CYTOGENETIC ANALYSIS AND RESPONSE TO STRESS ENVIRONMENTS IN RICE

THESIS

SUBMITTED TO THE KURUKSHETRA UNIVERSITY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN THE FACULTY OF DAIRYING, ANIMAL HUSBANDRY AND AGRICULTURE

BY

V. G. MOHANAN NAIR

DIVISION OF GENETICS AND PLANT PHYSIOLOGY

CENTRAL SOIL SALINITY RESEARCH INSTITUTE

KARNAL 132 001

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Dated 16 July, 1985

CERTIFICATE

I certify that the work reported in the thesis, entitled "Cytogenetic Analysis and Response to Stress Environments in Rice", was carried out by Mr.V.G. Mohanan Nair under my guidance and direct supervision in the Division of Genetics and Plant Physiology at the Central Soil Salinity Research Institute, Karnal, for the requirement of the degree of DOCTOR OF PHILOSOPHY in the Faculty of Dairying, Animal Husbandry and Agriculture, Kurukshetra University, Kurukshetra, and that no part of the thesis has been submitted for any other degree.

R.S. RANA

A C K N O W L E D G E M E N T S

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(V.G. MOHANAN NAIR)

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I N T R O D U C T I O N

Rice plant belongs to the genus Oryza of the grass family Gramineae. This genus comprises of nearly 26 taxa and the cultivated rices belong to two species, namely, sativa and glaberrima (Vavilov 1926, 1951; Tateok, 1963). Archeological findings have pushed the antiquity of cultivated rice forms to around 4500 years B.C. (Vishnu Mittre, 1973). Asian rices (O. sativa) are more widely cultivated than the African rice (O. glaberrima) and possess higher yield potential, better adaptability and superior grain quality (Parter'es 1959, Angladette 1966). Asian rices have further differentiated during their long history of cultivation into three sub-species, namely, japonica, javanica and indica, in response to agro-climatic demands and regional preferences. Depending on the conditions of their cultivation in terms of soil topography and water availability, cultivars are classified as lowland, upland, rainfed, irrigated and deep water rices. Besides enormous variation regarding morphology and growth habit as well as remarkably wide range of adaptation to agro-climatic and soil characteristics, rice varieties also differ a great deal in respect of grain quality.

Rice is the major source of calories, and to some extent of protein as well as vitamins and minerals, in south-east Asia. Though the protein content of rice is poor amongst the cereals, its essential aminoacid spectrum is well balanced and nutritionally it is the best among all cereals (CRRI, 1980). According to FAO estimates (1984), an area of about 143.7×10^6 hectares is under rice cultivation yielding nearly 437.9×10^6 tonnes with a world

productivity average of 3.05 t/ha. India's share is 28.1% in area (i.e., 40.3×10^6 ha) and 19.5% in production (i.e. 85.4×10^6 tonnes). Average paddy yield per ha in India is still only 2.12 tonnes which is 30.4% less than the world average (FAO Report 1984).

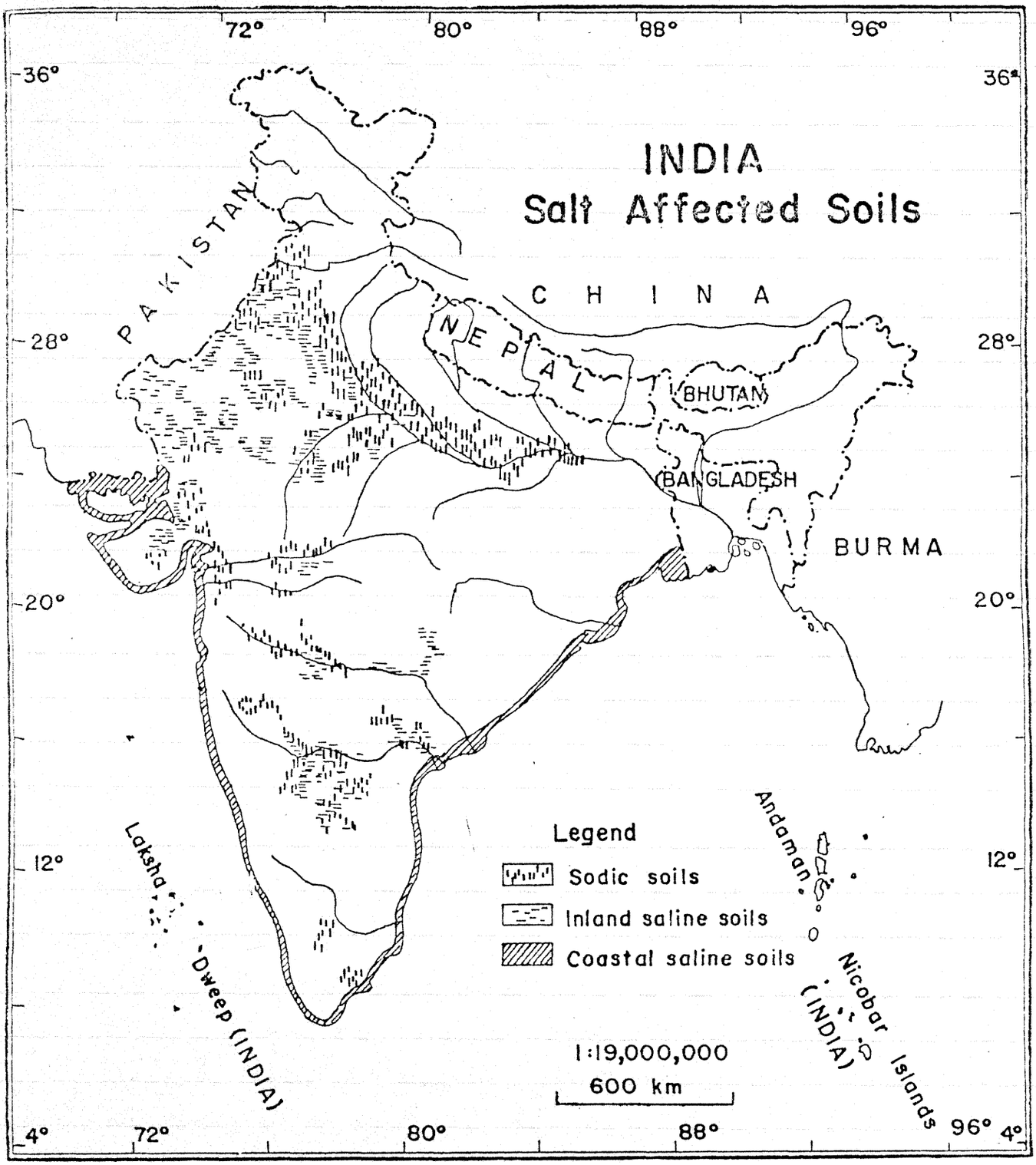
Until about 1950, increase in world food demand was met largely by an increase in the cultivated area. But, during the period 1950 to 1975, world population increased faster than the cropped land area leading to a drop in percapita area from 0.241 to 0.184 ha (Brown 1981). The situation is more alarming in Asia where the population density is considerably high, especially in the rice belt as compared to others. In case the present trend persists, world population is likely to become 6.3 to 6.7 billion by the year 2,000 A.D. and the food need will amount to nearly 3 billion tonnes (Hopper, 1981). If this challenge is to be accomplished, increased production must come not only from the land already cultivated, but also from reclamation and better utilization of degraded and marginal lands, including salt-affected areas. In addition, the grain productivity and production need to be stabilised by developing varieties which are relatively better buffered against unfavourable climate and soil conditions. Increased agricultural production is obviously the prime consideration for the economic uplift of the poor and developing countries.

Environmental stresses affecting crop production include too much or too little rainfall, temperature extremes, less favourable soils, disease incidence, insect damage and weed

problems. Soil salinity and alkalinity are two serious constraints encountered in several rice growing countries. Although no regular systematic surveys has been made in India, but estimates of salt affected lands have varied from seven to over 20 million ha (Abrol and Bhumbla, 1971; Agarwal et al., 1979). This problem is particularly serious in semi-arid tracts of Indogangetic alluvial plains, coastal regions and penninsular India which are the major rice producing areas. Expanded use of saline waters for irrigation together with the poor management practices are further aggravating the soil problems in India (Paliwal, 1972; Framji, 1976; Rana, 1977; Agarwal et al., 1979).

Salinity denotes the soil condition where the saturated extract of soil contains neutral salts like chlorides and sulphates of sodium, calcium and magnesium in such proportion that plant growth gets adversely affected. An electrical conductivity of the soil saturation extract of 4 dS/m is usually set as the lower limit of saline soil. Alkali soils, on the other hand, are characterised by high pH and predominant presence of carbonates and bicarbonates of sodium. Physical conditions of alkali soils are very poor for plant growth as these soils are highly dispersed having low permeability to water and air. Alkali soils are very sticky when wet and very hard when dry causing difficulty in proper preparation of seed-beds. Soils having exchangeable sodium percentage (ESP) above 15 and pH_2 over 8.2 are considered to be alkali soils or 'sodic soils'.

Figure 1 Map of India showing distribution of salt-affected soils


INDIA
Salt Affected Soils
72°
80°
88°
96°
36°
28°
20°
12°
4°
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
BURMA
Laksha Dweep (INDIA)
Andaman & Nicobar Islands (INDIA)
Legend
Sodic soils
Inland saline soils
Coastal saline soils
1:19,000,000
600 km

Until recently, the problems of crop production in saline and alkali soils were being dealt with almost exclusively by manipulating the mineral substrate relying on reclamation and drainage technology. However, there are situations where soil-amendment based reclamation is either not possible or not economically feasible owing to numerous reasons. Infact, soil salinity and alkalinity problems cannot be entirely eliminated when the water available for leaching is of poor quality, soil properties are marginal and adequate drainage is not available. It has now become increasingly evident that the approach of selecting and breeding salt resistant crop varieties is not only promising under these conditions but also less energy expensive and non-pollutant (Rana, 1978). Obvious pre-requisites to achieve this objective are proper understanding and critical evaluation of the level of salt tolerance available in plants of our interest including their present day cultivated forms as well as wild relatives.

Vast potential of genetic approach towards solving problems of soil salinity and alkalinity is now widely recognised and the information generated on the subject has been reviewed periodically (See: Bernstein, 1975; Wright, 1976; Jung, 1978; Holleander et al., 1979; Rains et al., 1980; Levitt, 1982). Recent reports of exploitable intra-specific variation regarding adaptation to distinct edaphic environments have opened up new vistas to search for plant-based solutions to the challenge of saline and alkali soils which are among the major desertification processes diminishing productivity of agricultural lands

(Epstein et al., 1980; Nelson,1983; Yeo and Flowers, 1983; Saric and Loughman, 1983; Kingsbury and Epstein, 1984; Rana, 1984; Staples and Toenniessen, 1984).

There are two essential requirements for developing a suitable breeding strategy to combine salt tolerance with good yield potential. Firstly, critical information on the nature and range of genetic variability for salt tolerance within a crop is to be obtained. Secondly, it is necessary to quantify and understand relationship between yield and its major components under saline and alkali soil conditions so as to develop reliable selection criteria (Lehman et al., 1984). This is so because the yield by itself has low heritability unlike many of its component traits. Correlation coefficients measure strength of mutual associations among character pairs but this information is not enough for a breeder because component traits affect the yield both directly and indirectly. Thus, separation of correlations into measures of direct and indirect effects of different variables on yield by adopting path coefficient analysis technique, developed by Dewey and Lu (1959), becomes necessary to understand arrays of interacting phenomena that lead to observed correlations in a correlated series of variables.

Furthermore, identification of desirable genotypes having stable performance over a wide range of soil and climatic conditions has considerable significance in rice improvement work, particularly in areas where soil salinity and alkalinity problems are of a spotty nature (confined to

certain patches in rice fields) or where such stresses occur with unpredictable periodicity and intensity. Phenotypes are the result of interactions between genotypes and environments. In this context, effective methods have been developed in the recent past to obtain reliable estimates of these interactions (Eberhart and Russell, 1966; Perkins and Jinks, 1968; Freeman and Perkins, 1971).

Salinity problems drew the attention of Indian rice workers many decades ago and several rice growing states identified/developed salt tolerant materials suited to their specific situations such as Patnai 23, Nona Sail and Nona Bokra in W. Bengal; SR26B in Orissa; MCM types in Andhra Pradesh; PVR-1 and AU-1 in Tamil Nadu; Pokkali in Kerala; Karekagga, Bilekagga and Arya in Karnataka; Kalarata and Bhurarata selections in Maharashtra and Jhona 349 in Punjab. However, Bhattacharyya (1976) reported that many of these varieties showed poor performance under Karnal conditions in soils having ECe value more than 5 to 6 dS/m. In addition, most of the varieties identified to be salt-tolerant are tall, prone to lodging and photosensitive genotypes which are unsuitable for wide cultivation as they are adapted to specific climatic and soil conditions (Rana, 1979). Although considerable progress has been made in rice improvement in India for irrigated and favourable soils, work on developing superior varieties suited to adverse soil conditions has lagged far behind for want of more systematic and sustained research support. Since rice is grown under widely different agro-

climatic-soil complexes in our country, there is an urgent need for location-specific research to evolve varieties best suited to representative situations (Desai, 1983).

In view of the afore-mentioned considerations, the present investigation was undertaken primarily to evaluate responses to salinity and alkalinity stresses of some genetically diverse rice varieties, representing a wide range of adaptations and maturity characteristics, with a view to assessing intervarietal differences in this regard. Replicated experiments were conducted for this purpose under monitored conditions in laboratory, pot culture and specially-designed screening plots employing both seedling and adult plant criteria. Observations were recorded on seed germinability, rate of germination, seedling growth, days to flowering, plant height, panicle bearing tillers, panicle length and weight, dry matter production, grain yield, grain weight and harvest index. Data so obtained were subjected to analysis of variance, stability analysis, correlation estimation and path coefficient analysis. In addition, cytological observations on stomatal features, meiotic behaviour and pollen grains were also made in some locally-adapted cultivars, that are still grown traditionally in our country under different situations of salt-affected soils, with a view to characterising these valuable indigenous materials.

REVIEW OF LITERATURE

Study of plant response to saline environments and other adverse soil conditions is of immense interest to research workers of many disciplines, especially to those concerned with agricultural production. Voluminous literature has accumulated on this subject and numerous comprehensive reviews have been published in recent years dealing with interaction of plants with edaphic stress environments including soil salinity and alkalinity (sodicity).

Aspects that have been reviewed and discussed elaborately include tolerance of different plant species (Hayward, 1956); response of glycophytes and halophytes (Strogonov, 1964); metabolic pathways and production of toxic intermediates under various types of salinity (Strogonov and Kabarov, 1964); structure and function of plant cells under saline condition (Strogonov et al., 1970); plant response to salinity in relation to energy expenditure (Greenway, 1973); relevant agricultural problems and means of amelioration (Poljakoff-Mayber and Gale, 1975); mechanisms of salt tolerance in halophytes (Flowers et al., 1977); response of crops to salinity in terms of yield (Maas and Hoffman, 1977); mechanisms of salt tolerance in nonhalophytes (Greenway and Munns, 1980; Stavarek and Rains, 1983); genetic approach to saline culture of crops (Epstein et al., 1980); and appropriate breeding strategies (Christiansen and Lewis, 1982; Ponnamperuma, 1982; Staples and Toenniessen, 1984).

Considering the fact that the subject has been reviewed at fairly regular intervals, the present attempt is largely confined to the topic of this investigation with a view to highlighting some advances made so far and pointing out certain aspects where critical information is still inadequate.

2.1 Soil salinity and alkalinity effects on crop plants

Excess of soluble salts in soil solution and high exchangeable sodium in soil-complex relevant to plants' rootzone have intense influences on establishment, survival, growth and yield of plants growing in such adverse soil conditions. In fact, agricultural production in many parts of the world is limited by detrimental effects associated with these conditions. In alkali soils, the plant growth is drastically affected mainly because of nutritional imbalances and poor development of root system due to unfavourable physical conditions of the soil. In saline soils, however, a large number of workers have inferred that soluble salts cause reduction in plant growth largely by creating a "physiological drought" (Bernstein, 1962; Strogonov, 1964; Riley, 1969). In general, excessive accumulation of salts in the soil solution may retard or inhibit plant growth by three possible mechanisms of action: (1) osmotic effects, (2) specific ion effects, and (3) nutrient deficiences and imbalances. These mechanisms, however, may not be easily distinguisable and independent of each other (Casey, 1972). Plants make physiological adjustments in

many ways under unfavourable environments and they show remarkable variation in their ability to grow and yield under such adverse soil conditions. Plant variables affecting crop performance in a given stress situation include the genotype, ploidy status, the growth stage exposed to the stress condition, anatomical features, growth habit, maturity characteristics and method of reproduction (Rana, 1977). Allo-polyploid forms have been reported to show remarkable adaptability to extreme environmental conditions, as compared to their diploid progenitors (Jain and Rana, 1963; Stebbins, 1966; Rana,1967; Rana et al., 1980; Lumaret, 1984). In addition to plant variables, numerous soil and climatic factors have been reported to modify plant response to edaphic stress environments.

2.1.1 Vegetative phase response to salinity/sodicity

Germination and early stages of plant growth are more detrimental in saline-sodic conditions as they largely influence the later development, growth and, ultimately, the crop yield. It has been pointed out that salt tolerance in many crop plants could largely be a reflection of salt tolerance during germination (Chapman and Hart, 1977). Notable crop differences in this respect have been reported by Maliwal and Paliwal (1967, 1969); Kanwar and Singh (1968); Raziuddin and Ahmed (1976); Malik et al. (1977); Caro et al.(1978); Hanna et al. (1978); Bole and Wells (1979); Maliwal (1980); Mukhiya et al. (1981); Reddy and Vaidyanath (1982) and Kumar (1984).

Whereas crusting in alkali soil adversely affects seedling emergence, salinity appears to retard the rate of germination more than the total germination (Ayers and Hayward, 1948; Ayers, 1952; Bernstein et al., 1955; Bhumbla and Singh, 1966; Waisel, 1972; Weimberg, 1975; Ray et al. 1977; Ansari et al. 1977; Ramage, 1980; Mukhiya et al. 1981). Miyamoto et al. (1984) found that both emergence and seedling survival rates of guayule were highly and negatively correlated with salinity of surface soil.

Plants grown on saline soils are characterised by slow growth, thick dark foliage, small leaves, and have stunted appearance. Occasionally symptoms such as browning of the tip, leaf mottling, leaf curling and incipient chlorosis were also noted (Black, 1968). Bhivare and Nimbalkar (1984) observed that NaCl lowered chlorophyll content in French beans though an opposite trend was observed with Na_2SO_4. Schwarz and Gale (1984) observed that under salt stress stomatal conductance was lowered leading to a fall in intercellular CO_2 pressure and limiting photosynthesis. They found that CO_2 supplimentation increased plant tolerance to salinity and total drymatter production.

2.1.2 Reproductive phase response

Responses of crops to salinity in terms of yield have been reviewed by Wright (1976), Maas and Hoffman (1977), Christiansen and Lewis (1982) and Staples and Toenniessen (1984) among others. Differential salt

tolerance, as measured in terms of growth and yield, among various crop species, and also within varieties of a species, have been reported by a large number of research workers. After examining the relationships between salinity levels and crop yields in field trials, Franklin (1977) concluded that there was no decrease in crop yields unless there was an appreciable build-up of salt in the soil beyond specific threshold levels.

Growth of barley, as measured by stem height and straw weight, got decreased markedly while sustaining essentially full grain yields under mild saline conditions (Ayers et al., 1952). Pearson (1959) on the other hand, reported that beyond critical salinity levels, rice gave normal straw yields but produced little or no grain. Torres (1973) found that salinity reduced tillering, ear formation, vegetative growth and grain yield in four varieties of Mexican wheat but there were marked inter-varietal differences in this regard. Kishore et al. (1983) observed that flowering was delayed and fruit set percentage depressed in brinjal genotypes with increase in salinity level beyond 6 dS/m.

Gill (1979) studied six barley varieties and found that decrease in grain yield owing to excessive neutral salts (ECe 12.5 dS/m) was accompanied by an increase in the length of the effective grain filling period and a decrease in grain filling efficiency per day.

Apparent salt tolerance has also been reported to vary with the soil fertility level (Ravikovitch and Porath, 1967; Ravikovitch and Yoles, 1971; Maas and Hoffman 1977). Ogo and Morikawai (1965) observed decrease in salt tolerance with excess nitrogen application in case of rice and wheat materials.

Maas and Hoffman (1977) computed relative crop yields as a linear function of ECe of soil for different crops and grouped them into four divisions, viz. sensitive, moderately sensitive, moderately tolerant and tolerant using the following two parameters: (a) the initial salinity threshold level at which the yield reduction became statistically significant, and (b) percent reduction in yield per unit increase in salinity beyond the threshold level. Bresler et al. (1982) suggested measuring the EC of the soil saturation extract as an early warning criterion for predicting crop yield depression as a consequence of rootzone salinity in preference to the visible appearance of toxicity symptoms in plants.

2.1.3 Cytological observations

Organisms adapt to environmental factors employing all the devices available to them and an adaptive effect can be achieved at various levels of organization. Since cells are the structural and functional elements of a multicellular organism, they take part in realization of every adaptation of the latter to the environment (Alexandrov, 1977). Jahnavi et al. (1981) inferred that

the occurrence of meiotic abnormalities in a species, that was normally fertile and productive, indicated the existence of some homeostatic mechanism related to survival.

Gaidamakina (1969) found in barley and sunflower that the disruption of growth in the presence of salinity was linked with a change in the rate of cell division and extension. Reduction in mitotic index of root tip cells caused by salinity has been reported in maize (Lutsenko, 1981) and in barley (Sevast'yanov et al., 1980).

Deficiency of N, P and K was found to induce meiotic abnormalities like early separation, laggards, fragments, bridges in wheat and rice, whereas mitosis in the root tip cells was observed to be normal under the same conditions (Das and Sen, 1976). Sevast'yanov et al. (1980) observed increased frequency of chromosome rearrangements at the meiotic anaphase I and II in barley induced by salinity.

Catarino (1965) found in Lobularia martina that nuclear growth by chromonematic replication was promoted by NaCl and concluded that the increased succulence was a result of endopolyploidy. The electron microscopic studies of Werker et al. (1983) revealed condensation of chromatin in the nuclei of barley root tip epidermal and cortical cells grown in saline medium.

Salinity was also found to suppress protein and nucleic acid synthesis (Nieman, 1965; Davydova, 1981; Gopal and Rao, 1983). However, Tsenov et al. (1983) observed that salinization with NaCl increased the DNA

content and decreased RNA content, mainly of high molecular weight fraction, in pea leaves. Nieman (1965) opined that salinity suppressed cell enlargement and cell division proportionately in beans but it apparently had no effect on regulatory system that terminated DNA synthesis.

Werker et al. (1983) reported increase in ribosome number and appearance of translucent area in slightly swollen mitochondria of barley caused by salinity whereas Alina and Klyshev (1982) reported a decrease in free ribosome number in chloroplasts in pea.

Chuprinina (1977) found that increase in sterility and partially inviable pollen in the anthers of barley was associated with an increase in salinity level. He suggested that salinity affected changes in fluorescence of the archisporial tissues and developing pollen grain were related to the breakdown in the structure of nucleoprotein. Germination of pollen in rice was found to be adversely affected by salinity and resulted in a lower percentage of fertilization of the florets in the panicle (Ota et al. 1956).

Gill and Dutt (1982) observed that salinity (ECe 7.48 to 10.4 dS/m) caused an increase in stomata frequency and decrease in stomata size, particularly on the upper leaf surface of wheat and barley. Kumar (1984) reported in Brassica juncea, that the tolerant cultivars exhibited a higher magnitude of reduction in number of stomata per unit area at the critical salinities (12 dS/m) of irrigation water as compared to the sensitive ones. Aberrations in stomatal characteristics induced by salinity were also reported in groundnut (Saradadevi and Rao, 1980).

2.2 Genetic diversity for salt tolerance

2.2.1 Inter-specific variation

Plants differ widely in salt resistance and this property is not limited to a few plants (Mudie, 1974). The most resistant forms are the obligate halophytes. Flowers et al., (1977) enumerated 94 orders of flowering plants and noted that 38 included halophytic species. Most of the crop plants are glycophytes but there is a wide spectrum of salt resistance among them ranging from a maximum in beet roots to a minimum in carrots (Strogonov, 1964). Among the grain crops, barley was reported to be more resistant than oats and wheat (Ballantyne, 1962). Simonneau and Aubert (1963) studied a large number of crop plants and concluded that the most tolerant ones were datepalm, cotton, lucerne, sweet clover, asparagus, beets, leeks and radish. They also reported that the least tolerant ones were citrus, strawberry and beans. Levitt (1972) opined that the order of resistance might not be the same in all soils as resistance of a given species was not the same for different soils and also for various salts.

2.2.2 Intra specific variation

Depending upon their genetic constitution, genotypes within a species showed distinct tolerance capacities to tolerate varying degrees of environmental stress (Maas and Hoffman, 1977, Epstein et al., 1980). Enormous differences regarding tolerance to soil stresses among varieties and ecotypes within a species have been reported and convincingly

established. Work done at the CSSRI demonstrated significant varietal differences regarding tolerance to salinity and alkalinity conditions in wheat (Rana and Singh, 1976; Sarin et al., 1975; Joshi et al., 1980; Singh et al., 1982; Babu, 1983), rice (Sinha and Dutt, 1974; Dargan et al., 1974; Bhattacharyya, 1976), barley (Chandra, 1976), pearlmillet (Singh, 1979); mustard (Singh et al., 1974) and castor (Singh and Rana, 1981). Kishore et al., (1983) studied effect of salinity in 23 brinjal genotypes and found that varietal differences were significant and persisted at different salinity levels. Rai and Sinha (1976) observed that, in rice, apart from the differential varietal response, differential trait response could also be seen under saline conditions.

Epstein et al. (1979) concluded that within a given crop species, there occurred a very large genetically governed variability with respect to salt tolerance and this might sometimes be as large as that observed between species holding out encouragement to programs of selection and breeding efforts aimed at combining high salt resistance with superior yield.

2.3 Mechanims of salt resistance

Plants make physiological adjustments in various ways under unfavourable environments and they show remarkable variation in their ability to grow and yield under such conditions. Mechanisms of salt tolerance in halophytes, that grow rapidly at high salinity have been reviewed by

Flowers et al. (1977). Mechanisms of tolerance in non-halophytes have also been recently discussed and summarised (Greenway and Munns, 1980).

2.3.1 Avoidance

Plants avoid salt stress using any one of the three methods: (1) they can exclude the salt passively, (2) they can extrude it actively, and (3) they can dilute the entering salt. All the three methods have been reported in various plant species (Levitt, 1980). In case of plants possessing the exclusion mechanism, the cells maintain the normal ionic balance in the presence of high concentrations of monovalent cations by a high, preferential adsorption of Ca^{++} on the plasma membrane. Salt avoidance due to excretion requires a Na extrusion pump that continues to operate in the presence of high external concentration of salt. The dilution type of salt avoidance depends on the succulent mechanism in which thin, plastically extensible cell walls permit cell expansion by a water uptake sufficient to balance every salt increment in the cell (Levitt, 1972, 1980). In case of periodic, cyclin or seasonal stresses, some plants have developed an adaptation called "stress evasion" and they complete their life cycle before the onset of the stress. This adaptation is obviously not a mechanism of salt resistance.

2.3.2 Tolerance

The term 'tolerance' has been used in the literature for any plant possessing salt resistance, simply on the basis of salinity in the external medium. This includes

both tolerance and avoidance. In fact, it is not easy to draw a sharp line between tolerance and avoidance. Greenway (1965) pointed out that, when halophytes and non-halophytes were compared, ion accumulation (tolerance) appeared to be a superior mechanism for growth in saline habitat. In terms of stress terminology, osmotic and nutritional salinity effects were secondary salt induced stresses, while toxic salinity effects were referred to as primary salt injury. Plants combat the dehydration problem of soil salinity by increasing their own internal osmotic potential through the accumulation of organic solutes like sugar, organic acids etc. or by absorbing inorganic salts from the surrounding medium (Epstein, 1972; Rains,1972; Rains and Valentine, 1980). Bernstein and Ayers (1953) reported that the accumulation of metabolites resulted in an increase in sap concentration and in osmotic adjustment, independent of ion uptake, which in turn resulted in growth retardation because it reduced the amount of metabolites available for growth. The primary salt tolerance could be either by excreting the absorbed salt into vacuole or due to tolerance of ion-balance strain, for which protoplasmic organells and their substances would have to possess special properties permitting normal functioning although subjected to an increase in ion concentration and a change in balance (Levitt, 1972, 1980).

According to Kramer (1983), in many plant species, salt tolerance was based on particular transport processes across the plasmalemma and that typical features of transfer

cells could be observed in many cases of adaptation to salt stress suggesting that their function was probably associated with high rates of trans-plasmalema transport.

Osmotic regulation, based on electrolytes, appears probably to be the only way to combine productivity with salt tolerance. Greenway and Munns (1980) concluded that salt sensitivity of some non-halophytes might be due to insufficient uptake of electrolytes for turger pressure or volume maintenance, particularly in the expanding tissues. The key factor seems to be a synchronization of ion compartmentation, i.e., accumulation in the vacuole by the leaf cells with a high rate of ion transport to the shoot.

2.4 Genetics of resistance to salt stress

Salt tolerance in plants has been a topic of keen interest since long and remarkable differences among plant species as well as within species have been noted (Berg, 1950; Ayers et al., 1951; Bernstein and Ayers, 1953; Richards, 1954; Dudley and Powers, 1960; Ehling, 1960; Dewey, 1962; Greenway, 1962; Elzam and Epstein, 1969; Ayoub, 1974; Taylor et al., 1975; Rush and Epstein, 1976; Epstein and Noryln, 1977; Lauchi and Wieneke, 1977; Ratanadilok et al., 1978; Kramer, 1983; Sajjad, 1983; Stavarek and Rains, 1983; Yeo, 1983; Mesdag and Balkema-Boomstra, 1984). It is surprising, however, that information on inheritance of exploitable plant mechanisms confiring specific tolerance is conspicuously limited (Rana et al.,1980).

For formulating appropriate breeding strategy, on the other hand, determination of genetic mechanisms controlling particular edaphic response is of utmost importance.

Bernstein (1977) concluded that absorption of chloride and sodium ions in crop plants appeared to be under the control of single genes but osmotic effects appeared to be complex and under multigenic control. Ratanadilok et al. (1978) studied the inheritance of salt tolerance in sorghum during germination and seedling growth and inferred that salt tolerance was controlled by complementary gene action, incomplete dominance and dominance or additive effects of several genes.

According to Gorslive et al. (1968), the accumulation of Ca and strontium in corn leaves was controlled by two or three genes acting in an additive manner. Prabhakarashetty et al. (1978) studied a series of MR rice varieties, derived from Karekagga x IR8 cross, and concluded that MR series inherited their tolerance to salinity from their maternal parent Karekagga. Mahadevappa et al. (1981) observed that most of the alkali tolerant rice varieties were tolerant to zinc deficiency and zinc deficiency was under polygenic control showing continuous variation. Abel (1964) reported a major gene pair in soybean, NCl ncl, controlling chloride exclusion from plant tops. Chloride exclusion was found to be completely dominant.

In a diallele experiment involving two salt tolerant, two moderate and two susceptible rice varieties,

Moeljopawiro and Ikehashi (1981) observed that both general and specific combining abilities were significant. They further reported over dominance for salt tolerance in a cross between two salt tolerant cultivars of rice. The heritability of the accumulation of Mg, Ca, K, P and the ratio of K:(Ca + Mg) in Tall Fescue grass (Pestuca arundinacia) was studied by Sleper et al. (1977) using two diallel mating sets. They found that general combining ability was more important than specific combining ability while heritability values indicated that breeding for higher mineral levels should be effective. Campbell and Lafever (1979, 1981) studied heritability and gene effects of aluminium tolerance in wheat and found the genetic control of aluminium tolerance to be complex. Genetic variation among the F_1s was observed to be mostly additive and heritability estimates were high.

Several reviews have been published on genetic control and differential responses of plants to mineral elements and edaphic stress (Brown, 1963; Epstein, 1963; Epstein and Jefferies, 1964; Epstein, 1972; Foy, 1974; Wright, 1976; Foy et al., 1978; Clark and Brown, 1980). Available information suggests that genetic improvement of crop plants for tolerance to mineral stress, salinity, alkalinity and low pH conditions appears to be worthwhile (Reid, 1971;1976; Devine, 1976; Christiansen and Lewis, 1982; Staples and Toenniessen, 1984).

2.5 Screening methods for salt tolerance

A myriad of experimental procedures have been used by different workers for determining salt tolerance of crop plants. Crop salt tolerance has usually been expressed as the yield decrease expected for a given level of soluble salts in root medium as compared with yield under non-saline conditions (Berg, 1950; USDA, 1954; Allision, 1964; Bernstein, 1964; deForges, 1970; Bernstein, 1974). Maas and Hoffman (1977) concluded that absolute tolerance that reflects predictable inherent physiological responses by plants could not be determined as many interactions among plant, soil, water and other environmental factors influenced the plants' ability to tolerate salts.

Protoplasmic salt tolerance was considered as a reliable test for salt tolerance in agricultural plants (Gertrand et al., 1959; Repp et al., 1959). Staining with Evan's blue solution after exposure of plant cells to solutions of high salt concentrations was suggested for testing the survival of plant cells in high salinity or osmotic stress by Talyor and West (1980).

Jones (1979) used rate of labelled CO_2 uptake by leaf discs in NaCl solution as a means to screen rice varieties for salt tolerance. Leaf sodium concentration was used as an index of salt tolerance in tomatos by Rush and Epstein(1980). A non-destructive method suggested by Smile and Nott (1982) used the measurement of chlorophyll fluoresence of leaf disc.

Janardhan and Murthy (1970) studied the pattern of injury on successive leaves of rice seedlings whereas Fageria et al. (1981) calculated the percent of dead leaves after four weeks of transplanting to evaluate tolerance of rice varieties to salinity.

Jones and Stenhouse (1983) suggested a method for rapidly evaluating rice varieties by compairing seedling root growth in salinized and non-salinized culture solutions. In this method, salinity tolerance was calculated as the tolerance ratio of root growth after four days in salt solution to the root growth after four days in non-saline solution.

Reddy and Vaidyanath (1982) suggested simple parameters like germination percent and early seedling growth characteristics to identify salt tolerance in rice varieties. Gill and Dutt (1979) observed, however, that germination percentage was not always found to be linearly related to salt level and opined that the slope of regression line was a better criterion for evaluating salt tolerance as it took the entire spectrum of response curve into consideration. Atanasiu and Thiagalingam (1978) used change in relative germination rate, plant height and drymatter to evaluate salt tolerance in rice.

Maurya et al. (1976) studied varietal tolerance in paddy to saline-alkali soils with a group of 36 indica varieties including tall types and semidwarfs belonging to three maturity groups. Variety IR 8 (medium duration)

was found to be the most tolerant on the basis of grain yield *per se*. IR 20 and Pokkali (both late), FH118(early) and IR8 and Padma (medium duration) were, however, more tolerant on the basis of grain yield reduction while IR20, Krishna (early), IR8, Jaya, FH109 (early) and Vijaya (late) were found to be more tolerant on survival basis. Variety IR8 turned out to be the most tolerant when all the three parameters were considered together.

Jones and Wilkins (1984) developed a rapid generation advance method to screen rice varieties and crosses by artificially inducing flowering and found that the mean salt tolerance of all varieties and crosses increased with each generation.

Mishra and Bhattacharyya (1980) suggested that rice varieties should be screened for tolerance to sodicity under the soil ESP of 73 since tolerant varieties showed less than 50% reduction at this level with respect to grain yield and other yield contributing characters.

Richards (1983) argued that because most of the yield from saline soils which were typically very patchy in their salinity, came from the least saline areas, the best breeding strategy for improving the overall yield of crops growing on them was to select for high yield on non-saline soils. This conclusion was derived from comparing the effects on total yield of four different breeding goals, viz. (i) a 10% increase in yield on non-saline soils, (ii) a 20% increase in the threshold salinity that first reduced yield, (iii) a doubling of yield at an ECe 20 dS/m, and (iv) a combination of (i) and (ii) approaches.

Udovenko (1981) opined that characters such as tillering response to salinity, the ratio of coefficient of variation of grains per ear to 1000 grain weight and correlation between plant resistance and the duration of sowing to seedling period on saline medium could possibly be used as markers in determining the degree of salt tolerance of cultivars and individual plants.

2.6 Response of rice materials to soil salinity and alkalinity

Growing resistant crop varieties in soils affected by salinity or sodicity is an important step for ensuring some productivity and simultaneously initiating land reclamation processes even in the absence of soil amendments. Rice is considered to be the best crop suited to salt affected soils (Pearson and Ayers, 1960; Swaminathan, 1984) and for low alkali soils (Rana, 1976; Verma et al., 1983). Rice plant is highly adaptable to varying environmental conditions. It is grown in north-eastern China at a laltitude of 53°N and also in New South Wales, Australia (35°S). In India, it is cultivated in Kerala, below sea level and also in Kashmir above 2000 M. It can grow in upland conditions as well as in 1.5 to 5 M deep waters (Yoshida, 1981).

Rice is generally reported as a moderately salt-tolerant crop but no rice variety is reported to withstand high salinity throughout its growth cycle and no rice is grown as a dryland crop in salt-affected land. Many authors have reported that the tolerance of rice varies throughout its life cycle (Pearson, 1959; Pearson and Bernstein, 1959; Pearson and Ayers, 1960; Castyo and Sabade, 1977).

2.6.1 Seed germination and seedling response

Germination of rice seeds has been reported to be normal upto ECe 4.5 dS/m (Narale et al., 1969) but higher salt concentrations cause delay in germination (Kaddah,1963; Patolia and Iyengar, 1979; Krishna and Iyengar, 1980; Reddy and Vaidyanath, 1982) and reduction in percent germination (Pearson et al., 1966; Naralae et al., 1969; Rao et al., 1973; Paliwal and Gandhi, 1975; Subromanian, 1979; Datta and Pradhan, 1981; Reddy and Vaidyanath, 1982). According to Pearson et al., (1966) 50 percent reduction in rice seed germination was observed at EC value of 21.2 to 30.5 dS/m.

Varietal differences in germination response to salinity were observed by Rao et al., (1973); Krishna and Iyengar (1980), Datta and Pradhan (1981). Gill and Dutt(1979) found that germination percentage of rice varieties was not always linearly related to salt level. The germination of a particular variety under saline conditions was a complex phenomenon depending upon osmotic concentration and individual salt species (Rao et al., 1969).

Seeds obtained from photoperiod - sensitive winter rice varieties grown in saline plots were found to be poorer in viability retention and lost viability after four months whereas retention of 90 percent germination capacity for more than seven months was noticed in seeds from non-saline plots by Datta and De (1982).

Eventhough rice crop was most tolerant to salinity during germination, young seedlings were found to be highly sensitive (Pearson, 1959; Kaddah, 1963; Pearson et al.,1966; CRRI, 1980). Hence Pearson et al. (1966) concluded that the ability of rice seed to germinate at high salinity values was of no practical significance.

Reduction in seedling height, plumule and radicle length was observed in rice varieties when they were germinated in saline water (Krishna and Iyengar, 1980). Datta and Pradhan (1981) found that root growth was depressed more than shoot growth.

In seedling experiments, irrigation with sea water (0.2% NaCl) at fourth leaf stage showed two patterns of leaf injury. Janardhan and Murthy (1970) found that leaf injury was restricted to older leaves in known tolerant types whereas it was observed even on the young and actively growing leaves in case of susceptible types.

Baser and Gilmour (1982) reported that the salinity damage to rice seedlings was related to soil electrical conductivity and salt source with chloride and nitrate salts being much more toxic than sulphate salts.

Kaddah (1963) concluded that eventhough rice varieties differed in their tolerance to salts at the seedling stage, the order of tolerance might not agree with the known varietal order for grain production when salinity was introduced after the seedling stage.

2.6.2 Growth and yield response

After the first sensitive period at first to second leaf stage, the salt tolerance of rice was found to

increase during the tillering stage (CRRI, 1980), but a second peak of susceptibility occurred at flowering stage (Pearson and Bernstein, 1959; CRRI, 1980).

Growth (Narlae, 1969; Datta, 1972), dry matter production (Janardhan et al., 1976) and yield (Datta, 1972; Lam and McLean, 1979) were found to be drastically reduced by salinity in rice. Sajjad (1983) observed that effect of salinity was greater on yield than on panicle fertility. Verma and Neue (1984) observed that the yield and yield contributing characters decreased significantly with an increase in soil salinity level and zinc application increased the yield of variety IR28. Fakhry (1961) reported that the response was directly related to the duration of exposure to salinity.

High alkalinity (SAR-Na absorption ratio) in irrigation water depressed growth, drymatter production, chlorophyll content and the activity of Fe enzymes, catalase and peroxidase (Agarwala and Mehrotra, 1978). Under sodic soil, delay in maturity was observed in rice by Singh and Sharma (1984) and they further observed that the mean pH of the sodic soil decreased because of rice cultivation. Mishra and Bhattacharyya (1980) reported that the reduction percentage of all characters studied increased with the increase of ESP level, irrespective of varieties and further they noted that the salt tolerant rice varieties were also found to be highly tolerant to sodic conditions.

Datta and Som (1973, 1981) reported that salinity considerably reduced the thickness of internode, diameter of lumen, air sacs, cortical cells, thickness of cortex,

diameter of vasular bundles and metaxylem of rice stem. Anatomically clear differences between physical (drought) and physiological (salinity) drought were described by them and suggested that there existed an opposite relationship between xylem and phloem under salinity and drought in rice.

2.6.3 Mechanism of salt tolerance in rice

The major reason that rice is grown on saline land, where virtually no other crop would grow, is the aquatic nature of the crop (Moorman and van Breeman, 1978). Rice has an efficient system of air passage from shoot to root that makes it adaptable to a wide range of environmental conditions (Swaminathan, 1984). The ability of rice crop to withstand adverse environmental conditions could be explained, and also manipulated, by biochemical processes (CRRI, 1980). Mercado (1978) reported physiological osmotic adjustment in rice to regulate ion uptake at higher NaCl concentration. Lower uptake of sodium in salt resistant rice varieties Getu and SR26B suggested the possible existance of a sodium ion exclusion mechanism in rice (Janardhan et al., 1976). Contrary to this, Kannan (1978) reported that salt tolerant rice variety PVR-1 accumulated significantly higher amounts of sodium than the salt sensitive variety and that showed the halophytic feature of the variety PVR-1.

Rathert (1983) studied interaction of ion-regulation and carbohydrate metabolism in response to varietal salt tolerance in rice varieties and inferred that the differences

within the carbohydrate metabolism contributed to the metabolic tolerance of rice varieties when grown in saline environment.

Differences in internal distribution are physiologically significant aspects of salinity resistance. According to Yeo and Flowers (1982), preferential distribution of sodium ions into older leaves, resulting in a gradient of sodium content, permitted rice plants to maintain atleast some young leaves with sublethal salt content.

Changes in initial sodium uptake, chlorophyll breakdown and activity of malate dehydrogenase as well as nitrate reductase enzymes in nine rice varieties were studied by Yeo and Flowers (1983) who concluded that eventhough initial sodium uptake had predictive value for salinity resistance in rice varieties, there were other characters which were masked by excess salt entry and no single factor appeared to confer salt resistance.

Janardhan and Murthy (1970) found that higher moisture content of the leaf tissue and lower chloride concentration in the seedlings were associated with lower injury rate of leaves in salt tolerant rice varieties. According to Quadar *et al.* (1980) pretreatment of rice seedlings with salts such as $CaCl_2$ and $Ca(NO_3)_2$, which resulted in better plant growth in saline conditions might have helped in the accumulation of Ca in root cells enabling them to maintain their permeability delaying thereby, and also reducing, the accumulation of Na in the plant.

To sum up, there have been both extensive as well as intensive research efforts in recent years to study and analyse genetic variation in plant tolerance/adaptation to soil stresses. Contradicting reports on response functions of many crops have been noted and it seems that these differences were largely owing to the fact that variables, including plant as well as soil and climatic factors, affecting plant response were not properly taken care of. Vital information on genetic analysis of inter-varietal differences regarding salt resistance and stability of varietal performance over a wide range of sub-optimal environments is either entirely lacking or is inadequate for formulating appropriate breeding strategy and methodology needed for developing improved crop varieties best suited to specific situations of salt-affected soils. For combining high yield potential and superior salt-tolerance, it is indeed necessary to evaluate more critically the varietal responses to precisely defined edaphic stresses and also to understand genetic mechanisms governing salt tolerance. In this context, phenotypic and cytogenetic study of crop varieties, still grown traditionally in different salt-affected areas, assumes special significance for understanding not only the adaptive features of these valuable genotypes but also the evolutionary development of processes of adaptation that have enabled them to grow and yield over long periods under such unfavourable edaphic environments with little management care.

MATERIALS AND METHODS

The present investigation comprised of a series of inter-related experiments that were conducted on rice materials grown in petriplates, pots and also in specially designed stress-plots. Studies were carried out at the Central Soil Salinity Research Institute, Karnal (latitude 29°43'N, longitude 76°58'E, altitude 245 m above mean sea level) during the wet season (kharif) of years 1981 and 1982. Monthwise meteorological data are given in Appendix I for the relevant crop seasons.

3.1 Experimental materials

Fifty five varieties of rice, representing a wide spectrum of variability with respect to geographical origin, plant height, growth pattern, maturity, grain characteristics and yielding ability, formed the materials for different studies. These genotypes are listed and briefly described in Appendix II. Based on the information obtained from a pilot study conducted on these materials 39 varieties were selected and evaluated critically for their response to soil salinity and alkalinity in two successive seasons. In addition, eighteen indigenous locally-adapted varieties were also studied for their comparative phenology and cytogenetic characteristics.

3.2 Experimental methods

3.2.1 Response evaluation in laboratory tests

Varietal response to salt stress, based on response of seed germination and seedling growth was evaluated by

conducting experiments in petriplates kept in the laboratory under controlled and comparable conditions.

3.2.1.1 Seed germination and seedling response to salinity

With a view to studying varietal response to salinity during seed germination and young seedling stage effects of two treatments (tap water, acting as the control and a solution of 1% NaCl) were compared with three replications. Twenty five seeds of each of the 25 rice varieties, selected, for this study, were placed in petriplates lined with blotting paper made wet with tap water in one set and with salt solution (1% NaCl) in the other set. The seeds were earlier treated with 0.1% mercuric chloride to avoid fungal contamination. The experiment was conducted at an average room temperature of 25 ± 2°C with 12 hours lighting arrangement and observations were recorded on the following three parameters:

i) Seed germination (%)

ii) Seed germination rate index, and

iii) Fresh seedling weight (mgs) at the end of the experiment

3.2.1.2 Comparative study of seed materials harvested from plants grown in favourable and unfavourable soil environments

Another experiment was conducted using the seeds harvested from different varieties grown in favourable, alkali and saline soil environments to study the effects of these growth conditions on seeds as reflected in germination and seedling vigour. Seeds of each variety, obtained from three environments were kept in petriplates lined with blotting paper made wet with tap water. Temperature

and lighting arrangements were maintained as described in the previous experiment. Data were recorded on seed germination (%) and seedling height (cms).

3.2.2 Response evaluation in stress plots

During the kharif season of 1981, all the selected fifty five varieties were sown in test-plots under soil conditions (pH_2 8.3 and ECe 1.2 dS/m). One month old seedlings were transplanted in the test plots under favourable (pH_2 8.3 ECe 1.2 dS/m), alkali (pH_2 9.3 to 9.00) and saline (ECe 6.2 to 8.5 dS/m) environments. The experimental lay out was a randomized block-design with four replications. Transplanting was done with a hill to hill spacing of 20 cms in a row and an inter-row spacing of 30 cms. One row, measuring three meters length was allotted per genotype at random. Border rows were planted all around the plot to avoid border effect. Recommended agronomic practices, including application of fertilizers and plant protection measures were adopted. Salinity and alkalinity levels were periodically monitored during the entire course of study and salt treatments were given wherever necessary in order to maintain the desired stress levels. The experiment was repeated in 1982 kharif season with 39 varieties which were selected from the 55 varieties studied during the 1981 kharif season by excluding strongly photo-sensitive genotypes.

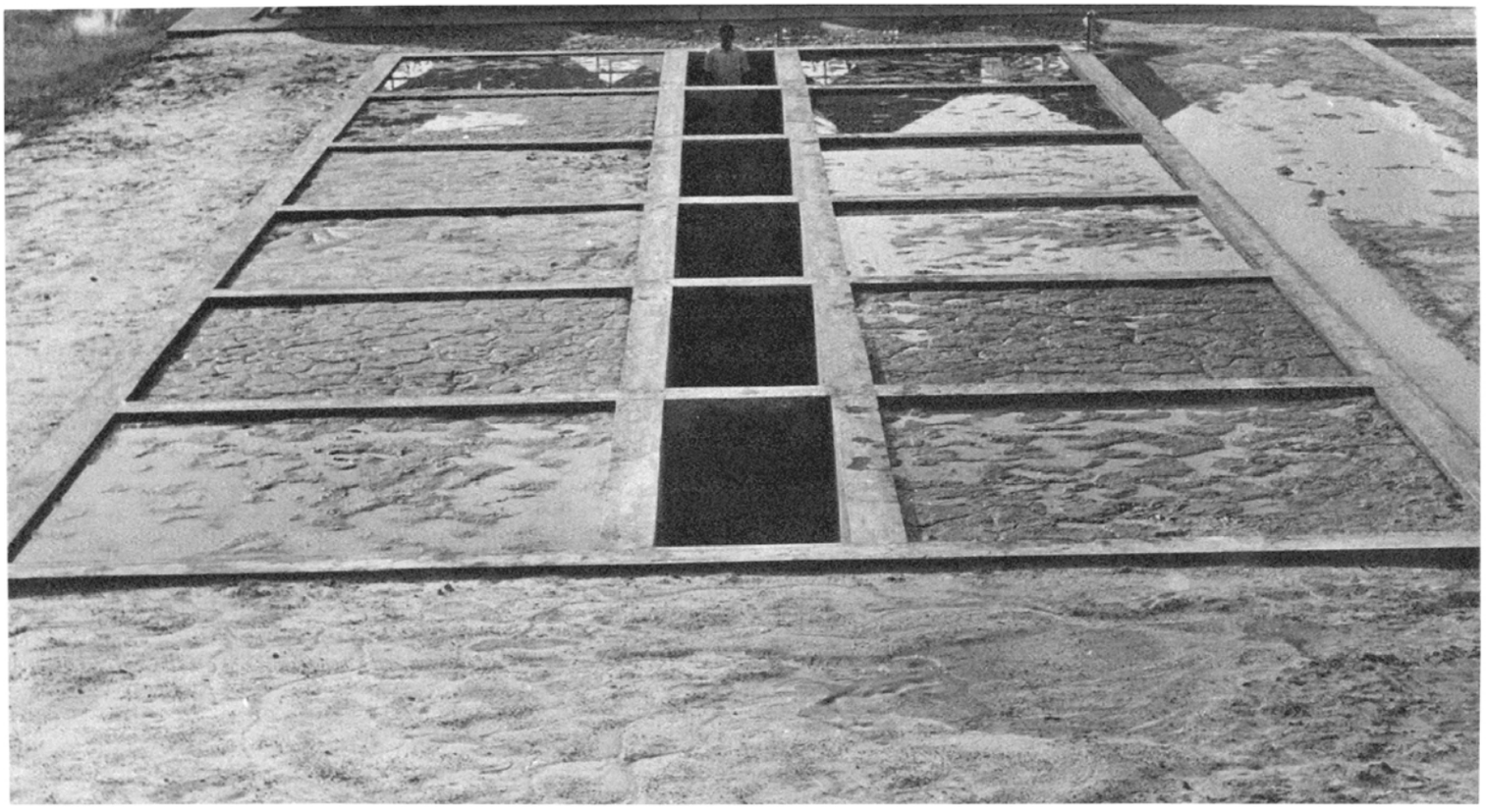
The following characters were studied during this experiment:

(1) Days to 50% flowering

(2) Plant height (cms)

Figure 2 A view of the screening plots developed for evaluation of plant response to alkali and saline soils

Figure 3 A comparative view of differential response of rice varieties to salinity stress




CR 215
CR 214
KALINGAT
DAMODAR
GETU
TR 17
IR 2053
M 148
PANKAJ
JAYA
EC 8

(3) Length of the panicle (cms)

(4) Panicle bearing tillers per hill

(5) Main panicle dry weight (gms)

(6) Straw weight per hill (gms)

(7) 1000 grain weight (gms)

(8) Harvest index

(9) Grain yield per hill (gms)

For every entry, four hills, comprising of two plants each, were taken at random from every replication and tagged for recording detailed observations.

3.2.3 Cytological observations

Ten indigenous rice varieties, cultivated traditionally in salt-affected areas and adapted to specific stress situations, were grown in glazed porcelain pots containing either favourable (pH_2 8.2, ECe 1.5 dS/m) or alkali (pH_2 9.2) or saline (ECe 8.0 dS/m) soil. These materials were used for a cytological study of differentiation, if any, among these locally adapted cultivars. Observations were recorded on the following characteristics:

3.2.3.1 Meiotic process

Young panicles of appropriate growth stage were fixed in freshly prepared Acetic-Alcohol solution (1 part glacial acetic acid and 3 parts absolute ethyl alcohol) for 48 hours. The fixative was changed once after 24 hours. Thereafter, the fixative was drained out materials were stored in 70% alcohol at low temperature ($\sim$ 5°C).

Meiotic preparations were made following standard smear technique using 2% acetocarmine stain. Observations were made as described below:

3.2.3.1.1 Chiasma frequency: Data on number of chiasmata, visible on every bivalent, were recorded critically at the diakinesis stage from ten well spread pollen mother cells (PMC) of ten indigenous cultivars in respect of three environments. Comparative observations on the number of chiasmata per cell were used to study varietal differentiation as well as response of this character to different edaphic environments.

3.2.3.1.2 Anaphase abnormalities: About fifty pollen mother cells in anaphase stage were screened for each entry for gross abnormalities like precocious or late separation of bivalents, formation of bridges, irregular distribution of chromosomes, presence of laggards and chromosome fragments etc.

3.2.3.2 Pollen fertility (viability)

This was judged on the basis of a stainability test using acetocarmine. Undehised mature anthers were tapped in 1:1 glycerol-acetocarmine (2%) and kept overnight for staining. The fully stained, properly developed and well-filled pollen grains were counted as fertile. Unstained, partially stained and poorly developed pollen grains were taken as sterile. Pollen fertility was expressed as percentage of fertile in relation to total number of pollen grains examined for this purpose.

3.2.3.3 Pollen size

Diameter of pollen grains, including the exine, was measured in microns using a calibrated optical micrometer. Materials prepared for the pollen stainability test were used for these measurements.

3.2.3.4 Stomata frequency and size

Stomatal characteristics were studied from carefully prepared replicas of the lower leaf surface by using a 10% thermocole-xylene solution. A thin layer of this solution was applied on the lower side of fully developed leaves of different rice varieties grown under comparable conditions. Following the evaporation of xylene a transparent thermocole film was left on the leaf surface. This thermocole layer was peeled off and mounted in water on thin glass slides which were examined under the microscope for recording frequency of stomata. For a comparison of stomatal size, the slit length of the stomata was measured with the help of a micrometer.

3.3 Recording of experimental data

Procedure adopted for recording observations on different characters is described as follows:

(1) Seed germination percentage

Germination counts were recorded every day until there was no further increase in counts for three successive days. The seed germination was expressed as percentage of germinated seeds in relation to the number of seeds sown.

(2) Seed germination index

Seed germination index (SGI) was calculated following the method described by Maguire (1962). Number of germinated

seeds on a particular day was divided by the number of days following the time when the seeds were initially laid out for germination. The values so obtained at each count were then summed up at the end of the germination test to obtain the SGI values.

(3) Seedling height

Seedling height was recorded in centimeters on the tenth day from the date of sowing.

(4) Seedling fresh weight

Blotted dry seedlings were used for recording their fresh weight immediately on concluding the experiment using an electric balance.

(5) Days to 50% flowering

This was recorded as the days taken from the date of sowing to the day when 50% of the plants flowered in each replication.

(6) Plant height

This was recorded in four mature plants, taken at random, measuring from the base of stem to the base of panicle.

(7) Length of the panicle

Panicle length was measured in centimeters from the base of the panicle to its tip excluding awns, using main tillers of four plants taken at random.

(8) Panicle bearing tillers per hill (PBT)

Number of panicle bearing tillers per hill (i.e., two plants) was counted just before harvesting at four randomly taken hills in each varietal row under all replications.

(9) Panicle dry weight

Panicles of four main tillers, taken at random, collected separately and weighed after drying in an oven to constant weight.

(10) Straw weight per hill

Shoots of individual hills (i.e. two plants) were harvested separately, by cutting very close to the ground and dried in an oven at 80°C after removing the panicles. Dry weight was then recorded using an electric balance.

(11) 1000 grain weight

From the grain yield of individual hills, one thousand grains were counted at random and weighed using an electric balance.

(12) Harvest index

It was expressed as the ratio of grain yield to the total biological yield (straw weight + total grain weight) per hill.

(13) Grain yield per hill

Total grain yield (husked) was recorded at four hills, taken at random and comprising of two plants each, in every replication.

3.4 Statistical analysis

The experimental data on different characters recorded in various experiments were subjected to the following statistical analyses:

3.4.1 Analysis of variance

Genotypic differences among the varieties under study were tested separately for each of the six environments

using randomized block design as follows:

$$Y_{ij} = m + G_i + b_j + e_{ij}$$

where

Y_{ij} = observation in the i^{th} treatment and j^{th} block

m = general mean

G_i = effect of i^{th} treatment

b_j = effect of j^{th} block, and

e_{ij} = random error associated with i^{th} treatment and j^{th} block

Variance components were split up, as shown below, for all the traits under study.

Analysis of variance

Source of variation	d.f.	Mean squares	Expected mean squares
Blocks	b - 1	M_b	$\sigma_e^2 + t\ \sigma_b^2$
Treatments	t - 1	M_t	$\sigma_e^2 + b\ \sigma_t^2$
Error	(b-1)(t-1)	M_e	σ_e^2

where

b = number of blocks

t = number of treatments

M_b = mean sum of squares due to blocks

M_t = mean sum of squares due to treatments (genotypes)

M_e = mean sum of squares due to error

The treatment mean squares (M_t) were tested against error mean squares (M_e), at $n_1 = (t - 1)$ and $n_2 = (t-1)(b-1)$ degrees of freedom.

3.4.1.1 Estimation of mean value and standard error

Mean values were calculated as replication average for each treatment separately.

The standard error of mean (SEM) was calculated as follows:

$$\text{Standard error of mean} = \sqrt{\frac{\sigma_e^2}{r}}$$

where σ_e^2 is error variance

r is number of replications

The critical difference between any two means was calculated as under:

Critical difference (CD) = t error d.f. X SEM X $\sqrt{2}$

3.4.2 Analysis of Phenotypic Stability

Stability of performance is one of the desirable properties of a genotype to be released as a variety for wide cultivation. Eberhart and Russell (1966) model was used for the estimation of phenotypic stability of different characters. For this purpose, unilocation trials over two seasons in different environments (favourable, alkali and saline soils) were conducted.

It may be briefly stated here that Finley and Wilkinson (1963) developed a technique, for analysing the stability and adaptation of individual genotypes, which involves regression of yield of each variety on an index of the yield potential of that environment. They proposed two parameters for judging the phenotypic stability and adaptation of a genotype over a range of environmental conditions:

i) mean yield over all environments, and

ii) regression coefficient related to environmental index.

Eberhart and Russell (1966) further refined the above mentioned approach and proposed an additional stability parameter, namely, deviation from linear regression. The genetical model defining these parameters is as follows:

$$Y_{ij} = \mu_i + B_i I_j + \delta_{ij}$$

where

Y_{ij} = mean of the i^{th} variety at j^{th} environment

μ_i = mean of i^{th} variety overall environments,

B_i = regression coefficient of i^{th} variety on environmental index which measures the response of this variety to varying environments.

I_j = environmental index which is defined as the deviation of the mean of all the varieties, at a given location or environment, from the overall mean.

δ_{ij} = deviation from regression of the i^{th} variety at j^{th} environment.

Environmental index is calculated as follows:

$$I_j = \left[\sum_i Y_{ij}/\ G\right] - \left[\sum_i \sum_j Y_{ij}/\ (G)\ (E)\right]$$

$$\text{and} \sum I_j = 0$$

where

G = Total number of genotypes

E = Total number of environments

This model for stability analysis partitions the genotype x environment (G x E) interaction for each variety into two parts, viz. (i) the variation due to response of the variety to varying environmental index (sum of squares due to regression) and (ii) the unexplainable deviation from the linear regression.

3.4.2.1 Analysis of variance

Observed variation for different traits was analysed as follows:

ANOVA

Source	d.f.	Sum of Squares	Mean S.S.
Replications (R)	(R-1)		MR
Genotypes (G)	(G-1)	$\frac{1}{E}\sum_j Y_i^2 - (\sum_i \sum_j Y_{ij})^2$	MG(M S_1)
Environments (linear)	1	$\frac{1}{G}(\sum_j Y_{ij} I_j)^2 / \sum_j I_j^2$	M'E
GxE(linear)	G(E-1)	$\sum_i (\sum_i Y_{ij} I_j)^2 / \sum_i I_j^2$ - Env.	M'GxE(MS_2)
Pooled deviation	G(E-2)	$\sum_i \sum_j \sigma_{ij}^2$	MD(MS_3)
Pooled error	E(R-1)(G-1)		M'_e (σ_e^2)

Where

G = Number of genotypes

E = Number of environments

R = Number of replications

MR = Mean sum of squares due to replications

MG = Mean sum of squares due to genotypes

M'E = Mean sum of squares due to environments

M'GxE = Mean sum of squares due to GxE (linear) interaction

MD = Mean sum of squares due to pooled deviation

M'_e = Mean sum of squares due to pooled error

Genotype x environment interaction (linear) measures the differences among the regression coefficients of the different individuals. Deviation mean square results from unexplainable deviation from the regression as the environmental index.

3.4.2.2 'F' test of significance

Significance of difference among genotypic means was tested using 'F' test as follows:

$$F = \frac{MG}{MD}$$

The hypothesis that there are no genetic difference among varieties for their regression on the environmental index, was tested by the 'F' test as given below:

$$F = \frac{M'G \times E}{MD}$$

The appropriate test of deviation from regression for each variety was obtained as under:

$$F = \left[\left(\sum_j \sigma_{ij}^2 \right) / (E-2) \right] \Big/ \text{Pooled error}$$

After testing the significance of differences among the varieties for their phenotypic stability over the environments, the three stability parameters, viz., (i) mean value over all environments, (ii) regression coefficient, and (iii) deviation from linear regression, were calculated for each of the genotype under study.

3.4.2.3 Mean value over all the environments

Mean value of a genotype over all environments ($\bar{Y}_i$) was calculated from the means of that particular genotype over all the environments.

Thus, $\bar{Y}_i = \sum_j Y_{ij} / E$

3.4.2.4 Regression coefficient

Regression coefficient (b_i) was estimated as follows:

$$b_i = \sum_j Y_{ij} I_j / \sum_j I_j^2$$

Standard error of b_i for testing the significance of individual b_i was calculated as given below:

$$SE(b_i) = \sum_j \frac{\sigma_{ij}^2}{R-2} / \sum_j I_j^2$$

3.4.2.5 Deviation from linear regression

The third parameter, that is, deviation from linear regression ($\bar{S}_{di}^2$) was estimated as follows:

$$\bar{S}_{di}^2 = \left[\left(\sum_j \sigma_{ij}^2 \right) / (E-2) \right] - (S_e^2/R)$$

Where, (S_e^2/R) = estimate of pooled error

$$\sum_j \sigma_{ij}^2 = \left[\sum_j Y_{ij}^2 - \frac{Y_i^2}{E} \right] - \left[\sum_j Y_{ij} I_j^2 \right] / \sum_j I_j^2$$

The significance of individual $\bar{s}_{di}^2$ was tested by an appropriate 'F' test as shown below:

$$F = \left[\left(\sum_j \sigma_{ij}^2 \right) / (E-2) / s_e^2 \right]$$

for (E-2) and E(R-1)(G-1) degrees of freedom.

3.4.3 Correlation studies

Correlation coefficient (r), the measure of relationshi between any two traits or variables, was calculated as follows:

$$r_{xy} = \frac{\text{Cov}(x.y)}{\sqrt{\text{Var}(x).\text{Var}.(y)}}$$

Where r_{xy} = Correlation coefficient of x on y

Cov(xy)= Covariance of character x and character y

Var(x)= Variance of character x

Var(y)= Variance of character y

3.4.3.1 Genotypic and phenotypic correlations

Genotypic and phenotypic correlation coefficients between different pairs of characters were computed by the method described by Robinson et al. (1951).

The two variance-covariance matrices necessary for calculating genotypic and phenotypic correlation coefficient were obtained from the mean sum of squares and sum of products of variances and of the error for different characters measured in replicated experiments.

Analysis of variance for all the characters under study in all the environments was conducted as follows:

Source	df	MSS	Expected mean square
Replications	(r-1)	Mr_{11}	σ^2_{e11} $+t\ \sigma^2_{r\ 11}$
Treatments	(t-1)	Mt_{11}	$\sigma_e{}^2{}_{11}$ $+r\ \sigma_g{}^2{}_{11}$
Error	(r-1)(t-1)	Me_{11}	$\sigma_e{}^2{}_{11}$ +

Where

r = number of replications

t = number of treatments

σ^2_{g11} = genotypic variance of character x_1 and

σ^2_{e11} = environmental variance of character x_1

The genotypic and phenotypic covariances were calculated as follows:

$$\sigma_{g_1 g_2} = \frac{Mt_{12} - Me_{12}}{r}$$

$$\sigma_{P_1 P_2} = \sigma_{g_1 g_2} + Me_{12}$$

Where, Mt_{12} and Me_{12} are the mean sum of products due to treatments and due to error from analysis of covariances between character x_1 and character x_2, respectively and

$\sigma_{P_1P_2}$, the phenotypic covariance of character x_1 and character x_2.

Correlation coefficients were calculated for different environments separately. The formulae applied are:

$$\text{Phenotypic correlation } r_{12}(P) = \frac{\sigma_{P_1P_2}}{\sqrt{\sigma^2_{P11} \times \sigma^2_{P22}}}$$

and

$$\text{genotypic correlation } r_{12}(G) = \frac{\sigma_{g_1g_2}}{\sqrt{\sigma^2_{g11} \times \sigma^2_{g22}}}$$

Where

$\sigma_{P_1P_2}$ = Phenotypic covariance between characters x_1 and x_2

σ^2_{P11} = Phenotypic variance of character x_1

σ^2_{P22} = Phenotypic variance of character x_2

$\sigma_{g_1g_2}$ = genotypic covariance between character x_1 and x_2

σ^2_{g11} = genotypic variance of character x_1

σ^2_{g22} = genotypic variance of character x_2

Correlation coefficients were compared against 'r' values given by Fisher and Yates (1953) at t-2 degrees of freedom both at 5% and 1% probability levels of significance.

3.4.4 Path analysis

It is more meaningful and useful to represent the whole system of variables in the form of a path diagram when the cause and the effect relationship is well defined. Hence, the direct and indirect effects of various characters to grain yield at genotypic and phenotypic levels were calculated with the help of the following simultaneous equations of correlation coefficient at genotypic level as described by Dewey and Lu (1959);

$$r(x_1y) = a + r(x_1x_2)\,b + r(x_1x_3)\,c + \text{----} + r(x_1x_n)\,k$$

$$r(x_2y) = a.r.(x_2x_1) + b + r(x_2x_3)\,c + \text{----} + r(x_2x_n)\,k$$

$$r(x_3y) = a.r.(x_3x_1) + r(x_3x_2)\,b + c + \text{----} + r(x_3x_n)\,k$$

$$r(x_ny) = a.r.(x_nx_1) + r(x_nx_2)\,b + r(x_nx_3)\,c + \text{--} + k$$

Where

$x_1, x_2, x_3, \text{-------}, x_n$ are various characters

y = grain yield

$a, b, c, \text{------}, k$ are direct effect of the characters $x_1, x_2, x_3, \ldots\ldots, x_n$ respectively.

$r(x_1y), r(x_2y), r(x_3y), \ldots\ldots\ldots, r(x_ny)$ are the genotypic correlation coefficients between grain yield and character $x_1, x_2, x_3, \ldots\ldots\ldots, x_n$ respectively.

$r(x_1x_2)$, $r(x_1x_3)$, $r(x_2x_3)$, $r(x_3x_n)$ etc. are the genotypic correlation coefficient of different pairs of characters.

These simultaneous equations were solved for the unknowns and the values of direct effects were estimated. The matrices were as follows:

$$\begin{bmatrix} r(x_1y) \\ r(x_2y) \\ r(x_3y) \\ r(x_ny) \end{bmatrix} = \begin{bmatrix} r(x_1x_1) & r(x_1x_2) & r(x_1x_3) & \ldots . r(x_1x_n) \\ r(x_2x_1) & r(x_2x_2) & r(x_2x_3) & \ldots . r(x_2x_n) \\ r(x_3x_1) & r(x_3x_2) & r(x_3x_3) & \ldots . r(x_3x_n) \\ r(x_nx_1) & r(x_nx_2) & r(x_nx_3) & \ldots . r(x_nx_n) \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ k \end{bmatrix}$$

$$\begin{bmatrix} a \\ b \\ c \\ k \end{bmatrix} = \begin{bmatrix} r(x_1y) & r(x_1x_1) & r(x_1x_2) & r(x_1x_3) & \ldots . r(x_1x_n) \\ r(x_2y) & r(x_2x_1) & r(x_2x_2) & r(x_2x_3) & \ldots . r(x_2x_n) \\ r(x_3y) & r(x_3x_1) & r(x_3x_2) & r(x_3x_3) & \ldots . r(x_3x_n) \\ r(x_ny) & r(x_nx_1) & r(x_nx_2) & r(x_nx_3) & \ldots . r(x_nx_n) \end{bmatrix}$$

$$\begin{bmatrix} a \\ b \\ c \\ k \end{bmatrix} = \begin{bmatrix} r(x_1y) \\ r(x_2y) \\ r(x_3y) \\ r(x_ny) \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} & C_{13} & \ldots . & C_{1n} \\ C_{21} & C_{22} & C_{23} & \ldots . & C_{2n} \\ C_{31} & C_{32} & C_{33} & \ldots . & C_{3n} \\ C_{n1} & C_{n2} & C_{n3} & \ldots . & C_{nn} \end{bmatrix}$$

Where, C_{11}, C_{12}, ...,C_{nn} are the respective elements of inverse matrix. The unknowns were solved as follows:

$$a = C_{11}\, r(x_1y) + C_{12}\, r(x_2y) + C_{13}\, r(x_3y) + ...C_{1n}\, r(x_ny)$$

$$b = C_{21}\, r(x_1y) + C_{22}\, r(x_2y) + C_{23}\, r(x_3y) + ...C_{2n}\, r(x_ny)$$

$$c = C_{31}\, r(x_1y) + C_{32}\, r(x_2y) + C_{33}\, r(x_3y) + ...+C_{3n}\, r(x_ny)$$

$$k = C_{n1}\, r(x_1y) + C_{n2}\, r(x_2y) + C_{n3}\, r(x_3y) + ...+C_{nn}\, r(x_ny)$$

The indirect effects of specific characters through other characters were obtained in the following way:

Indirect effect of i^{th} character via j^{th} character

$$= r(x_ix_j) \times P$$

Where, P is the direct effect of j^{th} character.

Similarly, the direct and indirect effects at phenotypic level were calculated while using respective correlation coefficient at phenotypic level.

R E S U L T S

This investigation comprised of several inter-related studies conducted primarily with a view to assessing the magnitude and nature of variability for salt tolerance among 55 rice varieties. Besides undertaking a cytogenetic analysis of locally adapted rice varieties, a special feature of these studies was the monitoring of soil status and meteorological conditions during the entire course of investigation so as to facilitate critical interpretation of observations and drawing valid inferences.

Results obtained from different experiments are described below under the following sub-headings:

(1) Phenotypic characteristics of locally adapted cultivars

(2) Cytological studies

(3) Petriplate experiments

(4) Screening-plots experiments

4.1 Characterisation of locally-adapted indigenous cultivars

Comparative characteristics of 20 promising locally-adapted rice varieties collected from different parts of the country are listed in Table 1. All the varieties were diploids with 2n = 24 chromosomes showed normal chromosome pairing behaviour during meiosis but revealed significant variation regarding several phenotypic characters under study. Most of them were tall growing and late flowering types. Varieties Arya, Nonabokra, Nonasail, Pokkali and SR 26B were very tall measuring more than 2 meters in height. Nonabokra, Nonasail,

Table 1 Comparative characteristics of 20 promising rice varieties observed at Karnal

Varieties	Source	Chromosome number (2n=)	Pollen size (μ)	Stomata size (μ)	Stomata frequency per.21mm²	Days to 50% flowering (average)	Plant height (cm)	Grain yield per plant (gms)	Grain colour
Kalinga-I	CRRI, Cuttack	24	16.90	11.87	28.10	79.88	83.24	19.92	White
Kalinga-II	CRRI, Cuttack	24	16.35	11.10	31.20	77.75	83.15	20.65	White
Jehma 349	Punjab	24	16.30	14.20	18.70	88.00	132.11	38.47	White
Bas 370	Punjab	24	16.00	14.20	25.40	111.25	168.88	21.06	White
Kalarate	Maharashtra	24	15.85	13.68	19.55	123.75	147.00	23.87	Dark red
Bhararate	Maharashtra	24	15.80	12.91	25.10	119.75	135.00	37.40	Dark red
Karekagga	Karnataka	24	17.25	14.20	19.30	93.00	149.39	30.37	Dark red
Bilekagga	Karnataka	24	16.75	14.45	20.05	93.50	152.69	27.65	Dark red
Arya	Karnataka	24	16.80	12.65	24.05	136.75	201.88	31.50	Red
Damodar	W. Bengal	24	16.95	9.81	24.90	135.25	151.50	20.30	White
Dasal	W. Bengal	24	16.30	13.68	27.75	135.50	154.75	20.57	White
Getu	W. Bengal	24	16.10	11.61	23.65	135.75	145.38	23.71	White
Nona bokra	W. Bengal	24	15.35	11.87	24.05	152.00	229.60	15.50	White
Nona sail	W. Bengal	24	16.35	11.87	22.55	147.00	210.60	6.15	White
Pokkali	Kerala	24	15.95	10.07	22.70	138.50	227.88	25.42	Red
MCM-I	Andhra Pradesh	24	17.05	12.91	31.15	126.00	179.00	51.61	White
SR 26 B	Tamil Nadu	24	15.65	10.32	26.25	159.50	209.00	8.56	White
SR 3-9	Tamil Nadu	24	16.05	16.00	18.45	141.13	159.25	19.25	White
SR 10032	Tamil Nadu	24	15.65	10.58	25.20	141.25	170.63	13.43	White
Giza 159	Egypt	24	16.65	14.71	24.90	96.75	111.41	28.28	White

SR 26B, and SR 10032 were very late-flowering taking more than 140 days to flower under Karnal conditions and this adversely affected the grain setting as the onset of winter coincided with flowering and grain development period. Six varieties were characterised by deeply pigmented grains while two among them namely Kalarata and Karekagga, were also having black glumes.

Data presented in Table 1 showed that stomatal size ranged from 9.81 to 16.00 μ whereas the stomata frequency ranged from 18.45 to 31.20 stomata per microscopic field area of 0.21 mm^2. The pollen size ranged from 15.35 μ in Nonabokra to 17.25 μ in Karekagga.

4.2 Cytological observations

Cytological study of ten indigenous salt-tolerant cultivars, alongwith two standard varieties Jaya and M-1-48, revealed that all the genotypes were diploids having somatic chromosome number of 2n = 24 and regularly formed 12 bivalents during meiosis as observed in pollen mother cells. Comparative morphology of chromosome sets, studied in root tip squashes, did not show any notable difference in this regard among different varieties. Regularity of meiotic behaviour was also examined, recording observations on chiasma frequency and occurrence of anaphase abnormalities under non-stress, alkali and saline soil conditions. These observations are described below.

4.2.1 Chiasma frequency per cell

Observed chiasma frequency among the 12 varieties grown under non-stress (control) as well as alkali and saline environments are given in Table 2. Number of chiasmata per cell ranged from 22.6 to 25.3 in the control, 22.8 to 27.4 in alkali soil and 23.1 to 27.2 in saline soil environments. Configuration of the

Table 2 Effect of soil salinity and alkalinity on chiasma frequency and anaphase abnormalities in 12 rice varieties

Genotypes	Chiasma frequency/cell			Anaphase abnormalities per cent		
	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline
Damodar	24.0±0.30	25.1±0.23**	25.9±0.23**	2.56	1.59	2.90
Dasal	24.8±0.20	25.8±0.22**	26.1±0.18**	0	4.35**	0
Karekagga	24.3±0.21	25.7±0.21**	25.0±0.21**	4.00	9.46**	7.94**
Bhurarata	23.3±0.30	22.9±0.48	23.4±0.37	2.10	9.20**	7.92**
Kalarata	22.6±0.31	22.8±0.20	23.3±0.34**	1.67	16.42**	13.43**
SR-3-9	23.6±0.27	25.1±0.28**	26.0±0.26**	1.67	6.97**	7.84**
SR 10032	25.3±0.15	25.8±0.25	26.5±0.17**	0	10.81**	9.67**
MGM-1	24.8±0.25	27.4±0.27**	27.2±0.20**	1.49	1.64	3.13
Pokkali	25.0±0.21	25.5±0.17*	26.7±0.21**	1.00	1.59	1.05
Jhona 349	25.1±0.35	25.7±0.37*	25.2±0.25	0	7.69**	7.94**
Jaya	22.9±0.28	22.8±0.22	23.1±0.35	0	6.25**	8.33**
M-1-48	23.1±0.31	23.1±0.30	23.4±0.33	1.67	4.17*	6.35**

CD at P=0.05	Varieties	0.72
	Environments	0.45

* Significant at P=0.05, ** Significant at P=0.01

Table 3 Analysis of variance for chiasma frequency and anaphase abnormalities of 12 rice varieties grown in optimal, alkali and saline environments

Sources of variation	d.f.	M.S.S.	
		Chiasma frequency	Anaphase abnormalities
Varieties	11	4.84**	50.13*
Environments	2	3.96**	321.44**
Error	22	0.28	16.70

* Significant at 5% level

** Significant at 1% level

bivalents were predominantly ring shaped. However, one or two bivalents of rod-shape were also observed. The nucleolar organising bivalents seemed to be mostly held by a single chiasma of the open ring type. Statistical analysis of these observations, presented in Table 3, showed that varietal differences and treatments' effects were significant. Variety SR10032 recorded the highest chiasma frequency per cell (25.3) followed by Jhona, Pokkali, Dasal, MCM-1 and Karekagga. These differences were, however, not significant statistically under the favourable environment. Under stress environments, however, MCM-1 showed the highest chiasma frequency of 27.4 and 27.2 per cell in alkali and saline soil environments respectively. Interestingly, variety Jaya recorded the lowest chiasma frequency per cell in non-stress soil (22.7) as well as in alkali (22.8) and saline (23.1) soil environments.

In general, salt stress appeared to increase the chiasma frequency excepting for varieties Jaya, M-1-48 and Bhurarata. The highest salt-induced increase in chiasma frequency was shown by the varieties MCM-1 (10.4 and 9.68 per cent) and SR 3-9 (6.36 and 10.17 per cent) under alkali and saline environments respectively.

4.2.2 Anaphase abnormalities

Observed anaphase abnormalities included late separation of chromosomes and occurence of bridges, fragments and laggards. These abnormalities were found to be increased by the salt stress. Data on the incidence of anaphase irregularities are given in Table 2 and their analysis of variance in Table 3. Varieties Damodar, Pokkali and MCM-1 were outstanding in showing no significant increase in anaphase abnormalities both under alkali and saline soil environments as compared to the non-alkali and

non-saline soil conditions. Interestingly, variety Dasal showed significant increase in anaphase abnormalities under alkali soil environments only. Higher number of abnormalities were recorded in case of varieties Kalarata (16.42 and 13.43%) and SR 10032 (10.81 and 9.67%) grown under alkali and saline soil conditions respectively.

4.2.3 Pollen size and viability

Data on pollen size and viability, judged on the basis of acetocarmine stainability test, are presented in Tables 4 and 5. Most of the varieties showed pollen viability of more than 95% excepting the very late flowering varieties, namely, SR 26B, SR 10032, Nonabokra, and Nonasail. Pollen size ranged from 15.35 to 17.35 μ in diameter. Salt stress was found to decrease both the pollen viability as well as the size. Significant V x E interactions were reeorded. Varieties SR 3-9, Pokkali, Damodar and MCM-1 did not show any significant stress-induced reduction both in pollen viability and pollen-size. The observed reduction in pollen viability, however, was not found to be correlated with the grain yield under stress environments.

4.2.4 Stomatal frequency and size

Observations on stomatal frequency of 29 varieties, presented in Tables 6 and 7, revealed significant variation among the varieties. It ranged from 18.45 stomata per microscopic field area (0.21 mm^2) in the variety SR3-9 to 36.4 stomata in M-1-48. The phenotypic and genotypic coefficient of variances were 19.42 and 16.00 per cent respectively with a broad sense heritability value of 67.88 per cent over the mean.

Table 4 Effect of soil alkalinity and salinity on pollen viability and pollen size of 18 rice varieties

Genotypes	Pollen fertility (percentage)			Pollen size (μ)		
	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline
CR 222	94.74	94.23	94.32	17.00	16.90	16.20
Jhona 349	95.87	90.32	91.01	16.30	15.10	15.80
Jaya	94.43	92.75	94.09	17.35	17.00	16.75
SR-3-9	94.00	93.28	92.82	16.05	16.40	16.10
Kalarata	96.70	95.37	95.83	15.85	15.00	15.15
Bhurarata	99.03	98.16	97.55	15.80	15.90	15.70
Karekagga	95.65	93.65	94.45	17.25	17.05	16.90
Bilekagga	95.27	93.01	93.71	16.75	16.10	16.00
Arya	83.01	75.87	83.33	16.80	15.30	15.60
Damodar	94.95	95.37	95.16	16.95	16.80	16.50
Dasal	99.18	97.23	97.88	16.30	16.35	16.15
Getu	98.67	98.20	97.43	16.10	15.95	15.75
Nona bokra	89.67	82.08	82.94	15.35	14.80	15.00
Nona sail	93.04	86.97	89.85	16.35	15.90	15.90
Pokkali	89.78	90.76	92.54	15.95	15.65	15.95
SR 26B	85.22	82.01	82.16	15.65	15.65	15.20
SR 10032	88.65	79.21	88.05	15.65	14.95	15.25
MGM-1	96.32	95.25	96.12	17.05	16.85	16.85
Mean	93.57	90.76	92.18	16.36	15.98	15.93
CD at P=0.05	for varieties		1.21			0.18
	for soils		0.50			0.07
	for vars x soils		2.10			0.32

Table 5 Analysis of variance for pollen viability and pollen size of 18 rice varieties grown in optimal, alkali and saline soil environments

Sources of variation	d.f.	M.S.S. Pollen fertility	Pollen size
Replication	3	7.300*	0.017
Varieties	17	377.838**	4.515**
Environments	2	145.474**	3.993**
VxE	34	9.698**	0.282**
Error	159	2.289	0.052

* Significant at 5% level

** Significant at 1% level

Table 6 Mean values of stomata frequency and stomatal size of 29 rice varieties

Genotype	Stomata frequency per 0.21 mm^3	Stomata size (μ)
Kalinga I	28.10	11.87
Kalinga II	31.20	11.10
CR 214	23.05	14.71
CR 222	20.20	12.13
Jhona 349	18.70	14.20
Jaya	27.70	10.84
BG 94-1	29.25	11.61
Giza 159	24.90	14.71
Bas 370	25.40	14.20
TR 17	27.70	13.16
M-1-48	36.40	12.91
IR 2053	30.35	11.36
IR 2031	24.90	8.78
IR 2055	22.95	12.91
SR 3-9	18.45	16.00
Kalarata	19.55	13.68
Bhurarata	25.10	12.91
Karekagga	19.30	14.20
Bilekagga	20.05	14.45
Arya	24.05	12.65
Damodar	24.90	9.81
Dasal	27.75	13.68
Getu	23.65	11.61
Nona bokra	24.05	11.87
Nona sail	22.55	11.87
Pokkali	22.70	10.07
SR 26B	26.25	10.32
SR 10032	25.20	10.58
MGM-1	31.15	12.91
Mean	25.02	12.44
CD at P=0.05	3.82	1.86

Table 7 Analysis of variance for stomata frequency and stomatal size of 29 rice varieties

Sources of variation	Stomata frequency		Stomata size	
	d.f.	M.S.S.	d.f.	M.S.S.
Replications	3	7.99	9	2.09
Varieties	28	71.67**	28	29.93**
Error	84	7.58	252	4.50

** Significant at 1% level

The stomata size also showed significant varietal differences. The range was from 8.78 μ in IR2031 to 16.0 μ in SR3-9. This character showed a phenotypic coefficient of variance of 21.33 per cent and genotypic coefficient of variance of 12.82 per cent. Heritability value was low (36.11%) with expected genetic advance of 15.84% over the mean.

Total stomatal opening per unit area was found to be significantly correlated with grain yield. Interestingly this relationship was negative in the early flowering rice varieties ($r = -0.579$), but positive ($r=+0.620$) in the late flowering group.

4.3 Petriplate experiments

Experiments were conducted in petriplates, kept under controlled conditions, to evaluate varietal performance regarding seed germination and young seedling stages under optimal and sub-optimal environments. Observations were recorded on total seed germination, seed germination index indicating the rate of germination and seedling weight. The environments were control (Tap water of EC 0.30 dS/m) and 1% NaCl solution EC $\sim$ 10 dS/m).

4.3.1 Seed germination percentage

Data on seed germination percentage of 25 rice varieties raised under two environments, under comparison, are presented in Table 8 and analysis of variance in Table 9. In general, total seed germination was not drastically reduced by salinity excepting five varieties, viz. Bilekagga (61.3%), Giza 159 (48.05%), Pokkali (46.56%), Arya (35.56%) and Karekagga (24.0%). No significant reduction was observed in case of varieties OSR-5, Jhona 349, IR2031, Bhurarata, SR 26B, SR 10032, SR3-9, TR-17 and OSR-4.

Table 8 Effect of salinity (1% NaCl) on total seed germination, seed germination index and fresh seedling weight of 25 rice varieties

Genotypes	Seed germination (%)		Seed germination index		Seedling weight (mg)	
	Control	Saline	Control	Saline	Control	Saline
CSR 4	100.0	98.7	8.26	3.17	70.13	21.66
CSR 5	98.7	98.7	8.14	3.73	65.96	23.87
Jhona 349	100.0	100.0	8.28	4.94	78.53	40.40
Jaya	100.0	94.7	8.17	3.71	76.93	32.44
Giza 159	69.3	36.0	4.20	1.09	48.22	20.82
Bas 370	100.0	94.7	7.26	3.14	51.87	21.68
TR 17	100.0	98.7	8.28	4.35	58.27	28.89
M-1-48	100.0	96.0	8.19	4.32	59.07	26.57
IR-2053	100.0	98.7	7.92	3.43	54.53	16.64
IR 2031	100.0	100.0	8.11	4.05	50.53	25.47
IR 2055	100.0	97.3	8.30	4.09	66.40	32.94
SR-3-9	100.0	98.7	8.33	5.34	49.20	32.90
Kalarata	100.0	86.7	8.08	3.83	80.27	18.61
Bhurarata	100.0	100.0	8.33	4.98	77.47	33.87
Karekagga	100.0	76.0	4.32	1.89	76.67	09.84
Bilekagga	100.0	38.7	3.66	0.92	72.53	11.57
Arya	97.3	62.7	8.02	2.05	93.14	13.28
Damodar	98.7	94.7	8.19	3.61	62.82	27.82
Getu	98.7	93.3	8.09	3.34	64.00	17.15
Nona bokra	53.3	48.0	4.14	1.90	74.41	25.18
Nona sail	50.7	42.7	3.63	1.24	45.89	17.23
Pokkali	97.3	52.0	8.03	1.62	82.74	25.36
SR 26 B	26.7	26.7	1.82	0.86	62.83	28.18
SR 10032	86.7	86.7	7.01	3.39	61.34	21.19
MCM-1	100.0	89.3	8.22	2.71	62.93	15.53
CD at P=0.05 for vars.	7.75		0.54		4.43	
for treats.	2.19		0.15		1.25	
for vars. x treats.	10.97		0.77		6.27	

Table 9 Analysis of variance for total seed germination, seed germination index and seedling weight of 25 rice varieties raised with tap water (control) and 1% NaCl solution

Sources of variation	d.f.	M.S.S.		
		Seed germination %	S.G.I	Seedling fresh weight
Replications	2	49.52	0.27	44.61
Varieties	24	241.48**	15.04**	306.60**
Environments	1	4798.10**	567.77**	67109.37**
VxE	24	1796.69**	2.27**	320.23**
Error	98	46.96	0.231	15.85

** Significant at 1% level

Table 10 Salinity induced reduction(%) in total seed germination, seed germination index and seedling fresh weight of 25 rice varieties grown in 1% NaCl solution

Genotypes	Reduction (% of the corresponding control)		
	Seed germination percentage	Seed germination index	Seedling weight (mg)
CSR 4	1.30	61.62	69.11
CSR 5	0	54.18	63.81
Jhona 349	0	40.34	48.55
Jaya	5.30	54.59	57.83
Giza 159	48.05	74.05	56.82
Bas 370	5.30	56.75	58.20
TR 17	1.30	47.46	50.42
M-1-48	4.00	47.25	53.33
IR-2053	1.30	56.69	69.48
IR-2031	0	50.06	49.59
IR-2055	2.70	50.72	50.39
SR-3-9	1.30	35.89	33.13
Kalarata	13.30	52.60	76.82
Bhurarata	0	40.22	56.28
Karekagga	24.00	56.25	87.17
Bilekagga	61.30	74.86	84.05
Arya	35.56	74.44	85.74
Damodar	4.05	55.92	55.71
Getu	5.47	58.71	73.20
Nona bokra	9.94	54.11	66.16
Nona sail	15.78	65.84	62.45
Pokkali	46.56	79.83	69.35
SR 26 B	0	52.75	55.15
SR 10032	0	51.64	65.45
MCM-1	10.70	67.03	75.32

4.3.2 Seed germination index

Eventhough total seed germination was not drastically affected in some varieties by salinity, seed germination was prolonged by the imposed stress. Thus, seed germination index was found to be more sensitive test for differentiating varietal responses to salinity as compared to total seed germination values.

Salinity induced reduction for seed germination index is given in Table 10. Varieties SR3-9, Jhona 349, Bhurarata and TR17 germinated quickly and therefore recorded higher seed germination index values (4.35 to 5.34), while it was observed to be much lower in case of varieties Bilekagga, Giza 159 and Nonasail.

4.3.3 Weight of 10-day old seedlings

Data given in Tables 8 and 9 showed that the varieties under study had significant differences for this character under both non-stress and saline environments. Under non-stress environment high seedling weight (76.67 to 93.14 mgs) was noticed in varieties Arya, Pokkali, Kalarata, Bhurarata, Jaya and Karekagga. Low seedling weight under comparable conditions was observed in the variety Nonasail (45.89 mgs). Other varieties at par with Nonasail were SR3-9, Giza 159 and IR2031. The lowest salinity induced reduction was observed in the variety SR3-9 (33.13%). Other varieties recording less than 50% reduction were Jhona 349, IR2031, IR2055 and TR17. Higher reductions were observed in varieties Arya (85.74%), Karekagga (87.17%) and Bilekagga (84.05%).

The response of rice varieties at seedling stage was not found to be correlated with the grain yield response. However, variety SR 3-9 recorded remarkably better performance under saline

conditions during seed germination and seedling stages followed by Jhona 349, IR2031 and TR17 in descending order.

4.4 Screening plots experiments

To compare grain yield and eight component characteristics under non-stress (pH_2 8.2 and EC_e 1.9 dS/m) and sub-optimal soil (saline soil EC_e 5.0 to 8.0 dS/m and alkali soil pH_2 8.8 to 9.1) environments of 55 genetically diverse rice varieties, a study was undertaken in kharif season of 1981 in specially designed screening plots developed for this purpose. This experiment was repeated in the following kharif season excluding 16 varieties which were either very late-flowering types, (whose yield was affected by the onset of winter) or showed high phenotypic heterogenity. This study was thus conducted on 39 varieties grown in 6 environments and data were recorded on grain yield, days to flowering, plant height, panicle length, panicle bearing tillers (PBT), panicle weight, straw weight, 1000 grain weight, and harvest index.

Analysis of the data was done after grouping the varieties into three classes based on the days to flowering. Fifteen varieties which flowered within 95 days were marked as the early flowering group, 11 varieties which flowered between 96 to 115 days were grouped as the medium flowering group while 13 varieties which took more than 115 days for 50% flowering were grouped as the late flowering group. However, the grouping of varieties based on maturity periods showed that varieties PAU 269 and Bhurarata should have been placed in the medium group rather than in the late group. Likewise, variety IR54 should belong to the late maturity group as judged by its duration from seedling to maturity instead of the consideration of days to

50% flowering. These differences obviously relate to differences in grain development period and also by differential varietal sensitivity to gradually declining temperature during grain rippening. Even so, varieties in this study were grouped according to the flowering criterion as rice is reported to be very sensitive during that period to salt stress and maturity dates were nearly always variable because of occasional low temperature particularly beyond November.

The data obtained on various characters under different edaphic environments for the three maturity groups are presented in Tables 11 to 19.

4.4.1 Analysis of variance and per se performance of the genotypes

Analysis of variance presented in Tables 20 to 22 revealed that mean sum of squares due to varieties for yield and eight component characters were significant showing that there was adequate variability among the varieties. Environments were also found to be distinct from each other. Under alkali soil environment, the recorded mean reduction for grain yield ranged from 23.06% in early flowering group to 33.56% in medium flowering group, whereas under saline soil environment it was 39.41% in early flowering group to 55.30% in late flowering group revealing that the imposed stress levels were mild as desired, but the chosen level of salinity stress was more detrimental than the alkalinity stress. The significant V x E interaction showed that varieties differed in their response to soil stress conditions. The observed responses with respect to individual characters are summarised below.

4.4.1.1 Days to 50% flowering

The mean performance for days to 50 per cent flowering in non-stress environment showed that variety CR 237-1 took minimum days (68.50) for its 50% flowering. Among the early flowering group, variety Pusa 150 took the maximum days (93.88) for 50 per cent flowering and was at par with varieties CR 143-2-2, Bilekagga and Karekagga.

In the medium flowering group, minimum and maximum days for 50 per cent flowering ranged from 96.75 to 115.25 days for varieties Giza 159 and IR54 respectively with an overall group mean of 105.81 days. Number of days to flowering of varieties HAU-6-163, Jaya, PR106 and M-1-48 was at par with that of the group mean.

The late flowering group took on an average, 130 days for 50 percent flowering. Variety PAU 269 took 119.50 days and was followed by Bhurarata (119.75) and IR2055 (120.25) while varieties SR10032, and SR3-9 took maximum time of 141.25 days and 141.13 days respectively.

In general, flowering was delayed by both saline and alkali soil stresses in all the groups. Delay was more severe in saline soil environment as compared to that in case of alkali soil environment. In saline soil environment, maximum delay amounted to 5 days in variety Bilekagga of the early group, 9 days in varieties HAU-5-298, Bas 370 of the medium group and 13 days in SR3-9, SR10032 of the late flowering group.

Table 11 Mean values of plant height, panicle length, panicle weight, straw weight/hill and grain yield/hill of 15 early flowering rice varieties grown in non-stress, alkali & saline soil environments

Genotypes	Plant height(cm)			Panicle length(g)			Panicle wt.(g)			Straw wt/hill(g)			Yield/hill(g)		
	Soil environments			Environments			Environments			Environments			Environments		
	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline
CR237-1	100.19	88.75	82.73	24.35	20.96	23.29	2.33	1.99	1.79	38.46	24.85	18.81	36.81	20.63	21.51
Kalinga II	83.15	71.35	61.48	24.68	21.73	22.30	3.01	2.28	1.89	32.72	24.48	23.33	41.30	35.13	22.51
Kalinga I	83.24	70.16	58.31	25.80	24.85	22.54	2.90	2.26	1.75	36.26	25.26	21.36	39.84	34.09	22.50
P2-21	78.21	65.95	61.83	26.04	24.85	24.51	4.80	3.39	2.87	41.63	24.29	17.71	48.34	40.38	30.04
CR222	83.35	68.63	61.86	26.83	25.58	24.93	4.53	3.98	3.24	30.18	28.11	17.49	48.82	49.12	33.47
CR214	85.23	68.10	61.10	27.80	25.30	24.83	4.63	3.55	2.92	33.93	19.56	19.79	54.32	40.63	36.07
IET1444	88.51	73.25	69.13	27.45	26.11	25.20	3.74	2.81	2.52	29.97	27.64	22.83	44.71	36.82	32.59
CSR-4	80.76	68.26	64.16	24.54	21.61	21.48	4.12	2.98	2.78	30.21	22.86	18.98	52.38	37.30	33.95
Jhona 349	132.11	110.81	101.73	28.66	24.04	25.16	6.30	4.55	3.47	55.51	37.07	27.69	76.94	50.32	37.17
Pusa 167	82.42	71.64	62.23	28.86	26.41	25.98	4.67	3.14	2.97	29.40	26.54	20.37	49.66	36.97	34.13
CSR-5	85.38	64.29	63.31	29.35	28.25	27.50	5.24	3.28	3.31	40.30	26.58	26.32	75.52	44.82	38.17
CR143-2-2	82.58	65.79	62.66	25.64	24.70	23.88	4.39	3.79	3.58	33.19	20.28	20.89	37.26	32.42	29.02
Pusa 150	78.14	69.04	60.35	28.33	24.73	25.45	3.59	2.56	2.44	34.00	25.49	21.37	46.19	35.94	34.94
Bilekagga	152.69	137.55	121.63	36.13	32.01	29.88	6.80	4.83	3.91	73.94	53.17	49.70	55.29	47.58	31.69
Karekagga	149.39	133.14	122.54	39.51	35.01	28.41	6.54	4.63	2.71	66.90	52.98	46.99	60.74	48.87	27.75
Mean	96.36	82.11	74.34	28.26	25.74	25.02	4.50	3.33	2.81	40.44	29.28	24.91	51.21	39.40	31.03
CD at P=0.05	5.58	5.73	6.49	1.71	1.81	1.72	0.94	0.67	0.56	8.01	7.32	7.07	9.16	9.05	6.72

Table 12 Mean values for days to 50% flowering, PBT/hill, 1000 grain weight and harvest index of 15 early flowering rice varieties grown in non-stress (C), alkali (A) and saline (S) soil environments

Genotypes	Days to 50% flowering			PBT/hill			1000 grain weight(gm)			Harvest index		
	Soil environments			Environments			Environments			Environments		
	C	A	S	C	A	S	C	A	S	C	A	S
CR 237-1	68.50	72.00	69.00	22.38	15.75	16.56	22.07	21.48	18.55	0.489	0.455	0.529
Kalinga II	77.75	79.88	76.25	19.13	22.25	19.63	23.57	22.51	19.00	0.559	0.590	0.490
Kalinga I	79.88	81.63	80.25	18.44	21.00	20.00	22.19	20.99	18.23	0.524	0.576	0.512
P 2-21	82.85	86.00	84.00	14.19	15.50	14.31	22.69	20.92	18.99	0.550	0.624	0.630
CR 222	85.75	88.75	86.75	15.25	16.50	17.44	25.58	24.36	22.03	0.618	0.634	0.656
CR 214	85.75	88.13	85.75	16.38	16.75	17.38	25.51	24.15	22.04	0.615	0.675	0.648
IET 1444	86.13	89.50	87.38	17.00	19.38	19.31	21.34	21.36	19.43	0.600	0.571	0.589
CSR-4	86.88	89.63	87.25	17.50	18.31	16.63	21.71	20.14	18.52	0.633	0.620	0.641
Jhona 349	88.00	90.88	90.75	17.63	16.44	16.00	24.92	23.49	22.05	0.579	0.576	0.573
Pusa 167	92.50	96.00	93.50	15.56	17.69	18.38	21.16	19.02	17.24	0.629	0.583	0.626
CSR-5	92.50	94.88	92.88	20.31	19.69	18.81	22.13	20.54	18.65	0.656	0.620	0.591
CR 143-2-2	93.63	95.00	94.00	11.94	12.44	11.06	22.37	20.11	19.21	0.530	0.616	0.579
Pusa 150	93.88	96.00	95.88	18.75	17.69	19.63	19.67	19.49	17.72	0.567	0.583	0.620
Bilekagga	93.50	95.25	98.88	11.44	15.13	12.50	33.66	31.60	29.50	0.428	0.477	0.390
Karekagga	93.00	95.88	96.63	13.50	15.06	17.69	33.85	34.02	30.04	0.477	0.479	0.378
Mean	86.72	89.29	87.94	16.72	17.30	17.02	24.16	22.94	20.75	0.563	0.579	0.563
CD at P=0.05	1.53	2.54	1.40	2.95	3.23	3.15	0.89	1.10	1.06	0.051	0.033	0.046

Table 13 Mean values for plant height, panicle length, panicle weight, straw weight/hill and grain yield/hill of eleven medium flowering rice varieties grown in non-stress(C), alkaline(A), and saline(S) soil environments

Genotypes	Plant height(cm) Soil environments			Panicle length(g) Environments			Panicle wt.(g) Environments			Straw wt/hill(g) Environments			Yield/hill(g) Environments		
	C	A	S	C	A	S	C	A	S	C	A	S	C	A	S
Jaya	111.41	94.81	85.60	25.69	23.60	23.21	4.83	3.39	3.50	46.97	27.88	20.74	56.56	41.45	28.48
IR 2053	116.58	98.95	90.79	25.01	22.94	23.16	5.14	2.86	2.98	46.98	24.71	36.34	50.68	36.53	30.22
TAU5-298	99.88	87.25	73.50	32.88	29.25	26.50	4.60	2.95	2.44	57.46	34.62	29.91	67.04	38.19	26.38
TAU6-163	94.13	85.76	80.88	27.13	25.85	27.50	5.48	3.23	3.69	61.01	38.78	38.14	70.54	42.35	40.12
PET 4141	87.25	82.00	78.13	26.25	24.75	24.00	3.66	3.11	2.37	53.53	31.57	24.57	42.66	31.96	24.45
IR 106	89.13	77.40	71.16	27.50	25.80	25.08	5.70	3.57	2.96	56.05	37.06	33.00	68.18	42.29	36.20
Jaya	84.31	71.60	63.85	27.58	25.80	24.54	6.50	4.44	3.01	54.54	34.34	30.59	71.54	46.33	32.44
T-148	93.80	80.23	76.44	29.24	26.58	27.69	3.74	3.22	2.47	42.32	23.87	20.09	36.23	25.22	18.24
IR 17	94.63	81.25	68.19	27.39	25.50	25.50	4.37	2.95	2.58	56.69	34.56	25.65	58.26	39.74	29.39
Jas 370	168.88	144.75	118.75	34.25	31.63	28.63	3.36	2.57	2.74	71.71	59.44	34.84	42.12	30.98	29.48
IR 54	75.00	62.75	49.75	28.38	26.00	21.86	4.53	3.10	3.04	50.97	33.36	28.03	59.91	39.29	30.68
Mean	101.36	87.89	77.37	28.30	26.15	25.24	4.72	3.22	2.89	54.38	34.56	29.26	56.70	37.67	30.46
CD at P=0.05	6.30	6.45	6.94	2.04	1.87	2.30	0.75	0.64	0.68	6.89	7.84	7.99	9.37	7.10	6.57

Table 14 Mean values for days to 50% flowering, PBT/hill, 1000 grain weight and harvest index of eleven medium flowering rice varieties grown in non-stress (C), alkali (A) and saline (S) soil environments

Genotypes	Days to 50% flowering			PBT/hill			1000 grain weight(gm)			Harvest index		
	Soil environments			Environments			Environments			Environments		
	C	A	S	C	A	S	C	A	S	C	A	S
Giza 159	96.75	98.13	97.88	16.69	15.38	11.75	26.95	24.67	23.37	0.545	0.600	0.578
IR 2053	99.25	105.25	106.50	14.00	14.94	16.75	21.12	20.28	18.71	0.520	0.595	0.456
HAU 5-298	103.25	107.75	112.25	21.16	20.44	18.94	22.51	20.88	19.15	0.538	0.524	0.470
HAU 6-163	105.00	109.00	108.75	20.06	17.94	18.56	28.98	28.13	24.99	0.536	0.521	0.561
IET 4141	107.25	114.00	111.75	16.50	14.69	15.56	21.62	21.07	18.92	0.450	0.504	0.503
PR 106	106.75	111.00	110.00	16.75	17.50	16.50	23.08	21.58	19.73	0.550	0.534	0.529
Jaya	106.88	109.00	109.75	14.88	16.13	15.81	30.08	27.64	25.51	0.566	0.573	0.515
M-1-48	105.00	107.00	105.75	13.25	10.00	11.00	21.99	21.36	19.50	0.461	0.516	0.478
TR 17	107.25	110.50	109.00	19.44	18.81	18.88	22.71	21.83	19.26	0.506	0.535	0.533
Bas 370	111.25	113.75	120.13	18.63	16.75	13.06	19.42	20.18	17.02	0.369	0.354	0.458
IR 54	115.25	118.75	122.50	19.25	19.56	14.56	22.01	20.56	17.73	0.539	0.543	0.526
Mean	105.81	109.47	110.39	17.33	16.56	15.58	23.68	22.56	20.36	0.507	0.527	0.510
CD at P=0.05	2.28	2.42	1.47	2.74	2.79	3.72	0.86	0.84	1.14	0.032	0.035	0.049

Table 15 Mean values for plant height, panicle length, panicle weight, straw weight/hill and grain yield/hill of thirteen late flowering rice varieties grown in non-stress(C), alkali(A) and saline(S) soil environments

Genotypes	Plant height(cm)			Panicle length(g)			Panicle wt.(g)			Straw wt/hill(g)			Yield/hill(g)		
	Soil environments			Environments			Environments			Environments			Environments		
	C	A	S	C	A	S	C	A	S	C	A	S	C	A	S
PAU 269	116.88	101.25	86.13	28.00	26.38	26.50	3.69	2.72	2.22	55.70	42.10	47.31	44.87	33.48	30.54
Bhurarata	135.00	121.25	96.25	24.63	21.75	20.75	3.37	3.07	2.27	123.33	99.02	48.53	74.80	62.08	32.48
IR 2055	74.88	68.25	51.13	26.13	25.50	25.50	3.41	2.70	2.08	56.17	44.36	36.50	54.44	48.25	31.09
MCM-1	179.00	149.38	124.63	30.13	27.38	25.50	5.07	4.67	2.63	144.02	95.36	81.09	103.22	58.09	24.71
Kalarata	147.00	128.75	98.25	18.63	19.63	16.25	2.54	2.30	2.06	131.61	100.35	61.60	47.73	44.67	29.92
IR 2031	136.00	118.13	83.75	26.63	24.50	24.50	3.79	3.33	2.12	87.50	51.63	42.26	42.75	34.35	11.14
Getu	145.38	113.13	110.50	22.25	21.13	20.75	3.68	3.08	1.96	105.62	73.97	69.97	47.42	37.80	31.90
Damodar	151.50	130.88	113.38	24.38	20.88	19.25	3.20	2.48	2.01	93.78	64.01	53.21	40.59	29.87	24.25
Dasal	154.75	136.25	113.75	22.88	21.00	19.75	3.09	2.80	2.14	91.72	75.50	70.11	41.14	34.72	27.13
Pokkali	227.88	186.25	157.25	27.13	28.13	24.25	5.52	5.45	3.80	144.32	68.10	61.89	50.83	30.93	23.63
Arya	201.88	164.50	134.50	28.13	24.25	22.00	4.33	3.56	1.90	160.43	130.49	81.79	62.99	41.61	12.72
SR 3-9	159.25	138.00	99.88	27.25	25.13	22.00	3.64	3.62	2.15	109.42	73.62	57.65	38.49	34.18	14.75
SR 10032	170.63	135.00	91.13	22.50	22.13	20.75	3.26	3.09	1.70	99.74	55.30	53.11	26.86	19.88	8.96
Mean	148.47	131.46	104.65	25.28	23.67	20.86	3.74	3.30	2.23	107.95	74.91	58.85	52.01	39.23	23.25
CD at P=0.05	7.54	11.09	10.56	2.03	1.97	1.59	0.61	0.65	0.50	24.45	20.53	16.56	7.96	7.19	6.70

Table 16 Mean values for days to 50% flowering, PBT/hill, 1000 grain weight and harvest index of thirteen late flowering rice varieties grown in non-stress(C), alkali (A) and saline (S) soil environments

Genotypes	Days to 50% flowering			PBT/hill			1000 grain weight(gm)			Harvest index		
	Soil environments			Environments			Environments			Environments		
	C	A	S	C	A	S	C	A	S	C	A	S
PAU 269	119.50	121.50	123.63	17.25	18.88	22.19	20.72	19.32	18.11	0.446	0.444	0.375
Bhurarata	119.75	119.75	124.25	33.38	31.50	30.06	25.71	24.66	19.49	0.380	0.384	0.400
IR 2055	120.25	121.13	129.50	22.50	23.19	25.50	21.63	20.99	17.54	0.490	0.519	0.459
MQM-1	126.00	129.50	135.75	24.56	21.00	17.50	22.39	18.92	22.10	0.419	0.380	0.236
Kalarata	123.75	125.00	134.75	29.06	29.63	32.13	26.10	26.64	22.00	0.268	0.309	0.329
IR 2031	127.50	129.00	133.75	15.13	16.00	14.50	15.16	15.25	11.63	0.330	0.401	0.209
Getu	135.75	136.75	140.50	21.69	20.69	24.69	20.66	21.16	16.50	0.356	0.369	0.318
Damodar	135.25	136.25	141.50	18.00	18.00	20.81	21.12	20.79	17.38	0.303	0.320	0.313
Dasal	135.50	136.00	140.25	19.75	18.88	21.13	21.23	20.58	16.59	0.324	0.318	0.270
Pokkali	138.50	137.25	145.75	10.81	7.06	10.00	30.48	30.37	25.04	0.261	0.316	0.279
Arya	136.75	137.25	145.50	21.31	20.81	21.50	29.59	28.14	23.83	0.285	0.245	0.134
SR 3-9	141.13	141.38	154.25	20.44	19.69	16.81	13.09	12.41	10.12	0.264	0.314	0.209
SR 10032	141.25	141.00	154.00	12.81	9.50	10.75	18.60	19.54	15.88	0.215	0.274	0.143
Mean	130.07	131.06	138.72	20.51	19.60	20.58	22.03	21.44	18.17	0.334	0.353	0.282
CD at P=0.05	1.41	1.23	1.16	3.54	3.06	3.83	0.88	1.15	1.23	0.041	0.044	0.064

Table 17 Reduction percentage in plant height, panicle length, PBT/hill, one panicle weight, straw weight/hill, 1000 grain weight, harvest index and grain yield/hill of 15 early flowering rice varieties grown in test-plots under alkali and saline soil environments

Genotypes	Plant height		Panicle length		PBT/hill		Panicle weight	
	Alkali	Saline	Alkali	Saline	Alkali	Saline	Alkali	Saline
CR 237-1	11.42	17.43	13.92	4.37	29.61	25.99	14.41	23.23
Kalinga II	14.19	26.07	11.96	9.63	-16.34	-2.61	24.42	37.21
Kalinga I	15.71	29.95	3.68	12.66	-13.91	-8.49	22.07	39.83
P 2-21	15.68	20.95	4.55	5.86	-9.27	-0.88	29.48	40.31
CR 222	17.67	25.78	4.66	7.08	-8.20	-14.33	12.04	28.51
CR 214	20.09	28.31	8.99	10.70	-2.29	-6.11	23.43	36.93
IET 1444	17.24	21.90	4.88	8.20	-13.97	-13.59	25.00	32.75
CSR 4	15.48	20.55	11.92	12.47	-4.63	5.00	27.70	32.56
Jhona 349	16.12	23.00	16.14	12.21	6.75	9.22	27.80	44.88
Pusa 167	13.09	24.50	8.44	10.00	-13.66	-18.09	32.69	36.44
CSR 5	24.70	25.84	3.75	6.30	3.08	7.39	37.34	36.87
CR 143-2-2	20.33	24.12	3.65	6.87	-4.19	7.33	13.78	18.45
Pusa 150	11.65	22.76	12.69	10.15	5.68	-4.67	28.69	32.03
Bilekagga	9.91	20.34	11.37	17.30	-32.27	-9.31	28.92	42.53
Karekagga	10.88	17.97	11.39	28.09	-11.56	-31.00	29.15	58.61

Continued

Table 17 Continued

Genotypes	Straw weight/hill		1000 grain weight		Harvest index		Yield/hill	
	Alkali	Saline	Alkali	Saline	Alkali	Saline	Alkali	Saline
CR 237-1	35.40	51.09	2.76	16.03	6.95	-8.08	43.96	41.57
Kalinga II	25.17	28.69	4.52	19.39	-5.64	12.36	14.94	45.50
Kalinga I	30.35	41.11	5.41	17.83	-9.92	2.29	14.42	43.53
P 2-21	41.65	57.47	7.78	16.31	-13.36	-14.55	16.47	37.86
CR 222	6.66	42.06	4.75	13.88	-2.59	-6.24	-0.60	31.44
CR 214	42.36	41.68	5.35	13.62	-9.68	-5.29	25.20	33.60
IET 1444	7.79	23.82	-0.12	8.93	4.83	1.92	17.65	27.12
CSR-4	24.32	37.18	7.23	14.69	2.06	-1.34	28.79	35.19
Jhona 349	33.21	50.12	5.72	11.50	0.43	1.04	34.60	51.69
Pusa 167	9.74	30.71	10.12	18.53	7.32	0.40	25.55	31.28
CSR 5	34.04	34.69	7.18	15.73	5.49	9.91	40.65	49.45
CR 143-2-2	38.91	37.12	10.10	14.13	16.23	-9.15	12.98	22.12
Pusa 150	25.04	37.16	0.94	9.94	-2.82	-9.44	22.19	24.37
Bilekagga	28.10	32.78	6.13	12.36	-11.58	8.89	13.95	42.69
Karekagga	20.81	29.76	-0.52	11.24	-0.42	20.78	19.54	54.37

Table 18 Reduction percentage in plant height, panicle length, PBT/hill, one panicle weight, straw weight/hill, 1000 grain weight, harvest index and grain yield/hill of eleven medium flowering rice varieties grown in test-plots under alkali and saline soil environments

Genotypes	Plant height		Panicle length		PBT/hill		Panicle weight	
	Alkali	Saline	Alkali	Saline	Alkali	Saline	Alkali	Saline
Giza 159	14.90	23.17	8.13	9.64	7.87	29.59	29.71	27.48
IR 2053	15.12	22.12	8.30	7.40	-6.70	-19.64	44.24	42.05
HAU 5-298	12.64	26.41	11.03	19.39	3.43	10.51	35.76	47.02
HAU 6-163	8.88	14.08	4.70	-1.38	10.59	7.48	41.00	32.77
IET 4141	6.02	17.34	5.71	8.57	10.98	5.68	15.00	35.17
PR 106	13.16	20.15	6.18	8.82	-4.48	1.47	37.47	48.06
Jaya	15.08	24.27	6.44	11.02	-8.40	-6.30	31.67	53.68
M-1-48	14.47	18.51	9.11	5.30	24.53	16.98	14.13	33.99
TR 17	14.13	27.94	6.89	6.89	3.22	2.89	32.39	40.89
Bas 370	14.29	29.68	7.66	16.42	10.07	29.87	23.44	18.38
IR 54	16.33	33.67	8.37	22.95	-1.62	24.35	31.63	32.98

Continued

Table 18 Continued

Genotypes	Straw weight/hill		1000 grain weight		Harvest index		Yield/hill	
	Alkali	Saline	Alkali	Saline	Alkali	Saline	Alkali	Saline
Giza 159	40.65	55.84	8.44	13.28	-10.09	-5.98	26.71	49.64
IR 2053	47.40	22.65	3.99	11.41	-14.42	12.26	27.92	40.37
HAU 5-298	39.75	47.95	7.27	14.95	2.56	12.56	43.03	60.66
HAU 6-163	36.43	37.49	2.93	13.78	2.80	-4.66	39.96	30.37
IET 4141	41.04	54.10	2.56	12.50	-11.94	-11.67	25.09	42.70
PR 106	33.89	41.14	6.50	14.52	2.95	3.86	37.97	46.90
Jaya	37.04	43.90	8.13	14.93	-1.10	9.05	35.24	54.66
N-1-48	43.60	52.54	2.87	11.34	-11.92	-3.52	30.37	49.66
TR 17	39.03	54.76	3.90	15.18	-5.68	-5.19	31.80	49.55
Bas 370	17.11	51.42	-3.93	12.35	4.07	-24.07	26.44	30.00
IR 54	34.54	45.01	6.59	19.44	-0.70	2.32	34.42	48.79

Table 19 Reduction percentage in plant height, panicle length, PBT/hill, one panicle weight, straw weight/hill, 1000 grain weight, harvest index and grain yield/hill of thirteen late flowering rice varieties grown in test-plots under alkali and saline soil environments

Genotypes	Plant height		Panicle length		PBT/hill		Panicle weight	
	Alkali	Saline	Alkali	Saline	Alkali	Saline	Alkali	Saline
PAU 269	13.37	26.31	5.80	11.16	-9.42	-28.62	26.16	39.95
Bhurarata	10.19	28.70	11.68	24.37	5.62	9.93	8.86	32.55
IR 2055	8.85	31.72	2.39	5.26	-3.06	-13.33	20.70	38.83
MGM-1	16.55	30.38	9.13	18.26	14.50	28.75	8.06	48.09
Kalarata	12.41	33.16	-5.37	24.16	-1.94	-10.54	9.40	18.80
IR 2031	13.14	38.42	7.98	17.37	-5.79	4.13	11.98	44.03
Getu	9.80	23.99	5.06	10.67	4.61	-13.83	16.15	46.63
Damodar	13.61	25.17	14.36	20.00	0	-15.63	22.52	37.22
Dasal	11.95	26.49	8.20	16.39	4.43	- 6.96	9.31	30.69
Pokkali	18.27	30.99	-3.69	11.98	34.68	7.51	1.20	31.14
Arya	18.51	33.37	13.78	23.56	2.34	-0.88	17.70	56.22
SR 3-9	13.34	37.28	7.80	27.98	3.67	17.74	0.52	40.87
SR 10032	20.88	46.59	1.67	17.22	25.85	16.10	4.99	47.95

Continued

Table 19 Continued

Genotypes	Straw weight/hill		1000 grain weight		Harvest index		Grain yield/hill	
	Alkali	Saline	Alkali	Saline	Alkali	Saline	Alkali	Saline
PAU 269	24.42	15.07	6.77	12.61	0.56	15.97	25.38	31.93
Bhurarata	19.71	60.65	4.10	24.20	-0.99	-5.26	17.02	56.58
IR 2055	21.03	35.03	2.95	18.94	-5.87	6.38	11.32	42.89
MGM-1	33.79	43.70	15.48	1.27	9.25	43.58	43.72	76.06
Kalarata	23.76	53.20	-2.04	15.73	-15.42	-22.90	6.41	37.32
IR 2031	40.99	51.71	-0.61	23.26	-21.59	36.74	19.64	73.94
Getu	29.96	33.75	-2.41	20.11	-3.51	10.88	20.29	32.73
Damodar	31.75	43.26	1.58	17.70	-5.79	-3.31	26.41	40.25
Dasal	17.69	23.56	3.06	21.84	1.93	16.60	15.59	34.05
Pokkali	52.81	57.12	0.35	17.83	-21.05	-6.70	39.14	53.52
Arya	18.67	49.02	4.90	19.44	14.04	53.07	33.94	79.81
SR 3-9	32.72	47.32	5.23	22.71	-18.96	20.85	11.18	61.68
SR 10032	44.56	46.75	-5.04	14.61	-27.33	33.72	25.99	66.64

4.4.1.2 Plant height

In the early flowering group, mean value for plant height ranged from 78.14 to 152.69 cm with a group mean of 96.35 cm under optimal soil condition. The genotypic and phenotypic coefficients of variance were 26.48 and 26.80 respectively with a heritability value of 97.57%. Varieties Bilekagga (152.69 cm) and Karekagga (149.39 cm) were the tallest followed by Jhona 349 (132.11 cm). Variety Pusa 150 (78.14 cm) recorded lowest plant height followed by Kalinga I, Kalinga II, P-2-21, CSR-4, Pusa 167 and CR143-2-2 which were statistically at par with Pusa 150.

Under saline and alkali soil environments varieties showed differential reductions in their height as presented in Table 17. In general higher reductions were observed in saline environment. Under both alkali and saline environment varieties Bilekagga (9.91 and 20.34%) and Karekagga (10.88 and 17.98%) recorded lower reductions.

Data presented in Table 13 show that among the medium flowering varieties grown under non-alkali-non-saline soil environment, mean plant height ranged from 75.00 to 168.88 cm, with a group mean of 101.36 cm. The genotypic and phenotypic coefficient of variances were 24.67 and 25.08 respectively with a heritability value of 96.8%. Variety Bas 370 was the tallest and IR54 the shortest.

Reduction under alkali and saline soil stress was found to be high in varieties, IR54 (16.33 and 33.67%), Bas 370 (14.29 and 29.68%), Jaya (15.08 and 24.27%) and TR17 (14.13 and 27.94%). On the other hand, low reduction was recorded in IET 4141 (6.02 and 17.34%) and HAU-6-163 (8.88 and 14.08%).

In late flowering group, 11 out of 13 varieties were tall, with plant height measuring more than 135 cm, excluding panicle length as presented in Table 15. Variety IR2055 was dwarf (74.88 cm) and PAU 269 was of medium tall (116.99 cm). Pokkali recorded the maximum height of 227.88 cm. The genotypic and phenotypic coefficient of variance were 27.01 and 27.25% with a heritability value of 98.79% under optimal condition which was highest among the three flowering groups.

Data given in Table 19 reveal that in late growing varieties, salinity stress was found to reduce plant height drastically rather than alkalinity stress. The reduction ranged from 23.99% to 46.59% under salinity stress, whereas in alkali stress, the range was 8.85 to 20.88%. Variety SR 10032 showed maximum reduction both in alkali and saline stress (20.88 and 46.59%) followed by Arya (18.51 and 33.37%). Variety Getu (9.80 and 23.96%) and Dasal (11.95 and 26.19%) showed low reduction both in alkali and saline environments. The dwarf variety IR2055 recorded lowest reduction (8.85%) only in alkali soil.

Under stress conditions, the heritability value for plant height was found to be decreased in all the three flowering groups. However, the genotypic and phenotypic coefficient of variances were found to be increased by stress in early group and a reverse tendency was found in medium group. In late flowering group, it decreased under alkali environment but increased under saline conditions. The genetic advance values for this character also showed a similar trend. Under non-stress soil environment, the genetic advance values were 53.88, 50.00 and 55.13 per cent over mean for early, medium and late group respectively. Under alkali and saline stresses, the corresponding

values were 62.11 and 62.46 for early group, 48.21 and 47.23 for medium group and 44.06 and 54.90 for late group respectively.

Reduction in plant height under stress condition was not found to be correlated with respective yield reduction in early and medium flowering varieties. However, it was found to be significantly and positively correlated with grain yield reductions of the late flowering group under both saline ($r=0.624$) and alkali ($r=0.686$) stresses.

4.4.1.3 Panicle length

Among the early flowering group grown in favourable soil, variety Karekagga was observed to have the maximum panicle length (39.51 cm) followed by Bilekagga (36.13 cm). Both these varieties were tall ones. However, among the dwarf varieties CSR-5 recorded maximum panicle length (29.35 cm). Pusa 167, Pusa 150 and Jhona 349 varieties were statistically at par with CSR-5. Minimum length of the panicle was recorded in CR 237-1 (24.35 cm).

Salinity and alkalinity stresses were found to reduce panicle length. The group means were 25.74 cm and 25.02 cm in alkali and saline environments respectively as compared to 28.26 cm in favourable soil condition. The two tall varieties Karekagga and Bilekagga recorded maximum panicle length both in saline and alkali environments. However, the reduction percentage was high for these varieties in saline environments (28.09 and 17.30% respectively). Low reduction and high mean value was recorded in CSR5.

Among the medium flowering varieties the panicle length ranged from 25.01 to 34.25 cm with a group mean of 28.30 cm.

The tall variety Bas 370 recorded the maximum panicle length followed by HAU 5-298 (32.88 cm) whereas variety IR2053 recorded the minimum length. In alkali soil, HAU-5-298 showed maximum reduction (11.03%) followed by M-1-48 (9.11%). HAU-6-163 and IET 4141 recorded low reduction. In saline soil, IR54 recorded the maximum reduction of 22.95% followed by HAU-5-298 (19.39%) and Bas 370 (16.42%). Variety HAU-6-163 showed no significant difference in panicle length.

Under non stress environment, the panicle length of late flowering varieties ranged from 18.63 to 30.13 cm with the group mean of 25.28 cm. Variety MCM-1 recorded the maximum panicle length of 30.13 cm. Arya, which recorded a panicle length of 28.13 cm was at par with MCM-1. Kalarata recorded shortest panicle length of 18.63 cm.

Under salt stress conditions, IR2055, Getu and SR10032 did not show any significant reductions. Bhurarata, Arya and MCM-1 showed maximum reduction under both stress conditions. Pokhali, Dasal and Kalarata recorded panicle length statistically at par with control in alkali stress.

The phenotypic coefficient of variances for panicle length of early, medium and late flowering varieties grown in non-stress environment were 15.56, 11.85, and 13.64, respectively, whereas under alkali stress they were 15.48, 11.00, 13.28 and in saline environment 11.80, 12.24 and 17.28 respectively. Heritability value was found to be reduced by stress conditions except for the late group. Heritability values recorded in non-stress, alkali and saline soil environments were 92.15, 89.26 and 82.42% in the early group, 80.73, 78.10 and 71.04% in the medium group and 81.94, 79.54 and 89.84% in the late group.

4.4.1.4 Panicle bearing tillers per hill

Under the favourable environment, higher values for this trait were recorded in varieties Kalinga II, CSR-5 and CR237-1 (19.13 to 22.38) of the early group; IR54, TR17, HAU-6-163 and HAU-5-298 (19.25 to 21.06) of the medium group; and MCM-1, Kalarata and Bhurarata (24.56 to 33.38) of the late group. High reductions from that of the normal soil were noticed in varieties CR237-1 (> 25%) in early group; M-1-48, Bas 370 and Giza 159 (> 20%) in medium group; MCM-1 and SR10032 (> 15%) in late group under saline and alkali soil environments, whereas significant increase was noticed in varieties Karekagga, Damodar, Getu and PAU 269.

The variability measured in terms of PCV and GCV and heritability were higher in the late flowering group (30.58, 33.01 and 85.79% respectively). The data further indicates that the average coefficient of variances and heritability estimates were higher under stress environments as compared to non-stress environment.

4.4.1.5 Panicle weight

Under favourable soil conditions, panicle weight ranged from 2.33 to 6.80 gm with a group mean of 4.50 gm in early group. The GCV, PCV and heritability estimates were 29.16, 32.75 and 79.09% respectively. Varieties Bilekagga, Karekagga and Jhona 349 had higher panicle weight (6.30 to 6.80 gm) while lower values were noticed in CR 237-1, Kalinga I and Kalinga II (2.33 to 3.01 gm).

High reductions were observed in Karekagga, Jhona 349 and Bilekagga (58.61, 44.88 and 42.53% respectively), while low reductions were observed in CR143-2-2, CR237-1 and CR222

(18.48, 23.23 and 28.51% respectively) under salinity stress. However, per se performance was highest in Bilekagga, CR143-2-2 and Jhona 349 followed by CSR-5 and CR222.

Panicle weight ranged from 3.36 to 6.50 gm in the medium group with a group mean, GCV, PCV and heritability values of 4.72 gm, 21.83%, 24.69% and 78.23% respectively under non-stress soil environment. Jaya recorded the highest and Bas 370 recorded the lowest panicle weight. High reductions induced by alkali stress were observed in IR2053 (44.24%) and HAU-6-163 (41.0%) whereas salinity stress induced high reductions in Jaya (53.68%), PR-106 (48.06%) and HAU-5-298 (47.02%). Varieties Giza 159 and Bas 370 recorded low reduction, 27.48 and 18.38% respectively under salt stress.

The GCV and PCV values increased in stress environment, which was higher in saline environment. However, the heritability values recorded were lower than that in the non-stress environment.

The ranges of panicle weight recorded in late flowering group were 2.54 to 5.52 gm in non-stress environment, 2.30 to 5.45 gm in alkali stress and 1.70 to 3.80 gm in salt stress. The mean values were 3.74, 3.30 and 2.23 gm respectively. 21.08, 28.66 and 24.07% were the GCV values and 24.16, 31.95 and 28.99% were the PCV values recorded in non-stress, alkali and saline soil environments respectively. The estimate of heritability was 76.14% in normal soil, whereas it increased in alkali (80.46%) and decreased in saline (68.96%) soil environments. In all the three environments Pokkali recorded the maximum panicle weight. No significant reduction for panicle weight was recorded in Kalarata in both stress environments. High reductions were recorde in Arya (56.22%) and MCM-1 in saline and PAU 269 in alkali (26.16%) stresses.

4.4.1.6 Straw weight per hill

The straw weight per hill ranged from 29.40 gm in Pusa 167 to 73.94 gm in Bilekagga with a group mean of 40.44 gm in non-stress soil condition in the early group. In general, straw weight recorded an average reduction of 28% in alkalinity stress and 38% in salinity stress. No significant reduction was observed in the variety IET 1444 under both stresses. In alkalinity stress, CR222, CSR4 and Pusa 167 also recorded straw weight statistically at par with respective controls. However, high reductions under salinity stress were observed in P-2-21, CR237-1 and Jhona 349 (> 50%) and under alkalinity stress in CR214, P2-21, CR-143-2-2 and CR237-1 (> 35%).

The heritability values were reduced to 79.77% and 78.12% respectively under alkalinity and salinity stresses as compared to 86.42% in control, whereas the PCV recorded an increasing trend from 38.8 to 43.8%.

In the medium group, the tall variety Bas 370 recorded the maximum straw weight of 71.71 gm followed by HAU-6-163 (61.01 gm). Varieties Jaya, TR17, PR106 and HAU-5-298 were at par with HAU-6-163. High stress induced reductions were observed in IR2053 (47.40%) and MI-48 (43.60%) in alkali soil. More than 50% reduction in saline soil was recorded in M 1-48, TR17, Bas 370, Giza 159 and IET4141.

The GCV and PCV estimates were 17.81 and 20.00 respectively under non-stress soil condition, which recorded an increase of two fold (31.19 and 35.22%) in alkali stress and an increase of lower magnitude in saline soil stress (21.26 and 28.99%). Heritability estimate of 79.26% recorded in non-stress soil condition was drastically reduced to 53.77% in salt stress. However, in alkalinity stress it was 78.43%.

In the late group, straw weight ranged from 55.70 gm in PAU269 to 160.43 gm in Arya with a group mean of 107.95 gm. Low reductions were observed in alkali stress in Dasal, Arya and Bhurarata (17.69 to 19.71%) whereas in saline soil stress, Dasal, Getu, IR2055 and PAU269 (15.07 to 35.03%) recorded low reductions. High reductions were observed in IR2031, Pokkali, MCM-1 and SR 10032 (40 to 57%).

The recorded GCV and PCV estimates of 30.69 and 34.77% in non-stress soil were found to be increased by alkalinity stress to 33.99 and 39.32% whereas it was reduced to 24.90 and 32.13 respectively in salinity stress. The heritability estimates recorded in saline (60.05%) and alkali (74.70%) were comparatively lower than that recorded in non-stress soil (77.91%).

4.4.1.7 1000-Grain Weight

Under favourable soil environment varieties, Karekagga (33.85 gm), Bilekagga (33.66 gm) recorded higher grain weight followed by CR222, CR214 and Jhona 349 among the early flowering group. Low grain weight was noticed in the varieties Pusa 150 (19.67 gm), Pusa 167, CSR-4 and IET 1444 (21.16 to 21.71 gm). Alkalinity stress did not induce any significant change in the grain weight of the varieties CR237-1, IET1444, Pusa 150 and Karekagga. Salinity induced reductions were high in Kalinga II, Kalinga-I, Pusa 167 and P2-21 (16.31 to 19.39%). Low reductions were observed in IET1444 (8.93%) and Pusa 150 (9.94%). However, the *per se* grain weight was high in Karekagga, Bilekagga, Jhona 349, CR222 and CR214 in all the environments.

In the medium group, Jaya recorded the maximum grain weight of 30.08 gm, followed by HAU-6-163 (28.98 gm). Lowest grain weight was recorded in Bas 370 (19.42 gm). IR2053,

IET 4141 and M 1-48 were the other varieties which showed low grain weight (21.12 to 21.99 gm). Salinity induced reduction ranged from 11.34% in M 1-48 to 19.44% in IR54 and in alkali stress grain weight was at par with respective controls except for varieties Giza 159, HAU 5-298, PR106, Jaya and IR54.

In the late flowering group, varieties SR3-9 and IR2031 recorded lowest grain weight of 13.09 and 15.16 gm respectively under non-stress soil condition. High grain weight was recorded in Pokkali (30.48 gm) and Arya (29.59 gm). Alkali stress did not show significant reduction in grain weight in this group. However, salinity stress induced significant reductions in grain weight except for the variety MCM-1. The reduction ranged from 12.61% in PAU269 to 24.20% in Bhurarata.

Grain weight recorded high heritability estimates in all the three groups, 97.82, 96.77 and 98.50% respectively, which remained more or less constant in stress environment. The GCV values were 17.81, 14.40 and 23.19% respectively for the three groups which recorded a marginal increase in salt stress. The PCV values were very close to that of GCV values.

4.4.1.8 Harvest index

Harvest index ranged from 0.428 to 0.656 in early group. The two tall varieties, Karekagga and Bilekagga recorded the lowest harvest index values. CSR-5 recorded the highest harvest index value. This was followed by CSR-4, Pusa 167, CR222, CR214 and IET 1444 (0.600 to 0.633) which were at par with CSR-5. The broad sense heritability recorded was 75.43% with GCV and PCV estimates of 11.52 and 13.26% respectively.

In the medium flowering varieties harvest index ranged from 0.360 in Bas 370 to 0.566 in Jaya. Varieties PR106, Giza 159, IR54, HAU-5-298 and HAU-6-163 recorded harvest index ranging from 0.536 to 0.550 which were at par with Jaya. Heritability estimate was higher than the early group (86.36%). The GCV and PCV were 11.37 and 12.23% respectively.

The harvest index ranged from 0.215 to 0.490 in late duration rice varieties with a mean value of 0.334. Variety IR2055 recorded the maximum value of 0.490 followed by PAU269 (0.446) and MCM-1 (0.419). Lowest value was recorded in SR 10032. The heritability estimate was 87.65%. The GCV and PCV values were higher than the early and medium flowering varieties (23.63 and 25.24% respectively).

4.4.1.9 Grain yield/plant

Among the 15 early group varieties, the grain yield per plant ranged from 36.81 gm in CR237-1 to 76.94 gm in Jhona 349 with a group mean of 51.21 gm under non-stress soil environment. The variety CSR-5 gave an yield of 75.52 gm which was at par with Jhona 349. Values presented in Table 11 show that under alkali stress, Jhona 349 recorded highest *per se* yield of 50.32 gm followed by CR222, Karekagga, Bilekagga and CSR-5 which were at par with Jhona 349. In saline soil, the grain yield ranged from 21.51 gm to 38.17 gm with a mean of 31.03 gm. Highest *per se* yield was recorded in CSR-5 even though it recorded a reduction of 49.45% as compared to non-stress environment. Jhona 349, CR214, Pusa 150, Pusa 167, CSR-4 and CR222 were at par with CSR-5 in *per se* performance. Kalinga-II, Kalinga-I and CR237-1 were the lowest yielders (21.51 to 22.51 gm).

The GCV and PCV values estimated were 24.05 and 27.29% which showed a decreasing trend under stress environment. The heritability value of 77.65% in optimal soil condition was reduced to 58.88% in alkali soil and to 55.63% in saline soil condition.

Mean grain yield and grain yield reductions among the eleven medium flowering rice varieties studied are presented in Tables 13 and 18 respectively showed that the grain yield ranged from 36.23 to 71.54 gm with a group mean of 56.70 gm. Jaya, HAU-6-163, PR106 and HAU-5-298 were the high yielders whereas IET4141, Bas 370, and M-1-48 were the low yielders. Per se yield in alkali soil was highest for Jaya (46.33 gm) followed by HAU-6-163, PR106, Giza 159 and TR17. The lowest yielders were M-1-48 (25.22 gm), Bas 370 and IET 4141. However, the stress induced yield reduction in alkali soil ranged from 25.09% for IET 4141 to 43.03% for HAU-5-298. In saline soil, varieties Jaya, HAU-5-298, M-1-48, Giza 159 and TR17, recorded high reduction (49.55 to 60.66%). Per se yield was high in HAU-6-163 (49.12 gm) followed by (36.20 gm) PR106.

The heritability values recorded were 78.73% in non-stress soil condition, 62.08% in alkali and 74.76% in saline soil. GCV and PCV estimates were 22.94 and 25.85% in non-stress environment which was reduced to 17.41 and 22.10% in alkali stress and increased to 26.78 and 30.98% in salt stress respectively.

Grain yield per plant ranged from 26.86 gm to 103.22 gm in the late flowering group with an overall mean of 52.01 gm in non-stress soil environment. Variety MCM-1 recorded the

highest grain yield followed by Bhurarata (74.80 gm) and Arya (62.99 gm). Low yield was recorded in SR 10032 (26.86 gm) and SR 3-9 (38.49 gm). In alkali soil stress, per se yield was high for Bhurarata and MCM-1 (62.38 and 58.09 gm). This was followed by Kalarata, Arya, Getu and IR2055. A mean reduction of 24.75% was recorded under alkali stress. Lowest reduction of 6.41% was recorded in Kalarata and highest reduction of 43.72% was recorded in MCM-1. Other varieties which showed less than 20% reduction were Bhurarata, IR2055, Dasal and SR3-9.

Salt stress induced an average of 55.16% reduction in grain yield among the late maturing varieties. The average yield was 23.32 gm/plant. Bhurarata recorded the highest yield of 32.48 gm. Varieties Getu, IR2055, PAU269, Kalarata and Dasal were the other high yielders in saline soil which were at par with Bhurarata. Lowest yield was recorded in IR2031, Arya, SR 10032 and SR3-9 (8.96 to 14.75 gm). Varieties Getu, Dasal, Kalarata and PAU269 recorded less than 38% reduction whereas MCM-1, IR2031 and Arya recorded more than 70% reduction.

4.4.2 Stability Analysis

The extent of genotype x environment interactions was studied by stability analysis using the method developed by Eberhart and Russell (1966). Thirty nine varieties from three maturity groups were raised under six environments. The results obtained are summarised in Tables 20 to 32.

Mean squares due to varieties for all the nine characters were significant revealing that there was enough variability among the varieties. Mean squares due to environments were

Table 20 Analysis of variance for stability of nine characters in fifteen early flowering rice varieties grown in three edaphic environments for two years

Sources of variation	d.f.	Mean squares								
		Days to flowering	Plant height (cm)	Panicle length (cm)	PBT/ hill	Panicle weight (gm)	Straw weight/ hill (gm)	1000 grain weight (gm)	Harvest index	Yield/ hill (gm)
Varieties (V)	14	333.10**	3518.76**	66.46**	36.84**	5.04**	747.78**	103.51**	0.0269**	351.38**
Environments (E)	5	55.14**	1977.60**	41.51**	36.44**	11.48**	798.81**	55.30**	0.0011**	1261.99**
VxE	70	1.60*	17.21*	2.96**	6.30*	0.35*	29.70*	1.33**	0.0012*	39.37*
Environment (linear)	1	275.78**	9888.00**	207.57**	182.18**	57.42**	3994.03**	276.52**	0.0054*	6309.95**
VxE(linear)	14	1.38	31.27**	7.41**	11.79**	0.89**	45.59*	1.08	0.0020*	82.02**
pooled deviation	60	1.54**	12.78**	1.72**	4.60**	0.20**	24.01**	1.30**	0.0010**	26.79**
Pooled error	252	1.45	16.72	1.55	4.98	0.27	28.97	0.52	0.0010	35.28

* Significant at P=0.05, ** Significant at P=0.01

Table 21 Analysis of variance for stability of nine characters in fifteen early flowering rice varieties grown in three edaphic environments for two years

Sources of variation	d.f.	Mean squares								
		Days to flowering	Plant height (cm)	Panicle length (cm)	PBT/hill	Panicle weight (gm)	Straw weight/ hill (gm)	1000 grain weight (gm)	Harvest index	Yield/ hill
Varieties (V)	10	184.28**	2697.04**	32.00**	36.12**	1.74**	299.60**	55.96**	0.0139**	389.42**
Environments (E)	5	84.21**	1442.29**	24.95**	54.69**	11.41**	1580.87**	38.80**	0.0016	1661.34**
VxE	50	7.92**	41.72**	3.36*	7.01*	0.38*	50.21**	0.87**	0.0012*	44.67*
Environments (linear)	1	421.05**	7214.67**	124.76**	273.46*	57.04**	7904.37**	194.04**	0.0058*	8306.71**
VxE (linear)	10	15.64**	109.31**	4.94	10.21	0.60	22.06	1.27	0.0019*	81.49*
Pooled deviation	44	5.44**	22.57**	2.70**	5.64**	0.30**	52.05**	0.70	0.0009**	32.24**
Pooled error	180	1.95	19.59	2.23	4.96	0.24	28.00	0.67	0.0008	28.28

* Significant at P=0.05

** Significant at P=0.01

Table 22 Analysis of variance for stability of nine characters in thirteen late flowering rice varieties grown in three edaphic environments for two years

Sources of variation	d.f.	Mean squares								
		Days to flowering	Plant height (cm)	Panicle length (cm)	PBT/hill	Panicle weight (gm)	Straw weight/hill (gm)	1000 grain weight (gm)	Harvest index	Yield/hill (gm)
Varieties (V)	12	526.08**	5049.71**	4934**	241.56**	2.97**	3002.28**	132.67**	0.036**	784.28**
Environments (E)	5	335.06**	6219.54**	63.81**	27.37*	7.03**	7077.03**	49.17**	0.014**	2263.43**
VxE	60	16.07**	281.25**	1.93*	8.48*	0.15	240.09*	3.56**	0.002*	95.57**
Environments (linear)	1	1675.34**	31097.78**	319.03**	136.84**	35.13**	35385.17**	245.85**	0.072**	11317.12**
VxE(linear)	12	36.13**	352.88	3.33*	12.32	0.32**	567.23**	5.99*	0.005**	350.98**
Pooled deviation	52	10.21**	243.10**	1.46**	6.94**	0.09**	146.13**	2.73**	0.001**	29.28**
Pooled error	216	0.80	39.37	1.79	6.29	0.17	219.31	0.54	0.001	28.46

* Significant at P=0.05

** Significant at P=0.01

significant for all characters, excepting for harvest index in early and medium duration rice varieties, indicating that environments created in this study were distinct. Pooled analysis of variance presented in Tables 20 to 22, revealed significant G x E interactions for all characters studied, excepting panicle weight in late maturing varieties, suggesting that the varieties were unable to maintain consistant performance under different environments. Mean squares due to environments (linear) were highly significant. The genetic differences among varieties for their regression on environmental index were indicated by significance of mean squares due to G x E (linear) for plant height, panicle length, panicle bearing tillers, panicle weight, straw weight, harvest index and grain yield per plant in early group; days to flowering, plant height, harvest index and yield per plant in medium group; and for all characters studied except for plant height and panicle bearing tillers in late flowering group. Mean squares due to pooled deviation were significant for all the nine characters. Thus, the existance of non-linear component of G x E interaction in respect of these characters was evident.

4.4.2.1 Environmental indices

During the present investigation, varieties were grown under six environments at one location. The environmental additive effects (I_j) for each character over the environments, expressed as deviation from general mean is presented in Tables 23 to 25. Considering the grain yield per plant, the additive environmental effects (I_j) were highest for the first two environments (E_1 & E_2) corresponding to optimal

Table 23 Estimates of environmental indices for nine characters in 15 early flowering rice varieties grown in three edaphic environments for two years

Environments	Characters								
	Days to flowering	Plant height (cm)	Panicle length (cm)	PBT/ hill	Panicle weight (gm)	Straw weight/ hill (gm)	1000 grain weight (gm)	Harvest index	Yield/ hill (gm)
Non-stress	-2.12	11.94	2.15	-0.60	1.08	9.39	1.36	-0.0024	11.4
Non-stress	-0.42	12.46	1.69	-0.12	0.84	8.44	1.73	-0.0075	9.83
Alkali	-0.90	-9.41	-1.24	1.52	-0.60	-4.49	-0.72	0.0130	-3.07
Alkali	3.52	4.66	0.04	-0.88	0.17	-0.10	1.38	0.0072	0.79
Saline	-0.57	-15.75	-0.21	2.14	-1.23	-6.70	-3.31	-0.0087	-10.17
Saline	0.48	-3.89	-0.51	-2.07	-0.24	-6.54	-0.43	-0.0015	- 8.86
General mean	87.98	84.27	26.34	17.01	3.55	31.54	22.62	0.5683	40.55

Table 24 Estimates of environmental indices for nine characters in eleven medium flowering rice varieties grown in three edaphic environments for two years

Environments	Characters								
	Days to flowering	Plant height (cm)	Panicle length (cm)	PBT/ hill	Panicle weight (gm)	Straw weight/ hill (gm)	1000 grain weight (gm)	Harvest index	Yield/ hill (gm)
Non-stress	-3.76	14.40	2.33	1.37	1.60	15.04	1.03	-0.0030	16.32
Non-stress	-1.73	10.58	1.14	0.31	1.06	14.92	1.92	-0.0116	13.86
Alkali	0.79	-2.46	-0.67	2.17	-0.94	-4.16	-0.13	0.0154	-3.34
Alkali	1.04	0.49	-0.16	-2.03	0.16	-5.52	0.85	0.0095	-4.55
Saline	4.36	-17.23	-1.90	1.58	-1.34	-12.99	-3.48	-0.0037	-14.01
Saline	-0.69	- 5.78	-0.75	-3.40	-0.10	- 7.29	-0.20	-0.0064	- 8.29
General mean	108.55	88.87	26.56	16.49	3.61	39.40	22.20	0.5146	41.61

Table 25 Estimates of environmental indices for nine characters in thirteen late flowering rice varieties grown in three edaphic environments for two years

Environments	Characters								
	Days to flowering	Plant height (cm)	Panicle length (cm)	PBT/ hill	Panicle weight (gm)	Straw weight/ hill (gm)	1000 grain weight (gm)	Harvest index	Yield/ hill (gm)
Non-stress	-6.15	25.19	2.40	-0.92	0.67	19.21	1.79	0.0172	11.61
Non-stress	-0.28	22.42	1.62	1.48	0.63	35.56	1.18	0.0022	16.03
Alkali	-4.17	-5.26	-0.27	-0.16	-0.16	-10.27	0.70	0.0261	-1.79
Alkali	-0.28	8.27	1.08	-1.09	0.58	1.05	1.08	0.0351	3.87
Saline	8.12	-36.69	-3.69	2.08	-1.01	-26.10	-3.19	-0.0488	-17.60
Saline	2.75	-13.92	-1.13	-1.39	-0.70	-17.34	-1.56	-0.0316	-12.12
General mean	133.28	128.20	23.27	20.23	3.09	80.57	20.55	0.3226	38.16

condition as compared to the last four (E_3, E_4 and E_5 , E_6) environments corresponding to str ss environments (alkali and saline respectively). Similar pattern was followed by plant height, panicle length, panicle weight, straw weight and 1000 grain weight in all the three maturity groups. However, the days to 50% flowering had high mean values under stress environments as compared to the normal soil condition. Therefore, optimal environmental condition was favourable for most of the characters under study.

4.4.2.2 Estimation of stability parameters

The average performance ($\bar{x}_i$) of each variety along with two stability parameters, viz. bi and S_d^2 , in respect of all the characters under study are presented in Tables 26 to 31. Information pertaining to individual traits on this aspect is described below.

4.3.2.2.1 Days to 50% flowering

In early maturing group eleven varieties were free from G x E interaction as revealed by their non-significant bi and $\bar{S}_d^2$ values (Table 27). Significance of b_i and $\bar{S}_d^2$ revealed that both linear and non linear portion of G x E interactions were present for the variety Bilekagga. Varieties CR 237-1, Kalinga II, P2-21, CR222 and CR-214 were the earliest in days to flower ($\bar{x}_G < \bar{x}_p$) with regression values not significantly different from 1.00, whereas varieties Jhona 349, Pusa 167, CSR-5, Pusa 150 and Karekagga recorded above average days to flower with average stability.

Data presented in Table 29 show that in the medium group, only PR106 and HAU-6-163 were free from G x E interaction. The significance of both the components of G x E interaction

Table 26 Estimates of stability parameters of 15 rice genotypes for plant height, panicle length, panicle weight, straw weight/hill and grain yield/hill in early flowering group in three edaphic environments for two years

Genotypes	Plant height (cm)			Panicle length (cm)			Panicle weight (g)			Straw wt/hill (g)			Grain yield/hill (g)		
	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2
CR 237-1	90.55	0.95	19.01	22.87	0.52	2.03	2.03	0.28	-0.01	27.37	1.29	7.21	26.31	0.83	21.74
Kalinga II	71.99	0.98	9.45	22.90	0.93	0.48	2.39	0.61	0.02	26.84	0.68	0.97	32.98	0.95	24.87
Kalinga I	70.57	1.04	8.92	24.39	0.70	1.52	2.30	0.60	0.02	27.63	0.97	4.78	32.14	0.85	5.86
P-2-21	68.66	0.80	-0.86	25.13	0.47	0.45	3.69	1.12	-0.05	27.88	1.56	101.49**	39.58	0.94	41.89
CR 222	71.28	0.95	2.78	25.78	0.48	-0.21	3.91	0.68	0.08	25.28	0.67	10.43	43.80	0.72	24.23
CR 214	71.48	1.08	2.04	25.98	0.78	0.56	3.70	0.96	-0.03	24.42	0.96	1.38	43.67	0.87	9.61
IET 1444	76.96	0.83	15.46	26.25	0.70	-0.23	3.02	0.74	-0.02	26.81	0.42	-1.48	38.04	0.60	3.59
OSR-4	71.06	0.82	-1.34	22.54	0.93	-0.10	3.29	0.78	0.01	24.01	0.68	-3.11	41.21	0.92	3.53
Jhona 349	144.88	1.48	31.10	25.95	1.34	0.97	4.77	1.49	0.25	40.09	1.69	3.10	54.81	1.94	6.83
Pusa 167	72.09	0.90	-1.78	27.08	0.91	-0.14	3.59	1.25	0.38	25.44	0.53	-2.42	40.25	0.80	-2.04
OSR-5	72.66	1.01	4.69	28.37	0.42	0.92	3.94	1.19	0.09	31.07	0.88	74.87*	52.84	1.81	77.69*
CR143-2-2	70.34	0.93	4.11	24.74	0.54	0.47	3.92	0.60	0.36	24.78	0.87	12.66	32.90	0.45	13.54
Pusa 150	69.18	0.68	9.20	26.17	0.95	2.67	2.87	0.87	0.15	26.95	0.79	-6.53	39.02	0.60	2.85
Bilekagga	137.29	1.44	11.45	32.67	2.28	4.11*	5.17	1.84	0.12	58.94	1.66	44.06	44.85	1.12	17.49
Karekagga	135.02	1.08	14.74	34.31	3.05	5.45**	4.62	1.99	0.53	55.62	1.35	4.07	45.78	1.59	17.89
Mean	84.27	1.00		26.34	1.00		3.55	1.00		31.54	1.00		40.55	1.00	
S.E.±	1.60	0.14		0.59	0.35		0.20	0.23		2.19	0.30		2.31	0.25	

* Significant at P=0.05, ** Significant at P=0.01

Table 27 Estimates of stability parameters of 15 rice genotypes for days to 50% flowering, PBT/hill, 1000 grain weight and harvest index in early flowering group grown in three edaphic environments for two years

Genotypes	Days to flowering			PBT/hill			1000 grain wt(g)			Harvest index		
	$\bar{x}$	b_i	Sd_i^2	x	b_i	Sd_i^2	x	b_i	Sd_i^2	x	b_i	Sd_i^2
CR 237-1	69.83	0.86	0.98	18.23	-0.99	11.75*	20.70	0.98	0.26	0.49	-2.85	0.0004
Kalinga II	77.96	0.66	1.88	20.33	-0.26	2.54	21.69	0.94	2.84*	0.55	3.40	0.0014
Kalinga I	80.58	0.83	0.08	20.15	0.60	-0.33	20.47	0.82	1.06	0.54	2.99	0.0003
P 2-21	84.29	0.96	0.16	14.67	1.25	3.84	20.87	1.05	-0.03	0.60	1.40	0.0025*
CR 222	87.08	0.97	0.22	16.46	0.68	3.56	23.99	1.02	-0.12	0.64	-0.17	0.0001
CR 214	86.54	1.13	1.67	16.90	1.77	-0.41	23.90	1.00	-0.05	0.65	2.90	0.0002
IET 1444	87.67	1.24	-0.23	18.56	1.20	0.36	20.71	0.52	0.48	0.59	-1.43	-0.0002
CSR-4	87.92	1.48	1.05	17.48	1.02	2.01	20.13	0.89	-0.05	0.63	-1.00	-0.0001
Jhona 349	89.88	0.97	0.39	16.69	1.44	1.77	23.49	1.01	0.65	0.58	0.15	-0.0002
Pusa 167	94.00	0.80	1.09	17,21	2.18	1.92	19.13	1.21	0.37	0.61	-2.38	-0.0001
CSR-5	93.42	1.23	0.21	19.60	1.21	5.22	20.44	1.22	0.50	0.62	0.52	0.0018
CR143-2-2	94.21	0.50	-0.29	11.81	-0.49	1.18	20.58	0.93	0.37	0.58	4.05	0.0008
Pusa 150	95.25	0.95	0.13	18.69	0.97	1.50	18.96	0.81	0.42	0.59	-0.14	0.0010
Bilekagga	95.87	1.48	1.86**	13.02	1.75	1.10	31.58	1.63	3.43**	0.43	4.31	0.0002
Karekagga	95.25	0.96	1.77	15.42	2.64	9.62	32.64	0.97	7.49**	0.44	3.23	0.0024*
Mean	87.98	1.00		17.01	1.00		22.62	1.00		0.57	1.00	
S.E.±	0.56	0.29		0.96	0.62		0.51	0.27		0.01	1.62	

* Significant at P=0.05, ** Significant at P=0.01

Table 28 Estimates of stability parameters of eleven rice genotypes for plant height, panicle length, panicle weight, straw weight/hill and grain yield/hill in medium flowering group grown in three edaphic environments for two years

Genotypes	Plant height (cm)			Panicle length (cm)			Panicle weight (g)			Straw weight (g)			Grain yield/hill (g)		
	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2
Giza 159	97.28	1.19	21.44	24.17	0.87	0.18	3.91	1.01	0.15	31.86	1.04	-2.06	42.16	1.06	20.10
IR 2053	102.10	1.10	13.97	23.70	0.83	0.57	3.66	1.36	0.64*	36.01	0.62	101.33**	39.14	0.79	31.25
HAU-5-298	86.88	1.04	9.17	29.54	2.06	0.78	3.33	1.10	0.04	40.66	1.12	-4.32	43.87	1.53	3.02
HAU-6-163	86.92	0.56	11.13	26.83	0.06	0.32	4.13	1.32	0.71*	45.98	0.98	2.91	54.00	0.98	55.77
IET 4141	80.46	0.66	21.18	25.00	0.70	1.50	3.05	0.68	0.05	36.56	1.14	152.53**	33.03	0.66	60.98*
PR 106	79.23	0.73	0.84	26.13	0.73	+0.24	4.08	1.25	0.23	42.04	0.92	-4.31	48.89	1.22	1.02
Jaya	73.25	0.82	-2.93**	25.97	0.85	-0.12**	4.65	1.46	0.52*	39.82	0.95	13.49	50.11	1.46	42.83
M-1-48	83.49	0.68	100.40	27.83	0.48	13.06	3.14	0.62	0.05	28.76	0.88	-3.61	26.56	0.65	-1.70
TR 17	81.35	1.05	1.75	26.13	0.61	-0.30	3.30	1.01	0.00	38.97	1.19	-0.52	42.46	1.08	-2.79
Bas 370	144.13	2.04	8.08	31.50	1.73	1.16	2.89	0.43	-0.01	55.33	1.24	204.99**	34.19	0.51	8.96
IR 54	62.50	1.13	9.36	25.41	2.08	6.61*	3.55	0.76	0.23	37.45	0.90	35.10	43.29	1.07	57.43
Mean	88.87	1.00		26.56	1.00		3.61	1.00		39.40	1.00		41.61	1.00	
S.E.±	2.12	0.19		0.73	0.49		0.24	0.23		3.23	0.27		2.54	0.21	

* Significant at P=0.05, ** Significant at P=0.01

Table 29 Estimates of stability parameters of eleven rice genotypes for days to 50% flowering, PBT/hill, 1000 grain weight and harvest index in medium flowering group grown in three edaphic environments for two years

Genotypes	Days to flowering			PBT/hill			1000grain wt(g)			Harvest index		
	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2
Giza 159	97.58	0.28	2.76	14.60	1.09	4.06	25.00	1.06	0.56	0.57	1.97	0.0001
IR 2053	103.67	1.60	1.92	15.23	2.01	10.74*	20.03	0.73	0.17	0.52	4.75	0.0017
HAU-5-298	107.75	2.10	21.51**	20.18	1.07	1.12	20.85	0.82	1.93**	0.51	0.45	0.0011
HAU-6-163	107.58	0.88	0.29	18.85	1.03	-0.35	27.37	1.15	0.09	0.54	-1.04	0.0001
IET 4141	111.00	1.16	4.23*	15.58	0.35	6.77	20.54	1.01	0.18	0.49	2.04	0.0006
PR 106	109.25	0.69	0.82	16.92	0.68	4.32	21.47	1.06	0.14	0.54	0.16	0.0000
Jaya	108.54	0.61	1.55	15.60	0.95	1.75	27.77	1.45	0.36	0.55	1.66	0.0007
M-1-48	105.92	0.18	10.00**	11.42	1.72	3.72	20.95	0.44	0.79	0.49	2.31	-0.0001
TR 17	108.92	0.36	1.19	19.04	2.06	2.07	21.27	0.99	0.22	0.52	0.90	-0.0001
Bas 370	115.04	1.54	6.01**	16.15	1.36	5.65	18.87	1.03	2.10**	0.39	-2.42	-0.0034**
IR 54	118.83	1.58	4.27*	17.79	0.23	8.57	20.10	1.26	-0.11	0.54	0.54	0.0004
Mean	108.55	1.00		16.49	1.00		22.20	1.00		0.51	1.00	
S.E.±	1.04	0.37		1.06	0.48		0.37	0.20		0.01	1.33	

* Significant at P=0.05, ** Significant at P=0.01

Table 30 Estimates of stability parameters of thirteen rice genotypes for plant height, panicle length, panicle weight, straw weight/hill and grain yield/hill in late flowering group grown in three edaphic environments for two years

Genotypes	Plant height (cm)			Panicle length (cm)			Panicle wt (g)			Straw wt/hill (g)			Grain yield/hill (g)		
	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2
PAU 269	101.42	0.64	35.27	26.42	0.81	0.23	2.87	0.91	0.10	48.37	0.15	15.24	36.30	0.42	20.51**
Bhurarata	117.50	0.75	94.00*	21.67	1.43	1.43	2.91	0.74	-0.01	90.29	1.50	327.38	56.45	1.58	10.61
IR 2055	64.75	0.53	8.51	25.46	0.35	-0.32	2.73	0.86	0.05	45.67	0.41	-47.04	44.60	0.55	5.75
MCM-1	151.00	1.28	115.58*	27.38	1.18	0.35	4.12	1.58	0.01	106.82	1.38	40.29	62.01	2.66	54.69
Kalarata	124.67	1.07	21.19	17.46	1.18	2.10	2.30	0.36	-0.02	97.85	1.28	88.03	40.77	0.64	9.88
IR 2031	108.50	1.01	59.57	24.38	1.19	0.54	3.08	1.24	0.11	60.46	0.85	36.50	29.41	1.09	15.83
Getu	129.29	0.74	14.99**	21.08	0.56	-0.17	2.91	1.17	-0.02	83.19	0.99	389.04	39.04	0.57	3.85
Damodar	118.92	0.37	1052.27**	21.58	0.87	2.22	2.56	0.72	0.01	70.33	0.83	-43.04	31.57	0.56	-1.45
Dasal	140.13	1.05	233.44**	21.00	0.78	-0.28	2.67	0.67	-0.03	79.11	0.48	-34.34	33.99	0.52	-7.04
Pokkali	178.75	1.14	850.57**	26.38	0.73	1.52	4.92	1.36	0.17	91.44	1.71	150.13	35.13	0.91	19.83
Arya	166.96	1.33	157.48**	24.63	1.30	3.89*	3.26	1.42	0.16	124.23	1.37	246.78	39.11	1.68	17.39
SR 3-9	132.42	1.34	219.21**	24.00	1.68	0.46	3.13	0.99	0.05	80.23	1.04	15.02	29.14	0.88	48.54
SR 10032	132.25	1.75	197.28**	21.08	0.94	1.03	2.68	0.99	0.04	69.39	1.02	2.98	18.56	0.63	-5.83
Mean	128.20	1.00		23.27	1.00		3.09	1.00		80.57	1.00		38.16	1.00	
SE ±	6.97	0.32		0.54	0.24		0.14	0.19		5.41	0.23		2.42	0.18	

* Significant at P=0.05, ** Significant at P=0.01

Table 31 Estimates of stability parameters of thirteen rice genotypes for days to 50% flowering, PBT/hill, 1000 grain weight and harvest index in late flowering group grown in three edaphic environments for two years

Genotypes	Days to flowering			PBT/hill			1000 grain wt(g)			Harvest index		
	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2	$\bar{x}$	b_i	Sd_i^2
PAU 269	121.54	0.37	4.44**	19.44	2.53	17.19*	19.38	0161	1.38*	0.42	0.99	-0.0000
Bhurarata	115.25	1.97	30.93**	31.65	0.65	8.46	23.29	1.58	0.01	0.39	-0.19	-0.0001
IR 2055	103.63	1.07	-0.07	23.73	3.29	2.85	20.05	1.11	0.17	0.49	0.83	-0.0002
MGM-1	130.42	0.89	3.03**	21.02	-0.90	16.13*	21.14	-0.57	12.06**	0.35	2.24	0.0021
Kalarata	127.83	0.21	0.46	30.27	1.16	3.01	24.91	1.34	1.58*	0.30	-0.39	0.0006
IR 2031	130.08	0.75	9.40**	15.21	1.07	5.74	14.01	0.88	0.99	0.31	2.80	0.0026
Getu	137.67	0.40	1.39	22.35	1.19	4.67	19.44	1.26	0.89	0.35	0.68	0.0001
Damodar	137.67	0.57	1.63	18.94	1.33	0.95	19.76	0.89	0.70	0.31	0.05	-0.0002
Dasal	137.25	0.47	0.47	19.92	0.98	-0.66	19.46	1.07	1.78**	0.30	0.73	0.0001
Pokkali	140.50	0.86	11.06**	9.29	0.88	1.03	28.63	1.55	1.58*	0.29	0.36	0.0003
Arya	139.83	1.05	1.70	21.21	0.97	5.80	27.19	1.52	8.20**	0.22	1.77	0.0015
SR 3-9	145.58	1.49	23.16**	18.98	-0.43	3.47	11.87	0.76	0.09	0.26	1.42	0.0000
SR 10032	145.42	1.89	42.48**	11.02	0.28	1.15	18.00	0.97	4.30**	0.21	1.71	0.0000
Mean	133.28	1.00		20.23	1.00		20.55	1.00		0.32	1.00	
S.E.±	1.43	0.28		1.18	0.81		0.74	0.38		0.01	0.39	

* Significant at P=0.05, ** Significant at P=0.01

was associated in varieties HAU-5-298, M-1-48, Bas 370 and IR54. Linear component was significant in varieties Giza 159, IR2053, Jaya and TR17. In IET 4141 only non linear component was significant. Both HAU-6-163 and PR106, which showed stability for days to flowering, recorded mean values not significantly different from the population mean (108.55).

Data presented in Table 31 reveal that among the late flowering varieties both linear and non linear components were significant in PAU269, Bhurarata, SR3-9 and SR 10032. Varieties IR2055, Kalarata and Arya were free from G x E interaction. Linear component was significant in Getu, Damodar and Dasal whereas only non linear component was significant in MCM-1, IR2031 and Pokkali.

4.4.2.2.2 Plant height

Considering both b_i and $\bar{S}_d^2$ values of the genotypes among the early flowering group presented in Table 26, it is evident that G x E interactions were absent for nine varieties viz. CR237-1, Kalinga II, Kalinga I, CR222, CR214, Pusa 167, CSR-5, CR143-2-2 and Karekagga. In six varieties, only linear portion of G x E interaction was significant. Among the stable varieties Karekagga and CR237-1 recorded mean values significantly higher than population mean.

From Table 28 it is observed that in the medium flowering group linear as well as non-linear components of G x E interactions were significant only in the variety M-1-48. Varieties IR2053, HAU 5-298, Jaya, TR17 and IR54 were free from G x E interaction. The regression values of the remaining varieties significantly deviated from unity, showing that they were highly responsive to adverse environmental changes.

A comparison of three stability parameters, viz. mean, b_i and $\bar{s}_d^2$ of individual varieties presented in Table 30, revealed that varieties Kalarata and Getu had average mean accompanied by non-significant b_i and $\bar{s}_d^2$. Variety IR 2031 was having unit regression (b_i = 1.01) and non-significant $\bar{s}_d^2$ value, but had mean value (108.5 cm) less than the population mean (128.20 cm). Both linear and non-linear components were significant for 4 varieties and linear component for two varieties. For the remaining 4 varieties only non-linear component was significant.

4.4.2.2.3 Panicle length

Estimates of stability parameters for panicle length are presented in Table 26 for early, 28 for medium and 30 for late flowering groups.

In early flowering group, both linear and non-linear component of G x E interaction were significant for the varieties Bilekagga and Karekagga. For five varieties the linear portion was significant (b_i significant and $\bar{s}_d^2$ non-significant). Eight varieties were free from G x E interaction. Out of these varieties, Pusa 150, CR214, IET 1444 and Jhona 349 had average mean (26.34 cm) for panicle length. Pusa 167 recorded above average performance whereas varieties Kalinga I, Kalinga II and CSR-4 recorded below average performance with non-significant b_i and $\bar{s}_d^2$ values.

In the medium flowering group, six varieties were free from G x E interaction. Varieties TR17, Jaya and PR106 recorded mean values not significantly different from the group mean (26.56 cm), while Giza 159, IR2053 and IET 4141 had below

average mean. In varieties M-1-48 and IR54, presence of both linear and non-linear components of G x E interactions were indicated by significant b_i and $\bar{S}_d^2$ values. In remaining three varieties, only linear component was significant.

Test of significance of the two measures of G x E interaction, namely b_i and $\bar{S}_d^2$ of the individual varieties among late flowering group showed the absence of G x E interaction in six varieties. In variety Arya, both the components were significant. Remaining six varieties showed only linear portion of G x E interaction. Among the stable varieties PAU 269, MCM-1 and IR2031 recorded above average performance ($\bar{x}$, > 23.27 cm), whereas varieties IR 10032, Damodar and Kalarata recorded below average performance.

4.4.2.2.4 Panicle bearing tillers per plant

Considering both b_i and $\bar{S}_d^2$ values of the individual varieties, presented in Table 27, it became evident that G x E interactions were absent for eight varieties, viz., Kalinga I, P2-21, CR222, IET 1444, CSR-4, Jhona 349, CSR-5 and Pusa 150. The linear component of G x E interaction was present in Kalinga II, CR214, Pusa 167, CR143-2-2, Bilekagga and Karekagga. However, both linear and non-linear components were significant in variety CR237-1 only.

In medium group, only IR2053 showed significant b_i and $\bar{S}_d^2$ values. In varieties M-1-48, TR17, IR-54 and IET 4141, the linear component of G x E interaction was significant. Remaining six varieties were free from G x E interaction. Of these, Giza 159 was below average, HAU-5-298 and HAU-6-163 were above average, while PR106, Jaya and Bas 370 were average in their performance as compared to the group mean (16.49 ± 1.06 PBT/plant).

In late flowering group of varieties, only four varieties showed G x E interaction for PBT, as seen from the data presented in Table 31. Among them, both linear and non-linear components of G x E interaction were present in varieties PAU-269 and MCM-1, whereas only linear component was significant in IR2055 and SR3-9. The remaining nine varieties were free from G x E interaction. Among them, the performance of varieties Bhurarata, Kalarata, and Getu were above the group mean ($\bar{x}Gi$, = > 20.23 ± 1.18).

4.4.2.2.5 Panicle weight

From Table 26 it is observed that non-linear component of G x E interaction was significant for none of the varieties in early flowering group. Estimates of b_i values significantly deviated from unity for ten varieties. Non-significant b_i and $\bar{s}_d^2$ values were recorded in varieties P2-21, CR214, CSR-4, CSR-5 and Pusa 150. Stable above average performance was noticed in CSR-5 whereas average performance was noticed in P2-21 and CR214.

In medium flowering varieties, significant b_i and $\bar{s}_d^2$ values were recorded in IR2053, HAU-6-163 and Jaya. Only linear portion of G x E interaction was recorded in IET 4141, PR106, M-1-48 and Bas 370. The stability for panicle weight was noticed in four varieties, namely, Giza 159, HAU-5-298, TR17, and IR54. Among them only Giza 159 recorded above average performance ($\bar{x}$ > 3.61 ± 0.24 gm).

In late flowering group, five varieties were free from G x E interaction. Variety SR 3-9 recorded average performance whereas the other four stable varieties viz., PAU 269, IR2055,

Getu and SR 10032 recorded below average performance ($\bar{x}$ < 3.09 ± 0.14 gm). The remaining eight varieties were responsive to environmental changes as indicated by their significant b_i values.

4.4.2.2.6 Straw weight/plant

Considering both b_i and $\bar{s}_d^2$ values of individual genotypes in the early group, it became evident from Table 26 that G x E interactions were absent for five varieties, namely, CR237-1, Kalinga-I, CR214, CR143-2-2 and Pusa 150. The presence of only linear portion of G x E interaction was indicated by eight genotypes, while CSR-5 exhibited non-linear portion of G x E interaction. Both b_i and $\bar{s}_d^2$ were significant for P-2-21.

A comparison of the three stability parameters viz., mean, b_i and $\bar{s}_d^2$ of individual varieties in medium flowering group presented in Table 28, revealed that the varieties HAU-5-298, PR106, Jaya, TR17 and IR54 showed average mean ($\bar{x}_i$ = 39.40 ± 3.23 gm) accompanied by non-significant b_i and $\bar{s}_d^2$; while Giza 159 and M-1-48 recorded below average performance but were stable. However, HAU-6-163, which showed average stability and above average performance was found to be best suited for poor environment with respect to straw yield in this group. Both linear and non-linear components were significant for variety IR2053. In varieties Bas 370 and IET 4141 only non-linear component was significant.

None of the varieties in the late group showed significant non-linear component of G x E interaction. However, in eight varieties regression coefficient b_i significantly deviated from unity. Five varieties were free from G x E interaction, as shown by their non-significant b_i and $\bar{s}_d^2$ values. They

were Getu and SR3-9 with average straw yield (80.57 ± 5.41 gm); IR2031, Damodar and SR 10032 with below average straw yield.

4.4.2.2.7 1000 grain weight

Among the fifteen early flowering varieties, the linear component of G x E interaction for 1000 grain weight was observed only in IET 1444 and Bilekagga. However, non-linear portion was significant for Bilekagga, Karekagga and Kalinga II. Eleven varieties were free from G x E interaction. Among them the performance of varieties CR222, CR214 and Jhona 349 were above the group average ($\bar{x}_i$ > 22.62 ± 0.51 gm).

There were five medium flowering varieties, which exhibited absence of G x E interactions, while the rest of the varieties showed presence of G x E interaction. Two varieties were found to have only non-linear portion and four varieties were having only linear portion of the G x E interaction. The varieties Giza 159 and HAU-6-163 were stable with above average performance, whereas IET 4141, PR106 and TR17 were below average in their performance ($\bar{x}_i$ < 22.2 ± 0.37 gm).

A total of five, out of thirteen late duration varieties, exhibited absence of G x E interaction. Both b_i and $\bar{s}_d^2$ were significant for four varieties. Three varieties showed only non-linear component of interaction while Bhurarata exhibited only linear component of G x E interaction. Variety IR2055 recorded average performance ($\bar{x}_i$ = 20.55 ± 0.74 gm) while the performance of IR2031, Getu, Damodar and SR3-9 were below average with average stability.

4.4.2.2.8 Harvest Index

Varieties CR222, CSR-5 and Pusa 150 had above average mean while Jhona 349 had average mean along with non-significant b_i and $\bar{s}_d^2$ in the early group as seen from the data presented in Table 27.

Nine varieties had significant b_i while variety P-2-21 had significant $\bar{s}_d^2$ value. Both b_i and $\bar{s}_d^2$ values were significant for the variety Karekagga.

It is evident from the data presented in Table 29 that in the medium group, both linear and non-linear portion of G x E interaction were present only in Bas 370. Linear component was significant in IR2053 and HAU-6-163. In the remaining eight varieties both b_i and $\bar{s}_d^2$ values were non-significant showing they were stable for harvest index.

Considering both b_i and $\bar{s}_d^2$ values of the individual varieties of late maturing group, it became evident that G x E interactions were absent for four varieties namely, PAU 269, IR2055, Getu and Dasal. In nine varieties, significant linear portion of G x E interaction was observed. None of the varieties exhibited significance of non-linear portion or of both linear and non-linear portions of G x E interaction.

4.4.2.2.9 Paddy yield/plant

In the early group, there were eight varieties which exhibited absence of G x E interaction, while the rest of varieties showed presence of G x E interaction. Only one variety, CSR5, was found to have both linear and non-linear portion of G x E interaction. Six varieties had only linear portion of G x E interaction. The varieties Bilekagga and

CR214 had above average mean ($\bar{x}_i > 40.55 \pm 2.31$ gm) and unit regression associated with non-significant $\bar{s}_d^2$ were the best yielders. Varieties CSR-4, Pusa 167 and P-2-21 had average mean while Kalinga I, Kalinga II, and CR237-1 had below average mean, with non-significant b_i and $\bar{s}_d^2$ values.

In the medium group, four varieties were free from G x E interaction. They were Giza 159, TR17, IR54 and HAU-6-163. Of these four varieties except HAU-6-163 had average mean ($\bar{x}_i = 41.61 \pm 2.54$ gm); on the other hand HAU-6-163 had above average yield (54.00 gm). Variety IET 4141 had both b_i and $\bar{s}_d^2$ values significant. Varieties HAU-5-298, PR106, and Jaya had above average mean but were responsive ($b_i > 1.00$).

Four out of thirteen late duration varieties exhibited stability for yield. They were IR2055 with above average mean ($\bar{x} > 38.16 \pm 2.42$ gm), IR2031, SR3-9 and Pokkali with below average mean. Bhurarata had above average mean (56.45 gm) but was unstable as indicated by significant b_i and $\bar{s}_d^2$. The remaining eight varieties showed linear portion of G x E interaction significant.

4.4.3 Correlations

The genotypic and phenotypic correlation coefficients of all possible combinations among nine characters were worked out based on mean values of the varieties of three maturity groups grown in control (non-stress) alkali and saline environments separately and these are presented in Tables 32 to 37. Genotypic correlation coefficients were higher than the phenotypic correlation coefficients for all characters in all the environments. Characterwise relationships are described as follows:

4.4.3.1 Days to 50% flowering

Positive significant genotypic and phenotypic correlations (r), ranging from 0.3856 to 0.6000, were observed with panicle length, panicle weight and grain yield under normal, alkali and saline environments in early group. However, negative and significant correlation (r=-0.4586) was found with PBT under non-stress environment. Under saline stress straw weight and 1000 grain weight also showed significant positive correlation.

In the medium group, none of the characters was having significant phenotypic correlation with days to 50% flowering. However, genotypic correlation with 1000 grain weight under saline soil environment and with harvest index under alkali environment were significant and negative.

Significant negative correlations were observed with PBT and harvest index in late flowering varieties under normal, alkali and saline soil environments. The correlation with plant height was positive in normal and alkali environments, whereas significant negative correlations (r = -0.5154 and -0.5666) were observed with grain yield under stress conditions only.

4.4.3.2 Plant height

From Table 32 it is observed that in early group, plant height was significantly and positively correlated with panicle length, straw weight, 1000 grain weight while significant negative correlation (r = -0.54 to -0.6676) was observed with harvest index in all environments. Significant positive correlations were also found with panicle weight and grain yield under control as well as alkali environments. Significant

Table 32 Phenotypic correlation coefficient (r) among nine characters in 15 early flowering rice varieties grown in non-stress (C), alkali (A) and saline(S) soil environments

Characters		Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index	Yield/hill
Days to flowering	C	0.2367	0.5340**	-0.4586*	0.6000**	0.2544	0.2544	0.1001	0.3856*
	A	0.2741	0.5906**	-0.3224	0.5797**	0.3548	0.2634	0.1274	0.4853**
	S	0.3516	0.5798**	-0.1862	0.5267**	0.4809**	0.4250*	-0.0999	0.4886**
Plant height	C		0.7742**	-0.2929	0.6362**	0.8203**	0.8140**	-0.5444**	0.3918*
	A		0.6502**	-0.2955	0.6188**	0.8674**	0.8569**	-0.6759**	0.4295*
	S		0.5500**	-0.2910	0.3581	0.7670**	0.8487**	-0.6676**	0.0436
Panicle length	C			-0.4137*	0.6733**	0.6712**	0.7657**	-0.3403	0.3876*
	A			-0.2103	0.6299**	0.7315**	0.7324**	-0.3186	0.5517**
	S			-0.3126	0.5967**	0.5480**	0.6175**	-0.2595	0.3638*
PBT/hill	C				-0.5257**	-0.1505	-0.3988*	0.1728	0.1454
	A				-0.4866**	-0.0758	-0.3101	0.1216	0.0955
	S				-0.6840**	-0.0246	-0.3882*	0.0254	0.0967
Panicle weight	C					0.6167**	0.5692**	-0.0819	0.6465**
	A					0.6199**	0.6393**	-0.0648	0.6833**
	S					0.2501	0.4961**	0.1079	0.5161**
Straw weight/ hill	C						0.7246**	-0.6739**	0.5111**
	A						0.7860**	-0.6303**	0.6379**
	S						0.7536**	-0.7941**	0.1705
1000 grain weight	C							-0.5161**	0.2473
	A							-0.4869**	0.4628**
	S							-0.5910**	0.0858
Harvest index	C								0.1835
	A								0.1473
	S								0.4239*

* Significant at P=0.05, ** Significant at P=0.01

Table 33 Genotypic correlation coefficient (r) among nine characters in 15 early flowering rice varieties grown in non-stress (C), alkali (A) and saline (S) soil environments

Characters		Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index	Yield/ hill
Days to flowering	C	0.2434	0.5622**	-0.5480**	0.6757**	0.2753	0.2607	0.1209	0.4462*
	A	0.2863	0.6380**	-0.4326*	0.6731**	0.4012*	0.2838	0.1265	0.6174**
	S	0.3597	0.6304**	-0.2050	0.5686**	0.5489**	0.4299*	-0.1158	0.6439**
Plant height	C		0.8208**	-0.3645*	0.7146**	0.8799**	0.8351**	-0.6323**	0.4400*
	A		0.6857**	-0.4206*	0.6752**	0.9626**	0.8765**	-0.7439**	0.5053**
	S		0.6111**	-0.3548	0.3938*	0.8855**	0.8745**	-0.7486**	0.0118
Panicle lenght	C			-0.5123**	0.7674**	0.7418**	0.8128**	-0.4060*	0.4465*
	A			-0.3089	0.6905**	0.8319**	0.7822**	-0.3802*	0.6620**
	S			-0.4284*	0.6532**	0.6844**	0.6960**	-0.3772*	0.3775*
PBT/ hill	C				-0.6165**	-0.2365	-0.4637**	0.1512	0.0346
	A				-0.6569**	-0.3557	-0.3799*	0.2316	-0.2250
	S				-0.8339**	-0.1425	-0.4469*	0.0472	-0.0601
Panicle weight	C					0.6913**	0.6624**	-0.1453	0.6925**
	A					0.7183**	0.7174**	-0.1292	0.8136**
	S					0.2667	0.5634**	0.0622	0.5111**
Straw weight/ hill	C						0.8005**	-0.7101**	0.5383**
	A						0.9030**	-0.6717**	0.6087**
	S						0.8452**	-0.8535**	0.0280
1000 grain weight	C							-0.5951**	0.3045
	A							-0.5432**	0.6095**
	S							-0.6365**	0.1104
Harvest index	C								0.2494
	A								0.1518
	S								0.4811**

* P=0.05, ** P=0.01 significance

Table 34 Phenotypic correlation coefficient (r) among nine characters of eleven medium flowering rice varieties grown in non-stress (C), alkali (A) and saline (S) soil environments

Characters		Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index	Yield/hill
Days to flowering	C	-0.1214	0.2240	0.1650	-0.2156	0.2482	-0.2367	-0.2784	-0.0724
	A	-0.0929	0.1746	0.2564	-0.1296	0.3023	-0.2046	-0.4189	-0.0886
	S	-0.1814	-0.1435	0.2087	-0.2862	0.0979	-0.5712**	-0.2299	-0.0499
Plant height	C		0.4753*	0.0302	-0.3157	0.4112	-0.3698	-0.6225**	-0.3164
	A		0.4402*	-0.1276	-0.2142	0.5085*	-0.1774	-0.6052**	-0.2212
	S		0.5023*	-0.2798	0.2396	0.3182	0.0626	-0.2718	0.1211
Panicle length	C			0.3426	-0.2085	0.4924*	-0.2807	-0.3848	0.0049
	A			0.0249	-0.0175	0.5099*	-0.1840	-0.6574**	-0.1608
	S			0.0125	0.0340	0.2480	0.1902	-0.1673	0.1803
PBT/hill	C				-0.1558	0.5971**	-0.0395	-0.0009	0.4287*
	A				-0.4543*	0.3979	-0.0790	-0.0268	0.5345*
	S				-0.5011*	0.1967	-0.2099	-0.0120	0.1963
Panicle weight	C					0.0865	0.5982**	0.6514**	0.7104**
	A					-0.0960	0.4361*	0.2038	0.2334
	S					0.4009	0.5805**	0.2524	0.5798**
Straw weight/ hill	C						-0.0303	-0.3342	0.4200
	A						-0.0679	-0.7557**	0.3184
	S						0.2235	-0.3274	0.7303**
1000 grain weight	C							0.5481**	0.5195*
	A							0.2969	0.4174
	S							0.3662	0.4993*
Harvest index	C								0.7008**
	A								0.4022
	S								0.3797

* Significant at P=0.05, ** Significant at P=0.01

Table 35 Genotypic correlation coefficient (r) among nine characters in eleven medium flowering rice varieties grown in non-stress (C), alkali (A) and saline (S) soil environments

Characters		Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index	Yield/hill
Days to flowering	C	-0.1209	0.2865	0.1972	-0.2244	0.2985	-0.2566	-0.3222	-0.0844
	A	-0.1071	0.2132	0.3080	-0.1553	0.3608	-0.2310	-0.4713*	-0.1058
	S	-0.1987	-0.1790	0.2443	-0.3336	0.1034	-0.5917**	-0.3421	-0.0869
Plant height	C		0.5350*	0.0601	-0.4011	0.4449*	-0.3830	-0.6738**	-0.3793
	A		0.5282*	-0.1315	-0.2868	0.5631**	-0.2052	-0.6769**	-0.3484
	S		0.5666**	-0.3100	0.2541	0.4561*	0.0391	-0.4122	0.1401
Panicle length	C			0.4077	-0.2832	0.5694**	-0.3322	-0.4931*	-0.0538
	A			0.0255	-0.0558	0.6579**	-0.2278	-0.8070**	-0.2301
	S			-0.0110	-0.0614	0.2565	0.1890	-0.2876	0.1271
PBT/hill	C				-0.0871	0.6777**	-0.0301	0.0227	0.5122*
	A				-0.5578**	0.3845	-0.0798	-0.0237	0.5792**
	S				-0.5866**	0.0072	-0.2377	0.1319	0.1173
Panicle weight	C					0.0228	0.6871**	0.7239**	0.7712**
	A					-0.1978	0.4979*	0.2331	0.1641
	S					0.5448**	0.6600**	0.3572	0.6679**
Straw weight/ hill	C						-0.0295	-0.3999	0.3410
	A						-0.0805	-0.8173**	0.1621
	S						0.2896	-0.0745	0.8068**
1000 grain weight	C							0.5914**	0.6011**
	A							0.3095	0.5165*
	S							0.5743**	0.5971**
Harvest index	C								0.7217**
	A								0.4022
	S								0.5095*

* Significant at P=0.05, ** Significant at P=0.01

Table 36 Phenotypic correlation coefficient (r) among nine characters of thirteen late flowering rice varieties grown in non-stress (C), alkali(A) and saline(S) soil environments

Characters		Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index	Yield/hill
Days to flowering	C	0.4454*	-0.0513	-0.4762*	0.1774	0.2565	-0.0863	-0.5998**	-0.3348
	A	0.5499**	0.0377	-0.5718**	0.2454	0.0427	-0.1189	-0.5528**	-0.5154**
	S	-0.2128	-0.3107	-0.4339*	-0.0885	0.2126	-0.1923	-0.6658**	-0.5666**
Plant height	C		0.1262	-0.1746	0.3705	0.5699**	0.3394	-0.5002**	0.1425
	A		0.1550	-0.3401	0.6175**	0.5116**	0.3888*	-0.6700**	-0.0620
	S		0.1820	-0.2918	0.4991**	0.5664**	0.5010**	-0.3020	0.0060
Panicle length	C			-0.1860	0.5853**	0.0699	-0.0344	0.3217	0.4192*
	A			-0.3994*	0.6687**	-0.0926	-0.0054	0.2661	0.1167
	S			-0.3555	0.4346*	0.0465	0.1728	0.1576	0.1528
PBT/hill	C				-0.3540	0.2764	0.1816	0.2309	0.5086**
	A				-0.4534*	0.4242*	0.0361	0.1860	0.6600**
	S				-0.3604	0.0452	0.0504	0.4383*	0.4818*
Panicle weight	C					0.4028*	0.3188	0.0664	0.4822*
	A					0.2063	0.2015	0.0954	0.1761
	S					0.0756	0.4248	0.2214	0.2705
Straw weight/ hill	C						0.4918*	-0.4942*	0.4895*
	A						0.4402*	-0.5425**	0.5381**
	S							-0.4103*	0.1903
1000 grain weight	C							-0.0279	0.3664
	A							-0.2502	0.1948
	S							0.1211	0.3164
Harvest index	C								0.4389*
	A								0.3524
	S								0.7561**

* Significant at P=0.05, ** Significant at P=0.01

Table 37 Genotypic correlation coefficient (r) among nine characters in 13 late flowering rice varieties grown in non-stress(C), alkali(A) and saline(S) soil environments

Characters		Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index	Yield/hill
Days to flowering	C	0.4512*	-0.0595	-0.5106**	0.2019	0.2949	-0.0887	-0.6472**	-0.3483
	A	0.5748**	0.0475	-0.6057**	0.2835	0.0483	-0.1191	-0.6011**	-0.5590**
	S	0.2211	-0.3289	-0.4670*	-0.1085	0.2681	-0.1997	-0.7427**	-0.6452**
Plant height	C		0.1412	-0.1941	0.4241*	0.6375**	0.3416	-0.5298**	0.1481
	A		0.1625	-0.3688	0.6791**	0.5715**	0.3966*	-0.7392**	-0.0755
	S		0.1881	-0.3252	0.5919**	0.7540**	0.5168**	-0.3537	0.0040
Panicle length	C			-0.2305	0.7505**	0.0911	-0.0374	0.3707	0.4761*
	A			-0.4334*	0.7389**	-0.1559	-0.0283	0.3303	0.1323
	S			-0.4137*	0.4881*	0.0416	0.1788	0.1885	0.1707
PBT/hill	C				-0.3327	0.2639	0.2070	0.3127	0.5578**
	A				-0.4793*	0.4438*	0.0419	0.2414	0.7088**
	S				-0.4338*	-0.0310	0.0580	0.5544**	0.5627**
Panicle weight	C					0.4879*	0.3563	0.0540	0.5111**
	A					0.2050	0.1978	-0.1475	0.1139
	S					0.1607	0.4627*	0.1704	0.2101
Straw weight/ hill	C						0.5614**	-0.4811*	0.5006**
	A						0.5014**	-0.5131**	0.5501**
	S						0.4490*	-0.4199*	0.1279
1000 grain weight	C							-0.0362	0.3835
	A							-0.2768	0.2097
	S							0.1014	0.3177
Harvest index	C								0.4654*
	A								0.3852
	S								0.8158**

* Significant at P=0.05, ** Significant at P=0.01

negative correlation with PBT in control and alkali environments were observed only at genotypic level.

In medium group significant negative correlation was observed with harvest index under control and alkali environments. Significant positive correlations at genotypic level were observed with panicle length and straw weight under all environments.

Plant height was significantly and positively correlated with straw weight both at phenotypic and genotypic level under all environments in late flowering group. Significant positive correlations under both stress environments were observed with panicle weight and 1000 grain weight. Significant correlations with harvest index were negative and with plant height were positive except under saline soil environment.

4.4.3.3 Panicle length

This character showed high positive correlation with days to flowering, plant height, panicle weight, straw weight, 1000 grain weight and grain yield both at phenotypic and genotypic level, while significant negative correlation with harvest index was observed only at genotypic level under control, alkali and saline environments. Negative correlation with PBT was significant at phenotypic level only in non-stress ($r = -0.4137$) environment whereas at genotypic level it was also significant under saline soil ($r = -0.4284$).

In the medium group panicle length exhibited significant positive correlation with plant height in all environments whereas with straw weight it was significant and positive only under control and alkali stress. Negative correlation

with harvest index was significant at phenotypic level only in alkali environment and at genotypic level it was significant under both control and alkali environments.

Under control, alkali as well as saline environments panicle length of late flowering varieties showed significant positive correlation only with panicle weight. Grain yield was also positively and significantly correlated under non-stress environment. The genotypic correlation with PBT was negative and significant under both stress environments.

4.4.3.4 Panicle bearing tillers per hill

It is observed from Tables 32 and 33 that both genotypic and phenotypic correlations were negative and significant with panicle weight under all the three environments in early group. Under non-stress environment negative correlations were observed with days to flowering, panicle length and 1000 grain weight. At genotypic level days to flowering, plant height, 1000 grain weight under alkali stress and panicle length, 1000 grain weight under saline stress were negatively and significantly correlated with PBT.

As shown in Table 34, in medium flowering varieties PBT recorded significant positive correlation with straw weight under non-stress condition and with grain yield under control as well as alkali environments. Under stress environments significant negative correlation both at phenotypic and genotypic levels were observed with panicle weight.

Significant positive correlation with grain yield and negative correlation with days to flowering were observed under all the three environments in late flowering varieties. In

alkali soil, panicle length, panicle weight were negatively and straw weight was positively correlated with PBT. Under saline soil, harvest index was positively correlated whereas the negative correlation observed with panicle length were significant only at genotypic level.

4.4.3.5 Panicle weight

Panicle weight of early flowering varieties was positively and significantly correlated with days to flowering, panicle length, 1000 grain weight and grain yield. While significant negative correlation was observed with PBT under all environments. Eventhough significant positive correlations were observed with plant height as well as with straw weight under control and alkali environments, it was non-significant in saline environment at phenotypic level.

In the medium flowering varieties panicle weight showed significant positive correlation with 1000 grain weight under normal, alkali and saline environments. It was positively correlated with harvest index under non-stress environment whereas,with grain yield under both control and saline environments. Correlation was negative and significant with PBT under both stress environments.

The character panicle weight of late flowering varieties had positive and significant correlations with panicle length under all environments studied; with straw weight and grain yield under non-stress environments; with plant height under both stress environments and with 1000 grain weight only in saline environment. However, it was negatively correlated with PBT under alkali stress.

4.4.3.6 Straw weight/hill

Genotypic correlation coefficients of this character are presented in Tables 33, 35 and 37, while phenotypic correlation coefficients are presented in Tables 32, 34 and 36.

Straw weight of early flowering rice varieties was significantly and positively correlated with plant height, panicle length and 1000 grain weight under all the three environments. With grain yield and panicle weight significant positive correlation was found only under non-stress and alkali environments. However, negative correlation was noticed with harvest index under non-stress, alkali and saline environments. At genotypic level it was also found to be significantly and positively correlated with days to flowering under both stress environments.

In medium group straw weight was correlated positively with panicle length, PBT under non-stress environment; with plant height, panicle length under alkali environment and with grain yield under saline environment at phenotypic as well as genotypic level. However at genotypic level it was also correlated positively with plant height under non-stress and saline environments as well as with panicle weight under saline environment. Significant negative correlation was found only with harvest index under alkali stress.

Significant positive correlations with plant height and negative correlation with harvest index were observed in late flowering varieties under all environments. Under non-stress and alkali environments grain yield as well as 1000 grain weight showed significant correlation with straw yield, whereas with panicle

weight and PBT showed positive correlation only in control and alkali environments respectively. Genotypic correlation with 1000 grain weight under saline environment also was found to be significant and positive.

4.4.3.7 1000 Grain Weight

This character in early flowering group recorded significant positive correlation with plant height, panicle length, panicle weight and straw weight, while significant negative correlation with harvest index under all environments. Under saline environment with days to flowering and under alkali environment with grain yield, the correlations were found to be significantly positive. Genotypic correlation with PBT was significant and negative under all environments but phenotypic correlation was not significant under alkali stress.

Significant positive correlations under all environments were found with panicle weight in medium flowering group. Eventhough genotypic correlation with grain yield were significant and positive under all environments, phenotypic correlation was not significant in alkali environment. In non-stress environment the positive correlation with harvest index was also significant whereas the correlation with days to flowering was negatively significant.

In late group 1000 grain weight was significantly correlated positively with straw weight under non-stress environment; with plant height, straw weight under alkali stress and with panicle weight under saline environment.

4.4.3.8 Harvest index

Negative significant correlation was found with plant height, straw weight and 1000 grain weight under all environments in early flowering rice varieties. However, at genotypic level, the negative correlation with panicle length was also significant. The only positive correlation found was with grain yield ($r = 0.4239$) under saline environment.

In medium group harvest index was found to be negatively correlated with plant height under both non-stress and alkali stress and with panicle length, straw weight under alkali stress. Positive significant correlation was found with panicle weight, 1000 grain weight and grain yield under non-stress environment. At genotypic level negative correlation was also found with days to flowering under alkali, with panicle length under non-stress environment, and positive correlation with 1000 grain weight as well as grain yield in saline soil.

Harvest index of varieties belonging to late flowering group recorded significant negative correlation with days to flowering and straw weight under all environments. With yield the correlation was positive and significant in control ($r = 0.4389$) and saline ($r = 0.7561$) soil. In saline soil, the correlation with PBT ($r = 0.4383$) was also positive. Significant negative correlation was observed with plant height under control and alkali soil.

4.4.3.9 Grain yield/hill

In early group grain yield showed significant positive correlation under all environments with days to flowering, panicle length and panicle weight (as presented in Tables 32 and

33). Plant height and straw weight showed positive significant correlation except in saline environment. Thousand grain weight in alkali environment and harvest index in saline environment showed significant positive correlation with grain yield.

In medium flowering group, under non-stress environment, PBT (0.4287), panicle weight (0.7104), 1000 grain weight (0.5195), harvest index (0.7008) showed positive correlation with grain yield. In alkali soil, PBT (0.5345) and in saline soil panicle weight (0.5798) as well as 1000 grain weight (0.4993) recorded positive correlation. 1000 grain weight and harvest index had positive significant correlation under alkali and saline environments respectively only at genotypic level.

Grain yield of late flowering varieties showed significant positive correlation with PBT (0.4818 to 0.6000) under all environments and with panicle length, straw weight, harvest index under non-stress environment. In saline soil environment harvest index (0.7561) and in alkali soil straw weight (0.5381) also recorded significant positive correlation. However, significant negative correlation was found with days to flowering (-0.5154 and -0.5666) under both stress environments.

4.4.4 Path Analysis

The path coefficient analysis was carried out with an intention to assess the direct and indirect contributions of eight traits towards grain yield per plant. The phenotypic path is presented in Tables 38, 39 and 40 and genotypic path in appendices 3, 4 and 5. In general, the values of direct and indirect effects at genotypic level were higher than that at the phenotypic level. Phenotypic level effects are described below:

4.4.4.1 Grain yield vs. days to 50% flowering

Data presented in Table 38 show that the direct contribution of days to 50% flowering was found to be positive under non-stress environment (0.0412), while it was negative under stress environments (-0.0944 alkali; -0.0431 saline) in the early group. The indirect effects via plant height, panicle weight and straw weight were positive, while, via PBT as well as 1000-grain weight were negative under all environments. The contribution via panicle length was negative under non-stress environment and it was positive under both stress environments. The indirect effect via harvest index was positive under control and alkali environments but was negative under saline environment.

Direct contribution of days to flowering of medium flowering varieties was negative (-0.0079) under non-stress environment and was positive under both stress environments (alkali 0.0419; saline 0.0733) as presented in Table 34. Indirect contribution was highest and positive through straw weight, while through harvest index it was negative under all environments. Indirect effects via panicle weight and 1000 grain weight were positive. The contribution of days to flowering via panicle length was positive in non-stress and alkali stress, whereas it was negative in salt stress.

Data presented in Table 40 show that in late group, the direct effects of days to flowering were negative under all environments (non-stress -0.0679; alkali -0.0981; saline -0.0880). Indirect effects via straw weight and 1000 grain weight were positive while via harvest index

Table 38 Direct and indirect effects at phenotypic level of component characters on grain yield/ hill in 15 early flowering rice varieties grown in non-stress(C), alkali(A) and saline(S) soil environments

Characters		Days to flowering	Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight/ hill	1000 grain weight	Harvest index
Days to flowering	C	0.0412	0.0093	-0.0347	-0.1026	0.1240	0.2838	-0.0274	0.0920
	A	-0.0944	0.0357	0.0045	-0.0334	0.0894	0.4168	-0.0478	0.1146
	S	-0.0431	0.0561	0.0063	-0.0555	0.1929	0.5537	-0.0956	-0.1262
Plant height	C	0.0097	0.0395	-0.0504	-0.0655	0.1315	0.9152	-0.0878	-0.5004
	A	-0.0259	0.1304	0.0049	-0.0306	0.0954	1.0189	-0.1556	-0.6079
	S	-0.0152	0.1596	0.0060	-0.0867	0.1311	0.8830	-0.1909	-0.8434
Panicle length	C	0.0220	0.0306	-0.0650	-0.0926	0.1392	0.7489	-0.0826	-0.3129
	A	-0.0557	0.0848	0.0076	-0.0218	0.0971	0.8593	-0.1330	-0.2866
	S	-0.0251	0.0878	0.0109	-0.0932	0.2185	0.6315	-0.1359	-0.3278
PBT/hill	C	-0.0189	-0.0116	0.0269	0.2237	-0.1087	-0.1679	0.0430	0.1588
	A	0.0304	-0.0385	-0.0016	0.1035	-0.0750	-0.0890	0.0563	0.1094
	S	0.0080	-0.0465	-0.0034	0.2980	-0.2505	-0.0283	0.0873	0.0320
Panicle weight	C	0.0247	0.0251	-0.0438	-0.1176	0.2067	0.6880	-0.0614	-0.0753
	A	-0.0547	0.0807	0.0048	-0.0504	0.1542	0.7282	-0.1161	-0.0583
	S	-0.0227	0.0572	0.0065	-0.2038	0.3662	0.2880	-0.1116	0.1364
Straw weight/ hill	C	0.0105	0.0324	-0.0437	-0.0337	0.1275	1.1157	-0.0781	-0.6195
	A	-0.9335	0.1131	0.0056	-0.0078	0.0956	1.1747	-0.1427	-0.5670
	S	-0.0207	0.1224	0.0060	-0.0073	0.0916	1.1513	-0.1696	-1.0033
1000 grain weight	C	0.0105	0.0321	-0.0498	-0.0892	0.1177	0.8084	-0.1078	-0.4745
	A	-0.0249	0.1117	0.0056	-0.0321	0.0986	0.9233	-0.1816	-0.4378
	S	-0.0183	0.1355	0.0067	-0.1157	0.1817	0.8677	-0.2250	-0.7467
Harvest index	C	0.0041	-0.0215	0.0221	0.0387	-0.0169	-0.7519	0.0557	0.9191
	A	-0.0120	-0.0881	-0.0024	0.0125	-0.0100	-0.7404	0.0884	0.8993
	S	0.0043	-0.1066	-0.0028	0.0076	0.0395	-0.9143	0.1330	1.2632

Table 39 Direct and indirect effects at phenotypic level of component characters on grain yield/hill in eleven medium flowering rice varieties grown in non-stress(C), alkali(A) and saline(S) environments

Characters		Days to flowering	Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index
Days to flowering	C	-0.0079	0.0078	0.0076	0.0026	-0.0164	0.1736	-0.0036	-0.2360
	A	0.0419	0.0046	0.0109	0.0397	-0.0154	0.3462	-0.0241	-0.4925
	S	0.0733	0.0002	-0.0105	0.0203	-0.0342	0.0813	-0.0357	-0.1445
Plant height	C	0.0096	-0.0642	0.0168	0.0005	-0.0240	0.2876	-0.0056	-0.5277
	A	-0.0039	-0.0496	0.0275	-0.0198	-0.0254	0.5823	-0.0209	-0.7115
	S	-0.0133	-0.0012	0.0369	-0.0271	0.0286	0.2642	0.0039	-0.1709
Panicle length	C	-0.0018	-0.0305	0.0338	0.0055	-0.0159	0.3444	-0.0044	-0.3263
	A	0.0073	-0.0218	0.0625	0.0039	-0.0021	0.5839	-0.0217	-0.7728
	S	-0.0105	-0.0006	0.0735	0.0012	0.0041	0.2059	0.0119	-0.1051
PBT/hill	C	-0.0013	-0.0019	0.0116	0.0159	-0.0119	0.4176	-0.0006	-0.0008
	A	0.0108	0.0063	0.0016	0.1549	-0.0539	0.4556	-0.0093	-0.0315
	S	0.0153	0.0003	0.0009	0.0970	-0.0599	0.1633	-0.0131	-0.0075
Panicle weight	C	0.0017	0.0203	-0.0071	-0.0025	0.0761	0.0605	0.0091	0.5522
	A	-0.0054	0.0106	-0.0011	-0.0704	0.1186	-0.1099	0.0514	0.2396
	S	-0.0209	-0.0003	0.0025	-0.0486	0.1195	0.3328	0.0363	0.1587
Straw weight/ hill	C	-0.0020	-0.0264	0.0167	0.0095	0.0066	0.6994	-0.0005	-0.2833
	A	0.0127	-0.0252	0.0319	0.0616	-0.0114	1.1452	-0.0080	-0.8884
	S	0.0072	-0.0004	0.0182	0.0191	0.0479	0.8302	0.0139	-0.2058
1000 grain weight	C	0.0019	0.0237	-0.0097	-0.0006	0.0455	-0.0212	0.0152	0.4646
	A	-0.0086	0.0088	-0.0115	-0.0122	0.0517	-0.0777	0.1178	0.3491
	S	-0.0419	-0.0001	0.0140	-0.0204	0.0693	0.1856	0.0624	0.2302
Harvest index	C	0.0022	0.0399	-0.0130	-0.00001	0.0496	-0.2338	0.0083	0.8475
	A	-0.0176	0.0300	-0.0411	-0.0042	0.0242	-0.8654	0.0350	1.1754
	S	-0.0168	0.0003	-0.0123	-0.0016	0.0301	-0.2718	0.0229	0.6284

Table 40 Direct and indirect effects at phenotypic level of component characters on grain yield/hill in thirteen late flowering rice varieties grown in non-stress(C), alkali (A) and saline(S) soil environments

Characters		Days to flowering	Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index
Days to flowering	C	-0.0679	0.0640	-0.0014	-0.1339	0.0456	0.1646	0.0101	-0.4158
	A	-0.0981	0.0205	-0.0038	-0.1218	0.0633	0.0346	0.0067	-0.4216
	S	-0.0880	-0.0159	0.0241	0.0094	-0.0068	0.1374	0.0041	-0.6309
Plant height	C	-0.0302	0.1437	0.0035	-0.0491	0.0952	0.3658	-0.0396	-0.3468
	A	-0.0512	0.0372	-0.0157	-0.0725	0.1592	0.4136	-0.0218	-0.5110
	S	-0.0187	-0.0748	-0.0141	0.0063	0.0381	0.3660	-0.0106	-0.2862
Panicle length	C	0.0035	0.0181	0.0275	-0.0523	0.1505	0.0449	0.0040	0.2230
	A	-0.0035	0.0058	-0.1013	-0.0851	0.1724	-0.0749	0.0003	0.2029
	S	0.0273	-0.0136	-0.0775	0.0077	0.0332	0.0301	-0.0037	0.1493
PBT/hill	C	-0.0323	-0.0251	-0.0051	0.2813	-0.0910	0.1774	-0.0212	0.1601
	A	0.0533	-0.0127	0.0404	0.2130	-0.1169	0.3430	-0.0020	0.1418
	S	0.0382	0.0218	0.0276	-0.0217	-0.0275	0.0292	-0.0011	0.4153
Panicle weight	C	-0.0120	0.0532	0.0161	-0.0996	0.2570	0.2585	-0.0372	0.0460
	A	-0.0229	0.0230	-0.0677	-0.0966	0.2578	0.1668	-0.0113	-0.0731
	S	0.0078	-0.0373	-0.0337	0.0078	0.0763	0.0488	-0.0090	0.2098
Straw weight/ hill	C	-0.0174	0.0819	0.0019	0.0777	0.1035	0.6418	-0.0574	-0.3426
	A	-0.0040	0.0190	0.0094	0.0904	0.0532	0.8085	-0.0247	-0.4138
	S	-0.0187	-0.0424	-0.0036	-0.0010	0.0058	0.6463	-0.0074	-0.3888
1000 grain weight	C	0.0059	0.0488	-0.0009	0.0511	0.0819	0.3156	-0.1167	-0.0193
	A	0.0111	0.0145	0.0005	0.0077	0.0519	0.3559	-0.0560	-0.1908
	S	0.0169	-0.0375	-0.0134	-0.0011	0.0324	0.2255	-0.0212	0.1147
Harvest index	C	0.0407	-0.0719	0.0089	0.0649	0.0171	-0.3172	0.0033	0.6931
	A	0.0515	-0.0249	-0.0269	0.0396	-0.0247	-0.4387	0.0140	0.7626
	S	0.0586	0.0226	-0.0122	-0.0095	0.0169	-0.2652	-0.0026	0.9474

it was negative. Under non-stress as well as alkali stress the contribution of days to flowering via panicle length and PBT was negative while under saline soil it was positive.

4.4.4.2 Grain yield vs. plant height

In the early group, the direct contribution of plant height was positive under non-stress (0.0395), alkali (0.1304) and saline (0.1596) environments. The indirect contribution was positive and high through straw weight (0.9152, 1.0189, 0.8830 in non-stress, alkali and saline soil environments respectively). The contribution through PBT, 1000 grain weight and harvest index was negative under all environments. The direction of indirect contribution through days to flowering was positive under non-stress environment but it changed to negative under both stress conditions. A reverse trend was observed via panicle length.

The direct effect of plant height in the medium flowering varieties was negative under non-stress (-0.0642), alkali (-0.0496) and saline (-0.0012) soil environment. Highest positive indirect effect was through straw weight and negative indirect effect was through harvest index. The indirect contribution via days to flowering and PBT were positive under non-stress environment, but under both stress environments the effects were negative.

Plant height had positive direct effect under non-stress (0.1437) as well as alkali (0.0372) environments, while under saline environment negative effect (-0.0748) was observed. High positive indirect effect was observed via straw weight.

High negative indirect effect was observed via harvest index, followed by 1000 grain weight and days to flowering. The contribution via panicle length was positive in non-stress condition while in stress environments the contribution was negative.

4.4.4.3 Grain yield vs. panicle length

In the early group panicle length recorded negative direct effect (-0.0650) under non-stress environment and positive direct effect under stress environment (0.0076 alkali; 0.0109 saline). Maximum positive indirect effect was observed via straw weight under all environments (0.7489, 0.8593 and 0.6315 under control, alkali and saline environments respectively). Negative indirect effects were noticed via PBT, 1000 grain weight and harvest index, while positive indirect effects were noticed via plant height, panicle weight. Through days to flowering indirect effects were positive under non-stress and negative under stress environments.

The direct effects of panicle length in the medium flowering varieties were positive under non-stress (0.0338), alkali (0.0625) and saline (0.0735) soil environments. The indirect effects were positive via straw weight and PBT. While effects were negative via harvest index as well as plant height. Under non-stress and alkali soil environments indirect effects were negative via panicle weight and 1000 grain weight, whereas under saline soil environment they were positive.

Positive direct effect was observed with panicle length (0.0275) under non-stress and negative effects were observed

under both stress environments, in the late flowering group. Under non-stress environment positive indirect effects were noticed via days to flowering, plant height, panicle weight, straw weight, 1000 grain weight as well as harvest index, whereas negative indirect effect was noticed via PBT. Indirect effects via plant height, panicle weight, 1000 grain weight, and harvest index were positive whereas via days to flowering, PBT, straw weight were negative under alkali stress. In saline soil indirect effects were positive except via plant height and 1000 grain weight.

4.4.4.4 Grain yield vs. PBT/hill

As presented in Table 38, PBT had positive direct effect under all environments in the early flowering group. The maximum direct effect was observed in saline soil (0.2980) followed by non-stress environment (0.2237) and low direct effect was observed under alkali soil stress (0.1035). The indirect effects via 1000 grain weight and harvest index were positive. Negative indirect effects were observed through plant height, panicle weight and straw weight. The contribution through panicle length was positive under non-stress environment and negative under both stress environments. A reverse trend was observed with days to flowering.

In the medium group the direct effects were positive under all environments (0.0159, 0.1549, 0.0970 in non-stress, alkali and saline soil environments respectively). Maximum positive indirect effects were observed via straw weight. The indirect effects through panicle weight, 1000 grain weight and harvest index, were negative. Through days to flowering

and plant height, the indirect contributions were negative under nonstress environment, while under stress environments they were positive.

In the late flowering group, the direct contributions of PBT under non-stress, alkali and saline soil environments were 0.2813, 0.2130 and -0.0217 respectively. Positive indirect contributions were observed via days to flowering, straw weight as well as harvest index and negative via panicle length and 1000 grain weight under all environments.

4.4.4.5 Grain yield vs. panicle weight

In the early flowering group, panicle weight had its positive direct contribution to be 0.2067, 0.1542, 0.3662 under non-stress, alkali and saline soil environments respectively, whereas its maximum indirect effects were through straw weight (0.6880, 0.7282, and 0.2880) followed by plant height. Contributions of panicle weight to grain yield via PBT and 1000 grain weight were found to be negative under all environments. Indirect contribution through panicle was negative under non-stress and positive under stress environments.

In the medium group, the direct effects of panicle weight were found to be 0.0761 (non-stress), 0.1186 (alkali) and 0.1195 (saline). Positive indirect contribution of panicle weight via harvest index was observed to be maximum (0.5522) in non-stress environment which reduced to 0.2396 in alkali and to 0.1587 in saline soil environments. However, under saline soil environment, the indirect contribution was found to be high via straw weight.

The direct effect of panicle weight in the late flowering group was found to be 0.2570, 0.2578 and 0.0763 under non-stress, alkali and saline soil environments respectively. Maximum positive indirect effect was noticed via straw weight (0.2585). Maximum negative indirect effect was observed via PBT in control as well as alkali environments, however the magnitude and direction of its indirect effect in saline environment changed to low and positive.

4.4.4.6 Grain yield vs. straw weight/hill

From Table 38, it is observed that straw weight had maximum direct effect in the early flowering group and the respective values under non-stress, alkali and saline soil environments were 1.1157, 1.1747 and 1.1513. Its indirect effect on grain yield via harvest index was found to be high and negative. Indirect contribution via 1000 grain weight as well as PBT were also found to be negative. Positive indirect contributions were noticed via plant height, panicle weight in all environments and via days to flowering in non-stress environment.

In the medium group, as presented in Table 39, straw weight had high direct effect of 0.6994 in non-stress, 1.1452 in alkali and 0.8302 in saline soil environments. Among the indirect effects the magnitude was high via harvest index but the direction was negative. The indirect effect via plant height was also negative under all environments. Positive indirect effects were observed via panicle length, PBT under all environments; via panicle weight under non-stress environment;

via days to flowering in both stress environment and via panicle weight as well as 1000 grain weight under saline soil environment.

The direct contributions of straw weight to grain yield in the late flowering varieties were 0.6418, 0.8085, 0.6463 in non-stress, alkali and saline environments respectively which is presented in Table 40. Negative indirect effects were high via harvest index followed by 1000 grain weight and days to flowering under all environments. Contributions via plant height, panicle length and PBT were positive under non-stress as well as alkali soil environments whereas the contributions were negative under saline soil environments.

4.4.4.7 Grain yield vs. 1000 grain weight

In the early group, 1000 grain weight showed maximum negative indirect effect via harvest index (-0.4745, -0.4378 and -0.7467) with its own negative direct effect of -0.1078, -0.1816, and -0.2250 under non-stress, alkali and saline soil environments respectively. The maximum positive indirect effects were observed via straw weight (0.8084, 0.9233 and 0.8677), followed by panicle weight and plant height. Contribution via panicle weight was negative in non-stress (-0.0498) while under stress environments the magnitude was reduced and direction changed to positive. Just an opposite trend was recorded via days to flowering.

The direct effects of grain weight to grain yield of the medium flowering varieties were 0.0152 in non-stress, 0.1178 in alkali and 0.0624 in saline soil environments. The indirect contributions were positive via panicle weight and harvest index, whereas it was negative via PBT under all

environments. Contributions via panicle length and straw weight were negative under non-stress as well as alkali soil environments but were positive under saline soil.

The direct effects of 1000 grain weight in the late flowering rice varieties to grain yield were -0.1167, -0.0560, -0.0212 under non-stress, alkali and saline soil respectively. Maximum indirect contribution was observed via straw weight followed by panicle weight and days to flowering under all environments. Under non-stress environment the indirect effects via plant height and PBT were positive whereas that via panicle length and harvest index were negative.

4.4.4.8 Grain yield vs. harvest index

The direct effect of harvest index to grain yield in the early group was high as compared to indirect effects via other characters. The values were 0.9191 in non-stress, 0.8993 in alkali and 1.2632 in saline soil environments. Maximum indirect contribution was through straw weight which was negative in direction followed by plant height. Positive indirect contributions were observed via PBT and 1000 grain weight. The contribution through panicle length was positive under non-stress while under both stress environments, the contributions were negative and lower in magnitude.

In the medium group, the direct contributions of harvest index were 0.8475, 1.1754 and 0.6284 in non-stress, alkali and saline soil environments respectively. The indirect contributions through plant height, panicle weight as well as 1000 grain weight were positive and through panicle length, PBT, straw weight were negative. Contribution of days to flowering was positive in non-stress and negative in stress environments.

Amongst all the characters under study, harvest index showed maximum direct positive effect on grain yield in the late group (non-stress, 0.6931; alkali 0.7626; saline, 0.9474). Under the non-stress environment days to flowering, panicle length, PBT, panicle weight, 1000 grain weight had positive indirect effect and plant height as well as straw weight had negative indirect effect. Under alkali stress, however, days to flowering, PBT, and 1000 grain weight had positive while plant height, panicle length, panicle weight and straw weight had negative indirect effects. On the other hand, the indirect effects under soil salinity conditions were observed to be positive via days to flowering, plant height as well as panicle weight and negative via panicle length, PBT, straw weight and 1000 grain weight.

4.5 Comparative study of seed materials harvested from plants grown in favourable and unfavourable soil environments

Effects of alkali and saline soil environments on seeds, as reflected in seed germination and seedling vigour, were studied using the seeds harvested from varieties grown in different soil environments. Observations, recorded on total seed germination and height of 10-day old seedlings, are presented in Table 41 and their analysis of variance in Table 42. Mean sum of squares due to varieties, environments and V x E interactions were found to be significant showing that the performance of seeds harvested from different stress environments was not at par with that obtained from non-stress environments. Furthermore, varieties under study showed differential response to adverse effects of stress environments.

Table 41 Mean values of seed germination and seedling growth of 29 rice varieties harvested from non-stress, alkali and saline soil environments

Genotypes	Seed germination percentage			10-day old seedling height cm		
	Non-stress	Alkali	Saline	Non-stress	Alkali	Saline
CR 237-1	96.0	98.7	82.0	10.33	8.87	8.57
P2-21	85.3	76.0	85.3	8.65	6.94	8.11
CSR 4	82.7	89.3	98.7	6.27	6.14	6.13
CSR 5	85.3	96.0	61.3	7.28	7.23	7.02
CR 214	93.3	90.7	88.0	8.10	7.34	6.68
CR 222	93.3	85.3	93.3	8.17	7.84	7.80
Jhona 349	97.3	82.7	74.7	9.71	8.77	8.86
CR143-2-2	81.3	48.0	96.0	6.77	4.36	5.90
Jaya	98.7	96.0	100.0	5.75	5.38	4.76
Giza 159	96.0	57.3	94.7	6.12	4.27	5.72
Bas 370	92.0	74.7	90.7	4.46	3.74	4.01
Pusa 150	81.3	36.0	32.0	5.31	2.64	3.74
Pusa 167	78.7	48.0	68.0	4.15	2.90	4.22
PR 106	100.0	98.7	100.0	6.21	5.69	6.02
HAU-6-163	96.0	77.3	100.0	4.93	4.53	4.00
TR 17	100.0	100.0	100.0	6.15	6.00	5.60
IR 2053	100.0	46.7	100.0	4.60	2.38	3.98
IR 2031	97.3	86.7	100.0	4.42	3.46	3.71
IR 2055	100.0	88.0	97.3	4.78	2.79	4.21
IET 1444	92.0	69.3	94.7	6.70	4.93	6.94
IET 4141	100.0	94.7	100.0	5.78	4.82	5.38
Kalarata	100.0	96.0	97.3	6.34	7.71	5.90
Bhurarata	100.0	100.0	100.0	6.01	6.42	5.50
Arya	94.7	100.0	96.0	5.28	4.46	3.59
Damodar	98.7	92.0	97.3	5.00	4.25	4.50
Getu	98.7	90.7	98.7	4.37	4.43	4.13
Pokkali	100.0	98.7	97.3	5.53	3.68	3.91
MGM-1	100.0	100.0	97.3	5.66	5.59	5.47
IR 54	100.0	80.0	98.7	5.06	4.41	4.65
M-1-48	98.7	0	96.0	4.38	-	4.09
Mean	94.58	79.91	91.18	6.08	5.24	5.44
CD at P=0.05	VxE = 4.0, E=0.42,			VxE=0.43, E=0.14		

Table 42 Analysis of variance for seed germination and seedling growth of 29 rice varieties harvested from non-stress, alkali and saline soil environments

Sources of variations	d.f.	Mean sum of squares	
		Seed germination	Seedling height
Replications	2	338.24**	0.179
Varieties	28	1055.55**	22.437**
Environments	2	2850.12**	16.793**
VxE	56	275.48**	0.951**
Error	176	51.88	0.072

** Significant at 1% level.

4.5.1 Total seed germination

It may be seed from the data presented in Table 41 that mean values of germination of seeds harvested from non-stress soil environment was 94.6% and 91.2% in case of saline stress but it was reduced to 79.2% in seeds harvested from alkali soil. However, stress conditions did not have any significant effect on the seed germination of varieties Bhurarata, Pokkali, MCM-1, Kalarata, TR17, PR106, and Jaya. In marked contrast to saline environment, seeds harvested from alkali soil environment of variety M 1-48 failed to germinate while seed germination of varieties IET 1444, IR 2053, HAU 6-163, Bas 370, Giza 159 was found to be drastically reduced, ranging from 46.7 to 77.3%. Seeds of varieties Pusa 150 and Pusa 167, harvested from both stress environments, recorded low seed germination (32 to 68%).

4.5.2 Seedling height

Mean height of 10-day old seedlings, raised from seeds harvested from non-stress environment, ranged from 4.15 cm in variety Pusa 167 to 10.33 cm in variety CR237-1. Over-all mean of 6.08 cm among controls was found to be reduced to 5.24 and 5.44 cm in case of seeds harvested from alkali and saline soil environments respectively. No adverse environmental effects were observed in case of varieties CSR-4, CSR-5, Getu, MCM-1 and CR222. On the other hand, alkalinity and salinity induced reductions in seedling height were highly significant in varieties Pusa 150, IR2053, Pokkali, IR2031 and CR143-2-2. In marked contrast to others, varieties Giza 159, Pusa 167, IET 1444, IET 4141 and IR54 revealed significant reductions under alkali soil conditions only.

D I S C U S S I O N

Soil salinity and alkalinity problems have become serious threats to crop production in our country affecting large areas and there is an urgent need to develop crop varieties having genetic resistance to specific soil problems. Stresses that develop under these adverse soil conditions include diverse effects such as high pH, excess Na^+ in the cationic exchange pool, surface crusting, high concentrations of neutral salts, mineral deficiencies/toxicities, inadequate aeration, moisture stress, waterlogging etc. Resultant consequences of this vast array of interacting factors are usually of a complex nature under field conditions and often prove detrimental to seed germination, seedling emergence, plant growth, survival and yield.

Until recently, the problems of crop production in saline and alkali soils were being dealt with almost exclusively by manipulating the mineral substrate ("technological fix"). It has now become increasingly evident, however, that the approach of selecting and breeding salt resistant crop varieties ("biological fix") is not only a more promising and feasible alternative but it is also less energy-expensive and non-pollutant (Rana, 1977). Furthermore, this approach of "living with the salt and related problems" is likely to be of significant help in improving socio-economic conditions of small farmers who may own such marginal lands but have little cash inputs and other resources needed for land reclamation. Cultivation of salt-resistant crop varieties

will not only reduce the requirement of soil amendments *vis-a-vis* cost of reclamation but will also accelerate the process of reclamation itself.

In a breeding programme designed to improve a crop plant, it is essential for the plant breeder to understand the nature and extent of variability present in his materials for the desired traits. In this context, the need for basic work to find out the genetic mechanism of salt tolerance in plants, systematic approach for proper choice of parents and suitable breeding techniques, alongwith an integrated approach for incorporating multiple resistance, were highlighted in a group discussion on "Genetics and Physiology of stress with special reference to salt tolerance in crop plants" held in 1982 at the Central Soil Salinity Research Institute, Karnal. Various aspects of this subject have also been thoroughly discussed in symposia/seminars/workshops held in different countries and the information emanating from these discussions has been published providing critical reviews of the progress made at regular intervals. Some relevant volumes of direct interest to the present investigation are listed below:

i) Plant Adaptation to Mineral Stress in Problem Soils (M.J. Wright, ed.), Cornell Univ., Ithaca, 1976.

ii) Genetic Diversity in Plants (A. Muhammad *et al.*, eds.), Plenum Press, New York, 1977.

iii) The Biosaline Concept (A. Hollaender *et al.*, eds.), Plenum Press, New York, 1979.

iv) Breeding Plants for Less Favourable Environments (M.N. Christiansen and C.F. Lewis, eds.) John Wiley & Sons, New York, 1982.

v) Genetic Aspects of Plant Nutrition (M.R. Saric and B.C. Loughman, eds.) Martinus Nijhoff, The Hague, 1983.

vi) Salinity Tolerance in Plants: Strategies for Crop Improvement (R.C. Staples and G.H. Toenniessen, eds.) John Wiley & Sons, New York, 1984.

These publications, together with numerous reports on this subject make it amply clear that cataloguing of available indigenous germplasm and evaluation of their responses to different stresses, including salinity and sodicity, are the prime needs of our time.

Numerous experimental procedures have been used by various workers for measuring salt resistance of crops and their varieties under a wide range of environmental conditions. It appears that, in most cases, important variables influencing the observed plant tolerance to soil stresses were either not controlled or were not even properly measured. It is not surprising, therefore, that reproductibility of data obtained from such field investigations is often poor and there are glaring inconsistencies in results. In marked contrast to field based investigations, on the other hand, studies conducted in laboratories and test plots enable us to understand plant response to specific stresses which can be monitored under controlled conditions. Again, our pilot studies revealed that

plant performance in specially designed test plots was significantly correlated with that under field conditions but it was not so in case of pot culture evaluation.

Considering these aforementioned points, the present investigation was conducted in specially designed test-plots for varietal evaluation and cytogenetic studies. Studies on germination and seedling responses were also conducted under defined conditions in the laboratory. To start with, 55 genetically divergent rice varieties, including locally adapted cultivars of salt-affected areas, were evaluated for their response to saline and alkali soil environments created in test-plots. It was observed that some of the photosensitive late flowering varieties failed to yield at Karnal conditions as the onset of winter conditions affected flowering and seed setting of these varieties. Accordingly, 39 genotypes were finally selected from this group of 55 varieties to study their yield and yield component responses to soil stresses.

Data reported by Lunin et al. (1961), Kaddah and Fakhry (1961), Kaddah and Ghowail (1964) and Meiri and Poljakoff-Mayber (1970) showed that plant responses were directly related to duration of exposure to salinity. Apparent salt tolerance may also vary with changes in climatic conditions, such as temperature, humidity, rainfall, air pollution etc. (Bernstein, 1975; Maas and Hoffman, 1977; Levitt, 1980). Metereological conditions monitored during the present investigation revealed that atmospheric temperature, relative humidity and rainfall were not uniform during the two kharif

seasons. Furthermore, taking into consideration the fact that rice plants are sensitive to salt stress during flowering stage (Pearson and Bernstein, 1959; CRRI, 1980), varieties under study were grouped into three categories according to the number of days taken to flowering so that the climatic conditions and the duration of exposure to salinity of the varieties, analysed within a group, remained more or less comparable.

5.1 Characterisation of locally-adapted indigenous cultivars

Diversity is the most striking aspect emerging from a survey of current knowledge of the plant kingdom's responses and adaptation to salt stress (Hanson, 1984). Genetic differentiation among populations of plant species occupying heterogenous environments is widely observed (Gray et al., 1979). Recent ecological studies suggest that variation in soil nutrient levels influences species composition and maintenance of species diversity by niche differentiation (Etherington, 1975). In the traditional agriculture, dominated by local cultivars, the soils are often sub-optimal and inputs by way of soil amelioration are rather minimal. In this context, efforts were also made during this study to collect the locally adapted rice varieties and to characterise their phenotypic variability.

Most of the salt tolerant rice varieties cultivated locally were found to be tall, photosensitive and of late duration. These varieties are suitable only for low-lying and flood-prone coastal areas. Considering that rice-wheat

is the predominant rotation followed by farmers in reclaimed alkali soils zone of India, it may be pointed out that either early or medium duration rice varieties can be successfully grown in this region.

Six varieties included in this study were characterized by deeply pigmented grains still preferred in some coastal areas.

All the indigenous cultivars studied during the present investigation were found to be diploids (2n = 24) and showed regular meiotic behaviour and high fertility. Comparative data on several phenotypic and developmental traits revealed remarkable variability among them with regard to duration, days to flowering ranging from 77.75 days for Kalinga-II to 159.5 days for the variety SR 26B, plant height ranging from 83.15 cm to 229.60 cm for Kalinga-II and Nona bokra respectively, tillering ranging from 10.81 for Pokkali to 33.38 tillers per plant for Bhurarata, yielding ability (19.92 to 51.61 gm per plant in Kalinga-I and MCM-1 respectively), and characteristic features of glume, grain (white to dark red), stomata size ranging from 9.81 μ in Damodar to 16.0 μ in SR3-9, stomata frequency ranging from 31.2 to 18.45 per microscopic field area (0.21 mm^2) in Kalinga-II and SR-3-9 respectively and pollen grain diameter ranging from 15.35 to 17.25 μ in Nonabokra and Karekagga respectively.

5.2 Cytological studies

Terrestrial plants that grow on saline soils are confronted with more complex problems than the marine organisms in which each cell is in contact with the same concentration of saline solution and, therefore, more or less independent in terms of nutrient supply. Another important aspect of plant adaptation to different environments is the differentiation of plant body. Since cells are the structural and functional elements of a multicellular organism, they take part in realisation of every adaptation of the latter to the environment (Alexandrov, 1977). However, plant cytology has not yet succeeded in offering universal explanation of how a salt-tolerant plant functions as it has not been possible so far to pin-point and identify any particular cellular structure that would explain the phenomenon of salt tolerance (Kramer, 1984).

Polypoid forms, especially allo-polyploids, have been reported to show remarkable adaptability to extreme environmental conditions, as compared to their diploid progenitors (Jain and Rana, 1963; Stebbins, 1966; Rana,1967; Rana *et al.* 1980; Lumaret, 1984). The species *Oryza coarctata*, a tetraploid (2n = 48) colonoizer plant, found on the Sunderban coast could withstand 48 hours of seawater submergence and showed optimum growth at electrical conductivity of 10 dS/M (IRRI, 1984). The potential value of this species in increasing salinity tolerance of the cultivated species *O. sativa*, through genetic engineering, is obviously exciting (IRRI, 1984).

During the present study, however, all the locally adapted varieties showed only diploid number of chromosomes (2n = 24) with normal meiotic behaviour. Interestingly, most of these varieties (Damodar, Dasal, Karakagga, MCM-1, SR 10032, Pokkali, Jhona 349) were found to have higher chiasma frequency (24.0 to 25.3 per cell) as compared to the improved high-yielding variety Jaya (22.7 ± 0.28 chiasma per cell) and the chiasma frequency was also found to be increased by soil alkalinity (up to 10.48% in MCM-1) and salinity (up to 10.17% in SR 3-9) stresses. Such an increase in chiasma frequency points out the capacity for release of variability by the organism which help in effective natural selection to these type of adverse soil stresses. It may also be noted here that most of the rice varieties of tropical origin, which are adapted to specific local conditions, eventhough show considerable uniformity for characters of longterm agronomic importance, there exists much variation to non-selected characters (Chang, 1974; Yeo and Flowers, 1984).

Nutritional imbalances, like deficiencies of N, P and K are reported to have increased meiotic abnormalities in pollen mother cells of wheat as well as rice while sustaining normal mitotic cell divisions in root-tip meristems (Das and Sen, 1976). Significant positive correlation between chromosome abnormalities and calcium deficiency has also been reported (Eversole and Tantum, 1956; Hyde and Paliwal, 1958) and this may be due to the effect of Ca deficiency on chromosome structure and stability (Hewitt, 1963; Devlin, 1975). Increased

frequency of chromosome rearrangements at meiotic anaphase - I and II in barley induced by salinity stress was also reported by Sevast'yanov et al. (1980).

During the present study, occurrence of meiotic abnormalities in pollen mother cells was observed to be increased by both soil salinity and alkalinity stresses(13.43 and 16.42% respectively in Kalarata). There were, however, remarkable varietal differences in this regard and salt-tolerant varieties like Damodar and Pokkali showed no significant increase in meiotic abnormalities due to imposed stresses. Observed abnormalities in meiotic divisions could possibly be due to the nutritional imbalances caused by soil salinity and alkalinity. The occurrence of meiotic abnormalities in a species, that was normally fertile and productive, indicated switching of some homeostatic mechanisms related to survival as suggested by Janavi et al. (1981).

Pollen fertility, as judged by acetocarmine stainability test, and pollen size were found to be affected adversely by both alkali and saline soil stresses though there were significant varietal differences in this respect. For example, in the varieties, Arya and SR 10032 under alkali soil stress, pollen fertility was reduced to 75.87 and 79.21 per cent respectively, while pollen size was reduced by 8.93 per cent under alkali and 7.14% under saline soil stresses in the variety Arya. No significant stress induced reduction was observed in the varieties SR 3-9, Pokkali, Damodar and MCM-1. Similar observations were also reported by Chuprinina(1977) who found the frequency of sterile and partially inviable pollen in the

anthers of barley increased by an increase in salinity level. However, it was observed during the present study that there was no significant correlation between the observed reduction in pollen fertility and paddy yield. The observed reduction in number of fertile spikelets under saline and alkali soil stresses, therefore, may possibly be due to the failure of pollen to germinate on stigma and/or due to ovular sterility. Ota et al. (1956) observed that salinity affected pollen germination on stigma adversely and that caused a lower percentage of fertilization of the florets in rice.

Investigating the effect of stomatal frequency and size on important plant processes as well as on productivity might be more meaningful if the extent of intraspecific variation in frequency and size of stomata is known. Significant variation in stomatal frequency within a species has been reported (Eckerson, 1908; Dobrenz et al., 1969; Ormrod and Renny, 1968). Cultivar variability in this regard in barley has also been reported by Miskin and Rasmusson (1970). Gill and Dutt (1982) suggested in this context that selecting cultivars with lesser increase in stomatal frequency under saline stress might help in avoiding excessive water loss due to transpiration without affecting the photosynthetic capacity under mild water stress. A wide variation in stomatal size ranging from 8.78 μ in IR 2031 to 16.00 μ in SR 3-9 and frequency ranging from 18.45 stomata per microscopic field area (0.21 mm^2) in SR-3-9 to 36.40 stomata per 0.21 mm^2 in the variety M-1-48, was observed during the present study. Heritability value for stomatal frequency was high (67.88%) as compared to stomatal size (36.11%) showing that selection for low stomatal frequency could be effective.

Water relations, and also the metabolism, of land plants depend to a large extent on the diffusion of water vapour and gases through the stomatal pores that occur on their aerial parts (Meidrner and Mansfield, 1968). It was observed during the present study that the total stomatal opening per unit area was significantly and negatively correlated ($r = -0.579$) with paddy yield in the early flowering group while it was positively ($r = + 0.620$) so in the late flowering group. This may be due to high temperature prevailing during the grain filling stage among the early maturing varieties which could lead to a higher rate of transpiration and subsequent loss of energy. As limited water availability is one of the major effects of soil salinity, selection for relatively lower stomatal frequency in leaves should be practised while breeding for salt tolerance so as to increase water use efficiency during period of high water stress and dry atmospheric condition, especially among the early duration rice varieties. It was observed that lower stomatal frequency reduced the amount of water transpired but did not affect the rate of photosynthesis (Miskin et al., 1972). On the other hand, low stomatal frequency was associated with high photosynthetic rates in beans (Izhars and Wallace, 1967).

5.3 Germination and seedling responses

Salt tolerance is a complex character and its expression largely depends on the interaction of genotypes with numerous variables (Rana, 1977; Maas and Hoffman, 1977; Ramage, 1980; Epstein et al., 1980). It has been convincingly

established that the response to salt stress varies with the stage of plant development (Pearson, 1959; Pearson and Bernstein, 1959; Pearson and Ayers, 1960; Bernstein, 1975; Castyo and Sabade, 1977; Srivastava and Jana, 1984). For the screening of large germplasm collections, seed germination and the seedling stage have been effectively and widely employed (Devine, 1982) even though relative salt tolerance during germination and that of the adult plant based on grain yield differ a great deal (Srivastava and Jana, 1984).

Responses of crop plants during germination and early growth need to be given importance while selecting for tolerance to soil stress as these stages of plant growth are more detrimental in saline/sodic conditions affecting the later development, growth and ultimately the crop yield. Accordingly, salt tolerance of different genotypes at seedling stage was also assessed during this investigation by recording germination percentage, seedling emergence index and seedling weight after specified time intervals. Results so obtained revealed that there were significant delay as well as reduction in germination caused by salt stress as compared with the corresponding controls. However, varietal differences in this regard were found to be significant indicating good scope for desirable selection. For example, varieties SR 3-9, Jhona 349, Bhurarata and TR 17 recorded higher seed germination percentage ($> 98\%$) and seed germination index (> 4.35) as compared to the varieties Giza 159, Pokkali

and Belikagga which recorded more than 46.56 per cent reduction in seed germination and high reductions (> 74.05%) in seed germination index. Varietal differences regarding germination responses to salinity were also observed in rice by Rao et al. (1973), Krishna and Iyengar (1980), Datta and Pradhan (1981).

No significant reduction in seed germination was observed in varieties CSR-5, Jhona 349, IR 2031, Bhurarata, SR 26B, SR 10032, SR 3-9, TR 17, and CSR-4. Interestingly, the rate of seed germination, as quantified by seed germination index, was found to resolve varietal responses to salinity (1% NaCl solution) better than the seed germination percentage. Variety SR 3-9 was observed to be very quick in germination under saline conditions followed by Bhurarata, Jhona 349 and TR 17. Delay in rice seed germination, caused by salinity, was also observed by Patolia and Iyengar (1979), Krishna and Iyengar (1980), and Reddy and Vaidyanath (1982).

Observed reductions in germination percentage and rate, noted during this investigation, may be due to an increase in the osmotic potential of the external solution to a point that will restrict the intake of water (Ayers, 1952; Bernstein, 1961) or by causing toxicity to the embryo (Rudolfs, 1925; Mehta and Desai, 1958). Narale et al. (1969) observed that rice seeds germinated normally in salt medium having ECe of 4.5 dS/m while seed germination was adversely affected at ECe 8.9 dS/m. Rao et al. (1973) also observed that ECe value more than 8.5 dS/m was critical in germinating

paddy. Although Pearson et al. (1966) observed 50% reduction in rice seed germination at EC value of 21.2 dS/m, yet concluded that the ability of rice seed to germinate at high salinity values was of no practical significance since the young seedlings are very much sensitive to saline conditions.

Weight of 10 days old seedlings showed significant varietal differences both under non-stress (45.89 to 93.14mg) and saline (1% NaCl) environment (9.84 to 40.40 mg). Higher seedling weight (76.67 to 93.14 mg) was observed in tall varieties Arya, Pokkali, Kalarata, Bhurarata and Karekagga, also having higher seed weight. Salinity induced reductions in seedling fresh weight and reductions were not uniform for all the varieties showing varietal differences in salinity tolerance at this stage. Lowest salinity induced reduction was observed in variety SR 3-9 (33.13%). Varieties Jhona 349, IR 2031, IR 2055 and TR 17 also showed remarkably low reductions. Such reductions in seedling height in rice varieties, when they were germinated in saline water, have also been reported by Paliwal and Gandhi (1975), Singh et al. (1979), Krishna and Iyengar (1980). In addition, Datta and Pradhan (1981) reported that root growth was depressed more than the shoot growth.

The response of rice varieties at seedling stage was not found to be correlated with grain yield response, however, these experiments conducted in petriplates under controlled conditions for studying rice varietal response to salinity based on germination and young seedlings

characters revealed that variety SR 3-9 was outstanding. Varieties Jhona 349, IR 2031 and TR 17 also showed better performance under saline conditions. Rice, being a transplanted crop in the Karnal-Kurukshetra region, salt tolerance at germination and seedling stages may not be of very much importance as such. Nevertheless, the identified salt tolerant varieties could be used for raising the nursery in salt-affected soils or with saline water irrigation and also where direct seeding is practised on saline soils.

5.4 Growth and yield response

A second peak of susceptibility to salt stress occurs in rice during the flowering stage (Pearson and Bernstein, 1959; CRRI, 1980) following high sensitivity observed at the first to second leaf stage. Krasnikova (1979) noticed also that different rice varieties showed salt tolerance at different growth stages. In this context, three main effects of salt injury reported by Bernstein (1964) were: (i) general osmotic effect in which growth and yield depressions or quality impairment were determined by osmotic pressure of the medium (ii) nutritional imbalances or deficiencies which depress growth and yield or impair quality, and (iii) toxic effects which cause characteristic injury symptoms in the plants. Enormous differences regarding tolerance to soil stresses among plant species and within species are commonly reported and have been convincingly established (See: Ayers et al. 1951; Bernstein and Ayers, 1953; Richards, 1954;

Ehling, 1960; Dewey, 1962; Greenway, 1962; Elzam and Epstein, 1969; Ayoub, 1974; Taylor et al. 1975; Rush and Epstein, 1976; Epstein and Noryln, 1977; Lauchi and Wieneka, 1977; Ratanadilok et al., 1978; Sajjad, 1983; Stavarek and Rains, 1983; Yeo, 1983; Mesdag and Balkema-Bookstra, 1984; Rana, 1984; Staples and Toenniessen, 1984; Bansal and Bhattacharyya, 1984).

During the present investigation, effects of salinity (ECe 5 to 8 dS/m) and alkalinity (pH_2 8.8 to 9.1) on grain yield per plant, days to flowering, plant height, panicle length, panicle bearing tillers per plant, straw weight per plant, panicle weight, 1000 grain weight and harvest index of rice varieties representing three flowering groups were studied. Analysis of variance showed significant genetic variability among the materials under study and also confirmed distinct differences among environments. Both salinity and alkalinity levels depressed the grain yield and its components. Under the alkali soil environment, mean reduction in grain yield ranged from 23.06% in the early flowering group to 33.56% in the medium flowering group. Under saline soil environment, on the other hand, there was a progressive increase in yield reduction percentage from early flowering group (39.41%) to late flowering group (55.30%). This supports the earlier reports of Lunin et al. (1961); Kaddah and Fakhry (1961); Kaddah and Ghowal (1964) and Meiri and Poljakoff-Mayber (1970) that plant responses were directly related to the duration of exposure to salinity.

Stress levels, imposed during the present study, were mild but the chosen level of salinity stress was found to be more detrimental than the alkalinity stress. Under the non-stress (favourable) environment, higher yield levels were obtained in the test-plots as compared to field conditions and pot culture, especially in some of the tall varieties, owing to better management care including the prevention of lodging by giving artificial support.

Flowering was found to be delayed by both saline and alkali soil stresses in all the three flowering groups. Delay was, however, more severe in saline soil environment as compared to that in case of alkali soil environments. In saline soil environment, maximum delay amounted to 5 days in variety Bilekagga of the early group, 9 days in varieties HAU 5-298 and Bas 370 of the medium group and 13 days in SR 10032 of the late flowering group. Stress-induced delay in the late flowering group also affected very severely the subsequent grain filling stage due to the onset of winter conditions at Karnal.

Under the non-stress edaphic environment, varieties Jhona 349 and CSR-5 of the early group, Jaya, HAU 6-163, PR 106 and HAU 5-298 of the medium flowering group as well as MCM-1, Bhurarata and Arya of the late flowering group recorded significantly higher grain yield per plant as compared to others. Under both saline and alkali soil environments, all the varieties under study exhibited reductions in grain yield and its component characters. The quantum of reduction,

however, differed among the varieties as well as the stress environments. Yield per se under alkali stress was higher in varieties Jhona 349, CR 222, Karekagga, Bilekagga, CSR-5 of the early flowering group; Jaya, HAU 6-163, PR 106, Giza 159, TR 17 of the medium flowering group; and Bhurarata, Arya, Kalarata, Getu, IR 2055 of the late flowering group. Under saline soil stress, on the other hand, per se yield was higher in varieties CSR-5, Jhona 349, CR 214 and Pusa 150 of the early flowering group; HAU 6-163, PR 106 and Jaya of the medium flowering group; and Bhurarata, Getu, IR 2055, PAU 269 and Kalarata of the late flowering group.

Relative performance (yield reduction) of varieties is considered more important than the per se performance when selection is done under recombination breeding programmes. Among the early flowering varieties grown under alkali soil stress, Bilekagga, CR 143-2-2, Kalinga-I and Kalinga-II showed low reductions for grain yield while CR 222, IET 1444 and Pusa 167 recorded low reductions with respect to dry matter production. Variety CR 237-1 was found to be very sensitive both to salinity and alkalinity soil stresses. Under saline soil stress, varieties IET 1444, CR 143-2-2 and Pusa 150 recorded low reduction for grain yield. Considering both per se yield performance and per cent yield reductions under soil stress conditions, varieties Bilekagga and Karekagga under alkali soil and CSR-5 and Jhona 349 under saline soil conditions were found to be better performers.

In the medium flowering group, per cent reductions in yield were high for variety HAU 5-298 under both the stress conditions. Low reduction under mild alkali soil stress was observed in varieties IR 2053, Giza 159, Bas 370 and IET 4141. Under mild saline soil stress, varieties HAU 6-163 and Bas 370 recorded low reductions. Considering both *per se* performance as well as per cent reductions, varieties HAU 6-163 and PR 106 were found to be more suitable under mild alkali and saline soil stresses. Interestingly, it was noted that the response of variety IR 2053 to saline and alkali soil stresses with respect to two important characters, namely, yield and straw weight per hill, showed an opposite trend. Under alkali stress, straw weight showed higher reduction than that of yield reduction while under saline soil stress yield reduction was higher than that of straw weight reduction. This lower reduction of straw weight seems to be due to increased tillering under saline soil stress.

In the late flowering group, yield reductions under alkali soil stress were low for Kalarata, SR 3-9, IR 2055 and Dasal whereas low reductions under saline soil stress were observed in PAU 269, Getu, Dasal and Kalarata. Considering *per se* performance as well as yield reductions, varieties Getu, Kalarata and PAU 269 were found to be suitable for mild saline soil stress and Kalarata, IR 2055 and Dasal were found to be suitable for mild alkali stress. The low yield observed in Arya and SR 3-9 as well as in SR 10032 may be due to the fall in atmospheric temperature during flowering and grain setting period under Karnal conditions.

Varietal differences in yield reductions under saline and alkali soil conditions in different crops have been reported extensively in literature. Ray et al. (1977), Anoop Singh et al. (1979), Mishra and Bhattacharyya (1980), Babu (1983) and Singh et al. (1983) in alkali soil and Aboul-Shod and Ashour (1974), Maurya et al. (1976), Balasubramanian and Rao (1977), Gabr et al. (1977), Iyengar et al. (1977), Sourour et al. (1977), Ansari et al. (1978), Kumar (1978), Sevast'yanov and Sevin (1978), Bole and Wells (1979), Gill (1979), Chauhan et al. (1980), Morozova (1980), Datta and Pradhan (1981), Babu (1983), Kingsbury and Epstein (1984), Norlyn and Epstein (1984) in saline soil environments observed adverse effects on growth and yield in different crops and varieties. The observed adverse effects on growth and related processes are generally associated with an increase in specific ion concentration and or lowering of water potential of the substrate (Bernstein, 1964).

5.5 Stability analysis

Identification of desirable genotypes having wide adaptation over a range of soil and climatic conditions is of considerable significance in crop improvement, particularly in areas where soil salinity and alkalinity problems are of a spotty nature or where such stresses occur with unpredictable periodicity and intensity. Phenotypes are the result of genotypes, environments and the interaction between genotypes and environments. It is well known that genotype x environment

interaction is widely present and contributes substantially to the non-realisation of expected gains from selection (Comstock and Moll, 1963). Relative importance of the main and interaction effects may vary from genotype to genotype and also with the environments.

Finlay and Wilkinson (1963) considered linear regression slope as a measure of stability whereas, Eberhart and Russell (1966) and Freeman and Perkins (1971) emphasised the need of considering both linear (b_i) and non-linear (Sd_i^2) components of G x E interactions in judging the phenotypic stability. Breese (1969) and Paroda and Hayes (1971) also advocated that linear regression could be regarded as a measure of the response of the genotype whereas, deviation could be considered as the measure of stability.

In the present study, mean squares due to varieties for all the nine characters and those due to environments were found to be significant indicating that there was enough variability among the varieties and also that the environments created were distinct. Observed significant mean sqaures due to G x E interaction revealed that varieties were unable to maintain consistant performance under different environments. Furthermore, any generalisation regarding stability of cultivars belonging to particular flowering group or of individual cultivars for all the characters was difficult as they did not exhibit uniform stability (non-linear G x E) and response (linear G x E) which appeared to be specific for individual character of a genotype. This may be explained on the basis of compromises

and compensations among the developmental patterns of the different characters. Similar observations were also made by Babu (1983) in wheat under soil stress conditions and evidences are available which suggest the importance of component compensation mechanism in imparting homeostasis for complex traits (Grafius, 1956; Bains and Gupta, 1974).

Characters such as harvest index and grain yield per plant showed the presence of high linear component of G x E interaction consistently in all the three maturity groups which can be easily manipulated for identifying stable and superior genotypes. However, non-linear portion was significant for days to flowering and 1000-grain weight in the early flowering group; panicle length, panicle bearing tillers per plant, panicle weight, straw weight, 1000-grain weight in the medium flowering group, and plant height as well as panicle bearing tillers per plant in the late flowering group, indicated the unpredictable behaviour of these traits over the environments.

Considering the X_1, b_1, and Sd_1^2 for various traits under study, an attempt was made to identify the most stable and also the most responsive genotypes. In the early flowering group, varieties Bilekagga, CR 214 and CSR-4 were found to have stable yield performance. Among them, variety CR 214 was also found to have stable performance for six other component characters including straw weight, panicle weight, 1000-grain weight and panicle length; variety Bilekagga, on the other hand showed stability only for grain yield. In the medium flowering

group, varieties TR 17 and Giza 159 showed stable performance for grain yield and six component characters, whereas, variety HAU 6-163, which showed stable and above average yield performance, recorded stability in performance for two component characters only, namely, straw weight and 1000-grain weight. In the late flowering group, varieties IR 2055, IR 2031, SR 3-9 and Pokkali were found to have stable performance for grain yield. Variety Getu recorded stable performance for six component characters, including straw weight, but its performance for grain yield was not stable.

Varieties Karekagga, and CR 143-2-2 of the early flowering group; Bas 370, IET 4141 and M-1-48 of the medium flowering group as well as MCM-1, Bhurarata and PAU 269 of the late flowering group were found to be very responsive in respect of yield as well as most of the component characters. Bradshaw (1965) suggested that maximum fitness could be obtained by adjustment in the plastic component traits. In a homeostatically buffered population, to perform well for the final trait under changing environments, the expression of the component traits might shift in a compensating manner, otherwise high unpredictable G x E interaction would result. It was observed in the present investigation that rates of responses to the environment were different for different varieties. Stability of straw weight, 1000-grain weight, panicle bearing tillers per plant, panicle weight as well as panicle length appeared to vary in a compensating manner in different genotypes and ultimately conferred homeostasis for yield.

5.6 Estimation of correlation coefficients

When plant characteristics are sought to be modified in a population through selection, there is a possibility of unintentionally altering other characteristics affecting crop performance. Such changes may result from pleiotropic responses and genetic linkages (Devine, 1982). When breeding for higher yield potential, information on the nature and magnitude of association between yield and its component traits as well as the environmental influences on these characters is very essential. Most of the literature available on correlation of different component characters with grain yield deals with normal (non-stress) soil condition only. In the present study, on the other hand, correlation coefficients among yield and its eight component characters of 39 rice varieties, belonging to three distinct flowering groups, were estimated separately under favourable (non-stress), alkali and saline soil environments.

It has been observed that the correlation coefficients at genotypic levels for all the pairs of characters under all the environments had a similar trend with greater magnitude at the genotypic level. Higher values of correlation coefficients at the genotypic level than that at the phenotypic level had also been reported in other crops by many workers (Robinson et al., 1951; Johnsen et al., 1955; Shanker et al., 1963; Bhattacharyya, 1976; Sharma and Singh, 1976; Dua, 1978; Sasmal, 1982; Singh and Chowdary, 1983; Babu, 1983). Higher values of observed genotypic correlation indicated a strong

inherent association that would result in a higher response in respect of yield as would have been expected if selection was made for both these components. Somehow the estimates of phenotypic correlations between yield and panicle weight under saline soils environment of the early flowering group, and between straw weight and harvest index of the late flowering group under non-stress as well as alkali environments were found to be higher than those of the genotypic correlations. Similar observations between grain yield and plant height were also reported by Roychowdary (1968) and Bhattacharyya(1976). According to Roychowdary (1968), higher phenotypic correlation values than the genotypic ones were perhaps due to narrower field of variation of the former than of the latter.

It has been observed during the present study that the main contributing component characters for yield among varieties of the early flowering group were panicle weight, panicle length and straw weight. In medium and late flowering groups, on the other hand, in addition to panicle weight and straw weight, panicle bearing tillers also showed significant positive correlation with the grain yield under non-stress soil conditions. It was noted that even though the direction of significant correlation between pairs of characters remained the same for most of the characters under different soil environments the magnitude of correlations changed. There was no specific pattern in this respect either for different stress environments (i.e., alkali and saline soil stresses) nor for different flowering groups (Figures 4 to 6). Significant positive correlation between grain yield and

Text continued on page 184

Figure 4 Genotypic correlations between paddy yield and 8 component characters based on 15 early flowering varieties grown in three edaphic environments

Genotypic correlation coefficients between grain yield and its eight component traits in 15 rice varieties of early flowering group

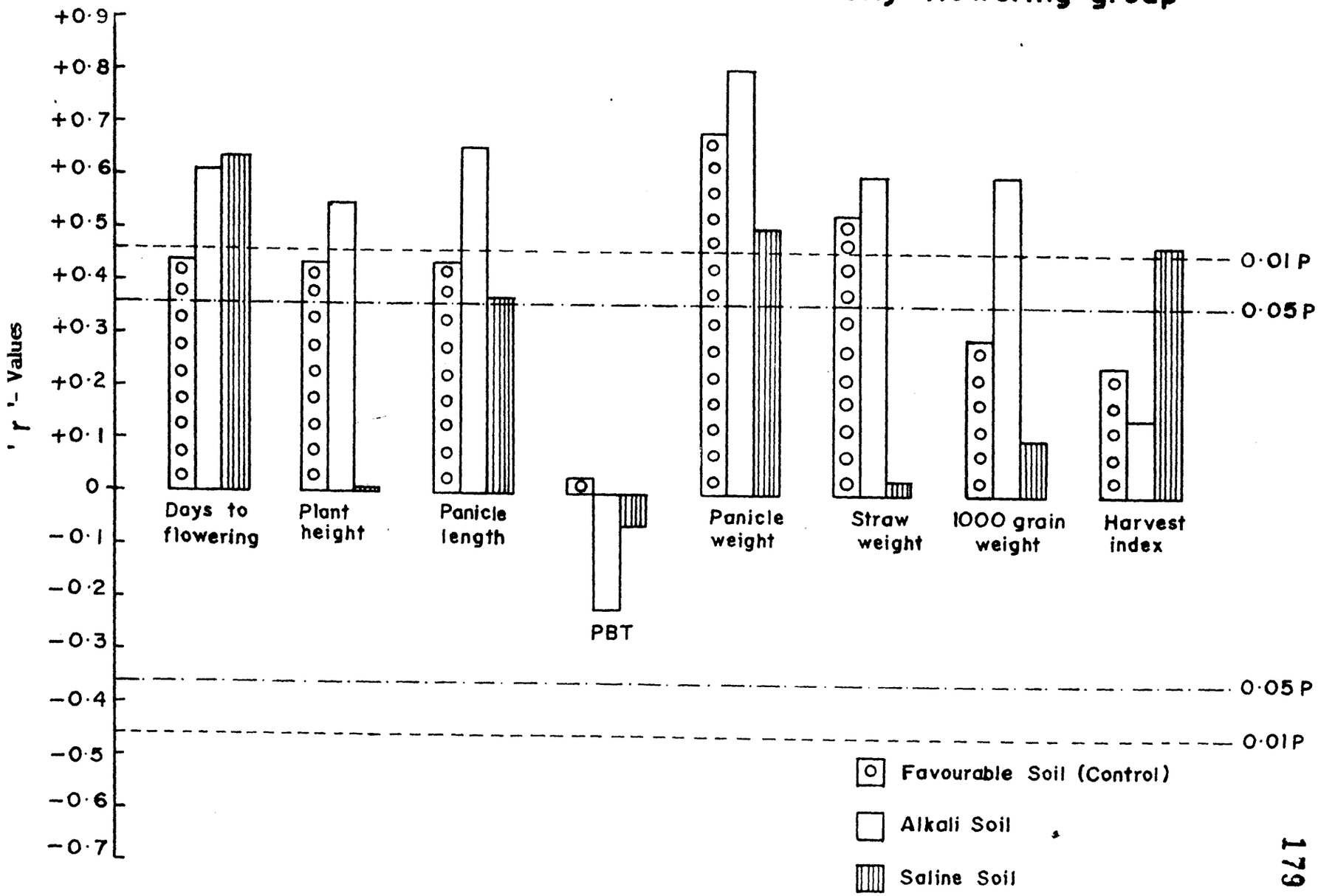


Figure 5 Genotypic correlations between paddy yield and 8 component characters based on 11 medium flowering varieties grown in three edaphic environments

Genotypic correlation coefficients between grain yield and its eight component traits in 11 rice varieties of medium flowering group

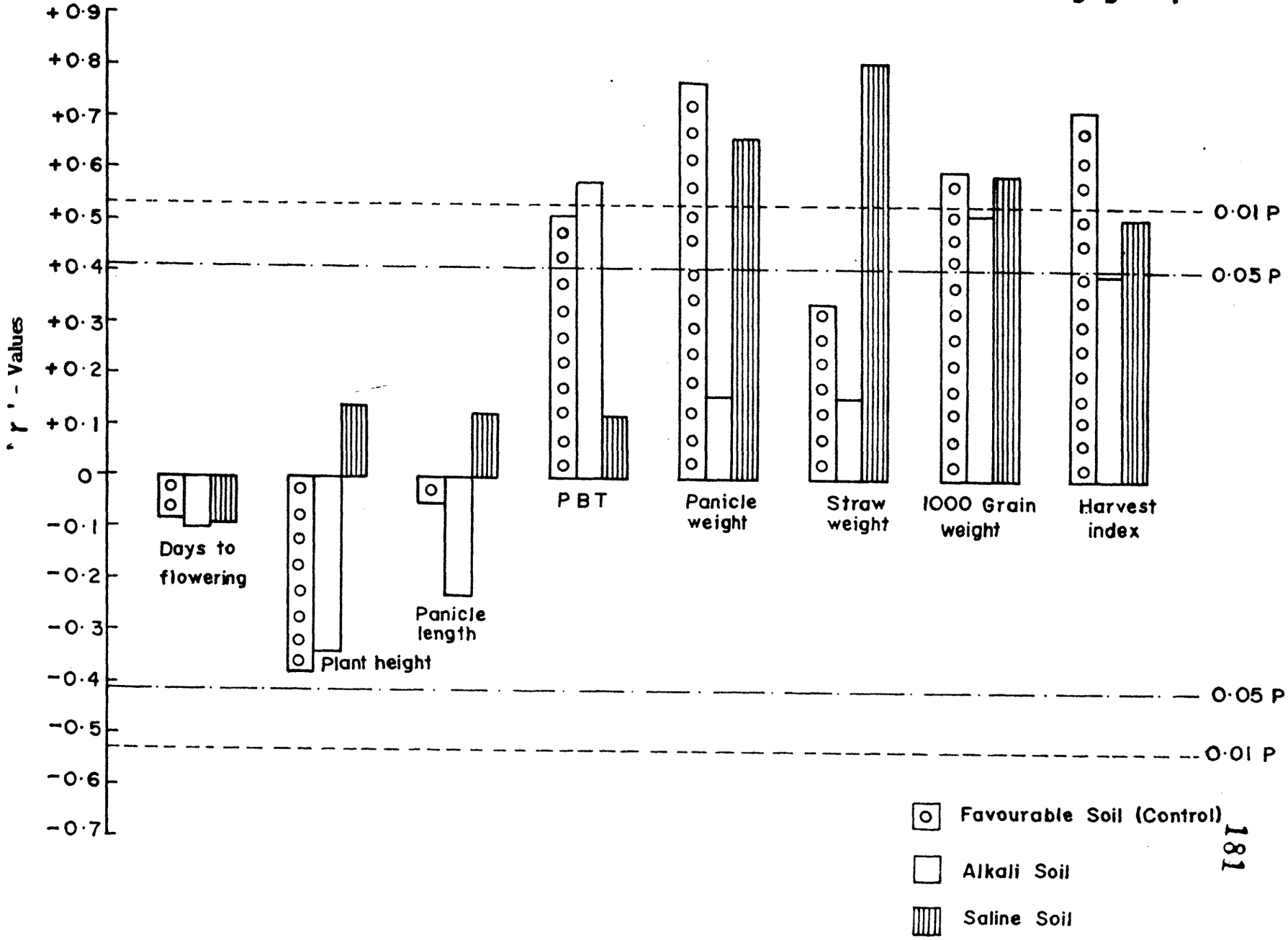
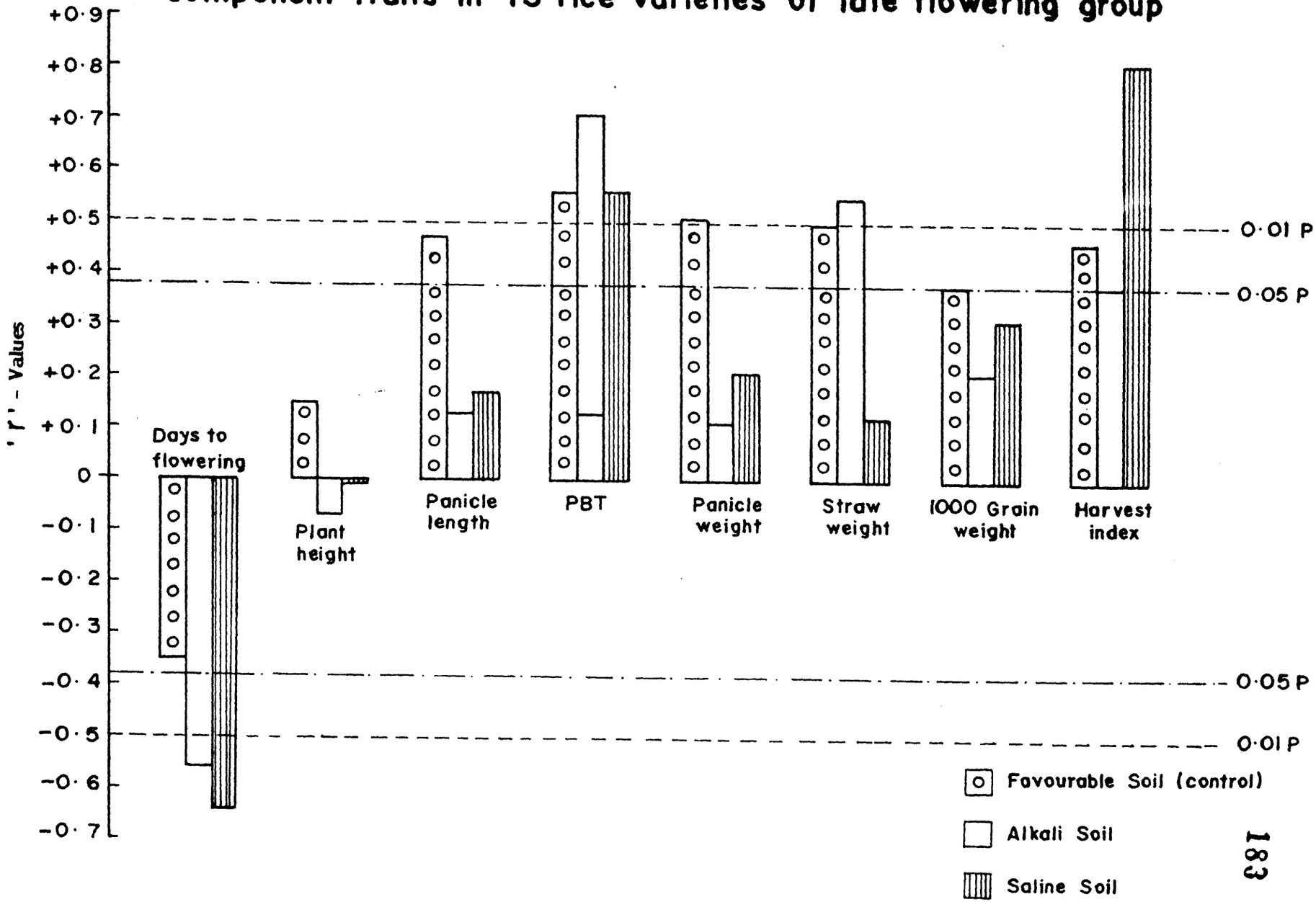


Figure 6 Genotypic correlations between paddy yield and 8 component characters based on 13 late flowering varieties grown in three edaphic environments

Genotypic correlation coefficients between grain yield and its eight component traits in 13 rice varieties of late flowering group



straw weight observed in normal soil as well as alkali soil environment of the early and late flowering groups were found to be reduced to a non-significant level under saline environment. In marked contrast, however, the medium flowering group showed just the opposite trend. Magnitude of these correlations was found to be increased among varieties of the early and late flowering groups but not so among those of the medium flowering groups.

These significant interacting effects of soils stress conditions and maturity period upon estimates of genotypic correlations among yield and yield component characters of rice showed that the selection criteria for grain yield performance in the three flowering groups under favourable (non-stress) and stress conditions should be different. Singh and Chowdary (1983) studied influence of different environments on the magnitude of correlations in mustard and also observed similar results. Lehman et al., (1984) studied the association between seed yield and characteristics in the seedling stage as well as those that could be selected on visual basis with a view for predicting yield under salinity (4 dS/m) stress in rice and suggested that relatively high correlations of tillers at seedling stage with panicle length and panicle weight provided possible use of tillers and panicle length in selecting for resistance to salinity. Thus, it is amply clear from this study that various genetic effects varied under different environments among and within the three maturity groups for the same character due to the influence of adverse

soil stresses. Present findings show that environments play a significant role in determining strength of association of various traits with yield and, hence, comprehensive studies should be conducted in a number of defined environments before coming to a conclusion about key characters whose selection would prove to be effective under specific stress environments.

5.7 Path analysis

Correlation coefficients measure the strength of mutual associations among character pairs but this information is not enough for a breeder because component traits affect the yield both directly as well as indirectly. Thus, separation of correlations into measures of direct and indirect effects of different variables on yield by adopting path coefficient analysis techniques (Dewey and Lu, 1959) becomes necessary to understand arrays of interacting phenomena that lead to observed correlations in a correlated series of variables because the path analysis specifies the causes and also measures the relative importance of each casual factor. Several workers have observed conflict between total correlation and path coefficient analysis as shown by reports of Dewey and Lu (1959) in crested grass, Ramanujam and Rai (1963) in Brassica campestris, Srivastava and Singh (1971) in wheat, Sengupta and Kataria (1971) in soybean, Chandraratna (1964), Mishra et al. (1973) and Bhattacharyya (1976) in rice. Furthermore, the influence of different environments also needs to be examined carefully in this context while aportioning direct and indirect effects of different traits upon grain yield.

In the present study, path coefficient analysis has been computed with phenotypic coefficients for the phenotypic path and with genotypic correlations for the genotypic path. But phenotypic as well as genotypic paths were found to be more or less similar. The magnitude of both direct and indirect effects varied from environment to environment and in many cases even the trend was found to be changed. There was no discernible specific trend under all the environments except for the straw weight. Sasmal (1982) also observed differential reaction in the direct and indirect yield contribution of three characters namely, grains per panicle, 1000 grain weight and tillers per plant under different levels of nitrogen in rice. In all the three flowering groups, the direct contribution of straw weight was high and its magnitude increased under both saline and alkali soil stresses. Even though correlation coefficient for the straw weight under saline soil stress was found to be drastically reduced, path analysis showed that the direct contribution was higher than that in case of the non-stress soil and the reduction in observed correlation coefficient value was due to the high negative indirect contribution through harvest index as well as 1000-grain weight. Again, even though the correlation coefficient of 1000-grain weight with grain yield was positive in the early as well as in the late flowering groups, the direct effect was found to be negative. This observed positive correlation was found to be due to high indirect positive effect through straw weight.

Similarly, the significant positive correlation with plant height in the early flowering group was also found to be due to high indirect positive effect through straw weight.

Path analysis, thus, revealed that straw weight and panicle weight were the main yield contributing characters even under soil stress conditions with maximum positive direct effects and high indirect effects through other component characters among varieties of all the three flowering groups. However, Mishra et al. (1973) observed grains/panicle had the largest contribution, and Lenka and Mishra (1973) considered ear bearing tillers and grains per panicle contributed the most on grain yield while, Bhattacharyya (1976) found that ear bearing tillers, spikelets/panicle and spikelet sterility were the main contributing factors. Rao et al. (1980) studied seven late maturing rice varieties and found that panicle bearing tillers, grain number per panicle and 1000 grain weight were the main yield contributing components. 1000 grain weight was also reported to be having high positive direct contribution to grain yield by Yadav and Singh (1979) in semidwarf rice varieties and by Sasmal (1982) in four true breeding rice crosses under different nitrogen levels. The effects which were not in agreement with earlier studies might have been due to the differences in environmental conditions and genotypes used in the present study.

5.8 Comparative performance of seed materials harvested from plants grown in non-stress and stress soil environments

Effects of alkali (pH_2 8.8 to 9.1) and saline (ECe 5 to 8 dS/m) soil environments on ripening seeds, as reflected in seed germination and seedling vigour in the following generation, were studied using the seeds harvested from varieties grown in favourable and adverse soil environments. Results showed that both salinity and alkalinity stresses reduced seed germination as well as seedling height but alkalinity effects were more detrimental than salinity effects. Significant V x E interaction revealed that the varietal responses to adverse effects of stress environments were notably differential.

Prevailing stress conditions did not have any significant effect on seed germination of varieties Bhurarata, Pokkali, MCM-1, Kalarata, TR 17, PR 106 as well as Jaya and also on seedling height of varieties CSR-4, CSR-5, Getu, MCM-1 and CR 222. Varieties M-1-48, IET 1444, Giza 159 and IR 2053 were found to be highly sensitive to alkali stress while varieties Pusa 150 and Pusa 167 were highly sensitive to both alkali and saline soil stresses.

Datta and De (1982) also studied the viability of seeds harvested from seven photoperiod-sensitive winter rice varieties grown under saline water irrigation and found that seeds of varieties from saline irrigated plots lost viability after 4 to 5 months. Varieties Matla and Hamilton were identified by them based on higher viability retention. In the present study, the seeds were germinated after 4

months of harvest and the observed reductions in germination may be due to the loss of viability of the salt affected seeds. These results suggest the need to critically evaluate the viability retention capacity of seeds of different varieties released or to be released for cultivation in salt affected soils and to make proper recommendations whether the farmers should necessarily use seeds from non-stress soil every time for commercial cultivation.

5.9 Conclusions and suggestions

The major objective of this investigation was to assess and analyse the magnitude and nature of genetic variability for resistance to soil alkalinity and salinity in rice. Fifty five rice varieties of diverse origin were used for different studies on their cytological, vegetative and reproductive characteristics. Results of these studies showed that significant variability for alkalinity/salinity resistance existed among the varieties under evaluation and this fact supported the inference that breeding rice varieties suited to salt-affected soils appeared to be a feasible and promising proposition. It has been concluded that immediate attention should first be devoted to collection, maintenance and exploitation of genetic variability for salt stress tolerance within relevant maturity groups so as to avoid possible complications in obtaining the desirable recombinations owing to differences in growth habit, photosensitivity, maturity, etc.

Studies on indigenous rice cultivars, grown traditionally in salt-affected areas, showed remarkable genetic variability with respect to vegetative and reproductive characteristics. All these varieties were, howev-er, diploids ($2n = 24$) with regular meiotic behaviour. Most of the locally adapted varieties were observed to have significantly higher chiasma frequency as compared to the improved highyielding variety Jaya. Frequency of chiasma formation and occurrence of meiotic abnormalities appeared to have increased by soil salinity and alkalinity. The observed reduction in pollen fertility under soil stress conditions was not found to be correlated with seed setting and paddy yield.

Rate of seed germination, total seed germination as well as seedling fresh weight were found to be reduced by salt stress. Seed germination index was found to resolve differences in varietal response to salinity (1% NaCl solution) better than the total seed germination. Varietal response to salt stress based on these tests was, however, not found to be correlated with that based on grain yield.

Analysis of variance based on the data on grain yield and eight component traits, studied in screening plots on 39 rice varieties representing three flowering groups, showed significant genetic variability among the materials under study and also confirmed distinct differences among the environments.

Promising salt tolerant varieties, identified on the basis of *per se* performance and component analysis under Karnal conditions, included Jhona 349 and CSR-5 in the early flowering group, Jaya and HAU-6-163 in the medium flowering group, and Bhurarata, Getu and IR 2055 in the late flowering group. Stability analysis of varietal performance under six environments revealed that major portion of G x E interaction was of linear type for most of the characters. Varieties Bilekagga, HAU-6-163 and IR 2055 showed stability with above average yield performance.

Detailed studies on association of pairs of important plant characters as well as their direct and indirect contribution to the grain yield revealed that panicle weight and straw weight were the main yield contributing characters even under soil stress conditions. However, significant interacting effects of soil stress conditions and maturity period upon estimates of genotypic correlation as well as path among yield and yield component characters showed that environments played a significant role in the association of various traits with yield.

A study of seeds harvested from alkali and saline soils showed that their germination (%) as well as seedling vigour were adversely affected by the unfavourable soil conditions, alkalinity being more detrimental in this respect than salinity. There were, however, significant varietal differences.

Demonstration of significant differences regarding saline and alkali soil tolerance among 39 rice genotypes belonging to three distinct maturity groups is expected to provide the necessary fillip to critical studies on physiological mechanisms of soil salinity/alkalinity resistance in this crop. Furthermore, the basic research into the structural, functional and cytogenetic aspects of salt tolerance/adaptation, which has not yet been given the due attention, is expected to provide suitable leads to work regarding breeding for salt tolerance through recombination breeding and distant hybridization.

Sensitivity of the growth stage, at which a specific stress is imposed, should be an important consideration while evaluating varietal response to stress environments. Texture and other physical properties of salt-affected soils add more complexity, as do spatial and temporal variation in weather conditions. Nature and strength of association between grain yield and its components traits under specific environments have to be studied critically with a view to evolving reliable selection criteria since, as shown by the results of this investigation, environment plays a significant role in determining association of different traits with the grain yield.

A desirable rice variety for Haryana, Punjab and Western U.P. is expected to combine salt tolerance of Jhona 349 with maturity period and high yield potential of Jaya, superior grain quality of Basmati type and also

genetic resistance to important pests and diseases like bacterial leaf blight alongwith, if practicable, lower stomatal frequency of SR 3-9. In formulating a breeding programme for improvement of salt resistance, special care needs to be taken to define and regularly monitor both soil and weather variables with a view to providing valid interpretation of data and also proper utilization of information obtained at different research centres.

To sum up, ability of a crop variety to tolerate a given level of salinity/alkalinity has now become a paramount proposition in managing salt-affected soil and water resources. For this reason, there has been an upsurge of interest in recent years in tailoring crop plants to suit salt-affected environments. This new outlook contrasts the past approaches which exploited a greater abundance of better quality water and cheaper energy resources (soil amendments) to modify the environment to suit the plant. Current research efforts are mainly focussed upon critical assessment of inter-varietal genetic variability and its exploitation for improving crop salt-tolerance both by conventional breeding (intra-specific hybridization and recovery of desired recombinations) and by in vitro methods that include tissue culture technique and recombinant DNA technology.

Notwithstanding the observed genetic variability for tolerance to alkali and saline soil conditions among the rice varieties studied during this investigation, there is a need to collect and evaluate more indigenous cultivars from areas where salt stress is recurrent and has been exerting a

selection pressure over long years both in coastal and inland situations. Moeljapawiro and Ikehashi (1981) crossed two salt-tolerant rice cultivars and noted overdominance for salt tolerance in the F_1 and also found many progeny lines of the F_3 that were more tolerant than either parent. It looks quite promising that multiple crosses involving tolerant cultivars may lead to upgrading of salt tolerance in rice.

Elucidation of plant mechanisms that impart salt tolerance is likely to accelerate selection and breeding programmes aimed at developing crop varieties suited to specific situations of salt-affected soils. Although much information is already available on the physiology and biochemistry of glycophytes and halophytes yet it is only recently that researches have begun to study closely related plant types in a comparative way to determine the mechanisms underlying heritable differences in salt tolerance. At present, plant breeders do not have suitable markers for salt tolerance and this handicap has greatly affected the progress of their efforts. Since physiologists, biochemists and geneticists have now at their disposal a greater range of plant materials differing in salt tolerance, both at the intra - and inter-specific levels, the onus to unravel the plant mechanisms/ processes, conferring salt tolerance, and their genetic control is on them. It may also be pointed out that the validation of the putative markers of salt resistances, worked out by the on-going inter-disciplinary efforts, will

necessarily require close cooperation with the plant breeders if breeding crop varieties for tolerance of salt stresses is to make an impact.

Finally, rice is the most important food crop for the developing countries in Asia, Africa and Latin America. Equally significant is the fact that cultivation of this crop is also the main livelihood of rural population living in these developing regions. Rice is also the major, often the sole, crop grown in salt-affected soils subjected to flooding or where water availability is not a constraint. In the context of prevailing socio-economic scenario in the rice belt, particularly in coastal areas, even a modest improvement in rice productivity in salt-affected lands, over the current level of less than one tonne per hectare, will mean not only substantial gain in rice production but, will also go a long way to improve economic condition of the concerned farmers who have no option but to live with the salt problem.

SUMMARY

This investigation was undertaken with a view to studying diversity of response to saline and alkali (sodic) soil stresses among 55 rice genotypes representing a wide range of adaptation and maturity characteristics. Replicated experiments for this purpose were conducted in laboratory, pot culture and specially designed stress plots employing both seedling and adult plant criteria for comparative evaluation. Observations were recorded on seed germinability, rate of germination, seedling growth, days to flowering, plant height, panicle bearing tillers, panicle length and weight, dry matter production, grain yield, 1000 grain weight and harvest index. Data so obtained were subjected to analysis of variance, stability analysis, correlation estimation and path analysis. Besides comparing and analysing varietal response to edaphic stress, cytological observations on stomatal features, meiotic behaviour and pollen grain characteristics were also made in some indigenous locally-adapted cultivars that are grown traditionally in India under situations of salt-affected soils. Salient features of the findings are summarised as follows:

1. Ten indigenous rice cultivars grown traditionally in different situations of salt-affected areas were characterised regarding their growth habit, plant height, flowering time, glume and grain pigmentation, paddy yield and its component traits, pollen and stomatal characteristics, and meiotic behaviour.

Salt stress resistant varieties, like Pokkali and Jhona 349, were observed to have significantly higher chiasma frequency as compared to the improved high-yielding variety Jaya which recorded the lowest number of chiasmata per cell and showed stability over different environments.

2. Frequency of chiasma formation as well as occurrence of meiotic abnormalities appeared to have increased by soil salinity and alkalinity stresses. Varietal differences in this regard were, however, significant.

3. Pollen size ranged from 15.35 to 17.35 μ and was found to be reduced under stress conditions and showed significant V x E interactions. Varieties SR3-9, Pokkali, Damodar and MCM-1 were remarkably stable in this respect. Pollen fertility, as judged by acetocarmine stainability test, was affected adversely by both edaphic stresses but there was not significant correlation between the observed reduction in pollen fertility with that in paddy yield.

4. Stomata frequency ranged from 18.45 to 36.40 per 0.21mm^2 (microscopic field area), salt sensitive var. M1-48 having the highest frequency. Varietal differences in this respect were significant and heritability estimate for this trait was high. Grain yield was found to be significantly correlated with total stomatal opening per unit area though its direction was different in early vs late flowering groups. Stomatal slit lengths varied from 8.7 to 16.0 μ among different varieties but these differences had low heritability.

5. Rate of seed germination, quantified by seed germination index (SGI), was found to resolve varietal response to salinity (1.0% NaCl solution) better than the seed germination percentage. These varietal differences were confirmed by the data on seedling weight, performance of varieties SR3-9 and Jhona 349 being superior in both these tests. Varietal response to salt-stress based on these tests was, however, not found to be correlated with that based on grain yield.

6. Analysis of variance, based on data on yield and eight component traits studied in screening plots, showed significant genetic variability among the materials under study and also confirmed distinct differences among environments. Overall yield reductions ranged from 23 to 34% under alkali soil (pH_2 around 9.1) and 39 to 55% under saline environment (ECe around 9 dS/m). Significant V x E interactions indicated differential response of varieties to adverse soil conditions.

7. Grouping of varieties on the basis of their flowering time led to a more meaningful interpretation of observations. Three broad groups were made, viz., early flowering (15 varieties taking 65 to 95 days from seeding to panicle emergence), medium flowering (11 varieties; 96 to 115 days), and late flowering group (13 varieties; 120 to 145 days). Classification on the basis of maturity characteristics was not practicable because of inconsistency caused by declining temperatures, particularly beyond mid November.

Salinity caused delay in flowering by about 5 days in the early group, 9 days in the medium group and 13 days in the late group.

8. Promising salt tolerant varieties, identified on the basis of *per se* performance under Karnal conditions as well as quantum of stress-induced reduction in paddy yield of individual plants, included Jhona 349 and CSR5 in the early group, Jaya and HAU6-163 in the medium group, and Bhura, Rata, Getu (CSR 3) and IR 2055 in the late flowering group. These conclusions were largely supported by component analysis taking into consideration panicle length, panicle weight, panicle bearing tillers/hill, straw weight, grain weight and also harvest index. However, varieties Bilekagga and Karekagga were found to be outstandingly superior on the basis of total dry matter production.

9. Stability analysis revealed that major portion of G x E interaction was of linear type for all the characters under study in the early and the late flowering groups. In the medium flowering group, however, linear component of G x E interaction appeared to play predominant role in case of three traits only, viz., plant height, days to flowering and grain yield/plant *per se*. Varieties Bilakagga, HAU-6-163 and IR2095 showed stability with above average yield performance. While Jhona 349 was found to have stable and above average performance regarding panicle-bearing tillers and grain weight,

CSR 5 showed stability with above average performance with respect to panicle weight and harvest index.

10. Grain yield, under favourable soil conditions, was found to be significantly correlated with panicle weight, panicle length, days to flowering, plant height and straw weight among 15 varieties of the early flowering group. Among varieties of the medium and late flowering groups, however, grain yield had a significant correlation with panicle-bearing tillers, grain weight and harvest index in addition to panicle weight. Among 11 varieties of the medium flowering group, grain yield was found to be correlated with panicle-bearing tillers and grain weight under alkali soil conditions, and with panicle weight, grain weight, straw weight and harvest index under saline soil conditions. Path coefficient analysis revealed further that panicle weight and straw weight were the main yield contributing characters under stress conditions with maximum positive direct effects and high indirect effects through other characters among varieties of all the three flowering-groups.

11. A study of seeds harvested from alkali and saline soils showed that their germination (%) as well as seedling vigour (growth rate) were adversely affected by the unfavourable soil conditions, alkalinity being more detrimental in this respect than salinity. There were, however, significant varietal differences. Whereas

seeds harvested from these problem soils were found to be severely affected in case of M1-48, Bas.370, HAU 6-163, IET 1444, Giza 159 and IR 2053; they were relatively unaffected in varieties Bhura Rata, Kala Rata, MCM-1, Getu, CSR 4 and CSR 5.

12. In view of the observed intervarietal differences regarding tolerance to saline and alkali soil conditions, it has been inferred that breeding rice varieties suited to salt-affected soils appears to be a feasible and promising proposition. It has been concluded that immediate attention should first be devoted to exploitation of genetic variability for salt-stress tolerance within relevant maturity groups so as to avoid complications owing to growth habit and photosensitivity, etc. A desirable variety for Haryana, Punjab and Western U.P. is expected to combine salt tolerance of Jhona 349 with maturity period and high yield potential of Jaya (particularly the panicle weight and harvest index), superior grain quality and also genetic resistance to important diseases like bacterial leaf blight. Essential requirements of such a breeding programme are already available but its pace and success will depend largely upon critical evaluation of germplasm collections and segregating materials under defined and regularly monitored, if not entirely controlled, conditions of soil and weather variables so as to ensure valid interpretation of data and proper utilisation of information obtained at different research centres.

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Appendix I Meteorological data for the rice crop seasons of 1981 (A) and 1982 (B)

Month	Rainfall mm		Temperature °C Maximum		Minimum		Relative humidity % A		B	
	A	B	A	B	A	B	M	E	M	E
June	17.2	32.4	39.0	39.3	25.5	25.0	61	39	63	34
July	479.2	85.9	32.5	35.9	25.9	26.6	88	72	77	57
August	79.6	112.6	33.5	33.6	25.6	25.4	87	68	90	72
September	28.6	5.2	33.7	34.5	22.7	21.7	87	58	83	50
October	-	1.4	31.8	32.0	15.3	17.4	87	41	84	40
November	79.8	0.6	24.8	26.8	12.0	12.1	91	47	88	38
December	0.6	26.4	22.2	22.4	5.6	7.9	87	33	87	42

M = Morning, E = Evening

Appendix II List of rice genotypes studied for their response to saline and alkali soils

S.No.	Genotype	Source	Days to flowering	Average plant height (cm)
1	CR 237-1	CRRI	69	100.2
2	Kalinga II	CRRI	78	83.2
3	Kalinga I	CRRI	80	83.2
4	CR 214	CRRI	86	85.3
5	CR 222	CRRI	86	83.3
6	IC 6475	CRRI	93	102.9
7	CR 143-2-2	CRRI	94	82.6
8	IC 6473	CRRI	107	105.8
9	CSR-4	CSSRI	93	102.9
10	CSR-5	CSSRI	93	85.4
11	TR 17	BARC	107	94.6
12	P-2-21	IARI	83	78.1
13	Pusa 167	IARI	93	82.4
14	Pusa 150	IARI	94	78.1
15	Pusa 44-33	IARI	106	100.6
16	IET 1444	AICRIP	86	88.5
17	Sona	AICRIP	105	94.1
18	Jaya	AICRIP	107	84.3
19	IET 4141	AICRIP	107	87.3
20	IR 2053	IRRI	99	116.6
21	IR 54	IRRI	115	75.0
22	IR 2055	IRRI	120	74.9
23	IR 2031	IRRI	128	136.0
24	HAU-1-227	HAU	92	114.5
25	HAU-5-298	HAU	103	99.9
26	HAU-30-444	HAU	105	118.2
27	HAU-6-163	HAU	105	94.1
28	PR 106	PAU	107	89.1
29	PAU 269	PAU	120	116.9
30	Jhona 349	Punjab	88	132.1

Continued

Appendix II Continued

S.No.	Genotype	Source	Days to flowering	Average plant height(cm)
31	Bas 370	Punjab	111	168.9
32	B 80-16	Basmati selection	107	158.8
33	Bhurarata	Maharashtra	110	135.0
34	Kalarata	Maharashtra	124	147.0
35	PNL 11-2	Panvel(M)	99	116.8
36	PNL 28-23	Panvel(M)	103	124.8
37	PNL 32-10	Panvel(M)	104	106.8
38	PNL 5-30	Panvel(M)	104	118.2
39	MK 47-22	Karjat (M)	107	147.0
40	Damodar	W. Bengal	135	151.5
41	Dasal	W. Bengal	136	154.8
42	Getu	W. Bengal	136	145.4
43	Nona sail	W. Bengal	147	182.0
44	Nona bokra	W. Bengal	152	204.6
45	MCM-1	Machhilipatnum (AP)	126	179.0
46	Karekagga	Karnataka	93	149.4
47	Bilekagga	Karnataka	94	152.7
48	Arya	Karnataka	137	201.9
49	Pokkali	Kerala	139	227.9
50	SR 3-9	Tamil Nadu	141	159.3
51	SR 10032	Tamil Nadu	141	170.6
52	SR 26 B	Tamil Nadu	160	186.2
53	Giza 159	Egypt	97	111.4
54	BG 94-1	Ceylon	99	104.0
55	M-1-48	Indonesia	105	93.8

Appendix III Direct and indirect effects at genotypic level of component characters on grain yield/hill in 15 early flowering rice varieties grown in non-stress(C),alkali(A) and saline (S) soil environments

		Days to flowering	Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight	1000 grain weight	Harvest index
Days to 50% flowering	C	0.1025	0.0483	-0.0867	-0.1040	0.0024	0.3788	-0.0299	0.1348
	A	-0.1503	0.1897	0.1594	-0.0386	0.1343	0.2501	-0.0619	0.1347
	S	1.4954	1.2804	1.2300	-0.2431	-1.2948	-7.5151	1.6961	0.5363
Plant height	C	0.0250	0.1984	-0.1266	-0.0692	0.0026	1.2105	-0.0958	-0.7050
	A	-0.0430	0.6627	0.1713	-0.0375	0.1347	0.6001	-0.1911	-0.7920
	S	1.7822	3.5593	1.1192	-0.4206	-0.8967	-12.1236	3.4505	3.4684
Panicle length	C	0.0576	0.1629	-0.1543	-0.0973	0.0028	1.0205	-0.0932	-0.4526
	A	-0.0959	0.4545	0.2498	-0.0276	0.1377	0.5187	-0.1705	-0.4047
	S	3.1230	2.1749	1.9512	-0.5079	-1.4876	-9.3695	2.7458	1.7474
PBT/hill	C	-0.0562	-0.0724	0.0790	0.1898	-0.0022	-0.3253	0.0532	0.1686
	A	0.0650	-0.2787	-0.0772	0.0892	-0.1310	-0.2217	0.0828	0.2466
	S	-1.0157	-1.2628	-0.8358	1.1857	1.8989	1.9514	-1.7633	-0.2185
One Panicle Weight	C	0.0693	0.1418	-0.1184	-0.1170	0.0036	0.9511	-0.0760	-0.1620
	A	-0.1012	0.4475	0.1725	-0.0586	0.1995	0.4478	-0.1564	-0.1375
	S	2.8169	1.4015	1.2746	-0.9887	-2.2773	-3.6509	2.2230	-0.2881
Straw weight/ hill	C	0.0282	0.1746	-0.1144	-0.0449	0.0025	1.3758	-0.0918	-0.7917
	A	-0.0603	0.6380	0.2078	-0.0317	0.1433	0.6235	-0.1969	-0.7150
	S	2.7194	3.1518	1.3353	-0.1690	-0.6073	-13.6909	3.3346	3.9540
1000 Grain Weight	C	0.0267	0.1657	-0.1253	-0.0880	0.0024	1.1013	-0.1147	-0.6634
	A	-0.0427	0.5809	0.1954	-0.0339	0.1431	0.5630	-0.2180	-0.5783
	S	0.2130	3.1128	1.3580	-0.5299	-1.2831	-11.5714	3.9454	2.9489
Harvest index	C	0.0124	-0.1255	0.0626	0.0287	-0.0005	- 0.9770	0.0682	1.1146
	A	-0.0190	-0.4931	-0.0950	0.0207	-0.0258	- 0.4188	0.1184	1.0643
	S	-0.5735	-2.5647	-0.7360	0.0559	-0.1416	11.6845	-2.5113	-4.5323

Appendix IV Direct and indirect effects at genotypic level of component characters on grain yield/hill in eleven medium flowering rice varieties grown in non-stress (C), alkali (A) and saline (S) soil environments

		Days to flowering	Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight/ hill	1000 grain weight	Harvest index
Days to 50% flowering	C	-0.0131	0.0112	0.0237	-0.0303	0.0236	0.2670	-0.0053	-0.3613
	A	0.3632	-0.0074	0.1052	-0.0385	0.0193	0.5524	-0.0489	-1.0512
	S	0.0852	0.0108	-0.0307	0.0530	-0.1155	0.0647	0.0046	-0.1590
Plant height (cm)	C	0.0016	-0.0927	0.0442	-0.0092	0.0422	0.3980	-0.0079	-0.7555
	A	-0.0389	0.0687	0.2607	0.0165	0.0357	0.8622	-0.0435	-1.5098
	S	-0.0169	-0.0541	0.0971	-0.0673	0.0880	0.2852	-0.0003	-0.1916
Panicle length(cm)	C	-0.0038	-0.0496	0.0826	-0.0627	0.0298	0.5095	-0.0068	-0.5529
	A	0.0774	0.0363	0.4937	-0.0033	0.0069	1.0073	-0.0482	-1.8002
	S	-0.0153	-0.0307	0.1714	-0.0024	-0.0213	0.1604	-0.0015	-0.1337
PBT/hill	C	-0.0026	-0.0056	0.0337	-0.1537	0.0092	0.6064	-0.0006	0.0254
	A	0.1119	-0.0090	0.0131	-0.1251	0.0694	0.5887	-0.0169	-0.0528
	S	0.0208	0.0168	-0.0019	0.2170	-0.2031	0.0045	0.0019	0.0613
One Panicle weight(gm)	C	0.0029	0.0372	-0.0234	0.0134	-0.1052	0.0204	0.0141	0.8117
	A	-0.0564	-0.0197	-0.0276	0.0698	-0.1244	-0.3029	0.1054	0.5199
	S	-0.0284	-0.0137	-0.0105	-0.1273	0.3463	0.3407	-0.0051	0.1660
Straw weight/ hill	C	-0.0039	-0.0413	0.0471	-0.1042	-0.0024	0.8947	-0.0006	-0.4485
	A	0.1310	0.0387	0.3248	-0.0481	0.0246	1.5311	-0.0170	-1.8230
	S	0.0088	-0.0247	0.0440	0.0016	0.1887	0.6254	-0.0023	-0.0346
1000 grain weight(gm)	C	0.0034	0.0355	-0.0274	0.0046	-0.0723	-0.0264	0.0206	0.6632
	A	-0.0839	-0.0141	-0.1124	0.0100	-0.0620	-0.1233	0.2118	0.6904
	S	-0.0505	-0.0021	0.0324	-0.0516	0.2285	0.1811	-0.0078	0.2669
Harvest Index	C	0.0042	0.0625	-0.0407	-0.0035	-0.0762	-0.3578	0.0122	1.1213
	A	-0.1712	-0.0465	-0.3984	0.0030	-0.0290	-1.2513	0.0655	2.2301
	S	-0.0292	0.0223	-0.0493	0.0286	0.1237	-0.0466	-0.0045	0.4545

Appendix V Direct and indirect effects at genotypic level of component characters on grain yield/hill in 13 late flowering rice varieties grown in non-stress(C), alkali(A) and saline (S) soil environments

		Days to flowering	Plant height	Panicle length	PBT/hill	Panicle weight	Straw weight/ hill	1000 grain weight	Harvest index
Days to 50% flowering	C	-0.1090	0.0508	0.0009	-0.0359	0.0178	0.2769	0.0183	-0.5681
	A	-0.1454	0.0414	-0.0040	-0.0925	0.0571	0.0404	0.0106	-0.4667
	S	-0.1705	-0.0308	0.0774	0.1861	0.0135	0.2286	0.0070	-0.9566
Plant height(cm)	C	-0.0492	0.1126	-0.0021	-0.0137	0.0374	0.5987	-0.0706	-0.4650
	A	-0.0836	0.0721	-0.0135	-0.0563	0.1367	0.4783	-0.0353	-0.5738
	S	-0.0377	-0.1393	-0.0443	0.1296	-0.0735	0.6429	-0.0182	-0.4555
Panicle length(cm)	C	0.0065	0.0159	-0.0150	-0.0162	0.0661	0.0856	0.0077	0.3254
	A	-0.0069	0.0117	-0.0831	0.0662	0.1487	-0.1305	0.0021	0.2564
	S	0.0561	-0.0262	-0.2354	0.1649	-0.0606	0.0355	-0.0063	0.2428
PBT/hill	C	0.0556	-0.0219	0.0034	0.0704	-0.0293	0.2478	-0.0428	0.2745
	A	0.0880	-0.0266	0.0360	0.1527	-0.0965	0.3714	-0.0037	0.1874
	S	0.0796	0.0453	0.0974	-0.3985	0.0539	-0.0264	-0.0020	0.7135
One panicle weight(gm)	C	-0.0220	0.0478	-0.0112	-0.0234	0.0881	0.4582	-0.0736	0.0474
	A	-0.0412	0.0489	-0.0614	-0.0732	0.2013	0.1716	-0.0176	-0.1145
	S	0.0185	-0.0825	-0.1149	0.1729	-0.1242	0.1371	- 0.0163	0.2195
Straw weight/hill (gm)	C	-0.0321	0.0718	-0.0014	0.0186	0.0430	0.9391	-0.1160	-0.4223
	A	-0.0070	0.0412	0.0130	0.0678	0.0413	0.8370	-0.0447	-0.3983
	S	-0.0457	-0.1050	-0.0098	0.0123	-0.0200	0.8527	-0.0158	-0.5408
1000 Grain weight(gm)	C	0.0097	0.0385	0.0006	0.0146	0.0314	0.5272	-0.2066	-0.0318
	A	0.0173	0.0286	0.0019	0.0064	0.0398	0.4197	-0.0891	-0.2149
	S	0.0340	-0.0720	-0.0421	-0.0231	-0.0575	0.3829	-0.0353	0.1307
Harvest index	C	0.0705	-0.0597	-0.0055	0.0220	0.0048	-0.4518	0.0075	0.8777
	A	0.0874	-0.0533	-0.0274	0.0369	-0.0297	-0.4294	0.0247	0.7762
	S	0.1266	0.0493	-0.0314	-0.0208	-0.0212	-0.3580	-0.0036	1.2878