GENETIC ANALYSIS OF ROOT AND SHOOT MORPHOLOGICAL CHARACTERS RELATED TO DROUGHT AVOIDANCE IN RICE (*Oryza sativa* L.)

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CERTIFICATE

*This is to certify that the thesis entitled "***Genetic analysis of root and shoot morphological characters related to drought avoidance in rice (*Oryza sativa* L.)***" submitted in partial fulfillment of the requirement for the degree of Doctor Of Philosophy in Genetics and Plant Breeding to the University of Agricultural Sciences, Bangalore, is a record of research work done by* **Mr. DHANANJAYA, M. V** *under my guidance and supervision and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.*

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INTRODUCTION

I INTRODUCTION

Rice (*Oryza sativa* L.) is the second most important staple food grain next to wheat in the world. It supplies 23 per cent of global human per capita energy and 16 per cent of per capita protein requirement. Around 40-50 per cent of the worlds population consumes rice as major ingredient in their daily diet. Worldwide rice is grown on an area of 131.5 m ha in that Asian countries account for 89% followed by African nations (5%), Latin American countries (4%) and 2% area is with the rest of the world (FAO, 1999). Of the current total rice growing area of the globe nearly 53% is under assured irrigation and 28% is under rainfed condition (IRRI 1993). The average yield in India is 2.69 tonnes per hectare and it is 2.35 tonnes/ha in Karnataka (Hunter, 1995).

Rice growing habitats are classified into five types namely irrigated, rainfed low land, deep water, rainfed uplands and tidal wetlands (Anon, 1995). Among these habitats, rainfed lowland rice occupies 28 per cent of world rice growing area (Pandey *et al.,* 1997). Rainfed lowland rice areas are characterized by uncertain and erratic rainfall, which destabilizes yield, resulting in yearly fluctuations. Drought is therefore a major environmental stress limiting rice production and productivity.

Plants have evolved various adaptive mechanisms to either escape, avoid or tolerate water stress. Root system forms one of the important components of drought tolerance or resistance and thus determinant of yield. It plays an important role in the regulation and extraction of water from deep soil layers (Thanh *et al.,* 1999).

In the root system, among various root morphological traits, maximum root length and root thickness are found to be associated with drought tolerance under upland condition. Deep-rooted genotypes help in maintenance of better plant water and nutrient status (Mumbani and Lal, 1983; Lilley and Fukai, 1994). The other root parameters associated with drought tolerance mechanisms are greater root length density below 30 cm soil layer and moisture stress induced dynamic responses in the 10-30 cm depth soil layer.

Eventhough, considerable progress has been achieved in increasing productivity of rice grown under irrigated condition over the past few decades by improving yield and yield attributing characters, there is tremendous scope to increase productivity of rice to meet the ever increasing food demands of fast growing population of the world. One avenue is to improve tolerance to biotic and abiotic stresses in addition to high yielding ability.

However, very few attempts have been made so far in this direction. Hence, there is an urgent need to understand genetic basis of root system of rice plants known to be associated with drought avoidance mechanisms to evolve improved cultivars. However, screening of rice genotypes for root characters have rarely been incorporated into various breeding approaches employed so far. The polygenic control of many root morphological characters is an added complication to evolve rice varieties, which possess genes for enhanced productivity in addition to tolerance to water stress conditions during its growth period. Genetic parameters like assessment of variability parameters, character association and path analysis associated with drought avoidance mechanisms are not well established. Few researchers have addressed combining ability and exploitation of heterosis phenomenon for various root morphological traits.

In addition, rice research workers need to intensify efforts to utilize other promising sources of male sterility in hybrid breeding. Hence, utilization of other sources like temperature sensitive genic male sterile (TGMS) lines to develop drought tolerant high yielding rice varieties and thus avoid problems associated with narrow genetic base of the male sterile lines which are currently in use has become the need of the hour.

Present study was undertaken with the following objectives to realize the importance and need for development of drought tolerant rice cultivars for different rainfed habitats with enhanced grain yielding ability.

(1) To evaluate selected local cultivars, promising restorer and male sterile lines and DH-lines of IR-64 x Azucena cross, for various genetic parameters for root and shoot characters under well watered condition and to score parents and hybrids for physiological characters viz., leaf rolling and tip firing under moisture stress condition.

(2) To estimate nature and extent of association between various root and shoot morphological characters associated with drought tolerance and their relative influence on maximum root length and total root dry weight through path coefficient analysis.

(3) To assess combining ability effects, gene action and estimation of magnitude of heterosis for various root and shoot morphological traits under wellwatered and low moisture stress conditions.

(4) To estimate magnitude of standard heterosis for important grain yield and its attributes

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Exploitation of heterosis through development of F_1 hybrids has been a major breeding tool for crop breeders to increase productivity. Heterosis in rice was first utilised in China using cytoplasmic genic male sterility (CGMS) system. The success of hybrid rice in China encouraged other countries across the globe to concentrate research in hybrid rice breeding. After success of rice hybrids for irrigated rice habitats, extention of this to rainfed rice ecosystem is logical. Use of just a single wild abortive (WA) cytoplasm may lead to genetic vulnerability to various biotic and abiotic stresses. Therefore, it is necessary to identify and utilise different sources of male sterility for hybrid rice breeding. The literature available on various aspects of breeding rice for rainfed ecosystem is reviewed under the following heads.

1. Rice habitat, drought resistance concept
2. Root morphology – growth and development
3. Genetic parameters, character association and path co-efficient analysis amongst root and shoot characters.
4. Combining ability and gene action for root and shoot morphological traits.
5. Heterosis and identification of transgressive segregants for root and shoot morphological traits.

2.1 Rice habitat, drought resistance concept

2.1.1 Rice habitat

Rice (*Oryza sativa* L.) is a semiaquatic species grown in wide range of climatic conditions. Of the 147 million hectares occupied by rice globally, 30m hectares is irrigated. Rice breeders have contributed enormously to increase production of rice by developing fertilizer responsive, high yielding, photoperiod sensitive, semi dwarf to dwarf statured rice varieties with moderate tolerance to biotic and abiotic stresses. More than one crop per year has been taken up with yields ranging from 3-9 t/ha (Yuan *et. al.*, 1989).

The present investigation pertains to rainfed rice improvement. Characteristics of rainfed rice ecosystem are briefed here.

Rainfed rice area occupy one fourth of the world's total rice land contributing 19 per cent to the global rice supply (IRRI, 1995). Rainfed rice is grown only once in a year in bunded fields, which are flooded atleast for a part of the growing period and in lands which are unbunded without surface water accumulation. These rice fields experience moisture stress at some stages of growth due to unpredictable rainfall (O'Toole and Moya 1978). These fields also experience the problems of floods and drought. As there are no improved varieties for these conditions, there is an urgent need to develop rice varieties or hybrids with tolerance to drought with moderate to high yielding abilities.

2.1.2 Drought resistance concept

Blum (1982) has related drought resistance to yield as a major economic consideration and as an integrator of the effects of plant drought stress in time and space and also opined that drought resistance is process-specific and its definition linked to plant processes at any given level of organisation. Levitt (1980) classified drought resistance into drought escape and drought tolerance. Drought escape is due to the plants ability to mature before soil water deficit becomes a serious problem. This mechanism needs developmental plasticity and rapid phenological adjustment by the plants. Plant's ability to sustain minimum injury to crop growth at lower levels of turgor pressure of various tissues reflects its dehydration tolerance capacity also called as dehydration postponement.

Adaptive mechanisms of plants in response to drought has been reviewed and reported by several scientists (Mcwilliam, 1989, Arrandean, 1989, Bindinger *et al.*, 1989; Ludlow and Muchow, 1990; Fukai and Cooper, 1995).

Plants response to drought and its relevance to type of drought environments are listed below

A Drought escape :	Resistance to type of low moisture stresses
- Early maturity	Terminal
- Photoperiod sensitivity	Terminal
- Delay in flower initiation	Intermittent
- Staggered tiller development	Intermittent
B Drought tolerance :	
1. Dehydration avoidance (post ponement)	
- Rooting depth and density	Intermittent
- Large root and culm xylem vessels	Terminal
- Epicuticular wax	Terminal and Intermittent
- Leaf rolling and tip firing	Intermittent
2. Dehydration tolerance :	
- Remobilisation of assimilates	Terminal
- Osmotic adjustment	Terminal and intermittent

2.2 Root morphology-growth and development

A number of physiological and morphological traits have been reported to improve the performance of crops affected by drought. Root system is one of the important components of drought resistance (Passioura, 1982).

Yoshida and Hasegawa (1982) presented a detailed analysis of tillering and rooting pattern of rice plant. The fibrous root system of rice consists mainly of numerous nodal roots and their laterals. A tiller and its roots come simultaneously from the same node i.e. when the leaf emerges, a tiller and its roots start emerging from $(n\text{-}3)^{th}$ node.

Rice root growth exhibits plasticity in response to external factors viz., soil profile characters, soil moisture, air temperature and growth stage. Aerobic conditions of dryland rice field favours root hair formation, while flooded soils impair it (Yoshida and Hasegawa, 1982; Beyrouty, *et al.*, 1988).

Yoshida and Hasegawa (1982) reported that root growth reaches its peak around flowering but branching continues until maturity. While, Cruz *et al.* (1986) reported that root length was maximum after heading stage and subsequently declined until maturity. Beyrouty *et al.* (1988) reported root growth to be most rapid during vegetative growth phase with maximum root length at panicle initiation and it plateaued or declined during reproductive phase.

Rice has a high rooting density in the surface soil compared to other crops is attributed to root tillering and nodal rooting habit of rice. Banba and Ohkuba (1989) reported that 80% of root dry matter is concentrated in the top six inches of soil in a study on root distribution of upland rice. Compared to maize and sorghum, rice has a shallow root system makes it susceptible to water stress (Inthapan and Fukai, 1988; Fukai and Inthapan, 1988).

Significant differences in root length density between upland and lowland rices have been reported by Yoshida and Hasegawa (1982). While, Chang *et al.* (1982) revealed that, upland and low land types shared common traits such as greater root length of main axis, larger root diameter and a lower degree of branching. Upland rices exhibited plasticity response by adjusting rooting depth to maintain water supply but no such response is seen in lowland rice.

Jun-Abe and Shingenari (1994) opined that, the growth direction of the nodal roots in rice affects the spatial distribution of the root system in soil and seemingly related to lodging resistance. They also opined that internal factors such as planting density and nitrogen application affects the growth and direction of nodal roots probably by changing the tillering pattern of the shoot. Price *et al.*, (1997) reported that, upland varieties possessed a more pronounced root system than the low land varieties.

The final configuration of the root system under field conditions is largely determined by factors such as chemical gradients, moisture content, mechanical impedance and aeration (Lynch, 1995) are in turn affected by soil, climate and cropping system. Large genetic variation for root characters has been reported in germplasm adapted to different agro ecological conditions (O' Toole and Bland, 1987). Courtois *et al.*, (1996) inferred that, cultivars of upland origin are more deeply rooted and have a larger diameter of main root axis compared with cultivars of low land origin.

Price *et al.*, (1997) and Thanh *et al.*, (1999) opined that root growth is an important component of adaptation of rice to drought prone environments. Drought is a major constraint to the productivity of rice in upland ecosystem and the rice root system plays an important role in the regulation of water uptake and extraction of water from deeper soil layers.

2.2.1 Root morphology: Growth and development

Nasiruddin and Haque (1981) observed low positive and or negative correlations among the root traits namely root length, root weight, root number and drought tolerance. Armenta-Soto *et al.*, (1983) attributed differential response of rice genotypes to soil and atmospheric water stress on the root system characteristics.

Ekanayake *et al.* (1985) reported that root length, root thickness, number of thick roots and root volume were significantly correlated to filed recovery from drought. Further, they also opined that resistance or tolerance to water stress in crop plants is the combined result of many interacting morphological and physiological characters.

Chang *et al.*, (1986) investigated genetic variability in root characters among rice cultivars and reported that, deep thick root system avoid drought better than those with shallow thin root system.

O'Toole and Bland (1987) reviewed the genotypic variation in root systems and reported that, plant root system has the capability of coping with changes in the environmental factors such as water status and temperature. Gomathinayagam *et al.*, (1988) reported significant genotypic difference with respect to root length, root dry weight and leaf water potential.

Jena and Mani (1990) studied root characters and grain yield on some upland rice varieties, indicting, apart from high root length density and root weight, the duration of the crop was important for selecting drought tolerant genotypes.

A deep and thick root system with high ratio of deep root weight to shoot weight and high root density are the factors contributing to resistance to intermittent drought stress in upland rice (Fukai and Cooper, 1995).

Ray *et al.*, (1996) opined that penetrating ability is another important factor for rice drought resistance in areas with soils subjected to both compaction and periodic water deficits. Breeding for root penetration ability is inhibited by difficulties associated with measuring root traits. Lilley and Ludlow (1996) reported that, a rice variety 'Bala' possessing considerable drought resistance mechanism by virtue of leaf related drought mechanisms inspite of having poor root system.

Thanh *et al.*, (1999) after reporting positive correlations between the root traits, inferred that, the selection based on many of the root traits especially the easily measurable one, may provide breeders an opportunity to develop drought resistant upland cultivars.

2.2.1.1 Root length

Puchridge and O'Toole (1981) reported that a deep-rooted rice cultivar 'Kinangdang patang' extracted more water at 40-70 cm depth than two shallow rooted cultivars namely IR 20 and IR 36.

O'Toole (1982) indicated that, for relatively large soil water reservoirs (deep soils), increase in rooting depth, conductance and root to shoot ratio (by weight) results in increased soil water uptake capacity. Passioura (1982) reported that in deep wet soils, larger root density at depth is necessary to extract water from deeper layers. Mumbani & Lal (1983) indicated similar results from their studies conducted on response of upland rice varieties to drought stress. O'Toole and DeDatta (1986) reported that increased rooting depth and density would increase the plant's capacity to extract water in rice.

Mumbani and Lal (1983) also opined that, rice plants with deep root system maintain high leaf water potential and delay in leaf drying or death. Deep roots may also reduce the productions of chemical signals from roots under drought conditions. Which may other wise reduce leaf growth, expansion and stomatal conductance (Turner *et al.*, 1986).

When plants are subjected to a moderate stress, it is supposed to put forth longer roots to absorb moisture from deeper layers, but Cruz *et al.*, (1986) and Thangaraj *et al.*, (1990) in their studies on line – source -- sprinkler system with induced moisture gradient have reported decreased root length. They attributed this decrease in root length to increased soil mechanical impedance.

Root studies are arduous under actual field conditions. For convenience, some scientists have conducted root studies in aerponics and hydroponics. Gomathinayagam *et al.*, (1988a) studied seminal roots with drought resistance. Similar associations between total root length and drought tolerance observed in aeroponic study by Gomathinayagam *et al.*, (1992).

Several studies have been conducted to determine the root length at different stages of crop growth. During vegetative stage, the root growth was rapid and declined towards the reproductive stage. Maximum root length observed at panicle initiation stage by Beyrouty *et al.*, (1988). Though, root growth was rapid during vegetative stage, Gomathinayagam *et al.*, (1988a) could not discriminate rice genotypes with respect to root length at and after 45 days from sowing.

Quadratic relationships between plant height and root length at each growth stage Armenta-Soto *et al.* (1983) found substantial transgression for maximum root length in two out of three crosses (i.e. DS x IR8 and Moroberekan xO54) reported contrasting findings to earlier reports. They opined that, taller plants with shallower roots at vegetative stage. But, at milky stage (reproductive stage) they had longest root systems.

Sorte *et al.*, (1993) quantified reduction in root length under water stress. They imposed water stress for five days at 30 days after sowing and observed

19 per cent reduction in root length when the reduction in the moisture content was 44 per cent.

Rao *et al.* (1994) studied the root system under stress. They supplied the roots with water at deeper zones to relieve the stress but the stress was not relieved. This led them to give a divergent conclusion that, water deficit occurring upto a depth of 30-40 cm was critical in determining the drought tolerance and not the length of the root system.

Deeper and more extensive root system was advantages for extraction of soil water from deeper layers during low moisture tresses (Wade, 1997).

Venuprasad (1999) reported that tall genotypes maintain long, thick and few roots under water stress conditions. He also indicated increase in number of roots in some genotypes.

2.2.1.2 Root thick ness

Studies on thirty-five rice selections indicated that the mean diameter of thick roots had high correlations with higher levels of drought resistance O'Toole and Chang (1979) also reported that root diameter at the base was positively correlated with drought resistance in upland rice cultivars.

Robertson *et al.* (1985) reported easy measurement of root thickness even under field conditions, which is not so in other root characters. A deep and thick root system is a drought avoidance mechanism. Moreover thick roots are positively correlated to the number of xylem vessels and vessel area (Anon., 1986). These traits are vital to the conductance of water from soil to upper parts of the plants to meet the evaporative demand. Rice cultivars with deep and thick roots maintain high leaf water potential during drought than the cultivars with shallow and thin roots (Anon., 1987).

Root thickness was found to vary between aeroponic and hydroponic cultures when same varieties were screened for different root characters (Haque *et al.*, 1989). The number of thick roots produced by the plant was a deciding factor for growing under water stress condition (Islam *et al.*, 1991). The ability of the thick roots to penetrate soils of high bulk density is proved beyond doubt, but Gomathinayagam *et al.* (1992) reported thicker roots in case of drought susceptible lines.

In addition to moderating drought effects, deep root system is expected to absorb more nutrients especially nitrogen from deep soil layers resulting in better plant growth (Yoshida and Hasegawa, 1982; Virk *et al.*, 1994). Price *et al.* (1997) found that root thickness and root length were having wide variation compared to other root characters in their study comprising 28 rice varieties.

Plants with more tillers tend to posses thinner roots and less root dry weight (Venuprasad, 1999).

Zhang *et al.* (2001) reported that, root thickness, root penetration index (RPI), root pulling force (RPF) and osmotic adjustment capacity apparently contributed to increased drought resistance.

2.2.1.3 Root dry weight

Root dry weight along with root thickness, root volume and number of thick roots found to be significantly correlated to root pulling resistance (Ekanayake *et al.*, 1986). Okuyama and Colasante (1987) speculated that root dry weight increase with increase in duration of crop growth.

On imposition of water stress, the root weight decreased which was attributed to decrease in the associated traits (Cruz *et al.*, 1986). Jena and Mani (1990) proposed root weight as selection criteria in selecting drought tolerance genotypes.

Sorte *et al.* (1992) inferred from their studies that, 74% reduction in root weight when soil moisture content was reduced by 44%. Survival during stress reflects on the roots capacity to function. The drought tolerant genotypes should have greater root weight as compared to upland and drought susceptible cultivars (Vijayalakshmi and Nagarajan, 1994).

2.2.1.4 Root number

When IR 54 was subjected to a gradient of soil moisture conditions using a line-source-sprinkler system, 19 days of mild water stress at vegetative stage resulted in decrease in the number of roots (Cruz *et al.,* 1986). A study on developmental changes in root mass was conducted by Suga and Yamazaki (1988) wherein, root mass correlated with leaf mass and the primary root number was found to increase exponentially the plant age expressed interns of leaf number. The consistency in production of roots was experimented by Haque *et al.,* (1989). They used four genotypes of all Auns types and four of the hill type along with a drought resistant and a susceptible check. These were grown in aeroponic and hydroponic cultures, root number of these varieties differed in these cultures.

2.2.1.5 Root to shoot ratio

Cruz *et al.,* (1986) presented that, per cent reduction in shoot dry mass was less than that of total root dry mass, there by decreasing root to shoot ratio under mild stress condition during vegetative stage in rice. They attributed this to a high soil strength or mechanical impedance, which decreased root length.

Haque *et al.,* (1989) conducted root studies in both aeroponic and hydroponic cultures. They estimated all the root parameters required for determining drought reaction. They reported variation in root to shoot ratio between the two cultures. Sorte *et al.,* (1992) differed from the general hypothesis of increase in root growth during stress.

2.2.1.6 Root volume

Ekanayake *et al.* (1985) found predominately additive gene effects for root volume and root thickness. But Price *et al.* (1997) failed to detect significant additive or dominant gene effects for these traits.

Zuno–Altoveros *et al.* (1990) conducted an experiment to determine the root volume of some selected upland and low land rice varieties. They found that "Rikuto Noriun12" a Japanese upland variety had a very high root volume while, the low land variety IR 20 exhibited low root volume. Correlation of root volume with root length and shoot length was positive and significant. They also suggested that plant height could be used as a criterion for selecting drought resistant genotypes.

2.2.1.7 Leaf rolling and tip firing

O' Toole and Moya (1978) conducted studies on visual scoring and diurnal sampling of leaf water potential (LWP) in 20 days old plants and reported that leaf rolling and tip firing were highly correlated with maintenance of LWP.

O'Toole and Chang (1979) observed that, leaf rolling under controlled conditions decreased the rate of transpiration by upto 50 per cent . Leaf rolling is one of the water stress symptoms of rice utilised in visual scoring symptoms (O'Toole and Maguling, 1981). Leaf rolling decreases transpiration from rice leaves and along with stomatal closure may contribute to varietal difference in maintaining LWP. Leaf rolling and leaf death occurs as a result of soil water deficits. Turner (1982) regarded leaf rolling (LR) as an alternate drought adaptive mechanism with reversible decrease in leaf area and is one of the effective ways of radiation shedding.

Hsiao *et al.* (1984) reported that, when leaves roll, the effective area of light interception is reduced and the diffusive resistance to CO_2 is increased, both of which will reduce photosynthesis. However, Turner (1986) contradicted this and opined that as leaf rolling (LR) does not occur in the absence of water stress and because it is reversible and reduces light interception there would be no yield penalty. They observed genotypic difference with reference to LR and attributed this to delayed or reduced LR to better osmatic adjustment in rice.

2.2.1.8 Plant height and tillering

De Datta (1975) reported that, tiller number was reduced generally due to stress during vegetative stage than reproductive stage in rice. Moisture stress at vegetative stage generally reduced plant heights as well as tiller number (IRRI, 1977). Drought at tillering stage in rice reduced plant height and leaf area by inducing LR and leaf drying (Murthy and Ramakrishnayya, 1982).

Plants subjected to drought stress show symptoms of leaf and tiller drying. Turner (1982) reported that even though some soluble carbon and nutrients are remobilised from drying tillers to living, assimilates held up in dead tillers were wasted by the plants.

2.3. Genetic parameters, character association and path coefficient analysis amongst root and shoot characters

2.3.1 Heritability, genetic advance and coefficients of variation

Heritability estimates helps the breeders to select the genotypes for the characters of his interest. There are numerous reports published for these genetic parameters in several crop species.

Chang *et al.* (1986) reported moderate to high heritability for maximum root length (61%), root tip and root base diameters (62%). Hemamalini (1997) reported similar results. Ekanayake (1985) reported high narrow sense heritability estimates for root dry height, root thickness and root length density. Also reported, moderate heritability estimates for root volume, thick root number and low heritability estimates for maximum root length. Armenta-Soto *et al.* (1983) reported moderate to high heritability for root length, root thickness, root dry weight and root length density.

In a study on root systems under aeropanic culture it was observed that root length and root thickness exhibited high heritability (65% to 75%) estimates. Whereas, root number and root weight showed 50 to 65% heritability (Anon., 1984).

Ekanayake *et al.* (1985) studied inheritance of root traits. Heritability estimates computed were higher for root dry weight, root thickness and root length density in comparison to other traits. Heritability estimates for maximum root length and number of thick roots were low to intermediate ranging from 33% to 55%. Root volume had recorded low heritability of 18%. Based on their studies on F_2 plants, obtained from a cross between IR20 and MGL-2, they opined that, unimodal and continuous distribution for all the root characteristics. They observed slightly skewed distribution towards higher values for thick root number, root dry weight and root length. They also found high heritability estimate for root number. Similar reports were reported by Anon (1980).

Hemamalini (1997) and Girish (1999) reported higher heritability value for root number and lower value for root thickness.

In a study on 24 rice cultivars, Shashidhar *et al.* (1990) revealed high heritability estimates for five root characters. Das *et al.* (1991) reported high heritability values for root length and root thickness. They also observed high environmental coefficient of variability in case of root length, root dry weight, shoot dry weight, root to shoot ratio and number of tillers.

High heritability and high genetic advance were noted for root dry weight (Gomathinayagam *et al.*, 1990, Shashidhar *et al.*, 1994). Root dry weight was found to be more stable as compared to root length and root number from the PCV and GCV estimates. Hajra and Hajra (1988) observed high variability for root systems with moderately high heritability for primary root length. Root length and root number recorded moderate heritability estimates and genetic advance (Gomathinayagam *et al.*, 1990). Yadav *et al.* (1995) reported heritability estimate of 58% and 84% for root to shoot ratio and root thickness.

Zheng *et al.* (1996) reported significant variation for root traits such as, number of roots, root length, root thickness and root growth ability in eight varieties which they studied. Latha (1997) reported high heritability estimate of 94.05% for root dry weight followed by 87.26% for shoot dry weight, 86.52% for root number, 80.5% for root volume, 77.63% for number of tillers and 72.35% for root length. Also reported moderate heritability estimates for other root and shoot traits. She also reported high estimate of genetic advance for root dry weight and lower estimate for root thickness. Hemamalini (1997) reported highest expected genetic advance as per cent mean for root volume and lowest for root diameter.

Babu *et al.* (1996) reported from their experiment with 12 cultivars that, after withholding water from 50^{th} day after sowing to induce drought stress wilting occurred with in about 35 days. They also reported large variation for osmatic adjustment among the cultivars with highest osmatic adjustment of 1.76 M Pa for the cultivar IR 62266. Azucena, CT9993, Morobereken and IR 52561 exhibited lower osmatic adjustments of 0.86, 0.81, 0.80 and 0.50 M Pa respectively.

Price *et al.* (1997) observed additive and dominant gene effects for root length and reported moderate heritability estimate for the trait root length. They also found high and moderate heritability estimates for root thickness and root volume respectively

2.3.2 Correlation among root and shoot characters

Correlations between root characters and resistance to drought was studied and reported by Anon (1982). Root length,root number and root to shoot ratio were not significantly associated with field reaction to drought during vegetative stage.

Positive association between plant height and shoot dry weight, root length and root thickness were reported by Anon., (1984). Also reported high positive association between tiller number with root number and shoot dry weight. Ekanayake *et al.*, (1985) reported that, root thickness and root number were correlated with plant height, tiller number and shoot weight. They also found that, root length, root thickness and root volume were significantly associated with recovery from drought. They observed positive link amongst root characters and reported significant association between plant height and root characters.

Salam and Subramanian (1988) reported positive association between root dry weight and shoot characters such as plant height, tillers and dry matter production of rice at all growth stages.

Zuno– Altoveros *et al.* (1990) studied root volume of selected upland and low land rice cultivars and reported that, root volume was positively association with root and shoot length. Root volume was found negatively correlated ($r = -0.85$) with damage caused by drought in the reproductive phase.

Shashidhar (1990) observed significant association of root weight with root length ($r=0.69$) and root volume ($r=0.63$). Shahid *et al.*, (1994) revealed positive association between root length, root dry weight, shoot dry weight stomatal frequency and drought tolerance.

Genotypic correlation between root dry weight and root length density was extremely high indicating that root dry weight though, easy to measure can act as an excellent predictor of root length density (Yadav *et al.,* 1995).

Latha (1997) reported highest association between shoot dry weight and total dry weight. Also reported significant association between other root traits. Hemamalini (1997) found positive association between all the root parameters under well-watered conditions.

Price *et al.* (1997) reported from a hydroponic culture, positive significant association between root length and root thickness. Loresto *et al.* (1983) observed good agreement between root growth in liquid culture and in both pot and field conditions. They concluded that, maximum root length and thickness are important attributes contributing to drought resistance in paddy.

Thanh *et al.* (1999) studied 33 upland rice accessions and reported significant positive association amongst all the root traits except root number. The highest correlation co-efficient amongst root characters was recorded between maximum root length and total dry weight (r = 0.65). In addition, plant height found to be significantly correlated with root thickness, maximum root length and total root dry weight (r=0.80). Similar results recorded by Champoux *et al.* (1995).

Venuprasad (1999) recorded non significant association of grain yield with any of the root morphological traits studied.

Girish *et al.* (2000) from their studies on 99 recombinant inbred lines (RILs) indicated significant and positive association among all the root traits considered except root thickness.

2.4 Combining ability and gene action for various root and shoot morphology traits

The combining ability is the ability of an inbred to transmit desirable performances to its hybrids. The information on the nature of combining ability of parents and hybrids for various root and shoot parameters will facilitate appropriate choice of parents in breeding programme. The average performance of a particular inbred in a series of hybrid combination is known as its "general combing ability (GCA)". Specific combining ability (SCA) refers to the performance of two specific inbreds in a particular cross combination. The term "specific combining ability" is used to designate those cases in which certain combinations do relatively better or otherwise than the expected on the basis of the average performance of the lines involved (Spraque and Tatum 1952).

Kempthorne (1957) precisely defined the general combining ability and specific combining ability variances in terms of co-variance of half sibs (HS) and full sibs (FS) in a random mating population, where GCA variance is co-variance of half sibs and SCA variance is co-variances of FS minus 2 x co-variance of (HS).

Ekanayake *et al.* (1985) found predominantly additive gene effects for root volume and root thickness. But, Price *et al.* (1997) failed to detect any significant additive or dominance gene effect for these traits. They also reported root length to be controlled by a combination of additive and dominant gene effects.

Zhang *et al.* (1992) in an incomplete diallele cross of six male sterile lines and five restores for assessing 16 characters, reported that the GCA effects were more important than SCA in most of the cases. In hybrids each character was influenced by the GCA of both male sterile line and the restores line and also by the SCA effect of the combination, together designated as total combining ability.

Anandakumar and SreeRangaswamy (1984) carried out line x tester analysis in rice using 8dwarf as females (lines) and 2 tall (testers) as males. The analysis of variance revealed significant difference for GCA and SCA effects for all the four characters studied.

Variance due to SCA for plant height, panicle length and per plant yield indicated predominance of non-additive gene action (dominance or epistasis). Among the sources of dwarfs 07414 and 07107 showed good combining ability for yield and 06184 for dwarf nature. The crosses 7414 x PLR 2, 07107 x ASD 8 and 06184 x PLR-2 were identified as best combiners based on *per se* performance and SCA effect.

Thendapani (1986) in a line + tester analysis for 12 quantitative characters using 7 induced semi dwarf mutants as line (female) and three tall as testers (males), reported both additive and non-additive gene action for yield traits. Among the parents, CO29 D, TKM-6 D, TKM 6, M120, TKM-9 and IR 50 were found to be the best general combiners.

Jain Ying Peng and Virmani (1990) found significant GCA and SCA variances for yield, dry matter, days to flowering and plant height from a line x tester analysis involving seven maintainers and eleven restore lines

Dhaliwal and Sharma (1990) in their diallele analysis of hybrids from seven diverse rice parents indicated non-additive genetic variance for days to flowering, plant height and panicle per plant.

Patnaik *et al.* (1991) reported that the frequency of heterotic crosses and specific combining ability effects were found to be higher in crosses between the parents with intermediate genetic divergent crosses than the extreme ones.

Banumathi and Prasad (1991) reported higher SCA variance for plant height, number of filled grains per panicle, per cent spikelet sterility and grain yield per plant indicating the prevelance of non-additive gene action in the expression of these traits. Additive gene action was important for number of productive tillers and length of the panicle. Among the parents evaluated IR 62829A was found to be a good general combiner of grain yield, plant height and number of filled grain per panicle. The cross IR62829A x IR 50 expressed high positive significant SCA effect for plant height.

Kenneth and Ronald *et al.* (1993) reported that general combining ability (GCA) were more important than specific combining ability (SCA), accounting for 70 per cent of the variation for yield, 89 per cent for plant height and 84 per cent for panicle number.

He-Yuquing *et al.* (1995) derived information on combining ability on 10 yield components in 4 EGMS lines, 5 restores lines, and their hybrids following an incomplete diallel. Heterosis was affected by SCA of both the sterile and restores lines. The total combining ability and total GCA were closely related for all most all the yield parameters.

Yang-Guifen *et al.* (1997) reported that, the GCA effects of introduced upland rice were better than that of the local varieties. It is suggested that selection emphasis should be on the characters plant height and day to heading in earlier generations, and on panicles per plant, spikelets per panicles, grains per panicle and fertility in advanced generations. The best general combiners were IRAT 216, IRAT104, Tos 2300 and Meng Wangn.

Kalita and Upadhaya (2001) reported that, maximum root length, tillers per plant and root weight per plant were under the control of additive gene action. They also indicated non-additive gene action for root thickness, root volume and root number. For root branching, root to shoot ratio and proportion of thick roots per plant, combination of additive and non-additive gene actions were found.

2.5 Heterosis and identification of transgressive segregates for root and shoot morphological traits

Singh and Singh (1978) reported heterosis in desirable direction for plant height and productive tillers in the cross between Cauvery and T_3 genotypes. Srivastava and Seshu (1982) reported similar results for plant height in crosses between eleven semi dwarfs and four traditional tall.

Armenta-Soto *et al.* (1983) found substantial transgression for maximum root length in two out of three crosses (i.e. DS x IR8 and Moroberekan xO54).

Ekanayake *et al.* (1985) did not find transgressive segregants for root thickness in their study. But, transgressive segregation (Ekanayke *et al.*, 1986) was reported for root length density and root weight. Based on their study on F_1 plants obtained from the cross between IR20 and MGL-2, they reported positive per cent age heterosis for root length, thick root number, root length density and root dry weight.

Ekanayake *et al.* (1986) reported that, F_1 plants of the cross between Zhenshan 97A and IR 64 showed rooting performance substantially higher than the parents but had almost similar seedling heights.

Hemamalini (1997) reported transgressive segregation for different root traits. Heterobeltiosis in desirable direction for most of the root parameters was reported by Girish (1999) from 2 crosses DBN x P210 and P333 x DBN. He also reported high per cent age heterobeltiosis for root dry weight in both the crosses amounting 206.97% and 220.38% for DBN x P210 and P222 x DBN respectively. Both the crosses showed same trend for all the traits except for number of tillers per plant for which the cross P333 x DBN showed negative heterosis compared to DBN x P210 where in the trait recorded positive heterosis.

Zheng *et al.* (1996) reported significant heterosis for root traits such as number of roots, root length, root thickness and root growth ability in a 4 x 4 incomplete dialled cross involving 8-cultivars.

Cheng *et al.* (1997) reported that hybrid rice seedlings of Shanyon 63 F_1 plants were more vigorous in root development and plant growth than parental lines (female Zhen Shan 97A and Male Minghvi 63).

Price *et al.* (1997) observed transgressive segregation for root thickness and root volume.

2.5.1 Heterosis for grain yield parameters

Young and Virmani (1990) reported 23.2 to 28.5%, -35.5 to 21.6% and –36.0 to 16% of heterosis, heterobeltiosis and standard heterosis for the character plant height. They also reported –22.0 to 20.7% -26.4 to 9.7% and –34.2 to 7.0% of mid parent heterosis, heterobeltosis and standard heterosis for the character days to fifty per cent flowering.

Vidyachandra (1991) reported standard heterosis of –35.9 to +30.0%, -35.9 to 30.3%, -56.2 to 9.6% and –45.1 to 18.0% for the character plant height, days to fifty per cent flowering, panicles per plant and number of spikelets per panicle respectively. He also reported –86.6 to 62.1% for grain yield/plant.

Leenakumari (1994) reported standard heterosis of –21.0 to 38.5%, -42.1 to 67.6%, -15.8 to 28.5%, -22.5 to 105%, -82.7 to 81.5% an –79.9 to 111% for the character plant height, panicles per plant, panicle length, number of spikelets per plant, number of filled spikelets per panicle and grain yield per plant respectively.

Patel *et al.* (1994) gathered information on heterosis for 10 yield components in 30 F_1 hybrids from line x tester crosses of 13 rice genotypes grown during 1987 in Navasari. Estimates of heterotic effects were highest for days to 50% flowering, grain per panicle and yield per plant, whereas days to maturity, panicle length and harvest index had the least heterotic effect. Hybrids kalhari x S34-36, khalhari x GR3, IRTP 9298 x IRTP 10800 and N 53 x GR 3 had the greatest heterosis for yield.

Reddy and Nerkar (1995) reported information on heterosis and inbreeding depression (ID) from upland rice crosses. There was highly significant mid parent and better parent heterosis for grain yield in 4-hybrid combinations. In the F_2 population of these 4-hybrids there was inbreeding depression (ID). They also concluded that, high heterosis for yield was due to additive heterotic effect of one or more yield components. They indicated high heterosis and ID for effective tillers per plant and number of filled grains per panicle indicating non-additive gene affects governing these traits.

Hegde (1996) reported standard heterosis of –15.3 to 11.1%, 0.12 to 83.1%, -5.94 to 22.5% and –24.9 to 78.5% for the characters panicles per plant, number of spikelets / panicle, Test weight and grain yield per plant respectively.

Hemareddy (1996) reported standard heterosis of –10.32 to 10.32%, -25.54 to 32.86% -15.19 to 40.14% and –45.88 to 121.60% for the characters days to fifty per cent flowering, plant height, 1000 grain weight and grain yield per plant respectively. Lingaraju (1997) reported maximum negative heterobeltosis for sterility per cent in the hybrid IR58025A x IR5290-9-13-1-1R. The same hybrid recorded maximum negative standard heterosis over Jaya for the character sterility per cent. He also reported heterobeltiosis for 1000-grain weight in the cross IR 64608A X PAU 1126-47-2-1R. But none of the hybrids exhibited significant positive standard heterosis over Jaya for the character

1000grain weight. He also concluded that selection of good hybrids could be through *per se* performance, standard heterosis for important yield components.

Murthy (1996) reported that when selected hybrids were grown under purely rainfed conditions recorded yield to the range of 0.7 to 3.2 t/ha. The highest yielding hybrids were APHR2, MTUHR 2023, MTUHR 2029 and MTUHR 2028. Form their studies it is evident that the hybrids MTUHR 2000, MTUHR 2023, MTUHR 2028, MTUHR 2029 and APHR-2 exhibited higher productivity under natural moisture stress situation have better prospects under rainfed ecosystem.

Chen-Shun Huei *et al.* (1997) reported 13.9 to 20.4% heterosis for grain yield per plant and 26.8 to 29.9% heterosis for spikelets / panicle in the crosses TGMS x WCVs and WCVs x TGMS hybrids respectively. They also reported negative heterosis for fertility, plant height and days to heading.

They indicated that, yield per plant appeared to be controlled by non-additive effects. While, plant height and heading days were conditioned by additive gene effects.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The materials used and the methods adopted in different experiments for the present investigation are presented below.

3.1. Evaluation of parents for various genetic parameters among root and shoot morphological traits under well watered condition

Root studies were conducted using two sets of experiments with 27 and 39 rice genotypes during *summer* and *Kharif* 97 respectively. The details of the genotypes used in both the experiments along with means were listed in annex-1&annexII.

The experiments were conducted in PVC pipes with a dimension of 18 cm diameter and 100 cm length. The experiments were laid out in randomised complete block design (RCBD) with 4 and 3 replications respectively for the experiments with 27 and 39 genotypes at botanical garden, dry land, Hebbal, UAS, Bangalore. Pipes were placed in pits of 1 m. depth, so that the plants could grow at ground level. The pipes then filled with top surface soil and FYM in the ratio of 4:1. The fertilizer application was done according to the recommended package of practices for rice. Seeds were direct seeded in each pipes and after the germination only one seedling was allowed to grow. The plants were well watered daily through out the experimental period.

On 70^{th}day,root sampling was made. The pipes were removed carefully and soaked in water for overnight to loosen the soil. The next day, roots were cleaned thoroughly and carefully using a fine jet of water. The intact root system of each plant was collected and stored. Thereafter, observations were recorded on various root parameters.

3.1.2 Recording of observations

The following observations were recorded from the root samples as detailed below.

1. **Plant height:** On 70th day before root sampling the height of the plants from ground level to the tip of the longest leaf was measured in 'cm'.

2. **Number of tillers per plant:** The total number of tillers were counted and recorded on the day of sampling for each genotype.

3. **Maximum root length:** This was measured from the base of the plant (collar region) to the tip of the longest root in 'cm'.

4. **Total root numbers:** Number of roots per plant were counted at the base of the root system manually.

5. **Root thickness:** The average thickness of nodal roots were measured from the sampled five root pieces of one cm length removed from the base of the root system in 'mm'. Standardized stage micrometer and ocular lens were used to determine the root thickness.

6. **Root volume:** Root volume was measured based on the Archimedes principle. A graduated measuring cylinder was filled with water and the initial volume was recorded, then the root system was immersed in the measuring cylinder and the final volume was noted down after the proportionate water displacement was occurred. The difference of the two readings give root volume in "cc."

7. **Dry weights:** The root and shoot of each plant oven dried after separation at 60°c for 145 hours. The dry weights of root and shoot samples were recorded in grammes.

8. **Computed observation**

a) **Total length:** This was calculated for each genotype by adding plant height and total root length of the particular sample plant.

b) **Deep root length:** This was computed for each genotype by deducting the total root length by 30 cm to know the root length below 30 cm soil depth for all the genotypes. The so obtained value was recorded in "cm".

c) **Root growth rate:** This parameter indicates the growth of root length per day during total experimental duration. This was computed by dividing the maximum root length by total no of days (70) for sampling from the date of sowing. This was recorded as cm/per day.

d) **Root to Shoot ratio:** This was computed by dividing the root dry weight of a sample plant by its shoot dry weight.

3.1.3 Statistical procedures followed:

The mean values of all the characters were analysed for their variance by following RCBD design (Sunderraj *et al.*, 1972).

3.1.4 Estimation of genetic parameters:

The co-efficient of variability both at phenotypic and genotypic levels for all the characters were computed according to the formulae suggested by Burton and Dewane (1953) and Burton (1952).

3.1.4.1 Genotypic and phenotypic co-efficient of variation

$$GCV\% = \frac{\text{Genotypic standard deviation}}{\text{General Mean}} \times 100$$

$$PCV\% = \frac{\text{Phenotypic standard deviation}}{\text{General Mean}} \times 100$$

Per cent PCV and GCV were classified 0-10% low, 10-20% moderate and 20% and above as high as suggested by Sivasubramanian and Menon (1973).

3.1.4.2 Estimation of heritability values

Heritability estimates (broad sense) for different characters were computed using formula (Hanson *et al.*, 1956).

$$h^2\,\% = \frac{Vg}{Vp} \times 100$$

Where h^2 %= heritability expressed in percentage.

V_g and V_p are genotypic and phenotypic variances respectively.

The heritability estimates were categorised as 0-30 % low ; 30-60% moderate and >60% as high (Robinson *et al.*, 1949).

3.1.4.3 Genetic advance:

Genetic advance was calculated using the formula given by Johnson *et al.* (1955).

$$GA = h^2 \times K \times {}^{\sigma}p$$

Where, h^2 = Heritability in broad sense.

K = Selection differential which is 2.06 at 5% intensity of selection (Lush, 1949).

${}^{\sigma}P$ = Phenotypic standard deviation

$$\text{GA as percent mean} = \frac{GA}{\overline{X}} \times 100$$

$\overline{X}$ = General mean

GA = Genetic advance

The genetic advance as percent mean was categorised as 0–10% low; 10-20% moderate and 20% & > 20%as high, as suggested by Johnson *et al.* (1955b).

3.2 Assessment of nature and extent of association among various root and shoot morphological traits and path analysis

Correlation coefficients were computed to find the association amongst characters studied using the formula suggested by Sunderraj *et al.*, (1972).

$$r_{12} = \frac{COV\,(X_1\,X_2)}{\sqrt{V\,(X_1) \times V\,(X_2)}}$$

Where,

r_{12} = correlation coefficients between X_1 & X_2 characters.

$COV\,(X_1X_2)$ = Covariance between X_1 and X_2

Phenotypic and genotypic correlations were computed using the formula given by Singh and Chaudhary (1985).

$$r_{p12} = \frac{COV_P\,(X_1\,X_2)}{\sqrt{V_p\,(X_1) \times V_p\,(X_2)}} \qquad rg_{12} = \frac{COV_g\,(X_1\,X_2)}{\sqrt{V_g\,(X_1)\,V_g\,(X_2)}}$$

Where, r_{p12} and r_{g12} are phenotypic and genotypic correlations respectively. COV_P (X_1X_2) and COV_g (X_1X_2) are phenotype and genotypic covariances respectively.

$V_P\,(X_1)$ and $V_P\,(X_2)$ are phenotypic variances and $V_g\,(X_1)$ and $V_g\,(X_2)$ are genotypic variances for X_1 and X_2 characters respectively.

Significance of correlation coefficients were tested at (n-2) degrees of freedom table value from Fischer and Yates table at 5% and 1% level of significance.

3.2.1 Path co-efficient analysis

To estimate the direct and indirect contribution of various root parameters on root length and total root weight, path co-efficient analysis was done as suggested by Wright (1921). Direct and indirect effects of different traits were calculated by solving a set of simultaneous equations by the abbreviated Doo-little technique described by Goulden (1959) and illustrated by Dewey and Lu (1959).

3.3 Assessment of combining ability, gene action and estimation of heterosis for various root and shoot morphological parameters.

Experiments related to combining ability analysis and estimation of heterosis were conducted during *summer* 1998 and 1999 involving 27 hybrids and their 12 parents under two environments i,e well watered and water stress conditions respectively. For L x T analysis parents were selected randomly to have variation for root characters. For the experiment under well watered condition, plants were watered daily to throughout the experimental duration. In the experiment conducted under low-moisture stress, upto 50 days after sowing (DAS) plants were watered daily. Moisture stress was imposed during the peak vegetative phase of the crop, watering was withheld completely for 15 days from 51^{st} DAS. To prevent irrigation by unexpected rainfall, a polythene sheet was erected above the experimental site. Observations were recorded on different root morphological traits for both the environments. The location of the experiments was botanical garden, dryland, UAS, Hebbal, Bangalore. The details of parents and hybrids (along with means) used in the study were listed in annex-III.

Production of hybrid seeds

The crosses required for this study were effected during *kharif* 1997. For this purpose the seeds of male sterile lines were staggered sown on three different dates with 10 days interval between each sowing. The seeds of male (restorers) and female parents (male sterile lines) raised in well prepared dry nursery beds. 22 days old seedlings were transplanted with a spacing of 20 x 15cm. To prevent any amount of cross pollination a barrier of 2 m length was erected around the male sterile lines. The crosses were effected by hand pollination according to the combinations required using the male sterile lines as female parents. One of the panicle of the female plant was bagged before flower opening to record seed set in male sterile lines of CGMS background. For the TGMS line manual emasculation was done during the early morning hours i.e., with in 7 AM, to ensure 100 per cent sterility as the crossing work was done during (*kharif*) unfavourable temperature regimes for their sterility behaviour.

The crossed seeds were collected from those plants only if the bagged panicles showed no seed set in case of CGMS lines confirming male sterility of females. All the seeds set on TGMS line were collected and used for further investigations.

3.4 Experiment related to estimation of standard heterosis for grain yield parameters

Seeds of 27 F_1s and three checks were sown in well prepared dry nursery bed. Twenty five days old seedlings were transplanted with a spacing of 20 x 15 cm at single seedling per hill in the well prepared main field at wet land, MRS Hebbal, Bangalore during *Kharif*-1998. Randomised complete block design with three replication were adopted for this experiment. The checks used were Jaya, Rasi and Mangala. Recommended package of practice were followed to raise the crop.

3.4.1 Details of observations recorded

For root morphological studies : The observations were recorded as per the information provided in the earlier experiments (3.1) related to estimation of genetic parameters from parents for various root morphological traits.

3.4.2 For grain yield parameters

Estimation of heterosis for yield parameters under well-watered condition, among the confirmed F_1 plants, 3 plants were selected to record the observation as detailed bellow

1. **Days to fifty percent flowering:** Number of days required for fifty percent of the plants to show flowering counted from the date of sowing was recorded.

2. **Plant height:** Height of the plant from ground level to tip of the longest leaf was measured in "cm".

3. **Number of tillers per plant:** This was recorded by counting the total tillers present per plant at the time of harvesting.

4. **Number of productive tillers:** This was recorded by counting the panicle bearing tillers per plant.

5. **Panicle length:** Mean length of the randomly selected 5 panicles per hill was measured in cm.

6. **Total number of spikelets per panicle:** Number of spikelets per panicle was counted and recorded.

7. **Number of filled grains per panicle:** Number of filled spikelets per panicle were counted and recorded.

8. **1000 grain weight:** Thousand well filled grains were counted from the random sample and the weight was taken in 'g'.

9. **Grain yield per plant:** Grain yield per plant was recorded in 'g' by weighing all the filled grains of ear bearing panicles per plant, after threshing, cleaning and drying (moisture level of 14%).

10. **Per cent spikelet fertility (computed character):** The ratio of filled grains to total number of spikelets was expressed in percentage.

3.4.3 L x T analysis

The mean values recorded from two different environments on various root morphological traits of 27 hybrids and 12 parents were subjected to line x tester analysis as suggested by Kempthorne (1957). The biometrical analysis was carried out as per Singh and Choudhary (1985).

ANOVA for L x T analysis

Source	Df	MSS	Expected MSS
Replication	r-1	M	
Lines	(f-1)	M_1	$\sigma e^2 + r\,\sigma sca^2 + r.m.\,\sigma gca^2$
Testers	(m-1)	M_2	$\sigma e^2 + r\,\sigma sca^2 + r.f.\,\sigma gca^2$
L X T	(f-1) (m-1)	M_3	$\sigma e^2 + r\,\sigma sca^2$
Error	(r-1) (g-1)	M_4	σe^2

Where "g" in error "df "column = (m + f + mf)

Where,

r = Number of replications

m = Number of male parents (testers)

f =Number of female parents (lines)

σ^2_{gca} (Variance due to gca) = Cov HS (avg)

σ^2_{sca} (Variance due to sca) = [Covs FS –2 cov HS]

From the mean sum of squares, co-variance of full sibs and half sibs were estimated as per Singh and Chaudhary (1985).

$$\text{Covariance of full sibs (FS)} = \frac{[M_1+M_2+M_3-3M_4 + 6r.Cov\,(HS)-r\,(m+f)]Cov.(HS)}{3r}$$

$$\text{Covariance of half sibs (avg)} = \frac{M_1 + M_2 - 2\,M_3}{r\,(m+f)}$$

$$\sigma^2_{gca} \text{ for lines (females)} = \frac{M_1-M_3}{r.m}$$

$$\sigma^2_{gca} \text{ for testers (males)} = \frac{M_1-M_3}{r.\,f}$$

$$\sigma^2_{sca} \text{ for hybrids (Females)} = \frac{M_3-M_4}{r.}$$

Where, M_1, M_2, M_3 and M_4 are mean sum of squares due to lines, testers, L x T and error respectively.

3.4.3.1 Combining ability effects

Line x Tester model as suggested by Kempthrone (1957) was adopted for combining ability analysis. The mathematical model used to estimate combining ability effects are as follow.

$$X_{ij} = \mu + g_i + g_j + s_{ij} + r_k + e_{ijk}$$

μ = Population mean

g_i = GCA effect of i^{th} female parent (line)

g_j = GCA effect of j^{th} male parent (tester)

s_{ij} = SCA effect of ij^{th} combination

e_{ijk} = Error associated with ij^{th} cross in k^{th} replication

r_k = K^{th} replication effect

i= Number of female parents

j = Number of male parents

k = Number of replications

3.4.3.2 General combining ability

a) Lines:

$$gi = (\text{GCA effect of } i^{th} \text{ line}) = \frac{x_i}{m.r} - \frac{x....}{m.f.r}$$

Where Xi.... = Total of i^{th} female parent over all male parents and replications

X ....= Total of hybrid over all the replications.

$$\text{b) Testers } g_j \text{ (GCA effect of } j^{th} \text{ tester)} = \frac{X_j}{f.r} - \frac{x....}{m.f.r}$$

x_j = Total of j^{th} male parents over all the female parents on replications

3.4.3.3 Specific combining ability

$$S_{ij} = \frac{X_{ij}}{r} - \frac{X_{i.}}{mr} - \frac{X_{j.}}{fr} - \frac{X....}{m.f.r}$$

Where,

S_{ij} = Specific combining ability effects of ij^{th} combination

X_{ij} = Total of ij^{th} combination over all the replications

The standard error (SE) of estimates of GCA and SCA effects were estimated using the following formulae.

Standard error (SE) of g_i's (Female) = $\sqrt{\frac{M_4}{m.r}}$

Standard error (SE) of g_j's (Male) = $\sqrt{\frac{M_4}{f.r}}$

Standard error (SE) of s_{ij}'s (Hybrids) = $\sqrt{\frac{M_4}{r}}$

Where, M_4, m, f and r take the same meaning as described earlier.

The estimates of 't' for g_i's g_j's and s_{ij}'s for statistical significance were given by .

$$t_{gi} = \frac{g_i - o}{SE\ (g_i)} \qquad t_{gj} = \frac{g_j - o}{SE\ (g_j)} \qquad : \qquad ts_{ij}\text{'s} = \frac{s_{ij} - o}{SE\ (s_{ij})}$$

Scoring index for leaf rolling and tip firing parameters

1. Leaf rolling: Leaf rolling was assessed on plants for 4 days from 61 DAS to 65 DAS between 12.30 PM to 2.30 PM. The index followed was 0 (completely rolled) to 5 (no rolling). Mean scores obtained by an individual genotype over 3-replications was used for final interpretation along with means for root length and root volume. The classification and scores assigned were as detailed below.

				Score
1).	0.00	to	1.66	3
2).	1.67	to	3.33	2
3).	3.34	to	5.00	1

II Tip firing: All the plants were assessed phenotypically for 4 days from 60 DAS to 65 DAS to give a score on 65th day (i.e the final day of stress period). The index followed was 0 (all the leaves are green) to 5 (most of the leaves with tip firing >5cm length). Mean scores obtained by an individual genotype over 3-replications were used for analysis. The following classification was followed for scoring.

				Score
1).	0.00	to	1.66	1
2).	1.67	to	3.33	2
3).	3.34	to	5.00	3

3.5 Estimation of magnitude of heterosis for various root, shoot and yield parameters

The analysis was done using the mean values of observations recorded on root morphological traits from single plant per replication and yield parameters from 5 randomly selected plants from parents, hybrids and checks.

The analysis of RCBD was carried out following the methods described by Panse and Sukathme (1976).

The details of ANOVA are furnished below.

Source	df	MSS	F cal
Replications	r-1	Vr	Vr/Ve
Parents /hybrids/checks	t-1	Vt	Vt/Ve
Error	(t-1) (r-1)	Ve	

The standard error and critical differences for comparison of means were calculated as detailed below:

S.E. M $= \sqrt{2\,{}^{\sigma}e^2/r}$

C.D. $= \sqrt{2\,{}^{\sigma}e^2/r.}$ x " t" value at 5% level of probability

3.5.1 Estimation of heterosis

The magnitude of heterosis was estimated as heterosis over mid parent, better parent (heterobeltiosis) and over check variety for different root and shoot traits. Heterosis was calculated as percentage increase or decrease of F_1 mean performance over the mean performance of line in question. Significance of heterosis was tested using simple student 't' test.

a) Percentage heterosis over the mid parent:

$$HMP\,\% = \frac{\overline{F}_1 - MP}{MP} \times 100 \qquad MP = \frac{\overline{P}_1 + \overline{P}_2}{2}$$

Where, HMP% = Heterosis over mid parent value

b) Percentage heterosis over better parent

$$HBP\,\% = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100,$$

Where, HBP% = Heterosis over better parent

c) Percentage heterosis over standard variety :

$$SH\% = \frac{\overline{F}_1 - \overline{\text{std. var}}}{\overline{\text{Std. var}}} \times 100,$$

Where, SH% = Heterosis over check variety

Standard error of mean and t values

1) $$SE\,(HMP) = \frac{2\,Ve}{r}$$

$$\text{'t' value} = \frac{\overline{F}_1 - MP}{S.E.\,(MP)}$$

2) SE (HBP) = $\frac{2\,Ve}{r}$

$$\text{'t' value} = \frac{\bar{F}_1 - \overline{BP}}{S.E.\ (\overline{BP})}$$

3) SE (SH) = $\frac{2\,Ve}{r}$

$$\text{'t' value} = \frac{\bar{F}_1 - \overline{std.var}}{S.E.\ (std.\ \overline{var})}$$

Where,

Ve = Error mean sum of squares from RCBD ANOVA

$\bar{F}_1$ = Mean of F_1

MP = Average of means of both the parents involved in that cross.

$\overline{BP}$ = Mean of Better parent in that particular cross.

$\overline{Std.\ var}$ = Mean of Standard variety

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

4.1 Studies on variability and character association

Experiment: 1A: (with 27-genotypes)

Twenty seven genotypes comprising few selected DH lines of IR64 x Azucena cross, male sterile and restores lines of three line hybrid rice breeding, TGMS lines and few checks were evaluated for eleven root and shoot morphological parameters during *Summer*-1997. From this experiment the following genetic parameters were estimated viz., phenotypic coefficients of variability (PCV), genotypic coefficients of variability (GCV), heritability (h^2) and genetic advance as per cent mean in addition to range for means of all the characters.

Analysis of variance

The mean values of all the genotypes for eleven root morphological traits are presented in Annex-1. Analysis of variance indicated highly significant difference among genotypes for all the characters studied (Table 1) indicating ample variability among the genotypes under study.

4.1 A Variability and genetic parameters

The variability parameters for all the 11 characters are furnished in table 2. The graphical representation of per cent PCV, GCV, heritability and genetic advance as per cent mean are depicted in Fig. 1.

4.1A.1 Plant height

A wide variation was observed with mean values ranged from 42.55 (IR62829A) to 83.25 cm (Azucena) with over all mean of 52.10 cm. The phenotypic and genotypic coefficient of variability for plant height were moderate with 19.96 and 17.70 per cent respectively. Higher estimates of

Table :1 : Mean sum of squares for 11-root and shoot morphological traits in 27 rice genotypes (S*ummer* 1997) :

Source	Df	CH_I	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	CH_8	CH_9	CH_{10}	CH_{11}
Replications	3	27.55	280.25	373.63	280.25	0.06	9.31	139.13	0.01	149.28	13.48	0.98
Treatments	26	363.15**	1214.57**	2129.09**	1214.57**	0.25**	80.20**	2211.49**	0.05**	747.24**	74.54**	2.45**
Error	78	23.18	131.79	166.67	131.79	0.03	17.00	130.63	0.01	153.50	11.50	0.81
Total	107	413.87	1626.60	2669.38	1626.60	0.33	106.51	2481.25	0.06	1050.02	99.51	4.24

* = Significance at 5% level of probability

** = Significance at 1% level of probability

CH_1 = Plant height (cm)

CH_2 = Number of tillers

CH_3 = Maximum root length (cm)

CH_4 = Total length (cm)

CH_5 = Deep root length (cm)

CH_6 = Root growth rate (cm/day)

CH_7 = Number of roots

CH_8 = Root thickness (mm)

CH_9 = Root dry weight (gms)

CH_{10} = Shoot dry weight (gms)

CH_{11} = Root to shoot ratio

Table- 2 : General mean (GM), Range, PCV%, GCV%, h^2% and GA-as per cent mean for 11-root and shoot morphological traits in 27 rice genotypes (*Summer* 1997)

Sl No.	Characters	RANGE							GA at K=2.06	GA as per cent mean
		GM	(SEm±)	Min	Max	PCV%	GCV%	h^2%		
1	Plant height (cm)	52.10	3.40	42.45	83.25	19.96	17.70	78.60	16.83	32.30
2	Number of tillers	19.64	8.12	12.50	23.25	29.16	20.24	48.20	5.68	28.92
3	Maximum root length (cm)	48.91	9.11	27.10	90.00	41.02	33.64	67.30	27.80	56.84
4	Total length (cm)	107.91	8.12	71.07	188.75	27.75	25.05	81.50	50.29	46.59
5	Deep root length (cm)	18.91	0.12	-2.90	60.00	106.11	87.02	67.30	27.80	147.04
6	Root growth rate (cm/day)	0.70	8.49	0.39	1.29	41.02	33.64	67.30	0.40	57.22
7	Number of roots	59.12	8.08	28.25	120.53	43.15	38.58	79.90	42.01	71.06
8	Root thickness (mm)	0.68	0.06	0.45	0.87	19.59	15.60	63.40	0.17	25.15
9	Root dryweight (gms)	21.85	8.76	4.30	62.15	79.51	55.75	49.20	17.60	80.53
10	Shoot dryweight (gms)	13.58	2.40	6.60	22.65	38.46	29.24	57.80	6.22	45.82
11	Root to shoot ratio (R:S)	1.63	0.64	0.53	2.94	67.86	39.31	33.60	0.76	46.63

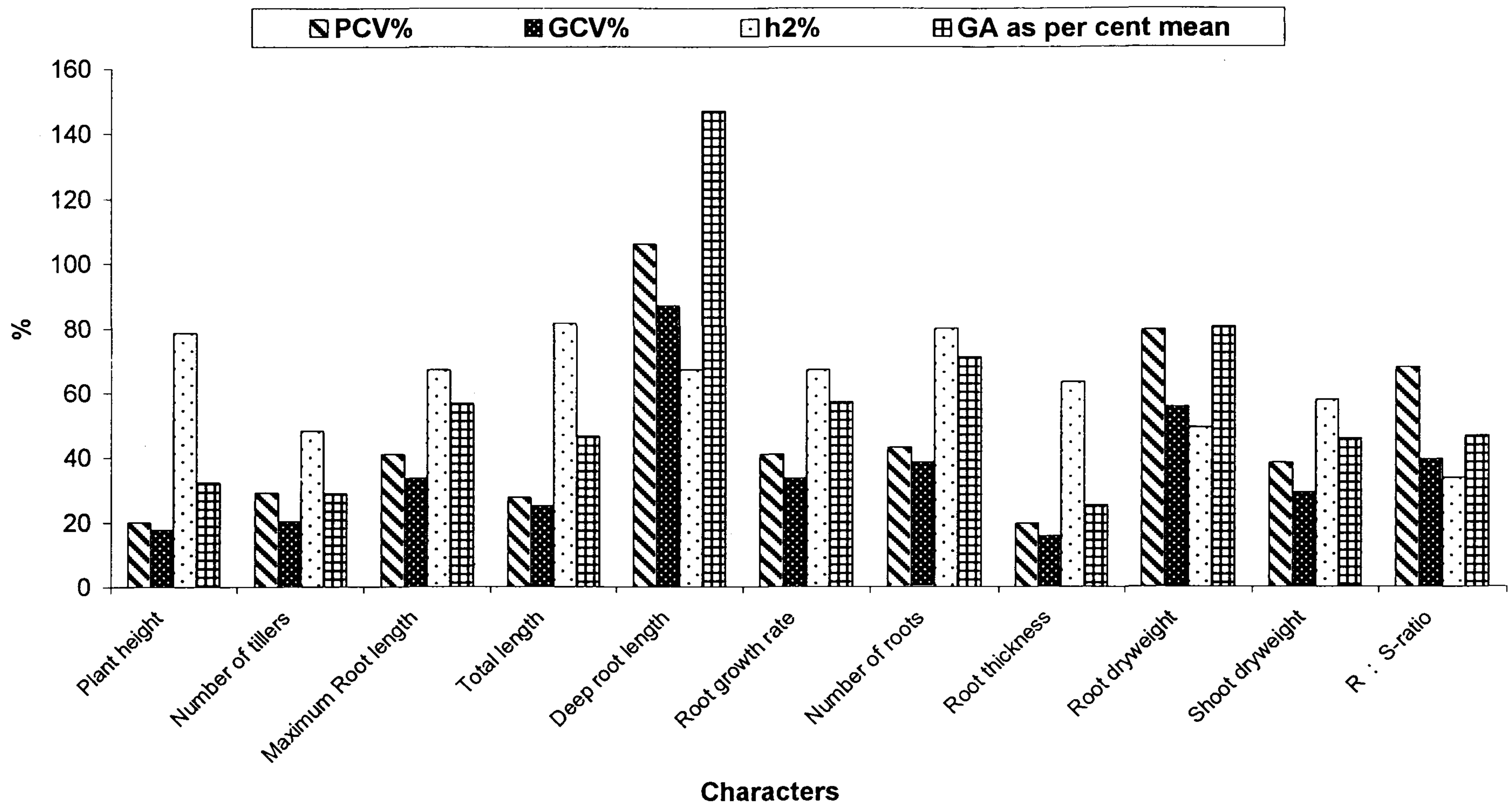

Fig 1 : Percent PCV, GCV, h^2 and GA as per cent mean for 11-root and shoot morphological traits in 27rice genotypes

heritability (78.60%) and genetic advance as per cent mean (32.30%) were exhibited by this trait.

4.1A.1.2 Number of tillers per plant

High magnitude of variation was exhibited and it ranged from 12.50 (IR47310-94-4-3-1R) to 23.25 (Hyb-1) with general mean of 19.64. This character recorded 29.16 and 20.24 per cent of PCV ad GCV respectively indicating influence of environment. Moderate heritability estimate of 48.20 per cent and genetic advance as per cent mean (28.92%) were observed for this character.

4.1A. 1.3 Maximum root length

This character also showed higher magnitude variation. The mean values ranged from 27.10 cm (IR68949-11-5-31) to 90.00 cm (Azucena) with over all mean of 48.91 cm. Moderate difference were observed between PCV & GCV estimates. The PCV per cent was 41.02 and GCV was 33.64 per cent. This trait recorded 67.30 per cent of heritability estimate with high genetic advance as per cent mean (56.84).

4.1A .1.4 Total length

Over all mean recorded for this trait was 107.91 cm, with wide range of variation observed in means for genotypes ranging from 71.07 (IR62829B) to 153.25cm (Azucena). High phenotypic and genotypic coefficients of variability of 27.75 to 25.05 per cent were observed for this character respectively. Heritability estimate of 81.50 per cent and 46.59 per cent of genetic advance as per cent mean were accounted.

4.1A.1.5 Deep root length

This character recorded a general mean of 18.91 cm with range from -2.90 cm (IR68949-11-5-31) to 60.00 cm (Azucena). PCV per cent of 106.11

and GCV estimate of 87.02 per cent were recorded for this trait indicating moderate difference between them. This character exhibited heritability estimate of 67.30 per cent and 147.04 per cent of genetic advance as per cent mean.

4.1A. 1.6 Root growth rate

Marked variability was observed for this trait with an over all mean of 0.70 cm/day. The range for this character was from 0.39 cm/day (IR68949-11-5-31) to 1.29 cm/day (Azucena). This root character recorded PCV and GCV estimates of 41.02 per cent and 33.64 per cent respectively. Higher estimates of 67.30 per cent and 57.22 per cent were recorded for heritability and genetic advance as per cent mean respectively.

4.1A .1.7 Number of roots

A range of 28.25 (IR47310-94-4-3-1R) to 120.50(IR48275-13-13-141-2R) with general mean of 59.12 was recorded for this character indicating highest degree of variation. Phenotypic coefficient of variability estimate of 43.15 per cent and genotypic coefficient of variability per cent of 38.58 were observed. Number of roots also recorded heritability estimate of 79.90 per cent and genetic advance as per cent mean of 71.06 per cent.

4.1A. 1.8 Root thickness

Moderate to high degree of variation was recorded with a general mean of 0.68 mm and range of 0.45 mm (IR65507-58-1-3-R) to 0.87 mm (Azucena) for this trait. PCV recorded was 19.59 per cent and GCV was 15.60 per cent. Heritability estimate (63.40%) and genetic advance as per cent mean (25.15%) recorded for this trait were in higher magnitude.

4.1A. 1.9 Root dry weight

This root parameter exhibited high degree of variation ranging from 4.30 g (IR62829A) to 62.15 g (Azucena) with a general mean of 21.85g.

Moderate difference was recorded between PCV (79.51%) and GCV estimates (55.75%) indicating influence of environment on this character. Heritability estimate and genetic advance as per cent mean of 49.20 per cent and 80.53 per cent were recorded respectively indicating moderate to high magnitudes for these genetic parameters.

4.1A. 1.10 Shoot dry weight

High range of 6.60 g (IR58025B) to 22.65 g (Azucena) with a over all mean of 13.58 g were recorded for this trait. Moderate difference was observed between PCV (38.46 per cent) and GCV (29.24 per cent) estimates for this root character. Heritability estimate of 57.80 per cent (moderate) and high genetic advance as per cent mean of 45.82 per cent were exhibited by this character.

4.1A. 1.11 Root to shoot ratio

General mean recorded for this trait was 1.63 with a range of 0.53(IR36) to 2.94 (IR68945-4-33-4-14) indicating considerable amount of variation existed for this trait. PCV of 67.86 per cent and 39.31 per cent of GCV were recorded. Heritability estimate recorded was 33.60 per cent (moderate) with higher genetic advance as per cent mean of 46.63 for this trait.

4.1A. 2. Phenotypic and genotypic correlation coefficients amongst nine root and shoot morphological traits

The genotypic and phenotypic correlation coefficients among all the characters are presented in Table-3.

In general, the genotypic correlation coefficients were found to be higher than the respective phenotypic correlation co-efficient except between the traits total length and number of tillers per plant.

Significant positive associations were recorded for the traits maximum root length (0.45), total length (0.70), root dry weight (0.74), shoot dry weight (0.43) and Root to shoot ratio (0.65) with plant height at genotypic level. At

Table:3 : Phenotypic (P) and Genotypic (G) correlation coefficients amongst nine root and shoot morphological traits in 27 rice genotypes (*Summer* 1997)

Sl.No.	Characters		Plant height	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	CH_8
CH_2	Number of tillers	P	-0.20	1.00						
		G	-0.32	1.00						
CH_3	Maximum root length	P	0.35	0.10	1.00					
		G	0.45*	0.18	1.00					
CH_4	Total length (cm)	P	0.65**	0.03	0.88**	1.00				
		G	0.70**	0.01	0.88**	1.00				
CH_5	Number of roots	P	0.23	0.33	0.31	0.36	1.00			
		G	0.26	0.45*	0.41*	0.433*	1.00			
CH_6	Root thickness (mm)	P	0.05	0.04	0.41*	0.33	0.29	1.00		
		G	-0.04	0.03	0.53**	0.37	0.37	1.00		
CH_7	Root dry weight (gms)	P	0.48*	0.11	0.61**	0.70**	0.53**	0.26	1.00	
		G	0.74**	0.16	0.93**	0.99**	0.69**	0.48*	1.00	
CH_8	Shoot dry weight (gms)	P	0.32	0.20	0.47*	0.57**	0.37	0.23	0.55**	1.00
		G	0.43*	0.17	0.57**	0.70**	0.55**	0.28	0.78**	1.00
CH_9	Root to shoot ratio	P	0.32	0.01	0.38	0.43*	0.33	0.10	0.74**	-0.03
		G	0.65**	0.11	0.79**	0.84**	0.50*	0.31	0.74**	0.22

* = Significance at 5% level of probability

** = Significance at 1% level of probability

phenotypic level total length and root dry weight exhibited significant positive association with plant height. Number of tillers per plant, number of roots and root thickness recorded non-significant negative association with plant height. While, other parameter viz., maximum root length, number of roots, root thickness, shoot dry weight and root to shoot ratio exhibited non-significant positive association with plant height at phenotypic level.

Number of tillers per plant had positive significant (0.45) association with number of roots only. While this trait had positive non-significant association with all other traits both at genotypic and phenotypic levels.

Maximum root length exhibited significant positive correlation with total length (P=0.88; G=0.87), root thickness (P=0.41; G=0.53), root dry weight (P=0.61; G=0.93) and shoot dry weight (P=0.47; G=0.57) at both the levels. However, number of roots (0.41) and root to shoot ratio had positive significant association (0.79) at genotypic level only. While these traits showed non-significant association with maximum root length at phenotypic level.

Numbers of roots (0.43), root dry weight (0.99), shoot dry weight (0.70) and root to shoot ratio (0.84) exhibited highly significant positive association with total length at genotypic level. At phenotypic level the association between number of roots and total length was positive non significant. Root thickness showed positive association with total length at both the levels but were non-significant.

However, number of roots exhibited significant positive association with root dry weight (0.69), shoot dry weight (0.55) and R: S ratio (0.50) at genotypic level. While root dry weight (0.53) was the only trait, which recorded significant positive association with number of roots at phenotypic level, the other traits had non-significant positive association with number of roots.

Root thickness recorded positive association with root dry weight, shoot dry weight and R: S ratio at both the levels. But, significant association at genotypic level was observed between the traits root dry weight and root thickness (0.48).

Root dry weight exhibited highly significant positive association with shoot dry weight (P=0.55; G=0.78) and R:S ratio (P=0.757 ; G=.738) at both levels.

Negative non-significant association was observed between shoot dry weight and R: S ratio at phenotypic level, while it was in positive direction at genotypic level without significance.

4.1A.2.1 Path analysis

The phenotypic path coefficients of maximum root length with other drought avoidance related plant characters in rice genotypes are presented in Table 4.

Total length exhibited the highest direct effect of 0.960 on maximum root length followed by root dry weight (0.260) and root thickness (0.060). Low, magnitude negative direct effects were found on maximum root length by plant height (-0.360), shoot dry weight (-0.210), root to shoot ratio (-0.189) and number of roots –0.038 in the decreasing order.

Plant height showed positive indirect effects on maximum root length through total length (0.730), root dry weight (0.120) and root thickness (0.003) in the decreasing order.

Number of tillers exhibited very low magnitude positive indirect effects on maximum root length *via* plant height (0.070), total length (0.029) root dry weight (0.029) and root thickness (0.003). Low magnitude negative indirect effects of –0.043, -0.012 and –0.002 were recorded by shoot dry weight, number of roots and root to shoot ratio respectively on maximum root length through number of tillers.

'able 4 : **Direct (Diagonal) and Indirect (Below / Above diagonal) effects of eight root and shoot morphological traits on maximum root length in 27 rice genotypes (phenotypic level)**

l No.	Character	CH_1	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	CH_8	Correlation with maximum root length
CH_1	Plant height (cm)	**-0.360**	-0.005	0.725	-0.009	0.003	0.124	-0.067	-0.060	0.351
CH_2	Number of tillers	0.073	**0.024**	0.029	-0.012	0.003	0.029	-0.043	-0.002	0.100
CH_3	Total length (cm)	-0.233	0.001	**1.122**	-0.014	0.022	0.181	-0.121	-0.810	0.878**
CH_4	Number of roots	-0.082	0.008	0.406	**-0.038**	0.019	0.137	-0.078	-0.063	0.308
CH_5	Root thickness (mm)	-0.016	0.001	0.371	-0.011	**0.060**	0.068	-0.048	-0.018	0.413*
CH_6	Root dry weight (gms)	-0.171	0.003	0.782	-0.020	0.017	**0.260**	-0.117	-0.143	0.611**
CH_7	Shoot dry weight (gms)	-0.114	0.005	0.640	-0.014	0.015	0.143	**-0.212**	0.006	0.469*
CH_8	R : S	-0.114	0.001	0.481	-0.013	0.006	0.197	0.007	**-0.189**	0.376

Residual effect (R) = 0.1338

Total length recorded highest positive direct effect of 1.122 on maximum root length, also showed positive indirect effects through root dry weight (0.181), root thickness (0.022) and number of tillers (0.001) in the descending order of magnitude. Moderate to high negative indirect effects of –0.810 and –0.233 were exhibited by root to shoot ratio and total length on maximum root length respectively. The indirect effects of the remaining characters on maximum root length were low in magnitude and negative.

Number of roots exhibited low negative direct effect (-0.04) on maximum root length, however recorded positive indirect effects through total length (0.406) followed by root dry weight (0.132), root thickness (0.019) and number of tillers (0.008) in the declining order of magnitude. The remaining characters recorded lower magnitude negative indirect effects through total length on maximum root length .

Moderate positive indirect effect of 0.37 was exhibited by root thickness through total length on maximum root length. This character showed positive indirect effects *via* root dry weight and number of tillers. Negative indirect effects observed through plant height, root: shoot ratio, shoot dry weight and number of roots on maximum root length were found to be very low.

Root dry weight recorded second highest positive direct effect (0.26) on maximum root length also, exhibited higher magnitude positive indirect effects *via* total length (0.782). This character showed moderate negative indirect effect on maximum root length through plant height (-0.171) and R:S ratio (-0.143). The remaining characters exhibited low magnitude positive and negative effects through root dry weight on maximum root length. Very low magnitude positive indirect effects of 0.005, 0.006 and 0.015 were exhibited by number of tillers, R: S ratio and root thickness *via* shoot dry weight respectively. While, moderate positive effect of 0.14 was exhibited by root dry weight *via* shoot dry weight on maximum root length. Total length had exhibited highest positive indirect effect (0.640) on maximum root length through shoot dry weight.

The character total length recorded high magnitude positive indirect effect (0.481) *via* R: S ratio followed by root dry weight (0.197) on maximum root length *via*, root to shoot ratio very low positive effects of 0.001, 0.006 and 0.007 on maximum root length were displayed by number of tillers, root thickness and shoot dry weight respectively.

Experiment: 1B (39 – genotypes)

4.1B : Analysis of variance

In another experiment with 39 genotypes which mainly comprised of rain fed local rice collections and DH-lines derived from the cross IR64 x Azucena were evaluated for variability. Few check varieties were also included in this experiment. This experiment was conducted during *kharif*-1997 to assess genetic parameters, character association and path analysis mainly from local rain fed varieties.

The mean values of all the genotypes for various root and shoot morphological traits associated with drought avoidance are presented in Annex-II. Analysis of variance showed highly significant variation among experimental lines for all the ten-characters studied (Table 5) indicating sufficient variability.

4.1B.1 Variability and genetic parameters

The variability parameters are furnished in Table 6. The graphical representative of PCV (%), GCV (%), heritability estimates (%) and genetic advance as per cent mean are depicted in Fig. 2.

4.1B. 1.1 Plant height

Substantial amount of variation was observed for mean values and ranged from 57.90 (IR68949–11-5-31) to 106.23 (Azucena) cm. PCV and GCV estimates were moderate for this trait with 17.93 and 14.67 per cent respectively.

Table : 5 : Mean sum of squares for 10-root and shoot morphological traits in 39 rice genotypes (*Kharif*-1997)

Source	Df	CH_1	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	CH_8	CH_9	CH_{10}
Replications	2	40.41	14.27	57.75	133.94	133.94	2.73	90.69	0.35	322.06	0.09
Treatments	38	463.33**	82.53**	2673.41**	1430.77**	1430.77**	0.29**	2753.51**	26.41**	4277.07**	24.08**
Error	76	65.60	7.62	116.80	52.99	52.99	0.01	52.11	2.15	375.09	1.59
Total	116	569.33	104.40	2847.96	1617.69	1617.99	3.03	2896.30	28.91	5003.12	25.76

* = Significance at 5% level of probability

** = Significance at 1% level of probability

CH_1 = Plant height (cm)

CH_2 = Number of tillers

CH_3 = Total length (cm)

CH_4 = Maximum root length (cm)

CH_5 = Deep root length (cm)

CH_6 = Root growth rate (cm/day)

CH_7 = Number of roots

CH_8 = Total root dry weight (gms)

CH_9 = Root volume (cc)

CH_{10} = Root weight (<30 cm soil depth) (gms)

Table 6 : General mean (GM), Range , PCV%, GCV%, h^2%and GA as per cent mean for 10 root and shoot morphological traits in 39 rice genotypes (*Kharif* -1997)

Sl. No.	Characters	GM	SEm±	RANGE		PCV%	GCV%	h2%	GA at K=2.06	GA as (%) mean
				Min	Max					
1	Plant height (cm)	78.51	6.61	57.90	106.23	17.93	14.67	66.90	19.40	24.71
2	Number of tillers	20.37	2.25	11.00	29.67	28.03	24.53	76.60	9.01	44.24
3	Total length (cm)	133.66	8.82	90.60	226.73	23.29	21.84	87.90	56.40	42.20
4	Maximum root length (cm)	55.15	5.94	30.03	120.50	41.04	38.86	89.70	41.80	75.79
5	Deep root length (cm)	25.15	5.94	0.03	90.50	89.99	85.21	89.70	41.80	166.20
6	Root growth rate (cm/day)	0.79	0.09	0.43	1.72	41.03	38.85	89.60	0.60	76.14
7	Number of roots	99.35	5.89	37.67	171.00	31.07	30.20	94.50	60.10	60.49
8	Total root dry weight (gms)	6.99	1.20	3.03	13.20	45.74	40.66	79.00	5.21	74.49
9	Root volume (cc)	96.80	15.81	37.33	191.33	42.29	37.26	77.60	65.45	67.62
10	Root dry weight (<30cm soil depth) (gms)	6.19	1.03	1.60	12.47	48.74	44.27	82.50	5.12	82.78

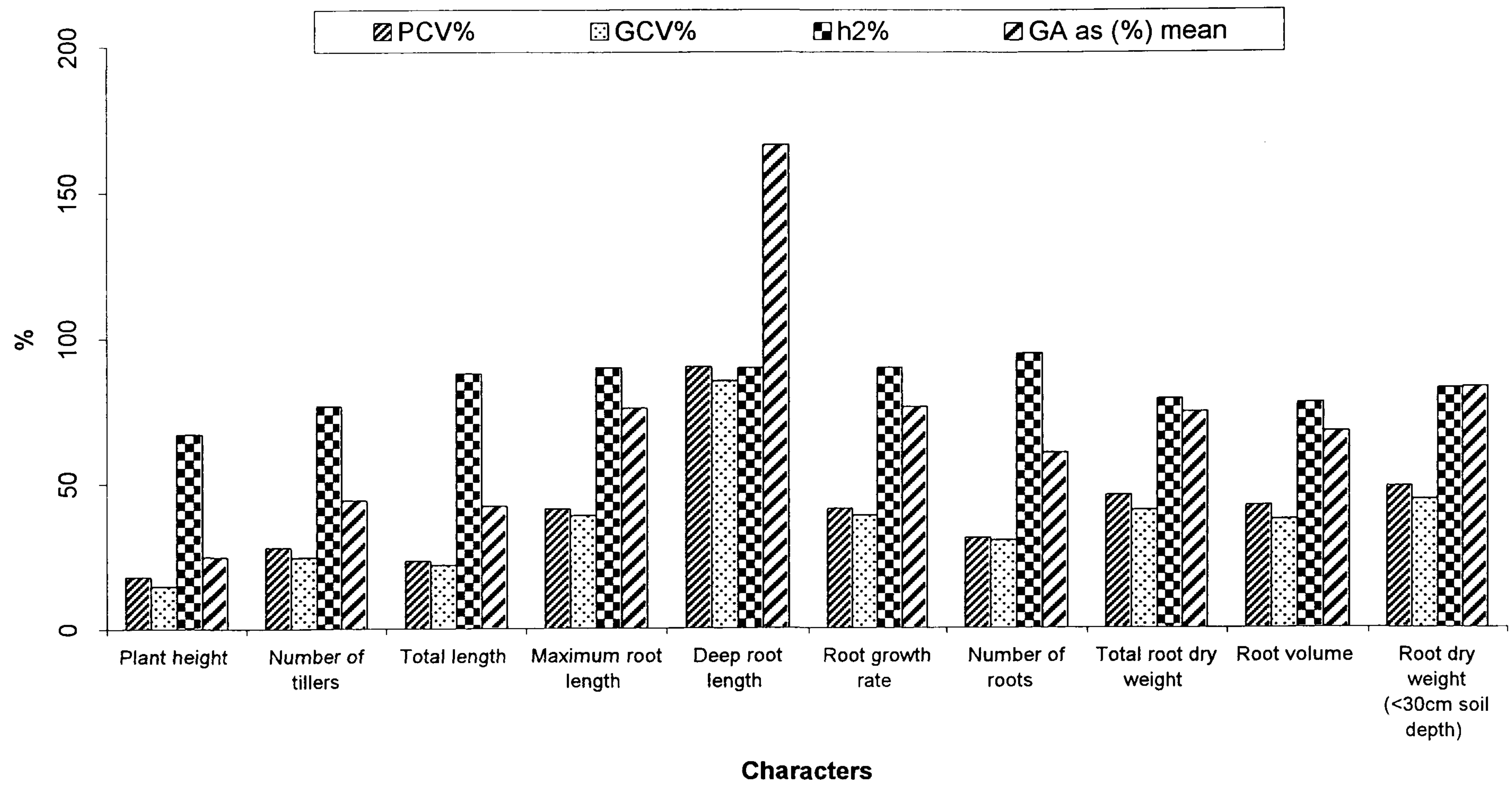

Fig 2 : Percent PCV, GCV, h2 and GA as per cent mean for 10-root and shoot morphological traits in 39 rice genotypes

This character recorded high heritability estimate of 66.90 per cent and 24.71 per cent of genetic advance as per cent mean.

4.1B. 1.2 Number of tillers

High magnitude variation was observed for this trait with a range of 11.00 (P163) to 29.67 (Hyb-1) and a general mean of 20.37. This character exhibited high PCV and GCV per cent of 28.03 and 24.53 respectively. Heritability estimate recorded for this trait was 76.60 per cent with genetic advance as per cent mean of 44.24 per cent indicating high magnitude values.

4.1B. 1.3 Total length

This character recorded a general mean of 133.66 cm with means of genotypes ranged from 90.60 cm (Hyb-1) to 226.73 cm (Azucena). High estimates of PCV, GCV per cent of 23.29 and 21.84 were recorded respectively. This character reflected very high heritability estimate (87.90%) with 42.20 per cent of genetic advance as per cent mean

4.1B. 1.4 Maximum root length

A range of 30.03 (Co-39) to 120.50 cm (Azucena) and general mean of 55.15 cm were observed for this trait. Higher PCV and GCV estimates of 41.04 and 38.86 per cent and heritability estimate of 89.70 per cent were noticed for this character. Genetic advance as per cent mean recorded for this trait was 75.79 per cent.

4.1B. 1.5 Deep root length

Substantial amount of variability was showed by this root parameter with a range of 0.06 (Co-39) cm to 90.50 cm (Azucena). General mean recorded for this trait was 25.15 cm. Very high phenotypic coefficient of variability (89.99%) and GCV (%) 85.21 were estimated for this character with highest genetic advance as per cent mean (166.20%).

4.1B. 1.6 Root growth rate

Marked variability was found with a general mean of 0.79 cm/day and a range for the means was from 0.43 cm/day (P 89) to 1.72 cm/day (Azucena) 41.03 % and 38.85% of PCV and GCV estimates were exhibited by this trait respectively. The heritability value calculated for this character was 89.60 per cent with high magnitude GA as per cent mean of 76.14 per cent.

4.1B. 1.7 Number of roots

This root parameter registered a general mean of 99.35 with a range for the means 37.67 (P 210) to 171.0 (P41). PCV and GCV estimates recorded for this character were 31.07% and 30.20% respectively. Highest heritability estimate (94.50%) was exhibited by this trait with GA as per cent mean of 60.49 per cent.

4.1B. 1.8 Total root dry weight

High range of 3.03 (P 192) to 13.20 gm (Budda) with an over all mean of 6.99 gm were observed for this trait. Moderate high estimates of PCV and GCV per cent of 45.74 to 40.66 were estimated for this root trait with heritability estimate of 79.00 per cent and GA as per cent mean of 74.49 per cent.

4.1B. 1.9 Root volume

Root volume exhibited substantial amount of variability with means ranged from 37.33 (P 124) to 191.33 cc (Rasi). General mean recorded was 90.80 cc.

High estimates of 42.29 and 37.26 per cent for PCV and GCV were noticed respectively for this root character. Heritability value of 77.60 per cent and genetic advance as per cent mean of 67.62 per cent were also exhibited by this trait.

4.1B. 1.10 Root dry weight up to 30 cm depth

High degree of variation ranging from 1.60 (P 89) to 12.47 gms (Budda), was observed for this character with an over all mean of 6.19 gm. Lesser difference was recorded for PCV (48.74%) and GCV (44.27%) estimates with heritability value of 82.50 per cent. This parameter registered high magnitude value of GA as per cent mean (82.78%).

4.1B. 2 Phenotypic and genotypic correlation coefficients amongst root and shoot morphological traits

The genotypic and phenotypic correlation coefficients among all the eight-characters were presented in table 7.

The phenotypic and genotypic correlation coefficients observed among all the 8-traits indicated, the values of genetic correlations coefficients were higher than the respective phenotypic coefficients.

Except for number of tillers, the correlation coefficients observed between plant height with all other traits were positive. Significant positive associations were noticed for total length (P=0.75; G=0.78), maximum root length (P=0.40; G=53) and root volume (P=0.33; G=0.47) with plant height. Positive non-significant correlations were observed for total root dry weight (P=0.13, G=0.26), root dry weight up to 30 cm soil depth (P=0.11; G=0.23) and number of roots (P = 0.08; G= 0.09) with plant height. The character number of tillers had significant negative correlation co-efficient (-0.36) at genotypic level with plant height and negative non-significant association at phenotypic level. This trait exhibited non-significant positive or negative association with all the other traits. Number of tillers exhibited positive but non-significant associations with number of roots (P=0.05; G=0.02) and root volume (P= 0.11; G=0.16). While, total length (P=-0.24. G=-0.31), maximum root length (P=-0.19; G=-0.23), root dry weight up to 30 cm soil depth (P=-0.06; G=-0.06) and total root

Table 7 : Phenotypic (P) and Genotypic (G) correlation coefficients amongst eight root and shoot morphological traits in 39 rice genotypes (*Kharif*- 1997)

Sl No.	Characters		Plant height	CH_{-2}	CH_{-3}	CH_{-4}	CH_{-5}	CH_{-6}	CH_{-7}
CH_2	Number of tillers	P	-0.23	1.00					
		G	-0.36*	1.00					
CH_3	Total length (cm)	P	0.75**	-0.24	1.00				
		G	0.78**	-0.31	1.00				
CH_4	Maximum root length (cm)	P	0.40*	-0.19	0.91**	1.00			
		G	0.53**	-0.23	0.94**	1.00			
CH_5	Number of roots	P	0.08	0.05	0.01	-0.04	1.00		
		G	0.09	0.02	-0.01	-0.07	1.00		
CH_6	Root volume (cc)	P	0.33*	0.11	0.60**	0.62**	0.16	1.00	
		G	0.47**	0.16	0.66**	0.64**	0.15	1.00	
CH_7	Root dry weight (< 30cm soil depth) (gms)	P	0.11	-0.06	0.28	0.31	0.06	0.54**	1.00
		G	0.23	-0.06	0.33*	0.33*	0.05	0.59**	1.00
CH_8	Total root dry weight (gms)	P	0.13	-0.04	0.31	0.34*	0.02	0.53**	0.98**
		G	0.26	-0.03	0.37*	0.37*	0.01	0.58**	0.98**

* = Significance at 5% level of probability

** = Significance at 1% level of probability

dry weight (P=-0.04; G=-0.03) exhibited negative non-significant association with number of tillers.

Maximum root length (P=0.91, G=0.94) and root volume (P=0.60, G=0.66) exhibited highly significant positive association with total length both at phenotypic and genotypic levels. The traits total root dry weight (P=0.31, G=0.37) and root dry weight up to 30 cm soil depth (P=0.28; G=33) possessed positive non-significant association at phenotypic level and significant positive association at genotypic level.

Maximum root length exhibited highly significant positive association with root volume (P=0.62, G=0.64) both at genotypic and phenotypic levels. This character had significant positive correlation co-efficient with total root dry weight (P=0.34; G=0.37) at both the levels. However, the character root dry weight up to 30 cm recorded significant positive association (r=0.33) with maximum root length at genotypic level and non-significant positive association (r=0.31) at phenotypic level. The association between maximum root length and number of roots was negative and non-significant both at genotypic and phenotypic levels.

Number of roots exhibited non-significant positive association with root volume (rp=0.16; rg=0.15), root dry weight up to 30 cm soil depth (rp=0.06; rg=0.05) and total root dry weight (rp=0.02; rg=0.01) at both the levels.

Root dry weight up to 30 cm soil depth (rp=0.54; rg=0.59) and total root dry weight (rp=0.53; rg=0.58) exhibited highly significant positive association with root volume at both phenotypic and genotypic levels.

The association between root dry weight upto 30 cm soil depth and total root dry weight was highly significant and positive at both the levels.

4.1B.2.1 Path Analysis

Path coefficients analysis of total root dry weight at phenotypic level with other root and shoot characters in rice are presented in Table 8.

Root dry weight up to 30 cm depth recorded highest positive direct effect (0.978) on total root dry weight, followed by maximum root length (0.263) and plant height (0.158). While, number of tillers exhibited low positive direct effect of 0.036 on total root dry weight. Total length (-0.294), number of roots (-0.036) and root volume (-0.032) had negative direct effects on total root dry weight in the decreasing order.

Plant height which recorded moderate to low positive direct effect on total root dry weight exhibited positive indirect effects *via* root dry weight up to 30 cm soil depth (0.108) and maximum root length (0.105). While, the character total length possessed moderate indirect effect (-0.23) on total root dry weight through plant height. The remaining traits viz., root volume (-0.011), number of tillers (-0.008) and number of roots (-0.003) registered low magnitude negative indirect effects on total root dry weight *via* plant height.

Number of tillers had very low positive (0.036) direct effect on total root weight. Indirect effects of all other traits except total length (0.071) were in negative direction and low in magnitude through number of tillers.

Though total length manifested negative direct effect (-0.29) on total root dry weight registered moderate positive indirect effects *via* root dry weight up to 30 cm soil depth (0.27) followed by maximum root length (0.239) and plant height (0.118). Negative indirect effects of –0.019, -0.009 and –0.0003 were recorded for root volume, number of tillers and number of roots on total root dry weight through total length respectively.

Maximum root length which exhibited second highest positive direct effect (0.263) on total root dry weight also, registered significant positive

Table 8 : Direct (Diagonal) and Indirect (Below / Above diagonal) effects of seven root and shoot morpological traits on total root dry weight in 39 rice genotypes (Phenotypic level).

Sl No.	Characters	CH_1	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	Correlation with Total root dry weight
1	Plant height (cm)	**0.158**	-0.008	-0.219	0.105	-0.003	-0.011	0.108	0.130
2	Number of tillers	-0.037	**0.036**	0.071	-0.049	-0.002	-0.004	-0.058	-0.042
3	Total length (cm)	0.118	-0.009	**-0.294**	0.239	-0.0003	-0.019	0.273	0.307
4	Maximum root length (cm)	0.063	-0.007	-0.267	**0.263**	0.0013	-0.020	0.307	0.341*
5	Number of roots	0.012	0.002	-0.003	-0.009	**-0.036**	-0.005	0.062	0.022
6	Root volume (cc)	0.053	0.004	-0.176	0.162	-0.006	**-0.032**	0.529	0.534**
7	Root dry weight (< 30cm soil depth) (gms)	0.017	-0.002	-0.082	0.082	-0.0023	-0.017	**0.978**	0.976**

Residual effect (R) = 0.0429

indirect effect of 0.307 on total root dry weight through root dry weight up to 30cm soil depth. Moderate negative indirect effect was observed for the trait total length (-0.267) through maximum root length on total root weight. Root volume (-0.019) and number of tillers (-0.007) registered low magnitude negative indirect effects on total root dry weight through maximum root length.

Number of roots which had low magnitude negative direct effect (-0.036) on total root dry weight however recorded positive indirect effects *via* root dry weight up to 30 cm soil depth (0.062), plant height (0.012) and number of tillers (0.002) with lower magnitudes. While, maximum root length (-0.009), root volume (-0.005) and total length (-0.003) exhibited very low magnitude of negative indirect effects in the order of descending on total root dry weight through number of roots.

Root volume exhibited moderate high positive indirect effects on total root dry weight through the characters root dry weight up to 30cm soil depth (0.529) and maximum root length (0.162). Low magnitude positive indirect effects were also found on total root dry weight by plant height (0.053) and number of tillers (0.004) through root volume.

Root dry weight up to 30 cm soil depth registered highest positive direct effect (0.978) on total root dry weight was also accounted for positive low magnitude of indirect effects *via* the characters maximum root length (0.082) and plant height (0.017). While, total length (-0.082), number of roots (-0.002) and number of tillers (-0.002) exhibited low negative indirect effects on total root dry weight through root dry weight up to 30cm soil depth.

4.3 Assessment of combining ability, gene action and estimation of heterosis from parents and crosses for various root and shoot morphological traits

27 F_1 hybrids and their 12 parents were evaluated using line x tester analysis under two moisture regimes (i.e. well-watered and low moisture

condition). The results obtained in the investigation have been presented as given under

4.3.1 Analysis of variance for parents and crosses

The analysis of variance of parents and hybrids for different characters under both well-watered and low moisture stress conditions are presented in Table (9) and ANOVA for combining ability was given in table (10).

It was observed from the Table-9 that, the mean sum of squares due to treatments were significant for all the eight-characters considered in the present study. Further partitioning of variance indicated similar significant differences for parents x crosses for all the characters under low moisture condition and non significant for plant height and number of root under well-watered condition.

The variance due to parents was further partitioned into variance due to lines, testers and line x testers.

The lines differed significantly for plant height and number of roots under both the environments. However, under low moisture condition the characters for which significant differences observed among lines were plant height, maximum root length, total length, root growth rate, deep root length and root volume. For number of tillers non-significant difference was observed among lines under both well-watered and low moisture stress condition.

The variance due to testers was significant for all the eight root morphological traits viz., plant height, number of tillers, maximum root length, total length, root growth rate, deep root length, number of roots and root volume under both the moisture regimes.

Crosses (LXT) differed significantly for all the eight-root shoot morphological traits under both well-watered and low moisture condition.

Table 9 : Mean sum of squares for eight root and shoot morphological traits for parents and crosses in rice under well-watered (ww) and low moisture stress condition (st)

Source	Df	Plant height		Number of tillers		Maximum root length		Total length		Root growth rate		Deep root length		Number of roots		Root volume	
		ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st
Treatments	38	535.82**	596.15**	351.67**	70.16**	437.06**	452.41**	1227.81**	1390.70**	0.089**	0.09**	437.05**	452.41**	32646.03**	21566.58**	7419.28**	6404.25**
Replications	2	76.27	5.19	29.03	6.91	73.82	26.20	566.27	44.62	0.02	0.01	73.81	26.15	1555.28	3344.27	217.59	491.03
Parents	11	1300.76**	1395.09**	161.48**	43.02**	422.53**	568.15**	2246.44**	3190.83**	0.09**	0.12**	422.53**	568.14**	73923.62**	50323.70**	9521.83**	3229.48**
Crosses	26	229.81**	276.53**	402.78**	81.04**	412.95**	317.78**	688.26**	531.67**	0.08**	0.07**	412.95**	317.79**	16362.43**	8052.47**	6291.41**	7885.76**
Parents x crosses	1	78.16	118.44*	1114.88**	85.59**	1223.60**	2679.68**	4051.56**	3924.94**	0.25**	0.55**	1223.60**	2679.71**	1970.25**	56606.25**	13615.94**	2807.53**
Lines	2	215.77*	292.91**	34.78	16.44	6.10	214.32**	448.42	836.30**	0.00	0.04**	6.10	214.30**	4646.78**	5334.78**	161.36**	346.36**
Tester	8	703.643**	720.02**	139.26**	43.93**	391.11**	468.90**	2000.96**	1715.57**	0.08**	0.10**	391.11**	468.90**	48449.68**	42824.60**	6065.08**	3349.45**
Error	76.00	47.99	18.24	41.41	12.89	36.61	20.32	169.11	63.20	0.01	0.00	36.61	20.32	839.33	474.30	236.52	108.10

* = Significance at 5 % level of probability

** = Significance at 1 % level of probability

Table 10 : ANOVA for combining ability for eight root and shoot morphological traits in 27 rice crosses and their parents under well watered (ww) and low moisture stress condition(st)

Source	Df	Plant height		Number of tillers		Maximum root length		Total length		Root growth rate		Deep root length		Number of roots		Root volume	
		ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st
Replications	2	67.99	2.44	71.94	5.17	126.45	14.33	356.15	7.35	0.03	0.01	126.45	14.35	2166.03	3643.41	161.49	392.57
Females (L)	2	937.96*	1057.84*	2673.57**	117.11	1416.31*	1148.93**	1117.52	1052.53	0.29*	0.23*	1416.32*	1148.94**	12837.23	12226.34	11488.91	9833.83
Males (T)	8	165.00	183.75	152.48	85.79	415.99	398.72	997.01	646.03	0.09	0.08	415.99	398.72	29102.05*	8864.99	9336.46	13220.40*
L x T	16	173.69**	225.25**	244.08**	74.16**	286.02**	173.42**	480.23**	409.38**	0.06**	0.04**	286.01**	173.42**	10433.27**	7124.47**	4126.69**	4974.94**
Error	52	59.12	21.79	47.98	17.12	41.63	23.74	142.71	79.33	0.01	0.01	41.63	23.74	1009.79	627.86	170.37	129.05

* = Significance at 5 % level of probability
** = Significance at 1 % level of probability

4.1.1.1 Combining ability analysis

The analysis of variance for combining ability (Table 10) for eight root and shoot morphological traits studied indicated the following results as detailed below.

The mean sum of squares due to lines were significant for the characters plant height, maximum root length, root growth rate and deep root length under both well-watered and low moisture conditions. While for number of tillers, non-significant difference was observed among lines.

The variance due to testers was significant for number of roots and root volume under well-watered condition. However, under low moisture condition non-significant difference was observed for all the eight characters considered for this present investigation. The variance due to line x tester was highly significant for all the characters under both the growing environments.

The estimates of variance for general combining ability (GCA) and specific combining ability (SCA) are also presented in Table 11 and pictorial representation of GCA and SCA variances are depicted in Fig 3.

The magnitudes of SCA variances were high for all the eight characters studied than their respective GCA variance. Variance due to general combining ability was highest for root number followed by root volume, number of tillers, deep root length, maximum root length, total length, plant height and root growth rate in the descending order under well-watered condition.

Under low moisture condition, root volume registered highest GCA variance followed by number of roots, maximum root length, deep root length total length, plant height, number of tillers and root growth rate.

Similarly, variance due to specific combining ability (SCA) was highest for the character root number followed by root volume, total length, maximum root length, deep root length number of tillers and root growth rate under well

Table 11 :Ratio of estimates of GCA and SCA variances for eight root and shoot morphological traits in 27 rice crosses under well-watered (ww) and low moisture stress condition (st) (*Summer* and *Kharif* 1998)

Sl No.	Characters	GCAww	SCAww	GCAst	SCAst	GCA : SCAww	GCA :SCAst
1	Plant height (cm)	20.99	38.19	21.98	67.82	1:1.8	1:3.1
2	No.of tillers	64.94	65.37	1.52	19.02	1:1	1:12.6
3	Maximum root length (cm)	35.01	81.46	33.54	49.89	1:2.3	1:1.5
4	Total length (cm)	32.06	112.51	24.44	110.02	1:3.5	1:4.5
5	Root growth rate(cm/day)	0.01	0.02	0.007	0.01	1:2.8	1:1.5
6	Deep root length (cm)	35.01	81.46	33.36	49.9	1:2.3	1:1.5
7	Root number	585.35	3141.16	190.07	2165.54	1:5.4	1:11.4
8	Root volume (cc)	347.56	1318.78	364.01	1615.3	1:3.8	1:4.4

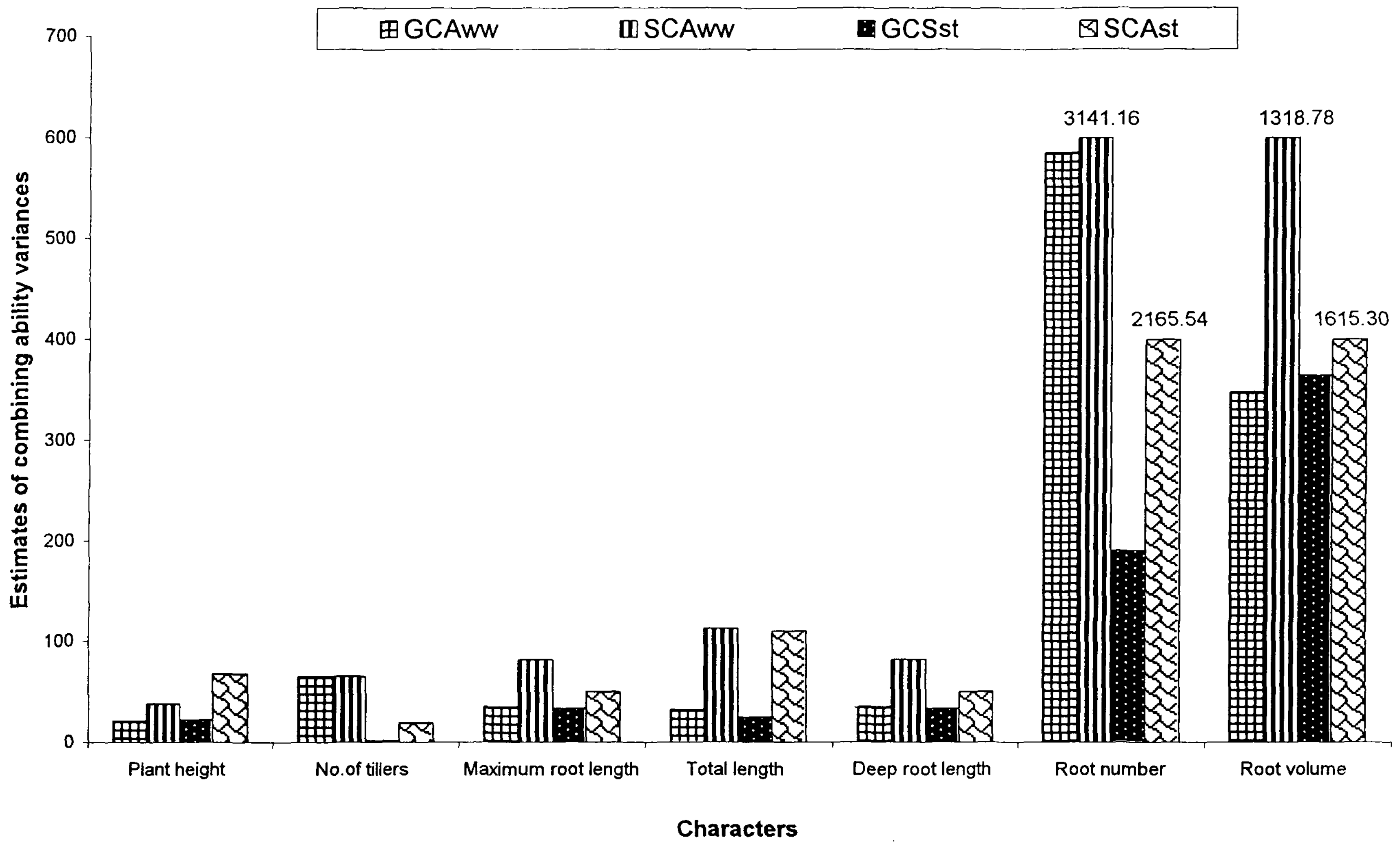

Fig 3 : Magnitude of estimates of GCA and SCA variances under wellwatered (ww) and low moisture stress (st) environment

watered condition. However, under low moisture stress condition, the estimate of SCA variance for number of tillers was very low as compared to its SCA variance in well watered condition. For the other characters similar behavior was noticed in respect of SCA magnitudes.

The ratio of GCA and SCA variance effects under well-watered condition reflected similar trends as that of estimates of variances under low moisture condition except for the character number of tillers, which exhibited least difference for GCA and SCA estimates. The ratio of GCA and SCA effects for maximum root length, deep root length and root growth rate reflected moderate degree of difference under low moisture condition. High degree of difference was observed for the traits number of tillers (1:12.55) followed by root number (1:11.39) and total length (1:4.5) with respect to variance due to GCA: SCA ratio respectively. While, under well-watered condition the ratio of variance due to GCA and SCA (1:1) for number of tillers was the least compared to other parameters.

4.3.1.2 Combining ability effects

The estimates of GCA-effects in respect of lines and testers and SCA-effects of crosses are given in Table 12 and 13 respectively for both the environments. Graphical representation of ranges for magnitude SCA effects are depicted in Fig 4. The salient features of the results about combining ability effects for all the root morphological traits were presented character wise for both well-watered and low moisture condition as detailed below.

4.3.1.2.1 Plant height

Breeding rice for drought tolerance through root dehydration avoidance mechanisms, significant positive combining ability is desired for the character plant height. Among the lines, under both well-watered and low moisture conditions IR68949-11-5-31 (TGMS-line) and IR62829A showed the desirable magnitude GCA effects. Under well-watered condition among lines GCA effect

Table 12 : Estimates of GCA effects and Standard error of mean (SEm±) for eight root and shoot morphological traits in 12 rice parents under well-watered (ww) and low moisture stress condition (st)

Sl No.	Lines / Testers	Plant height		Number of tillers		Maximum root length		Total length		Root growth rate		Deep root length		Number of roots		Root volume	
		ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st
	Lines																
1	IR 68949-11-5-31	3.11**	2.88**	-11.35**	-1.44**	-8.33**	-7.46**	-5.21**	-4.58**	-0.12**	-0.11**	-8.33**	-7.46**	6.38	6.67*	-20.58**	-21.65**
2	IR 62829A	3.68**	4.30**	7.25**	2.39**	3.50**	2.81**	7.19**	7.11**	0.05**	0.04**	3.50**	2.81**	17.90**	17.15**	20.57**	14.40**
3	IR 58025A	-6.80**	-7.18**	4.10**	-0.95	4.82**	4.65**	-1.97	-2.53*	0.07**	0.07**	4.82**	4.65**	-24.28**	-23.81**	0.01	7.24**
	SEm(±)	1.01	0.61	0.91	0.54	0.84	0.64	1.56	1.16	0.01	0.01	0.84	0.64	4.15	3.28	1.71	1.49
	Testers																
1	Budda	5.48**	9.14**	0.95	-1.13	10.97**	4.56**	16.44**	13.70**	0.16**	0.07**	10.97**	4.56**	4.53	39.04**	78.68**	88.17**
2	MM 125	4.48*	2.49*	0.06	-0.18	0.47	-1.55	4.94*	0.94	0.01	-0.02	0.47	-1.55	33.64**	-4.63	-7.88*	-19.34**
3	MM 111B	-1.31	0.40	1.84	6.31**	-0.75	-4.45**	-2.07	-4.05	-0.01	-0.06**	-0.75	-4.45**	-56.02**	-55.74**	-18.21**	-17.50**
4	TT 121	-7.08**	-7.50**	4.62**	-1.58	-4.97**	-5.64**	-12.04**	-13.14**	-0.07**	-0.08**	-4.97**	-5.64**	-39.80**	-17.19**	-7.88*	-3.56
5	P 331	4.20*	-2.46*	-1.83	0.98	7.10**	0.71	11.30**	-1.75	0.10**	0.01**	7.10**	0.71	112.64**	32.70**	-17.88**	-38.62**
6	P 333	-0.56	1.30	-9.83	-4.24**	-7.09**	-3.54**	-7.64*	-2.24	-0.10**	-0.05**	-7.09**	-3.54**	-48.47**	-17.07**	-23.32**	-11.11**
7	KMR 3R	1.59	-3.06*	0.62	-2.69**	6.75**	15.01**	8.33**	11.95**	0.10**	0.21**	6.75**	15.01**	-57.69**	-21.74**	20.90**	33.68**
8	IR42221-14-1-3-1-2R	-2.60	0.04	3.06	2.54*	-6.39**	1.20	-8.99**	1.24	-0.09**	0.02	-6.39**	1.20	12.98	15.15*	-17.43**	-11.83**
9	IR35454-18-1R	-4.19*	-0.36	0.51	-0.02	-6.09**	-6.30**	-10.28**	-6.66**	-0.09**	-0.09**	-6.09**	-6.30**	38.20**	29.48**	-6.99**	-19.89**
	SEm±	2.01	1.22	1.81	1.08	1.69	1.27	3.12	2.33	0.02	0.02	1.69	1.27	8.31	6.55	3.41	[illegible]

* = Significance at 5 % level of probability

** = Significance at 1 % level of probability

TABLE-13 : Estimates of SCA- effects and Standard error of mean(SEm +/-) for eight root and shoot morphological traits in 27 rice crosses under well-watered (ww) and low moisture stress condition (st)

Sl. No.	Crosses / Hybrids	Plant height		Number of tillers		Maximum root length		Total length		Root growth rate		Deep root length		Number of roots		Root volume	
		ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st
1	IR68949-11-5-31 x Budda	-4.56	-7.64**	-5.77*	-0.89	-13.56**	2.41	-18.12**	-5.23	-0.19**	0.03	-13.56**	2.41	-22.83	-30.11**	-77.20**	-84.47**
2	IR68949-11-5-31 x MM 125	-11.06**	-11**	10.46**	2.02	-2.06	2.46	-13.12**	-8.54**	-0.03	0.04	-2.06	2.46	-13.94	39.22**	-0.64	20.71**
3	IR68949-11-5-31 x MM 111B	5.9*	9.26**	-2.65	-2.00	-4.84*	2.16	1.06	11.41**	-0.07*	0.03	-4.84*	2.16	-28.60*	-3.33	-3.64	8.53**
4	IR68949-11-5-31 x TT 121	6.56*	-0.38	-5.43*	8.22**	2.37	8.55**	8.94*	8.17*	0.03	0.12**	2.37	8.55**	35.84**	58.44**	22.69**	24.77**
5	IR68949-11-5-31 x P 331	-12.45**	0.46	6.01*	3.66*	6.97**	1.49	-5.47	1.95	0.10**	0.02	6.97**	1.49	17.40	36.56**	19.36**	15.66**
6	IR68949-11-5-31 x P 333	10.48**	10.99**	2.01	2.55	4.83*	1.58	15.30**	12.57**	0.07*	0.02	4.83*	1.58	38.51**	33.00**	4.8	1.98
7	IR68949-11-5-31 x KMR 3R	1.83	4.66	-6.43*	-4.67**	-7.67**	-10.31**	-5.84	-5.65*	-0.11**	-0.15**	-7.67**	-10.31**	-30.27*	-33.33**	-4.42	-12.98**
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	3.69	-9.38**	-3.88	-4.89**	-0.2	-9.17**	3.48	-18.54**	0.00	-0.13**	-0.2	-9.17**	-4.94	-46.56**	5.58	2.20
9	IR68949-11-5-31 x IR35454-18-1R	-0.39	3.02	5.68*	-4.00**	14.16**	0.83	13.77**	3.86	0.20**	0.01	14.16**	0.83	8.84	-53.89**	33.47**	23.59**
10	IR62829 A x Budda	3.54	-3.64*	-4.02	2.28	14.94**	-11.18**	18.48**	-14.82**	0.21**	-0.16**	14.94**	-11.18**	-44.01**	-27.26**	4.99	-12.18**
11	IR62829 A x MM 125	12.77**	10.07**	4.53	2.32	6.61**	1.39	19.38**	11.47**	0.09**	0.02	6.61	1.39	130.88**	42.41**	48.54**	20.80**
12	IR62829 A x MM 111B	-3.87	-6.3**	-5.91*	-1.83	-2.67	2.63	-6.54	-3.68	-0.04	0.04	-2.67	2.63	-39.46**	-27.15**	-13.12**	-11.51**
13	IR62829 A x TT 121	-3.41	3.4*	8.98**	-3.94*	-7.59**	-4.72**	-11.00**	-1.32	-0.11**	-0.07*	-7.59**	-4.72**	-33.01**	-56.70**	-25.12**	-19.81**
14	IR62829 A x P 331	2.82	-6.47**	4.09	-1.83	6.27**	2.06	9.09*	-4.41	0.09**	0.03	6.27**	2.06	3.54	-5.59	-3.46	-8.72*
15	IR62829 A x P 333	-8.76**	-5.07**	-8.58**	1.72	-5.34*	7.15**	-14.10**	2.08	-0.08**	0.10**	3.00*	7.15**	-57.68**	-1.15	-16.35**	10.43*
16	IR62829 A x KMR 3R	1.09	5.9**	0.31	5.50**	-4.84*	-1.57	-3.74	4.32	-0.07*	-0.02	-4.84*	-1.57	12.54	28.19**	31.10**	43.98**
17	IR62829 A x IR42221-14-1-3-1-2R	-3.05	7.7**	8.53**	-2.05	-2.04	2.17	-5.09	9.87**	-0.03	0.03	-2.04	2.17	18.54	35.63**	-5.57	12.82**
18	IR62829 A x IR35454-18-1R	-1.13	-5.57**	-7.91**	-2.17	-5.34*	2.07	-6.47	-3.50	-0.08**	0.03	-5.34*	2.07	8.65	11.63	-21.01**	-35.79**
19	IR58025 A x Budda	1.02	11.28**	9.79**	-1.39	-1.38	8.77**	-0.36	20.05**	-0.02	0.13**	-1.38	8.77**	66.84**	57.37**	72.21**	96.65**
20	IR58025 A x MM 125	-1.71	0.92	-14.99**	-4.34**	-4.55	-3.85*	-6.26	-2.93	-0.06**	-0.05	-4.55	-3.85*	-116.94**	-81.63**	-47.90**	-41.51**
21	IR58025 A x MM 111B	-2.02	-2.95	8.57**	3.83*	7.51**	-4.78**	5.49	-7.74**	0.11**	-0.07*	7.51**	-4.78**	68.06**	30.48**	16.77**	2.98
22	IR58025 A x TT 121	-3.16	-3.02	-3.54	-4.28**	5.22*	-3.83*	2.06	-6.85*	0.07*	-0.05	5.22*	-3.83*	-2.83	-1.74	2.43	-4.95
23	IR58025 A x P 331	9.63**	6.01**	-10.10**	-1.83	-13.25**	-3.55*	-3.61	2.46	-0.19**	-0.05	-13.25**	-3.55*	-20.94	-30.96**	-15.90**	-6.93
24	IR58025 A x P 333	-1.71	-5.92**	6.57*	-4.28**	0.51	-8.73**	-1.20	-14.65**	0.01	-0.12**	0.51	-8.73*	19.17	-31.85**	11.54*	-12.41**
25	IR58025 A x KMR 3R	-2.92	-10.55**	6.12*	-0.83	12.51**	11.88**	9.59*	1.33*	0.18**	0.17**	12.51**	11.88**	17.73	5.15	-26.68**	-31.00**
26	IR58025 A x IR42221-14-1-3-1-2R	-0.64	1.68	-4.65	6.95**	2.24	6.99**	1.61	8.67**	0.13	0.10**	2.24	6.99**	-13.60	10.93	-0.01	-15.02**
27	IR58025 A x IR35454-18-1R	1.52	2.55	2.23	6.17**	-8.82**	-2.91	-7.30	-0.36	-0.13**	-0.04	-8.82**	-2.91	-17.49	42.26**	-12.46*	12.20**
	SEm ±	2.84	1.73	2.56	1.53	2.39	1.80	4.42	3.29	0.03	0.03	2.39	1.80	11.75	9.27	4.83	4.20

* = Significance at 5% level of probability

** = Significance at 1% level of probability

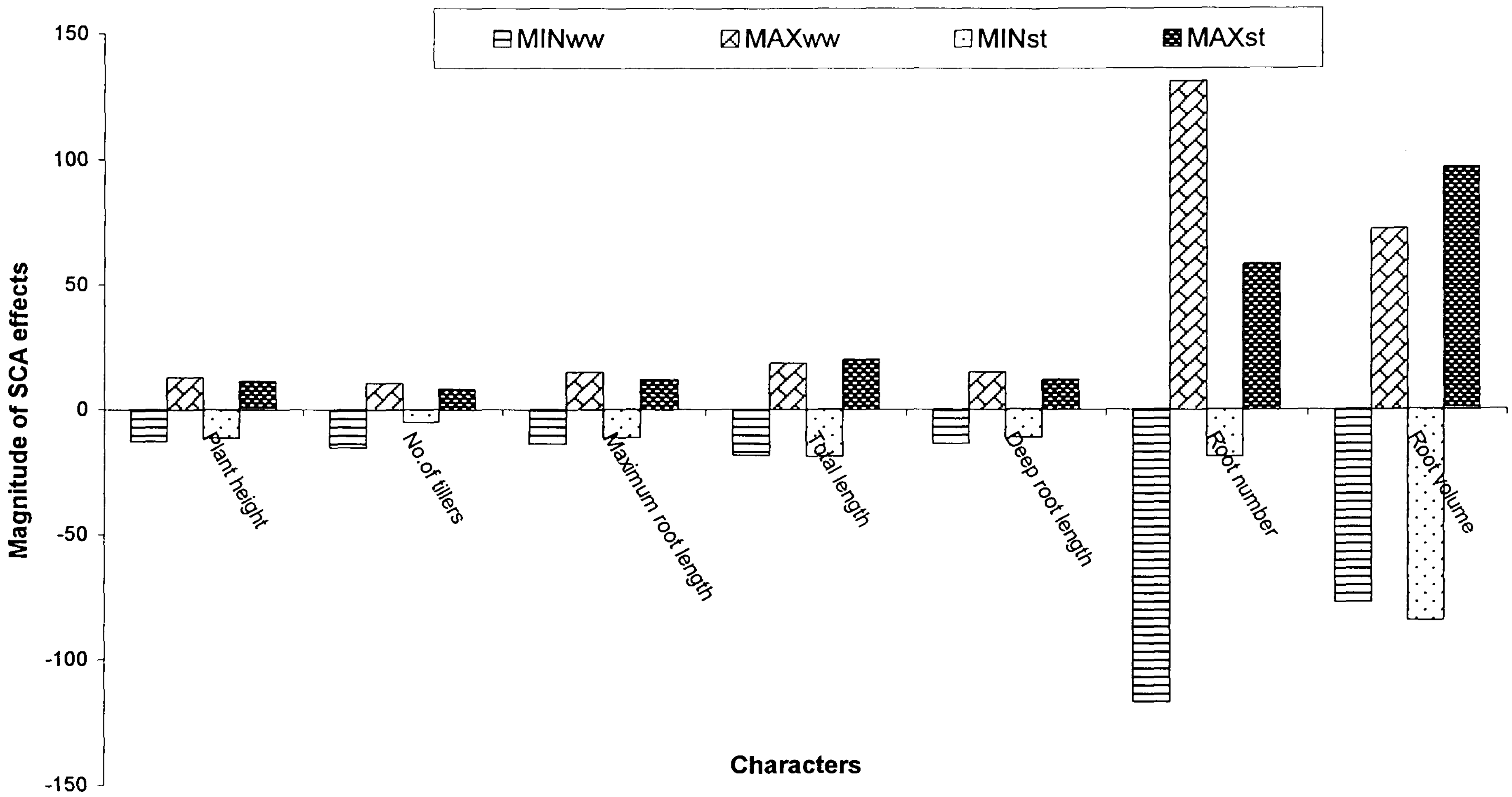

Fig 4 : Range of SCA effects for seven root and shoot characters under well watered (ww) and low moisture stress (st) condition in 27 rice crosses

for the character ranged from –6.80 (IR58025A) to 3.68 (IR62829A). However, under low moisture situation the range for GCA effect recorded was from –7.88 (IR58025A) to 2.88 (IR68949-11-5-31). Out of three lines, two exhibited positive significant GCA effects under low moisture and one recorded significant GCA effect under both the environments across all the 27 crosses for plant height.

Among testers, in both the environments Budda, and MM125 registered significant positive GCA effects for this trait. While, the tester P331 (DH- line) showed positive significant GCA-effect (4.20) under well-watered condition. However, the tester P 331 recorded negative (-2.46) and significant GCA effects under low moisture condition. Testers TT121 (-7.08) and IR35454-18-1R (-4.15) recorded significant negative GCA effects (undesirable) under well-watered condition. Under low moisture stress condition, in addition to the tester TT121 (-7.50), KMR 3R (-3.06) was also exhibited GCA-effect in the undesirable direction.

The analysis of SCA-effects for 27 crosses under two environments revealed that, under well-watered condition, for plant height, the crosses involving lines IR68949-11-5-31and testers MM 111B, TT121, P333 and line IR62829A with testers MM125 showed significant positive SCA- effects in desirable direction. Also, desirable magnitude positive significant SCA effect was observed for the cross IR58025AX P331, though the female parent (line) possessed significant negative GCA-effect across 27 hybrids.

Under low moisture stress condition, the following crosses exhibited significant positive SCA-effects viz., IR68949-11-5-31x MM111B, IR68949-11-5-31 x P333, IR68949-11-5-31x KMR3R, IR62829A x MM 125, IR62829AX TT121, IR62829A x KMR 3R, IR62829A x IR42221-14-1-3-1-2R, IR58025A x Budda and IR58025A x P331.

The range for SCA effects under well-watered condition for this trait observed was from –12.45 (IR68949-11-5-31x P331) to 12.77 (IR62829A x MM 125). Under low moisture stress condition it was from –11.00 (IR68949-11-5-31x MM125 A) to 11.28 (IR58025A x Budda).

4.3.1.2.2 Number of tillers

For this plant character positive significant combining ability was preferred. The line IR62892A was most promising under both the moisture regimes. However, the line IR58025A displayed GCA-effect in the desirable direction only under well-watered condition. The ranges for GCA effects observed among lines was from –11.35 (IR68949-11-5-31) to 7.25 (IR62829A and from –1.44 (IR68949-11-5-31) to 2.39 (IR62829A) for well-watered and low moisture stress condition respectively.

Among testers, TT121 (-1.58) and MM 111B (6.3) under low moisture were most promising with desirable magnitude and direction GCA effects. The range of GCA effects observed among testers were from –9.83 (P333) to 4.62 (TT121) and from –4.24 (P333) to 6.31 (MM111B) for well-watered and low moisture condition respectively.

The analysis of SCA effects revealed that nine crosses under well-watered condition and six under low moisture displayed SCA effects in the desirable direction and magnitude.

IR68949-11-5-31x MM 125(10.46) and IR68949-11-5-31x TT 121(8.22) were most promising combinations with significant SCA-effects under well watered and low moisture stress condition respectively.

The ranges for SCA effects observed under well watered and low moisture conditions for number of tillers were from –14.99 (IR58025A x MM 125) to 10.46 (IR68949-11-5-31x MM 125) and from –4.89 (IR68949-11-5-31x IR42221-14-1-3-1-2R) respectively.

4.3.1.2.3 Maximum root length

This is one of the tops most important root parameters associated with drought avoidance mechanism in rice. Therefore significant positive combining ability effects were preferred for this trait.

Among lines, IR58025A registered highest GCA effect (WWT = 4.82; STR = 4.65) followed by IR62829A (WWT = 3.50; STR = 2.81). Third line IR68949-11-5-31exhibited significant negative GCA effect (WWT = -8.33; STR=-7.46) which was highly undesirable.

The testers recorded a range of –7.09 (P333) to 10.97 (Budda) for GCA effects under well-watered condition. Positive significant-GCA effects were recorded by tester Budda (10.57) followed by P331 (7.10) and KMR 3R (6.75) in the decreasing order of magnitude. The tester MM 125 (0.47) recorded non significant but positive GCA-effect for maximum root length under well-watered condition.

Under low moisture condition, the testers KMR 3R (15.01) and Budda (4.56) exhibited high magnitude GCA-effects for maximum root length. However, P331 (0.71) and IR42221-14-1-3-1-2R registered non-significant positive GCA-effects. The range for GCA effects of testers under low moisture condition was from–6.33 (IR35454-18-IR) to 15.0 (KMR 3R).

SCA-effects of 27 crosses under both the environments revealed that, under well-watered condition crosses involving line IR68949-11-5-31and testers P331, P333, IR35454-18-1R and line IR62829A with testers Budda, MM125, P331 in addition to crosses IR58025A x MM111B, IR58025A x TT121, IR58025A x KMR 3R possessed highly significant positive SCA-effects. The range of SCA-effects for maximum root length under this environment was from –13.56 (IR68949-11-5-31 x Budda) to 14.94 (IR62829A x Budda). Non significant but positive SCA effects were exhibited by the crosses IR68949-11-5-31x TT 121, IR58025A x IR42221-14-1-3-1-2R and IR58025A x P333.

Under low moister stress environment, the range of SCA-effects recorded was from –11.38(IR62829A x Budda) to 11.88 (IR58025A x KMR 3R). Positive significant SCA-effects were noticed for the crosses, IR68949-11-5-31x TT121; IR62829A x P333; IR58025 A x Budda; IR58025A x KMR 3R and IR58025A x IR42221-14-1-3-1-2R. The crosses involving line IR68949-11-5-31 and testers Budda, MM125, MM111B, P331, P333 and IR35454-18-1R recorded positive but non significant SCA effects in addition to the crosses with line IR62829A and testers MM125, MM111B, P331, IR42221-14-1-3-1-2R, IR35454-18-1R.

4.3.2.4 Total length

This parameter reflects the desirability of a genotype for two important characters involved in drought avoidance mechanism viz., plant height and maximum root length. Significant positive combining ability for total length was highly desirable.

The estimates of GCA-effects among the lines indicated significant positive GCA effect of IR62829A (WWT=7.19 STR=7.11) under both the moisture regimes. 'Among' the other two lines the line IR68949-11-5-31registered significant negative GCA-effect under both the conditions.

The line IR58025A exhibited non-significant negative GCA effect in low moisture condition.

Among nine testers, three testers in well-watered condition and two in low moisture condition exhibited significant positive GCA-effects for this trait. The range of GCA effects recorded for this character was from –12.04 to 16.44 (well watered) and –13.44 to 13.70 (low moisture). Among testers 'Budda' possessed high significant positive GCA effect. Tester TT121 displayed highly significant negative GCA-effect under both the moisture regimes. The tester MM125 exhibited non significant but positive GCA effects under both well-watered and low moisture stress condition.

Among crosses, the range for SCA-effect under well-watered condition was from –18.12 (IR68949-11-5-31x Budda) to 19.38 (IR62829A x MM 125). While the range was from –18.54 (IR68949 x IR42221-14-1-3-1-2R) to 20.05 (IR58025A x Budda) under low moisture condition. Of the 27-crosses, seven crosses exhibited positive significant SCA effects under both the environments and five crosses registered non significant but positive SCA effects under well-watered condition. However, under low moisture condition, six-crosses displayed non-significant positive SCA effects for total length.

4.3.1.2.5 Root growth rate

Root growth rate was estimated to know the per day growth of maximum root length during the total experimental duration. Genotypes can be selected at any stage of crop growth for maximum root length by considering this character.

Among lines, IR68949-11-5-31 recorded highly significant negative GCA-effects (WWT= -0.12; STR = -0.11), which was highly undesirable. The other two lines registered positive significant GCA effects both under well-watered and low moisture conditions.

The range observed for GCA-effects among testers was from–10 (P333) to 0.16 cm/day (Budda) under well-watered condition. Under low moisture situation, IR35454-18-IRrecorded lowest GCA-effect (-0.09) and the tester KMR 3R accounted for highest GCA value (0.21). Positive but non-significant GCA effect (0.01) was noticed in the tester MM125 under well-watered condition. However, under low moisture stress, P331 and IR42221-14-1-3-1-2R registered significant GCA effects.

Among 27-crosses, 18 crosses exhibited significant SCA-effects under well-watered condition. While, eleven crosses displayed significant SCA-effects under low moisture stress condition. Of the 18 crosses, which showed significant SCA-effects, IR62829A x Budda recorded high magnitude of positive SCA-effect which, was highly preferred. IR68949-11-5-31 x Budda and IR58025A x

P331 were exhibited lowest SCA effect on root growth rate under well-watered condition. IR58025 x KMR3R and IR62829A x Budda, possessed highest positive (0.17) and negative (-0.16) SCA-effects under low moisture condition respectively.

4.3.1.6 Deep root length

The lines IR62829A and IR58025A exhibited significant positive and IR68949-11-5-31 (TGMS-line) recorded significant negative GCA-effects under both the environment.

Among testers, Budda and KMR3R recorded GCA-effects in the desirable direction and magnitude while the testers TT121, P333 and IR35454-18-1R exhibited significant negative GCA-effects under both well-watered and low moisture conditions. In addition, tester MM125 under well-watered condition, P331 and IR4221-14-1-3-1-2R under low moisture stress situation exhibited positive but non-significant GCA-effects for deep root length.

The range noticed for GCA-effects was from –7.09 (P333) to 10.97 (Budda) and was from–6.30 (IR35454-18-R) to 15.01 (KMR 3R) under well-watered and low moisture stress condition respectively.

SCA-effects of 27 cross combinations revealed that, for deep root length, nine crosses exhibited significant positive SCA–effects under well-watered condition. However, under low moisture stress environment, only five crosses displayed desirable direction and magnitude SCA effects.

The SCA-effects ranged from –13.56 (IR68949-11-5-31 x Budda) to 14.94 (IR62829A x Budda) and from–11.18 (IR62829A x Budda) to 11.88 (IR58025A x KMR3R) under well-watered and low moisture stress condition respectively.

4.3.1.7 Number of Roots

The line IR62829A (17.90) was most promising general combiner for the trait number of roots under well-watered as well as under low-moisture stress condition. Under low moisture condition, lines IR62829A (17.75) and IR68949-11-5-31 (6.67) possessed GCA effects in the desirable direction magnitude. In both the growing conditions, the line IR58025A registered significant GCA-effect in the undesirable direction.

Of the nine testers, three under well-watered and four testers under low moisture recorded GCA-effects in the desirable magnitude (positive). The most promising testers were P331 (112.64) and Budda (39.04) under well water and watered stress environments respectively. The ranges observed for GCA effects among testers under well-watered and low moisture stress condition were from -57-69 (KMR 3R) to 112.64 (P331) and from -55.74 (MM 111B) to 39.04 (Budda) respectively.

High magnitude of significant SCA-effects were observed for this trait in both negative and positive directions. Five crosses under well-watered condition and 10 under low moisture stress regime displayed significant SCA-effects in the desirable direction. The most promising cross combination with desirable SCA-effect was IR62829A x MM125 (130.88) under well-watered condition. Highest significant SCA-effect (desirable) under low moisture stress condition was observed with the cross IR68949-11-5-31x TT 121(58.44).

4.3.1.8 Root volume

Significant positive combining ability was preferred for the trait root volume.

The line IR62829A under well-watered and water stress conditions and lines IR58025A under low moisture stress exhibited significant positive GCA-effects for root volume, which was highly preferred.

Among testers only two testers namely Budda (78.68) and KMR 3R (20.90) registered high magnitude GCA-effects under both well-watered and low moisture conditions. The range for GCA effects observed among testers for root volume were from–23.32 (P333) to 78.68 (Budda) and from–38.62 (P331) to 88.17 (Budda) respectively for well-watered and low moisture conditions.

Significant SCA effects in desirable direction were observed for IR58025A x Budda (WWT= 72.21 and STR= 96.65) under both the environments followed by IR62829A x Budda (48.54) under well-watered condition and IR62829A x KMR3R (43.98) under low moisture condition.

SCA-effects for this trait ranged from –77.20 to 72.21 and from–84.47 to 96.65 for the crosses IR68649 x Budda and IR58025A x Budda for well-watered and low moisture conditions respectively.

4.3.1.3 Ranking of parents based on GCA effects

This was done to identify best lines and testers for drought avoidance mechanisms considering significant GCA effects in the desirable direction for root and shoot morphological traits. Comparative ranking for lines and testers were given in table 14 and 15 for well-watered and low moisture stress condition respectively.

The lines and testers were classified as high (H), average (A) and low (L) for GCA-effects for the characters studied as detailed below.

Class	Total Score
High	>4
Average	1-4
Low	<0

Table 14 : Ranking of Lines and Testers based on significant GCA effects in desirable direction for eight root and shoot morphological traits in rice (well-watered condition)

Sl No.	Lines / Testers	Plant height	Number of tillers	Maximum root length	Total length	Root growth rate	Deep root length	Root number	Root volume	Total score	Classification	Rank
	Lines											
1	IR 68949-11-5-31	1	-1	-1	-1	-1	-1	1	-1	-4	L	3
2	IR 62829A	1	1	1	1	1	1	0	1	6	H	1
3	IR 58025A	-1	1	1	0	1	1	-1	1	3	A	2
	Testers											
1	Budda	1	0	1	1	1	1	1	0	6	H	1
2	MM 125	1	0	0	0	0	0	0	-1	0	L	3
3	MM 111B	0	0	0	0	0	0	-1	-1	-2	L	4
4	TT 121	-1	1	-1	-1	-1	-1	-1	-1	-6	L	6
5	P 331	1	0	1	1	1	1	0	-1	4	A	2
6	P 333	0	-1	-1	-1	-1	-1	-1	-1	-7	L	7
7	KMR 3R	1	0	1	1	1	1	-1	0	4	A	2
8	IR42221-14-1-3-1-2R	0	0	-1	-1	-1	-1	1	-1	-4	L	5
9	IR35454-18-1R	-1	0	-1	-1	-1	-1	0	-1	-6	L	6

Where, 1 = Positive significant GCA effects
0 = Non significant GCA effects
-1 = Negative significant GCA effects

Classification :

Category	Total score
High (H)	>4
Average (A)	1-4
Low (L)	< 0

Table 15 : Ranking of Lines and Testers based on significant GCA effects in desirable direction for eight root and shoot morphological traits in rice (low moisture stress regime)

Sl No.	List / Testers	Plant height	Number of tillers	Maximum root length	Total length	Root growth rate	Deep root length	Root number	Root volume	Total score	Classification	Rank
	Lines											
1	IR 68949-11-5-31	1	-1	-1	-1	-1	-1	1	-1	-4	L	3
2	IR 62829A	1	1	1	1	1	1	1	1	8	H	1
3	IR 58025A	-1	0	1	-1	1	1	-1	1	1	A	2
	Testers											
1	Budda	1	0	1	1	1	1	1	1	7	H	1
2	MM 125	1	0	0	0	0	0	0	-1	0	L	4
3	MM 111B	0	1	-1	0	-1	-1	-1	-1	-4	L	6
4	TT 121	-1	0	-1	-1	-1	-1	-1	0	-6	L	7
5	P 331	-1	0	0	0	0	0	1	-1	-1	L	5
6	P 333	0	-1	-1	0	-1	-1	-1	-1	-6	L	7
7	KMR 3R	-1	-1	1	1	1	1	-1	1	2	A	2
8	IR42221-14-1-3-1-2R	0	1	0	0	0	0	1	-1	1	A	3
9	IR35454-18-1R	0	0	-1	-1	-1	-1	1	-1	-4	L	6

Where, 1 = Positive significant GCA effects
0 = Non significant GCA effects
-1 = Negative significant GCA effects

Classification :

Category	**Total score**
High (H)	>4
Average (A)	1-4
Low (L)	< 0

Well-watered condition

Among lines, IR62829A was grouped under high category combining ability class. This line exhibited significant GCA-effects in the desirable direction for six characters out of eight studied. TGMS line IR68949-11-5-31 was a poor general combiner for majority of the root parameters considered in the study.

Among testers, Budda was superior general combiner with significant GCA-effects in the desirable direction for six characters. This tester was fallen in the category 'high'. However the testers P 331 and KMR 3R were grouped under the category 'average' since they displayed significant GCA-effects in desirable direction for five characters and undesirable direction for one character. The rest of the testers were fallen under the category 'low'.

Under low moisture condition

The line IR62829A repeated its performance similar to well-watered condition with respect to significant GCA-effects in the desirable direction. This line was grouped under 'high' category since it secured highest total score of eight out of eight.

Budda a local rainfed variety was a superior general combiner for most of the root characters, hence grouped under 'high' category.

Testers KMR3R and IR42221-14-1-3-1-2R were average general combiners with total scores of two and one respectively. The remaining testers were grouped under 'low' class general combiners category.

4.3.1.4 Results on leaf rolling and tip firing (Summer-1999)

Mean score for the physiological characters leaf rolling (at 2.30 pm) and tip firing recorded from the experiment on root morphological characters under low moisture condition along with mean values for maximum root length and root volume for 27 hybrids and 12 parents were given in the Tables 16 to 18.

The visual scoring of 27 crosses and their 12 parents for tip firing and leaf rolling reflected the information as detailed below.

The crosses IR62829A X P333 and IR58025A x KMR 3R secured first place in the rank list since they registered highest scores for leaf rolling and tip firing in addition to maximum root length above 40 cm and root volume more than 75 CC under low moisture condition.

Second position was secured by two crosses viz., IR 62829Ax Budda and IR62829A x MM 125.

IR62829A x Budda which possessed significant SCA effects in desirable direction for majority of the characters under well-watered condition failed to perform well under low moisture condition since it exhibited SCA effects in undesirable direction for as may as seven out of eight root and shoot characters studied in the present investigation. IR62829A x MM 125 performed very well under both the moisture regimes as it registered significant SCA effects in desirable direction for all the characters considered in the present investigation.

As many as seven crosses secured third position in the rank list prepared by considering scores on leaf rolling, tip firing and treatment means for maximum root length and root volume.

Three crosses viz., IR68949-11-5-31 x MM 111B, IR68949-11-5-31 x P 333 and IR68949-11-5-31 x IR42221-14-1-3-1-2R occupied the final position in the rank list. The possible reasons for the lower position was due to their SCA-effects and *per se* performance for maximum root length. Also the total course for leaf rolling and tip firing characters were very low for the above three crosses. While, IR68949-11-5-31 x IR42221-14-1-3-1-2R in addition to lower

Table 16 : Treatment means for maximum root length, root volume and mean scores for leaf rolling and tip firing parameter under low moisture stress condition in 12 parents and 27 crosses in rice (Kharif-1998)

Sl No.	Crosses/parents	Maximum Root length	Root volume (cc)	Mean scores for Leaf rolling	Mean score for tip firing
1	IR68949-11-5-31 x Budda	38.60	58.33	2.17	0.33
2	IR68949-11-5-31 x MM 125	34.77	56.00	2.33	0.33
3	IR68949-11-5-31 x MM 111B	29.33	45.67	2.33	1.33
4	IR68949-11-5-31 x TT 121	34.53	58.33	2.00	0.67
5	IR68949-11-5-31 x P 331	33.83	31.67	1.67	0.00
6	IR68949-11-5-31 x P 333	29.67	45.50	3.00	0.00
7	IR68949-11-5-31 x KMR 3R	36.33	75.33	1.83	0.33
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	23.67	45.00	1.83	0.67
9	IR68949-11-5-31 x IR35454-18-1R	26.17	58.33	1.00	1.67
10	IR62829 A x Budda	35.27	166.67	1.00	4.00
11	IR62829 A x MM.125	41.73	92.13	1.17	1.67
12	IR62829 A x MM 111B	40.07	61.67	1.67	3.00
13	IR62829 A x TT 121	31.53	67.30	2.33	0.33
14	IR62829 A x P 331	44.67	43.30	1.00	4.00
15	IR62829 A x P 333	45.50	90.00	1.00	3.67
16	IR62829 A x KMR 3R	55.33	168.33	2.83	1.67
17	IR62829 A x IR42221-14-1-3-1-2R	45.27	91.67	2.17	2.33
18	IR62829 A x IR35454-18-1R	37.67	35.00	1.67	2.00
19	IR58025 A x Budda	57.07	268.33	2.50	1.67
20	IR58025 A x MM 125	38.03	22.67	1.50	2.00
21	IR58025 A x MM 111B	34.50	69.00	2.33	1.33
22	IR58025 A x TT 121	34.27	75.00	2.17	4.33
23	IR58025 A x P 331	40.90	37.97	1.00	3.00
24	IR58025 A x P 333	31.47	60.00	1.00	4.00
25	IR58025 A x KMR 3R	70.63	86.20	1.00	3.67
26	IR58025 A x IR42221-14-1-3-1-2R	51.93	56.67	1.00	3.00
27	IR58025 A x IR35454-18-1R	34.53	75.83	1.00	1.67
	Lines				
1	IR 68949-11-5-31	36.97	58.87	5.00	0.00
2	IR 62829A	27.57	51.50	2.50	3.00
3	IR 58025A	44.43	72.67	2.25	3.00
	Testers				
1	Budda	56.13	141.17	1.00	1.00
2	MM 125	78.67	125.00	1.00	1.00
3	MM 111B	60.63	80.17	1.50	1.00
4	TT 121	51.47	58.33	3.50	0.00
5	P 331	56.40	126.67	1.00	3.00
6	P 333	58.77	74.13	4.50	0.00
7	KMR 3R	36.17	117.53	1.00	0.00
8	IR42221-14-1-3-1-2R	52.63	71.67	1.00	0.00
9	IR35454-18-1R	38.57	131.30	1.50	5.00
	SEm±	3.68	8.49		

Table 17. Scoring of 27 rice crosses and their parents for important root and leaf parameters under low moisture stress condition

Sl No.	Crosses/parents	Maximum Root length (cm)	Root volume (cc)	Leaf rolling	Tip firing	Total score	Rank
1	IR68949-11-5-31 x Budda	2	2	2	1	7.0	6
2	IR68949-11-5-31 x MM 125	2	2	2	1	7.0	6
3	IR68949-11-5-31 x MM 111B	1	1	2	1	5.0	8
4	IR68949-11-5-31 x TT 121	2	2	2	1	7.0	6
5	IR68949-11-5-31 x P 331	2	1	2	1	6.0	7
6	IR68949-11-5-31 x P 333	1	1	2	1	5.0	8
7	IR68949-11-5-31 x KMR 3R	2	2	2	1	7.0	6
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	1	1	2	1	5.0	8
9	IR68949-11-5-31 x IR35454-18-1R	1	2	2	2	7.0	6
10	IR62829 A x Budda	2	3	3	3	11.0	2
11	IR62829 A x MM 125	3	3	3	2	11.0	2
12	IR62829 A x MM 111B	3	2	2	2	9.0	4
13	IR62829 A x TT 121	2	2	2	1	7.0	6
14	IR62829 A x P 331	3	1	3	3	10.0	3
15	IR62829 A x P 333	3	3	3	3	12.0	1
16	IR62829 A x KMR 3R	3	3	2	2	10.0	3
17	IR62829 A x IR42221-14-1-3-1-2R	2	3	2	2	10.0	3
18	IR62829 A x IR35454-18-1R	2	1	2	2	7.0	6
19	IR58025 A x Budda	3	3	2	2	10.0	3
20	IR58025 A x MM 125	2	1	3	2	8.0	5
21	IR58025 A x MM 111B	2	2	2	1	7.0	6
22	IR58025 A x TT 121	2	2	2	3	9.0	4
23	IR58025 A x P 331	3	1	3	2	9.0	4
24	IR58025 A x P 333	2	2	3	3	10.0	3
25	IR58025 A x KMR 3R	3	3	3	3	12.0	1
26	IR58025 A x IR42221-14-1-3-1-2R	3	2	3	2	10.0	3
27	IR58025 A x IR35454-18-1R	2	3	3	2	10.0	3
	Lines						
1	IR 68949-11-5-31	2	2	1	1	6.0	5
2	IR 62829A	1	2	2	2	7.0	4
3	IR 58025A	3	2	2	2	9.0	3
	Testers						
1	Budda	3	3	3	1	10.0	2
2	MM 125	3	3	3	1	10.0	2
3	MM 111B	3	3	3	1	10.0	2
4	TT 121	3	2	1	1	7.0	4
5	P 331	3	3	3	2	11.0	1
6	P 333	3	2	1	1	7.0	4
7	KMR 3R	2	3	3	1	9.0	3
8	IR42221-14-1-3-1-2R	3	2	3	1	9.0	3
9	IR35454-18-1R	2	3	3	3	11.0	1

Scoring index :

Root length > 40 cm (score 3)
30-40 cm (score 2)
< 30 cm (score 1)
Root volume : > 75cc (Score 3)
50 cc - 75 cc (score 2)
< 50 cc (score 1)

Leaf rolling : 0.00-1.66 (score 3)
1.67-3.33 (score 2)
3.34-5.00 (score 1)
Tip firing : 0.00-1.66 (score 1)
1.67-3.33 (score 2)
3.34-5.00 (score 3)

Table 18. List of superior cross combinations identified based on total score for maximum root length, root volume, leaf rolling and tip firing characters under low moisture stress condition

Sl No.	Total score	Rank	Crosses/Hybrids		No. of crosses
1	12	1st	IR62829A x P 333	IR58025A x KMR 3R	2
2	11	2nd	IR62829A x Budda	IR62829A x MM 125A	2
3	10	3rd	IR62829A x P 331 IR62829A x KMR 3R IR62829A x IR42221-14-1-3-1-2R IR58025A x Budda	IR58025A x P 333 IR58025A x IR42221-14-1-3-1-2R IR58025A x IR35454-18-1R	7
4	9	4th	IR62829A x MM 111B IR58025A x TT 121	IR58025A x P 331	3
5	8	5th	IR58025A x MM 125		1
6	7	6th	IR68949-11-5-31 x Budda IR68949-11-5-31 x MM 125 IR68949-11-5-31 x TT 121 IR68949-11-5-31 x KMR 3R	IR68949-11-5-31 x IR35454-18-1R IR68949-11-5-31 x TT 121 IR62829A x IR35454-18-1R IR58025A x MM 111B	8
7	6	7th	IR68949-11-5-31 xP 331		1
8	5	8th	IR68949-11-5-31 x MM 111B IR68949-11-5-31 x P 333 IR68949-11-5-31 x IR42221-14-1-3-1-2R		3

<u>Scoring index :</u>

Root length > 40 cm (score 3)
30-40 cm (score 2)
< 30 cm (score 1)
Root volume : > 75cc (Score 3)
50 cc - 75 cc (score 2)
< 50 cc (score 1)

Leaf rolling : 0.00-1.66 (score 3)
1.67-3.33 (score 2)
3.34-5.00 (score 1)
Tip firing : 0.00-1.66 (score 1)
1.67-3.33 (score 2)
3.34-5.00 (score 1)

scores for leaf rolling and tip firing also registered SCA-effects in undesirable direction for as many as seven out of eight root and shoot characters.

Among parents, except TGMS line IR68949-11-5-31 all the 11 parents possessed moderate to high scores for maximum root length, root volume, leaf rolling and tip firing characters. The lines IR62829 A, IR58025z and testers TT 121, P 333 and IR42221-1-14-3-1-2R registered moderate scores for maximum root length, root volume, leaf rolling and tip firing characters. The remaining five testers recorded higher scores for the characters maximum root length, root volume, leaf rolling and tip firing.

Among 27 crosses, 4-possesed lower total scores for these traits viz., IR68949-11-5-31 x MM 111B, IR68949-11-5-31 x P 331, IR68949-11-5-31 x P 333 and IR68949-11-5-31 x IR42224-14-1-2-1R. Highest total scores for leaf physiological parameters observed in as many as 11crosses. In general, crosses with TGMS line IR68949-11-5-31 as female parent performed very poorly for drought avoidance.

4.3.3 Estimation of heterosis over mid parent value, better parent and check variety Rasi for root and shoot morphological traits in rice under well-watered and low moisture condition

The data obtained from experiment conducted during *summer* and *kharif*-1998 involving 27- hybrids, twelve parents and one check variety "Rasi" were used to estimate heterosis. The mean values for all the eight root and shoot morphological characters from 27 hybrids were compared with mid parent value, better parent mean and mean of check variety "Rasi" for the respective characters and the differences were expressed as percentage heterosis. The magnitude of heterosis along with SEm± and means of check varieties are presented in Table 19 and the means of parents and hybrids for all the 8-characters studied two environments are presented in Annexure –III. Pictorial representation of ranges for heterosis were depicted in Fig 5, 6 and 7.

Table19 : Per cent heterosis over mid parent (MP), better parent (BP) and check variety (SH) for eight root and shoot morphological traits under well watered (wwt) and low moisture stress (str) in 27 rice crosses *(Summer* and *Kharif* - 1998)

Sl No.	Crosses	Plant height						Number of tillers					
		MP (%)		BP (%)		SH (%)		MP (%)		BP (%)		SH (%)	
		wwt	str	wwt	str	wwt	str	wwt	str	wwt	str	wwt	str
1	IR68949-11-5-31 x Budda	4.73	8.72*	-13.58*	-9.48*	-5.57	-4.57	-24.27*	7.22	-39.60	-5.45	-40.01	-19.53
2	IR68949-11-5-31 x MM 125	-10.28	-17.04**	-28.30**	-36.18**	-14.85*	-16.91**	54.45**	3.41	19.72	-21.48*	30.73	-1.40
3	IR68949-11-5-31 x MM 111B	-4.17	20.56*	-26.96**	-0.59	-1.03	5.56	8.51	63.22**	-7.27	57.78**	-21.55	10.23
4	IR68949-11-5-31 x TT 121	15.14*	-10.96**	3.07	-29.08**	-7.34	-16.05**	-11.30	52.94**	-32.89	30.00*	-21.55	20.93
5	IR68949-11-5-31 x P 331	-11.58	-3.28	-28.92**	-22.96	-16.90*	-8.89**	62.96**	41.18**	57.14*	20.00	1.52	11.63
6	IR68949-11-5-31 x P 333	26.02**	58.13**	9.40	55.07**	5.57	8.77*	-49.15**	23.26	-62.03**	20.45	-53.85*	-17.67
7	IR68949-11-5-31 x KMR 3R	22.13**	17.53**	10.00	3.34	-2.47	-4.44	-52.94**	-33.33**	-68.42**	-45.45**	-44.62	-44.19**
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	16.41*	-9.93*	3.38	-26.79**	-5.36	-17.90**	-17.74	-7.27	-40.00*	-25.00	-21.55	-20.93
9	IR68949-11-5-31 x IR35454-18-1R	20.02*	23.36**	16.89*	11.45*	-12.37	-3.09	17.07	-7.07	-14.29	19.30	10.75	-28.84
10	IR62829 A x Budda	31.14**	34.95**	-3.72	-3.12	5.16	2.22	63.93**	41.75**	56.25**	32.73*	53.80*	13.02
11	IR62829 A x MM 125	35.81**	25.88**	-2.88	-14.85**	15.34*	10.86*	90.70**	17.83	73.24**	-6.17	89.20**	17.67
12	IR62829 A x MM 111B	-6.12	16.77**	-35.36**	-16.04**	-12.41	-11.85**	71.68**	78.49**	67.24**	72.92**	49.19*	28.84
13	IR62829 A x TT 121	14.95*	9.97*	-9.86	-23.65**	-18.97**	-9.53*	123.88**	-1.85	97.37**	-11.67	130.73**	-17.67
14	IR62829 A x P 331	22.24**	2.71	-12.17*	-28.70**	2.68	-15.68**	132.00**	24.07	100.00**	11.67	78.45**	3.72
15	IR62829 A x P 333	11.76**	60.01**	-14.53*	34.53**	-17.52**	-9.26*	-21.17	34.78**	-31.65	29.17*	-16.94	-3.72
16	IR62829 A x KMR 3R	39.27**	42.82**	9.77	6.90	-2.67	-1.11	30.23	36.84**	-1.75	18.18	72.27**	20.93
17	IR62829 A x IR42221-14-1-3-1-2R	22.00	32.74**	-4.95	-6.42	-12.99	4.94	101.40**	22.41	69.41**	4.41	121.50**	10.23
18	IR62829 A x IR35454-18-1R	38.70**	32.51**	16.61*	1.28	-12.57	-11.98**	22.54	20.00	6.57	10.53	33.82	-2.33
19	IR58025 A x Budda	8.14	28.05**	-18.49**	0.90	-10.92	6.42	149.06**	-6.31	106.25**	-7.14	103.05**	-19.53
20	IR58025 A x MM 125	-3.05	-10.54*	-28.89**	-34.41**	-15.54*	-14.57**	-2.65	-32.85**	-22.54	-43.21**	-15.41	-28.84
21	IR58025 A x MM 111B	-19.46**	-5.76	-43.24**	-25.61**	-23.09**	-21.98**	170.10**	78.22**	138.18**	60.71**	101.52**	39.53*
22	IR58025 A x TT 121	-5.93	-23.79**	-23.94**	-42.23**	-31.62**	-31.73**	74.58**	-27.59*	35.53	-30.00*	58.42*	-34.88*
23	IR58025 A x P 331	13.88*	-4.39	-16.05*	-27.65**	-1.86	-14.44**	52.38*	-1.72	52.38**	-5.00	-1.57	-11.63
24	IR58025 A x P 333	2.96	17.82**	-18.93**	11.96*	-21.77**	-24.44**	48.76**	-32.00*	13.92	-22.73*	38.44	-47.44**
25	IR58025 A x KMR 3R	10.16	-15.95**	-10.47	-30.38**	-20.61**	-35.56**	53.85**	-19.67	5.26	-25.76*	84.59**	-24.19
26	IR58025 A x IR42221-14-1-3-1-2R	4.80	-3.59	-15.86*	-25.69**	-22.96**	-16.67**	49.61**	41.94**	11.76	29.49*	46.15	36.28*
27	IR58025 A x IR35454-18-1R	19.19*	13.62**	3.69	-3.50	-22.27**	-16.05**	-71.43**	38.05**	28.57	36.84*	66.13**	20.93
	Means of check variety Rasi					80.83	81.00					21.64	21.50
	SEm±	4.90	3.02	5.66	3.49	5.66	3.49	4.55	2.54	5.25	2.93	5.25	3.38

Continued ....

Sl No.	Crosses	Maximum root length (3)						Total length (4)					
		MP (%)		BP (%)		SH (%)		MP (%)		BP (%)		SH (%)	
		wwt	str	wwt	str	wwt	str	wwt	str	wwt	str	wwt	str
1	IR68949-11-5-31 x Budda	-38.44**	-17.08*	-48.30**	-3.24	-42.99**	-15.90*	-17.70*	-1.49	-25.97**	-18.11**	-18.84*	-8.45
2	IR68949-11-5-31 x MM 125	-42.73**	-43.73	-55.11**	-58.64**	-40.74**	-29.19**	-28.01**	-28.14**	-38.47**	-45.77**	-24.03**	-21.09**
3	IR68949-11-5-31 x MM 111B	-53.21**	-39.89**	-64.02**	-57.62**	-49.74**	'-36.17**	-27.28**	-4.08	-6.74	-21.15**	-18.31*	-9.32
4	IR68949-11-5-31 x TT 121	-19.53	-21.90**	-13.92	-32.90**	-42.99**	-24.84**	-5.47	-14.98**	-8.66	-30.41**	-19.99*	-19.04**
5	IR68949-11-5-31 x P 331	-3.04	-23.48**	-21.25*	-34.26**	-5.47	-26.36**	-15.23*	-10.69*	-26.16**	-26.91**	-12.85	-14.93**
6	IR68949-11-5-31 x P 333	-40.97**	-38.02**	-52.17**	-49.52**	-42.22**	-35.29**	-8.04	13.71*	1.15	3.88	-11.39	-6.95
7	IR68949-11-5-31 x KMR 3R	-22.82*	-0.64	-26.36*	-1.71	-39.23**	-20.92**	-2.93	11.05*	-2.31	2.40	-15.52	-10.11
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	-46.35**	-47.17**	53.86**	-55.03**	-51.99**	-48.37**	-14.92	-24.00**	-10.84	-'37.15**	-21.90**	-28.75**
9	IR68949-11-5-31 x IR35454-18-1R	7.68	-30.77**	7.25	-32.15**	-18.97	-43.92**	4.79	3.22	-2.64	-3.98	-14.72	-17.30**
10	IR62829 A x Budda	65.20**	-15-73	34.01**	-37.17**	47.81**	-23.09**	32.08**	14.39**	9.71	-16.62**	20.28*	-6.79
11	IR62829 A x MM 125	5.05	-24.43	-20.17*	-46.95**	5.40	-9.15	14.12	5.69	-9.44	-28.56**	11.81	3.95
12	IR62829 A x MM 111B	-21.58*	-9.15	-41.55**	-33.92**	-18.23	-12.64	-18.37**	5.91	-37.60**	-23.48**	-14.48	-12.01*
13	IR62829 A x TT 121	-9.58	-20.20*	-8.31	-38.73**	-38.78**	-31.37**	-4.00	-1.27	-9.41	-28.92**	-26.00**	-17.30**
14	IR62829 A x P 331	26.76*	13.03*	-0.38	13.21	19.58	-2.61	14.09	6.55	-7.91	-23.29**	8.67	-10.74
15	IR62829 A x P 333	-35.05**	5.41	-49.07**	-22.58**	-38.49**	-0.87	-15.49	33.56**	-28.61**	4.94	-24.96**	-6.00
16	IR62829 A x KMR 3R	24.07*	73.64**	13.64	53.00**	-6.21	20.48*	20.86**	53.99**	11.08	21.90**	-3.94	6.95
17	IR62829 A x IR42221-14-1-3-1-2R	-18.33	12.88	-32.23**	-14.00*	-29.48**	-1.31	-3.65	25.10**	-15.44	-9.20*	-18.84*	2.92
18	IR62829 A x IR35454-18-1R	-11.55	13.91*	-15.59	-2.33	-36.24**	-17.83*	7.05	25.43**	5.13	0.00	-20.94*	-13.90*
19	IR58025 A x Budda	24.54*	13.49*	3.40	1.66	14.04	24.40**	9.43	21.83**	-10.68	1.20	-2.08	13.19*
20	IR58025 A x MM 125	-18.71	-37.72**	-36.93**	-51.27**	-16.72	-16.56*	-12.83	-22.58**	-31.94**	-14.61**	-15.97	-15.09**
21	IR58025 A x MM 111B	1.20	-34.33**	-23.06	-43.10**	7.65	-24.84**	-14.92*	-18.31**	-35.93**	-32.89**	-12.19	-22.83**
22	IR58025 A x TT 121	33.26*	-28.54**	39.33**	-33.42**	-6.98	-25.27**	2.11	-25.68**	-5.60	-39.22**	-22.89**	-29.30**
23	IR58025 A x P 331	-18.48	-14.70*	-34.50**	-20.53**	-21.38	-10.89	-2.63	-8.49	-22.71**	-25.16**	-8.78	-12.95*
24	IR58025 A x P 333	-19.80	-39.02**	-35.71**	-46.45**	-22.35*	-31.37**	-10.56	-10.51	-25.77**	-18.31**	-21.98**	-26.86**
25	IR58025 A x KMR 3R	74.79**	75.27**	64.55**	95.30**	35.79**	53.81**	27.56**	19.96**	14.92	10.53*	-0.61	-3.00
26	IR58025 A x IR42221-14-1-3-1-2R	-6.02	7.01	-20.12	-1.33	-16.88	13.07	-4.20	0.75	-17.49*	-16.75**	-20.81*	-5.69
27	IR58025 A x IR35454-18-1R	-20.63	-16.79*	-22.05	-10.46	-41.10**	-24.84**	-1.68	1.17	-5.49	-5.96	-28.95**	-19.04**
	Means of check variety Rasi					44.43	45.90					125.27	126.60
	SEm±	4.28	3.19	4.94	3.68	4.94	3.68	9.20	5.62	10.62	6.49	10.62	7.29

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Sl No.	Crosses	Root growth rate						Deep root length					
		MP (%)		BP (%)		SH (%)		MP (%)		BP (%)		SH (%)	
		wwt	str	wwt	str	wwt	str	wwt	str	wwt	str	wwt	str
1	IR68949-11-5-31 x Budda	-38.46**	-17.02*	-48.33**	-31.19**	-42.86**	-14.29**	-141.85	-48.04*	-124.56**	-67.09**	-132.36**	-45.91*
2	IR68949-11-5-31 x MM 125	-42.69**	-43.74**	-53.09**	-58.66**	-39.68**	-28.57**	-122.94**	-90.89**	-112.79**	-94.79**	-125.43**	-84.28**
3	IR68949-11-5-31 x MM 111B	-53.20**	-39.84**	-64.08**	-51.58**	-49.21**	-42.86**	-143.23**	-103.55**	-123.83**	-102.18**	-153.15**	-104.40**
4	IR68949-11-5-31 x TT 121	-19.57*	-21.85**	-23.91*	-32.86**	-42.86**	-28.57**	-414.48**	-'-68.11**	-241.41**	-78.88**	-132.36**	-71.70**
5	IR68949-11-5-31 x P 331	-3.02	-23.48**	-21.26*	-34.27**	-4.76	-28.57**	-9.89	-73.04**	-48.57*	-82.14**	-16.84	-76.10**
6	IR68949-11-5-31 x P 333	-40.96**	-38.00**	-52.17**	-49.50**	-41.27**	-42.86**	-132.14**	-101.87**	-118.31**	-101.16**	-130.01**	-101.89**
7	IR68949-11-5-31 x KMR 3R	-22.79*	-0.57	-26.35*	0.52	-38.10**	-28.57**	-160.20**	-3.55	-145.00**	-9.09	-120.79**	-60.38**
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	-46.42**	-47.12**	-53.94**	-54.99**	-52.38**	-57.14**	-188.74**	-142.79**	-153.39**	127.98**	-160.08**	-139.62**
9	IR68949-11-5-31 x IR35454-18-1R	7.71	-30.74**	7.23	-32.18**	-19.05	-42.86**	74.76	-149.36**	68.22*	-144.75**	-58.42	-123.90**
10	IR62829 A x Budda	65.25**	-15.70*	34..05**	-37.13**	49.21**	-28.57**	265.81**	-55.56*	87.72**	-79.85**	147.19**	-66.67**
11	IR62829 A x MM 125	5.05	-21.48*	-20.17*	-46.98**	6.35	-14.29*	15.43	-49.24*	-41.28*	-75.89**	16.63	-26.42
12	IR62829 A x MM 111B	-21.53**	-9.1	-41.52**	-33.87**	-17.46	-14.29*	-61.22	-28.61	-80.31**	-67.14**	-56.13	-36.48
13	IR62829 A x TT 121	-9.65	-20.19*	-8.41	38.71**	-38.10**	-28.57**	-3460.00**	-83.89**	-660.00**.	-92.86**	-119.40**	-90.57**
14	IR62829 A x P 331	26.80**	12.99	-0.35	-13.24	20.63	-14.29*	94.13**	54.12*	-0.86	;-31.68	60.29	-7.55
15	IR62829 A x P 333	-35.02**	5.32	-49.04**	-22.64**	-38.10**	0.00	-122.07**	17.72	-111.27**	-46.12**	-118.50**	-2.25
16	IR62829 A x KMR 3R	24.11*	73.57**	13.69	52.97**	-4.76	14.29*	225.58**	1255.00**	75.00	310.81**	-19.13	59.12*
17	IR62829 A x IR42221-14-1-3-1-2R	-18.33	12.89	-32.24**	-13.97	-28.57**	-14.29*	-84.06	51.16*	-91.79**	-32.55*	-90.78**	-3.77
18	IR62829 A x IR35454-18-1R	-11.58	13.86*	-15.64	-2.36	-36.51**	-28.57**	-181.97**	150.00**	-146.73**	-10.51	-111.57**	-51.57*
19	IR58025 A x Budda	24.52*	13.50*	3.38	1.70	14.29	14.29*	93.45**	33.44*	8.37	3.57	43.24	70.44**
20	IR58025 A x MM 125	-18.69*	-37.73**	-36.91**	-51.28**	-15.87	-28.57**	-54.89	-73.59**	-75.58**	-82.88**	-51.49	-47.80**
21	IR58025 A x MM 111B	1.21	-34.35**	-23.05*	-43.11**	7.94	-28.57**	3.28	-80.63**	-44.56*	-85.31**	23.56	-71.70**
22	IR58025 A x TT 121	33.21**	-28.53**	39.23**	-33.41**	-6.35	-28.57**	1014.75**	-76.23**	378.87**	-80.12**	-21.48	-72.96**
23	IR58025 A x P 331	-18.49	-14.72*	-34.51**	-20.53**.	-20.63	-14.29*	-61.61	-39..28*	-78.86**	-49..22**	-65.84	-31.45
24	IR58025 A x P 333	-19.83*	-39.01**	-35.74**	-46.75**	-22.22*	-42.86**	-65.43	-93.21**	-80.99**	-94.90**	-68.81*	-90.57**
25	IR58025 A x KMR 3R	74.25**	75.22**	64.61**	95.29**	36.51**	-42.86**	571.59**	294.50**	355.00**	558.92**	110.19**	155.35**
26	IR58025 A x IR42221-14-1-3-1-2R	-6.03	7.07	-20.13	-1.24	-15.87	0.00	-25.45	18.35	-57.29*	-3.09	-51.98	37.74
27	IR58025 A x IR35454-18-1R	-20.59*	-16.75*	-22.03*	-10.41	-41.27**	-28.57**	-029.21**	-60.58*	-207.48**	-47.08**	-126.54**	-71.70**
	Means of check variety Rasi					0.63	0.70					14.43	15.9
	SEm±	0.061	0.046	0.07	0.053	0.068	0.05	4.278	3.19	4.94	3.68	4.94	3.69

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Sl No.	Crosses /hybrides	Number of roots						Root volume					
		MP (%)		BP (%)		SH (%)		MP (%)		BP (%)		SH (%)	
		wwt	str	wwt	str	wwt	str	wwt	str	wwt	str	wwt	str
1	IR68949-11-5-31 x Budda	121.91**	132.06**	109.30**	121.63**	35.34**	48.34**	-2.76	-42.25**	-26.29	-59.25**	-25.99	-30.01**
2	IR68949-11-5-31 x MM 125	-7.74	42.79**	-43.03**	1.05	56.77**	62.83**	-55.04**	-39.09**	-72.32**	-55.20**	-37.99*	-32.77**
3	IR68949-11-5-31 x MM 111B	-25.14**	67.62**	-50.29**	64.33**	-2.06	9.98	-68.47**	-34.31**	-80.83**	-43.04**	-54.00**	-45.14**
4	IR68949-11-5-31 x TT 121	56.51**	42.9**	-20.93**	0.23	43.42**	66.55**	18.58	29.41**	-10.00	28.52*	-10.00	-9.00
5	IR68949-11-5-31 x P 331	55.33**	56.45**	0.78	9.73	118.99**	82.35**	-30.12**	-45.96**	-53.75**	-46.21**	-25.99	-61.94**
6	IR68949-11-5-31 x P 333	53.61**	209.75**	19.01	127.53	40.04**	52.28**	-40.41**	-31.58**	-56.90*	-38.62**	-49.99**	-45.38**
7	IR68949-11-5-31 x KMR 3R	-36.48**	-17.31	-59.60**	-45.13**	-3.95	12.24	-13.94	-14.59	-43.21**	-35.90**	-7.99	-9.6
8	IR68949-11-5-31 x IR42221-14-1-3-1-2R	25.93**	11.43	-13.62**	-20.76	50.19**	25.61*	-21.52	-31.05**	-39.58**	-37.21**	-42.00**	-45.98**
9	IR68949-11-5-31 x IR35454-18-1R	11.37	-9.52	-29.59**	-40.96**	72.18**	29.55**	-7.06	-38.65**	-39.53**	-55.57**	4.01	-30.01**
10	IR62829 A x Budda	165.26**	273.42**	128-81**	155.86**	29.89*	55.24**	209.19**	71.23**	121.12**	16.41	122.01**	100.12**
11	IR62829 A x MM 125	54.84**	85.67**	-11.00*	5.83	144.93**	70.50**	27.54**	4.40	-23.93**	-26.29*	70.41**	10.56
12	IR62829 A x MM 111B	-17.44	135.93**	-'-50.10**	59.36**	-1.69	2.48	-40.68**	-6.33	-65.50**	-23.08*	-16.00	-25.93*
13	IR62829 A x TT 121	39.06**	13.94	-6.34	-35.29**	11.09	7.56	14.53	22.55**	-18.00	15.37	-18.00	-19.21
14	IR62829 A x P 331	68.44**	74.30**	0.17	-1.02	117.67**	64.52**	-5.51	-21.09	-40.00**	-25.71	-4.00	-48.02**
15	IR62829 A x P 333	16.21	414.98**	-21.57**	342.51**	-7.07	38.92**	-7.04	43.27**	-36.21**	21.40*	-25.99	8.04
16	IR62829 A x KMR 3R	-9.61	34.60**	-46.72**	-25.28**	26.70*	52.85**	79.34**	99.17**	13.58	43.22**	84.00**	102.04**
17	IR62829 A x IR42221-14-1-3-1-2R	58.04**	96.47**	-2.27	12.22	69.93**	77.83**	35.06**	48.85**	-2.08	27.91*	-6.00	10.08
18	IR62829 A x IR35454-18-1R	25.00**	42.50**	-26.98**	-21.42**	78.58**	72.42**	-18.22	-61.71**	-48.84**	-17.34**	-12.00	-57.98**
19	IR58025 A x Budda	337.56**	297.52**	197.02**	196.30**	68.61**	80.49**	313.08**	148.65**	176.89**	87.43**	178.02**	222.09**
20	IR58025 A x MM 125	-44.91**	-18.96*	-70.42	-51.93**	-18.61	-22.56*	-76.76**	-77.07**	-86.61**	-81.87**	-70.00**	-72.75**
21	IR58025 A x MM 111B	24.39*	137.52**	-31.39**	73.98**	35.15**	11.84	-30.56**	-9.71	-60.33**	-13.93	-4.80	-17.17
22	IR58025 A x TT 121	50.20**	17.74*	-12.04*	-30.54**	4.33	15.45	34.72**	14.5	-9.60	28.57*	-9.60	-9.96
23	IR58025 A x P 331	51.58**	29.63**	-17.13**	-23.53**	80.08**	27.07**	-41.92**	-42.04**	-64.75**	-34.91**	-43.60**	-54.38**
24	IR58025 A x P 333	62.13**	221.47**	-4.95	213.77**	11.84	-1.47	10.25	-18.26	-28.62**	-19.06	-17.20	-27.97**
25	IR58025 A x KMR 3R	-17.99**	-0.40	-55.49**	-42.92**	5.83	16.75**	-8.26	-9.36	-44.44**	-26.66**	-9.99	3.48
26	IR58025 A x IR42221-14-1-3-1-2R	31.85**	49.50**	-26.38**	-11.15	28.01*	40.83**	16.74	-21.48*	-20.83	-20.93	-24.00	-31.93**
27	IR58025 A x IR35454-18-1R	5.75	33.63**	-42.74**	-24.08**	40.04**	66.55**	-28.62*	-25.64**	-57.21**	-42.24**	-26.40	-9.00
	Means of check variety Rasi					177.33	177.30					83.83	83.30
	SEm±	20.486	15.4	23.65	17.78	23.65	17.78	10.75	7.35	12.56	8.49	12.56	8.49

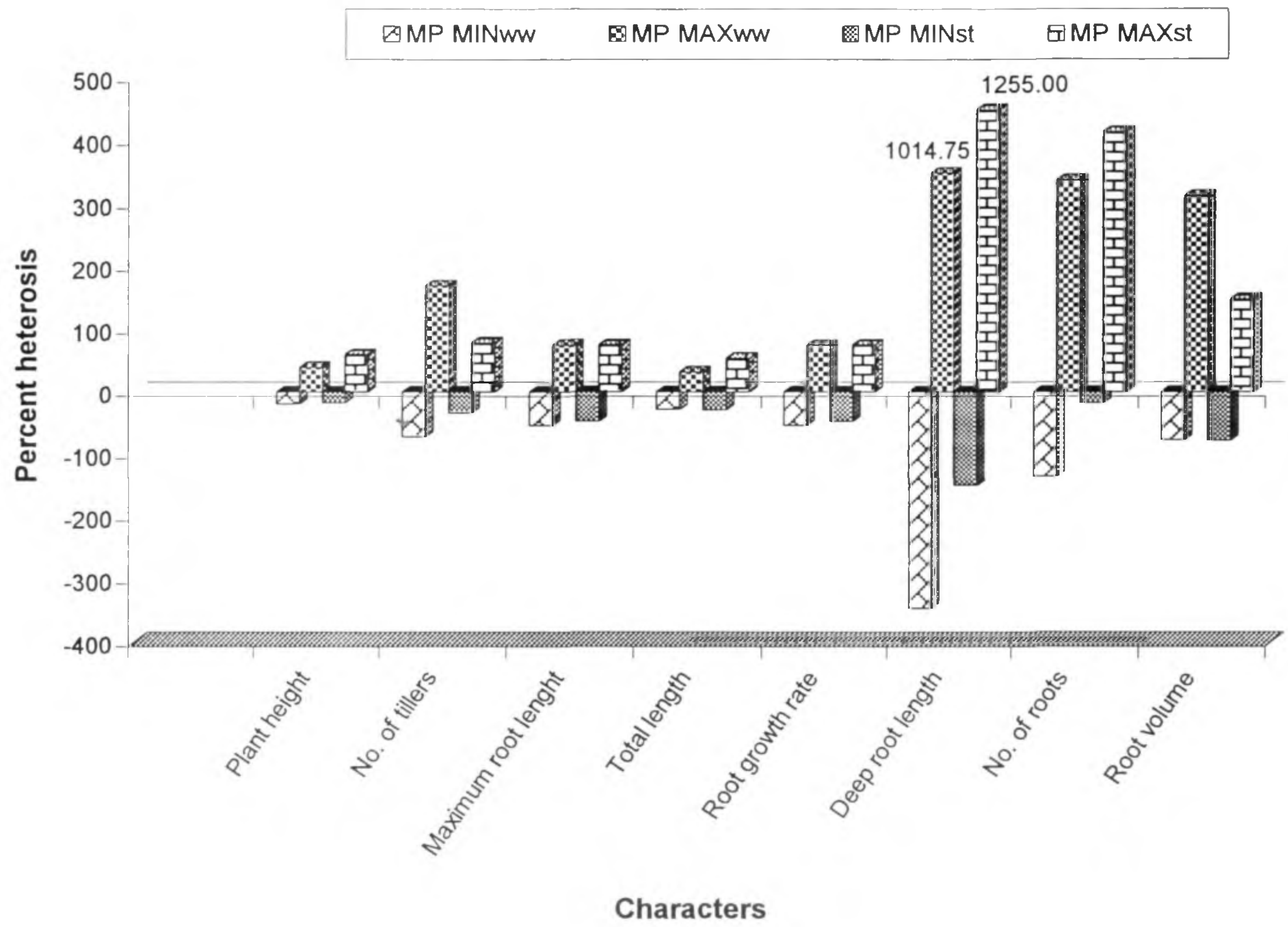

Fig 5 : Range for heterosis over midparent (MP) for eight root and shoot traits under well watered (ww) and low moisture stress (st) condition in 27 rice crosses

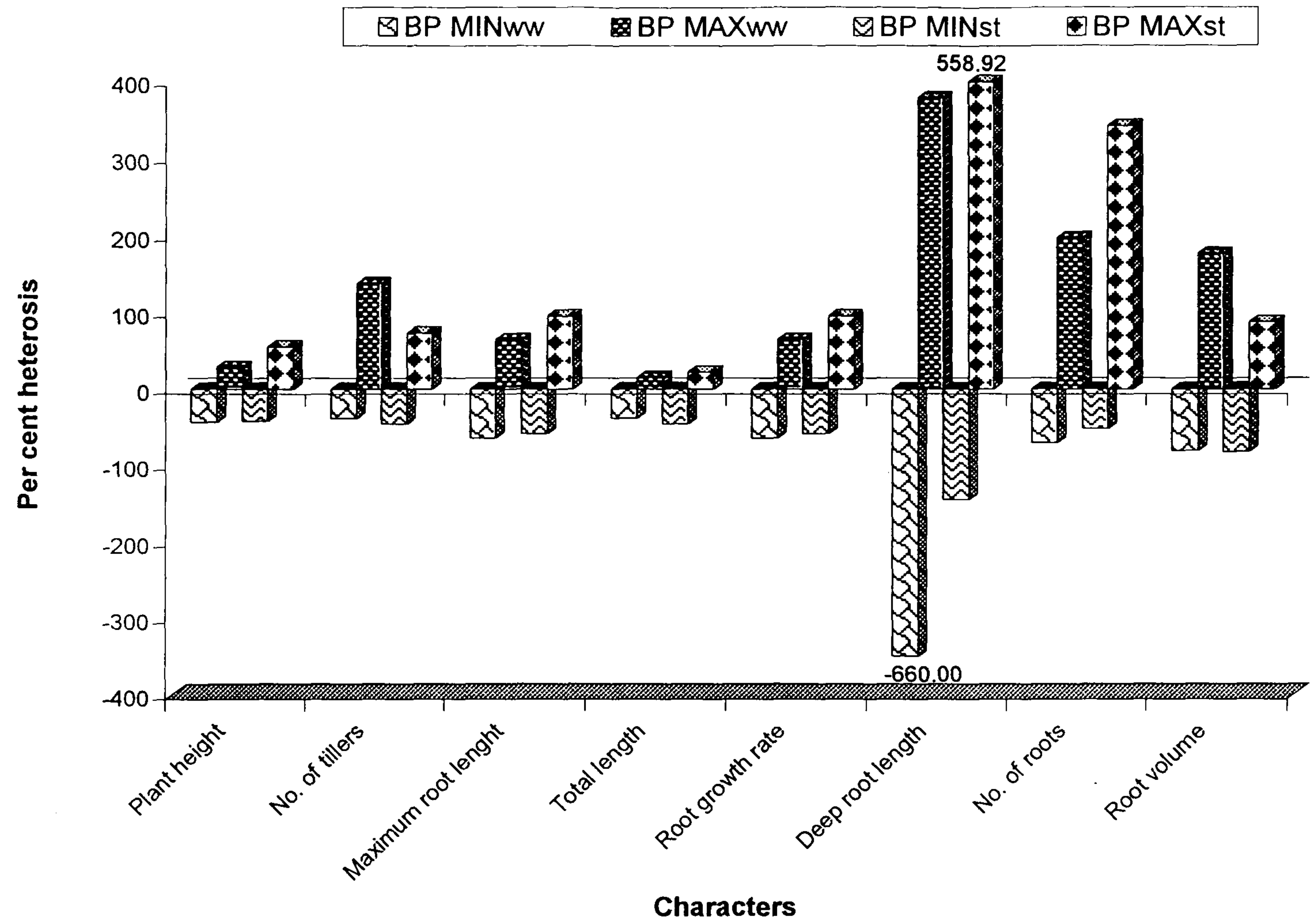

Fig 6 : Range for heterosis over better parent (BP) for eight root and shoot traits under well watered (ww) and low moisture stress (st) condition in 27 rice crosses

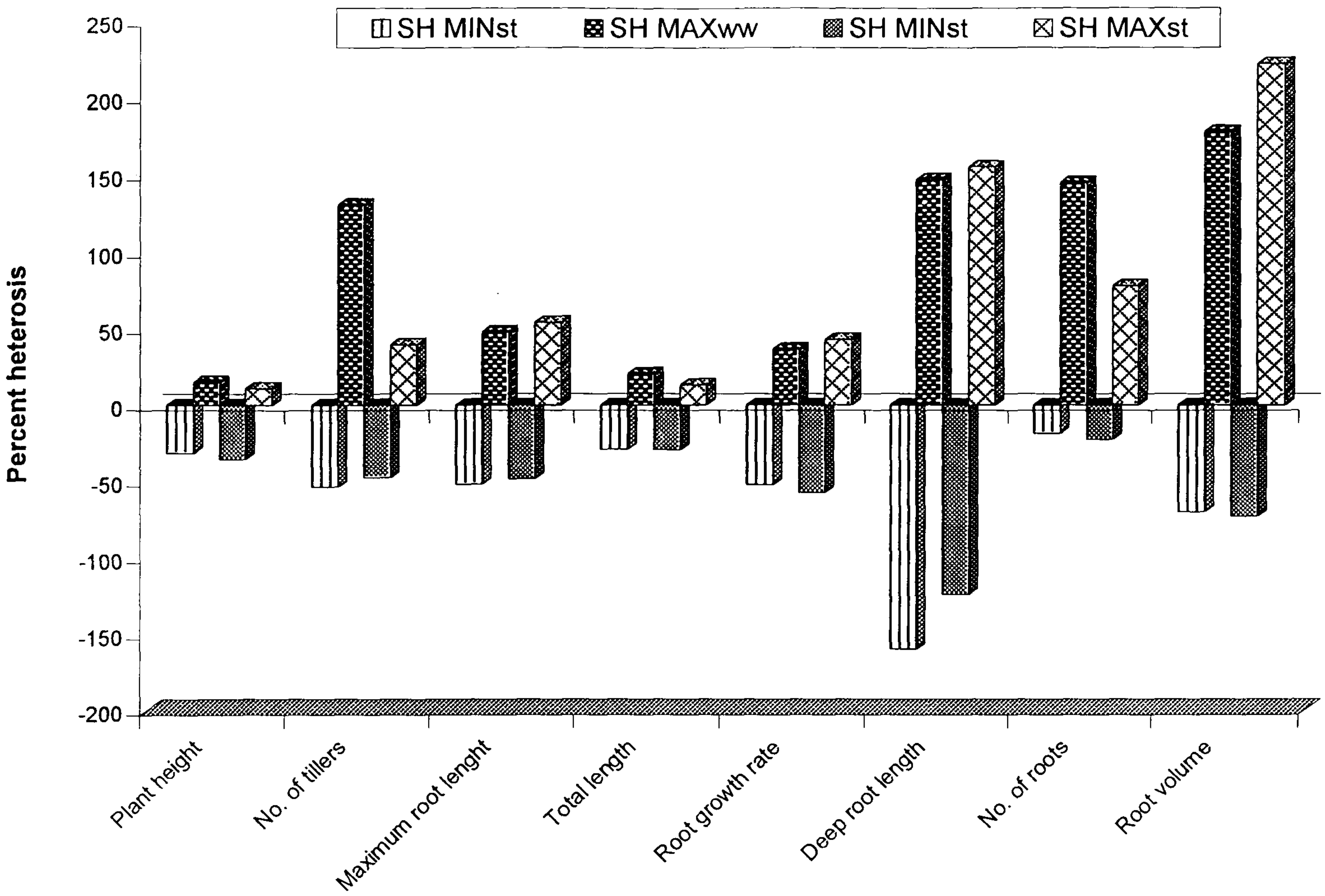

Fig 7 : Range for per cent standard heterosis (SH) over check "Rasi" for eight root and shoot traits in 27 rice crosses under well watered (ww) and low moisture stress (st) condition

4.3.3.1 Plant height

Mid parent heterosis for this trait ranged from –19.46 (IR58025 A x MM 111B) to 39.27 (IR62829A X KMR 3R) and from–17.04 (IR68949-11-5-31 X MM 125) to 60.01 (IR62829A X P 333) under well-watered and low moisture condition respectively. Of the 27 hybrids, 14 crosses under well-watered condition and 15 in low moisture stress regimes exhibited positive significant (desirable) heterosis over mid parent.

Out of 27 crosses, only two and four crosses registered significant positive heterosis over better parent under well-watered and low-moisture stress conditions respectively. For better parent heterosis the ranges observed were from -3.24 (IR58025 A x MM 111B) to 28.89 (IR58025 A x MM 125) and from -42.23 (IR58025 A x TT 121) to 55.07 (IR68949-11-5-31 X P 333) under well-watered and low moisture condition respectively.

Heterosis over check variety "Rasi" were positive and significant (desirable) in only one cross under well-watered condition. While, under low moisture stress condition two crosses registered magnitude of standard heterosis in the preferred direction. The highest positive standard heterosis recorded for this trait were 15.34 and 10.86 per cent for the cross IR62829 A x MM125 under well-watered and low moisture condition respectively.

4.3.3.2 Number of tillers

Positive significant heterosis was preferred for this trait.

Under well-watered condition

The hybrid IR62829A x P 331 (132.00) exhibited significant positive heterosis over mid parent value. Of the 27 crosses, 16 showed heterosis in the desirable direction and magnitude. The range for mid parent heterosis observed was from –71.43 (IR58025A x IR35454-18-1R) to +132.00 (IR62829A x P331).

For heterobeltiosis, 10-crosses displayed significant positive heterosis. IR58025A x MM 111B (+138.17%) was a superior cross combination out of all hybrids. Lowest negative heterobeltiosis (-68.42%) was observed in IR68949-11-5-31 x KMR 3R.

For heterosis over check 'Rasi' the range observed was from –53.85 per cent (IR68949-11-5-31 x P 333) to +130.73 per cent (IR62829A x TT 121). Totally, 12-cross combinations showed heterosis in the desirable direction and magnitude.

Under low moisture: Ten crosses registered significant positive mid parent heterosis. The cross IR62829A x MM 111B (79.49%) was the best cross for mid parent heterosis. Lowest heterosis (negative) was noticed in the cross IR68949-11-5-31 x KMR 3R (-33.33%).

For heterobeltiosis, the range observed was from -45.45 per cent (IR68949-11-5-31 x KMR 3R) to + 72.92 per cent (IR62829A x MM 111B). as many as eight-crosses exhibited desirable magnitude of heterobeltiosis under water limited environment. IR58025A x MM 111B (39.53%) was the best cross combination for positive heterosis over check 'Rasi'. Lowest standard heterosis noticed was –47.44 per cent for IR58025A x P333.

4.3.3.3 Maximum root length

Significant positive heterosis was preferred for this character. Maximum root length helps in maintaining optimum leaf water potential under reduced soil water status by extracting water from deeper soil layers.

Under well-watered condition, highest mid parent heterosis (74.79%) was noticed in IR58025 A X KMR 3R followed by IR62829 A x Budda (65.20%) and IR58025 A X TT 121(33.26). Mid parent heterosis was ranged from -53-21% (IR68949-11-5-31 X MM 111B) to 77.49% (IR58025A X KMR 3R).

The range for per cent heterosis over mid parent value observed under low moisture stress condition was from -47.17 (IR68949-11-5-31 x IR42221-14-1-3-1-2R) to 75.27 (IR58025 A x KMR 3R). Of the 27 hybrids, only four crosses recorded significant positive heterosis over mid parent value under low moisture stress regime.

The ranges of per cent heterobeltiosis observed were from -64.08 (IR68949-11-5-31 x MM 111B) to 64.55 (IR58025 A x KMR 3R) and from -58.64 (IR68949-11-5-31 X MM 125) to 95.30 (IR58025 A x KMR 3R) for well-watered and low moisture condition respectively.

Out of 27 crosses, six exhibited positive heterobeltiosis under well-watered condition and only three of them possessed significant (desired) heterobeltiosis for maximum root length. The number of crosses which registered positive heterobeltiosis and significant positive heterobeltiosis under low moisture condition were three and two respectively.

Highest positive standard heterosis was recorded by IR62829 A x Budda (47.81%) followed by IR58025 A X KMR 3R (35.79%) under well-watered condition. The range for per cent standard heterosis displayed under well-watered condition was from 47.81% (IR62829 A X Budda) to -51.99% (IR68949-11-5-31 x IR42221-14-1-3-1-2R).

Under limited water environment, totally four crosses exhibited positive per cent standard heterosis in that three crosses possessed significant positive (desirable) standard heterosis. Highest positive significant per cent standard heterosis was recorded for IR58025 A X KMR 3R (53.81%) followed by IR58025 A x Budda (24.40%). The cross IR68949-11-5-31 X IR42221-14-1-3-1-2R registered lowest negative significant per cent standard heterosis for this trait.

4.3.3.4 Total length

Total length indicates both plant height and maximum root length of a genotype, hence positive significant per cent heterosis was preferred for this trait.

Of the 27 crosses considered for estimating per cent heterosis, nine crosses recorded positive per cent heterosis over mid parent value and only three crosses had significant heterosis. IR62829A x Budda registered highest per cent heterosis (32.09) followed by the cross IR58025A x KMR 3R (27.56) under well-watered condition.

Under induced low moisture condition, totally 15 crosses displayed positive heterosis over mid parent and 9 crosses registered significant positive (desired) heterosis. The range observed for per cent mid parent heterosis was from–28.14% (IR68949-11-5-31 x MM 125) to (IR62829A x KMR 3R) 53.99%.

Highest negative and positive direction per cent heterobeltiosis were recorded for IR68949-11-5-31 x MM 125 (-38.47) and IR58025A x KMR 3R (14.92) under well-watered condition respectively. None of the crosses possessed significant positive per cent heterobeltiosis for total length under this environment. However, five crosses recorded heterobeltiosis in the positive direction.

Under low moisture condition, of the 27 crosses only seven crosses registered positive per cent heterobeltiosis and in that only two possessed significant heterosis. The cross IR68949-11-5-31 X MM 125 recorded lowest negative per cent heterobeltiosis (-45.77). While, IR62829A x KMR 3R (21.90%) displayed highest significant per cent heterobeltiosis in positive direction.

With respect to per cent standard heterosis, the cross IR62829A x Budda (20.28) was the only cross exhibited substantial amount of positive heterosis for total length under well-watered condition. The lowest per cent standard heterosis (negative side) was noticed in the cross IR58025A x IR35454-18-1R (-28.95).

For total length under low moisture condition, only one cross viz., IR62829A x Budda showed significant positive per cent standard heterosis. Non significant but positive per cent standard heterosis was observed among the crosses IR62829A x KMR 3R (+6.95), IR62829A x MM 125 (+3.95) and IR62829A X IR42221-14-1-3-1-2R (+2.92) in the order of decreasing trend.

4.3.3.5 Root growth rate

IR58025 A X KMR 3R (+74.85%) and IR62829A x Budda (+65.25%) occupied first and second position respectively for heterosis over mid parent under well-watered condition. Lowest per cent heterosis over mid parent in negative direction was recorded by IR68949-11-5-31 x MM 111B (-53.20%) under well-watered condition. Under low moisture condition only three crosses exhibited significant per cent heterosis (desired) over mid parent i.e IR58025 A x KMR 3R (+75.22%) followed by IR62829 A X KMR 3R (+73.57) and IR58025A x Budda (+13.50). However, another four crosses possessed non-significant but positive per cent mid parent heterosis.

For heterobeltiosis, six crosses registered positive heterosis. Highest per cent positive heterobeltiosis was observed with IR58025A x KMR 3R (64.61) followed by IR58025A x TT 121 (39.23) and IR62829 A x Budda (34.05) under well-watered condition.

Under low moisture stress condition, the range observed for per cent heterobeltiosis was from –58.66 (IR68949-11-5-31 x MM 125) to + 95.29 (IR58025 AX KMR 3R). In addition, one more cross (IR62829 A x KMR 3R) also recorded significant positive per cent heterobeltiosis along with the cross IR58025A x KMR 3R.

For the character root growth rate under well-watered condition, as many as six-crosses exhibited positive per cent standard heterosis with only two crosses displayed significant heterosis in the desirable direction. The highest per cent positive standard heterosis was recorded by IR62829A x Budda (49.21).

The range observed for per cent standard heterosis over check variety 'Rasi' was from –57.40 (IR68949-11-5-31 X IR42221-14-1-3-1-2R) to 42.86 (IR58025A x KMR 3R) under low moisture environment. Totally three crosses exhibited significant positive (desirable) standard heterosis over check variety "Rasi".

4.3.3.6 Deep root length

Range for per cent heterosis over mid parent value was from –3460.00 (IR62829A x TT 121) to +1014.75 (IR58025A x TT 121) under well-watered condition. Totally, seven crosses exhibited positive per cent heterosis over mid parent value for deep root length.

Under low moisture stress condition, IR62829A X KMR3R (1255.14), IR58025A x KMR 3R (294.50) and IR62829A x IR35454 –18.1R (150.00) exhibited significant positive per cent heterosis over mid parent value. Lowest negative per cent heterosis over mid parent was observed in the cross IR62829A x IR35454-18-1R (-149.36).

Per cent heterosis over better parent was ranged from –660.00 (IR62829A x TT 121) to 378.87 (IR58025 x TT 121) under well-watered condition. As many as 6 crosses exhibited per cent positive heterosis over better parent under this condition.

Under low moisture condition, range for heterobeltiosis observed was from –144.75 per cent (IR68949-11-5-31 x IR35454-18-1R) to +558.92 (IR58025A x KMR 3R).

The crosses, which displayed significant positive percent standard heterosis under well-watered condition were, IR62829A x Budda (+147.19) and IR58025A x KMR 3R (110.19). Lowest negative per cent standard heterosis was noticed with IR68949-11-5-31 x MM 111B (-153.15).

Under low moisture stress condition, IR58025A x KMR 3R (+155.35) registered highest per cent positive standard heterosis followed by IR58025A x Budda (+70.44) and IR62829A x KMR 3R (+59.12). Lowest negative per cent standard heterosis was exhibited by IR68949-11-5-31 x IR42221-14-1-3-1-2R (-139.62).

4.3.3.7 Number of Roots

Majority of the crosses exhibited significant positive mid parent heterosis for the trait number of roots under well-watered condition. Number of crosses with significant (desirable) magnitude heterosis over mid parent value were 17 in number. IR58025A x Budda (337.56%) was superior cross combination for number of roots with respect to mid parent heterosis.

Under low moisture condition, 21 crosses exhibited mid parent heterosis in desirable magnitude and direction. The range for mid parent heterosis observed was from –17.31 (IR68949-11-5-31 x KMR 3R) to +414.98 (IR62829A x P 333).

Heterobeltiosis in the desirable direction and magnitude were noticed in three crosses under well-watered condition and nine under low moisture stress condition. The ranges for per cent heterobeltiosis under well-watered and low moisture condition were from –70.42 (IR58025A x MM 125) to 197 .02 per cent (IR58025A x Budda) and –51.93 per cent (IR58025A x MM125) to 342.51 per cent (IR62828A x P333) respectively.

Per cent standard heterosis range observed for this trait was from –18.61 (IR58025A x MM 125) to +144.93 (IR62829A x MM125A) under well-watered condition. Eighteen crosses displayed standard heterosis in desirable direction and magnitude.

Under low moisture condition 19 crosses exhibited standard heterosis over check "Rasi" in desirable magnitudes for the trait number of roots. The range of -22.56 (IR58025A x MM 125) to +82.35 (IR68949-11-5-31 x P 331) was observed for standard heterosis.

4.3.3.8 Root volume

Higher magnitude of heterosis for root volume mainly contributed by deep root density than number of roots up to 30 cm soil depth was preferred among the cultivars for various kinds of low moisture under rain fed ecosystem. However in the present investigation, positive significant per cent heterosis was considered as desirable.

Desirable magnitude of heterosis over mid parent value for root volume was noticed in as many as six hybrids under well-watered condition. The range observed for percent mid parent heterosis was from –68.47 (IR68949-11-5-31 x MM 111B) to +313.08 (IR58025A x Budda).

Under low moisture condition, seven crosses possessed desirable magnitude of significant positive heterosis over mid parent. Highest heterosis in positive direction was observed in IR58025A x Budda (+148.65%).

For heterobeltiosis in desirable magnitude only two crosses were identified under well-watered condition. The highest positive per cent heterobeltiosis was noticed in IR58025A x Budda (176.89) seconded by IR62829A x Budda (+121.12).

Under low moisture stress condition, the cross IR58025A x Budda (+87.43) registered highest per cent heterobeltiosis. Only six crosses exhibited heterobeltiosis in desirable direction.

The cross IR58025A x Budda (+178.02) registered highest positive per cent standard heterosis followed by the crosses IR62829A X Budda (+122.01) and IR62829A x KMR 3R (+84.00) under well-watered condition. The lowest negative direction standard heterosis was noticed in the cross IR58025A x MM 125 (-70.00).

The range of –72.75 (IR58025A x MM125) to +222.09 (IR58025A x Budda) was observed for per cent standard heterosis over check 'Rasi' under low moisture condition. As may as three crosses exhibited significant positive standard heterosis (desirable) under low moisture environment.

Over all, by considering SCA-effects heterosis in the desirable magnitude and direction and per se performance, IR62829A x Budda was the top most cross combination followed by IR62829A x MM 125 under well-watered condition. Though, IR62829A x Budda displayed significant SCA effects for only four out of eight characters, registered significant per cent positive heterosis over mid parent for all the characters considered in the study. This cross also possessed significant (positive) heterobeltiosis for as many as six characters.

Under low moisture condition, IR62829A x KMR 3R was the most promising hybrid followed by IR58025A x Budda. However, IR62829A x KMR 3R though appeared inferior over IR58025A x Budda with respect to SCA-effects in the desirable direction and magnitude displayed significant per cent positive heterosis over mid parent for all the eight characters and heterobeltiosis for five out of eight characters considered in the study. Considering SCA-effects, heterosis in the desirable direction and magnitude and *per se* performance, IR58025A x Budda appeared most promising.

Under both moisture regimes, crosses involving TGMS line IR68949-11-5-31 were inferior for majority of the characters considered in the present investigation.

4.4 Estimation of magnitude of standard heterosis for yield parameters over three check varieties Mangala, Jaya and Rasi under irrigated condition

27-hybrids (including few cross combinations which were not used for L x T analysis) and three check varieties were grown under irrigated condition during Kharif-1998. The data recorded were used for estimation of standard heterosis. ANOVA for ten yield parameters reflected significant variation among the treatments for all the characters (Table 20). The experimental results obtained for 10 yield parameters were discussed character wise as detailed below and presented in Table 21..

4.4.1 Days to fifty per cent flowering

For this character significant negative heterosis was preferred.

The range observed for per cent standard heterosis over the check Mangala was from–8.42 to 22.21 and it was from -19.00 to 8.08 over the check Jaya. Standard heterosis range recorded over the check Rasi was from –5.31 to 26.36.

Over the check Mangala, only six crosses register per cent standard heterosis in the negative direction while the number was 23 and three over Jaya and Rasi respectively.

4.4.2 Plant height

For this trait, positive significant standard heterosis was preferred as this trait was positively correlated with maximum root length and total root dry weight among the cultivars of rain fed rice ecosystem.

Highest per cent standard heterosis over the check 'Mangala' was recorded for the cross IR58025A x MM 125 (+45.71). It was +33.34 (over Jaya)

Table 20 : Mean sum of squares for 10 grain yield characters in 27 rice crosses used in estimation of heterosis under irrigated condition

Source	Df	CH_1	CH_2	CH_3	CH_4	CH_5	CH_6	CH_7	CH_8	CH_9	CH_{10}
Replications	2	32.69	64.78	55.47	43.33	57.69	21.44	39.78	29.36	43.20	36.93
Treatments	29	154.91**	535.87**	33.13**	23.76**	6.53**	798.23**	1863.35**	732.32**	37.95**	84.08**
Error	58	2.17	15.74	2.23	1.90	1.58	18.71	28.85	18.59	1.62	33.24
Total	89	189.77	616.39	90.83	68.99	65.80	838.38	1931.98	780.27	82.77	154.25
SEm±		1.20	3.24	1.22	1.13	1.02	3.53	4.39	3.52	1.04	1.49
CV %		1.48	5.18	7.91	8.22	5.93	3.53	6.43	6.37	4.97	7.09
General mean		99.95	76.57	18.89	16.77	21.77	122.63	83.59	67.33	25.63	25.69

CH_1- Days to 50 % flowering
CH_2- Plant height (cm)
CH_3- Number of tillers
CH_4- Number of productive tillers
CH_5- Panicle length
CH_6- Number of spikelets /panicle
CH_7- Number of filled grains /panicle
CH_8- Per cent spikelet fertility
CH_9- 1000 grain weight
CH_{10}- Grain yield /plant

Table 21 : Per cent heterosis for 10 yield parameters in 27 rice crosses over the checks Mangala (CH_1), Jaya (CH_2) and Rasi (CH_3) in rice *(Kharif* 1998)

Sl No.	Crosses/ hybrids	Days to 50%flowering			Plant height			Number of tillers /plant			Number of productive tillers/plant		
		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	IR68949-11-5-31 x Budda	-8.42**	-19.00**	-5.31**	39.67**	27.81**	20.01**	-11.46	-22.32**	-2.05	-9.19	-19.81**	-1.58
2	IR68949-11-5-31 x IR9761	12.02**	-0.93	15.82**	2.18	-6.5	-12.20**	34.66**	18.15**	48.97**	35.17**	19.36**	46.50**
3	IR68949-11-5-31 x IR35454-18-1R	12.63**	-0.39	16.46**	26.33**	15.60**	8.50*	-28.44**	-37.21**	-20.83**	-21.86**	-31.00**	-15.32*
4	IR68949-11-5-31 x TT 121	-1.99	-13.32**	1.34	25.13**	14.50**	7.52*	18.23**	3.74	30.79**	25.98**	-11.25	35.54**
5	IR68949-11-5-31 x KMR 3 R	0.12	-11.46**	3.52**	-11.59**	-19.10**	-24.04**	-2.40	-14.37*	7.97	4.88	-7.40	13.67
6	IR68949-11-5-31 x IR42221-14-1-3-1-2R	6.67**	-5.57**	10.29**	-2.87	-11.12**	-16.54**	14.63*	0.57	26.81**	2.79	-9.23	11.40
7	IR68949-11-5-31 x P 333	1.28	-10.43**	4.72**	8.52	-0.67	-6.77	-12.66	-23.37**	-3.38	-10.65	-21.10**	-3.16
8	IR68949-11-5-31 x MM 111 B	2.45	-9.39**	5.93**	25.14**	14.52**	7.53*	-4.20	-15.95**	5.98	0.00	-11.70	8.38
9	IR68949-11-5-31 x MM 125	3.03*	-8.88**	6.53**	11.10*	1.67	-4.54	8.57	-4.74	20.11**	14.70*	+1.29	24.31**
10	IR62829A x IR42221-14-1-3-1-2R	18.01**	4.37**	22.02**	-3.55	-11.74**	-17.13**	-12.66	-23.37**	-3.38	-12.04	-22.33**	-4.67
11	IR62829A x P 331	-2.58*	-13.84**	0.73	-10.12*	-17.75**	-22.77**	31.00**	14.94*	44.93**	15.46*	1.96	25.14**
12	IR62829A x P 331	10.17**	-2.57*	13.91**	6.12	-2.89	-8.81*	41.92**	24.52**	57.00**	40.11**	23.73**	51.85**
13	IR62829A x MM 125	19.53**	5.71**	23.59**	-21.77**	-28.41**	-32.78**	12.83	-1.01	24.82**	12.67	-0.5	22.12**
14	IR62829A x IR35454-18-1R	-0.72	-12.20**	2.66*	-9.77*	-17.43**	-22.47**	37.00**	20.21**	51.57**	40.81**	24.34**	52.61**
15	IR62829A x MM 111B	22.21**	8.08**	26.36**	6.11	-2.90	-8.83*	-12.66	-23.37**	-3.38	-3.55	-14.83**	4.53
16	IR62829A x Budda	6.43**	-5.87**	10.05**	-26.08**	-32.36**	-36.49**	-22.43**	-31.94**	-14.19	-21.86**	-31.00**	-15.32*
17	IR62829A x KMR 3R	-2.45	-13.73**	0.86	22.73**	12.31**	5.46	18.89**	4.31	31.52**	31.62**	18.23*	42.65**
18	IR58025A x P 107	9.13**	-3.49**	12.83**	13.76**	4.10	-2.26	7.86	-5.36	19.32**	24.65**	10.07	35.10**
19	IR58025A x IR9761	2.80*	-9.08**	6.29**	-0.84	-9.26*	-14.80**	-1.75	-13.79*	8.67	-1.39	-12.93*	6.87
20	IR58025A x KMR 3R	6.08**	-6.18**	9.69**	-27.90**	-34.03**	-38.05**	-10.20	-21.21**	-0.66	-4.25	-15.44*	3.76
21	IR58025A x MM 125	5.97**	-6.28**	9.57**	45.71**	33.34**	25.20**	-7.21	-18.58**	2.66	-3.61	-14.89*	4.46
22	IR58025A x IR35454-18-1R	-4.21**	-15.29**	-0.96	-16.57**	23.66**	-28.31**	25.55**	10.15	38.89**	35.17**	+19.36**	46.50**
23	IR58025A x MM 111 B	5.73**	-6.50**	9.32**	5.74	-3.24	-9.14*	-6.00	-17.53**	3.99	-5.64	-16.68**	2.27
24	IR58025A x TT 121	9.59**	-3.08**	13.31**	-3.10	-11.33**	-16.74**	-10.86	-21.79**	-1.39	+1.39	10.46	9.89
25	IR58025A x IR42221-14-1-3-1-2R	10.62**	-2.17	14.38**	-18.07**	-25.02**	-29.60**	-2.35	-14.32*	8.03	-2.15	-13.60*	6.04
26	IR58025A x Budda	7.37**	-5.05**	11.01**	14.97**	5.20	-1.22	-9.77	-20.88**	-0.18	-9.88	-20.43**	-2.34
27	IR58025A x P333	-4.79**	-15.80**	-1.56	-1.29	-9.67*	-15.19**	-6.60	-18.05**	3.32	+3.42	-8.67	12.09
	Means of standard checks	95.00	107.42	91.88	73.5	80.32	85.54	18.32	20.88	16.56	15.78	17.87	14.56
	SEm±	1.20	1.20	1.20	3.24	3.24	3.24	1.22	1.22	1.22	1.13	1.13	1.13

CH_1 = Mangala , CH_2 = Jaya , CH_3 = Rasi

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Sl No.	Crosses/ hybrids	Panicle length			Number of spikelets per panicle			Number of filled grains / panicle			Per cent of spikelet fertility		
		CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3	CH1	CH2	CH3
1	IR 68949-11-5-31 x Budda	16.90**	10.24*	31.36**	27.69**	-08.01**	2.07	17.62*	-17.17**	-5.95	-8.25	-9.87*	-7.76
2	IR 68949-11-5-31 x IR9761	3.80	-2.11	16.64**	63.04**	17.34**	30.32**	30.22**	-8.29	4.12	-20.38**	-21.62**	-19.95**
3	IR 68949-11-5-31 x IR 35454-18-1R	0.39	-5.33	12.81*	42.94**	2.87	14.26**	48.57**	4.64	18.80**	3.13	1.52	3.69
4	IR 68949-11-5-31 x TT 121	-11.84*	-16.86**	-0.93	18.30**	-14.86**	-5.44	-34.19**	-53.65**	-47.38**	-44.71**	-45.58**	-44.41**
5	IR 68949-11-5-31 x KMR 3 R	-4.19	-9.65*	7.66	56.91**	12.92**	25.41**	13.5	-20.07**	-9.25	-28.14**	-29.26**	-27.75**
6	IR 68949-11-5-31 x IR 42221-14-1-3-1-2R	6.04	0.00	19.16**	62.93**	17.25**	30.22**	94.67**	37.10**	55.65**	18.95**	17.09**	19.59**
7	IR 68949-11-5-31 x P 333	2.83	-3.03	15.54**	18.38**	-14.84**	-5.41	44.11**	1.49	15.23**	21.10**	19.21**	21.76**
8	IR 68949-11-5-31 x MM 111 B	11.54*	5.19	25.34**	13.07**	-18.62**	-9.62**	-3.40	-31.96**	-22.76**	-15.07**	-16.40**	-14.61**
9	IR 68949-11-5-31 x MM 125	6.82	0.73	20.03**	61.76**	16.42**	29.30**	48.33**	4.47	18.61**	-8.94	-10.37*	-8.45
10	IR 62829A x IR 42221-14-1-3-1-2R	-7.45	-12.72**	4.00	16.90**	-15.87**	-6.56*	4.28	-26.56**	-16.62**	-11.33**	-12.72**	-10.85*
11	IR 62829A x P 331	3.12	-2.76	15.87**	35.87**	-2.22	8.60**	26.52**	-10.90*	1.17	-7.41	-8.86	-6.91
12	IR 62829A x P 331	1.70	-4.09	14.29*	33.44**	-3.97	6.66*	-22.45**	-45.39**	-37.99**	-42.23**	-43.13	-41.92**
13	IR 62829A x MM 125	-0.73	-6.38	11.55*	59.84**	15.03**	27.76**	77.24**	24.83**	41.72**	10.28*	8.55	10.88
14	IR 62829A x IR 35454-18-1R	3.95	-1.98	16.80**	70.25**	22.53**	36.09**	125.96**	59.14**	80.68**	31.98**	29.91**	32.69
15	IR 62829A x MM 111B	-4.19	-9.65*	7.66	61.90**	16.52**	29.41**	80.94**	27.43**	44.68**	11.11*	9.37*	11.71*
16	IR 62829A x Budda	3.65	-2.25	16.48**	38.69**	-0.19	10.85**	34.18**	-5.50	7.29	-3.81	-5.31	-3.29
17	IR 62829A x KMR 3R	9.16	2.94	22.66**	32.68**	-4.52	6.05	-41.82**	-59.02**	-53.48**	-56.43**	-57.11**	-56.20**
18	IR 58025A x P 107	3.12	-2.76	15.87**	33.33**	-4.04	6.58*	16.91*	-17.66**	-6.52	-11.90*	-13.27**	-11.42*
19	IR 58025A x IR 9761	13.59**	7.12	27.64**	65.76**	19.29**	32.49**	49.28**	5.13	19.30**	-10.21*	-11.62**	-9.73*
20	IR 58025A x KMR 3R	-4.53	-9.97*	7.28	61.38**	16.14**	29.00**	91.50	34.86**	53.12**	18.05**	16.21**	18.69**
21	IR 58025A x MM 125	16.85**	10.20*	31.31**	44.23**	3.79	15.28**	9.75	-22.70**	-12.24*	-24.34**	-25.53**	-23.94**
22	IR 58025A x IR 35454-18-1R	7.16	1.06	20.42**	43.57**	3.32	14.76**	72.02**	21.15**	37.54**	19.13**	17.27**	19.77
23	IR 58025A x MM 111 B	11.69*	5.33	25.51**	36.38**	-1.85	9.01**	38.58**	-2.40	10.81	1.04	-0.54	1.58
24	IR 58025A x TT 121B	2.78	-3.08	15.49**	19.36**	-14.10**	-4.59	15.31*	-18.79**	-7.80	-3.95	-5.45	-3.43
25	IR 58025A x IR 42221-14-1-3-1-2R	6.09	4.59	19.21**	58.72**	14.22**	26.87**	94.63**	37.07**	55.63**	21.93**	20.02**	22.59**
26	IR 58025A x Budda	4.68	-1.29	17.62**	42.29**	2.40	13.73**	21.03**	-14.76**	-3.23	-15.43**	-16.75**	-14.97**
27	IR 58025A x P333	-2.68	-8.22	9.36	61.15**	15.98**	28.81**	-4.29	-32.60**	-23.47**	-40.96**	-41.88	-40.64**
	Means of standard check	20.53	21.77	18.27	86.67	120.43	108.43	62.44	88.66	78.09	72.46	73.61	72.07
	SEm±	1.02	1.02	1.02	3.53	3.53	3.53	4.39	4.39	4.39	3.52	3.52	3.52

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Sl No.	Crosses /hybrides	1000 grain weight			Grain yield / plant		
		CH1	CH2	CH3	CH1	CH2	CH3
1	IR 68949-11-5-31 x Budda	23.52**	30.32**	29.09**	21.65**	21.07**	46.11**
2	IR 68949-11-5-31 x IR9761	39.72**	47.41**	46.02**	80.05**	79.18**	116.25**
3	IR 68949-11-5-31 x IR 35454-18-1R	12.97**	19.18**	18.05**	15.67**	15.11*	39.92**
4	IR 68949-11-5-31 x TT 121	8.19	14.14**	13.06**	-0.63	-1.11	19.35**
5	IR 68949-11-5-31 x KMR 3 R	3.45	9.14	8.10	30.85**	30.22**	57.16**
6	IR 68949-11-5-31 x IR 42221-14-1-3-1-2R	7.67	13.59**	12.52**	38.35**	37.68**	66.16**
7	IR 68949-11-5-31 x P 333	7.63	13.55**	12.47**	34.01**	33.37**	60.96**
8	IR 68949-11-5-31 x MM 111 B	12.88**	19.09**	17.96**	11.29	10.75	33.66**
9	IR 68949-11-5-31 x MM 125	-18.14**	-13.64**	-14.45**	29.15**	28.52**	55.11**
10	IR 62829A x IR 42221-14-1-3-1-2R	44.98**	52.95**	51.50**	51.29**	50.56**	81.71**
11	IR 62829A x P 331	12.92**	19.14**	18.01**	41.12**	40.42**	69.49**
12	IR 62829A x P 331	-0.43	5.05	4.05	-9.68	-10.12	8.47
13	IR 62829A x MM 125	35.46**	42.91**	41.56**	52.46**	51.72**	83.11**
14	IR 62829A x IR 35454-18-1R	0.52	6.05	5.04	66.52**	65.71**	100.00**
15	IR 62829A x MM 111B	15.77**	22.14**	20.98**	44.38**	43.68**	73.41**
16	IR 62829A x Budda	-4.31	0.95	0.00	33.43**	32.78**	60.26**
17	IR 62829A x KMR 3R	-5.69	-0.50	-1.44	-20.78**	-21.16**	-4.85
18	IR 58025A x P 107	11.07*	17.18**	16.07**	11.92	11.38	34.42**
19	IR 58025A x IR 9761	0.90	6.45	5.45	51.39**	50.65**	81.82**
20	IR 58025A x KMR 3R	31.11**	38.32**	37.01**	37.32**	36.65**	64.93**
21	IR 58025A x MM 125	29.12**	36.23**	34.94**	-8.08	-8.52	10.40
22	IR 58025A x IR 35454-18-1R	1.85	7.45	6.44	21.12**	20.53**	45.47**
23	IR 58025A x MM 111 B	13.01**	19.23**	18.10**	45.99**	45.28**	75.34**
24	IR 58025A x TT 121	30.68**	37.86**	36.56**	37.32**	36.66**	64.93**
25	IR 58025A x IR 42221-14-1-3-1-2R	-4.74	0.50	-0.45	43.80**	43.10**	72.71**
26	IR 58025A x Budda	13.96**	20.23**	19.09**	24.38**	23.78**	49.39
27	IR 58025A x P333	-2.33	3.05	2.07	-16.74*	-17.34*	0.00
	Means of standard checks	23.21	22.00	22.21	20.55	20.65	17.11
	SEm±	1.04	1.04	1.04	1.49	1.49	1.49

and +25.20 (over Rasi) for the trait plant height for the same cross IR58025A x MM 125.

The ranges for per cent standard heterosis observed were from –26.08 to +45.71, -34.03 to +33.34 and –38.05 to +25.20 for the crosses IR58025 x KMR 3R (negative side) and IR58025A x MM 125 (Positive side) over checks Mangala, Jaya and Rasi respectively.

4.4.3 Number of tillers per plant

Significant positive heterosis was preferred for this character.

As many as eight crosses over check Mangala, five over Jaya and 15 crosses over Rasi recorded high magnitude of heterosis in the desirable direction for this characters. IR62829A x TT121 was the superior hybrid over all the three checks used in the study.

4.4.4 Number of productive tillers per plant

Positive significant per cent standard heterosis was preferred.

Over check Mangala, six crosses exhibited non-significant positive per cent standard heterosis. However, four crosses possessed desirable magnitude of heterosis over Jaya and this number was 11 over the check Rasi.

4.4.5 Panicle length

This parameter reflects the density of spikelets per panicle was and considered as one of the most important characters, which decides grain yield per plant. Highest per cent standard heterosis displayed over the check Mangala was 16.90 (IR68949-11-5-31 x Budda) followed by 16.85 (IR580625 A x MM 125) and 13.59 (IR58025A x IR9761). Lowest per cent standard heterosis in negative direction was recorded by the cross IR68949-11-5-31 x TT 121 (-11.54) over check Mangala.

The range for per cent standard heterosis over check Jaya was from -16.86 to +10.24 for the same crosses IR68949-11-5-31 x TT 121(negative side) and IR68949-11-5-31 x Budda (Positive).

Per cent positive significant standard heterosis over check variety Rasi recorded by as many as 21 out of 27 crosses. Highest per cent heterosis was observed in the cross IR68949-11-5-31 x Budda.

4.4.6 Number of spikelets per panicle

Significant positive heterosis was preferred for this character.

Significant positive per cent heterosis for number of spikelet per panicle was observed in all the 27 crosses, 11 and 20 crosses respectively over the checks Mangala, Jaya and Rasi.

Highest positive per cent standard heterosis observed was +70.25, +22.53 and +36.09 for IR62829A x IR35454-18-1R over the checks Mangala, Jaya and Rasi respectively.

4.4.7 Number of filled grains per panicle

19 crosses were significantly superior over the check Mangala followed by seven over Jaya and 11 crosses over Rasi. IR62829A x IR35454-18-1R displayed maximum positive heterosis (125.96%) followed by IR68949-11-5-31 x IR42221-14-1-3-1-2R (94.67%) and IR58025A x KMR 3R (91.50) over the check Mangala.

Over the check variety Jaya, IR62829A x IR35454-18-1R registered highest positive heterosis (59.14%) and 80.66 per cent standard heterosis was observed over the check Rasi by the same cross.

4.4.8 Per cent spikelet fertility

As this parameter reflects the ability of respective male parent for fertility restoration in male sterile lines (CGMS) selection of superior hybrid for grain yield depends on this yield parameter.

For this trait, positive significant standard heterosis was preferred.

IR62829A x IR35454-18-1R (31.98%), IR68949-11-5-31 x P 333 (21.10%) and IR58025A x IR 35454-18-1R (19.13%) recorded positive significant heterosis over the check Mangala (undesirable) in the order of decrease.

Over the check Jaya, the same above crosses registered 29.91%, 19.21% and 17.27% heterosis for the trait per cent spikelet fertility.

The highest magnitude positive heterosis observed over the check Rasi was 32.69%, 21.76% and 19.77% by IR62829A x IR35454-18-1R, IR68949-11-5-31 X P 333 and IR58025A x IR35454-18-1R respectively.

4.4.9 1000-grain weight

Per cent positive significant heterosis for this yield contributing parameter was desirable.

IR62829 A x IR42221-14-1-3-1-2R, IR68949-11-5-31 x IR9761 and IR62829A x MM 125 registered significant per cent positive heterosis of +44.98, +39.72 and +35.46 respectively over the check Mangala. The same three crosses registered 52.95%, 47.41% and 42.91% standard heterosis over the check Jaya and 51.50%, 46.02% and 41.56% over Rasi for the character 1000 grain weight respectively.

IR68949-11-5-31 x MM125 recorded -18.14% (over Mangala) -13.64 per cent (over Jaya) and –14.45 per cent (over Rasi) standard heterosis in the negative direction.

4.4.10 Grain yield per plant

Ultimately, selection, release and recommendation of any new cultivar depends on the per se performance of that particular hybrid for grain yield per plant in addition to significant SCA-effects in the desirable direction and per cent standard heterosis. Usually, more than 20% standard heterosis was preferred and looked for this trait among new cultivars over the standard check variety of similar duration and region.

Over check Mangala, as many as 19 crosses possessed significant positive standard heterosis in the desired magnitude (i.e., >20%) followed by 19 over Jaya and 22 crosses over the check Rasi. IR68949-11-5-31 x IR9761, IR62829A x IR35454-18-1R, IR58025A x IR9761 and IR62829 x MM 125 were superior cross combinations for grain yield per plant in the decreasing order of heterosis over all the three check varieties under irrigated condition.

Among these crosses, for the crosses for which information on heterosis for both root and yield parameters available indicated that, except the cross IR62829A x MM 125,all other crosses exhibited contrasting behaviour for root and yield parameters. Also, since information derived on yield parameters were from irrigated conditions selection of superior crosses for both root as well as yield parameters should be done only after simultaneous evaluation of these crosses under both well-watered and low moisture environments. It appeared from the results pertaining to heterosis for both root as well as yield parameters under well-watered condition that, the cross IR62829A x MM 125 appeared most promising. Graphical representation of standard heterosis over the checks Mangala, Jaya and Rasi for 10 grain yield characters is depicted in Fig 8.

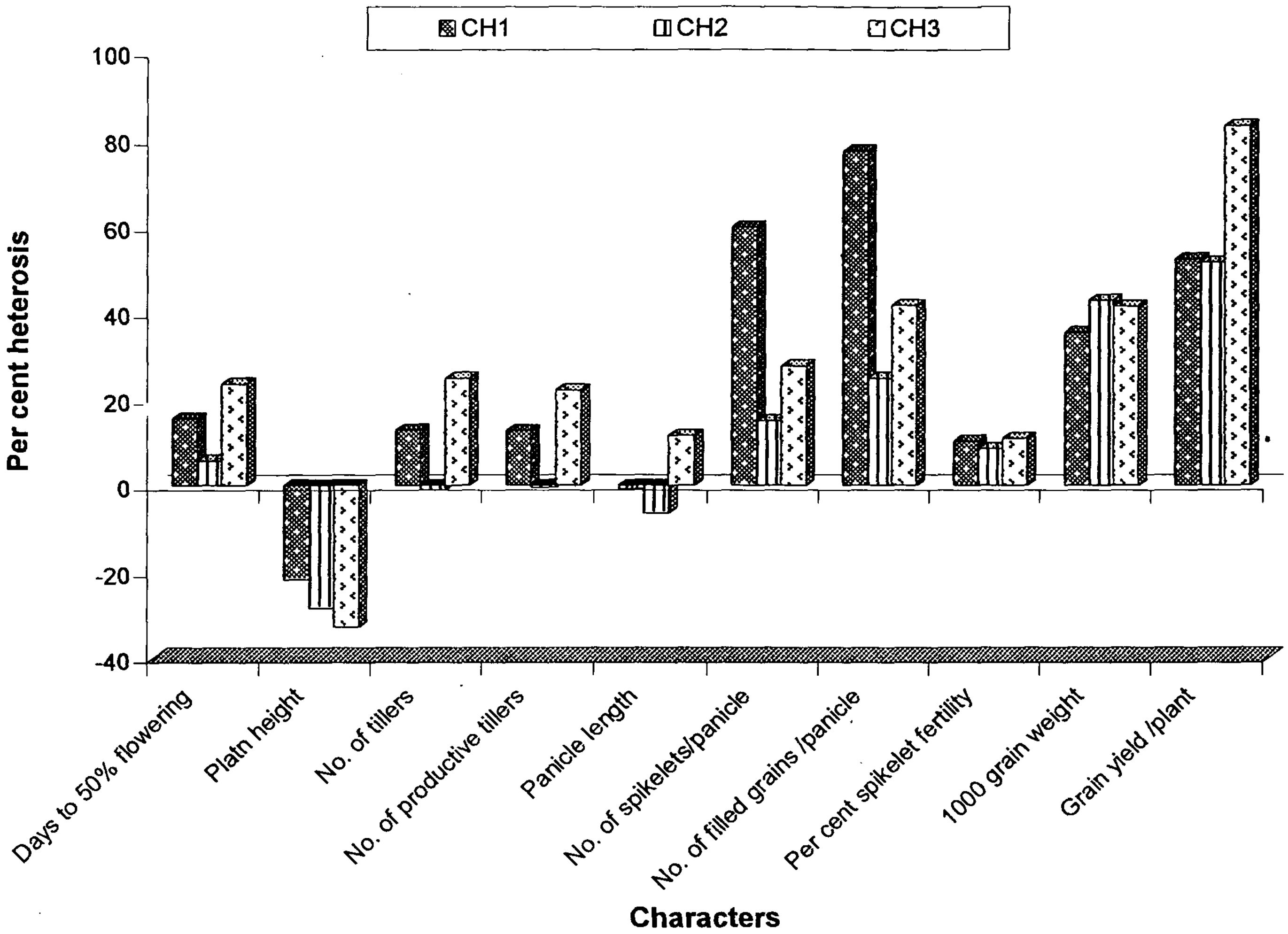

Fig 8 : Per cent heterosis over checks Mangala (CH_1), Jaya (CH_2) and Rasi (CH_3) for 10 yield characters in the promising cross for root traits IR62829A x MM 125 under irrigated condition

DISCUSSION

V DISCUSSION

The present investigation was undertaken to study genetic parameters, characters association, path coefficient analysis, combining ability and heterosis for various root and shoot morphological traits. Lack of convincing information on genetics of rice root system prompted this investigation.

The first two experiments with 27(1A) and 39(1B) rice genotypes were evaluated for descriptive statistics, character association and path coefficient analysis. The next two experiments related to assessment of combining ability and heterosis for root morphological traits comprises 27 hybrids (derived through crossing three lines with nine testers in L x T mating design), 12 parents and one check variety "Rasi". Two environments were imposed during *summer* 1998 (well-watered) and *summer*-1999 (low-moisture stress condition). The fifth experiment on estimation of standard heterosis for grain yield attributes from 27 hybrids over the checks viz., Mangala, Jaya and Rasi was conducted during kharif 1998 under irrigated condition.

The results of the above mentioned experiments are discussed in the following sections

1 Descriptive analysis and variability parameters

2. Characters association and path coefficient analysis

3. Combining ability analysis, gene action and estimation of magnitude of heterosis for eight root and shoot morphological traits

4. Scoring parents and hybrids for physiological parameters viz., leaf rolling and tip firing.

5. Estimation of standard heterosis for grain yield attributing parameters under irrigated condition

5.1 Descriptive analysis and variability parameters

ANOVA in both the experiments (IA and IB) revealed significant difference among genotypes for all the remaining characters studied even at one percent level of probability. Genetic parameters viz., phenotypic coefficient variability (PCV) and genotypic co-efficients of variability (GCV), heritability in broad sense and expected genetic advance (GA) as percent mean were workedout for 11 and 10 characters respectively for the experiments with 27 and 39 rice genotypes.

Among the characters studied in experiment IA, except characters plant height and root thickness all the characters found to have higher PCV (%) and GCV (%). The trend for plant height was similar in experiment IB also. However, plant height and root thickness possessed moderate PCV (%) and GCV (%). Similar results were reported by Latha (1997) and Hemamalini (1997).

In experiment IA, high heritability estimates were recorded by all the characters except number of tillers, root dry weight, shoot dry weight and root to shoot ratio which exhibited moderate heritability estimates in broad sense. Hence, for these characters scope for improvement through selection is still exist, as the influence of environment on these traits was at very low extent. From this we can infer that this characters are governed by additive gene action. Similar trends were observed for all the 10 characters studied in experiment 1B where high heritability estimates were reported for them. These findings were in accordance with results of Latha (1997) and Hemamalini (1997)

Chang *et al.* (1982) and Armenta-So to *et al.* (1983) reported moderately high heritability for root length. Armento so to *et al.*, (1983) also reported moderately high heritability estimate for value for root dry weight. Hemamalini (1997) got higher estimates number of roots. Shashidhar *et al.* (1994) and

Gomathinayagam *et al.* (1992) reported very high heritability for root dry weight.

Moderate heritability estimates for shoot dry weight, number of tillers and R:S ratio reflected influence of environment on the expression of these traits. These results are in accordance with Hemamalini (1997).

High heritability estimate for root thickness in experiment with 27 genotypes was supported by the findings of Ekanayake *et al.* (1985)

In both the experiments for all the characters studied, higher expected genetic advance (GA) as percent mean were found, hence good response to selection for these characters could be anticipated. These findings are in accordance with findings of Shashidhar *et al.* (1994); Gomathinayagam *et al.*, (1992) ; Latha (1997) and Hemamalini (1997).

5.2 Character association and path coefficient analysis

Since most of the characters associated with drought avoidance mechanisms in rice are polygenic in nature, understanding of association among these traits is essential to frame the research objectives aimed at combining one or more of these putative traits into single background. Information on the nature and magnitude of association among various putative traits facilitate the breeders in identification and selection of superior genotypes for complex trait such as drought avoidance.

In experiment with 27 rice genotypes (IA) plant height was found to possess significant positive association with maximum root length, total length, root dry weight, shoot dry weight and root to shoot ratio at genotypic level. The results are in conformity with Ekanayake *et al.* (1985); Latha (1997) ; Thanh *et al.* (1999). However, the characters number of tillers and root thickness exhibited negative non-significant association with plant height. Similar results were observed by Girish (1999).

Number of tillers was significantly correlated with only number of roots at five percent level of probability this was in accordance with the findings of Ekanayake *et al.* (1985) and Latha (1997). The association found among these characters over in the expected line since, emergence of an additional tiller leads production of new adventitious roots resulted in increased number of total roots per plant.

In experiment with 39 rice genotypes (most of the genotypes possessed deeper maximum root length since the genotypes were selected DH lines and local rainfed varieties) we failed to notice significant association between the traits total length, root length, number of roots, root volume and root dry weight with number of tillers. This observation is in the expected line among the genotypes which possessed few deep and thick roots which extract water from deeper layers with the ability to penetrate hard pans. The plants instead of diverting more assimilates to tillers development might have diverted additional photosynthates to increase maximum root length and thickness.

In experiment IA, maximum root length exhibited significant association with total length root thickness, root dry weight and shoot dry weight. Similar observation were noticed in experiment 1B but with the reduced magnitude. These findings are in consonance with Zuno-Altoveros *et al.*(1990), Hemamalini (1997) and Thanh *et al.* (1999).

Root to Shoot ratio showed significant positive association with root dry weight but showed negative non-significant association with shoot dry weight. Latha (1997) and Girish (1999) reported similar association.

The character root thickness possessed significant association with root dry weight at 5 percent level of probability in addition to maximum root length (at 0.01p). These are in accordance with the findings of Ekanayaka *et al.*, (1985) and Anon (1984).

Experiment IB displayed highly significant positive correlation among root volume, maximum root length and root dry weight, in addition to similar association between plant height and total length. Significant correlation between these traits indicates that, increase in any one of these traits will increase the other correlated traits providing selection advantages for simultaneous selection of more traits.

From experiments IA and IB an interesting observation noticed was that the nature and magnitude of association among some characters varied with the nature of experimental material used.

Path coefficient analysis among root parameters

For the experiment with 27-genotypes, phenotypic path co-efficients of maximum root length with other drought avoidance related root characters were studied at phenotypic level.

Total length recorded highest direct effect on maximum root length followed by root dry weight and root thickness. Low magnitude of negative direct effects were found with plant height, shoot dry weight, R:S ratio and number of roots in the descending order of magnitude.

The significant association of root thickness with maximum root length (0.413) was attributed to indirect influence of root thickness on maximum root length through total length (0.371) followed by root dry weight (0.067).

In addition to highest positive direct effect of 1.122 by total length on maximum root length, it also contributed moderate to low magnitude of positive indirect effects *via* root dry weight, root thickness and number of roots.

From this we can say that, total length, root thickness and root dry weight contributed more to maximum root length than the other traits considered for path analysis.

Positive non-significant associations were observed for maximum root length with plant height, number of roots and root to shoot ratio, though these three characters had negative direct effects on root length. This was attributed to high to moderate positive indirect effects of 0.48 and 0.19 by total length and root dry weight and *via* R:S ratio and plant height through total length (0.73) and root dry weight (0.12).

The lowest 'r' value between maximum root length and numbers of tillers was mainly due to very low positive direct effect of numbers of tillers on maximum root length coupled with its very low magnitude positive indirect effects of 0.073, 0.03, 0.03 and 0.003 through plant height, numbers of roots, root dry weight and root thickness on root length respectively.

Path analysis of total root dry weight at phenotype level with other root and shoot morphological trait was done using correlation co-efficients derived among the traits from experiment with 39-rice genotypes.

Maximum root length, root volume and root dry weight (up to 30 cm soil depth) possessed significant 'r' value with total root dry weight mainly because of high magnitude positive direct effects of maximum root length and root dry weight. In case of significant positive association between root volume and total root dry weight, the possible cause was not due to its direct effect (negative) but due to moderate to high magnitude of positive indirect effect of root volume on total root dry weight *via* root dry weight upto 30 cm soil depth (0.53), maximum root length (0.16) and plant height (0.05) in the descending order of magnitude.

No past research reports on path analysis for root morphological traits were available to compare the results of present investigations. Low residual effect in both the experiments suggested improvement of important characters viz., maximum root length and root dry weight is possible through the independent characters considered in the path analysis.

5.3 Combining ability analysis, gene action and estimation of magnitude of heterosis for root and shoot traits.

The concept of combining ability has assumed a greater importance in plant breeding as effective means of selecting the parents that have potential utility in developing hybrid varieties with desirable characters. Sprague and Tatum (1952) have proposed the concept of GCA and SCA as a measure of gene action operating for various plant characteristics. A technique of line x tester analysis was proposed to explain GCA and SCA variances in terms of co-variance of half sibs and co-variance of full sibs in a population by Kempthorne (1957). This mating design helps in screening a large number of genotypes for their relative potential and further utilization in exploitation of heterosis phenomenon for production of outstanding hybrids with ability to combat low moisture conditions through various dehydration avoidance mechanisms.

The combining ability studies on root and shoot traits were worked out involving two CGMS lines (IR58025A, IR62829A) and one TGMS line (IR68949-11-5-31) as female parents (lines) and three restorers (KMR 3R, IR42221-14-1-3-1-2R, IR35454-18-1R), two double haploid (DH) lines (P 331,P 333) and four local rainfed varieties (Budda, MM 125, MM 111B and TT121) as male parents (testers) in the present study.

Analysis of variance of parents and hybrids for eight root and shoot morphological traits in the present study indicated that, variances due to testers for all the characters were highly significant revealing genetic diversity for these characters towards combining ability. This may be attributed to selection of testers with varying genetic background.

Mean sum of squares due to lines for eight root morphological traits differed differently for two environments. Under well-watered condition, lines differed significantly for the traits plant height and numbers of roots. But under low moisture lines showed significant differences for the traits root length, total length, root growth rate, deep root length and root volume. Lines did not show any variation for number of tillers under both the environment.

ANOVA for combining ability indicated that, lines differed significantly for plant height, maximum root length, root growth rate and deep root length under both the environments. The mean sum of squares for eight characters of testers indicated significant differences among testers for number of roots under well-watered condition and root volume in low moisture stress situation.

However, the crosses exhibited enormous variability for all the eight characters under both the environments. Significant GCA and SCA variances for most of the root characters indicated the importance of both additive and non-additive effects for all the characters.

In general the magnitude of SCA variance was high for all the eight characters studied than their respective GCA variances indicating the predominance of non-additive gene action.

5.3.1 Plant height

Ratio between estimates of GCA and SCA variances in both the environments indicated that, non-additive gene action was more predominant in the inheritance of plant height.

The estimates of general combining ability effects (GCA) for lines and testers indicated that the line IR62829A followed by IR68949-11-5-31 were good general combiners for plant height under both the environments. Among testers Budda and MM 125 were promising with the general combining ability in desirable magnitude and direction.

The cross IR62829A x MM 125 displayed high positive significant SCA-effect followed by IR68949-11-5-31 x P 333 under well-watered condition. However, under low moisture condition, IR58025A x Budda showed highest positive and significant SCA-effect for this trait.

With respect to heterosis, IR62829 A x MM 125 exhibited significant positive heterosis for the trait plant height over mid parent value. and standard check under both the environments. But it failed to display similar trend over better parent (MM 125). While, IR58025A x Budda exhibited significant heterosis over mid parent only. The above observation for the trait plant height suggested the importance of heterosis along with SCA effects as selection criteria to identify best cross combinations. Similar behaviour was also noticed with IR68949-11-5-31 x P 333.

5.3.2 Number of tillers

Under well-watered condition, combination of additive and non-additive gene action and in water limited environment predominant non-additive (dominances or epistasis) gene action were noticed for number of tillers. Kalita and Upadhaya (2001) reported additive gene action for this trait under rainfed upland situation.

Among lines, IR62829A was most promising general combiner for the trait number of tillers under both the environments. However, under well-watered condition, the line IR58025A was the second best general combiner in addition to IR62829A.

Testers TT121 and MM 111B were identified as good general combiners for this trait under well-watered and low moisture conditions respectively.

Of the 27 hybrids, the crosses IR68949-11-5-31 x MM 125 (well-watered) and IR68949-11-5-31 x TT 121 (low moisture) were the top performers with respect to specific combining ability effect in the desirable direction and magnitude.

With respect to heterosis IR62829A x P331 (132.00%) under well-watered and low moisture conditions IR62829A x MM111B (78.49%) were the superior cross combinations for heterosis over mid parent. The possible reason could be the involvement of one or both the parents with best combining ability.

For heterobeltiosis, under well-watered environment, IR58025A x MM111B displayed highest significant positive heterosis over the best parent (male) MM111B. Under low moisture stress the same cross showed its superiority only with respect to mid parent heterosis.

Heterosis over the check variety 'Rasi' was highest (positive) for IR58025A x MM111B under water limited environment and under well-watered condition IR62829A x TT 121 exhibited significant heterosis.

However, while selecting superior cross combination for low moisture environment in addition to number of tillers heterosis for other putative root traits associated with drought avoidance should be looked into.

5.3.3 Maximum root length

The ratio of estimates of GCA and SCA variances indicated importance of both additive and non-additive gene actions for maximum root length under both moisture regimes. Combination of additive and non-additive gene actions were reported by Price *et al.* (1997) for maximum root length. Kalita and Upadhaya (2001) reported additive gene action for maximum root length.

Among lines, the line IR58025A was most promising followed by IR62829A. Though the line IR68949-11-5-31 recorded high mean value under well-watered condition and better mean value than IR62829A under low moisture stress condition, but was a poor general combiner for the trait maximum root length in both the environments. This indicates that, selection of parents based on phenotypic performance may not be ideal. Hence, breeders should consider the combining ability effects in addition to *per se* performance to utilize them for further crop improvement.

Among testers, Budda was most promising general combiner for maximum root length under well-watered condition followed by P 331 and KMR 3R. Under low moisture condition, KMR3R displayed highest GCA-effect for maximum root length followed by Budda and IR42221-14-1-3-1-2R.

IR62829A x Budda, IR68949-11-5-31 x IR35454-18-1R and IR58025A x KMR 3R were best specific combiners for maximum root length under well-watered condition. While under water limited condition, IR58025A x KMR 3R reported highest significant positive SCA effect followed by IR58025A x Budda, IR68949-11-5-31 x TT121 and IR58025A x IR42221-14-1-3-1-2R. However, IR62829A x MM 125 displayed significant and non significant positive SCA effect under well-watered and low moisture environments respectively. The possible explanation for the above results would be that, in both the above crosses, the desirable SCA effect is due to the involvement of good general combiners as their parents.

With respect to heterosis, IR62829A x Budda showed highly significant positive heterosis over mid parent, better parent and standard check Rasi under well-watered condition, but exhibited heterosis in undesirable direction under low moisture regime. However, IR58025A x KMR 3R which recorded highest SCA effect for maximum root length under low moisture condition, displayed significant heterosis over mid parent value and non significant heterosis over better parent and check 'Rasi'. Hence, once again it is very important to consider SCA effects and magnitude of heterosis as selection criteria, since heterosis values when consider alone were found to be misleading.

Varying behaviour of IR58025A x KMR 3R with respect to magnitude of heterosis over mid parent, better parent and standard check under two different environments supports the breeding approach where in varieties can be bred simultaneously under target as well as optimum growing conditions. This will aid in proper selection of parents, maintenance of valuable breeding materials and other resources with respect to time and capital. Ekanayake *et al.*, (1985) reported positive percent heterosis for root length. Vigorous root development and plant growth in F_1s were observed by Cheng *et al.* (1997) than the parents. Zheng *et al.* (1996) and Girish (1999) reported significant heterosis for maximum root length in their respective studies.

5.3.4 Total length

In this study, total length reflects both plant height and maximum root length of a genotype could make a better criterion for selection of parents with tolerance to low moisture conditions as positive association was noticed between plant height and maximum root length in the parental material.

Under both the growing conditions, for total length predominant non-additive gene action was noticed. This was evident from the ratio between estimates of GCA and SCA variances.

The line IR62829A was highly promising for both the environments with respect to general combining ability for this trait. Among testers 'Budda' stood first with respect to general combining ability estimates under both the environments. KMR 3R was the second best general combiner under low moisture regime and third best in well-watered condition. The tester P 331 exhibited second highest GCA effect on total length under well-watered condition.

SCA effects of 27 hybrids on total length reflected good performance with IR62829A x MM 125 under well-watered condition, though the tester MM 125 possessed non-significant positive GCA effect. From this we can draw the inference that, to obtain a cross with high SCA-effect for total length the cross need not have to involve both the parents with good GCA effect for this plant parameter.

There was no correlation between SCA effects and heterosis in IR62829A x MM 125 under both the environment. While, IR58025A x Budda exhibited high SCA effects and heterosis in low moisture stress condition.

5.3.5 Root growth rate

This root parameter makes one of the best criteria for selection of cultivars which differ significantly for total duration. Per day root growth irrespective of maturity duration facilitate the breeder in choosing genotypes with their true root growth ability during vegetative growth phase.

Ratio of estimates of GCA and SCA variances indicated prevalence of combination of additive and non-additive gene actions for this trait under both moisture regimes.

The line IR58025A appeared most promising with positive significant and higher magnitude of GCA effect for root growth rate under both the growing conditions.

Highest GCA effect observed with the tester KMR 3R reflected its supremacy in contributing significantly for the trait root growth rate under low moisture environment. However, the tester 'Budda' which displayed highest positive combining ability effect, was superior general combiner under well-watered condition. It was second best general combiner after KMR 3R under low moisture stress environment.

IR62829A x Budda and IR68949-11-5-31 x IR35454-18-1R were the best specific combiners for this trait under well-watered condition. Under low moisture condition IR58025A x KMR 3R which recorded high SCA effect appeared to be the best combinations followed by IR58025A x Budda and IR68949-11-5-31 x TT 121.

IR68949-11-5-31 x IR35454-18-1R registered significant positive SCA effect under well-watered condition for the trait root growth rate, though both the parents involved in the cross possessed significant negative GCA effects. This may be attributed to favourable interaction between the parents involved. The other option would be the *per se* performance of one or both parents of this particular cross with respect to root growth rate. The line IR68949-11-5-31 recorded highest mean value for root growth under well-watered condition and was the second best in low moisture environment. In all the other crosses, the SCA effects were attributed to significant positive GCA effects of either one or both the parents involved in the respective cross combinations. This suggest importance of *per* se performance of parents in producing superior hybrids.

With respect heterosis, only IR58025 A x KMR 3R manifested significant positive heterosis over mid parent, better parent and standard check under both the environments. This was in conformity with the substantial SCA effect noticed with this cross under both the environments.

Zheng *et al.*, (1996) reported considerable amount of heterosis for root growth ability.

5.3.6 Deep root length

For both the moisture regimes, combination of additive and non-additive gene actions were noticed for deep root length. Similar observations was noticed by Price *et al.* (1997).

Among lines, IR58025A was good general combiner for the trait deep root length. While, Budda was promising tester under well-watered condition with highest significant positive GCA effect followed by P 331 and KMR 3R. Under low moisture KRM 3R was most promising followed by Budda, IR42221-14-1-3-1-2R and P331.

IR62829A x Budda was superior with highest SCA effect under well-watered condition. But this cross has undesirable magnitude of combining ability under low moisture condition. While, under low moisture condition, IR58025A x KMR 3R was most promising with substantial magnitude of positive SCA effect. This observation reflected on the involvement of best general combiner as its parents.

Under low moisture stress condition, IR62829A x KMR 3R was the best cross with highest magnitude of positive heterosis over mid parent though it recorded negative non-significant SCA-effect. IR58025A x KMR3R possessed substantial magnitude of positive heterobeltiosis and standard heterosis under this environment.

Under well-watered condition, IR58025A x TT 121 displayed highest percent mid parent heterosis and heterobeltiosis. In the case of IR62829A x KMR 3R *per se* performance and for IR58025A x TT121, SCA effect with *per se* performance were the better criteria for selection.

Girish (1999) and Zheng *et al.*, (1996) found positive significant heterosis for the trait root length. However, Ekanayake *et al.*, (1986) reported positive percent heterosis for this trait which decides deep root length.

5.3.7 Number of roots

For number of roots, predominant non-additive (dominance or epistasis) gene action was observed under both the growing conditions. Non additive gene action was reported for number of roots by Kalita and Upadhaya (2001).

Significant positive combining ability and percent heterosis for number of roots along with desirable root morphological traits is preferred among crosses selected for low moisture stress condition. The possible explanation for this could be that, plants under low moisture stress need to share the assimilates judiciously among various putative plant traits associated with drought avoidance mechanisms and grain yielding ability.

The lines IR62829A under well-watered and IR68949-11-5-31 (in addition to IR62829A) under low moisture environments were promising general combiners for the trait number of roots.

Of the nine testers, P331 and Budda displayed desirable direction and magnitude of general combining ability effects under both moisture regimes.

IR62829A x MM 125 under well-watered condition and crosses IR68949-11-5-31 x TT121, IR58025A x Budda under low moisture were superior with significant specific combining ability effects.

With respect to heterosis, IR58025A x Budda and IR62829A x P333 were displayed highest percent (positive) heterosis over mid parent and better parent under well-watered and low moisture environments respectively. These crosses also exhibited significant heterosis over better parent under both the environments.

IR62829A x MM 125 displayed highest positive percent heterosis over check Rasi under well-watered condition and IR68949-11-5-31 x P331 under low moisture condition. This suggest that, selection of superior cross combination must be done by considering combining ability effects, magnitude of heterosis in the desirable direction in addition to *per se* performance.

Zheng *et al.* (1996) and Girish (1999) reported significant heterosis for number of roots in their studies.

5.3.8 Root volume

Root volume contributed mainly by root length, root thickness and deep root density below 30 cm soil depth was preferred among cultivars identified for rainfed rice ecosystem which normally encounter different kinds of low moisture stress during the crop growth period.

For this trait both additive and non additive gene actions were noticed under both the environments. Additive gene action was observed by Ekanayake *et al.*, (1986) for the trait number of roots. However, non additive gene action was noticed for root value by Kalita and Upadhaya (2001).

Among lines, line IR62829A was the most promising general combiner under well-watered and IR58025A under low moisture condition. Testers Budda and KMR3R were best general combiners under both the moisture regimes.

Among 27 crosses, IR58025A x Budda and IR62829A x MM 125 with higher magnitude of SCA effects for root volume, also possessed significant SCA effects for maximum root length under well-watered condition. But IR62829A x MM 125 registered higher magnitude of SCA effects for number of roots instead for maximum root length, as it involved both the parents with good general combining ability for number of roots under low moisture stress condition.

With respect to heterosis, IR58025A x Budda was found to possess substantial magnitude of mid parent heterosis under both well-watered and low moisture conditions. The same cross displayed highest heterobeltiosis and standard heterosis also. The magnitude of heterosis observed in IR58025A x Budda suggested involvement of superior general combiners 'Budda' as male parent under both the conditions. For root volume, both magnitude of SCA effects and heterosis are to be considered for selecting superior crosses.

In a nutshell, IR62829A x Budda was the superior cross combination under well-watered condition (Table 22) followed by IR62829A x MM 125 considering SCA effects, heterosis in the desirable direction and magnitude (Fig 9) and *per se* performance for most of the root and shoot parameters considered in the present investigation.

IR58025A x Budda and IR62829A x KMR 3R were the best combinations (Table 23) under low moisture environment. Graphical representation of magnitudes of heterosis for eight root and shoot characters in IR62829A x KMR 3R was depicted in Fig 10. Also, these crosses secured moderate scores for two physiological traits viz., leaf rolling and tip firing, indicating additional water conservation mechanisms in addition to good root

: 22 : **List of top five crosses with desirbale magnitude and direction of SCA-effects, heterosis and *per se* performance for eight root and shoot morphological traits in rice under well watered condition**

Characters	IR 62829A x MM 125A				IR 68949-11-5-31 x P 333				IR 68949-11-5-31 x IR 35454-18-1R				IR 58025A x MM 111B				IR 62829A xBudda			
	Mean	SCA effect	%Heterosis MP	BP	Mean	SCA effect	%Heterosis MP	BP	Mean	SCA effect	%Heterosis MP	BP	Mean	SCA effect	%Heterosis MP	BP	Mean	SCA effect	%Heterosis MP	BP
Plant height (cm)	93.23	+**	+**	-NS	85.33	+**	+**	+NS	70.83	-NS	+*	+*	62.17	-NS	-**	-**	85.00	+NS	+**	-NS
No. of tillers	41.00	+NS	+**	+**	10.00	+NS	-*	-**	24.00	+*	+NS	-NS	43.67	+**	+**	+**	33.33	-NS	+**	+*
Root length (cm)	46.83	+**	+NS	-*	25.67	+**	-**	-**	36.00	+**	+NS	+NS	47.83	+**	+NS	-*	65.67	+**	+**	+**
Total length (cm)	140.07	+**	+NS	-NS	111.00	+**	-NS	+NS	106.83	+**	+NS	-NS	110.00	+NS	+NS	-**	150.67	+**	+**	+NS
Root growth rate (cm/day)	0.67	+**	+NS	-*	0.37	+**	-**	-**	0.51	+**	+NS	+NS	0.68	+**	+NS	-*	0.94	+**	+**	+**
Deep root length (cm)	16.83	+**	+NS	-*	-4.33	+**	-**	-**	6.00	+**	+NS	+NS	17.83	+**	+NS	-*	35.67	+**	+**	+**
Number of roots	434.33	+**	+**	-*	248.33	+**	+**	+NS	305.33	+NS	+NS	-**	239.67	+**	+**	-**	230.33	-**	+**	+**
Root volume (cc)	142.00	+**	+**	-**	41.67	+NS	-**	-**	86.67	+**	-NS	-**	79.33	+**	-**	-**	185.00	+NS	+**	+**
r of characters with nt magnitudes		7	4	1		6	2	0		6	1	1		6	2	1		4	8	6

+ = Direction (desirable)

- = Negative direction (undersirable)

* = Significante at 5% level of probability

** = Singificant at 1% level of probability

NS = Non significant

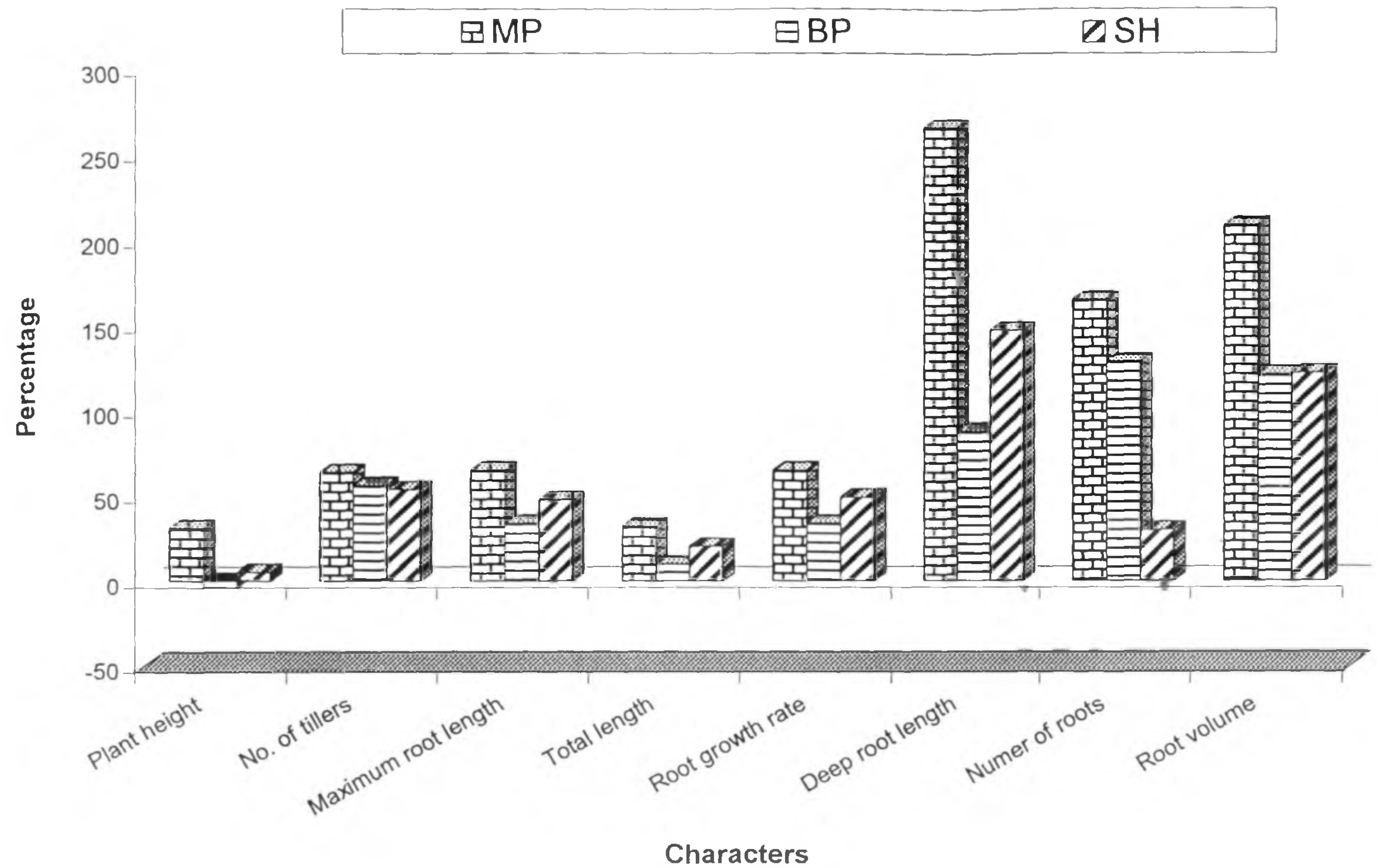

Fig 9: Magnitude of heterosis in the promising cross IR 62829A x Budda over mid parent (MP), better parent (BP) and check variety (SH) for eight root and shoot morphological traits under well watered condition

Table 23 : List of top five crosses with desirbale magnitude and direction of SCA-effects, heterosis and *per se* performance for 8-root and shoot morphological traits in rice under low moisture stress condition

Sl. No.	Characters	IR 68949-11-5-31 x TT 121A				IR 58025A x Budda				IR 62829A x MM 125A				IR 62829A xKMR 3R				IR 62829A x IR 42221-14-1-3-1-2R			
		Mean	SCA effect	%Heterosis MP	%Heterosis BP	Mean	SCA effect	%Heterosis MP	%Heterosis BP	Mean	SCA effect	%Heterosis MP	%Heterosis BP	Mean	SCA effect	%Heterosis MP	%Heterosis BP	Mean	SCA effect	%Heterosis MP	%Heterosis BP
1	Plant height (cm)	67.97	-NS	-**	-**	86.20	+**	+**	+NS	89.83	+**	+**	-**	80.10	+**	+**	+NS	85.00	+**	+**	-NS
2	No. of tillers	26.00	+**	+**	+**	17.33	-NS	-NS	-NS	25.33	+NS	+NS	-NS	26.00	+**	+**	+NS	23.67	-NS	+NS	+NS
3	Root length (cm)	34.53	+**	-**	+**	57.07	+**	+*	+NS	41.73	+NS	-**	-**	55.33	-NS	+**	+**	45.27	+NS	+NS	-*
4	Total length (cm)	102.50	+*	-**	+**	143.27	+**	+*	+NS	131.57	+**	+NS	-**	135.43	+NS	+**	+**	130.27	+**	+**	-*
5	Root growth rate (cm/day)	0.49	+**	-**	+**	0.82	+**	+*	+NS	0.60	+NS	-**	-**	0.79	-NS	+**	+**	0.65	+NS	+NS	-NS
6	Deep root length (cm)	4.53	+**	-**	+**	27.07	+**	+**	NS	11.73	+NS	-*	-**	25.33	-NS	-**	+**	15.27	+NS	+*	-*
7	Number of roots	295.33	+**	+**	+NS	320.00	+**	+**	+**	302.33	+**	+**	+NS	271.00	+*	+**	-**	315.33	+**	+**	+NS
8	Root volume (cc)	58.33	+**	+**	+*	268.33	+**	+*	+**	92.13	+**	+NS	+NS	168.33	+**	+**	+**	91.67	+**	+**	+*
Number of characters with signficant magnitudes			7	3	6		7	7	2		4	2	0		4	7	5		4	5	1

+ = Positive direction (desirable)
- = Negative direction (undersirable)
* = Significante at 5% level of probability
** = Singificant at 1% level of probability
NS = Non significant

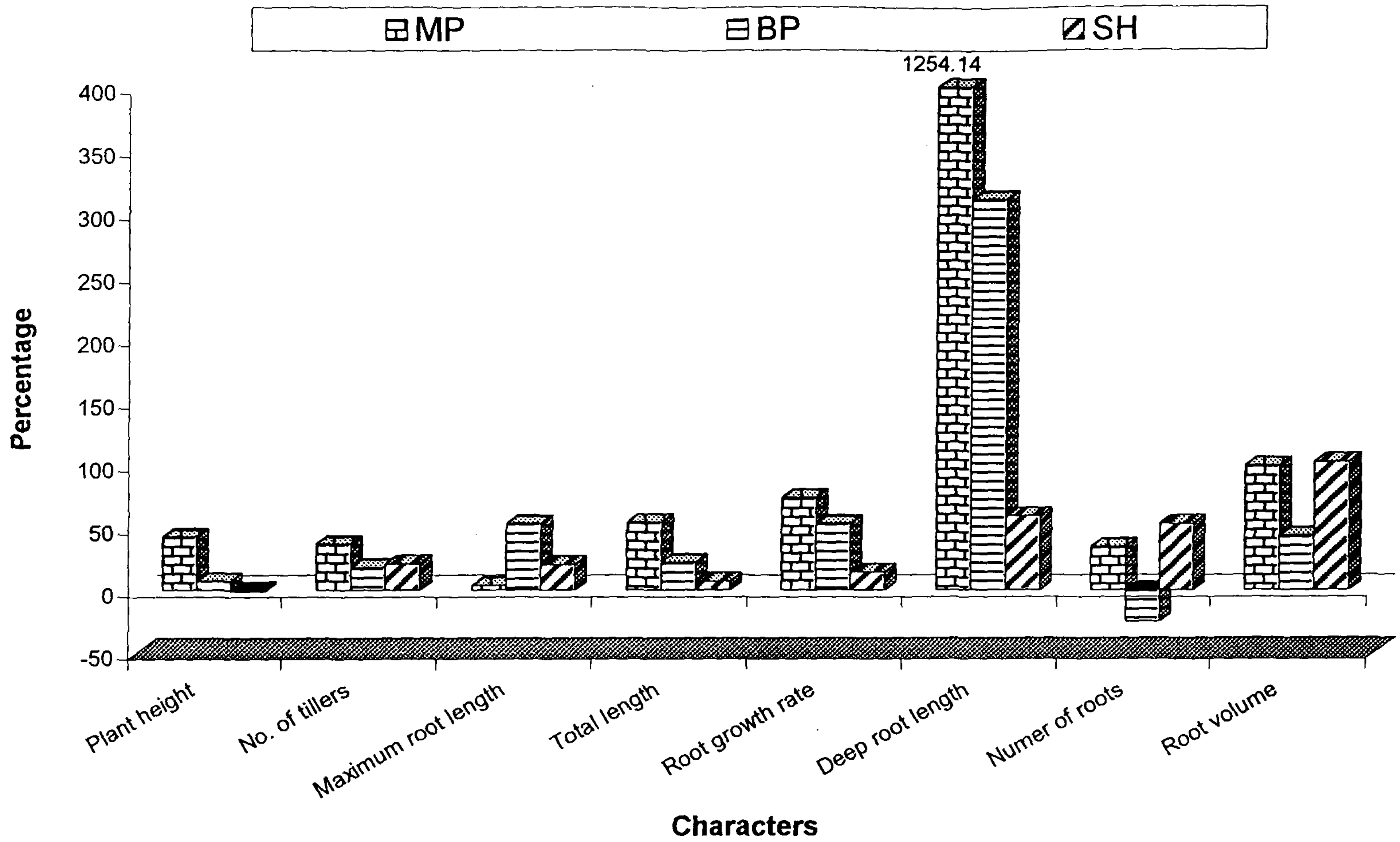

Fig 10 : Magnitude of heterosis in the promising cross IR 62829A x KMR 3R over mid parent (MP), better parent (BP) and check variety (SH) for eight root and shoot morphological traits under low moisture stress condition

system. This suggests that breeders must consider *per se* performance, heterosis and SCA effects in the desirable direction and magnitude for the characters considered.

Girish (1999) reported heterobeltiosis in the desirable direction for root volume from his studies with two cross combinations.

5.4 Ranking of parents and crosses based on scores for leaf rolling and tip firing in addition to maximum root length and root volume

IR58025A x KMR 3R and IR62829A x P 333 were toppers in the rank list prepared by considering performance for root length, root volume, leaf rolling and tip firing. These crosses also exhibited significant SCA-effects for three out of eight characters considered in the present study under low moisture condition. The results suggest that the above crosses in addition to good root system for better extraction of soil moisture from deeper layers also possessed additional moisture conservation mechanisms in shoot through leaf rolling and tip firing.

The superior cross under well watered condition IR62829A x Budda, though recorded moderate maximum root length (ie. Between 30 cm to40 cm) and higher scores for leaf rolling and tip firing was performed very poorly under low moisture environment. This reflected by its poor performance with respect to significant SCA effects for seven characters out of eight studied under low moisture stress condition.

Through root influenced leaf rolling and tip firing phenomenon, few crosses may able to perform well even with moderate scores for maximum root length and root volume. By means of leaf rolling, plants were able to reduce radiation load on leaf surface and there by reduce evapo-transpiration loss. Leaf tip firing helps plants to reduce leaf surface area interns transpiration loss through radiation shedding. Under these conditions, plants may divert portion of photosynthates from shoot to root system to increase maximum root length for extracting soil water from deeper layers to maintain tissue turgor. There by plants survive for an extended period with normal metabolism.

5.5 Estimation of standard heterosis for yield parameters under irrigated condition

For days to fifty percent flowering six crosses registered percent standard heterosis in the negative direction over the check Mangala, 23 over Jaya and three over check Rasi. Negative and significant heterosis of-19.00 and -5.30 percent for days to fifty percent flowering were recorded over the checks Jaya and Rasi. This was in accordance with the findings of Vidyachandra, 1991 and Leenakumari *et al.*, 1994.

IR58025A x KMR 3R recorded negative and significant standard heterosis of –28.08 % over Mangala, -34.03% over Jaya and –38.05 over the check Rasi. Vidyachandra 1991; Hemareddy (1996) and Hegde (1996) reported similar results for the trait plant height.

Of the 27 crosses, 17 crosses over check Mngala, eight crosses over Jaya and 15 crosses over Rasi recorded higher magnitude of standard heterosis for number of tillers.

For number of productive tillers per plant, six crosses displayed non-significant positive percent standard heterosis over the check variety Mangala. This number was four over Jaya and 11 over Rasi.

IR68949-11-5-31xBudda registered significant positive standard heterosis over all the 3-checks varieties for panicle length. The highest magnitude observed was +16.90 percent over the check variety Mangla. Hemareddy (1996), Leenakumari (1994) and Hegde (1996) reported similar results for standard heterosis for the character panicle length.

Spikelet number per panicle is another important yield component. Highest significant positive standard heterosis (70.25 %) over check Mangala was reported by IR62829 A x IR35454-18-1R. These findings are in accordance with the observation made by Hemareddy (1996), Hegde (1996) and Leenakumari (1994).

IR62829 A x IR35454-18-1R displayed substantial magnitude of positive standard heterosis (125.96%) over the check Mangala for the trait filled grains per panicle. IR62829A x IR42221-14-1-3-2R (94.67%) was in the second position. Both positive and negative heterosis was observed depending upon cross combination by many rice workers (Vidyachandra 1991 ; Hemareddy 1996 and Leenakumari 1994).

Many hybrids exhibited higher positive standard heterosis for spikelet fertility which is preferred by the rice breeders. Higher magnitude of standard heterosis of 31.98%, 32.69% and 29.91 was displayed by IR62829A x IR35454-18-1R over the checks Mangala, Rasi and Jaya respectively.

Significant and positive standard heterosis for the trait 1000-grain weight was observed by IR62829A x IR42221-14-1-2-1R followed by IR68949-11-5-31 x IR9761 and IR62829A x MM125. These results are in accordance with the finding of many rice workers (Leenakumari 1994, Hemareddy 1996 and Vidyachandra 1991).

As many as 19 crosses possessed significant positive standard heterosis in the desirable magnitude over Mangala and Jaya for grain yield and 22 crosses over the check Rasi. This was attributed to moderate to high fertility restoration of male sterile lines by majority of the male parents used in the present investigation.

IR68949-11-5-31 x IR9761, IR62829A x IR35454-18-1R, IR58025A x IR9761 and IR62829A x MM 125 were the superior cross combinations for grain yield per plant.

IR62829A x IR35454-18-R and IR62829A x MM 125 appeared most promising cross combinations for both root as well as yield parameter under well-watered conditions.

Ultimately, the selection, release and recommendation of any new cultivars depend on the *per se* performance of these varieties over several locations and environments for grain yield. In addition SCA-effects, magnitude of standard heterosis (usually over 20%) over ruling variety of a particular region, duration and rice ecosystem should be considered.

However, the performance of these hybrids for grain yield and other yield attributing parameters under actual low moisture environment should be undertaken before final selection. Also, performance of these crosses for drought avoidance mechanisms through efficient root system and dynamic root influenced shoot parameters like leaf rolling, tip firing and tillers drying need to be assessed.

5.5 Future line of work

Well-watered condition

From this investigation under well-watered condition IR62829A x Budda appeared most promising for majority of the root traits. This cross displayed significant SCA effects in desirable direction for the characters viz., maximum root length, total length, root growth rate and deep root length. With respect to heterosis, IR62829A x Budda displayed significant mid parent heterosis for all the eight characters studied in the present investigation. It also exhibited significant positive heterobeltiosis for number of tillers, maximum root length, deep root length, number of roots and root volume indicating presence of non additive gene action for these characters. The above observations for IR62829A x Budda was attributed to the involvement of both the parents with high general combining ability effects for majority of the characters. This reflected additive x additive interaction for majority of the characters suggesting the breeders to employ the breeding methods, selection of superior transgressive segregants for root and yield parameters from the segregating material to evolve superior cultivars.

Under low moisture stress

The present investigation identified IR62829A x KMR 3R and IR58025A x Budda as most promising combinations for low moisture environments based on SCA effects, heterosis, *per se* performance and scores for physiological leaf parameters considered in the present study. IR62829A x KMR 3R which registered significant SCA effects for the characters plant height, number of tillers, number of roots and root volume possessed higher magnitude positive percent mid parent heterosis for all the eight characters and heterobeltiosis for as many as five characters viz., root length, total length, root growth rate, Deep maximum root length and root volume. This may be attributed to involvement of best general combiner (IR62829A) as female parent and average general combiner as male parent (KMR 3R) in this specific cross combination. Here it is the case of additive x dominance gene action. In this situation, breeders could think of the breeding methods for exploitation of heterosis and selection in segregating population of later generations to identify superior individual for further stabilization to develop superior cultivars for different rainfed rice ecosystem.

SUMMARY

VI SUMMARY

Five experiments were conducted between *summer* 1997 to *summer* 1999 to assess variability under well-watered condition from selected rice genotypes, combining ability and magnitude of heterosis under two environments and estimation of standard heterosis for grain yield attributes under irrigated condition. The out come of all the five experiments are summarized below.

Assessment of variability parameters, character association and path coefficient analysis

ANOVA from the two experiments (27 and 39 rice genotypes) on variability parameters revealed highly significant differences for all the characters considered in the present investigation.

In experiment with 27 genotypes (1A), plant height and root thickness exhibited lowest percent PCV and GCV estimates. Deep root length registered highest PCV (106.11%) and GCV (87.02%). Except for number of tillers, root dry weight, shoot dry weight and root to shoot ratio (R: S) all other character displayed higher heritability indicating limited influence of environment on these character. Genetic advance as per cent mean observed for the eleven characters considered in the study indicated predominance of additive gene action for these characters as (majority of) the genotypes used were homozygous and homogeneous in nature.

In the experiment with 39 promising rice genotypes for root characters (1B), except for plant height, all other characters recorded higher per cent estimates of PCV, GCV, heritability and GA as per cent mean indicating prevalence of predominant additive gene action which was less prone to environmental influences. In both the experiments deep root length registered highest estimate for GA as per cent mean. This suggest ample scope for improvement of this character through selection.

Plant height exhibited non-significant associations with number of tillers, number of roots and root thickness in experiment with 27 homozygous rice genotypes. Similar association was noticed between root thickness and number of roots and also between shoot dry weight and root to shoot ratio.

Highest correlations among root characters were found between maximum root length and total length (rp = 0.89; rg= 0.88), maximum root length and root dry weight (rp = 0.61; rg= 0.93) and between total length and root dry weight (rp = 0.70; rg = 0.99). In both the experiments number of tillers was not associated with any other root or shoot characters at phenotypic level. Similar trend was observed in genotypic level except association between number of tillers and number of roots in experiment 1A.

In experiment with 39 promising rice genotypes for root characters, highest association was observed between root dry weight in the top 30 cm of soil to total root dry weight (r_p = 0.98; r_g = 0.98) at both phenotypic and genotypic levels. Number of tillers possessed negative non-significant association with root length. Breeders of rain fed drought prone habitat need to consider information on associations between and amongst various root parameters either to go for simultaneous selection for more than one root characters and or to avoid characters which exhibited negative association with important root and shoot parameters.

Cause and effect relationship of various root and shoot parameters at phenotypic level on maximum root length and total root dry weight indicated major direct contribution of total length, root thickness and root dry weight on maximum root length in experiment with 27 genotypes and maximum root length and root dry weight (up to 30 cm soil depth) on total root dry weight in experiment 1B. This information will facilitate quantification of contribution of various root and shoot parameters on important root morphological traits associated with drought avoidance either directly or indirectly.

Experiments on combining ability effect and heterosis in the desirable direction and magnitude for eight root and shoot morphological traits

Adopting line x tester mating design, experiments were conducted simultaneously in two moisture regimes (well-watered and low moisture) during *summer* 1998 and summer-1999. The experiments comprised 27 hybrids, three lines (IR58025A, IR62829A and IR68949-11-5-31 (TGMS line) and eight diverse testers. Rasi was used to estimate magnitude of standard heterosis using the data on hybrids and their parents.

Eight characters namely, plant height, number of tillers, maximum root length, total length, root growth rate, deep root length, number of roots and root volume were considered for estimating combining ability effects and heterosis.

Variances due to testers for all the characters studied were highly significant in both the environments. This may be attributed to selection of testers with varying background. However under well-watered condition, lines differed significantly for plant height and number of roots only. The mean sum of squares for lines were significant for maximum root length, total length, root growth rate, deep root length and root volume in low moisture stress condition. In both moisture regimes lines did not differ significantly for number of tillers.

Variances from combining ability ANOVA revealed highly significant difference among crosses (L x T) for all the eight characters studied under both the environments.

In general, estimates of SCA variances were higher in magnitude compared to their respective GCA variances for all characters indicating prevalence of combination of additive and non-additive gene effects. However, for total length, number of roots and root volume predominant non-additive (Dominance or epistasis) gene action was noticed.

Among the 'lines' IR62829A was the most promising general combiner under both moisture regimes as its GCA effects were significant for all eight root and shoot parameters under low moisture stress condition and for plant height, number of roots, maximum root length, total length, root growth rate and deep root length under well-watered environment. TGMS line IR68949-5-11-31 was a poor general combiner for most of the root and shoot characters associated with drought avoidance.

Among the testers, Budda was a good general combiner in both moisture regimes as its GCA effects were significant in desirable direction for as many as six characters under well-watered condition and seven under low moisture condition.

IR62829A x MM 125 was a promising specific combiner under well-watered condition for most of the root and shoot parameters. IR58025A x Budda was the best under low moisture condition. Except for number of tillers, IR62829A x MM125 displayed significant SCA effects for all the characters in desirable direction. Under well-watered condition, IR58025A x Budda displayed significant SCA effects in desirable direction for seven out of eight characters.

Based on *per se* performance, magnitude of heterosis and SCA effects in desirable direction, IR62829A x Budda was most promising hybrid under well-watered condition for majority of the root and shoot parameters. It also exhibited significant heterobeltiosis in desirable direction for important root parameters associated with drought avoidance.

For low moisture stress condition, IR62829A x KMR 3R seems to have prospects, as it possessed significant SCA effects in desirable direction for four most important root parameters in addition to significant mid parent heterosis for all the eight characters and heterobeltiosis for as many as four important root parameters considered as putative traits associated with drought avoidance mechanism.

Performance of parents and hybrids for two important physiological traits associated with shoot moisture conservation mechanism viz., leaf rolling and tip firing revealed moderate scores for the best cross combinations identified for both moisture regimes. Hybrids identified for better root system also possessed additional moisture conservation mechanisms in shoot through leaf rolling and tip firing.

Information on standard heterosis from 27 hybrids under irrigated condition revealed that, majority of the crosses possessed significant heterosis for grain yield per plant over all the three check varieties Mangala, Jaya and Rasi. IR62829A x MM 125 was among the top five crosses identified for higher grain yield and looked most promising for both root and yield parameters under optimum moisture condition.

Finally, selection of superior cross combinations should be based on their performance for better root system, additional shoot moisture conservation mechanisms and enhanced grains yielding ability under varied low moisture regimes.

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* Original not seen

APPENDICES

Annex - I : Treatment means for 11-root and shoot morphological traits in 27 rice genotypes under well watered condition

Sl No.	Genotypes	Plant height	Number of tillers	Maximum root length	Total length	Deep root length	Root growth rate	Number of roots	Root thickness	Root dry weight	Shoot dry weight	Root to shoot ratio
1	IR 35454-18-1R	45.62	14.75	45.92	90.55	15.93	0.66	70.75	0.79	11.38	9.20	1.24
2	IR 62829A	42.55	21.00	30.62	73.18	0.62	0.44	33.00	0.86	4.30	8.15	0.54
3	IR 42221-14-1-3-1-2R	50.62	24.00	49.00	99.62	19.00	0.70	90.75	0.67	20.83	10.08	2.19
4	IR 37399-1013-3-2-1R	53.75	24.50	52.95	106.70	22.95	0.76	66.75	0.67	25.62	15.30	1.72
5	IR 21567-18-3R	43.38	17.75	31.95	75.32	1.95	0.46	49.00	0.74	13.00	17.45	0.74
6	IR 62829B	42.12	20.50	28.95	71.07	-1.05	0.41	77.75	0.72	11.08	10.85	1.00
7	IR 58025A B	45.62	18.75	42.00	87.62	12.00	0.60	36.25	0.64	8.38	6.60	1.38
8	IR 65507-58-1-3-1R	43.62	20.75	42.35	95.98	12.35	0.60	56.00	0.45	21.35	13.62	1.54
9	IR 48275-13-13-141-2R	49.20	28.25	61.25	110.45	31.25	0.88	120.50	0.83	35.50	14.53	2.44
10	IR 55722-13-13-6-2R	50.75	25.25	56.78	107.53	26.77	0.81	50.75	0.70	28.15	12.05	2.40
11	IR 534679-13-13-2-1-1	58.15	17.00	40.08	98.22	10.07	0.57	50.50	0.68	11.50	12.15	0.93
12	IR 58025A	44.88	14.75	31.47	76.35	1.48	0.45	32.50	0.58	5.62	10.12	0.58
13	IR 47310-94-4-3-1R	45.12	12.50	33.35	78.47	3.35	0.48	28.25	0.67	8.35	11.20	0.73
14	IR 64	59.05	17.50	54.42	113.25	24.20	0.77	49.50	0.65	17.83	15.00	1.22
15	IR 36	49.08	23.75	41.42	90.50	11.43	0.59	45.75	0.49	5.83	10.83	0.53
16	KMR 3R	55.88	19.50	42.28	98.15	12.27	0.60	37.50	0.51	25.25	12.73	2.12
17	IR 49491-192-1-1	51.55	22.25	71.40	122.95	41.40	1.02	40.25	0.63	21.88	14.17	1.69
18	IR 30864	52.55	15.50	43.80	111.85	13.80	0.63	56.00	0.61	17.75	17.48	1.05
19	Jaya	42.80	24.75	43.10	110.65	13.10	0.62	49.50	0.69	23.80	14.38	1.66
20	IR 9761	48.97	16.25	30.30	95.53	0.30	0.43	55.00	0.63	9.48	13.82	0.69
21	Azucena	83.25	15.50	90.00	173.25	60.00	1.29	95.75	0.87	62.15	22.65	2.76
22	Hyb-2	53.83	23.25	58.58	135.65	28.58	0.84	62.00	0.71	27.18	20.58	1.33
23	IR 68945-4-33-4-14 (TGMS)	49.12	15.75	50.65	115.52	20.65	0.72	51.25	0.61	19.12	6.68	2.94
24	Hyb-1	48.31	28.50	51.00	99.31	21.00	0.73	105.25	0.64	35.85	21.75	1.69
25	IR 68949-11-5-31	77.75	13.50	27.10	104.85	-2.90	0.39	61.00	0.52	29.30	11.10	2.81
26	P 331	55.55	16.00	87.25	144.80	57.25	1.25	86.50	0.83	50.75	20.52	2.34
27	P 333	54.58	18.50	82.75	137.33	52.75	1.18	38.25	0.85	33.85	13.55	2.85
	GM	52.10	19.64	48.91	101.01	18.91	0.70	59.12	0.68	21.85	13.57	1.63
	CV (%)	9.24	20.99	23.47	11.93	60.72	23.47	19.33	11.86	56.69	24.98	55.32
	CD at 5%	6.82	15.26	18.28	16.26	0.23	5.84	16.19	0.11	17.55	4.80	1.28
	CD at 1 %	9.80	21.64	24.34	21.65	0.31	8.50	21.55	0.15	23.36	6.39	1.70
	SEm±	3.404	8.117	9.113	8.117	0.116	8.416	8.082	0.057	8.761	2.398	0.637

Annex -II Treatment means for 10-root and shoot morphological traits associated with drought avoidance in 39 rice genotypes under well-watered condition

Sl No.	Genotypes	Plant height	Number of tillers	Total length	Maximum root length	Deep root length	Root growth rate	Number of roots	Total root dry weight	Root volume	Root dry weight (<30 cm soil depth)
1	P 12	73.67	24.67	130.97	57.30	27.30	0.82	44.67	9.77	136.67	8.13
2	P 27	64.27	17.33	106.63	42.37	12.37	0.61	109.67	10.60	80.00	10.33
3	P 36	63.00	21.00	106.83	43.83	13.83	0.63	64.67	4.57	71.67	4.07
4	P41	61.50	26.00	94.33	32.83	2.83	0.47	171.00	6.50	66.67	6.23
5	P 48	78.33	19.33	173.47	95.13	65.13	1.36	74.33	10.83	150.00	9.60
6	P 88	67.10	27.33	108.77	41.67	11.67	0.60	125.67	6.63	106.67	5.60
7	P 89	71.07	26.67	101.27	30.20	0.20	0.43	64.00	4.93	41.67	1.60
8	P107	76.87	26.33	131.83	54.97	24.97	0.79	106.67	6.37	83.33	5.30
9	P 124	78.87	13.00	134.10	55.23	25.23	0.79	84.33	5.57	37.33	4.27
10	P 146	81.93	13.33	144.08	62.13	32.13	0.89	66.67	4.63	66.67	4.07
11	P 163	85.12	11.00	125.53	40.40	10.40	0.58	104.33	9.47	38.33	8.33
12	P 171	84.53	18.33	121.27	36.73	6.73	0.52	61.33	11.23	86.67	10.50
13	P 192	70.53	15.67	109.80	39.27	9.27	0.56	126.00	3.03	70.00	2.77
14	P 200	94.20	13.67	147.40	53.20	23.20	0.76	75.67	5.07	73.33	4.23
15	P 210	64.10	19.33	161.37	97.27	67.27	1.39	37.67	5.80	73.33	5.23
16	P 238	72.43	27.33	109.07	63.63	6.63	0.52	109.33	6.27	89.00	5.50
17	P 331	67.23	16.33	130.63	63.40	33.40	0.91	91.33	12.23	115.67	10.80
18	P 333	83.33	19.67	133.93	50.60	20.60	0.72	90.67	7.63	85.67	6.57
19	P 374	79.30	20.00	166.13	86.83	56.83	1.24	120.00	10.77	136.67	9.27
20	P 391	94.77	19.00	148.60	53.83	23.83	0.77	71.00	8.70	158.33	7.97
21	P 403	84.00	22.00	160.03	76.03	46.03	1.09	128.00	5.43	133.33	4.30
22	P 558	91.57	12.33	162.87	71.30	41.30	1.02	119.33	12.40	106.73	11.52
23	P 1505	84.47	14.67	151.70	67.23	37.23	0.96	94.00	4.13	106.67	3.67
24	Azucena	106.23	16.33	226.73	120.50	90.50	1.72	94.67	6.70	156.67	5.77
25	Hyb-4	78.10	19.33	116.10	38.00	8.00	0.54	79.67	4.80	93.33	4.70
26	Co 39	74.80	17.67	104.83	30.03	0.06	0.43	82.67	2.57	63.33	2.57
27	IR 64	58.83	28.67	93.40	34.57	4.57	0.49	90.67	3.40	63.33	3.13
28	Jaya	72.20	20.67	106.23	34.03	4.03	0.49	161.67	5.63	123.33	5.43
29	Rasi	73.37	28.00	154.13	80.77	50.77	1.15	99.67	11.13	191.33	10.30
30	Hyb-1	60.33	29.67	90.60	30.27	0.27	0.43	87.33	5.20	53.33	5.13
31	TK 107	92.57	18.00	158.20	65.63	35.63	0.94	167.67	6.17	113.33	5.50
32	Budda	85.73	24.67	134.53	48.80	18.80	0.70	98.67	13.20	148.33	12.47
33	Balesule	88.00	19.33	125.53	37.53	7.53	0.54	115.00	6.10	81.67	5.53
34	MM 125	97.00	25.33	156.93	59.93	29.93	0.86	112.67	6.70	93.33	5.77
35	MM 113	100.63	18.67	174.53	73.90	43.90	1.06	117.33	5.27	128.33	4.77
36	TT 121	87.57	28.67	131.63	44.07	14.07	0.63	85.00	3.77	72.67	3.00
37	MM 111B	91.93	20.00	180.10	88.17	58.17	1.24	139.33	10.90	146.67	9.50
38	IR 68945-4-33-4-14	64.30	22.67	107.13	42.83	12.83	0.61	90.00	6.30	86.67	5.73
39	IR 68949-11-5-31	57.90	12.33	91.37	33.47	3.47	0.48	112.33	2.37	45.00	2.03
	General mean	78.51	20.37	133.63	55.15	25.15	0.79	99.35	6.99	96.80	6.19
	CV (%)	10.32	13.55	8.09	13.20	28.94	13.20	7.27	20.95	20.01	20.38
	CD at 5%	13.25	4.51	17.67	11.90	11.90	0.17	11.81	2.40	61.67	2.06
	CD at 1%	17.63	6.01	23.52	15.84	15.84	0.23	15.71	3.19	42.16	2.74
	SEm±	6.61	2.25	8.82	5.94	5.94	0.09	5.89	1.20	15.81	1.03

Annex- III : Treatmen means and SEm±- for eight root and shoot morphological traits in 27 rice crosses and their parents under well-watered (ww) and low moisutre stress (st) condition

Sl No.	Crosses/Parents	Plant height		Number of tillers		Maximum root length		Total length		Root growth rate		Deep root length		Number of roots		Root volume	
		ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st	ww	st
1	IR68949 -11-5-31 x Budda	76.33	77.33	13.00	17.33	25.33	38.60	101.67	115.93	0.36	0.55	-4.67	8.60	240.00	263.00	61.67	58.33
2	IR68949 -11-5-31 x MM 125	68.83	67.33	28.33	21.20	26.33	34.77	95.17	99.85	0.38	0.46	-3.67	2.52	278.00	288.67	51.67	56.00
3	IR68949 -11-5-31 x MM 111B	80.00	85.50	17.00	23.67	22.33	29.33	102.33	114.83	0.32	0.42	-7.67	-0.67	173.67	195.00	38.33	45.67
4	IR68949 -11-5-31 x TT 121	74.90	67.97	17.00	26.00	25.33	34.53	100.23	102.50	0.36	0.49	-4.67	4.53	254.33	295.33	75.00	58.33
5	IR68949 -11-5-31 x P 331	67.17	73.83	22.00	24.00	42.00	33.83	109.17	107.67	0.60	0.48	12.00	3.83	388.33	323.33	61.67	31.67
6	IR68949 -11-5-31 x P 333	85.33	88.13	10.00	17.67	25.67	29.67	111.00	117.80	0.37	0.42	-4.33	-0.33	248.33	270.00	41.67	45.50
7	IR68949 -11-5-31 x KMr 3R	78.83	77.43	12.00	12.00	27.00	36.33	105.83	113.77	0.39	0.52	-3.00	6.33	170.33	199.00	76.67	75.33
8	IR68949 -11-5-31 x IR 42221-14-1-2-1-3R	76.50	66.50	17.00	17.00	21.33	23.67	97.83	90.17	0.30	0.34	-8.67	-6.33	266.33	222.67	48.33	45.00
9	IR68949 -11-5-31 x IR 35454-18-1R	70.83	78.50	24.00	15.33	36.00	26.17	106.83	104.67	0.51	0.37	6.00	-3.83	305.33	229.67	86.67	58.33
10	IR 62829A x Budda	85.00	82.77	33.33	24.33	65.67	35.27	150.67	118.03	0.94	0.50	35.67	5.27	230.33	276.33	185.00	166.67
11	IR 62829A x MM 125	93.23	89.83	41.00	25.33	46.83	41.73	140.07	131.57	0.67	0.60	16.83	11.73	434.33	302.33	142.00	92.13
12	IR 62829A x MM 111B	70.80	71.37	32.33	27.67	36.33	40.07	107.13	111.43	0.52	0.57	6.33	10.07	174.33	181.67	70.00	61.67
13	IR 62829A x TT 121	65.50	73.17	50.00	17.67	27.20	31.53	92.70	104.70	0.39	0.45	-2.80	1.53	197.00	190.67	68.33	67.30
14	IR 62829A x P 331	83.00	68.33	38.67	22.33	53.13	44.67	136.13	113.00	0.76	0.64	23.13	14.67	386.00	291.67	80.00	43.33
15	IR 62829A x P 333	66.67	73.50	18.00	20.67	27.33	45.50	94.00	119.00	0.39	0.65	-2.67	15.50	163.67	246.33	61.67	90.00
16	IR 62829A x KMr 3R	78.67	80.10	37.33	26.00	41.67	55.33	120.33	135.43	0.60	0.79	11.67	25.33	224.67	271.00	153.33	168.33
17	IR 62829A x IR 42221-14-1-2-1-3R	70.33	85.00	48.00	23.67	31.33	45.27	101.67	130.27	0.45	0.65	1.33	15.27	301.33	315.33	78.33	91.67
18	IR 62829A x IR 35454-18-1R	70.67	71.33	29.00	21.00	28.33	37.67	99.00	109.00	0.40	0.54	-1.67	7.67	316.67	305.67	73.33	35.00
19	IR58025A x Budda	72.00	86.20	44.00	17.33	50.67	57.07	122.67	143.27	0.72	0.82	20.67	27.07	299.00	320.00	231.67	268.33
20	IR58025A x MM 125	68.27	69.20	18.33	15.33	37.00	38.33	105.27	107.53	0.53	0.55	7.00	8.33	144.33	137.33	25.00	22.67
21	IR58025A x MM111B	62.17	62.23	43.67	30.00	47.83	34.50	110.00	97.73	0.68	0.49	17.83	4.50	239.67	198.33	79.33	69.00
22	IR58025A x TT 121	55.27	55.27	34.33	14.00	41.33	34.27	96.60	89.53	0.59	0.49	11.33	4.27	185.00	204.67	75.33	75.00
23	IR58025A x P 331	70.33	69.33	16.33	19.00	43.87	40.90	114.20	110.23	0.63	0.58	4.93	10.90	230.00	225.33	40.33	37.97
24	IR58025A x P 333	63.23	61.17	30.00	11.33	34.50	31.47	97.73	92.63	0.49	0.45	4.50	1.47	198.33	174.67	69.00	60.00
25	IR58025A x KMR 3R	64.17	52.17	40.00	16.33	60.33	70.63	124.50	122.80	0.86	1.01	30.33	40.63	187.67	207.00	75.00	86.20
26	IR58025A x IR 42221-14-1-2-1-3R	62.27	67.50	31.67	29.33	36.93	51.93	99.20	119.43	0.53	0.74	6.93	21.93	227.00	249.67	63.33	56.67
27	IR58025A x IR 35454-18-1R	62.83	67.97	36.00	26.00	26.17	34.53	89.00	102.50	0.37	0.49	-3.83	4.53	248.33	295.33	61.33	75.83
	LINES																
1	IR 68949-11-5-31	57.43	56.83	13.00	14.00	33.30	36.97	99.00	93.80	0.48	0.53	3.30	6.97	114.67	118.67	43.17	58.87
2	IR 62829A	41.30	37.23	19.33	16.00	30.50	27.57	71.80	64.80	0.44	0.39	0.50	-2.43	73.00	40.00	36.00	51.50
3	IR 58025A	44.83	49.20	14.00	18.67	32.37	44.43	77.20	93.63	0.46	0.63	2.37	14.43	36.00	53.00	28.50	72.67
	TESTERS																
1	BUDDA	88.33	85.43	21.33	18.33	49.00	56.13	137.33	141.57	0.70	0.80	19.00	26.13	100.67	108.00	83.67	141.17
2	MM 125	96.00	105.50	23.67	27.00	58.67	78.67	154.67	184.17	0.84	1.12	28.67	48.67	488.00	285.67	186.67	125.00
3	MM 111B	109.53	85.00	18.33	15.00	62.17	60.63	171.70	145.63	0.89	0.87	32.17	30.63	349.33	114.00	200.00	80.17
4	TT 121	72.67	95.83	25.33	20.00	29.67	51.47	102.33	147.30	0.42	0.74	-0.33	21.47	210.33	294.67	83.33	58.33
5	P 331	82.00	89.47	34.00	24.00	42.67	56.40	124.67	145.87	0.61	0.81	23.33	26.40	196.67	207.33	118.33	126.67
6	P 333	78.00	54.63	26.33	14.67	53.67	58.77	131.67	113.40	0.77	0.84	23.67	28.77	208.67	55.67	96.67	74.13
7	KMR 3R	71.67	74.93	38.00	22.00	36.67	36.17	108.33	111.10	0.52	0.52	6.67	6.17	421.67	362.67	135.00	117.53
8	IR 42221-14-1-2-1-3R	74.00	90.83	28.33	22.67	46.23	52.63	120.23	143.47	0.66	0.75	16.23	22.63	308.33	281.00	80.00	71.67
9	IR 35454-18-1R	60.60	70.43	28.00	19.00	33.57	38.57	94.17	109.00	0.48	0.55	3.57	8.57	433.67	389.00	143.33	131.30
	SEm ±	5.65	3.49	5.25	2.93	4.94	3.68	10.62	6.49	0.07	0.05	4.94	3.68	23.65	17.78	12.56	8.49
	CV %	9.51	5.80	23.74	17.75	15.75	10.66	11.56	6.86	15.76	10.65	71.94	36.72	11.38	9.38	17.48	13.07
	General mean	72.85	73.65	27.10	20.20	38.41	42.28	112.49	115.91	0.55	0.60	8.41	12.28	254.65	232.74	87.96	79.54

Annex -IV Treatments mean and SEM(±) for 10 yield attributing parameters from 27 hybrids and 3-checks in rice under irrigated condition

Sl No.	Genotypes	Days to 50 % flowering	Plant height	Number of tillers/plant	No. of productive tillers/plant	Panicle length	No. of spikelets/panicles	No. of filled grains/panicle	Per cent spikelet fertility	1000 grian weight	Grain yield /plant
1	IR68949-11-5-31 x Budda	87.00	102.66	16.22	14.33	24.00	110.67	73.44	66.48	28.67	25.00
2	IR68949-11-5-31 x IR9761	106.42	75.10	24.67	21.33	21.31	141.31	81.31	57.69	32.43	37.00
3	IR68949-11-5-31 x IR35454-18-1R	107.00	92.85	13.11	12.33	20.61	123.89	92.77	74.73	26.22	23.77
4	IR68949-11-5-31 x TT 121	93.11	91.97	21.66	19.88	18.10	102.53	41.09	40.06	25.11	20.42
5	IR68949-11-5-31 x KMR 3 R	95.11	64.98	17.88	16.55	19.67	135.99	70.87	52.07	24.01	26.89
6	IR68949-11-5-31 x IR42221-14-1-3-1-2R	101.33	71.39	21.00	16.22	21.77	141.20	121.55	86.19	24.99	28.43
7	IR68949-11-5-31 x P 333	96.22	79.76	16.00	14.10	21.11	102.56	89.98	87.76	24.98	27.54
8	IR68949-11-5-31 x MM 111 B	97.33	91.98	17.55	15.78	22.90	98.00	60.32	51.54	26.20	22.87
9	IR68949-11-5-31 x MM 125	97.88	81.66	19.89	18.10	21.93	140.20	92.62	65.98	19.00	26.54
10	IR62829A x IR42221-14-1-3-1-2R	112.11	70.89	16.00	13.88	19.00	101.20	65.11	64.25	33.65	31.09
11	IR62829A x P 331	92.55	66.06	24.00	18.22	21.17	117.76	79.00	67.09	26.21	29.00
12	IR62829A x P 331	104.66	78.00	26.00	22.11	20.88	115.65	48.42	41.86	23.11	18.56
13	IR62829A x MM 125	113.55	57.50	20.67	17.78	20.38	138.53	110.67	79.90	31.44	31.32
14	IR62829A x IR35454-18-1R	94.32	66.32	25.10	22.22	21.34	147.56	141.07	95.63	23.33	34.22
15	IR62829A x MM 111B	116.10	77.99	16.00	15.22	19.67	140.32	112.98	80.51	26.87	29.67
16	IR62829A x Budda	101.11	54.33	14.21	12.33	21.28	120.20	83.78	69.70	22.21	27.42
17	IR62829A x KMR 3R	92.67	90.21	21.78	20.77	22.41	114.99	36.33	31.57	21.89	16.28
18	IR58025A x P 107	103.67	83.61	19.76	19.67	21.17	115.66	73.00	63.84	25.78	23.00
19	IR58025A x IR9761	97.66	72.88	18.00	15.56	23.32	143.66	93.21	65.06	23.42	31.11
20	IR58025A x KMR 3R	100.78	52.99	16.45	11.11	19.60	139.87	119.57	85.54	30.43	28.22
21	IR58025A x MM 125	100.67	107.10	17.00	15.21	23.99	125.00	68.53	54.82	29.97	18.89
22	IR58025A x IR35454-18-1R	91.00	61.32	23.00	21.33	22.00	124.43	107.43	86.32	23.64	24.89
23	IR58025A x MM 111 B	100.44	77.72	17.22	14.89	22.93	118.20	86.53	73.21	26.23	30.00
24	IR58025A x TT 121	104.11	71.22	16.33	16.00	21.10	103.45	72.00	69.60	30.33	28.22
25	IR58025A x IR42221-14-1-3-1-2R	105.09	60.22	17.89	15.44	21.78	137.56	121.53	88.35	22.11	29.55
26	IR58025A x Budda	102.00	84.50	16.53	14.22	21.49	123.32	75.57	61.27	26.45	25.56
27	IR58025A x P333	90.45	72.55	17.11	16.32	19.98	139.67	59.76	42.78	22.67	17.11
	Genera mean	99.95	76.57	18.89	16.77	21.18	122.63	83.59	67.73	25.63	25.70
	SEM±	1.20	3.24	1.22	1.13	1.02	3.53	4.39	3.52	1.04	1.49
	CV%	1.48	5.18	7.91	8.22	5.93	3.53	6.43	6.37	4.97	7.09
	Mean of check Mangala	95.00	73.50	18.32	15.78	20.53	86.67	62.44	72.46	23.21	20.55
	Mean of check Jaya	107.42	80.32	20.88	17.87	21.77	120.43	88.66	73.61	22.00	20.65
	Mean of check Rasi	91.88	85.54	16.56	14.56	18.27	108.43	78.09	72.07	22.21	17.11

Annex-V : Soil moisture determination by gravimetric method at 50th (at the start of stress imposition) and 65th DAS (at the end of stress period) of experiment on combining ability and heterosis under low moisture stress condition. Date of sowing 19-11-1998

At 50th DAS (the first day of stress imposition)

Sample No.	Fresh weight (gm)	Dry weight (gm)
1	152.43	125.42
2	158.42	119.58
3	148.82	122.77
4	150.76	131.93
5	153.22	124.92
6	150.73	126.92
Mean	152.4	124.92

Soil moisture = 21.99%

At 65th DAS (at the end of stress period)

Soil samples	Fresh weight (gm)	Dry weight (gm)	Soil moisture (%)
Top soil (<30 cm depth)	99.95	88.23	13.38
Middle layer (30 cm to 60 cm)	116.30	97.36	19.70
Bottom layer (>60 cm upto 100 cm	149.55	122.98	21.49

Annexure -VI : Monthly average rainfall and temperature data of UAS, Bangalore Campus for the period Jan-1998 to April-1999

Months	Rainfall (mm)	Temperature (°C)	
		Max	Min
1998 Jan	0.0	28.2	16.6
Feb	0.0	30.2	17.1
March	0.8	33.2	19.6
April	78.2	34.6	21.6
May	49.6	33.6	21.5
June	32.0	31.0	20.5
July	132.2	27.7	19.7
August	352.2	27.4	19.6
Sept	245.7	27.1	19.4
Oct	241.7	27.1	18.6
Nov	37.5	26.6	16.9
Dec	0.0	28.5	17.4
1999 Jan	0.0	27.0	13.6
Feb	7.8	29.2	15.4
March	0.0	32.9	17.6
April	53.8	33.3	19.5

Source : Daily weather data, Agrometerology unit, UAS, Bangalore-65