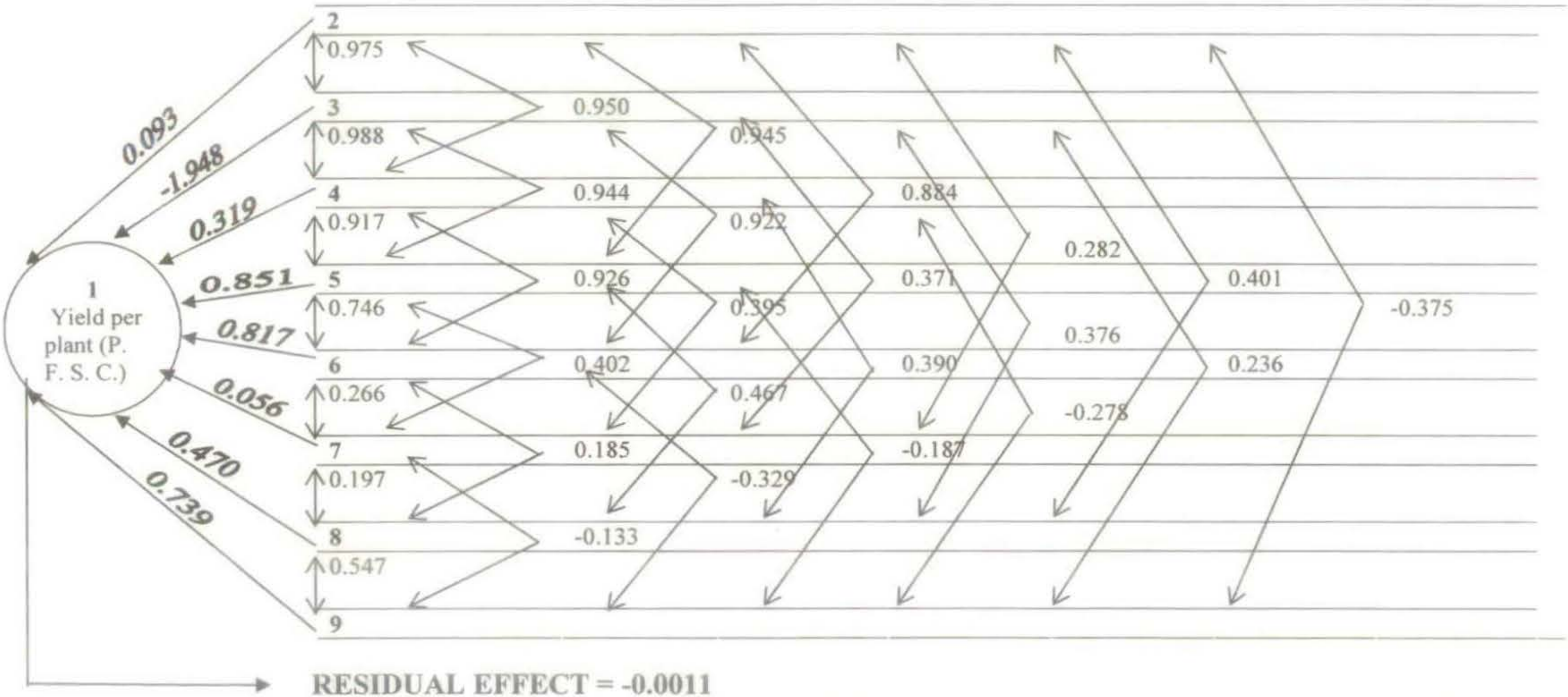
Table 4.3.2: Path coefficient analysis showing direct and indirect effect of different root attributes on yield under post flowering water stress condition in cowpea [*Vigna unguiculata* (L.) Walp.]

Characters	Flower initiation stage						Post flowering water stress condition		
	Root length (cm)	Fresh root weight (g)	Dry root weight (g)	Root volume (ml)	Root density (g/ml)	Root: shoot ratio	Biological yield (g)	Harvest index (%)	Genotypic correlation with grain yield
Root length (cm)	**0.093**	-1.900	0.303	0.804	0.723	0.016	0.188	-0.277	-0.050
Fresh root weight (g)	0.091	**-1.948**	0.315	0.803	0.753	0.021	0.177	-0.174	0.038
Dry root weight (g)	0.089	-1.924	**0.319**	0.780	0.757	0.022	0.183	-0.206	0.019
Root volume (ml)	0.088	-1.839	0.292	**0.851**	0.610	0.022	0.220	-0.138	0.106
Root density (g/ml)	0.083	-1.796	0.295	0.635	**0.817**	0.015	0.087	-0.243	-0.107
Root : shoot ratio	0.026	-0.723	0.126	0.342	0.217	**0.056**	0.093	-0.098	0.038
Biological yield (g)	0.037	-0.733	0.124	0.398	0.151	0.011	**0.470**	0.404	0.863**
Harvest index (%)	-0.035	0.459	-0.089	-0.159	-0.268	-0.007	0.257	**0.739**	0.897**

Residual effect = -0.0011

*and **significant at 5 and 1 per cent level of significance, respectively.

Fig. 2: Genotypic path diagram for association study of cowpea under post flowering water stress condition



RESIDUAL EFFECT = -0.0011

2-Root length, 3-Fresh root weight, 4-Dry root weight, 5- Root volum,e, 6- Root density, 7-Root: shoot ratio, 8-Biological yield, 9-Harvest index.

↔ Correlation coefficient, ⟶ Direct effects density (0.723), dry root weight (0.303), biological yield (0.188) and root: shoot ratio (0.016).

4.3.2.2 Fresh Root Weight (g)

Fresh root weight exhibited the highest negative direct effect (-1.948) amongst all traits on grain yield under post flowering water stress condition. Its positive non-significant association with grain yield (0.038) may be attributed to the positive indirect effect via root volume (0.803), root density (0.753), dry root weight (0.315), biological yield (0.177), root length (0.091) and root: shoot ratio (0.021). It showed negative indirect effect only via harvest index (-0.174).

4.3.2.3 Dry Root Weight (g)

Dry root weight exhibited very low positive and non-significant correlation with grain yield under post flowering water stress condition (0.019). Its direct effect was positive (0.319) and so were the indirect effect on grain yield via root volume (0.780), root density (0.757), biological yield (0.183), root length (0.089) and root: shoot ratio (0.022). It exhibited negative indirect effect via fresh root weight (-1.924) followed by harvest index (-0.206).

4.2.3.4 Root Volume (ml)

Root volume exhibited positive and non-significant association with grain yield under post flowering water stress condition (0.106). It depicted positive direct effect (0.851) on grain yield and positive indirect effect via root density (0.610), dry root weight (0.292), biological yield (0.220), root length (0.088) and root: shoot ratio (0.022). It showed negative indirect effect via fresh root weight (-1.839) and harvest index (-0.138).

4.3.2.5 Root Density (g/ml)

A negative and non-significant correlation was revealed for root density with grain yield under post flowering water stress condition (-0.107), though its direct effect on grain yield was high and positive (0.817). It exhibited negative indirect effects on grain yield via fresh root weight (-1.796) and harvest index (-0.243). It evinced positive indirect effect on grain yield via root volume (0.635), dry root weight (0.295), biological yield (0.087), root length (0.083) and root: shoot ratio (0.015).

4.3.2.6 Root: Shoot Ratio

Root: shoot ratio had non-significant and very low positive correlation with grain yield under post flowering water stress condition (0.038). Its direct effect on grain yield was also positive (0.056) and so were the indirect effect via root volume (0.342), root density (0.217), dry root weight (0.126), biological yield (0.093) and root length (0.026). It showed negative indirect effect via fresh root weight (-0.723) and harvest index (-0.098).

4.3.2.7 Biological Yield (g)

A highly significant positive correlation was observed for biological yield with grain yield under post flowering water stress condition (0.863). It also showed positive direct effect on grain yield (0.470). It also revealed positive indirect effect on grain yield via harvest index (0.404), root volume (0.398), root density (0.151), dry root weight (0.124), root length (0.037) and root: shoot ratio (0.011). The indirect effect on grain yield was negative only via fresh root weight (-0.733).

4.3.2.8 Harvest Index (%)

Harvest index exhibited the highest and highly significant positive correlation with grain yield under post flowering water stress condition (0.897). The direct effect of this trait on grain yield was positive (0.739). Indirect effects of this trait on grain yield were also positive via fresh root weight (0.459) and biological yield (0.257). However, it revealed negative indirect effect via root density (-0.268), root volume (-0.159), dry root weight (-0.089), root length (-0.035) and root: shoot ratio (-0.007).

4.3.3 Percent Injury Due to Post Flowering Water Stress in Yield as Dependent Trait (Table 4.3.3)

4.3.3.1 Root Length (cm)

The root length exhibited the highest positive and direct effect (1.148) on percent injury due to post flowering water stress in yield. Its negative and non-significant association with percent injury to yield (-0.095) may be attributed to the negative indirect effect via fresh root weight (-3.000), root: shoot ratio (-0.002) and percent injury to biological yield due to post flowering water stress (-0.178). The indirect effects on percent injury due to post flowering water stress in yield were positive via dry root weight (0.867), root density (0.563), root volume (0.470) and percent injury to harvest index due to post flowering water stress (0.037).

4.3.3.2 Fresh Root Weight (g)

Fresh root weight had negative and non-significant correlation on percent injury due to post flowering water stress in yield (-0.214). It exhibited

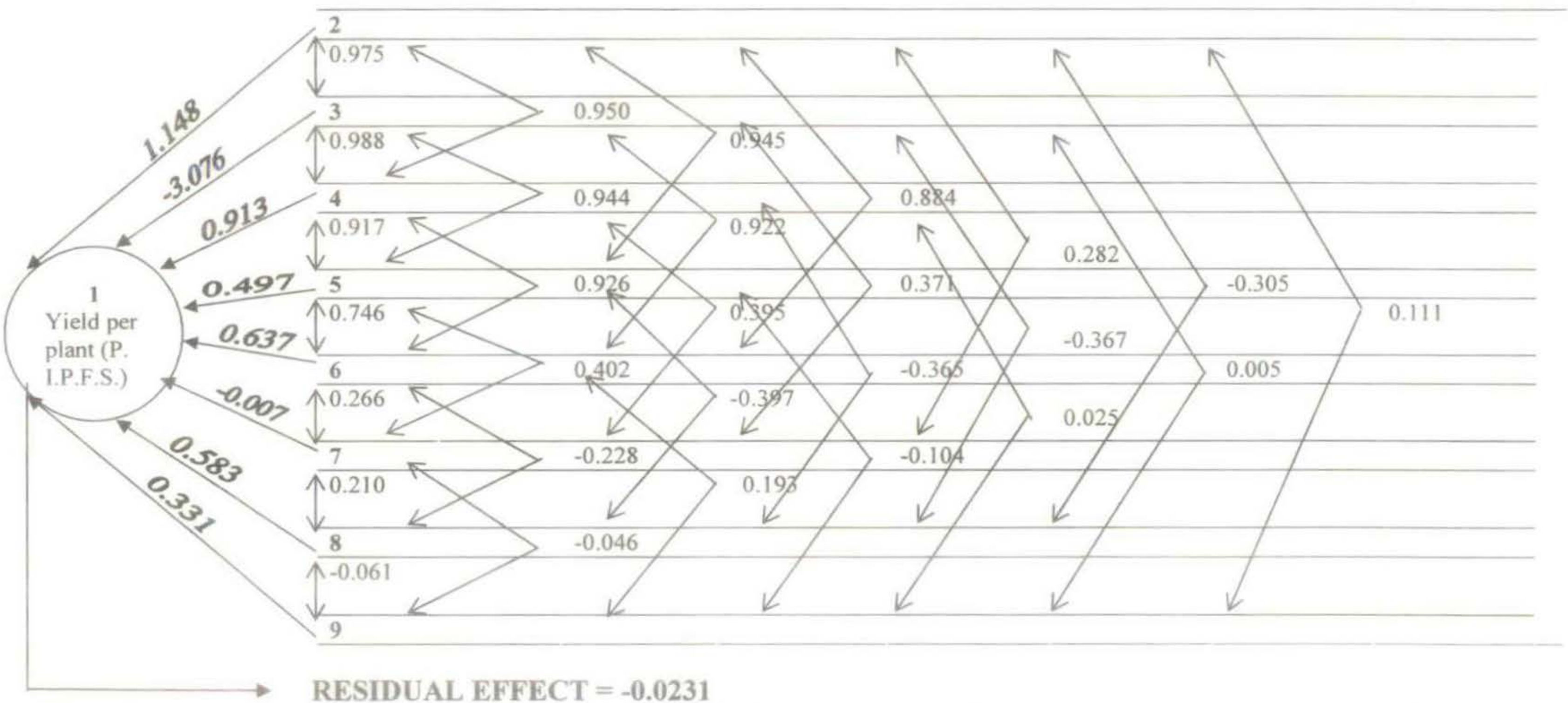
Table 4.3.3: Path coefficient analysis showing direct and indirect effect of different root attributes on percent injury in yield due to post flowering water stress in cowpea [*Vigna unguiculata* (L.) Walp.]

Characters	Initiation of flowering						Percent injury due to post flowering water stress as expressed through		
	Root length (cm)	Fresh root weight (g)	Dry root weight (g)	Root volume (ml)	Root density (g/ml)	Root: shoot ratio	Biological yield (%)	Harvest index (%)	Genotypic correlation with grain yield
Root length (cm)	**1.148**	-3.000	0.867	0.470	0.563	-0.002	-0.178	0.037	-0.095
Fresh root weight (g)	1.120	**-3.076**	0.902	0.469	0.587	-0.002	-0.214	0.002	-0.214
Dry root weight (g)	1.090	-3.039	**0.913**	0.456	0.590	-0.003	-0.213	0.008	-0.198
Root volume (ml)	1.085	-2.904	0.837	**0.497**	0.475	-0.003	-0.232	-0.034	-0.279
Root density (g/ml)	1.015	-2.836	0.845	0.371	**0.637**	-0.002	-0.133	0.064	-0.039
Root : shoot ratio	0.323	-1.142	0.360	0.200	0.169	**-0.007**	0.122	-0.015	0.011
Biological yield	-0.351	1.129	-0.333	-0.198	-0.145	-0.001	**0.583**	0.208	0.892**
Harvest index	0.128	-0.016	0.023	-0.052	0.123	0.000	0.366	**0.331**	0.903**

Residual effect = -0.0231

*and **significant at 5 and 1 per cent level of significance, respectively.

Fig. 3: Genotypic path diagram for association of yield per plant of cowpea with percent injury due to post flowering water stress condition



2-Root length, 3-Fresh root weight, 4-Dry root weight, 5- Root volum,e, 6- Root density, 7-Root: shoot ratio, 8-Biological yield, 9-Harvest index.

↔ Correlation coefficient, → Direct effects the highest negative direct effect (-3.076) amongst all the traits on percent injury to yield due to post flowering water stress. Percent injury to biological yield due to post flowering water stress (-0.214) and root: shoot ratio (-0.002) showed negative indirect effect with it. A positive indirect effect was manifested on percent injury due to post flowering water stress in yield via root length (1.120), dry root weight (0.902), root density (0.587), root volume (0.469) and percent injury due to post flowering water stress in harvest index (0.002).

4.3.3.3 Dry Root Weight (g)

Dry root weight had negative and non-significant correlation with percent injury due to post flowering water stress in yield (-0.198). Its direct effect on percent injury to yield was positive (0.913). it showed positive indirect effect via root length (1.090), root density (0.590), root volume (0.456) and percent injury due to post flowering water stress in harvest index (0.008) and negative indirect effects via fresh root weight (-3.039), root: shoot ratio (-0.003) and percent injury due to post flowering water stress in biological yield (-0.213).

4.3.3.4 Root Volume (ml)

A negative and non-significant correlation was observed for this trait with percent injury due to post flowering water stress in yield (-0.279). It showed positive direct effect (0.497) on percent injury to yield. A positive indirect effect was observed by this trait on percent injury to yield via root length (1.085), dry root weight (0.837) and root density (0.475). It had negative indirect effect on percent injury to yield via fresh root weight (-2.904), and root: shoot ratio (-0.003), percent injury due to post flowering water stress in biological yield (-0.232) and harvest index (-0.034).

4.3.3.5 Root Density (g/ml)

Root density showed positive direct effect (0.637) and very weak negative and non-significant correlation (-0.039) with percent injury due to post flowering water stress in yield. It had negative indirect effect on percent injury to yield via fresh root weight (-2.836), root: shoot ratio (-0.002) and percent injury due to post flowering water stress in biological yield (-0.133). Positive indirect effects were observed via root length (1.015), dry root weight (0.845), root volume (0.371) and percent injury to harvest index due to post flowering water stress (0.064).

4.3.3.6 Root: Shoot Ratio

Root: shoot ratio exhibited the lowest positive and non-significant correlation with percent injury due to post flowering water stress in yield (0.011). Its direct effect was low and negative (-0.007). It showed negative indirect effect on percent injury to yield via fresh root weight (-1.142) and percent injury due to post flowering water stress in harvest index (-0.015). Positive indirect effect on percent injury to yield were observed via dry root weight (0.360), root length (0.323), root volume (0.200), root density (0.169) and percent injury due to post flowering water stress in biological yield (0.122).

4.3.3.7 Biological Yield (%)

This trait exhibited positive and highly significant correlation with percent injury due to post flowering water stress in yield (0.892) and its direct effect was also positive (0.583). It exhibited positive indirect effect via fresh root weight (1.129) and harvest index (0.208) and negative indirect effect via root length (-0.351), dry root weight (-0.333), root volume (-0.198), root density (-0.145) and root: shoot ratio (-0.001).

4.3.3.8 Harvest Index (%)

Percent injury due to post flowering water stress in harvest index exhibited the highest positive and highly significant correlation with percent injury to yield due to post flowering water stress (0.903). It depicted positive direct effect (0.331) on percent injury to yield. It did not show any (0.000) indirect effect via Root: shoot ratio. It had negative indirect effect via root volume (-0.052) and fresh root weight (-0.016) and positive indirect effect via root length (0.128), root density (0.123) and dry root weight (0.023) and percent injury due to post flowering water stress in biological yield (0.366).

DISCUSSION

V. DISCUSSION

The present investigation was aimed to evaluate a set of thirty genotypes of cowpea for character association of root attributes with yield under normal growing condition as well as post flowering water stress condition. Success of any crop improvement programme is largely dependent on the extent of genetic variability present in the population and effectively the superior types are selected among them.

Global warming has led to many transitional changes in environment that harbinger changes in growing condition in the years to come. Rise in temperature, low difference between diurnal and nocturnal temperatures, high intensity rains with lesser number of rainy days followed by long dry spells are some of the salient features of change in environment during the last few years (Keeling *et al*., 1996 and Karl, 1997).

Evolution is a continuous but slow process in which the crops and individual genotypes adapt to the changed environmental conditions by producing narrow and diverse new gene constellations (Allard, 1960). It is therefore, expected that with global warming the crops too are adapting themselves to changes in environmental conditions. Cowpea is known for its versatility and adaptability to warm and dry conditions. The traditional populations of cowpea got adapted as long duration genotypes with profuse vegetative growth but poor productivity. The natural selection was consummately assisted by the breeders' interventions that catapulted the cowpea to a compact, short duration having lesser vegetative growth but more productivity. The latest endeavors to develop 60-days cowpea could make it possible to grow 4 to 5 crops in a year during different seasons pending negotiating changes in environmental conditions. Cowpea is the best candidate to adapt to warm and dry conditions though some genotypes are required for intensive farming too. However, as in other pulses cowpea is not responsive to irrigation and fertilizers and often lead to uncontrolled excessive vegetative growth with least conversion of dry matter produced in to economic production i.e. grains. Contrarily, the vegetative growth restricted under constrained moisture condition. Therefore, biological yield and harvest index are the two most important components for realizing high yield in cowpea under different growing conditions.

The nature has selected the subjective and fittest combination of under ground and above ground parts under a given growing situation. However, all crop improvement work inclusive selection and hybridization has mainly been dependent upon only upper visible parts. The yield components have been extensively tailored to aim yield enhancement. Various crop improvement technologies inclusive modern technologies like; biotechnology, marker assisted selection have been employed to increase absolute yield. These component characters have negative association (Hall, 2003; Iqbal *et al.*, 2003; Kelly *et al.*, 2003; Rubiales *et al.*, 2006 and Samizadeh *et al.*, 2007). Increase in the number of grains per pod usually associate with reduced grain weight and vice versa. Similarly, other characters also have negative associations.

The appropriate constitution as per growing conditions as also breaking the undesirable linkages have been targeted through specialized programme of crop improvement like bi-parental mating, diallel selective mating designs and such other designs involving high volume crossing. These all indicates that while aiming yield enhancements only upper parts have been considered and tailored to breed plants of appropriate height, duration, growth and spread. The underground parts have all together been neglected while targeting yield enhancement. In fact it is the underground part (root) that supports, nourishes and even contributes its accumulated dry matter magnanimously to the sink under trying conditions.

Cowpea is known to have special adaptation for stress conditions, which is predominantly attributed to versatile root system and their ability to absorb water and nutrients where other crops failed even to establish. Secondly, cowpea has immense plasticity to growing conditions. Thus, part of the versatility of the plants resides in versatility and efficiency of its root system (Nobrega *et al.*, 2005). Roots provide anchorage to plant and helps in absorbing nutrients and water from the soil. Roots are important from qualitative production point of view. Shallow and loosely anchored plants get uprooted during harvesting and there by add lot of trash to the produce there by deteriorating grain quality. The deterrent to conduct the detailed root studies have been intensive labour, resources crunch and specialized facilities required for root studies (Acharya *et al.*, 2007).

It is not wrong to simulate roots to the producer of a film where only the actors are given the credit without realizing the hard labour and resources invested by the producer in producing the film. Therefore, knowledge of the interrelationship of quantitative traits of economic importance with roots and among themselves is imperative in an economic but complex character like yield. The correlation studies give the vague idea of the association of the characters as they do not take cause and effect relationship into consideration, thereby, restricting their utility to the breeders for practical purposes. The technique of path-coefficient analysis devised by Wright (1921) and utilized for the first time in plants by Dewey and Lu (1959) in crested wheat grass is efficient in disintegrating the correlation between two variables into direct and indirect effects. These techniques could be used to understand the basis for selection of superior genotypes among the diverse breeding populations.

The analysis of variance revealed that the variances due to genotypes were significant for all the characters indicating considerable amount of variability present in the material (Table 4.1). This indicated that there is an ample scope to employ root attributes for isolating / developing high yielding desirable genotypes with simultaneous improvement of other characters provided the material is subjected to judicious selection pressure. The same is discussed here as under:

5.1 Correlation Coefficient

5.2 Path Coefficient Analysis

5.1 Correlation Coefficient

Crop improvement is a continuous process in which the breeders aim at improving characters of economic importance. Roots being underground are not visible as such. This deters the breeders to undertake extensive selection for yield on the basis of root attributes. Though sophisticated methods for root studies are available (Sarkar *et al.*, 2002 and Kashiwagi *et al.*, 2006) yet they are of limited utility in crop improvement programmes on account of large space required for screening large population. The root structures are cheap and simple and have been adequately utilized for screening for root attributes (Acharya *et al.*, 2007). However, for selection to be precise and effective, it is imperative that the consummate information regarding association of various root attributes with grain yield as also among themselves is generated. Therefore, the genotypic and phenotypic correlation coefficients were worked out between grain yield and root attributes.

The results showed that in majority of the cases, the values of genotypic correlation were higher than their phenotypic counter parts (Table 4.2). This indicated that there was a high degree of association between two variables at genotypic level. As such the phenotypic expression represented the genotypic expression and the influence of environment did not blur the genotypic expression to the extent that the selection becomes ineffective on the basis of phenotypic expression. As such the results have been discussed on the basis of genotypic correlations.

Under normal growing condition, grain yield per plant evinced highly significant and positive correlation with biological yieldat both the levels and with harvest index (Table 4.2). These results were in conformity with the results of Kumawat *et al.* (2005) and Eswaran *et al.* (2007) for biological yield and harvest index. The positive and significant correlation of grain yield per plant with biological yield under normal condition was in agreement with the findings of Singh *et al.* (1998b), Nigude *et al.* (2004) and Patil *et al.* (2004). These results were also in consonance with the findings of Rao and Nanda (1994), Alam *et al.* (1999), Nigude *et al.* (2004) and Dahiya *et al.* (2007) who also reported positive and significant correlation of grain yield per plant with harvest index.

The grain yield per plant under normal condition exhibited positive and non-significant correlation with root: shoot ratio at both the levels. Similar results were obtained by Rangasamy and Shanmugam (1984) and Aleem *et al.* (2000) for root: shoot ratio. However, it evinced negative and significant correlation with root length, fresh root weight, dry root weight, root volume and root density. These results were in conformity with the results of Sinha *et al.* (1977), Bertholdsson (1989), Tamboli and Daftardar (2002) for root length; Sinha *et al.* (1977) for root volume and root density and Rangasamy and Shanmugam (1984) for fresh root weight and dry root weight. This indicated that root: shoot ratio along with biological yield and harvest index were the most important traits in realizing higher yield under normal growing condition.

Grain yield per plant under post flowering water stress condition showed highly significant and positive correlation with biological yield and harvest index. The positive and significant correlation of grain yield per plant under post flowering water stress condition was in consonance with the findings of Singh *et al.* (1998b), Nigude *et al.* (2004) and Patil *et al.* (2004) for biological yield and Rao and Nanda (1994), Alam *et al.* (1999) and Nigude *et al.* (2004) for harvest index.

Grain yield per plant under post flowering water stress condition showed positive but non-significant correlation with fresh root weight, dry root weight and root volume. Contrarily, it evinced negatively non-significant correlation with root length and root density. These results were in conformity with the results of Sinha *et al.* (1977), Tamboli and Daftardar (2002) for root length; and Sinha *et al.* (1977) for root density. It showed that biological yield and harvest index are most important characters in realizing higher yield under post flowering water stress condition, though significance of fresh root weight, dry root weight and root volume can not be overlooked.

Percent injury in yield due to post flowering water stress showed high significant and positive correlation with percent injury in both biological yield and harvest index. The negative and non-significant correlation of percent injury in yield with root length, fresh root weight, dry root weight, root volume and root density at both the levels were observed. This indicated that the plants with long roots, more root volume, root density, fresh weight and dry weight are desirable for aiming selection for lower injury to yield under post flowering water stress condition. This should not be difficult to accomplish as the root length had positive and highly significant correlation with fresh root weight, dry root weight, root volume and root density at both the levels. Similar results were observed by Velich (1993) for root weight.

All the root attributes except root: shoot ratio exhibited negative and non-significant correlation with water stress injury as exhibited through seed yield. This indicated that larger, heavier and more voluminous are the roots, lesser is the water stress injury to the grain yield and thereby are important attributes in assigning post flowering water stress attribute in cowpea. Thus, the breeder should aim at selecting plants with larger, heavier and more voluminous roots under post flowering water stress condition. This is quite expected as the roots that act as suction for water and nutrients would be helpful to maintain water balance of the plant.

Biological yield is an indicator of the photosynthesis. All the root attributes studied evinced positive correlation with the biological yield under post flowering water stress condition. However, under normal condition only root length and root volume exhibited positive correlation with biological yield. Contrarily, all the root attributes revealed negative correlation with injury to biological yield attributable to post flowering water stress. This suggested that where as greater root length, fresh root weight, dry root weight, root volume and root density are important for realizing higher biological yield under post flowering water stress condition as also for lower injury to biological yield due to post flowering water stress condition, only root length and root volume were important under normal growing condition. Root: shoot ratio was positively correlated with biological yield irrespective of growing conditions.

Harvest index is an indicator of efficiency of diversion of assimilated total dry matter to the economical product i.e. grains. All the root attributes were negatively correlated with harvest index irrespective of growing conditions. This suggested that though the longer and voluminous roots are desirable for realizing higher biological yield under both normal and post flowering water stress condition, yet it was not reflected in higher harvest index under both the situations. The dry root weight, root volume and root: shoot ratio exhibited negative correlation with injury to harvest index due to post flowering water stress, indicating that higher values of these traits would be helpful in reducing the injury to harvest index due to post flowering water stress. As the harvest index is the most yield limiting factor in cowpea, significance of these characters can not be overemphasized.

The root length evinced positive and highly significant correlation with fresh root weight, dry root weight, root volume and root density. These results were in conformity with the results of Singh *et al.* (2002) for fresh root weight and Kanbar *et al.* (2004) for dry root weight. Similarly, fresh root weight also exhibited positive and highly significant correlation with dry root weight, root volume and root density. Positive and highly significant correlations were also exhibited by dry root weight with root volume and root density; and root volume with root density. Similar results were obtained by Kanbar *et al.* (2004) for root volume.

Genetic correlations are of great significance in any crop improvement programme as the efficiency of breeding programme largely hinges on efficiency of selection. If the two characters are positively correlated, the selection of one character is expected to improve the other character too. Empirically, efficiency of photosynthesis comprises the foundation of absolute productivity and is reflected in biological yield; more the dry matter accumulated due to efficient photosynthesis more is the biological yield (Salam *et al.*, 1990). It was found that all the root attributes studied, exhibited positive correlation with biological yield under post flowering water stress condition and negative correlation with injury to biological yield due to water stress. However, under normal growing condition, only root length and root volume was positively correlated to biological yield. Further, the biological yield is of little importance if it is not reflected in economical yield. Harvest index indicates the efficiency of the translocation of assimilated dry matter to the grains. All the root attributes were negatively correlated with harvest index irrespective of growing conditions. Harvest index is low in cowpea and emphasis on root attributes are not expected to improve harvest index. The grain yield too reflects the efficiency of the translocation of dry matter accumulated in different parts of the plant and is the final product in which the breeder is most interested (San Jose *et al.*, 2004). It was important to note that the root attributes like fresh root weight, dry root weight and root volume were of least importance under normal growing condition but were very important under post flowering water stress condition due to their positive and negative correlations with grain yield and injury to grain yield due to post flowering water stress, respectively. As such these root attributes may be helpful for selection for higher grain yield under water stress condition as also for lower injury to grain yield due to post flowering water stress. Further all the root attributes showed positive correlations among themselves indicating that they can be improved simultaneously. Therefore, these situation specific interrelationships may be exploited for improving yield in cowpea under different growing conditions.

5.2 Path Coefficient Analysis

The inclusion of large number of independent variables for studying inter-relationship with the dependent variable makes the situation too complex to be effective for any selection programme. The situation can be bailed out by calculating path coefficient along with correlation coefficient that helps in identification of suitable characters for assigning appropriate weightage during selection. Path analysis (Wright, 1921; Dewey and Lu, 1959) can be termed as weighted correlations through which it becomes possible to ascertain the relative contribution of different component characters to seed yield in terms of direct and indirect effects (Table 4.3.1, 4.3.2 and 4.3.3).

5.2.1 Grain Yield under Normal Condition (Table 4.3.1)

The highest positive direct effect on grain yield was recorded for fresh root weight followed by harvest index. However, it had significant negative correlation with yield that may be attributed to its negative indirect effects via other root attributes. Similar results were obtained by Topare (1994), Alam *et al.* (1999) for harvest index; and Singh *et al.* (1998a) and Zia *et al.* (1998) for fresh root weight. The negative direct effects on grain yield were recorded for root volume, biological yield, root density, dry root weight, root length and root: shoot ratio. Such negative direct effect was also reported by Singh *et al.* (1998a) for root: shoot ratio. Harvest index exhibited positive and highly significant correlation with grain yield that could be attributed to its positive direct effect as also to its positive indirect effect via root volume, dry root weight, root density, root length and root: shoot ratio. Similar results were also reported by Mehetre *et al.* (1997) for root length. It was important to note that fresh root weight though evinced highly significant and negative correlation with grain yield, yet it had the highest positive direct effect too. However, it exhibited high to low negative indirect effect via root volume, root density, dry root weight, root length, harvest index, root: shoot ratio and biological yield. Further, there was a negative correlation of fresh root weight with grain yield that was due to its insignificant indirect effects via other root attributes. This indicated that fresh root weight and harvest index are the two important characters worth consideration for aiming higher yield in cowpea under normal growing conditions.

Root length had significant negative correlation with grain yield per plant that was precisely due to its negative direct effect and negative indirect effects via root volume, root density, dry root weight, harvest index and root: shoot ratio. This consummately indicated that root length did not contribute to grain yield in cowpea under normal growing condition. Similar results have also been reported by Sasmal (1987). These results were not conformity with the results of Alam *et al*. (1999), Chakraborty and Borah, (2001), Pol *et al*. (2003) and Henshaw *et al.* (2007).

Dry root weight exhibited the highly significant and negative correlation with grain yield. In addition, it had negative direct and indirect effect via root volume, root density, root length, harvest index, root: shoot ratio and biological yield.

Root volume had negative and significant correlation with grain yield due to its highest negative direct and indirect effect via root density, dry root weight, harvest index and root: shoot ratio. The negative and significant correlation of root density with grain yield was due to its high negative direct effect and negative indirect effect via root volume, dry root weight, root length, harvest index, biological yield and root: shoot ratio. Root: shoot ratio evinced negative direct effect on grain yield. It had positive association with grain yield due to its positive indirect effect via fresh root weight, dry root weight and biological yield and negative indirect effect via root volume, root density, harvest index and root length.

Biological yield exhibited highly significant and positive correlation with grain yield. However, it evinced negative but insignificant direct effect and indirect effect via harvest index, fresh root weight, root: shoot ratio, root volume and root density. These findings are in parity with result observed by Singh *et al.* (1998a) for harvest index.

Path diagram depicts the consummate causal factors affecting the grain yield. Grain yield is a complex character and is dependent on different component characters. Practically, it might not be feasible to include all the component characters. Under these circumstances, the path diagram has the provision for residual effect, which takes care of all such factors that are not included in path diagram. In the present study, the residual effect at genotypic level was 0.0067, which is negligible and suggested that predominant component traits responsible to influence the grain yield per plant have been covered in the study. The path diagram suggested that fresh root weight besides harvest index had positive direct effect on grain yield suggesting that for the improvement of grain yield under normal growing condition emphasis should be laid on these traits. Indirect effect of root length, dry root weight, root volume, root density and root: shoot ratio via fresh root weight, root: shoot ratio, biological yield and harvest index with dry root weight; and root volume and root: shoot ratio with biological yield were substantial on grain yield under normal condition. These characters having positive direct and indirect on grain yield may be exploited for yield enhancement of cowpea under normal condition.

5.2.2 Grain Yield under Post Flowering Water Stress Condition (Table 4.3.2)

All the root attributes, except fresh root weight, evinced positive direct effect on grain yield under post flowering water stress condition. The highest positive direct effect on grain yield was recorded for root volume followed by root density, harvest index, biological yield, dry root weight, root length and root: shoot ratio. Similar results were obtained by Mehetre *et al.* (1997) for dry root weight, Topare (1994), Tikka *et al.* (2003) for harvest index, Singh *et al.* (1998a) for biological yield, Nigude *et al.* (2004) for harvest index and biological yield and Alam *et al.* (1999) for harvest index and dry root weight. In consonance to the present findings, Singh *et al.* (1998a) also reported negative direct effect of fresh root weight on grain yield under water stress condition.

Harvest index exhibited highly significant and positive correlation with grain yield due to its positive direct effect and positive indirect effect via fresh root weight and biological yield. The biological yield too revealed highly significant and positive correlation with grain yield that was attributable to its positive direct effect and positive indirect effect via harvest index, root volume, root density, dry root weight, root length and root: shoot ratio. Similar results have been reported by Singh *et al.* (1998a) for harvest index. Thus, harvest index and biological yield seem to be the most important traits for yield enhancement under post flowering water stress condition.

Root volume, dry root weight and root: shoot ratio exhibited non-significant and very weak positive correlation with grain yield despite their conspicuous positive direct effects mainly because of their high indirect effect via fresh root weight. Similarly root density and root length too showed very weak and non-significant negative correlation with yield despite positive direct effect.

Fresh root weight exhibited positive correlation with grain yield despite negative direct effect mainly attributable to positive indirect effect via root volume, root density, dry root weight, biological yield, root length and root: shoot ratio. Contrarily, root length showed negative correlation with grain yield despite positive direct effect and positive indirect effect via root volume, root density, dry root weight, biological yield and root: shoot ratio mainly because of conspicuous indirect effect via fresh root weight. Root density too evinced negative correlation with grain yield despite its conspicuous positive direct effect that was mainly due to negative indirect effect via fresh root weight and harvest index. The residual effect of genotypic level was -0.0011, which is negligible and suggested that predominant component traits responsible to influence the grain yield per plant under post flowering water stress condition have been covered in the study.

5.2.3 Percent Injury in Yield Due to Post Flowering Water Stress (Table 4.3.3)

It was important to note that despite the different root attributes evinced negative though non-significant correlation with grain yield, only two characters viz. fresh root weight and root: shoot ratio exhibited the negative direct effect on the percent injury in yield due to post flowering water stress condition. This was attributed to positive indirect effect via each other except via fresh root weight and root: shoot ratio that contributed negatively to percent injury to yield via other characters. Such negative direct effect was reported by Singh *et al.* (1998a) for root: shoot ratio. Positive direct effect on injury to grain yield was recorded for root length followed by dry root weight, root density, biological yield, root volume and harvest index. This indicated that increase in fresh root weight and root: shoot ratio is desired for breeding tolerance to post flowering water stress. This is expected as the root mass is an important component to extract water from soil and root: shoot ratio has significance in judicious utility of the moisture by maintaining proper balance between the moisture extracted by and appropriate transpiration by the shoot (Clemente *et al.*, 2005; Grossnickle and Folk, 2007 and Ouma, 2007).

Injury to biological yield and harvest index were positively correlated to injury in yield with positive direct effect on percent injury in yield due to post flowering water stress condition. This indicated that lower the injury to the biological yield and harvest index due to post flowering water stress, more tolerance can be expected to post flowering water stress. The percent injury to biological yield exhibited negative indirect effect via all the root attributes, except fresh root weight indicating that the tolerance to water stress can be expected by lowering injury to biological yield via root length, dry root weight, root volume, root density and root: shoot ratio. Similarly, percent injury to harvest index also exhibited negative indirect effects via root volume and fresh root weight suggesting that the improvement in tolerance can be achieved by selecting more fresh root weight and root volume.

Quantitative injury in yield due to post flowering water stress is a very complex character; it might not be feasible to include all the characters impacting injury to yield. The residual effect takes care of all such factors and the residual effect at genotypic level was -0.0231, which is negligible and suggested that predominant component traits responsible to influence the percent injury in yield due to post flowering stress have been covered in the study.

Imperially, the yield depends upon the source to sink relation and how much of the accumulated source is effectively diverted to the sink in terms of economic product. Root attributes are very important components in this scenario and helps in absorption of moisture and nutrients from the soil. Total biomass is the product of photosynthesis and precisely represents the dry matter accumulated (Sepaskhah *et al.*, 2006). The shoot attributes correspond to the photosynthesis besides water losses due to transpiration and evaporation and thereby root: shoot ratio is an indicator of judicious and effective use of water by the plant. Harvest index and finally yield hinges primarily on the development of appropriate sink and how precisely the accumulated dry matter is converted to the economic product. Thus, ideally plants with more root weight, more biomass and total shoot weight are expected to give higher yield. Economic and effective utilization of water is of great significance under water stress conditions. On the other hand plant with better photosynthesis and lesser transpiration is expected to do better under normal conditions (Sepaskhah *et al.*, 2006).

Thus, it seemed that biological yield and harvest index are the two important traits for realizing higher yield under both normal and post flowering water stress conditions. Root: shoot ratio assumes significance under normal condition while root attributes like fresh root weight, dry root weight and root volume are important traits under post flowering water stress condition. Importance of root length, root volume, root density, fresh root weight and dry root weight was also palpable in lowering injury to the grain yield due to post flowering water stress. Thus, the larger, heavier and more voluminous roots seemed preferable under post flowering water stress condition. This is quite expected as the roots act as suction for water and nutrients and thereby would be helpful to maintain water balance of the plant under water stress condition. Root: shoot ratio on the other hand, indicates effective comparative area of plant for transpiration in relation to moisture suction of roots (Viswanatha *et al.*, 2002; Anyia and Herzog, 2004; Sepaskhah *et al.*, 2006; Mendes *et al.*, 2007 and Kamoi *et al.*, 2008). More shoot mass would represent more leaf area and hence increase the transpiration and thereby expected to reduce the efficiency of the plant under normal condition. Thus, biological yield and harvest index, that are indicators of photosynthesis and effective carriage of carbohydrates synthesized to developed sink, respectively, appeared most important attributed under both normal and post flowering water stress condition (Khanna *et al.*, 1974; Salam *et al.*, 1990 and BinduRoy and Vivekanandan, 1998). However, these two characters needs complementation with root: shoot ratio under normal condition and larger, heavier and more voluminous roots under post flowering water stress condition. This was evident in analyzing the highest yielding genotype under normal condition (GC-0405) and post flowering water stress condition (GC-4). The best genotype under normal condition also evinced higher biological yield and higher harvest index along with high root:

shoot ratio. Contrarily, GC-4 exhibited the highest biological yield with high harvest index and good root attributes.

SUMMARY AND CONCLUSIONS

VI. SUMMARY AND CONCLUSIONS

Investigation entitled "Character Association of Root Attributes with Yield under Different Growing Condition in Cowpea [*Vigna unguiculata* (L.) Walp.]" was conducted during summer 2007 with thirty genotypes selected randomly from the germplasm maintained at the Main Pulses Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The experiment comprised three sets of thirty genotypes. The first set was conducted in root structure filled with uniform soil. The other two sets were sown in protected structures filled with the same uniform soil as in root structure. Each set was laid out in randomized block design with three replications. All the three sets were raised under normal irrigated conditions till flower initiation. After flower initiation, the set in root structure was used for root studies. The roots were excavated by gently washing the soil with the pressure of water till the entire mass of root is exhumed and observations on root length, fresh root weight, dry root weight, root volume, root density and root : shoot ratio were recorded. One of the sets in protected structure was exposed to water stress after flower initiation by discontinuing water application after flower initiation. The other set was maintained as normal and irrigation was applied whenever required. These two sets were used to study the biological yield, harvest index and grain yield under post flowering stress and normal conditions, respectively.

The salient findings are summarized below:

1. The genotypic differences were significant for all the characters indicating enormous variability present in the material studied.
2. There was little difference in the magnitude of genotypic and phenotypic correlation coefficients. Numerically, the genotypic correlations were slightly higher than their corresponding phenotypic correlation.
3. Under normal growing condition, grain yield per plant evinced highly significant and positive correlation with biological yield and harvest index. It also exhibited positive but non-significant correlation with root: shoot ratio. Thus, root: shoot ratio along with biological yield and harvest index appeared to be the most important traits in realizing higher yield under normal growing condition.
4. Yield per plant under post flowering water stress condition too exhibited highly significant and positive correlation with both biological yield and harvest index. However, it also showed positive though non-significant correlation with fresh root weight, dry root weight and root volume. It indicated the importance of biological yield and harvest index in realizing higher yield under post flowering water stress condition, though significance of fresh root weight, dry root weight and root volume can not be overlooked.
5. Percent injury in yield due to post flowering water stress showed highly significant and positive correlation with percent injury in both biological yield and harvest index. The negative and non-significant correlation of percent injury in yield with root length, fresh root weight, dry root weight,

root volume and root density indicated that the plants with long roots, more root volume, root density, fresh weight and dry weight are desirable for aiming selection for lower injury to yield under post flowering water stress condition.

6. Path coefficient analysis of grain yield under normal growing condition revealed high positive direct effect of fresh root weight, followed by harvest index. Harvest index also evinced high positive direct effects and indirect effects via root volume, dry root weight, root density, root length and root: shoot ratio on grain yield. Thus, fresh root weight and harvest index appeared as the two important traits for aiming higher yield in cowpea under normal growing conditions.
7. Under post flowering water stress condition, root volume evinced high positive and direct effect of on grain yield, followed by root density, harvest index, biological yield, dry root weight, root length and root: shoot ratio. Harvest index exhibited highly significant and positive correlation with grain yield due to its positive direct effect and positive indirect effect via fresh root weight and biological yield. The biological yield too revealed highly significant and positive correlation with grain yield that was attributable to its positive direct effect and positive indirect effect via harvest index, root volume, root density, dry root weight, root length and root: shoot ratio. Thus, harvest index and biological yield seem to be the most important traits for yield enhancement under post flowering water stress condition.

8. Only two characters viz. fresh root weight and root: shoot ratio exhibited the negative direct effect on the percent injury in yield due to post flowering water stress condition. This was attributed to positive indirect effect via each other except, via fresh root weight and root: shoot ratio that contributed negatively to percent injury to yield via other characters. This indicated that increase in fresh root weight and root: shoot ratio is desired for breeding least percent injury due to post flowering water stress.
9. Thus, it seemed that biological yield and harvest index are the two important traits for realizing higher yield under both normal and post flowering water stress conditions. Root: shoot ratio assumes significance under normal condition while root attributes like fresh root weight, dry root weight and root volume are important traits under post flowering water stress condition. Importance of root length, root volume, root density, fresh root weight and dry root weight was also palpable in lowering injury to the grain yield due to post flowering water stress. Thus, biological yield and harvest index, that are indicators of photosynthesis and effective carriage of carbohydrates synthesized to developed sink, respectively, appeared most important attributed under both normal and post flowering water stress condition. However, these two characters needs complementation with root: shoot ratio under normal condition and larger, heavier and more voluminous roots under post flowering water stress condition.

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*** Original not seen.**

APPENDIX

Appendix I: Mean weekly meteorological data recorded at Sardarkrushinagar during the experiment tenure in 2007

Month	Std. Week	Temperature (^0C)		Relative Humidity (%)		Rainfall	Rainy Days	Remarks
		Max.	Min.	Max.	Min.			
March	10	32.4	14.8	73.0	22.1	-	-	-
	11	33.1	17.7	68.6	19.9	-	-	-
	12	34.4	17.3	67.6	22.4	-	-	-
	13	38.6	18.7	62.7	10.3	-	-	Sowing of trial
April	14	39.1	19.5	53.3	10.1	-	-	-
	15	39.0	22.0	64.0	17.3	-	-	-
	16	41.0	23.8	68.0	20.3	-	-	-
	17	39.1	22.4	69.6	28.3	-	-	-
May	18	40.5	13.7	63.7	26.9	-	-	-
	19	40.7	25.1	75.6	30.4	-	-	-
	20	38.9	25.5	78.0	34.4	-	-	-
	21	38.9	25.6	80.4	31.7	-	-	-
	22	40.4	26.9	58.1	29.3	-	-	-

Source: Meteorological Observatory, Dry Farming Research Station, S.D. Agricultural University, Sardarkrushinagar

Appendix-II: Mean values of different characters of 30 genotypes of cowpea [*Vigna unguiculata* (L.) Walp]

		Flower initiation stage						Normal growing condition			Post harvest water stress condition			Percent injury due to post flowering water stress as measured through		
Sr. No.	Genotypes	Root length (cm)	Fresh root weight (g)	Dry root weight (g)	Root volume (ml)	Root density (g/ml)	Root: Shoot ratio	Yield per plant (g)	Biological yield (g)	Harvest index (%)	Yield per plant (g)	Biological yield (g)	Harvest index (%)	Yield per plant (%)	Biological yield (%)	Harvest index (%)
1	GC-3	103.80	10.79	6.36	12.80	0.84	0.54	20.97	96.28	21.81	7.23	47.72	15.17	65.49	50.62	30.67
2	GC-4	93.46	9.64	5.54	10.77	0.89	0.39	23.25	97.45	23.75	9.18	53.71	17.16	59.49	44.77	26.67
3	GC-5	91.06	9.48	5.98	11.43	0.87	0.47	23.88	96.25	24.82	7.83	49.61	15.18	67.16	48.32	36.67
4	GC-0502	90.50	6.82	4.12	9.37	0.72	0.51	23.73	103.48	22.89	6.30	41.73	15.19	72.94	59.83	33.00
5	GC-0503	81.97	5.54	2.65	8.13	0.67	0.54	24.21	92.58	26.16	5.63	40.93	13.78	76.47	56.00	46.67
6	GC-0504	91.33	8.58	4.93	11.37	0.75	0.58	25.10	113.70	22.07	4.69	40.15	11.75	81.27	64.67	47.00
7	GC-0505	93.07	9.52	5.25	11.47	0.83	0.30	21.64	82.03	26.37	6.00	38.26	16.05	72.14	53.67	39.33
8	GC-0405	89.57	5.15	2.45	8.47	0.60	0.43	29.42	107.79	27.23	8.43	42.17	20.12	71.10	61.00	26.33
9	GC-0408	84.30	4.49	1.86	7.80	0.57	0.25	24.94	89.65	27.78	6.78	35.10	19.62	72.96	60.67	29.67
10	GC-0410	90.90	5.90	3.18	8.87	0.67	0.37	24.73	99.75	24.80	5.51	38.65	14.67	77.73	61.00	41.00
11	GC-0311	96.87	9.71	5.10	10.27	0.95	0.44	28.42	100.09	28.37	5.16	42.12	12.33	81.82	58.67	56.67
12	CP-5	87.20	5.25	2.78	8.20	0.64	0.38	26.84	105.73	25.41	6.07	39.90	15.47	76.98	62.00	38.67
13	CP-6	85.77	4.54	1.86	8.53	0.53	0.40	28.84	104.93	27.43	7.01	46.27	15.11	75.27	55.67	44.67
14	CP-7	87.90	4.95	2.76	8.03	0.62	0.24	23.47	90.79	25.82	5.16	41.77	12.38	77.79	53.67	52.33
15	CP-8	90.27	6.95	4.32	8.77	0.79	0.33	26.53	101.14	26.14	4.58	39.07	11.79	82.65	61.00	54.67
16	CP-9	85.83	5.64	2.67	8.57	0.65	0.48	27.34	108.01	25.48	4.57	36.03	12.38	81.76	66.33	51.33
17	CP-12	83.50	4.45	1.69	8.13	0.54	0.25	22.37	87.46	25.48	7.93	51.57	15.39	65.98	41.00	39.67
18	CP-16	81.60	5.01	2.32	8.37	0.60	0.25	25.29	101.69	24.61	8.30	43.93	19.02	66.9	56.67	23.33
19	CP-18	85.90	5.07	2.52	8.57	0.59	0.26	25.54	101.04	25.17	5.28	38.11	14.11	79.08	62.00	43.00
20	IC-402099	79.43	4.41	1.90	7.27	0.60	0.33	22.47	88.67	25.43	6.76	35.59	18.77	70.24	59.67	26.67
21	IC-402101	91.73	7.89	4.35	10.70	0.73	0.34	21.13	90.67	23.23	4.18	32.83	11.20	80.32	56.67	52.33

Contd.......................................

22	IC-402159	82.40	4.96	2.44	8.47	0.68	0.38	24.42	88.43	27.59	4.70	35.57	13.32	80.57	59.33	54.67
23	IC-402161	83.60	5.61	2.51	7.87	0.71	0.38	26.87	103.84	25.89	6.10	43.43	14.09	81.29	57.00	56.67
24	IC-402174	91.50	7.23	2.65	9.63	0.75	0.23	24.16	96.48	25.05	5.55	42.60	12.99	77.17	60.67	42.33
25	IC-402182	86.20	4.77	2.42	8.47	0.56	0.39	26.87	103.03	26.24	5.02	44.33	11.42	79.21	57.33	50.67
26	EC-17574 -6	89.37	6.62	3.59	8.90	0.74	0.25	27.17	106.71	25.32	6.17	41.93	14.66	78.04	54.00	52.67
27	EC-1758413 -9	92.90	6.77	3.47	8.77	0.77	0.27	23.37	94.34	24.61	4.81	40.57	11.98	72.24	53.00	39.33
28	EC-394708	91.73	7.73	4.62	9.73	0.79	0.31	21.72	83.32	26.17	4.74	38.25	12.42	78.58	59.04	46.85
29	EC-458402	89.27	6.97	3.71	8.93	078	0.31	23.57	86.49	27.16	6.45	40.03	16.68	77.13	57.81	45.64
30	EC-472250	87.87	5.77	2.77	8.33	0.69	0.29	23.07	94.14	24.73	4.89	38.63	12.92	77.09	55.86	48.08
Mean		88.69	6.54	3.42	9.13	0.71	0.36	24.71	97.19	25.43	6.04	41.55	14.59	75.16	56.88	42.58
S. Em. ±		2.67	0.41	0.35	0.28	0.03	0.03	1.74	4.39	1.11	0.52	2.73	1.56	1.58	2.04	3.65
C.D. at 5%		7.50	1.15	1.00	0.78	0.09	0.09	4.88	12.36	3.12	1.47	7.67	4.39	4.47	5.78	10.33
C.V. %		5.21	10.83	17.93	5.24	8.10	15.26	12.17	7.83	7.54	14.97	11.36	18.52	6.31	10.76	25.72

CERTIFICATE

This is certify that, I have no objection for supplying to any scientist only one copy of any part of thesis at a time through reprographic process, if necessary for rendering reference service in a library or documentation centre.

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