# ANALYSIS OF GENOTYPE X ENVIRONMENT INTERACTION IN PIGEONPEA (*Cajanus cajan* (L.) Millsp.) SUBJECTED TO WATERLOGGING

BY

K L N PRASAD
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RAJENDRANAGAR, HYDERABAD 500 030.

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## CERTIFICATE

This is to certify that the thesis entitled **"ANALYSIS OF GENOTYPE X ENVIRONMENT INTERACTION IN PIGEONPEA (*Cajanus cajan* (L.) Millsp.) SUBJECTED TO WATERLOGGING"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** of the Andhra Pradesh Agricultural University, Hyderabad is a record of the bonafide research work carried out by **Mr K L N Prasad** under my guidance and supervision. The subject of the thesis has been approved by The Student Advising Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. Published part has been fully acknowledged. All assistance and help received during the course of the study has been duly acknowledged by the author of the thesis.

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**Mr K L N Prasad** has satisfactorily prosecuted the course of research and that the thesis entitled **"ANALYSIS OF GENOTYPE X ENVIRONMENT INTERACTION IN PIGEONPEA (*Cajanus cajan* (L.) Millsp.) SUBJECTED TO WATERLOGGING"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part there of has not been previously submitted by him for a degree of any university.

Date: 31/7/96

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## DECLARATION

I, **Mr K L N Prasad** declare that the Thesis entitled **"ANALYSIS OF GENOTYPE X ENVIRONMENT INTERACTION IN PIGEONPEA (*Cajanus cajan* (L.) Millsp.) SUBJECTED TO WATERLOGGING**" submitted to Andhra Pradesh Agricultural University for the degree of **MASTER OF SCIENCE IN AGRICULTURE** is a result of original research work done by me. I also declare that my material contained the thesis has not been published earlier.

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## ABSTRACT

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is an important pulse crop in the Semi-Arid tropics. In the tropics it is mainly grown on Vertisols and Alfisols. The productivity of the crop on these soils is very low due to the limitations imposed by abiotic and biotic stress factors. A wide range of maturity types varying from <100 days to 180 days duration are available in this crop. Matching the crop duration with the available soil moisture and resistance to stress factors can be an important strategy to maximize yield on these soils. In order to understand the relative adaptation of these genotypes to Alfisols and Vertisols, an experiment was conducted at ICRISAT Asia Center (IAC), Patancheru, Andhra Pradesh, India by simulating some of the growing conditions that are being experienced by the crop on these soils. The experiment was laid in a split-split plot design with three replications during 1994 rainy season. Rainfed and irrigated treatments were taken as the main plots and the 20 genotypes, 10 extra-short- (including 5 having genotype ICP 7035 as one of the parents), 5 short-, and 5 medium-duration genotypes as sub-plots. The data were analyzed by using analysis of variance procedure, regression statistics using GENSTAT Soft ware (GENSTAT manual, 1983) and additive main effects and multiplicative interaction effects (AMMI) statistical method (Rhizostatics 2.0, Cornell University, USA). Both, Alfisol and Vertisol were subjected to near saturated conditions by providing excess irrigation. Crop growth and function on Vertisol were very much affected due to decrease in oxygen concentration in the root zone. The crop showed symptoms of chlorosis and early senescence. These symptoms were more pronounced in the irrigated treatment than in the rainfed treatment. Yield losses due to waterlogging was comparatively larger (60%) on Vertisol than on Alfisol. The response to the additional irrigation supplied was positive (15%) on Alfisol and negative on Vertisol. Among the 20 genotypes tested, the grain yields of short-, and extra-short- genotypes along with wilt susceptible medium-duration genotypes were significantly reduced on Vertisol than on Alfisol. Genotypes ICPL 227 and ICPL 87119 which were tolerant to *Fusarium* wilt, produced the highest seed yield while, genotypes ICP 8379 and ICP 14199 which were tolerant to waterlogging produced the lowest due to their susceptibility

to *Fusarium* wilt. All the above four genotypes are of medium-duration type. The total biomass, chlorophyll content and leaf area index produced by the 20 pigeonpea genotypes were significantly correlated with the seed yield. A significant difference due to genotype, soil and soil x genotype interaction was observed for harvest index, seeds $pod^{-1}$, pods $m^{-2}$ and 100 seed weight. Among the yield components, seeds $pod^{-1}$ was found to be relatively more stable. There were significant differences due to soil, genotype, and soil x genotype interaction for per cent *Helicoverpa* pod borer damage and plant survival. The severity of *Helicoverpa* and plant mortality were more on Vertisol than on Alfisol and further aggravated with additional irrigation. A significant difference due to soil, genotype, soil x genotype and soil x irrigation was observed for days to flowering and maturity.

Yield system analysis (YSA) was used to compare the yields of the 20 pigeonpea genotypes grown in the four soil-moisture environments viz., Alfisol-rainfed, Alfisol-irrigated, Vertisol-rainfed and Vertisol-irrigated environments. The additive main effects and multiplicative interaction effects (AMMI) analysis revealed a significant difference due to genotypes (G), environments (E) and G x E interaction for all nine traits of YSA except for harvest index and total biomass $day^{-1}$ where, G x E interaction was non-significant. Of the total variation (96%) in seed yield G accounted for 26 per cent, E accounted 66 per cent, and G x E accounted 8 per cent. The significant first principal component axis (PCA 1) had accounted 81 per cent of the total G x E interaction. Of the several components of YSA, total biomass, days to flowering and maturity, yield $day^{-1}$, biomass $day^{-1}$, seedfill duration and yield $day^{-1}$ of seedfill duration all correlated significantly with seed yield across the 20 genotypes. All the values of these components were higher on Alfisol than on Vertisol. Across the four soil-moisture environments, a significant positive correlation was observed between total biomass, harvest index, yield $day^{-1}$, biomass $day^{-1}$, and yield $day^{-1}$ of seedfill duration with seed yield. While days to flowering, days to maturity and seedfill duration showed a negative correlation with seed yield. Among the 20 pigeonpea genotypes, the two wilt resistant medium-duration genotypes, ICPL 227 and ICPL 87119 performed better in terms of producing highest biomass $day^{-1}$, yield $day^{-1}$, yield $day^{-1}$ of seedfill duration. Among the short- and extra-short-duration genotypes, the performance of ICPL 87 and ICPL 86012 (both short-duration) was superior to the three medium-duration genotypes ICP 8379, ICP 14199 (wilt susceptible) and ICP 7035 (waterlogging susceptible). These genotypes produced higher total biomass, biomass $day^{-1}$, yield $day^{-1}$, harvest index and yield $day^{-1}$ of seedfill duration than the three medium-duration genotypes, ICP 8379, ICP 14199 and ICP 7035 indicating their relative tolerance to waterlogging. Among the nine traits of YSA, yield $day^{-1}$ of seedfill duration, seedfill duration and biomass $day^{-1}$ were found to be the main yield contributing factors on both waterlogging and waterlogging free environments. YSA-AMMI was successful in identifying genotypes that can optimize the yields under stress environments through quantifying the degree of adaptation of the genotype to that particular environment.

# *INTRODUCTION*

# CHAPTER I

# INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is the sixth most important grain legume crop grown worldwide (Nene and Shiela, 1990). As the crop is predominantly adapted to tropical and sub-tropical regions, it is widely cultivated in the semi-arid areas of India, Myanmar and Nepal in South Asia; Kenya, Malawi and the sub-humid regions of Uganda in Eastern Africa; and in the Caribbean region. Nevertheless, 90 per cent of world area and production of pigeonpea is accounted for by India. Here, the crop is grown mainly for its dry split seed, or dhal, but also for green seeds as vegetable, green leaves as fodder, stems as fuel wood and to make huts and baskets etc., and also for its soil ameliorating effects.

Due to increasing human population, the demand for pigeonpea is continuously growing. With productivity of the crop being virtually stagnant, its production is being increased by bringing more areas under its cultivation. Pigeonpea area in India increased from 2.6 m ha in 1979 to 3.6 m ha in 1990 and production from 1.9 m t in 1980 to 2.3 m t in 1990 (Agricultural situation in India, 1993). This is resulting in cultivation of pigeonpea crop on lands which are marginal for crop production

The productivity of pigeonpea is especially low in peninsular and central India (Sheldrake, 1979). The average grain yield of pigeonpea (1990-1995) in Andhra Pradesh is 297 kg $ha^{-1}$ ; 344 kg $ha^{-1}$ in Karnataka; 516 kg $ha^{-1}$ in Maharashtra; 553 kg $ha^{-1}$ in Tamilnadu and 901 kg $ha^{-1}$ in Madhya Pradesh (AICPIP Project Coordinator's report, 1996). In these states, pigeonpea is by and large grown on Vertisols and Alfisols. Vertisols are characterized by high clay content (40-60%) and can store 150-300 mm water in 1.5 to 2 m soil depth. The Alfisols are relatively shallow, 0.5 m to 1.0 m deep and have less clay content. These can retain up to 100 mm available water in the soil profile where roots are likely to be found. The soil texture and moisture holding capacity of the soil can influence the adaptation of pigeonpea through aeration and moisture supplying capacity and soil strength (Troedson et al., 1990).

The yield potential of pigeonpea is sufficiently high (Laxman Singh et al., 1971). However, this yield is generally not realized due to both biotic and abiotic constraints. Among the abiotic stress factors, temporary waterlogging and drought are the most important constraints affecting pigeonpea production (Chauhan et al., 1992). Although precise statistics are not available, nearly 6 m ha of cultivated land in India are considered prone to waterlogging, which is 10 per cent of the total irrigated area (National Commission on Agriculture, 1976). In Andhra Pradesh, most of the pigeonpea cultivated area is subject to waterlogging. Waterlogging causes nearly $ 110 million worth of damage and drought $ 570 million to pigeonpea production annually (Calculated according to the procedure followed for the ICRISAT Medium Term Plan 1992 to 1998).

Matching crop duration with periods of water availability is one of the important strategies for maximizing production on different soils under rainfed conditions. A wide range of maturity varying from extra-short-duration (<100 d), short-duration (≈120 d) and medium-duration (≈180 d) are available in pigeonpea which can readily permit such matching. While extra-short- and short-duration genotypes can escape terminal drought situation commonly experienced on Alfisols, medium-duration genotypes may better exploit long growing periods on Vertisols. For this reason the relative adaptation of extra-short-, short- and medium-duration genotypes may differ on Vertisol and Alfisols. Their adaptation may be conditioned further with the differences among genotypes in tolerance to moisture availability on these two soils. The understanding of the combined effect of phenology and tolerance to adverse moisture conditions may help in developing suitable strategies for maximizing production on Alfisol and Vertisols. This may require examination of responses of a range of genotypes that not only differ in phenology, but also in tolerance to adverse effects of abiotic stresses such as a drought and waterlogging. Quantification of variation caused by genotypes, environments and their interaction using appropriate statistical tools can be helpful in devising crop improvement and management strategies to tackle these stresses.

Many statistical methods for quantifying genotypes (G), environment (E) and their G x E interaction effects are available (Kang, 1990). However, a method called additive main effects and multiplicative interaction effects (AMMI) has been found particularly useful in visualizing these effects graphically (Zobel and Wallace, 1995). This in conjunction with yield system analysis (YSA) proposed by Wallace et al., (1993a) not only quantify the G x E interaction effects but also elucidate the physiological process that contribute to such effects. These two methods have by and large been applied to quantify photoperiod x temperature effects by Wallace et al., (1993c) How much they can be useful in understanding the genotypic responses to other environmental factors is not known.

The present investigation was therefore undertaken

1. To compare growth, dry matter production, yield and its components in extra-short-, short- and medium-duration pigeonpea genotypes on Alfisols and Vertisols under rainfed and simulated waterlogging environments.
2. To quantify main effects of soil, moisture environments, genotypes and their interactions.
3. To apply yield system analysis to elucidate genotype (G) x environment (E) interactions.

# *REVIEW*

# *OF*

# *LITERATURE*

# CHAPTER II

# REVIEW OF LITERATURE

## 2.0 Major stress factors affecting pigeonpea growth and yield on Alfisol and Vertisol in the Semi-Arid tropics

In the tropics and sub-tropics, food legume crops are grown in a wide range of environments such as arid, semi-arid, sub-humid. Depending on the climate, soil type and management systems, different crops are chosen for different cropping systems. Yield levels of all food legume crops in such environments are generally low because they are grown in marginal areas, on residual soil moisture, under rainfed condition and with very low production input (Carangal et al., 1986).

Pigeonpea is grown on a wide range of soils found in the tropics and sub-tropics including Entisols, Vertisols, Alfisols, Inceptisols, Ultisols and Oxisols. Depth, pH, nutrient status and moisture holding capacity vary widely in these soils. Both Entisols and Vertisols are generally deep and hold more than 200 mm plant-available water to a 1.5 m depth at the end of the rainy season, whereas Alfisols are usually less than 1 m deep and hold less than 90 mm plant-available water to a 1.0 m depth (Reddy and Virmani, 1981). Growth and yield of pigeonpea are influenced by a number of soil and climatic factors during the growing season. Production of pigeonpea varies greatly depending on the depth and moisture holding capacity of the soil. The crop generally thrives well on Entisols, but suffers from excess water during rainy season on Vertisols. In contrast, on Alfisol and Inceptisols the crop suffers from intermittent drought whenever there is a long dry spell in the rainy season and to terminal drought in the post-rainy season (Reddy and Virmani, 1981).

Water is the most important climatic factor that can modify the potential plant growth rates when either too much or too little is available (Scott and Batchelor, 1979). The effect of too much water is known as aeration stress and too little water is referred to a drought stress. The effects of temporary or continuous flooding on plant response have received little attention compared with plant response to water deficits (Kozlowski, 1984).

The yield potential of pigeonpea is sufficiently high (Laxman Singh et al., 1971). However, the full potential of the crop is seldom reached because of the limitations on physiological process imposed by environmental stresses such as abiotic and biotic constraints. Among the abiotic stress factors, temporary waterlogging and drought are the most important constraints affecting pigeonpea production (Chauhan et al., 1992). Turner and Kramer (1980) stated that drought is the most important factor that limits productivity and crop yield on a world wide basis. Although drought is common in semi-arid regions, there are many humid or sub-humid areas as well where either a deficit or an excess of water is a frequent limitation to crop productivity (Krizek, 1981; Raper and Kramer, 1983; Turner and Kramer, 1980). Therefore, water stress caused by the variation in the timing and intensity of rainfall during the growing season is considered as one of the important factors responsible for this yield gap. In addition, topographic and edaphic factors through their influence on runoff, infiltration, storage and subsequent availability of water also have a large effect on crop growth and yield (Lawn and Williams 1987). Despite the direct detrimental effects of abiotic stresses like drought and waterlogging, the crop also becomes predisposed to biotic stresses such as phytophthora blight and *Helicoverpa*.

## 2.1. Abiotic stress factors

### 2.1.1 Drought stress

In semi-arid environments, drought stress is a major factor responsible for yield loss (Simpson, 1981). Drought not only affects growth and yield of crops in arid and semi-arid environments, where crops frequently experience dry spells within the rainy season itself, but also in other areas where evaporative demand greatly exceeds rainfall during the growing season, depending upon the rainfall pattern, soil types and growth duration of the genotype. Pigeonpea is generally considered to be a crop adapted to drought conditions and ideally suited to semi-arid areas (Sheldrake, 1984). Although the roots of pigeonpea were effective in removing water from the 1.9 m soil profile, about half of its water was obtained from the upper 0.5 m of soil layer (Sardar Singh and Russell, 1981). Among the various types of pigeonpea, the medium- and long-duration pigeonpea are usually planted as mixed or intercropped crop with cereals in the rainy season (Singh and Das, 1987). These genotypes experience intermittent water deficit during flowering and especially suffer from terminal drought stress at pod filling stages during a period of ever-decreasing reserves of soil moisture. As a result, medium-duration pigeonpea yields are constrained to about half of what they could be if adequate water was to be supplied. Although medium-duration pigeonpea is drought tolerant and has deep roots and various other desirable characteristics, the yields are significantly reduced by moisture stress particularly on lighter soils such as Alfisols. In an experiment at ICRISAT Asia Center (IAC) in rainy season 1983 on response of the three medium-duration cultivars (C-11, BDN-1 and ICP 1-6) to irrigation given during their reproductive phase on both Alfisol and Vertisol, irrigation resulted in a 100 per cent increase in yield on Alfisol and a 19 per cent increase on Vertisol (Chauhan et al., 1983). This suggests that moisture stress during the reproductive phase of medium-duration genotypes may be a major limiting factor for yield, especially on Alfisol. Short-duration pigeonpea with a duration of about 100-140 days, escapes drought stress in regions where terminal drought stress reduces the yields of medium- and long-duration genotypes. But short-duration genotypes can suffer from moisture deficit during the vegetative and early reproductive growth period when there are gaps in the rains or if sowing is delayed, and also be affected by terminal drought stress at late stages. The large reduction in yield in response to moisture stressed conditions indicates that the relative sensitivity of short-duration genotypes to environmental factors associated with drought and the level of moisture stress experienced have been approximately three times greater in the reproductive phase than those imposed in vegetative phase (Keatinge and Hughes, 1981). Prolonged drought has been shown to affect the growth and yield of early cultivars more than those of longer duration as they have less compensation ability. Application of water to short-duration genotypes increased number of pods, seeds $pod^{-1}$ and seed weight (Sinha, 1981; Keatinge and Hughes, 1981; Muchow, 1985). It was reported that with supplemental irrigation on Inceptisol, the mean yield of twc early-flowering cultivars UW 17 and UW 26 during the Trinidad dry season was 2.48 t $ha^{-1}$ (Keatinge and Hughes, 1981). Imposition of moisture stress reduced yield by 1.41 t $ha^{-1}$. Water stress limited ratoonability of short-duration genotype, ICPL 87 in a multiple harvest system on Vertisol (Chauhan et al., 1987). Irrigation applied during the second flush increased seed yield up to 50 per cent when compared to no irrigation. The newly evolved pigeonpea plant types called extra-short-duration genotypes can be successfully used as catch crops for contingency cropping in the areas with low rainfall, short rainy season and on shallow-well-drained soils because of their earliness and the short pod filling period served as a mechanism of escaping drought stress (Nam et al., (1993).

### 2.1.2 Waterlogging

Pigeonpea is very susceptible to waterlogging, which is perhaps consistent with its adaptation to drier environments. Short-term waterlogging has also been considered to be a major problem limiting the growth of pigeonpea on deep Vertisols of India and also has been recognized as one of the major constraints affecting stability of production in most regions where pigeonpea is grown (Reddy and Virmani, 1981). At ICRISAT Asia Center (IAC) short-term waterlogging is quite common in the deep Vertisols in the month of July, August and September. Significant detrimental effects of excessive water in the root zone are observed in September when the soil profile is almost filled to capacity by rainfall of July and August (Reddy and Virmani, 1981). Excess soil moisture could inhibit various physiological processes which contribute to crop production but the response of the crops depends upon genotypes, environmental conditions, stages of crop development and the duration of the waterlogging period (Jackson 1979; Orchard and Jessop 1984). Waterlogging is especially harmful for short- and extra-short-duration pigeonpea types because their durations are short and thus they have less time to recover after a waterlogging event. Growth and grain yield of short-duration pigeonpea were reduced when grown during the rainy season on both Alfisol and Vertisol because it faced temporary waterlogging due to heavy rainfall events resulting in anaerobic conditions in the soil under a saturated condition (Okada et al., 1991). Further, the grain yield of short-duration genotypes on Vertisol which faced waterlogging during the rainy season was generally half of what could be obtained on well drained Alfisol (Chauhan et al., 1992).

The extra-short-duration genotypes are also highly sensitive to waterlogging. Dry matter production and seed yield of late sown extra-short-duration pigeonpea genotypes on Alfisol was reduced when their early growth stages coincided with saturated soil condition (Nam et al., 1993).

## 2.2 Biotic stress factors

### 2.2.1 *Phytophthora* Blight

*Phytophthora* blight is a recently recognized disease of pigeonpea. It was first suspected at New Delhi in India in 1966 (Williams et al., 1968). The disease was observed in epiphytotic form at New Delhi and Kanpur during 1968/69 (Pal et al., 1970; Williams et al., 1975). The disease appeared in a severe form in some of the experimental plots on Alfisol at ICRISAT Asia Center (IAC) during the 1976/77 season. Pal et al., (1970) observed that high humidity facilitates the rapid development of phytophthora blight. Williams et al., (1975) related high disease incidence to poor soil drainage, but also found the disease in epiphyotic form in a well-drained field near New Delhi. At IAC more disease incidence was found in low-lying areas of fields where temporary water stagnation occured after heavy rains. The disease incidence was relatively higher on Alfisols than on Vertisols (Reddy et al., 1990). Singh and Chauhan (1985) made similar observations.

At IAC phytophthora blight was observed to be relatively high in short- and extra-short-duration pigeonpea genotypes compared to medium- and long-duration genotypes. The close spacing used for short- and extra-short-duration genotypes could favour blight development. *Phytophthora* blight is more important in short- and extra-short-duration genotypes as the loss in stand due to this disease drastically reduces the yields, because these genotypes have neither time nor plasticity to compensate for lost plant stand in the way that medium- and long-duration genotypes can (Reddy et al., 1990).

#### 2.2.1.1 Host susceptibility and predisposition

Oxygen has a very low solubility and diffusion rate in water, and when a soil is flooded or saturated, oxygen may be depleted in sites of high metabolic activity (e.g. Drew and Lynch, 1980; Griffin, 1972; Stolzy, 1974). As a result, roots experience varying degrees of oxygen deficiency in saturated soils, and physiologic damage resulting from both the direct and indirect effects of low oxygen concentrations in soils may predispose to infection (Drew and Lynch, 1980; Stolzy, 1974). Actually, phytophthora root rots are among the most interesting examples of flood predisposed infections diseases, because the same wet soil conditions that enhance zoospore formation and dispersal can predispose some hosts roots to infection. Predisposition of Alfalfa was demonstrated by flooding plants in sterile soil before inoculating them with zoospores of *P. megasperma f sp. medicaginis* (Kuan and Erwin, 1980). The percentage of alfalfa seedlings killed after inoculation progressively increased from 50 to 90 as the duration of the flooding treatment before inoculation increased from 0 to 5 days. The mechanisms by which flooding predisposes alfalfa are not clearly known, but low oxygen levels may make roots more leaky and thus more attractive to zoospores (Kuan and Erwin, 1980). The predisposing effect of flooding on the susceptibility of the rhododendron cultivar caroline to root and crown rot is even more dramatic. Caroline, which is normally resistant, became severely diseased when it was flooded for 48 hr. before being inoculated with zoospores of *P. cinnamomi* (Blaker and Mac Donald, 1981).

The impact of low oxygen concentration in soil on the severity of *phytophthora* root rot was apparently first examined by Stolzy et al., (1965), they found root rot of *Citrus sinensis* in soil infested with *P. citrophthora* and *P. parasitica* to be greater under prolonged periods of soil saturation. Lack of compensating growth by uninfected roots was one of the reasons why low oxygen treatments increased the damage caused to *C. sinensis* by *phytophthora* species (Stolzy et al., 1965) and that high levels of soil moisture increased the severity of phytophthora root rot in soybean (Kittle and Gray, 1979). Because the growth of healthy roots are sensitive to oxygen concentration (Drew and Lynch, 1980; Stolzy, 1974), a lack of root regeneration is likely to aggravate any phytophthora root problem when soils are saturated for prolonged periods. It is also noteworthy that post inoculation treatments of cocoa pods with 2 or 4 per cent oxygen greatly increased the rate of pathogenic attack by *P Palmivora* (Spence, 1961). Such results suggest that the effects of low oxygen concentrations on the resistance mechanisms that are manifested in roots after infection warrant further investigation.

### 2.2.2 *Helicoverpa* pod borer

Pigeonpea provides very attractive and nutritious food, not only for humans but also for many animals. The seeds, and other parts of the plant, are fed upon by many insects, with over 200 species having been recorded in India alone (Lateef and Reed, in press). Some of these insects cause sufficient crop losses to be regarded as major pests, but the majority are seldom abundant enough to cause much damage or are of sporadic or localized importance, and as such may be regarded as minor pests.

Insects are found chewing or sucking pigeonpea plants from seedling to harvest, and no part of the plant is immune to attack. Plants that are heavily attacked before the flowering stage can lose a large proportion of their leaf area and will appear to be very badly damaged. However, pigeonpea has been described as a very forgiving plant, for it can recover from the many setbacks that it may encounter. Studies at IAC (Sheldrake and Narayanan, 1977) showed that the removal of upto 75 per cent of pigeonpea leaves for extensive periods resulted in only slight, and statistically insignificant, losses in seed yield.

Most pigeonpea genotypes produce an over abundance of buds and flowers, and most of these will be shed (Sheldrake et al., 1979), so the loss of a large proportion in insect attacks may not result in measurable yield loss. Even the total loss of the flowers may not greatly reduce yield, for the plants can grow on to produce a compensatory flush, that will have a large yield potential, provided the pest attacks abate, and the soil fertility, moisture, and climate remain favorable.

Pod damage or loss can greatly reduce crop yield, for the pigeonpea's potential to compensate for pod damage is limited. Thus, the pod-damaging insects are the most important pests on this crop of which the most important pod borer that attacks flowers and pods is the *Helicoverpa armigera*, formerly known as *Heliothis armigera*.

In order to improve the quality, yield and profitability of pigeonpea cultivation it is important that the interaction among the plants, the pests and the environment should be clearly understood. Pest attack, as measured by the average percentage of pods damage ranged from 24 per cent in 1980/81 to 68 per cent in 1978/79. Damage was greater in the crop grown on Vertisols than on Alfisols in every year, averaging 62 per cent on the black soil and 42 per cent on the Alfisol. No reason to this kind of observation has thus far been attributed. Within each season, the pest attacks were very different on the pigeonpea varieties of differing duration (Reed and Lateef, 1990). The extra-short-duration genotypes that were harvested in November, were even more severely damaged by these pests (up to 98% pod damage in some years) the long-duration genotypes that matured in January, tended to have lower pod borer damage, probably because *Helicoverpa* populations had declined and were attracted to chickpea. But, on these types the pod fly was an important pest (Reed and Lateef, 1990).

## 2.3 Effects of waterlogging on plant growth and yield

Waterlogging has been considered to be a major problem limiting the growth of pigeonpea, in particular during the rainy season when pigeonpea is normally grown on soils with high water holding capacity, such as deep Vertisols and Indo-Gangetic alluvium of India. It has been recognized as one of the major constraints affecting stability of production in most regions where pigeonpea is grown (Reddy and Virmani, 1981). Waterlogging of soil rapidly and dramatically alters both the physical and biological environment of plant roots which in turn affect their growth and development. Grain legumes are particularly more sensitive to waterlogging and considerable reduction in growth and yield can be observed (Krizek, 1982).

The response of crop to waterlogging stress varies with species, and duration and timing of waterlogging. Susceptible species include pea (Jackson, 1979; Belford et al., 1980); bean (Williamson, 1968; Forsythe et al., 1979); pigeonpea (Rachie and Roberts, 1974; Chauhan, 1987; Ariyanayagam and Griffith, 1987, Troedson et al., 1990) and some cultivars of cowpea and mungbean (Rachie and Roberts, 1974; Hong et al., 1977; Minchin et al., 1978; Lawn and Byth, 1978; Stanley et al., 1980). Soybean is relatively tolerant to waterlogging (Hunter et al., 1980; Troedson et al., 1989). Soil saturation can cause yield loss of mungbean to the extent of 73 per cent (Hamit et al., 1989).

It is generally considered that the longer the waterlogging period the more adversely are the crops affected. Minchin and Summerfield (1976) observed that the growth of cowpea was adversely affected by short-term waterlogging leading to major reduction in root and shoot dry weight and seed yield, while there was a decrease in total plant dry weight and nodule dry weight in soybean when flooded at 36 days after sowing (DAS) (Hunter et al., 1980). Waterlogging of peas at the preflowering stage restricted leaf expansion and internode extension, caused premature senescence of leaves and shoot apex quiescence was also observed (Belford et al., 1980). In sunflower and sorghum also reduction in growth and yield was related to duration of waterlogging and stage of development.

The stage of development seemed to be of greater importance than the duration of waterlogging on yield (Orchard and Jessop, 1984). Scott et al., (1989) observed that determinate soybean cultivars were more susceptible to prolonged flooding during early reproductive growth than early vegetative growth and when grown on the clayey soils than on the silt loams. It is also observed that the effect of waterlogging on growth and yield response varies within the same crop. Waldren et al., (1987) observed that *Geum rivale* L. was more tolerant than *G. urbanum* to flooding while, determinate pigeonpea genotypes (extra-short- and short-duration) were more susceptible to short term waterlogging than when compared to medium-duration and long-duration genotypes (Matsunaga et al., 1991). The yield loss of short-duration determinate species is primarily due to less time to recover from the stress.

Short-term waterlogging affects the morphological, anatomical and physiological attributes of a crop (Kozlowski, 1984; Jackson and Hall, 1987) The typical effects of waterlogging on plant growth and development are reduction in plant height, dry matter, leaf area and chlorosis of leaves (Krizek, 1982; Scott et al., 1989), loss of leaves, rotting of tap and lateral roots, dark brown lesions extending up the stem from below ground level, wilting and death of plants (Wearing and Birch, 1988). But prolonged waterlogging induces death of roots and nodules and thus a greater yield reduction than short term waterlogging.

The most common feature by which excessive soil moisture limits yield of the food legume crops is by a reduction in nitrogen fixation caused by reduction in oxygen supply to the nodules (Smith, 1987). Poor nodulation was observed in chickpea when grown under condition of excessive soil moisture (Argikar, 1970).

Susceptibility of short-duration pigeonpea to waterlogging is a major concern as it has very little time for compensatory growth. Growth and grain yield of short- duration pigeonpea were reduced when grown during the rainy season on both Alfisol and Vertisol because it faced temporary waterlogging due to heavy rainfall events resulting in anaerobic conditions in the soil under a saturated condition (Okada et al., 1991). The grain yield on Vertisol which faced waterlogging was generally half of what could be obtained on well-drained Alfisol (Chauhan et al., 1992). Extra-short-duration pigeonpea genotypes are also highly sensitive to waterlogging. Dry matter accumulation and seed yield of late sown extra-short-duration pigeonpea genotypes on Alfisol was reduced when their early growth stages coincided with a saturated soil condition (Nam et al., 1993).

Restriction of oxygen to aerobic plants can adversely affect nitrogen metabolism and physiological processes necessary for normal growth and development. Normally, sufficient quantities of oxygen diffuse from the atmosphere into the soil to meet the oxygen demand of organisms and roots living there. However, conditions of excessive rainfall, unfavorable soil porosity, high clay content and restricted surface drainage obstruct oxygen diffusion into soil. When the soil's oxygen supply is curtailed, oxygen concentration in soil can become low enough to limit root development and crop productivity (Turner et al., 1983). Chan and Hodgson (1981), Hodgson (1982) and Hodgson and Chan (1982) observed that furrow irrigation rapidly displaced most of the air from the root zone of a cracking grey clay and extended irrigation waterlogs the soil for several days and reduce the crop yields. Poor aeration in saturated soil profile of Alfisols and Vertisols, after a heavy rainfall or excess irrigation lowered oxygen concentration. Lal (1986) observed that the saturation water conductivity of an Alfisol is usually higher than that of Vertisol which causes higher aeration levels of Alfisol than Vertisol under excessive soil moisture condition.

Letey et al., (1961) and Stolzy et al., (1981) observed that root growth generally decreased with decreasing oxygen content above the soil surface. Root elongation has been shown to be closely related to soil oxygen concentration. Hopkins and Patrick (1969) and Tackett and Pearson (1964) using Sudan grass and cotton respectively, illustrated that soil oxygen levels below about 10 per cent suppressed the penetration of roots into the soil. Similarly, Huck (1970) investigated the effects of short-term fluctuations in soil oxygen on root elongation rates of "Biloxi" soybeans and found that seedling root elongation rates were not restricted until root zone oxygen level dropped below 10 per cent. However, Yentur and Leopold (1976) found that oxygen levels as low as 2.5 per cent did not reduce root elongation rate of 1- to 5-day-old 'Wayne' soybean seedlings grown in a moist chamber without soil. These apparent contrasting critical oxygen levels for root growth could be due to differences in plant species tolerance to low oxygen levels, differences in plant age or differences in temperature exposure.

### 2.3.1 Effect of anoxia on chlorophyll content

Gambrell et al., (1991) explained the effects of anoxia/hypoxia in reduced and anaerobic soils. Anoxia not only affects metabolism and functions of plants, by causing reduction in soil chemical compounds and their transformation into toxic forms but also damage to the plant indirectly. Under strict anoxia, the energy supply by oxidative phosphorylation is naturally switched off and the plant experiences an acute deficiency of energy. Blocking of oxidative phosphorylation under anoxia effects mitochondrial ultrastructure. Apart from the intensity of the anoxia in soils the duration is also very important. Chan and Hodgson (1981), Hodgson (1982) and Hodgson and Chan (1982) observed a breakdown in chlorophyll content, symptomatic of nitrogen deficiency when the waterlogging period was extended to 2-3 days. The effect of anoxia on chlorophyll content varies with crop species, duration and timing of anoxia. A large reduction of chlorophyll a, chlorophyll b, and total chlorophyll content was observed in four *Brassica* species when subjected to waterlogging treatment. The reduction in chlorophyll content was more pronounced in relatively tolerant *B. juncea* than the sensitive species, *B. napus* (Ashraf and Mehmood, 1990). These results do not conform to the findings of Talbot et al., (1987) who found a greater reduction in chlorophyll content of waterlogging sensitive *Salix caprea* but not in waterlogging tolerant *Salix cinera*. However, the results for *B. napus*, a waterlogging sensitive species, are in conformity with those of Talbot et al., (1987). The reduction in chlorophyll content of all four *Brassica* species at waterlogging treatment reflects the reduction in photosynthetic activity.

### 2.3.2 Adaptation of plants to waterlogging stress

#### 2.3.2.1 Morphological and anatomical response

Flooding can markedly change the direction of root growth. It has been found that roots of tomato and sunflower became diageotrophic (horizontally growing) rather than positively geotropic (downward growing) when they contact a saturated soil layer (Jackson, 1989). Furthermore, in maize, adventitious roots emerge from the shoot base in whorls of 4-6 from preformed initials with soil waterlogging, and such roots are thought to absorb mineral nutrients in flooded conditions (Jackson, 1989).

The most noticeable anatomical response to soil waterlogging or anoxia in roots of crop plants including wheat, barley, maize, tomato and various forage crops is the development of extensive aerenchyma in the cortex of roots, which greatly facilitates gas transport in water logged or anoxic root systems. It has been clearly demonstrated that ethylene gas is the principal mediating promoter in the development of aerenchyma in maize and other plants (Jackson 1985, 1987, 1989, 1990). However, the formation of aerenchyma in rice roots has been considered as under genetic control (Jackson and Drew, 1984).

There are several reports suggesting that nodulated grain legumes growing in waterlogged conditions generally fix less nitrogen and produce less dry matter and total nitrogen than in non-waterlogged conditions. This has been considered as a physiological adaptation as oxygen transport to and within the nodules is impaired (Walker et al., 1983). Justin and Armstrong (1987) reported that roots of peas and cowpea are basically non-aerenchymatous but occasionally form hexagonal air spaces throughout the cortex by both schizogenous and lysigenous development under waterlogged conditions. Minchin and Summerfield (1976) observed that there was increased nodule cortical cells and enlargement of lenticels on nodules of cowpea to facilitate continuous symbiotic nitrogen fixation when the crop plant was subjected to various periods of waterlogging (8, 16 and 32 day duration).

Turner et al., (1983) while studying the effect of anaerobiosis (exposing to pure nitrogen gas) on root development of selected soybean cultivars, soybean seedling roots or roots and shoots for up to 16 hours found that the soybean seedling roots survived better than anticipated under anaerobic conditions. When only the seedling shoot was in air, they observed that 14 per cent of the total oxygen present in air diffused down the stem. When the entire seedling was exposed to an anaerobic environment tap root elongation inhibited. The recovery from anaerobiosis was inversely proportional to the anaerobiosis duration. They also observed that cultivars do differ in their adaptation to anaerobiosis. Young pea plants under waterlogging do have some ability to regenerate new roots after waterlogging whereas older plants do not have such a mechanism.

#### 2.3.2.2 Physiological and biochemical response

A large number of changes in plants and soil due to waterlogging have been reported (Armstrong, 1979; 1982; Crawford, 1982; Talbot et al., 1987). The changes in soils include low rate of oxygen diffusion, ethylene formation and lowering of redox potential. Because of the limited supply of oxygen, anaerobic bacteria liberate toxic amounts of iron ($Fe^{2+}$), manganese ($Mn^{2+}$) and sulphide. Plants grown under waterlogged conditions undergo various physiological changes as an adaptive mechanisms. It has been reported that high concentration of $Fe^{2+}$ and $Mn^{2+}$ are toxic to plants, and plants which inhabit waterlogged soil use some protective mechanism to cope with high concentrations of $Fe^{2+}$ and $Mn^{2+}$ (Talbot et al., 1987). However plants under flooded conditions leak oxygen from their surface and oxidize the reduced form of iron and manganese before they reach the vascular system of plants (Armstrong, 1979; Bartlett, 1961; Talbot et al., 1987; Ashraf and Mehmood, 1990). The tolerant species are capable of controlling the uptake of these elements either by using an internal mechanism for tolerance of these elements and/or by the root exclusion system due to immobilization of elements in the roots (Armstrong and Boatman, 1967; Bartlett, 1961; Green and Etherington, 1977). Ashraf and Mehmood (1990) observed that in a given waterlogging regime, there was an increase in iron content in both shoots and roots in all four species of *Brassica*. The tolerant species *B. juncea* had accumulated a lower amount of iron in both shoots and roots as compared to other species whereas, the less susceptible species *B. carianta* had lower iron content in the roots. The four species did not differ for shoot manganese concentration but *B. carianta* had significantly higher manganese concentration in roots compared to other species. Another important adaptive mechanism was that plants which contain high reserves of utilizable rhizomes showed better survival in the long term (Brandle, 1991).

#### 2.3.2.3 Hormonal response

Flooding greatly changes the plant environment in relation to concentration of oxygen, carbon dioxide and ethylene relative to aerated environments and these changes are due to limited gaseous diffusion (Setter, 1992). The five active morphogens in plants are auxins, gibberellins, cytokinins, abscisic acid and ethylene. Ethylene especially is intimately involved in plant responses to flooding because its rate of diffusive loss from the plant is strongly inhibited by water, and because the biosynthesis is susceptible to oxygen supply (Jackson et al., 1992). Apart from ethylene, abscisic acid (ABA) also plays an important role in influencing the morphological adaptation of plants to poor aeration (Jackson et al., 1988). The effects of hormones in relation to morphological and anatomical modification in response to soil waterlogging or anoxia have been extensively discussed by Jackson and Drew (1984); Jackson, 1985, 1987; 1989; 1990; Jackson and Pearse, 1990; Drew 1987. Jackson et al., (1987) and Setter et al., (1989). Setter (1992) reported that high ethylene concentration under waterlogged condition increases chlorosis and eventually limits photosynthesis and subsequent oxygen and carbohydrate production. High carbon dioxide concentration increase photosynthesis and also interact with ethylene effects and with oxygen production and respiration. Jackson et al., (1988) found that in peas, there was no increase in ABA either in the flooded roots, or in the roots exposed to near-anaerobic condition in solution culture Whereas, Neuman and Smit (1991) found on doubling of ABA concentration in the xylem sap of detopped *Phaseolus vulgaris* plants after flooding. These seemingly incompatible results remain to be reconciled. One possible explanation is that, ABA originates in the leaves as an accumulation message (Jackson and Hall, 1987) and is recycled between roots and shoots using both xylem and phloem transport pathways. Whatever the source(s) of the increase in ABA finally turns out to acting as a mediator in the stomatal closure of flooded plants (Jackson et al., 1992).

## 2.4 Strategies for overcoming waterlogging stress

### 2.4.1 Management options

Grain legumes as a group are considered intolerant of waterlogging and, as a consequence, are not commonly irrigated by flood or furrow methods. Intolerance of grain legumes to waterlogging is commonly demonstrated in poorly-drained areas of non-irrigated fields following heavy rainfall. Such observations have discouraged many farmers from growing these crops under flood or furrow irrigation. However, waterlogging in non-irrigated fields may be more severe than in irrigated fields which have uniform slope and deep furrows for efficient drainage. It is likely that some of the waterlogging sensitive grain legumes such as pea (Jackson, 1979; Belford et al., 1980), bean (Williamson, 1968; Forsythe et al., 1979), pigeonpea (Rachie and Roberts, 1974) and some cultivars of cowpea and mungbean (Rachie and Roberts 1974; Minchin et al., 1978; Wien et al., 1979 can be grown successfully under well managed furrow-irrigation, but this possibility remain untested (Hodgson et al., 1989).

The severity of waterlogging during furrow irrigation can be reduced by completing irrigations quickly and then rapidly draining off excess water to expedite recovery. High application rate, short-run length, deep clean furrows, and increased field slope are recommended for this purpose (Hodgson, 1982; Hodgson and Chan, 1982). Apart from designing and managing the field to ensure adequate drainage of excess irrigation water to restrict waterlogging, kharif pulses can be grown on ridges instead of on flat beds to get higher yields even under adverse soil conditions (Choudhury and Bhatia, 1971; Kampen, 1982).

Choudhury and Bhatia (1971) demonstrated that ridge planting of kharif crops like pigeonpea, black gram and green gram yielded considerably more than those sown on the commonly practiced flat beds. This is attributed to better growth of the plants as the ridge planting provides a relatively well drained and well aerated rooting medium on wet soils to which these pulse crops are very sensitive. They also found that plants grown on ridged beds were healthier and they did not succumb easily to pests and diseases. On an average pigeonpea yielded 80.7 per cent, greengram 48.6 per cent and blackgram 58.8 per cent more per hectare when grown on ridges compared to flat beds. Moreover, greengram and blackgram had only low yields regardless of the method of planting. Therefore, it is much better economic choice to grow pigeonpea in preference to greengram and blackgram, on soils subject to waterlogging even for a short period. Their yield potential is relatively low and they also suffer more from pests and disease incidences. However, it is very important to clarify that ridge planting of pigeonpea on light sandy soils is not very beneficial as the ridges on such soils are not stable and collapse easily on receipt of heavy rains. Drainage and aeration of light soil are also not a problem

The third method in alleviating waterlogging stress is the tactical use of foliar nitrogen (Hodgson, 1982). When the soil is waterlogged, most roots are probably deprived of oxygen, their permeability to water may be rapidly decreased (Kramer and Jackson, 1954), leaf stomata may close (Sojka and Stolzy, 1980) and the uptake of water and soil nutrients may be rapidly reduced (Willey, 1970); thus a foliar spray of nitrogen before waterlogging might overcome a transient shortage in supply of nitrogen from the roots and maintain crop growth and yield (Hodgson and Macleod 1987) Hodgson (1982) found that the application of foliar nitrogen before furrow irrigation significantly increased yields, which were otherwise depressed by waterlogging. However, he found that nitrogen did not fully restore yields and concluded that the application rate might be insufficient or that some other factors were also limiting yields.

At IAC, experiments were conducted to study the effect of nitrogen as a top dressing to alleviate waterlogging effect of ICPL 87 (short-duration) genotype on Vertisol (Okada et al., 1991). During the 1991 experimental study at IAC, it was concluded that the waterlogging effect could be alleviated when pigeonpea is top dressed with nitrogen, especially at 50 kg N $ha^{-1}$. Nitrogen application was very effective and significant in increasing seed yield of waterlogged plants (ICRISAT Legumes Program Annual Report, 1991). In another experiment, conducted at IAC, using the same ICPL 87 (SD) genotype on Vertisol it was observed that transitional waterlogging reduced single-leaf photosynthetic rates. This reduction was attributed to the reduction in water vapor and/or leaf nitrogen concentration. Top dressing with nitrogen, especially at 50 kg N $ha^{-1}$, was found to be very effective in allowing waterlogged plants to recover quickly from the reduction in leaf photosynthesis (ICRISAT Legumes Program Annual Report, 1992). Recent studies on the application of nitrogenous fertilizers to soil during waterlogging stress have revealed that such treatment can also alleviate the stress (Matsunaga et al., 1991). However, these management options are often inadquate as well as expensive, To supplement or substitute these options development of cultivars that have increased ability to withstand waterlogging stress in necessary

### 2.4.2 Genetic option

Resistance to drought and waterlogging is conditioned by a number of components and may differ for different crops and in response to different types, intensity and duration of drought or flooding (Bradford and Yang, 1981, Kawase, 1981; Mc William, 1990). Therefore, it is necessary to develop understanding of the nature of physiological adaptation of pigeonpea genotypes under variable soil moisture availability.

In recent years, extra-short-duration pigeonpea genotypes that can mature in about 90-110 days have been developed, apart from short- (110-120 days) and medium-duration (> 190 days) genotypes. The extra-short-duration genotypes are suitable for intensive cultivation as sole crops and have been tested for adaptation to rainfed semi-arid environments (Chauhan et al., 1993). In some situations, the extra-short-duration genotypes are capable of producing even higher yield than medium-duration genotypes, which can be attributed to their better ability to match the length of growing season and escape from terminal drought (Chauhan, 1990). Although extra-short-duration genotypes have good yield potential, its realization seems very sensitive to soil moisture status. Large seasonal and locational differences in grain yields of extra-short-duration genotypes have been observed indicating a lack of stability in yield (Chauhan et al., 1993; Nam et al., 1993). These differences can largely be attributed to variation in soil moisture availability. Depending on the likely pattern of rainfall during the rainy season and consequent availability of soil moisture, extra-short-duration genotypes can face intermittent drought or waterlogging due to poor distribution of rainfall. With delayed sowing, it can also face excess soil moisture during vegetative stage (Chauhan et al., 1993; Nam et al., 1993). The effects are more drastic on short- and extra-short-duration genotypes than on medium- and long-duration genotypes due to shortage of recovery time in the farmer (ICRISAT Legumes Program Annual Report, 1991). Although irrigation is an effective option to alleviate drought effects in pigeonpea (Bhan and Khan, 1979; Makhan lal and Gupta, 1984), this is not a practical or economic approach for most pigeonpea growing areas. Further, if irrigation is followed by moderate or heavy rains this might result in waterlogging. Thus, selection of genotypes which are better able to resist both water deficit and its excess is likely to be a better option to increase yield and stability of production of pigeonpea, particularly that of shorter duration, grown in semi-arid regions.

#### 2.4.2.1 Identification of genotypes

Evidence of genotypic difference in pigeonpea in response to waterlogging has been reported by Chauhan (1987), and Dubey and Asthana (1987). Average survival after 6 days of waterlogging was 96 per cent in a tolerant genotype and 28 per cent in a susceptible genotype (Chauhan, 1987). During the two years of testing, 27 genotypes out of 123 consistently survived inundation, and wide variation for seed yield was observed among them (Dubey and Asthana, 1987).

### 2.5 Yield system analysis

A complete Yield System Analysis (YSA) developed by Wallace and Masaya 1988; and Wallace 1991 measures (1) Days to flowering, (2) Days to maturity, (3) the aerial biomass at the harvest maturity, and (4) the yield (Table 2.1). Calculated from these (Table 2.1) are: (5) days to seed fill (days to maturity minus days to flowering); (6) average rate of yield accumulation day$^{-1}$ to maturity (the economically relevant average partitioning rate to reproductive growth), (7) the average rate of yield accumulation day$^{-1}$ of seed fill (physiological origin of the economic rate); (8) the rate of accumulation of aerial biomass average across the days to maturity (measures the average crop growth rate and net photosynthetic efficiency) and (9) the harvest index, which is yield biomass divided by aerial biomass (the ratio quantifies the consummated partitioning).

The eight traits measured by YSA in addition to yield include yield's three major, genetically controlled components: the net accumulated biomass (YSA trait #3), the harvest index (YSA trait #9), and the days to harvest maturity ( trait #2). The other five traits encompasses all the major sub-components of all three major components. Inferred by 'major' is that the trait cannot be sub-divided into fewer components; The duration of growth (YSA trait #2) and the average biomass accumulated per day of growth (trait #8) are the two sub-components of the net accumulated biomass (trait #3). The two sub-components of harvest index (trait #9) are the duration of seedfill (trait #5) and the average rate of partitioning (rate of accumulation of yield day$^{-1}$ seedfill) (trait #7). Compared with the rate day$^{-1}$ of seedfill, the average rate of yield accumulated day$^{-1}$ of plant growth presents the true economic view point rather than physiological one. Two sub-components of time to harvest maturity are the pre-flowering and post-flowering durations. These are the vegetative and reproductive stages, respectively; the latter being the duration of seedfill (trait #5) (Wallace et al. 1993a).

**Table 2.1 Nine outputs from the Yield system of a cultivar.**

| Trait No. | Output | Interpretation |
|---|---|---|
| | Four direct Measurement within each yield trial. | |
| 1. | Days of flowering | Time used for development to flowering |
| 2. | Days to harvest maturity | Time used to develop to harvest maturity. |
| 3. | Aerial biomass | The overall net photosynthesis. |
| 4. | Yield | The economically important output. |
| | Five Calculations from the four direct measurements. | |
| 5. | Days to seedfill | Time used for actual yield accumulation. |
| 6 | Yield day$^{-1}$ to maturity | Efficiency of yield accumulation. |
| 7. | Yield day$^{-1}$ to seedfill | Efficiency of yield accumulation. |
| 8. | Biomass day$^{-1}$ of seedfill | Efficiency of photosynthesis. |
| 9. | Harvest index | Endpoint efficiency of partitioning to yield. |

Note: Trait # 6 and # 7 give the rate of partitioning of photosynthates.

### 2.5.1 Concepts of yield system analysis

According to Wallace et al., (1993a) yield system analysis incorporates the following eight concepts:

1. Indirect selections for yield will be most effective when applied to processes which have already integrated most of the genetic and environmental effects that lead to yield.

2. Levels of each major component of yield will be correlated with yield in most yield

trials. However, the levels and negative versus positive correlation will vary with the developmental stage(s) of the plants when stress or favorable environments occurs.

3. Almost every newly incorporated or excluded gene activity may cause G x E interaction that will affect yield and /or its physiological components (Blixt and Vose, 1984).

4. Almost every change in the level of an environmental factor may cause the G x E interaction that will alter yield and/or its physiological components

5. Within the environment of each yield trial, the variability for a component among the tested cultivars will quantify variation in the genetic control over that component.

6. The variation of yield and its components expressed by a genotype across environments of multiple seasons (at the same or different sites) will quantify the control of differences in the environment (Blixt and Vose, 1984; Mayo, 1987 and Zobel et al., 1988).

7. The superior levels measured for each YSA trait indicate adaptation of the genotype to the environment.

8. Measurement must be economically feasible for the large number of the genotypes, progenies, and environments required for effective selection.

**2.5.2 Implication of yield system analysis in genotype x environment interaction analysis:**

For ascertaining the yield potential of a genotype, the yield of the given genotype is compared with other genotypes grown across multiple yield trials. This type of evaluation is done because the G x E interaction is altered by each different environment, even by small differences between successive seasons at the same site and time of year. Yield trials will always be required to identify the best cultivars for growers. Application of YSA to each yield trial compares the differences in gene action among the cultivars within that site-season

(Scully and Wallace, 1990, 1991) and can improve our understanding of G x E interaction that will optimize yield in physiological components and sub-components for the site.

Comparison of YSA traits across repeated seasons or a site will identify the earliest to latest maturities and the G x E interaction with adaptation to that site. YSA will also quantify average correlation between these maturities and the aerial biomass and HI plus their rates and durations of accumulation.

According to Wallace et al., (1993a) application of YSA with Additive main effects and multiplicative interaction effects (AMMI) will helps in identifying the genotypes that accumulate the largest biomass day$^{-1}$, rather than these that just grow for a longer time, and the genotypes with highest harvest index due to either a higher rate of partitioning and/or a longer duration of seedfill. Genetic diversity for other desired traits can be incorporated into the gene pool at any time through YSA-AMMI of new germplasm and/or through crosses to exotic germplasm having traits presumed to be beneficial. Application of YSA-AMMI should improve our understanding of the genes and G x E that will optimize yield and of its physiological components and sub-components for the site. YSA-AMMI can test whether a hypothesized ideotype(s) will or will not give the highest yield for a given site and also helps in detecting alternate ideotype(s). YSA-AMMI can also facilitate rapid gain for each production site.

The usefulness of AMMI in YSA is to quantify the G x E interaction caused by the deviation due to each genotype and due to each environment for each of the yield's major- and sub-components (Wallace et al., 1993a). A large G x E interaction was revealed when YSA-AMMI analysis was applied to yield trials conducted across a region (Wallace et al., 1991). The YSA is also useful in quantifying the physiological genetic bases of yield difference due to affected levels of biotic and abiotic factors, or other agronomic treatments (Wallace et al., 1993b). YSA-AMMI can also facilitate mathematical modelling of plant development and yield (Charles-Edwards and Vanderlip 1985; Whisler et al., 1986) and its application to improving crop breeding and production practices. Application of YSA to on going trials will improve the efficiency of breeding for higher yields (Wallace et al., 1993c). Apart from the application of YSA to seed crops (Wallace et al., 1993a), YSA can also be applicable with some modification to root and tuber crops (Wolf et al., 1990) and other crops for which only a part of plant is the yield.

Recurrent YSA and selection of genotypes over repeated seasons, followed by recurrent intercrossing among the superior genes, can create the common pool with the large genetic variability and adaptation that is required for the efficient generation of new and superior genotypes (Mayo, 1987; Kelly and Adams, 1987; Singh et al., 1989; Kenworthy and Brim, 1979; Werner and Wilcox, 1990). Extensive application of YSA will not be economically feasible during the $F_2$ generation however, it may be beneficial as early as the $F_4$ generation (Cooper, 1988; Gomez, 1991).

### 2.5.3 Genotype x Environment (G x E) Interaction

Plant performance in an environment, is a reflection of the interplay of genetic and non-genetic factors, so that for many characters, the relative performance of genotypes may vary in different environments (Byth, 1981). Furthermore the effects of a genotype and environment are not independent. This interplay of genetic and non-genetic effect on plant development is termed as genotype x environment interaction (Shorter and Mungomery, 1981). Therefore G x E interaction arises when a given genotype is grown in environmentally diverse settings (Smith and Zobel, 1990).

### 2.5.4 Nature and scope of genotype x environment interaction

Genotype x Environment (GE) interaction has been an important and challenging issue among plant breeders, geneticists, and agronomists engaged in performance testing (Kang, 1990). The most important G x E interaction pattern in crop improvement is the one that leads to a significantly different rank order of genotypes in different environments and thorough understanding of the analysis of G x E interaction will enable us to understand the basis of stress tolerance, relative performance of genotype over environment, etc. (Baker, 1990).

G x E interaction is noticeable when genotypes being evaluated rank differently in different environments (years and/or locations). A significant G x E interaction for a quantitative trait, such as yield, reduces the usefulness of the genotype means over all environments for selecting superior genotypes. As the range of genotypic and environmental difference widens, G x E interactions often become large and more apparent. This interaction reduces the correlation between phenotypic and genotypic values, and has been shown to reduce progress from selection (Comstock and Moll,1963). The genetic correlation between environments can be used to quantify the importance of G x E interactions, as G x E interaction has a strong influence on genetic systems. The influence of G x E interaction on a genetic system increases with the decrease in the genetic correlation, making them more adaptable to the environments (Falconer,1952, 1989). Haldane (1947) explained the phenomenon of G x E interaction which is commonly observed when plant breeders conduct multi-environment trials (MET's) wherein the genotypes change in their relative performance across test environments and can take on many forms.

When G x E interaction is significant, its cause, nature and implications must be carefully considered in breeding programs (Kang and Martin, 1987). It is useful to examine the mechanism underlying the observed non-additivity or heterogeneity (Freeman, 1973). Freeman and Perkins (1971) stressed the use of physical measurements of environments in explaining G x E interactions, but only recently have the contribution of weather variables to G x E interaction begun (Saeed and Francis, 1984; Kang and Gorman, 1989; Kang et al., 1989; Gorman et al., 1989). Baker, (1990) and Gravois et al., (1990) have identified differential disease ratings of genotypes as contributing factors to G x E interaction. Therefore, a large proportion of biological research in agricultural sciences is concerned with study of G x E interaction the awareness of which will lead to greater interest and therefore will advance our understanding of the factors influencing plant growth and development, adaptation and strategies of plant improvement under varied environment (Byth, 1981).

### 2.5.5 Methods for analyzing G x E interactions

Formal statistical methods for analyzing interaction, in particular G x E interactions, dates back more than 50 years (Freeman, 1990) which include those of Freeman, 1973; Hill, 1975 in 1970's and Cox 1984; Freeman, 1985; and Westcott, 1986 in the 1980's. More recent work has been done by using multivariable methods by Callinski et al., (1987a, b) and Gauch (1988).

There is no universally good notation for even the simplest model of G x E interactions. The first method which probably must have been attempted to analyze G x E interactions as opposed to simply recognizing their existence was that of joint regression analysis by Yates and Cochran (1938) and which has been subsequently rediscovered several times. Later on, many developments in analyzing G x E interactions have followed from the use of joint regression including several definitions of the stability of genotype performance by Wricke (1962), and Eberhart and Russel (1966). The use of joint regression analysis continued into the 1980's even after it has been criticized for giving biased results.

The first attempt at investigating G x E interaction by means of principal component analysis (PCA) was that of Williams (1952) whose result was not immediately recognized. The fullest modern development of PCA methods for analyzing G x E interaction appears to be that of Gauch (1988), who used the so called additive main effects and multiplicative interaction effects (AMMI) model. The problem of finding the number of meaningful components in an interaction is the same as in any other PCA, and there is no universally agreed method in doing this. Thus the AMMI method is probably considered the best simple approach to the analysis of G x E interaction (Freeman, 1990). A slight variant to AMMI model is that of Freeman and Dowker (1973) where they considered explicit variation in between and within genotypes and environments (Zobel, 1990). The advantage in using AMMI model or its variant is that they use overall fitting, impose no restrictions on the multiplicative term and results in a least squares fit (Freeman, 1990; Gauch, 1993). The real advance of AMMI model is its ability to predict for new sites and new years (Gauch, 1988).

Moreover AMMI captures more of the G x E interaction than the commonly used (Finlay and Wilkinson, 1963) linear regression analysis (Yau, 1995; Gauch and Zobel, 1995).

When the data are in a two way set, with genotypes being regarded as individuals and their yields in different environments as observations, G x E data come into interplay and can be analyzed by using cluster analysis or pattern analysis (Calinski and Corsten, 1985). Clustering methods can also be used in conjunction with joint regression analysis (Lin and Thompson, 1975) which was found to be less reliable than application of cluster analysis alone (Lin, 1982; Ramey and Rosielle, 1983). As a variant to cluster analysis, pattern analysis was applied by Mungomery et al., (1974) to study the environmental adaptation of lines within breeding populations. The fullest development of multivariate methods using the only information from the genotypes themselves appear to be that of Calinski et al. (1987a, b); who considered the analysis of a series of experiments repeated in both space and time

It has been gradually realized that G x E interaction cannot always be explained in terms solely of genotypic variables and that when some external information is available it should be used. Beckett (1982) attempted to quantify the environmental factors responsible for observed interaction in yield by using linear regression which had a disadvantage of several independent variables being influenced even if they act additively. Virk et al., (1988) cited regression analysis for grain yield of 15 single cross hybrids evaluated in 20 environments at 19 sites throughout India with two fertilizer treatments. Six hybrids fitted the linear regression model, while the remaining nine showed a largely non-linear response.

A better approach to linear regression was that of multiple linear regression which in general relates the data matrix of dependent variable 'Y' to a possible explanatory matrix 'X' (independent variable). Wood (1976) extracted a linear combination of X-variables correlated with a linear combination of Y-variables. This approach is related to the canonical correlation, with showing sensitivity to multi collinearity in either independent 'X' or dependent variable 'Y'. An alternative to multiple linear regression method is factor regression analysis though it has nothing to do with factor analysis which was described by Denis (1988). Despite the practical motivation it was unclear whether this approach has been applied to real data. A useful method that has been applied on real data is that of partial least squares (PLS) regression, described by Aastveit and Martens (1986), which mostly relates several Y variables to several X-variables with separate PCA of X and Y at the same time. It is also provided with component estimates for predicting Y from X. The final set of methods using external variables is the 'Latent variable' model described by Burridge (1988). In this model the environmental variables are called the latent variables as they are unobserved.

### 2.5.6 Additive main effects and multiplicative interaction effects (AMMI) Model

AMMI statistical model is a hybrid model which makes use of standard ANOVA procedure first to separate the additive variance from the multiplicative variance (genotype by environment interaction) and then a multiplictive procedure - principal components analysis (PCA) to extract the pattern from the G x E portion of the ANOVA analysis. The resulting statistical model is a hybrid of two models and results in a least squares analysis, which, with further graphical representation. Biplot analysis,introduced by Gabriel (1971) enables a straight-forward interpretation of the underlying causes of genotypes and environment interaction (Zobel, 1990). A thorough discussion of the theory upon which this hybrid model and the graphical representation is based can be found in Gauch (1988) (further delineation is to be found in Gollob, 1968; Gabriel, 1971; Bradu and Gabriel, 1978) Gabriel (1971) first proposed the use of biplot for the results of PCA analysis, and Bradu and Gabriel (1978) demonstrated that the resulting patterns could be used to diagnose the appropriate statistical model to be used with a given two-way data set Kempton (1984) further used biplots to interpret variety by environment interactions. Yau (1995) explained that AMMI analysis uses ANOVA followed by PCA applied to the sums of squares which are allocated by the ANOVA to the G x E interaction which further quantifies multiplicative (G x E) interaction effects. Crossa et al., (1990) conducted an experiment using the AMMI model for analyzing data from two international maize cultivar trials. The results indicated tnat AMMI provided much insight into G x E interaction and it selected a different highest yielding genotype than did treatment means in 72 per cent of the environments. Whereas Zobel (1990) successfully used the AMMI model to diagnose G x E interaction pattern in a number of situations and for a number of characteristics from day length responses to yield to root numbers. The analyzed data showed a strong G x E interaction between soil temperature and basal root number, a phenomenon that could confuse heritability estimates if not appropriately taken into account. In many cases, empirical evidence using validation data as well as theoretical statistical arguments suggest that, this more accurate estimate of the true mean than the raw means or even means adjusted for error (Gauch and Zobel, 1988, 1989).

To identify appropriate genotype for particular environment, multilocation tests in the target environments are commonly conducted While these tests enable the identification of genotypes, they do not provide adequate understanding why a particular genotypes is higher yielding in a given particular environment Lack of such understanding impedes the development of more genotypes with enhanced yields. Yield system analysis in conjunction with AMMi analysis provide detailed analysis of yield contributing traits in relation to changes effected by stress environments. This holistic approach also provides insight into traits that are related to yield in a given set of environments and suggests that for further improvement. For instance, if the waterlogging effects are caused by through changes in a particular trait, that can be targeted for improvement

# *MATERIALS*

# *&*

# *METHODS*

# CHAPTER III

# MATERIAL AND METHODS

## 3.1 Site of experiment:

An experiment was conducted to study genotype x environment interaction at ICRISAT Asia Center, Patancheru, (18°, 78°E) Andhra Pradesh, India. The field experiment was conducted during the rainy season of 1994 on a medium deep Alfisol (Udic Rhodustalf), with plant available water holding capacity (PAWHC) of 50-100 mm. It is therefore prone to intermittent drought whenever there is a long dry spell in the rainy season and to terminal drought in the postrainy season, and on a Vertisol (Typic pellustert) with 200 mm PAWHC, wherein crop faces excess soil moisture above saturation during the rainy season. The relevant chemical properties of the soil are given in the Table 3.1.

**Table 3.1: Soil chemical properties from 0-15 cm soil layer of both the soils.**

| S No. | Soil type | pH | Electrical conductivity ($dSm^{-1}$) | Organic carbon (%) | Available[a] Olsen's P (mg $kg^{-1}$ soil) | Available[a] N (mg $kg^{-1}$ soil) | Total N[a] (mg $kg^{-1}$ soil) |
|---|---|---|---|---|---|---|---|
| 1. | Vertisol | | | | | | |
| | Mean | 8.03 | 0.20 | 0.47 | 7.30 | 15.70 | 558.80 |
| | SE(Mean) | 0.01 | 0.009 | 0.014 | 2.18 | 3.77 | 8.16 |
| 2. | Alfisol | | | | | | |
| | Mean | 6.98 | 0.35 | 0.48 | 33.10 | 55.40 | 781.00 |
| | SE(Mean) | 0.15 | 0.07 | 0.02 | 3.24 | 9.28 | 19.65 |

a :Analysis : Organic carbon (Nelson and Sommer, 1982)
Available nitrogen (Keeney and Nelson, 1982)
Available phosphorus (Olsen and Sommer, 1982)
Total nitrogen (Dalal et al., 1984)

## 3.2 Experimental design and layout

A split-split plot design (Fig. 3.1a and 3.1b) with 3 replications was adopted on each soil. The main plot size was 60 x 18 m and the sub-plot size 4 x 3.6 m. The two main plots were separated by a 4 m wide tram-way to facilitate chemical spraying by tractor as well as to prevent water seepage between the two main plots.

The treatments assigned to the main plots were

1. Irrigated

2. Rainfed

The following 20 pigeonpea genotypes of various durations assigned to the sub-plots were,

| | |
|---|---|
| 1. ICPL 90002 * | 11 ICPL 89012 # |
| 2. ICPL 90004 * | 12. ICPL 89008 # |
| 3. ICPL 90007 * | 13 ICPL 88009 # |
| 4. ICPL 90011 * | 14. ICPL 87 # |
| 5. ICPL 91002 * | 15 ICPL 86012 # |
| 6. ICPL 83015 ## | 16. ICP 8379 ** |
| 7. ICPL 84023 ## | 17. ICP 7035 ** |
| 8. ICPL 83010 ## | 18 ICP 14199 ** |
| 9. ICPL 88032 ## | 19. ICPL 227 ** |
| 10. ICPL 88039 ## | 20 ICPL 87119 ** |

Note .

* : Extra-short-duration (ESD*) pigeonpea genotypes with ICP 7035 (susceptible to waterlogging as one of the parents,

## : Extra-short-duration (ESD) pigeonpea genotypes

# : Short-duration (SD) pigeonpea genotypes

** : Medium-duration (MD) pigeonpea genotypes

Each replication block was separated from other replication block by a buffer plot of size 4 m length to prevent the seepage during the excess water treatment between the rainfed and irrigated treatment blocks. Each subplot consisted of 6 rows of plants in north-south direction on Vertisol and north-east to south-west on Alfisol.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| bp | | | | | | bp | | | | |
| 16 | 18* | 17 | 20 | 19 | | 15 | 14 | 12 | 11 | 13 |
| 15 | 13 | 11 | 12 | 9 | | 7@ * | 10 | 8 | 9 | 6 |
| 2 | 4 | 3 | 5 | 1 | | 4 | 3 | 5 | 1 | 2 |
| 10 | 16 | 8 | 7@ * | 9 | | 16 | 20 | 19 | 17 | 18* |
| bp | | | | | T | bp | | | | |
| 10 | 9 | 8 | 6 | 7@ * | R | 3 | 2 | 4 | 1 | 5 |
| 2 | 3 | 1 | 4 | 5 | A | 14 | 12 | 11 | 15 | 13 |
| 15 | 13 | 12 | 14 | 11 | M | 9 | 10 | 6 | 8 | 7@ * |
| 19 | 18* | 20 | 17 | 16 | | 20 | 18* | 16 | 19 | 17 |
| bp | | | | | | bp | | | | |
| 16 | 18* | 20 | 19 | 17 | W | 2 | 4 | 5 | 1 | 3 |
| 7@ * | 8 | 10 | 6 | 9 | A | 8 | 10 | 6 | 7@* | 9 |
| 2 | 1 | 3 | 5 | 4 | Y | 14 | 12 | 13 | 11 | 15 |
| 14 | 12 | 11 | 15 | 13 | | 17 | 16 | 18* | 19 | 20 |

**Fig.3.1a: Experimental design (split-split plot) and layout to analyze genotype x environment interaction in pigeonpea (*Cajanus cajan* (L.) Millsp.) subjected to waterlogging on Vertisol (Udic Rhodustalf) at ICRISAT Asia Center (IAC).**

Note:

Main plot: Treatments

I : Irrigated    R : Rainfed

Sub-plot: Pigeonpea genotypes

1. ICPL 90002
2. ICPL 90004
3. ICPL 90007
4. ICPL 90011
5. ICPL 91002
6. ICPL 83015
7. ICPL 84023
8. ICPL 85010
9. ICPL 88032
10. ICPL 88039
11. ICPL 89018
12. ICPL 89008
13. ICPL 88009
14. ICPL 87
15. ICPL 86012
16. ICP 8379
17. ICP 7035
18. ICP 14199
19. ICPL 227
20. ICPL 87119

1 to 5 : Extra-short-duration (ESD) genotypes with ICP 7035 as one of the parents.

6 to 10 : Extra-short-duration (ESD) genotypes.

11 to 15 : Short-duration (SD) genotypes.

16 to 20 : Medium-duration (MD) genotypes.

bp : buffer plots.

@ : Oxygen tube.

* : Neutron probe access tube.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| bp | | | | | | bp | | | | |
| 12 | 14 | 13 | 11 | 15 | | 20 | 19 | 16 | 17 | 18* |
| 8 | 9 | 10 | 6 | 7 @* | | 15 | 14 | 12 | 13 | 11 |
| 18* | 19 | 20 | 16 | 17 | | 3 | 4 | 1 | 2 | 5 |
| 1 | 4 | 5 | 2 | 3 | | 7@ * | 10 | 8 | 6 | 9 |
| bp | | | | | T | bp | | | | |
| 9 | 6 | 8 | 10 | 7 @* | R | 19 | 17 | 16 | 18* | 20 |
| 3 | 5 | 1 | 4 | 2 | A | 6 | 10 | 7@ * | 9 | 8 |
| 19 | 17 | 16 | 18* | 20 | M | 11 | 14 | 15 | 13 | 12 |
| 14 | 13 | 15 | 12 | 11 | | 5 | 4 | 1 | 3 | 2 |
| bp | | | | | | bp | | | | |
| 13 | 14 | 12 | 11 | 15 | W | 19 | 17 | 20 | 16 | 18* |
| 4 | 1 | 5 | 2 | 3 | A | 15 | 13 | 12 | 11 | 14 |
| 6 | 8 | 10 | 7@ * | 9 | Y | 8 | 7@ * | 10 | 6 | 9 |
| 20 | 17 | 18* | 16 | 19 | | 2 | 5 | 1 | 4 | 3 |

**Fig.3.1b: Experimental design (split-split plot) and layout to analyze genotype x environment interaction in pigeonpea (*Cajanus cajan* (L.) Millsp.) subjected to waterlogging on Vertisol (Typic Pellustert) at ICRISAT Asia Center (IAC).**

Note:

Main plot: Treatments

I : Irrigated R : Rainfed

Sub-plot: Pigeonpea genotypes

| | |
|---|---|
| 1. ICPL 90002 | 11. ICPL 89018 |
| 2. ICPL 90004 | 12. ICPL 89008 |
| 3. ICPL 90007 | 13 ICPL 88009 |
| 4. ICPL 90011 | 14. ICPL 87 |
| 5. ICPL 91002 | 15 ICPL 86012 |
| 6. ICPL 83015 | 16. ICP 8379 |
| 7. ICPL 84023 | 17 ICP 7035 |
| 8. ICPL 85010 | 18. ICP 14199 |
| 9. ICPL 88032 | 19. ICPL 227 |
| 10. ICPL 88039 | 20. ICPL 87119 |

| | | |
|---|---|---|
| 1 to 5 | : | Extra-short-duration genotypes (ESD*) with ICP 7035 as one of the parents. |
| 6 to 10 | : | Extra-short-duration (ESD) genotypes. |
| 11 to 15 | : | Short-duration (SD) genotypes. |
| 16 to 20 | : | Medium-duration (MD) genotypes. |
| bp | : | buffer plots. |
| @ | : | Oxygen tube. |
| * | : | Neutron probe access tube. |

### 3.3 Agronomic practices

Both fields were tilled and a basal dose of 100 kg $ha^{-1}$ diammonium phosphate (18% N and 46% $P_2O_5$) was incorporated before sowing. Then ridges spaced at 60 cm were established. Treated seed with Thiuram ® and Ridiomil ® (75%) at the rate of 3 g $kg^{-1}$ was used for sowing in order to check the soil borne fungal diseases. Sowings were done by hand in the shallow furrows opened at the top of the ridge with 60 cm inter row spacing and 5 cm (for short- and extra-short-duration) and 20 cm (for medium-duration) intra-row spacing between the seed hills. Sowings on Alfisol were taken on 23 June, 1994 and on Vertisol on 22 June, 1994. Two seeds were sown per hill and thinning to one plant per hill was done at 34-36 days after sowing (DAS) on Vertisol and 21-23 DAS on Alfisol so as to get the required plant density.

A pre-emergence herbicide tank mixture containing Fluchoralin 45 per cent @ 2.0 kg $ha^{-1}$, Prometryn ® 50 per cent @ 1.5 kg $ha^{-1}$ and Paraquat ® 0.25 per cent @ 3.0 kg $ha^{-1}$ was applied in Alfisol one day after sowing and the same chemical mixture at the rate of 2.25, 2.0 and 3.0 kg $ha^{-1}$ respectively was applied on Vertisol on the same day after sowing. Depending upon the weed infestation two hand weedings were also given at 32-days interval on Alfisol and 23-days interval on Vertisol in addition to one interculture operation, which was carried out 10 days before hand weeding in both soils.

Different pesticides were used. On Alfisol, sprays of Monocrotophos 36 per cent @ 1.0 kg $ha^{-1}$ and on Vertisols sprays of Quinolphos @ 2 kg $ha^{-1}$ were taken to control of blister beetle (*Mylabris pustulata*) and leaf webber (*Grapholita* (*cydia*) *critica*. Meyer) during flowering stage. During the pod filling stage, to minimize the losses from attack by pod borer (*Helicoverpa armigera*) and maruca spotted pod borer (*Maruca testulalis*) sprays of Quinolphos @ 2 kg $ha^{-1}$ or Fenvulerate @ 1.0 kg $ha^{-1}$ and Lanate @ 4.0 kg $ha^{-1}$ on Alfisol and sprays of Endosulfan 4.0 kg $ha^{-1}$, Lanate and Quinolphos @ 40 kg $ha^{-1}$ were taken on Vertisol to control these pests. Spotted borer and leaf webber were not reported over the economic threshold levels on Vertisol. The number of sprays given were about 12 on Alfisol and 11 on Vertisol during the crop growing period. This number though apparently high, was necessary due to variation in phenology. No serious problems from weeds effecting the crops was recorded on either soils.

### 3.4 Irrigation and excess water treatment

After sowing, both soils were uniformly irrigated to field capacity using perforated pipes (provided with check gates for the control of water flow) so that soil moisture was sufficient for seed germination and good crop establishment. Furrow method of irrigation was adopted.

The excess soil water treatments were created only to the irrigated treatment plots at a regular intervals depending upon the crop growth stage, crop condition and rainfall intensity and distribution. Small bunds were raised at the ends of each furrow of each sub-plot to retain standing water in furrows during the waterlogging treatment so that the soil became saturated with water, while the other treatment was kept under rainfed conditions. During the experiment, the rainfall events were so large that the soil moisture status on Vertisol remained very high (due to high water holding capacity), thereby reducing the number of excess irrigation water treatments to only 3. On Alfisol (low water holding capacity), the excess irrigation water treatments were given at a high frequency of 8 during the crop growing period so as to create the desired soil saturation level (Table 3.2).

The total water applied at each excess soil water irrigation treatment during the crop growth was recorded using a flow meter aligned on the main pipe line system and the rainfall data was recorded at the ICRISAT Asia Center meteorological station.

### 3.5 Observation and measurements

#### 3.5.1 Weather data

Weather data were obtained from the meteorological station located within the ICRISAT Asia Center campus. The seasonal weather data for the crop growing season from June 22, 1994 to January 5, 1995 are presented in the Appendix 4.1.

**Table 3.2: Amount (liters/360 $m^{-2}$) and date of excess water applied to irrigated treatment of Alfisol and Vertisol during the crop growing period.**

| S.No. | Soil | Treatment date | Area | Rep 1 | Rep 2 | Rep 3 | Total(lt) | = cm |
|---|---|---|---|---|---|---|---|---|
| 1. | Alfisol | 9.8.94 | 360$m^{-2}$ | 13000 | 16000 | 16000 | 45000 | 4.17 |
| | | 1.9.94 | | 7000 | 8000 | 7000 | 22000 | 2.037 |
| | | 7.9.94 | | 10000 | 11000 | 7000 | 28000 | 2.592 |
| | | 15.9.94 | | 12000 | 14000 | 12000 | 38000 | 3.519 |
| | | 22.9.94 | | 8200 | 11000 | 9000 | 28000 | 2.593 |
| | | 29.9.94 | | 9000 | 10000 | 9000 | 28000 | 2.593 |
| | | 11.11.94 | | 4000 | 7000 | 7000 | 18000 | 1.667 |
| | | 24.11.94 | | 7000 | 8000 | 9000 | 24000 | 2.222 |
| | | | | | | | | 21.393 |
| 2. | Vertisol | 8.8.94 | 360$m^{-2}$ | 22000 | 17000 | 19000 | 58000 | 5.37 |
| | | 2.9.94 | | 14000 | 17000 | 18000 | 49000 | 4.54 |
| | | 17.11.94 | | 19000 | 16000 | 13000 | 48000 | 4.44 |
| | | | | | | | | 14.350 |

### 3.5.2 Soil moisture:

Soil moisture during the crop growth in each main plot of both soil was monitored at 10-day intervals from sub-plots having genotypes ICPL 84032 (ESD) and ICPL 14199 (MD). A single aluminum access tube was installed in the center of the third row of each sub-plot to a depth of 1.2 m and was used for soil moisture content measurement at 0-15, 15-30, 30-45, 45-60, 60-75 and 75-90 cm layers of soil profile by using neutron probe (Model 2651 Troxler Electronic laboratories, Inc., USA). Soil moisture content in the 0-15 and 15-30 cm soil layer was simultaneously determined gravimetrically. All the soil water content values at different layers were converted into volumetric water content using the bulk density of 1.5 g $cm^{-3}$ in Alfisol and 1.3 g $cm^{-3}$ in vertisol and a calibration curve to convert neutron count to volumetric soil moisture content.

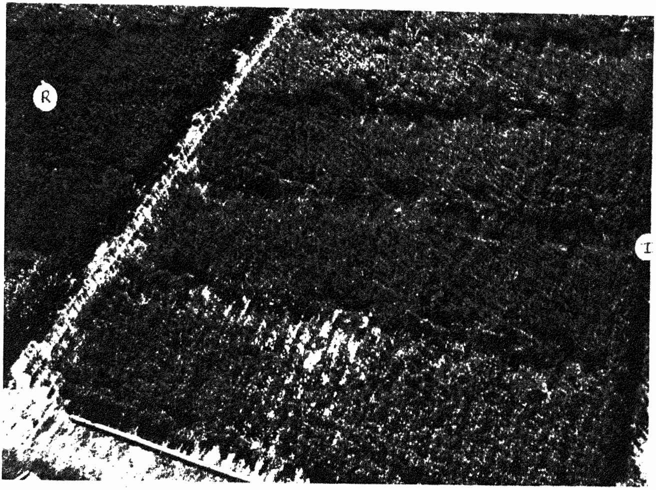
Total expo-transpiration ($E_t$) was estimated using the following water balance equation

$E_t = R + I + (S_1 - S_2) - R_o - Dr.$

Where.

R = Amount of rainfall(cm)

I = Amount of water applied to crop by irrigation (cm)



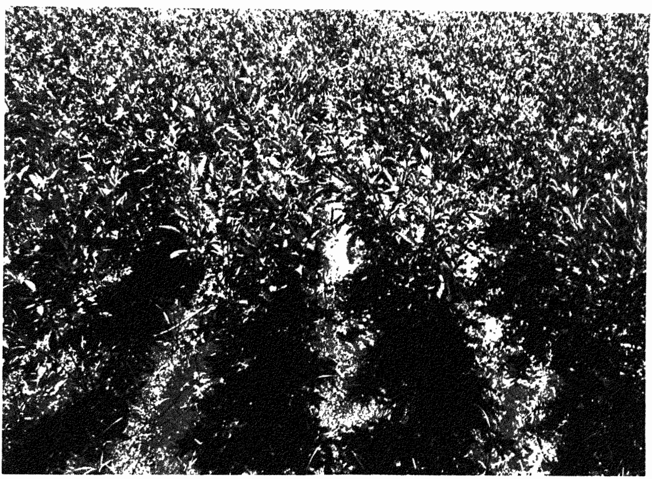


Plate 3.1 Irrigation water being applied in furrows on Alfisol (above) and Vertisol (below) so as to create near soil saturation.

$S_1$ and $S_2$ = Amount of water stored in the 100 cm soil profile at germination and maturity stage respectively.

Deep drainage (Dr) and surface runoff (Ro) during irrigation period were ignored.

### 3.5.3 Soil oxygen concentration

Soil air was sampled at 20 cm depth using stainless steel tubes as described by Okada et al., (1991). The oxygen concentration of soil air was measured by feeding the soil air from the sub-plots containing genotypes ICPL 84023 (ESD) using a disposable syringe to the oxygen analyzer (Toray Engineering Co. Ltd., Model C700F, Japan) which uses solid electrolyte as a detector.

### 3.5.4 Plant growth

#### 3.5.4.1 Phenological studies

Critical phenological stages were determined as given below :

##### 3.5.4.1.1 Days to 50 per cent flowering

Number of days from sowing to the date when 50% of the plants in the sub-plots had at least one open flower.

##### 3.5.4.1.2 Days to maturity

Number of days from sowing to the time when more than 75 per cent of pods on the pigeonpea plant had turned brown (dry pods)

#### 3.5.4.2 Canopy development

##### 3.5.4.2.1 Leaf area index

Leaf area index was determined during the early hours of the day (avoiding bright sunshine) by using an automatic leaf area meter LAI-2000 plant canopy analyzer, LI-COR, Inc. USA at weekly intervals in all sub-plots of Alfisol and Vertisol.

The readings were recorded by placing the sensor head, with its lens facing upward below the plant canopy, between third and fourth plant rows on a well laid flat surface. Three such readings were taken at 45° to one another below the canopy and one reading 0.3 m above the plant canopy with sensor head facing clear sky.

The output data from the sensor was directly recorded into a polycorder (OMNI DATA, International MC, USA) and later transferred to a computer for analysis

### 3.5.4.3 Growth analysis

#### 3.5.4.3.1 Chlorophyll analysis

Chlorophyll a, b and total contents of the plant tissue were estimated by using spectrophotometer (Shimadzu UV-160 A, UV-VIS Japan) at 663 and 645 mm wavelength.

Ten fully expanded leaves (3rd leaf in case of determinates and 6th or 7th leaf in case of indeterminates) were randomly selected from each sub-plot. The leaf samples were cut into discs of 1 cm diameter by using a leaf punch. The 10 discs weighing approximately 200 mg in fresh weight were immersed in a test tube containing 10 ml of 30 per cent acetone and transferred immediately to cold room maintained at 4°C in order to prevent photo-oxidation After 48 hours of immersion the extractant was made up to 50 ml by adding 5 ml of fresh 80 per cent acetone to 1 ml of extractant

The spectrophotometer was standardized with 80 per cent acetone solution as a reference, and absorbance was measured at 664 and 645 mm wavelength.

From the absorbance data, contents of chlorophyll are calculated as below :

$Chl\ total = 20.2 \times A_{645} + 8.02 \times A_{663}$

$Chl_a = 12.7 \times A_{663} + 2.69 \times A_{645}$

$Chl_b = 22.9 \times A_{645} - 4.68 \times A_{663}$

The resultant values are the chlorophyll contents (mg $g^{-1}$) on fresh weight basis

### 3.5.5 Abscission of plant parts

Perforated plastic trays of 36 x 26 x 4.5 cm dimensions were placed under plant canopy in each sub-plot containing genotypes ICPL 84023 (ESD) and ICPL 14199 (MD) in both Alfisol and Vertisol. Abscised leaves, flowers, and pods were collected at weekly intervals to determine dry mass of each component. Cumulative abscission of these components was determined as grams per plant.

### 3.5.6 Total dry matter at harvest and grain yield

Total dry matter at harvest and grain yield was determined by harvesting all plants in each net-plot. For calculating total dry matter (TDM), total number of plants in each net-plot was counted and then total fresh weight was recorded Then the fresh weight of a 5 plant sub-sample, which was randomly selected, was also taken and its dry weight was recorded after oven drying at 80°C to a constant weight. Finally, TDM in each net plot was determined and expressed as t $ha^{-1}$.

For determining grain yield, all pods of a net plot were picked and seeds were separated by threshing manually with mallets after drying the pods in the sun. Grain yields were expressed as t $ha^{-1}$ at 10% moisture level for all genotypes

### 3.5.7 Yield components

The five plant sub-samples which were used for calculation of total dry matter were also used for estimating yield components including, number of pod $m^{-2}$, number of seeds $pod^{-1}$ and 100 seed mass. Harvest index (HI) was calculated as a ratio of grain yield to total above ground dry matter (DM); this excluded fallen plant parts at harvest in each sub-plot.

## 3.6 Statistical analysis

**3.6.1 Genstat analysis** Experimental data were subjected to analysis of variance using a standard split-plot design analysis as described by Gomez and Gomez (1994) and using the GENSTAT package (GENSTAT Manual, 1983) in a VAX mainframe computer system at ICRISAT Asia Center.

### 3.6.2 Additive Main effects and Multiplicative Interaction effects (AMMI) Statistical analysis

AMMI analysis was done using Rhizostatics 2.0 Cornell University. USA. The AMMI statistical model is a hybrid model which makes use of standard ANOVA procedure to separate the additive variance from the multiplicative variance (genotype by environment interaction) and then uses a multiplicative procedure - Principal Component Analysis (PCA) to extract the pattern from the G x E portion of ANOVA analysis. The resulting statistical model is a hybrid of the two models and results in a least squares analysis. which with further graphical representation of the numerical results (Biplot analysis) often allows interpretation of the underlying causes of G x E Interaction (Zobel et al., 1988). Gauch (1988); Gollob (1968); Gabriel (1978); Bradu and Gabriel (1978);

The mathematical model for AMMI is

$$Y_{ge} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda_n \ \gamma_{gn} \cdot \delta_{en} + \varrho_{ge}$$

Where,

$g$ = Genotypes

$e$ = Environments

$Y_{ge}$ = Yield of genotype 'g' in environment 'e'

$\mu$ = Grand mean

$\alpha_g$ = Mean of the $g^{th}$ genotype minus the grand mean

$\beta_e$ = Mean of the $e^{th}$ environment minus the grand mean

$N$ = Number of IPCAs (Interaction Principal Component Axis) retained in the model

$\lambda_n$ = Singular value or square root of the eigen value of the PCA axis ' n '

$\gamma_{gn}$ = Principal component score for PCA axis n of the $g^{th}$ genotype

$\delta_{en}$ = Principal component score for PCA axis 'n' of the $e^{th}$ environment

$\varrho_{ge}$ = Residual

Note : Environment and genotype PCA scores are expressed as unit vector times the square root of $\lambda_n$ (i.e., environment PCA score = ${}^{0.5}\lambda_n \ \delta_{en}$ genotype PCA = ${}^{0.5}\lambda_n \ \gamma_{gn}$ ) (Zobel et al., 1988).

**3.6.2.1 AMMI Analysis procedure**

**3.6.2.1.1 Format**

AMMI analysis is a two factor analysis of variance (ANOVA) where the variance due to factor mean deviation from the grand mean is removed from the data matrix cells along with the grand mean, and the resulting matrix subjected to matrix algebra procedure called Singular value decomposition (SVD). And this process followed by representing the results on a two-factor scatter diagram called AMMI bi-plot, where the factor mean deviations from grand mean is represented on the X-axis and their interaction with each other (PCA 1) on Y-axis.

### 3.6.2.2 Mathematical basis for AMMI analysis

#### 3.6.2.2.1 Additive model

Two factor data are represented as a matrix with columns representing the different levels of one factor and rows representing the different levels of the second factor. In a replicated experiment, each replicate is represented as a separate matrix and then the means of each cell across all replicates are determined. Error variance is the variance of the replicate cell values from the mean and is assumed to be removed

Mathematical representation of the Additive model is:

$$Y_{rc} = \mu + \alpha_r + \beta_c + Q_{rc}$$

where,

$Y_{rc}$ = Actual cell valve

$\mu$ = Grand mean

$\alpha_r$ = Row mean deviation from grand mean

$\beta_c$ = Column mean deviation from grand mean

$Q_{rc}$ = Residual $= [\, Y_{rc} - (\mu + \alpha_r + \beta_c)\,]$

#### 3.6.2.2.2 Singular value decomposition (SVD)

Singular value decomposition is a one matrix algebra procedure that is effective in characterizing a data matrix. Mathematical representation of a complete SVD of a data matrix is

$$Y_{rc} = {}^{N}_{i=1}\Sigma\ \lambda_i \quad \gamma_{ir} + \delta_{ic}$$

where,

N = Smaller of the number of rows or columns.

$\lambda_i$ = Singular value (square root of the eigen value which in turn, is the sum of squares divided by the number of replications) for axis 'i'. (if the data is kg ha$^{-1}$, the given value is terms of kg ha$^{-1}$);

$\gamma_{ir}$ = Eigen vector for row 'r' in axis i,

$\delta_{ic}$ = Eigen vector for column 'c' in axis i

### 3.6.2.2.3 Principal component analysis (PCA)

Principal component analysis is the application of singular value decomposition (SVD) to a matrix after the removal of the grand mean from each cell. This removal results in so called covariance matrix.

Mathematical representation of PCA is

$$Y_{rc} = \mu + {}^{N}{}_{i=1}\Sigma \ \lambda_i \ \gamma_{ir} + \delta_{ic}$$

### 3.6.2.3 Interpretation of AMMI analysis

The key merit of AMMI analysis is the interpretability of the corresponding biplots. Each biplot will have points equal to sum of genotypes and environment For example we had 20 genotypes and 4 environments and therefore the biplot will compare among 24 points.

The cultivars and environments with highest and lowest averages are indicated visually. The magnitude of the cultivar and environment (positive or negative) to the contribution of G x E interaction identifies the genotypes and environments with the largest to smallest G x E interaction effect on the yield (or any other trait analyzed using AMMI analysis). And, any genotype or environment with zero or near zero contribution causes near zero G x E interaction, since zero times any other number is zero It is the magnitude and not the negative or positive sign which indicate the largest G x E interaction effect; a positive interaction exists when the genotype and environment have a PCA 1 score of same sign (positive or negative), since the product of two negatives is positive. While a combination of opposite sign results in negative interaction between them.

Therefore, especially those genotypes whose average yield is high and also had a high negative PCA score will have a yield advantage in the environment with negative PCA score.

The biplot provides an opportunity for using the existing or acquirable knowledge of known traits and characteristics of the genotypes, and of factors which differ among the environments, to derive physiological-genetic explanations of the larger cause of the G x E interactions.

**3.7 Yield system analysis**

Yield system analysis (YSA), as described by Wallace and

Wallace, (1991) was used to measure the four direct measurements of the yield trial (1) days to flowering (calendar days taken by plant from sowing to 50 per cent flowering), (2) days to maturity (calendar days taken by plant from sowing to physiological maturity), (3) the aerial biomass at the time of harvest, and (4) the seed yield at harvest. From these four traits the five indirect measurements of YSA are calculated. These five indirect measurements are (5) days to seed fill (days to maturity minus days to flowering), (6) yield day$^{-1}$ (total seed yield divided by total days to maturity), (7) yield day$^{-1}$ of seedfill duration (total seed yield divided by total days to seedfill), (8) biomass day$^{-1}$ (total biomass produced divided by total days to maturity), and (9) harvest index (ratio of seed yield to aerial biomass).

# *RESULTS*

# CHAPTER IV

# RESULTS

## 4.1 Meteorological Observations

The meteorological data for the year 1994, during the experimental period collected at the ICRISAT Asia center (IAC) are shown in figure 4.1 and Appendix 4.1. The total annual rainfall during the year 1994 at ICRISAT Asia center (IAC) was 848.3 mm about 10 per cent above the long term average. The total rainfall during the crop growing season extending from June 22, 1994 to January 10, 1995 was 684.9 mm (81% of the total annual rainfall). The seasonal rainfall was 20 per cent above the normal.

The rainy season arrived on time, on 10 June 1994. Crop sowings were done according to normal schedule. Crop establishment was good. June, July, August received sufficient rainfall, contributing 43 per cent of the total annual rainfall. Rainfall in September (62% deficit than the normal) November and December, however, was low causing water deficit at the end of the season. There was no serious damage due to water deficit to crops as the carried over soil moisture was adequate for short- and extra-short-duration pigeonpea genotypes which were in the late maturing stage. October recorded 248 mm of rainfall (thrice the monthly mean), this amount of rainfall was sufficient to recharge the soil profile moisture.

The total annual seasonal rainfall during 1994 at IAC was above normal, the heavy rainfall events which were well spread with little runoff made it more congenial to take up waterlogging experiment.

The minimum temperature during December and January were cooler than normal (by 3°C and 1°C respectively). Daily maximum and minimum air temperature were within 2°C of the long term average.

Of the total rainfall, the extra-short-duration pigeonpea genotypes received about 59.5 per cent during the vegetative phase and 40.5 per cent during the reproductive phase. Similarly the short-duration genotypes received about 61.2 per cent and 38.8 per cent of the

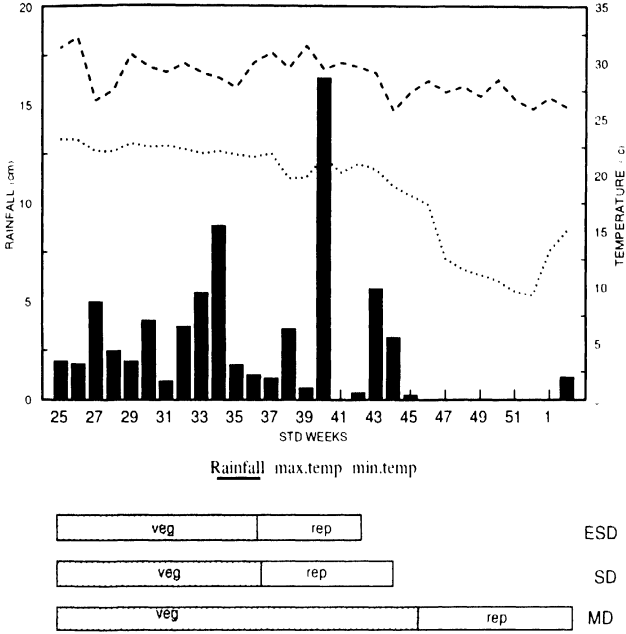



Fig 4.1: Temperature (Maximum, Minimum) and rainfall data during the crop growing season Kharif 1994, at ICRISAT Asia center, Patancheru, India. (Crop growth duration during vegetative (veg) and reproductive (rep) for extra-short- (ESD), short- (SD) and medium-duration (MD) pigeonpea genotypes are are indicated below the figure).

total rainfall during the vegetative and the reproductive phase respectively. The medium-duration genotypes received 95.1 per cent of the total rainfall during the vegetative phase and a meagre 4.9 per cent during reproductive phase.

**4.2 Total water supplied and soil moisture pattern during crop growth**

On both Alfisol and Vertisol, excessive soil moisture status was created by increasing water supplied to the crop through supplemental irrigation whenever there was a gap of rainfall during the crop growth cycle. The total amount of water supplied to the four pigeonpea groups viz., extra-short-duration genotypes (ESD*) with ICP 7035 as one of the parents, short-duration (SD), extra-short-duration (ESD) and medium-duration (MD) genotypes are presented in the Table 4.1. From Table 4.1 it is evident that the total amount of water supplied to different pigeonpea groups grown on Alfisol was thus 624.8 mm for ESD*, 766.4 mm for SD, 602.8 mm for ESD and 898.8 mm for MD to which the rainfall had contributed 66 per cent for ESD*, 72 per cent for SD, 64 per cent for ESD and 76 per cent for MD genotypes (Fig. 4.2). Whereas on Vertisol, the total water supplied was 691.5 mm for ESD*, 774.4 mm for SD, 690.5 mm for ESD and 828.4 mm for MD genotypes to which rainfall contributed 79.2 per cent for ESD*, 81.4 per cent for SD, 79.2 per cent for ESD and 82.7 per cent for MD genotype.

The total amount of water received by the crops during the vegetative stage of crop growth, when short- and extra-short-duration pigeonpea types are usually sensitive to excess soil moisture were 344.1 mm for ESD*, 393.5 mm for SD, 298.1 mm for ESD and 826.3 mm for MD genotypes, of which rainfall had contributed 88 per cent for ESD*, 89.4 per cent for SD, 86 per cent for ESD and 95 per cent for MD genotypes on Alfisol, whereas on Vertisol, the total water received by the four pigeonpea genotypes were 416 mm for ESD*, 434.4 mm for SD, 415.5 mm for ESD and 774.4 mm for MD genotypes of which rainfall contributed 87 per cent for ESD*, 88 per cent for SD and 87 per cent for ESD and 93 per cent for MD genotypes.

**Table 4.1: Total Rainfall plus Irrigation (mm) received by the four pigeonpea groups extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parents, extra-short-duration (ESD), short-duration (SD) and medium-duration (MD) genotypes during the crop growth on Alfisol and Vertisol during Kharif 1994 at ICRISAT Asala Center (IAC).**

| Genotype Group | Alfisol | | Vertisol | |
|---|---|---|---|---|
| | Vegetative Phase | Reproductive Phase | Vegetative Phase | Reproductive Phase |
| ESD* | 344.1 (37R+1I) | 280.7 (18R+5I) | 416 (44R+1I) | 275.5 (15R+0I) |
| ESD | 298.1 (35R+1I) | 304.7 (18R+5I) | 415.5 (43R+1I) | 275 (15R+0I) |
| SD | 393.5 (40R+1I) | 372.9 (18R+5I) | 434.9 (47R+2I) | 339.5 (18R+0I) |
| MD | 826.3 (64R+6I) | 72.5 (5R+2I) | 774.4 (59R+2I) | 54 (4R+1I) |

Note:

Values in perentheses are rainy days (R) and number of irrigations (I).

In general the cumulative water used from the 0-90 cm soil profile was relatively higher in irrigated treatment than in rainfed treatment (Fig 4.2). The cumulative water used from the 0-90 cm soil profile in the rainfed treatment of Alfisol was 47.6 cm for ICPL 84023 (ESD) and 54.2 cm for ICP 14199 (MD) while in Vertisol it was 54.19 cm for ICPL 84023 (ESD) and 43.9 cm for ICP 14199 (MD).

The cumulative water used from the 0-90 cm soil profile in the irrigated treatment of Alfisol was 73.7 cm for ICP 84023 (ESD) and 78.4 cm for ICP 14199 (MD) and in Vertisol it was 57.9 cm for ICPL 84023 (ESD) and 63.6 cm for ICP 14199 (MD). In comparison to the rainfed treatment, about 26-35 per cent more soil moisture was observed in the 0-90 cm soil profile of irrigated treatment of Alfisol. In Vertisol, about 6-31 per cent more soil moisture was observed in irrigated treatment compared to rainfed treatment.

### 4.3 Soil oxygen concentration

Analysis of the oxygen concentration at 20 cm root zone depth in the sub-plots containing genptype ICPL 84023 (ESD) was found to be significant due to soil, sampling time

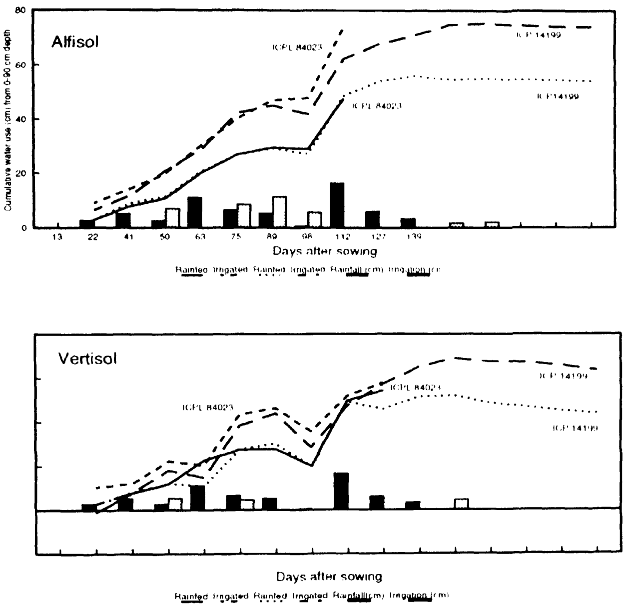



Fig. 4.2: Cumulative water use by ICPL 84023 (ESD) and ICP 14199 (MD) genotypes from 0-90 cm soil depth in rainfed and irrigated treatments of Alfisol and Vertisol during kharif 1994 season at ICRISAT Asia center

(STD. Week), treatment, soil x sampling time, soil x treatment and treatment x sampling time. In general, the concentration of oxygen in Alfisol was 19.7 per cent and 19.3 per cent in Vertisol (2% less than Alfisol). Between the treatments, oxygen concentration was 19.3 per cent in irrigated treament and 19.7 per cent in rainfed treatment. In Alfisol, oxygen concentration in the rainfed treatment was 4.5 per cent more than in the irrigated treament while in Vertisol, oxygen concentration in the irrigated treatment was 0.5 per cent more than in the rainfed treatment. In general, the oxygen concentration in the soil was around 20 per cent, but with the advance of the rainy season the oxygen level fell to less than 16 per cent in Alfisol anf less than 15 per cent in Vertisol (Table 4.2). The coeffecient of variation for concentration of oxygen in soil was 4.5 per cent.

**4.4 Plant Stand at Maturity**

A Comparison of plant stand or plant population $m^{-2}$ at the maturity stage of both, Alfisol and Vertisol is presented in Table 4.3. A highly significant difference was observed due to genotypes. The significant differences in plant density among the 20 pigeonpea genotypes was attributed to lower plant population $m^{-2}$ for medium-duration genotypes compared to short- and extra-short-duration genotypes (Appendix 4.2). The soil x genotype interaction also showed significant difference. No significant difference was observed due to soils, water stress treatments viz., rainfed and irrigated and soils x treatments x genotypes interactions. The plant density $m^{-2}$ for all the four pigeonpea groups were 8 per cent higher on Vertisol than on Alfisol. On both Alfisol and Vertisol, all the pigeonpea genotypes produced higher plant density $m^{-2}$ in the rainfed treatment (9.3%) compared to irrigated treatment. Among the four pigeonpea groups, ESD*, ESD, SD and MD, highest plants $m^{-2}$ was recorded in ESD genotype, ICPL 88039 (Table 4.3) while, lowest plants $m^{-2}$ was recorded in ESD* genotype, ICPL 91002. The plant density for ESD* genotype ranged between 14 and 24 plants $m^{-2}$ while for SD, ESD and MD genotypes, the ranges were 17 to 25, 22 to 24 and 4 to 5 plants $m^{-2}$. A significant negative correlation was observed between seed yield and plants $m^{-2}$ across the 20 pigeonpea genotypes ($r=-0.40^{**}$, $n=60$) while there was no significance across the four soil-

**Table 4.2 Comparision of soil oxygen concentration (%) at 20 cm root depth for ICPL 84023 (SD) grown in rainfed and irrigated treatments of Alfisol and Vertisol during Kharif 1994 at ICRISAT Asia center (IAC).**

| STD.Week | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| 29 | 19.8 | 20.0 | 19.9 | 19.9 | 20.2 | 20.0 |
| 30 | 20.3 | 20.4 | 20.4 | 19.3 | 19.6 | 19.4 |
| 31 | 19.8 | 20.0 | 19.9 | 20.4 | 20.6 | 20.5 |
| 32 | 20.9 | 20.8 | 20.8 | 18.7 | 19.1 | 18.9 |
| 33 | 20.2 | 19.8 | 20.0 | 13.7 | 15.9 | 14.8 |
| 34 | 16.6 | 15.7 | 16.2 | 18.9 | 16.4 | 17.6 |
| 35 | 20.5 | 19.4 | 20.0 | 20.1 | 19.6 | 19.8 |
| 36 | 20.7 | 19.9 | 20.3 | 17.4 | 18.7 | 18.0 |
| 37 | 20.5 | 18.9 | 19.7 | 20.2 | 20.1 | 20.1 |
| 38 | 20.2 | 17.7 | 18.9 | 20.2 | 19.9 | 20.0 |
| 39 | 20.0 | 17.7 | 18.8 | 19.5 | 19.3 | 19.4 |
| 40 | 20.6 | 19.0 | 19.8 | 20.6 | 20.3 | 20.5 |
| 41 | 21.8 | 21.3 | 21.5 | 20.1 | 20.2 | 20.1 |
| 42 | 20.4 | 19.7 | 20.1 | 20.9 | 21.2 | 21.0 |
| Mean | 20.2 | 19.3 | 19.7 | 19.3 | 19.4 | 19.3 |
| SEm± | | | | | | |
| Soil | | | | 0.17 * | | |
| Treatment | | | | 0.10 ** | | |
| STD. Week | | | | 0.45 ** | | |
| Soil x STD. Week | | | | 0.64 ** | | |
| Soil x Treatment | | | | 0.20 (0.14) ** | | |
| Treatment x STD. Week | | | | 0.52 (0.36) * | | |
| Soil x Treatment x STD. Week | | | | 0.73 (0.51) | | |
| CV % | | | | 4.5 | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor

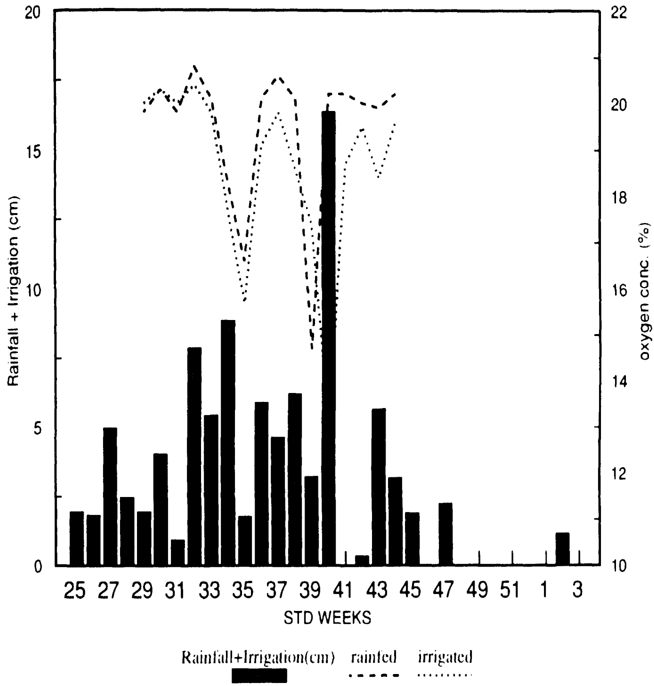



Fig. 4.3: Seasonal rainfall + irrigation (cm) against oxygen concentration (%) of soil air at 20 cm root depth of rainfed and irrigated treatment of Alfisol Kharif 1994, ICRISAT.

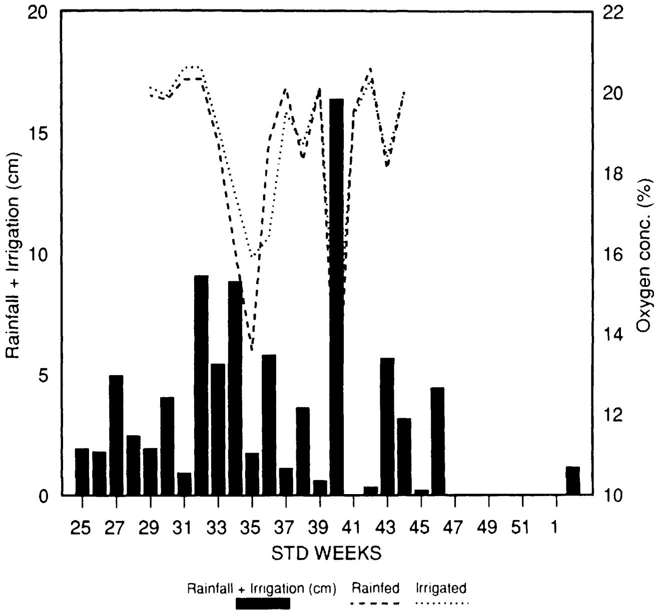



Fig 4.4: Seasonal rainfall + irrigation (cm) against oxygen concentration (%) of soil air at 20 cm root depth in rainfed and irrigated treatments of Vertisol, Kharif 1994, ICRISAT.

**Table 4.3: Comparision of total number of plant m$^{-2}$ at maturity for the five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 15.3 | 13.9 | 14.6 | 22.0 | 17.1 | 19.6 |
| ICPL 90004 | 21.0 | 21.6 | 21.3 | 24.2 | 22.6 | 23.4 |
| ICPL 90007 | 23.4 | 21.9 | 22.7 | 25.1 | 23.0 | 24.1 |
| ICPL 90011 | 19.2 | 18.8 | 19.0 | 24.6 | 16.9 | 20.8 |
| ICPL 91002 | 16.2 | 13.4 | 14.8 | 16.5 | 9.2 | 12.9 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 21.4 | 22.4 | 21.9 | 27.4 | 17.1 | 22.3 |
| ICPL 84023 | 23.3 | 20.6 | 21.9 | 24.4 | 23.7 | 24.1 |
| ICPL 85010 | 22.7 | 21.7 | 22.2 | 25.2 | 21.1 | 23.2 |
| ICPL 88032 | 21.6 | 21.7 | 21.7 | 27.7 | 24.7 | 26.2 |
| ICPL 88039 | 24.4 | 23.6 | 24.0 | 24.1 | 25.1 | 24.6 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 19.5 | 20.8 | 20.2 | 23.7 | 20.3 | 22.0 |
| ICPL 89008 | 17.0 | 16.1 | 16.6 | 18.3 | 16.7 | 17.5 |
| ICPL 88009 | 19.3 | 18.2 | 18.7 | 21.2 | 20.6 | 20.9 |
| ICPL 87 | 21.5 | 20.5 | 21.0 | 25.7 | 23.7 | 24.7 |
| ICPL 86012 | 19.8 | 18.2 | 19.0 | 27.9 | 22.7 | 25.3 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 5.5 | 5.4 | 5.5 | 3.8 | 4.4 | 4.1 |
| ICP 7035 | 4.2 | 4.1 | 4.1 | 4.2 | 3.2 | 3.7 |
| ICP 14199 | 4.6 | 5.5 | 5.0 | 3.8 | 4.0 | 3.9 |
| ICPL 227 | 5.0 | 5.2 | 5.1 | 5.5 | 5.0 | 5.3 |
| ICPL 87119 | 5.2 | 5.4 | 5.3 | 5.2 | 4.7 | 5.0 |
| Mean | 16.5 | 16.0 | 16.2 | 19.0 | 16.3 | 17.7 |
| SEm± | | | | | | |
| Soil | | | 0.58 | | | |
| Treatment | | | 0.90 | | | |
| Genotype | | | 0.84 ** | | | |
| Soil x Genotype | | | 1.29 (1.18) * | | | |
| Soil x Treatment | | | 1.07 (1.28) | | | |
| Treatment x Genotype | | | 1.47 (1.18) | | | |
| Soil x Treatment x Genotype | | | 10.95 (2.07) | | | |
| CV % | | | 17.1 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

moisture environments observed. The coefficient of variation for number of plants $m^{-2}$ was 17.1 per cent.

### 4.5 Plant Survival Percentage (%)

The mean percentage of survival of plants for 20 pigeonpea genotypes on both soils was found to be highly significant (Appendix 4.2) The soil and soil x genotype interaction was also highly significant. The difference due to treatments and soil x treatment x genotype interaction were not significant. The percentage survival of plants on Alfisol in comparison to Vertisol was 22 per cent higher (Table 4.4). Between the two treatments viz., rainfed and irrigated, genotypes showed higher survival rate in the rainfed treatment compared to irrigated treatment (3.4%). The variation in the per cent plant survival among the four pigeonpea groups were in the rank order of ESD* genotypes having a high mean survival rate (92%) followed by SD genotypes (90.3%), ESD genotypes (86.5%) and MD genotypes (72.9%). Among the 20 pigeonpea genotypes, the wilt susceptible MD genotypes ICP 8379 and ICP 14199 showed the lowest survival per cent (<50%), while wilt resistant MD genotypes ICPL 87119 showed the highest plant survival (97%). The coefficient of variation was 14.1 per cent Across the 20 pigeonpea genotypes (r=0.32*, n=60) and across the four soil-moisture environments (r=0.92**, n=12) a significant positive correlation was observed for per cent plant survival with seed yield.

### 4.6 Phenology

#### 4.6.1 Days to 50 per cent Flowering

The differences in days to 50 per cent flowering were highly significant for genotypes, soils, soil x genotype and soil x treatment interaction (Appendix 4.2). No significant difference was observed between the rainfed and irrigated treatments. On an average, the pigeonpea genotypes on Alfisol flowered 9 days earlier than the genotypes grown on Vertisol. Between the two treatments, the genotypes grown in the rainfed treatment flowered two days earlier than the genotypes grown in the irrigated treatment. Among the four pigeonpea genotype groups, the ESD* genotypes were the earliest to flower {66 to 69 days after sowing (DAS)}

**Table 4.4: Comparision of per cent plant survival for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 100 | 98 | 99 | 91 | 84 | 88 |
| ICPL 90004 | 100 | 100 | 100 | 93 | 92 | 93 |
| ICPL 90007 | 99 | 100 | 99 | 84 | 83 | 83 |
| ICPL 90011 | 99 | 100 | 99 | 89 | 75 | 82 |
| ICPL 91002 | 97 | 94 | 95 | 89 | 75 | 82 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 94 | 98 | 96 | 89 | 69 | 79 |
| ICPL 84023 | 99 | 100 | 99 | 94 | 83 | 88 |
| ICPL 85010 | 98 | 99 | 99 | 79 | 75 | 77 |
| ICPL 88032 | 92 | 99 | 95 | 83 | 72 | 78 |
| ICPL 88039 | 95 | 100 | 97 | 51 | 62 | 57 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 98 | 98 | 98 | 61 | 53 | 57 |
| ICPL 89008 | 93 | 99 | 96 | 83 | 77 | 80 |
| ICPL 88009 | 94 | 99 | 97 | 89 | 87 | 88 |
| ICPL 87 | 100 | 100 | 100 | 97 | 96 | 97 |
| ICPL 86012 | 100 | 99 | 100 | 91 | 92 | 92 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 85 | 61 | 73 | 2 | 5 | 4 |
| ICP 7035 | 98 | 83 | 90 | 77 | 88 | 83 |
| ICP 14199 | 88 | 63 | 75 | 1 | 2 | 2 |
| ICPL 227 | 99 | 97 | 98 | 82 | 81 | 82 |
| ICPL 87119 | 100 | 100 | 100 | 94 | 95 | 94 |
| Mean | 96 | 94 | 95 | 76 | 72 | 74 |
| SEm± | | | | | | |
| Soil | 0.5 ** | | | | | |
| Treatment | 2.0 | | | | | |
| Genotype | 3.5 ** | | | | | |
| Sol x Genotype | 4.8 (4.9) ** | | | | | |
| Soil x Treatment | 2.1 (2.9) | | | | | |
| Treatment x genotype | 5.2 (4.9) | | | | | |
| Soil x Treatment x Genotype | 7.1 (7.3) | | | | | |
| CV % | 14.1 | | | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

followed by ESD genotypes (63 to 69 DAS). All the SD genotypes flowered at 70 to 74 DAS except for the genotype ICPL 87 which was late by seven days (Table 4.5). MD genotypes flowered at about 126 to 131 DAS. A significant positive correlation across the 20 pigeonpea genotypes ($r=0.47^{**}$, n=60) and negative correlation across the four soil-moisture environments ($r=-0.81^{**}$, n=12) was observed for the days to 50 per cent flowering with seed yield. The days to 50 per cent flowering had the coefficient of variation of 3.4 per cent

### 4.6.2 Days to Maturity

The results for days to maturity of pigeonpea genotypes revealed highly significant differences due to soils, genotypes, soils x genotypes interaction and soil x treatment interaction (Appendix 4.2). The average days required for 20 pigeonpea genotypes to mature on Alfisol were 10 to 15 days earlier than for the genotypes grown on Vertisol. Between the two treatments, the genotypes matured 5 days earlier in the rainfed treatment compared to the irrigated treatment. The ESD* genotypes were first to mature at 104-109 DAS (Table 4.6) followed by ESD genotypes in 110-111 DAS, SD genotypes in 113 to 116 DAS with the exception of genotypes, ICPL 87 and ICPL 86012 which matured later than the other three SD genotypes by 30 days on both Vertisol as well as on Alfisol. The SD genotypes ICPL 87 and ICPL 86012 matured earlier by 30 to 35 days on Alfisol than on Vertisol. The MD genotypes matured between 185 to 187 DAS. Among the 5 ESD* genotypes, ICPL 85010 matured first and genotype ICPL 88032 was the last to mature. Similarly among the MD genotypes, ICP 8379 was first to mature and genotype ICPL 14199 was latest to mature. Mean days to maturity were earlier (2%) in the rainfed treatment compared to the irrigated treatment. There was no significant difference observed between treatment x genotype and soil x treatment x genotype interaction. A significant positive correlation across the 20 pigeonpea genotypes ($r=0.48^{**}$, n=60) and negative correlation across the four soil-moisture environments ($r=-0.78^{**}$, n=12) was observed for days to maturity with seed yield. The coefficient of variation for days to maturity was 2.5 per cent.

**Table 4.5: Comparision of days to flowering for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 64 | 63 | 64 | 74 | 75 | 75 |
| ICPL 90004 | 63 | 62 | 62 | 69 | 72 | 71 |
| ICPL 90007 | 63 | 63 | 63 | 70 | 73 | 72 |
| ICPL 90011 | 66 | 66 | 66 | 71 | 74 | 73 |
| ICPL 91002 | 62 | 61 | 61 | 67 | 75 | 71 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 60 | 62 | 61 | 66 | 73 | 69 |
| ICPL 84023 | 56 | 56 | 56 | 69 | 69 | 69 |
| ICPL 85010 | 60 | 60 | 60 | 67 | 70 | 69 |
| ICPL 88032 | 63 | 63 | 63 | 75 | 75 | 75 |
| ICPL 88039 | 62 | 63 | 63 | 70 | 73 | 72 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 70 | 71 | 71 | 77 | 79 | 78 |
| ICPL 89008 | 65 | 65 | 65 | 76 | 77 | 76 |
| ICPL 88009 | 64 | 64 | 64 | 76 | 76 | 76 |
| ICPL 87 | 71 | 74 | 72 | 81 | 81 | 81 |
| ICPL 86012 | 72 | 63 | 67 | 81 | 81 | 81 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 126 | 126 | 126 | 126 | 135 | 131 |
| ICP 7035 | 129 | 126 | 127 | 135 | 135 | 135 |
| ICP 14199 | 125 | 126 | 126 | 128 | 135 | 132 |
| ICPL 227 | 125 | 125 | 125 | 129 | 131 | 130 |
| ICPL 87119 | 125 | 124 | 124 | 127 | 128 | 128 |
| Mean | 79 | 79 | 79 | 87 | 89 | 88 |

| SEm± | |
|---|---|
| Soil | 0.3 ** |
| Treatment | 0.4 |
| Genotype | 0.8 ** |
| Soil x Genotype | 1.2 (1.2) ** |
| Soil x Treatment | 0.5 (0.6) * |
| Treatment x Genotype | 1.2 (1.2) |
| Soil x Treatment x Genotype | 1.7 (1.7) |
| CV % | 3.4 |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.6: Comparision of days to maturity for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 103 | 108 | 105 | 116 | 117 | 116 |
| ICPL 90004 | 102 | 108 | 105 | 116 | 117 | 116 |
| ICPL 90007 | 102 | 107 | 105 | 116 | 116 | 116 |
| ICPL 90011 | 103 | 107 | 105 | 116 | 115 | 116 |
| ICPL 91002 | 100 | 107 | 103 | 117 | 116 | 117 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 97 | 103 | 100 | 106 | 111 | 109 |
| ICPL 84023 | 96 | 104 | 100 | 116 | 113 | 114 |
| ICPL 85010 | 99 | 102 | 100 | 109 | 108 | 108 |
| ICPL 88032 | 101 | 106 | 104 | 112 | 118 | 115 |
| ICPL 88039 | 102 | 103 | 103 | 107 | 111 | 109 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 110 | 115 | 113 | 121 | 118 | 120 |
| ICPL 89008 | 103 | 110 | 107 | 120 | 121 | 120 |
| ICPL 88009 | 99 | 111 | 105 | 123 | 120 | 122 |
| ICPL 87 | 111 | 119 | 115 | 151 | 151 | 151 |
| ICPL 86012 | 111 | 115 | 113 | 144 | 151 | 148 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 177 | 183 | 180 | 186 | 190 | 188 |
| ICP 7035 | 181 | 182 | 182 | 192 | 191 | 192 |
| ICP 14199 | 179 | 181 | 180 | 194 | 193 | 193 |
| ICPL 227 | 180 | 180 | 180 | 190 | 192 | 191 |
| ICPL 87119 | 180 | 180 | 180 | 190 | 191 | 191 |
| Mean | 122 | 127 | 124 | 137 | 138 | 138 |
| SEm± | | | | | | |
| Soil | | | 0.6 ** | | | |
| Treatment | | | 0.4 ** | | | |
| Genotype | | | 0.9 ** | | | |
| Soil x Genotype | | | 1.5 (1.3) ** | | | |
| Soil x Treatment | | | 0.7 (0.5) ** | | | |
| Treatment x Genotype | | | 1.4 (1.3) | | | |
| Soil x Treatment x Genotype | | | 2.0 (1.9) | | | |
| CV % | | | 2.5 | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

### 4.7 Total Dry matter at Harvest

The combined analysis for both soils, Alfisol and Vertisol for the total dry matter at the time of harvest, excluding the abscised dry matter (Appendix 4.3) revealed that there were highly significant differences due to soils, genotypes, soil x genotype and soil x treatment interaction. In general, all genotypes on Alfisol produced 49 per cent more dry matter than on Vertisol. On Alfisol, mean dry matter of all genotypes was 13 per cent more in the irrigated treatment than in the rainfed treatment whereas, on Vertisol, it was 16 per cent more in the rainfed treatment than the irrigated treatment. Among the four pigeonpea groups all ESD* genotypes, except ICPL 91002, produced 4 to 4.5 t $ha^{-1}$ dry matter (Table 4.7). Genotypes ICPL 90002, ICPL 90007 and ICPL 91002 produced more dry matter in the irrigated treatment than in the rainfed treatment. Among the five SD genotypes, ICPL 87 and ICPL 86012 produced 6.1 to 6.6 t $ha^{-1}$ dry matter which was similar to the dry matter produced by the three wilt susceptible MD genotypes viz., ICP 8379, ICP 7035 and ICP 14199. The ESD genotypes produced the lowest mean dry matter among the four pigeonpea groups which ranged between 3.7 and 4.0 t $ha^{-1}$ while MD genotypes produced the highest dry matter (6.0 to 10.3 t $ha^{-1}$). Among the five MD genotypes the wilt susceptible genotypes ICP 14199, ICP 8375 and ICP 7035 produced mean dry matter in the range of 6.1 to 6.9 t $ha^{-1}$ whereas, wilt resistant genotypes ICPL 87119 and ICPL 227 produced an average dry matter of 10.3 t $ha^{-1}$.

Among the 20 pigeonpea genotypes, the MD genotype ICPL 87119 produced the highest dry matter at the harvest while ESD* genotype ICPL 91002 produce the lowest. A highly significant positive correlation was observed between total dry matter and seed yield across the 20 pigeonpea genotypes (r=0.81**, n=60) and across the four soil-moisture environments (r=0.99**, n=12). The coefficient of variation for total dry matter at harvest was 22.5 per cent.

### 4.8 Seed Yield

The variation in seed yield of all genotypes in both soils reflected similar trend as observed in the total dry matter produced by the four pigeonpea groups. In contrast to high

**Table 4.7: Comparision of total dry matter (t ha$^{-1}$) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-dutration (ESD*) | | | | | | |
| ICPL 90002 | 4.57 | 5.71 | 5.14 | 3.28 | 2.40 | 2.84 |
| ICPL 90004 | 5.33 | 6.31 | 5.82 | 3.30 | 1.80 | 2.55 |
| ICPL 90007 | 5.60 | 6.22 | 5.91 | 2.95 | 3.40 | 3.18 |
| ICPL 90011 | 5.45 | 6.42 | 5.93 | 3.27 | 1.89 | 2.58 |
| ICPL 91002 | 4.19 | 5.79 | 4.99 | 2.35 | 0.91 | 1.63 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 4.86 | 5.43 | 5.14 | 3.09 | 1.62 | 2.36 |
| ICPL 84023 | 4.46 | 5.59 | 5.02 | 2.48 | 2.17 | 2.33 |
| ICPL 85010 | 4.70 | 5.89 | 5.29 | 2.20 | 2.00 | 2.10 |
| ICPL 88032 | 4.72 | 5.51 | 5.12 | 2.71 | 2.75 | 2.73 |
| ICPL 88039 | 4.53 | 6.45 | 5.49 | 2.47 | 2.63 | 2.55 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 5.99 | 8.15 | 7.07 | 3.30 | 1.98 | 2.64 |
| ICPL 89008 | 4.17 | 6.55 | 5.36 | 2.56 | 2.22 | 2.39 |
| ICPL 88009 | 4.62 | 6.08 | 5.35 | 3.32 | 2.85 | 3.09 |
| ICPL 87 | 7.17 | 9.07 | 8.12 | 5.64 | 4.78 | 5.21 |
| ICPL 86012 | 6.53 | 6.86 | 6.69 | 7.05 | 4.09 | 5.57 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 12.16 | 9.51 | 10.84 | 2.08 | 2.71 | 2.40 |
| ICP 7035 | 8.89 | 9.66 | 9.28 | 4.56 | 4.44 | 4.50 |
| ICP 14199 | 8.95 | 10.39 | 9.67 | 2.42 | 2.45 | 2.44 |
| ICPL 227 | 10.74 | 11.88 | 11.31 | 9.30 | 9.05 | 9.18 |
| ICPL 87119 | 11.93 | 11.95 | 11.94 | 8.91 | 8.43 | 8.67 |
| Mean | 6.48 | 7.47 | 6.97 | 3.86 | 3.23 | 3.55 |
| SEm± | | | | | | |
| Soil | | | 0.084 ** | | | |
| Treatment | | | 0.165 | | | |
| Genotype | | | 0.342 ** | | | |
| Soil x Genotype | | | 0.479 (0.484) ** | | | |
| Soil x Treatment | | | 0.186 (0.234) ** | | | |
| Treatment x Genotype | | | 0.500 (0.484) | | | |
| Soil x Treatment x Genotype | | | 0.693 (0.707) | | | |
| CV % | | | 22.5 | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

yield in Alfisol, the seed yield declined steeply on Vertisol by 60 per cent. The seed yield in the irrigated treatment was 13 per cent more than the yield in the rainfed treatment (Table 4.8). In general, all genotypes produced 18 per cent more seed yield in the irrigated treatment on Alfisol whereas, on Vertisol the genotypes produced 11 per cent more seed yield in the rainfed treatment. The differences in seed yield due to genotypes, soils, treatments, soils x genotypes and soil x treatment interaction were all highly significant (Appendix 4.3). No significant interaction was observed for the treatment x genotype and soil x treatment x genotype interaction for seed yield. The yield range on Alfisol was 1.7 to 3.0 t $ha^{-1}$ while on Vertisol it varied between 0.05 and 2.3 t $ha^{-1}$. The highest seed yields were observed for ICPL 227 and ICPL 87119 (wilt resistant MD genotypes) while, the lowest yields were observed in genotypes, ICP 8379 and ICP 14199 (wilt susceptible genotypes). All the above four genotypes are MD genotypes.

The seed yield for the five ESD* genotypes ranged between 1.15 and 1.42 t $ha^{-1}$. Similarly, the seed yield range for SD was 1.19 to 1.48 t $ha^{-1}$, for ESD 1.16 to 1.46 t $ha^{-1}$ and for MD genotypes 1.09 to 2.68 t $ha^{-1}$ . The variation in the seed yield among the four pigeonpea groups were in the ranking order of ESD* < ESD < SD < MD. The coefficient of variation was 19.3 per cent.

Across the 20 genotypes a significant positive correlation of yield was observed with total dry matter, hundred seed weight, pod $m^{-2}$, per cent plant survival, days to 50 per cent flowering, days to harvest maturity, yield $day^{-1}$, biomass $day^{-1}$, seedfill duration and yield $day^{-1}$ of seedfill duration while, a negative correlation was observed with per cent pod borer damage and plants $m^{-2}$. Across the four soil-moisture environments a significant positive correlation of yield was observed with total dry matter at harvest, harvest index, hundred seed weight, seeds $pod^{-1}$, pods $m^{-2}$, per cent plant survival, yield $day^{-1}$, biomass $day^{-1}$ and yield $day^{-1}$ of seedfill duration. While a significant negative correlation was observed with per cent pod borer damage, days to 50 per cent flowering and days to harvest maturity.

**Table 4.8: Comparision of seed yield (t $ha^{-1}$) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) genotypes on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 1.58 | 2.07 | 1.82 | 0.93 | 0.72 | 0.83 |
| ICPL 90004 | 1.85 | 2.33 | 2.09 | 0.59 | 0.42 | 0.51 |
| ICPL 90007 | 1.93 | 2.16 | 2.05 | 0.81 | 0.79 | 0.80 |
| ICPL 90011 | 1.80 | 2.24 | 2.02 | 0.83 | 0.51 | 0.67 |
| ICPL 91002 | 1.46 | 2.15 | 1.80 | 0.72 | 0.29 | 0.50 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 1.68 | 2.03 | 1.86 | 1.03 | 0.53 | 0.78 |
| ICPL 84023 | 1.54 | 1.87 | 1.70 | 0.74 | 0.50 | 0.62 |
| ICPL 85010 | 1.55 | 1.97 | 1.76 | 0.76 | 0.67 | 0.72 |
| ICPL 88032 | 1.57 | 1.92 | 1.75 | 0.84 | 0.75 | 0.80 |
| ICPL 88039 | 1.66 | 2.09 | 1.88 | 0.72 | 0.97 | 0.85 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 1.75 | 2.36 | 2.05 | 0.71 | 0.45 | 0.58 |
| ICPL 89008 | 1.54 | 2.16 | 1.85 | 0.77 | 0.82 | 0.80 |
| ICPL 88009 | 1.70 | 2.15 | 1.93 | 0.80 | 0.67 | 0.74 |
| ICPL 87 | 1.54 | 2.25 | 1.89 | 0.98 | 1.08 | 1.03 |
| ICPL 86012 | 1.58 | 1.96 | 1.77 | 0.79 | 0.43 | 0.61 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 2.47 | 2.04 | 2.25 | 0.01 | 0.08 | 0.05 |
| ICP 7035 | 1.92 | 2.36 | 2.14 | 0.85 | 0.87 | 0.86 |
| ICP 14199 | 2.11 | 2.12 | 2.11 | 0.07 | 0.04 | 0.06 |
| ICPL 227 | 2.80 | 3.28 | 3.04 | 2.23 | 2.40 | 2.31 |
| ICPL 87119 | 2.58 | 3.01 | 2.79 | 1.91 | 2.20 | 2.05 |
| Mean | 1.83 | 2.23 | 2.03 | 0.86 | 0.76 | 0.81 |
| SEm± | | | | | | |
| Soil | | | 0.026 ** | | | |
| Treatment | | | 0.025 ** | | | |
| Genotype | | | 0.079 ** | | | |
| Soil x Genotype | | | 0.112 (0.112) ** | | | |
| Soil x Treatment | | | 0.036 (0.036) ** | | | |
| Treatment x Genotype | | | 0.112 (0.112) | | | |
| Soil x Treatment x Genotype | | | 0.158 (0.158) | | | |
| CV % | | | 19.3 | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

### 4.9 Yield components

#### 4.9.1 Number of pods $m^{-2}$

The combined analysis for both soils revealed that there were highly significant differences due to soils, genotypes and soil x genotype, and soil x treatment interaction (Appendix 4.3) for number of pods $m^{-2}$. No significant difference was observed between treatment, treatment x genotype and soil x treatment x genotype interaction. In general, all the genotypes in Vertisol produced 44 per cent less number of pods $m^{-2}$ than on Alfisol (Table 4.9). The genotypes showed inconsistency with respect to the production of pods $m^{-2}$. The ESD* genotypes, ICPL 90011, ICPL 91002 showed low pod number $m^{-2}$, while the MD genotypes, ICPL 87119 and ICPL 227 showed relatively higher pods $m^{-2}$. Genotype ICP 7035 (MD) had the lowest number of pods $m^{-2}$ (262) while, ICPL 227 (MD) had the highest pod number of 1048 $m^{-2}$. In general, all genotypes on Alfisol produced more number of pods $m^{-2}$ (up to 15%) in irrigated treatment while, on Vertisol, the genotypes produced 19 per cent more pods $m^{-2}$ in the rainfed treatment. Among the four pigeonpea groups, ESD* genotypes produced a mean of 400 to 600 pods $m^{-2}$. The number of pods $m^{-2}$ for SD genotype were 500 to 640, for ESD 500 to 600 and 260 to 1050 pods $m^{-2}$ for MD genotypes The variation of pods $m^{-2}$ among the four pigeonpea groups were in the rank order of ESD* < ESD < SD < MD genotypes. A significant positive correlation was observed for number of pods $m^{-1}$ with seed yield across the 20 pigeonpea genotypes (r=0.54**, n=60) and across the four soil-moisture environments (r=0.94**, n=12). The coefficient of variation observed for pods $m^{-2}$ was 33.5 per cent.

#### 4.9.2 Number of seeds $pod^{-1}$

The combined analysis for both soils revealed that the number of seeds $pod^{-1}$ were highly significant due to soils, genotypes and soils x genotype interaction (Appendix 4.3). The difference due to treatment, soil x treatment and soil x treatment x genotype interaction were not significant. All genotypes produced 18 per cent more number of seeds $pod^{-1}$ on Alfisol compared to the genotypes on Vertisol (Table 4.10). Comparing between the four pigeonpea

**Table 4.9: Comparision of total number of pods $m^{-2}$ for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 608 | 711 | 659 | 499 | 300 | 400 |
| ICPL 90004 | 737 | 810 | 774 | 655 | 252 | 453 |
| ICPL 90007 | 702 | 738 | 720 | 435 | 389 | 412 |
| ICPL 90011 | 638 | 655 | 647 | 463 | 178 | 321 |
| ICPL 91002 | 567 | 589 | 578 | 326 | 123 | 224 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 693 | 710 | 701 | 454 | 273 | 364 |
| ICPL 84023 | 704 | 904 | 804 | 496 | 272 | 384 |
| ICPL 85010 | 610 | 792 | 701 | 402 | 318 | 360 |
| ICPL 88032 | 555 | 650 | 602 | 403 | 374 | 388 |
| ICPL 88039 | 588 | 692 | 640 | 340 | 380 | 360 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 616 | 718 | 667 | 422 | 241 | 332 |
| ICPL 89008 | 728 | 787 | 757 | 477 | 456 | 466 |
| ICPL 88009 | 745 | 882 | 814 | 501 | 422 | 461 |
| ICPL 87 | 489 | 654 | 572 | 616 | 570 | 593 |
| ICPL 86012 | 466 | 506 | 486 | 643 | 494 | 569 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 1103 | 1158 | 1130 | 96 | 137 | 116 |
| ICP 7035 | 305 | 370 | 338 | 183 | 190 | 186 |
| ICP 14199 | 996 | 1243 | 1119 | 176 | 249 | 213 |
| ICPL 227 | 960 | 1470 | 1215 | 840 | 992 | 881 |
| ICPL 87119 | 731 | 903 | 817 | 665 | 796 | 731 |
| Mean | 677 | 797 | 737 | 455 | 367 | 411 |

| SEm± | |
|---|---|
| Soil | 24.3 ** |
| Treatment | 24.0 |
| Genotype | 55.5 ** |
| Soil x Genotype | 80.2 (78.5) ** |
| Soil x Treatment | 34.1 (33.9) ** |
| Treatment x Genotype | 80.1 (78.5) |
| Soil x Treatment x Genotype | 113.4 (113.3) |
| CV % | 33.5 |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.10: Comparision of total number of seed pod$^{-1}$ for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 3.1 | 3.6 | 3.4 | 2.7 | 3.0 | 2.8 |
| ICPL 90004 | 2.8 | 2.8 | 2.8 | 1.6 | 2.3 | 1.2 |
| ICPL 90007 | 3.1 | 3.5 | 3.3 | 2.5 | 2.7 | 2.6 |
| ICPL 90011 | 3.1 | 3.4 | 3.2 | 2.6 | 2.8 | 2.7 |
| ICPL 91002 | 2.7 | 3.9 | 3.3 | 2.8 | 2.4 | 2.6 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 3.2 | 3.5 | 3.3 | 3.1 | 2.7 | 2.9 |
| ICPL 84023 | 3.0 | 3.0 | 3.0 | 2.6 | 2.7 | 2.6 |
| ICPL 85010 | 3.2 | 2.9 | 3.1 | 2.5 | 2.6 | 2.5 |
| ICPL 88032 | 3.6 | 3.7 | 3.7 | 3.0 | 3.00 | 3.0 |
| ICPL 88039 | 3.1 | 3.4 | 3.3 | 2.9 | 3.3 | 3.1 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 3.8 | 3.9 | 3.9 | 2.7 | 2.8 | 2.8 |
| ICPL 89008 | 2.8 | 3.2 | 3.0 | 2.8 | 2.6 | 2.7 |
| ICPL 88009 | 2.8 | 3.1 | 3.0 | 2.6 | 2.4 | 2.5 |
| ICPL 87 | 3.5 | 3.4 | 3.4 | 2.3 | 2.4 | 2.3 |
| ICPL 86012 | 3.4 | 3.4 | 3.4 | 1.9 | 1.7 | 1.8 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 3.1 | 2.8 | 2.9 | 2.1 | 2.3 | 2.2 |
| ICP 7035 | 3.7 | 3.5 | 3.6 | 3.1 | 3.5 | 3.3 |
| ICP 14199 | 3.0 | 2.6 | 2.8 | 2.6 | 2.2 | 2.4 |
| ICPL 227 | 2.6 | 3.0 | 2.8 | 2.7 | 2.8 | 2.7 |
| ICPL 87119 | 2.8 | 2.8 | 2.8 | 2.7 | 2.8 | 2.7 |
| Mean | 3.1 | 3.3 | 3.2 | 2.6 | 2.6 | 2.6 |
| SEm± | | | | | | |
| Soil | 0.05 ** | | | | | |
| Treatment | 0.04 | | | | | |
| Genotype | 0.11 ** | | | | | |
| Soil x Genotype | 0.16 (0.15) ** | | | | | |
| Soil x Treatment | 0.07 (0.06) | | | | | |
| Treatment x Genotype | 0.16 (0.15) | | | | | |
| Soil x Treatment x Genotype | 0.22 (0.22) | | | | | |
| CV % | 12.9 | | | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

genotypes the number of seeds $pod^{-1}$ was in the order of ESD > SD > ESD* > MD genotypes. A significant positive correlation was observed for number of seeds $pod^{-1}$ with seed yield across the four soil-moisture environments (r=0.94**, n=12) only. A coefficient of variation of 12.9 per cent was observed for number of seeds $pod^{-1}$.

### 4.9.3 Hundred Seed Weight

The combined analysis for hundred seed weight revealed that a highly significant differences due to soils, genotypes, soils x genotypes and treatment x genotype interaction (Appendix 4.3). The genotypes grown on Alfisols had 15 per cent more weight for hundred seeds than for the genotypes grown on Vertisol (Table 4.11). Among the four pigeonpea groups, ESD* genotypes had a mean hundred seed weight of 8.0 to 9.3 g $hundred^{-1}$ seeds. The mean hundred seed weight were 7.1 to 8.8 g for SD genotypes, 6.8 to 8.3 g for ESD and 6.0 to 11.2 g for MD genotypes. A significant positive correlation was observed between hundred seed weight and seed yield across the 20 pigeonpea genotypes (r=0.43**, n=60) and across the four soil-moisture environments (r=0.86**, n=12). The coefficient of variation observed for hundred seed weight was 12.0 per cent.

### 4.9.4 Harvest Index

There were highly significant differences due to genotype, soil and soil x genotype interaction for harvest index (Appendix 4.3). Genotypes grown on Alfisol showed a higher HI (22%) than on Vertisol (Table 4.12). Among the genotypes, ESD genotype showed a higher HI (31-35%) followed by ESD* (30-33%), SD (20-37%) and MD genotypes (12-26%). No significant difference due to treatment, soil x treatment and soil x treatment x genotypes interaction were observed. A significant positive correlation was observed between harvest index and seed yield across the four soil-moisture environments (r=0.83**, n=12) only. Coefficient of variation for harvest index was 21.7 per cent.

## 4.10 Pod borer damage (%)

The combined analysis for percentage damage (with at least one hole) caused by the pod borer revealed a highly significant difference due to genotypes and soils (Appendix 4.2)

**Table 4.11: Comparision of hundred seed weight (g) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (ESD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 8.3 | 8.2 | 8.3 | 7.4 | 8.1 | 7.8 |
| ICPL 90004 | 9.0 | 10.2 | 9.6 | 6.7 | 7.6 | 7.2 |
| ICPL 90007 | 9.2 | 8.5 | 8.8 | 7.5 | 7.8 | 7.7 |
| ICPL 90011 | 9.2 | 10.1 | 9.7 | 7.6 | 10.2 | 8.9 |
| ICPL 91002 | 9.6 | 9.9 | 9.8 | 7.9 | 9.4 | 8.6 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 7.7 | 8.3 | 8.0 | 7.3 | 7.1 | 7.2 |
| ICPL 84023 | 7.3 | 6.9 | 7.1 | 6.2 | 6.9 | 6.6 |
| ICPL 85010 | 8.0 | 8.7 | 8.4 | 7.7 | 8.2 | 8.0 |
| ICPL 88032 | 7.8 | 8.0 | 7.9 | 7.1 | 6.8 | 7.0 |
| ICPL 88039 | 9.1 | 8.9 | 9.0 | 7.4 | 7.9 | 7.7 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 7.6 | 8.4 | 8.0 | 6.3 | 6.3 | 6.3 |
| ICPL 89008 | 7.7 | 8.7 | 8.2 | 6.0 | 7.3 | 6.6 |
| ICPL 88009 | 8.1 | 8.0 | 8.1 | 6.2 | 6.8 | 6.5 |
| ICPL 87 | 9.2 | 10.0 | 9.6 | 8.0 | 8.0 | 8.0 |
| ICPL 86012 | 10.0 | 11.4 | 10.7 | 7.7 | 6.2 | 6.9 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 7.3 | 6.0 | 6.7 | 5.9 | 4.6 | 5.3 |
| ICP 7035 | 17.2 | 18.0 | 17.6 | 14.7 | 13.2 | 14.0 |
| ICP 14199 | 7.2 | 7.1 | 7.1 | 6.6 | 6.8 | 6.7 |
| ICPL 227 | 11.6 | 9.2 | 10.4 | 9.8 | 9.5 | 9.7 |
| ICPL 87119 | 12.5 | 11.8 | 12.1 | 10.6 | 10.0 | 10.3 |
| Mean | 9.2 | 9.3 | 9.3 | 7.7 | 7.9 | 7.8 |
| SEm± | | | | | | |
| Soil | 0.23 ** | | | | | |
| Treatment | 0.18 | | | | | |
| Genotype | 0.30 ** | | | | | |
| Soil x Genotype | 0.47 (0.42) ** | | | | | |
| Soil x Treatment | 0.29 (0.25) | | | | | |
| Treatment x Genotype | 0.45 (0.42) * | | | | | |
| Soil x Treatment x Genotype | 0.65 (0.63) | | | | | |
| CV % | 12.0 | | | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of frist factor.

**Table 4.12: Comparision of harvest index (%) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 34.6 | 36.3 | 35.5 | 28.4 | 30.0 | 29.2 |
| ICPL 90004 | 34.8 | 37.1 | 35.9 | 18.7 | 32.6 | 25.6 |
| ICPL 90007 | 34.5 | 34.8 | 34.7 | 27.5 | 23.3 | 25.4 |
| ICPL 90011 | 33.1 | 35.0 | 34.1 | 26.1 | 26.3 | 26.2 |
| ICPL 91002 | 35.7 | 37.2 | 29.7 | 30.9 | 30.0 | 21.3 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 35.0 | 37.6 | 36.3 | 33.4 | 34.6 | 34.0 |
| ICPL 84023 | 34.6 | 33.5 | 34.0 | 30.3 | 24.5 | 27.4 |
| ICPL 85010 | 33.1 | 33.8 | 33.5 | 35.1 | 32.4 | 33.7 |
| ICPL 88032 | 33.4 | 35.1 | 34.3 | 31.3 | 28.0 | 29.7 |
| ICPL 88039 | 37.6 | 32.6 | 35.1 | 29.1 | 37.1 | 33.1 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 29.2 | 30.2 | 29.7 | 21.3 | 21.4 | 21.3 |
| ICPL 89008 | 37.1 | 34.1 | 35.6 | 30.4 | 45.1 | 37.8 |
| ICPL 88009 | 37.2 | 35.6 | 36.4 | 24.7 | 23.7 | 24.2 |
| ICPL 87 | 21.5 | 25.2 | 23.3 | 17.6 | 23.5 | 20.6 |
| ICPL 86012 | 24.2 | 28.5 | 26.3 | 14.3 | 11.1 | 12.7 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 21.4 | 20.2 | 20.8 | 0.3 | 2.7 | 1.5 |
| ICP 7035 | 21.7 | 24.1 | 22.9 | 18.1 | 20.1 | 19.1 |
| ICP 14199 | 23.5 | 20.9 | 22.5 | 1.8 | 1.5 | 1.6 |
| ICPL 227 | 26.0 | 27.6 | 26.8 | 24.0 | 26.6 | 25.3 |
| ICPL 87119 | 22.2 | 25.0 | 23.6 | 21.4 | 25.9 | 23.6 |
| Mean | 30.5 | 31.2 | 30.9 | 23.2 | 25.0 | 24.1 |
| SEm± | | | | | | |
| Soil | | | 0.93 ** | | | |
| Treatment | | | 1.19 | | | |
| Genotype | | | 1.72 ** | | | |
| Soil x Genotype | | | 2.54 (2.43) ** | | | |
| Soil x Treatment | | | 1.51 (1.68) | | | |
| Treatment x genotype | | | 2.65 (2.43) | | | |
| Soil x Treatment x Genotype | | | 3.67 (3.75) | | | |
| CV % | | | 21.7 | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

and significant difference due to treatment and soil x genotype interaction. Differences due to soil x treatment and soil x treatment x genotype interaction were not significant. In general, the per cent damage by the pod borer was 47 per cent which was significantly more on Vertisol than on Alfisol. Genotypes showed a high rate of pod borer damage (11%) in the rainfed treatment than in the irrigated treatment (Table 4.13). Among the four groups, the mean percentage of pod borer damage was observed for the ESD* genotypes was higher (47.6%) followed by SD (45.38%) ESD (37.8%) and MD genotypes (30.24%). A significant negative correlation was observed between per cent pod borer damage and seed yield across the 20 pigeonpea genotypes (r=-0.46**, n=60) and across the four soil-moisture environments (r=-0.97**, n=12). The coefficient of variation observed for per cent pod borer damage was 29.4 per cent.

### 4.11 Components of Yield System Analysis

#### 4.11.1 Daily yield productivity (yield day$^{-1}$)

The difference in daily productivity due to soils, genotypes, soils x genotypes, soils x treatment and soils x treatment x genotypes interactions were all highly significant (Appendix 4.4). The difference due to the two treatments was also significant. In general, the genotypes on Alfisol showed a daily average yield productivity of 17 kg ha$^{-1}$ d$^{-1}$ and on Vertisol 6 kg ha$^{-1}$ d$^{-1}$ (Table 4.14). Among the 20 pigeonpea genotypes, ESD genotypes showed highest daily yield productivity of 12.2 kg ha$^{-1}$ d$^{-1}$ followed by ESD* 12 kg ha$^{-1}$ d$^{-1}$, SD 11.5 kg ha$^{-1}$ d$^{-1}$ and MD genotypes of 9.8 kg ha$^{-1}$ d$^{-1}$. Genotypes, ICPL 227 (MD) showed the highest daily yield productivity (14 kg ha$^{-1}$ d$^{-1}$) while genotype ICP 14199 (MD) had the least productivity of only 6 kg ha$^{-1}$ d$^{-1}$. A significant positive correlation was observed between seed yield, and daily yield productivity across the 20 pigeonpea genotypes (r=0.56**, n=60) and across the four soil-moisture environments (r=0.99**, n=12).

The genotypes on Alfisol produced 16.6 per cent more seed yield day$^{-1}$, in the irrigated treatment than in the rainfed treatment, whereas, on Vertisol, the genotypes produced more (28.5%) seed yield day$^{-1}$ in the rainfed treatment. The coefficient of variation for the daily yield

**Table 4.13: Comparision of per cent pod borer damage for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 36 | 25 | 31 | 54 | 54 | 54 |
| ICPL 90004 | 41 | 31 | 36 | 76 | 64 | 70 |
| ICPL 90007 | 39 | 11 | 25 | 63 | 59 | 61 |
| ICPL 90011 | 49 | 28 | 38 | 59 | 53 | 56 |
| ICPL 91002 | 58 | 34 | 46 | 55 | 62 | 59 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 36 | 26 | 31 | 43 | 54 | 48 |
| ICPL 84023 | 16 | 19 | 17 | 44 | 60 | 52 |
| ICPL 85010 | 28 | 38 | 33 | 62 | 50 | 56 |
| ICPL 88032 | 27 | 6 | 17 | 44 | 52 | 48 |
| ICPL 88039 | 30 | 22 | 26 | 58 | 41 | 50 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 28 | 17 | 22 | 63 | 59 | 61 |
| ICPL 89008 | 29 | 29 | 29 | 69 | 56 | 63 |
| ICPL 88009 | 36 | 30 | 33 | 63 | 68 | 65 |
| ICPL 87 | 42 | 34 | 38 | 51 | 59 | 55 |
| ICPL 86012 | 36 | 36 | 36 | 57 | 48 | 52 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 19 | 19 | 19 | 62 | 58 | 60 |
| ICP 7035 | 22 | 22 | 22 | 45 | 28 | 36 |
| ICP 14199 | 16 | 19 | 17 | 49 | 56 | 53 |
| ICPL 227 | 18 | 15 | 17 | 30 | 27 | 29 |
| ICPL 87119 | 20 | 16 | 18 | 44 | 35 | 40 |
| Mean | 31 | 24 | 28 | 55 | 52 | 53 |
| SEm± | | | | | | |
| Soil | | | 1.9 ** | | | |
| Treatment | | | 1.4 * | | | |
| Genotype | | | 3.4 ** | | | |
| Soil x Genotype | | | 5.1 (4.9) * | | | |
| Soil x Treatment | | | 2.4 (1.9) | | | |
| Treatment x Genotype | | | 4.9 (4.9) | | | |
| Soil x Treatment x Genotype | | | 7.1 (7.0) | | | |
| CV % | | | 29.4 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.14: Comparision of daily yield productivity (kg ha$^{-1}$ d$^{-1}$) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 15.4 | 19.2 | 17.3 | 8.1 | 6.2 | 7.1 |
| ICPL 90004 | 18.3 | 21.7 | 20.0 | 5.1 | 3.6 | 4.3 |
| ICPL 90007 | 18.9 | 20.2 | 19.6 | 7.0 | 6.8 | 6.9 |
| ICPL 90011 | 17.5 | 20.9 | 19.2 | 7.2 | 4.4 | 5.8 |
| ICPL 91002 | 14.7 | 20.1 | 17.4 | 6.2 | 2.5 | 4.3 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 17.3 | 19.7 | 18.5 | 9.7 | 4.9 | 7.3 |
| ICPL 84023 | 16.0 | 18.0 | 17.0 | 6.4 | 4.5 | 5.5 |
| ICPL 85010 | 15.7 | 19.4 | 17.5 | 7.0 | 6.2 | 6.6 |
| ICPL 88032 | 15.5 | 18.1 | 16.8 | 7.6 | 6.4 | 7.0 |
| ICPL 88039 | 16.3 | 20.3 | 18.3 | 6.7 | 8.8 | 7.8 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 15.9 | 20.5 | 18.2 | 5.9 | 3.8 | 4.9 |
| ICPL 89008 | 15.0 | 19.6 | 17.3 | 6.5 | 6.8 | 6.6 |
| ICPL 88009 | 17.3 | 19.5 | 18.4 | 6.5 | 5.5 | 6.0 |
| ICPL 87 | 13.8 | 18.9 | 16.4 | 6.5 | 7.2 | 6.8 |
| ICPL 86012 | 14.3 | 17.1 | 15.7 | 5.5 | 2.9 | 4.2 |
| Medidum-duration (MD) | | | | | | |
| ICP 8379 | 13.9 | 11.1 | 12.5 | 8.2 | 0.6 | 4.4 |
| ICP 7035 | 10.6 | 13.0 | 11.8 | 4.4 | 4.5 | 4.5 |
| ICP 14199 | 11.8 | 11.7 | 11.7 | 3.3 | 0.0 | 1.2 |
| ICPL 227 | 15.6 | 18.2 | 16.9 | 11.7 | 12.5 | 12.1 |
| ICPL 87119 | 14.4 | 16.7 | 15.5 | 10.1 | 11.5 | 10.8 |
| Mean | 15.4 | 18.2 | 16.8 | 6.9 | 5.4 | 6.2 |
| SEm± | | | | | | |
| Soil | 0.16 ** | | | | | |
| Treatment | 0.15 * | | | | | |
| Genotype | 0.56 ** | | | | | |
| Soil x Genotype | 0.78 (0.79) ** | | | | | |
| Soil x Treatment | 0.22 (0.21) ** | | | | | |
| Treatment x Genotype | 0.78 (0.79) ** | | | | | |
| Soil x Treatment x Genotype | 1.11 (1.11) | | | | | |
| CV % | 16.8 | | | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

productivity was 16.8 per cent.

### 4.11.2 Total dry matter production day$^{-1}$ (biomass day$^{-1}$)

The differences in total dry matter production day$^{-1}$ due to soils, genotypes, soil x treatment and treatment x genotype interaction were found to be highly significant and significant due to soil x genotypes interaction (Appendix 4.4). No significant difference due to treatment and soil x treatment x genotype interaction was observed. The total biomass produced day$^{-1}$ was up to 55 kg ha$^{-1}$ day$^{-1}$ on Alfisol (about 51% more compared to the genotypes grown on Vertisol) and 27 kg ha$^{-1}$ day$^{-1}$ on Vertisol (Table 4.15). Among all the genotypes, ICPL 87119 (MD) and ICPL 227 (MD) produced highest, about 55 kg ha$^{-1}$ day$^{-1}$ of dry matter while the lowest dry matter day$^{-1}$ was produced by ESD* genotype, ICPL 91002 (31 kg ha$^{-1}$ day$^{-1}$). The MD genotypes had highest day$^{-1}$ dry matter at a level of 46.8 kg ha$^{-1}$ day$^{-1}$ followed by SD genotypes with a dry matter production of 43 kg ha$^{-1}$ day$^{-1}$, ESD* genotypes with a dry matter production of 37.6 kg ha$^{-1}$ day$^{-1}$ and ESD genotypes with 36.6 kg ha$^{-1}$ day$^{-1}$. All genotypes on Alfisol, produced higher biomass day$^{-1}$ (11.9%) in the irrigated treatment than in the rainfed treatment whereas, on Vertisol, the plants produced more total biomass day$^{-1}$ (23%) in the rainfed treatment than in the irrigated treatment. Between the seed yield and total biomass day$^{-1}$, a highly significant positive correlation was observed across the 20 pigeonpea genotypes (r=0.72**, n=60) and across the four soil-moisture environments (r=0.98**, n=12). The coefficient of variation for the total dry matter produced day$^{-1}$ was 8.6 per cent.

### 4.11.3 Seed fill duration

The analysis for seedfill duration revealed that highly significant differences due to genotype, soil, treatment, soil x genotype and soil x treatments interaction (Appendix 4.4). In general, the duration for seedfilling for the genotypes grown on Vertisol was 8 per cent more than the genotypes grown on Alfisol. On Alfisol, the duration for seedfilling in the irrigated treatment was 12.5 per cent more than the genotypes grown in the rainfed treatment (Table 4.16). On Vertisol, the duration for seedfilling was 6 per cent more in the rainfed treatment

**Table 4.15: Comparision of total dry matter produced day$^{-1}$ (kg ha$^{-1}$ d$^{-1}$) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 44.5 | 52.9 | 48.7 | 28.4 | 20.5 | 24.4 |
| ICPL 90004 | 52.5 | 58.6 | 55.6 | 28.5 | 15.3 | 21.9 |
| ICPL 90007 | 55.1 | 58.0 | 56.6 | 25.4 | 29.2 | 27.3 |
| ICPL 90011 | 53.0 | 59.8 | 56.4 | 28.1 | 16.5 | 22.3 |
| ICPL 91002 | 42.1 | 54.0 | 48.0 | 20.2 | 7.9 | 14.0 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 49.9 | 52.5 | 51.2 | 29.1 | 14.8 | 21.9 |
| ICPL 84023 | 46.3 | 53.9 | 50.1 | 21.3 | 19.5 | 20.4 |
| ICPL 85010 | 47.6 | 58.1 | 52.8 | 20.3 | 18.6 | 19.4 |
| ICPL 88032 | 46.6 | 52.1 | 49.3 | 24.3 | 23.3 | 23.8 |
| ICPL 88039 | 44.3 | 62.7 | 53.5 | 23.0 | 23.9 | 23.5 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 54.6 | 70.8 | 62.7 | 27.2 | 16.7 | 22.0 |
| ICPL 89008 | 40.5 | 59.3 | 49.9 | 21.4 | 18.2 | 19.8 |
| ICPL 88009 | 46.8 | 54.9 | 50.8 | 26.9 | 23.5 | 25.2 |
| ICPL 87 | 64.5 | 76.2 | 70.4 | 37.3 | 31.7 | 34.5 |
| ICPL 86012 | 59.1 | 59.6 | 59.3 | 48.0 | 27.1 | 37.5 |
| Medium-duration (MD)60.3 | | | | | | |
| ICP 8379 | 68.7 | 52.0 | 60.3 | 50.2 | 18.2 | 34.2 |
| ICP 7035 | 49.1 | 53.1 | 51.1 | 23.7 | 23.2 | 23.5 |
| ICP 14199 | 50.1 | 57.3 | 53.7 | 28.4 | 21.4 | 24.9 |
| ICPL 227 | 59.5 | 65.9 | 62.7 | 48.8 | 47.1 | 48.0 |
| ICPL 87119 | 66.3 | 66.2 | 66.3 | 46.9 | 44.1 | 45.5 |
| Mean | 52.1 | 58.9 | 55.5 | 30.4 | 23.0 | 26.7 |
| SEm± | | | | | | |
| Soil | 0.68 ** | | | | | |
| Treatment | 1.28 | | | | | |
| Genotype | 2.33 ** | | | | | |
| Soil x Genotype | 3.28 (3.29) * | | | | | |
| Soil x Treatment | 1.45 (1.80) ** | | | | | |
| Treatment x Genotype | 3.45 (3.29) ** | | | | | |
| Soil x Treatment x Genotype | 4.76 (4.88) | | | | | |
| CV % | 19.6 | | | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.16: Comparision of seedfilled duration (days) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994,ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 39 | 45 | 42 | 42 | 41 | 42 |
| ICPL 90004 | 39 | 46 | 42 | 47 | 45 | 46 |
| ICPL 90007 | 39 | 44 | 42 | 46 | 44 | 45 |
| ICPL 90011 | 37 | 41 | 39 | 45 | 41 | 43 |
| ICPL 91002 | 38 | 46 | 42 | 50 | 41 | 46 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 37 | 42 | 39 | 41 | 39 | 40 |
| ICPL 84023 | 40 | 48 | 44 | 47 | 43 | 45 |
| ICPL 85010 | 39 | 42 | 40 | 42 | 37 | 40 |
| ICPL 88032 | 38 | 43 | 40 | 37 | 42 | 40 |
| ICPL 88039 | 40 | 40 | 40 | 37 | 38 | 38 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 40 | 44 | 42 | 44 | 39 | 41 |
| ICPL 89008 | 38 | 46 | 42 | 44 | 44 | 44 |
| ICPL 88009 | 35 | 46 | 41 | 47 | 44 | 45 |
| ICPL 87 | 40 | 45 | 43 | 70 | 70 | 70 |
| ICPL 86012 | 39 | 53 | 46 | 64 | 70 | 67 |
| Medidum-duration (MD) | | | | | | |
| ICP 8379 | 52 | 57 | 54 | 55 | 55 | 55 |
| ICP 7035 | 52 | 56 | 54 | 57 | 56 | 57 |
| ICP 14199 | 53 | 56 | 55 | 61 | 57 | 59 |
| ICPL 227 | 56 | 56 | 56 | 62 | 61 | 62 |
| ICPL 87119 | 55 | 56 | 56 | 63 | 63 | 63 |
| Mean | 42 | 48 | 45 | 50 | 49 | 49 |
| SEm± | | | | | | |
| Soil | | | 0.6 ** | | | |
| Treatment | | | 0.7 * | | | |
| Genotype | | | 1.2 ** | | | |
| Soil x Genotype | | | 1.7 (1.7) ** | | | |
| Sol x Treatment | | | 0.9 (1.0) ** | | | |
| Treatment x Genotype | | | 1.8 (1.7) | | | |
| Soil x Treatment x Genotype | | | 2.5 (2.5) | | | |
| CV % | | | 8.6 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

than in the irrigated treatment. Between the two treatments, the genotypes in the irrigated treatment took less time (4%) than the genotypes grown in the rainfed treatment. Among the four pigeonpea groups, MD genotypes took 57 days for partitioning the photosynthates to the sink followed by SD genotypes in 48 days, ESD in 41 days and ESD* genotypes in 34 days. The SD genotypes, ICPL 87 and 86012 had similar duration to that of wilt susceptible MD genotypes (ICP 8379, ICP 7035 and ICP 14199). A significant positive correlation was observed for the days to seed filling and yield across the 20 pigeonpea genotypes ($r=0.46^{**}$, n=60) only. The coefficient of variation for seedfill duration was 8.6 per cent.

**4.11.4 Yield accumulation per day of seedfill duration**

The analysis revealed that there were highly significant differences due to soils, genotypes, soils x genotypes and treatment x genotype interaction and also for soil x treatment interaction (Appendix 4.4). In general, the genotypes grown on Alfisol had 60 per cent more yield accumulation $day^{-1}$ of seedfill duration than the genotypes grown on Vertisol (Table 4.17). The irrigated treatment had 3 per cent more yield accumulation $day^{-1}$ of seedfill duration than the rainfed treatment. The genotypes on Alfisol had faster rate of yield accumulation $day^{-1}$ of seedfill duration in the irrigated treatment than in the rainfed treatment. In contrast on Vertisol, genotypes showed faster rate of yield accumulation $day^{-1}$ of seedfill duration in the rainfed treatment than irrigated treatment. The rate of yield accumulation $day^{-1}$ of seedfill duration was very slow in wilt susceptible MD genotypes viz. ICP 8379, ICP 7035 and ICP 14199 along with SD genotypes, ICPL 87 and ICPL 86012, while, wilt resistant MD genotypes, ICPL 227 and ICPL 87119 had the fastest rate of yield accumulation $day^{-1}$ of seedfill duration. Across the 20 pigeonpea genotypes ($r=0.86^{**}$, n=60) and across the four soil-moisture environments ($r=0.99^{**}$ n=12) a significant positive correlation was observed between the yield accumulated $day^{-1}$ of seedfill duration and seed yield. The coefficient of variation for yield accumulated $day^{-1}$ of seedfill duration was 18.4 per cent. The mean yield accumulation $day^{-1}$ of seedfill duration for the four pigeonpea groups were in the rank order of MD (33.2 kg $ha^{-1}$ $d^{-1}$) > ESD (31.6 kg $ha^{-1}$) > ESD* (31.4 kg $ha^{-1}$ $d^{-1}$) > SD (29.6 kg $ha^{-1}$ $d^{-1}$).

**Table 4.17: Comparision of accumulation of yield day$^{-1}$ of seedfilled duration (kg$^{-1}$ ha$^{-1}$ d$^{-1}$) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 40.5 | 46.5 | 43.5 | 22.4 | 17.4 | 19.9 |
| ICPL 90004 | 47.9 | 51.4 | 49.6 | 12.8 | 9.2 | 11.0 |
| ICPL 90007 | 49.4 | 48.9 | 49.2 | 17.7 | 18.2 | 18.0 |
| ICPL 90011 | 48.1 | 54.6 | 51.4 | 18.8 | 12.5 | 15.7 |
| ICPL 91002 | 39.0 | 46.6 | 42.8 | 14.6 | 7.2 | 10.9 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 45.6 | 48.9 | 47.2 | 25.4 | 14.1 | 19.8 |
| ICPL 84023 | 38.4 | 39.6 | 39.0 | 16.7 | 11.9 | 14.3 |
| ICPL 85010 | 40.0 | 47.7 | 43.9 | 18.4 | 17.6 | 18.0 |
| ICPL 88032 | 41.4 | 44.9 | 43.2 | 23.1 | 17.7 | 20.4 |
| ICPL 88039 | 41.8 | 51.9 | 46.8 | 19.6 | 25.6 | 22.6 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 44.7 | 53.2 | 49.0 | 16.3 | 11.4 | 13.9 |
| ICPL 89008 | 40.2 | 47.3 | 43.8 | 17.9 | 18.7 | 18.3 |
| ICPL 88009 | 48.6 | 46.5 | 47.5 | 17.1 | 15.1 | 16.1 |
| ICPL 87 | 38.2 | 49.6 | 43.9 | 14.1 | 15.5 | 14.8 |
| ICPL 86012 | 41.0 | 38.4 | 39.7 | 12.7 | 6.2 | 9.5 |
| Medidum-duration (MD) | | | | | | |
| ICP 8379 | 47.8 | 35.6 | 41.7 | 23.7 | 2.0 | 12.8 |
| ICP 7035 | 37.4 | 41.8 | 39.6 | 14.8 | 15.4 | 15.1 |
| ICP 14199 | 39.4 | 38.2 | 38.8 | 15.5 | 6.9 | 11.2 |
| ICPL 227 | 50.4 | 58.8 | 54.6 | 36.1 | 39.2 | 37.6 |
| ICPL 87119 | 47.0 | 53.2 | 50.1 | 30.5 | 34.7 | 32.6 |
| Mean | 43.3 | 47.2 | 45.3 | 19.4 | 15.8 | 17.6 |
| SEm± | | | | | | |
| Soil | | | 0.36 ** | | | |
| Treatment | | | 0.73 | | | |
| Genotype | | | 1.67 ** | | | |
| Soil x Genotype | | | 2.33 (2.36) ** | | | |
| Soil x Treatment | | | 0.81 (1.03) ** | | | |
| Treatment x Genotype | | | 2.41 (2.36) ** | | | |
| Soil x Treatment x Genotype | | | 3.35 (3.41) | | | |
| CV % | | | 18.4 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

### 4.12 Chlorophyll analysis

#### 4.12.1 Chlorophyll A

The analysis for total chlorophyll A content in the plant leaf tissue revealed that the differences due to genotypes, soils were all highly significant whereas, the difference due to the treatment, soil x treatment, soil x genotype and soil x treatment x genotype interactions were nonsignificant (Appendix 4.5). On Alfisol all pigeonpea genotypes had significantly higher chlorophyll A content (up to 14%) than as on Vertisol (Table 4.18). In general, the mean chlorophyll A content in the plant leaf tissues of all pigeonpea genotypes was in the range of 0.32 to 0.62 mg $g^{-1}$ on fresh weight basis. Between the two treatments, the crop in the irrigated treatment contained higher (5%) amount of chlorophyll A in the leaf tissues compared to that in the rainfed treatment. ESD genotype, ICPL 83015 had the lowest chlorophyll A content in leaf tissue while SD genotype, ICPL 87 had the highest. Among the four pigeonpea groups MD genotypes had significantly higher chlorophyll A content (0.49-0.51) followed by SD (0.45-0.61), ESD* (0.39-0.48) and ESD (0.32-0.42) mg $g^{-1}$ on fresh weight basis genotypes. A significant positive correlation was observed between seed yield and chlorophyll A content across the 20 pigeonpea genotypes (r=0.31**, n=60) and across the four soil-moisture environments (r=0.69**, n=12). The coefficient of variation was 18.3 per cent.

#### 4.12.2 Chlorophyll B

The analysis for chlorophyll B content in the plant leaf tissue shows that there were significant differences due to genotypes, treatments and soils. Whereas the differences due to their interactions were not significant (Appendix 4.5). In general, the chlorophyll B content in the plant tissue of all pigeonpea genotypes was in the range of 0.09 to 0.17 mg $g^{-1}$ (fresh weight basis). Among the pigeonpea genotypes, ICPL 87 (SD) had highest chlorophyll B content while ICPL 83015 (ESD) had the lowest. On analysis of the leaf tissue, the results showed that all the pigeonpea genotypes grown on Alfisol, contained 13 per cent more chlorophyll B content than the genotypes grown on Vertisol (Table 4.19). Crop in the irrigated treatment contained higher chlorophyll B in leaf tissue (5.8%) than the genotypes grown in the

**Table 4.18: Comparision of chlorophyll A content (mg $g^{-1}$) fresh weight for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 0.53 | 0.50 | 0.51 | 0.27 | 0.41 | 0.34 |
| ICPL 90004 | 0.53 | 0.52 | 0.53 | 0.46 | 0.40 | 0.43 |
| ICPL 90007 | 0.50 | 0.46 | 0.48 | 0.28 | 0.49 | 0.39 |
| ICPL 90011 | 0.45 | 0.39 | 0.42 | 0.35 | 0.38 | 0.36 |
| ICPL 91002 | 0.51 | 0.51 | 0.51 | 0.33 | 0.32 | 0.33 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 0.35 | 0.42 | 0.38 | 0.23 | 0.30 | 0.27 |
| ICPL 84023 | 0.47 | 0.41 | 0.44 | 0.37 | 0.40 | 0.39 |
| ICPL 85010 | 0.42 | 0.43 | 0.42 | 0.32 | 0.35 | 0.34 |
| ICPL 88032 | 0.38 | 0.49 | 0.44 | 0.34 | 0.38 | 0.36 |
| ICPL 88039 | 0.49 | 0.43 | 0.46 | 0.36 | 0.41 | 0.38 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 0.48 | 0.42 | 0.45 | 0.46 | 0.40 | 0.43 |
| ICPL 89008 | 0.40 | 0.48 | 0.44 | 0.40 | 0.50 | 0.45 |
| ICPL 88009 | 0.38 | 0.52 | 0.45 | 0.41 | 0.49 | 0.45 |
| ICPL 87 | 0.64 | 0.59 | 0.62 | 0.59 | 0.65 | 0.62 |
| ICPL 86012 | 0.49 | 0.49 | 0.49 | 0.54 | 0.45 | 0.50 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 0.51 | 0.53 | 0.52 | 0.42 | 0.51 | 0.47 |
| ICP 7035 | 0.53 | 0.55 | 0.54 | 0.45 | 0.54 | 0.49 |
| ICP 14199 | 0.50 | 0.58 | 0.54 | 0.45 | 0.46 | 0.45 |
| ICPL 227 | 0.52 | 0.59 | 0.56 | 0.45 | 0.48 | 0.46 |
| ICPL 87119 | 0.48 | 0.49 | 0.49 | 0.46 | 0.47 | 0.46 |
| Mean | 0.48 | 0.49 | 0.49 | 0.40 | 0.44 | 0.42 |
| SE± | | | | | | |
| Soil | | | 0.012** | | | |
| Treatment | | | 0.009 | | | |
| Genotype | | | 0.024 ** | | | |
| Soil x genotype | | | 0.035 (0.034) | | | |
| Soil x Treatment | | | 0.015 (0.013) | | | |
| Treatment x Genotype | | | 0.034 (0.034) | | | |
| Soil x Treatment x Genotype | | | 0.049 (0.048) | | | |
| CV % | | | 2.3 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.19: Comparision of chlorophyll B content (mg $g^{-1}$) fresh weight for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 0.15 | 0.15 | 0.15 | 0.08 | 0.11 | 0.10 |
| ICPL 90004 | 0.15 | 0.15 | 0.15 | 0.13 | 0.11 | 0.12 |
| ICPL 90007 | 0.15 | 0.13 | 0.14 | 0.08 | 0.14 | 0.11 |
| ICPL 90011 | 0.13 | 0.12 | 0.12 | 0.08 | 0.11 | 0.09 |
| ICPL 91002 | 0.14 | 0.15 | 0.15 | 0.09 | 0.09 | 0.09 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 0.10 | 0.12 | 0.11 | 0.07 | 0.09 | 0.08 |
| ICPL 84023 | 0.13 | 0.12 | 0.13 | 0.11 | 0.12 | 0.12 |
| ICPL 85010 | 0.12 | 0.12 | 0.12 | 0.09 | 0.10 | 0.10 |
| ICPL 88032 | 0.11 | 0.14 | 0.13 | 0.10 | 0.11 | 0.11 |
| ICPL 88039 | 0.15 | 0.13 | 0.14 | 0.12 | 0.12 | 0.12 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 0.13 | 0.13 | 0.13 | 0.14 | 0.12 | 0.13 |
| ICPL 89008 | 0.12 | 0.14 | 0.13 | 0.13 | 0.14 | 0.13 |
| ICPL 88009 | 0.11 | 0.15 | 0.13 | 0.13 | 0.14 | 0.14 |
| ICPL 87 | 0.18 | 0.17 | 0.17 | 0.17 | 0.18 | 0.18 |
| ICPL 86012 | 0.15 | 0.15 | 0.15 | 0.16 | 0.13 | 0.15 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 0.13 | 0.14 | 0.13 | 0.12 | 0.14 | 0.13 |
| ICP 7035 | 0.14 | 0.15 | 0.14 | 0.12 | 0.15 | 0.13 |
| ICP 14199 | 0.12 | 0.15 | 0.14 | 0.12 | 0.12 | 0.12 |
| ICPL 227 | 0.17 | 0.14 | 0.16 | 0.12 | 0.13 | 0.13 |
| ICPL 87119 | 0.14 | 0.15 | 0.15 | 0.12 | 0.13 | 0.13 |
| Mean | 0.14 | 0.14 | 0.14 | 0.12 | 0.13 | 0.12 |
| SEm± | | | | | | |
| Soil | | | 0.003 ** | | | |
| Treatment | | | 0.001 ** | | | |
| Genotype | | | 0.007 ** | | | |
| Soil x Genotype | | | 0.010 (0.009) | | | |
| Soil x Treatment | | | 0.004 (0.002) | | | |
| Treatment x Genotype | | | 0.010 (0.009) | | | |
| Soil x Treatment x Genotype | | | 0.014 | | | |
| CV % | | | 2.37 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

rainfed treatment. Among the four pigeonpea groups, SD genotypes were significantly superior (0.13-0.17 mg $g^{-1}$) followed by MD (0.13-0.14 mg $g^{-1}$), ESD (0.09-0.12 mg $g^{-1}$) and ESD* (0.11-0.13 mg $g^{-1}$) genotypes. A significant positive correlation was observed across the 20 pigeonpea genotypes (r=0.27**, n=60) and across the four soil-moisture environments (r=0.73**, n=12) for chlorophyll B content and seed yield. The coefficient of variation for chlorophyll B was 18.6 per cent.

### 4.12.3 Total Chlorophyll content

The chlorophyll analysis revealed that there were highly significant differences due to genotypes, soils and also treatments. There were no significant differences observed due to soil x treatment, soil x genotype, treatment x genotype and soil x treatment x genotype interactions (Appendix 4.5). In general, on Alfisol the mean total chlorophyll content was 14 per cent higher than on Vertisol (Table 4.20). On both soils, the mean total chlorophyll content was higher in irrigated treatment (5%) compared to rainfed treatment. In general, the total chlorophyll content of all pigeonpea genotypes ranged 0.37 to 0.70 mg $g^{-1}$ (fresh weight). The lower amount of total chlorophyll content in the leaf tissue was observed in ESD genotype ICPL 83015 while the higher amount of total chlorophyll content was observed in SD genotype, ICPL 87. Among the four pigeonpea groups, the MD genotypes had higher total chlorophyll content (0.51-0.70 mg $g^{-1}$) in the leaf tissue followed by SD (0.55-0.57 mg $g^{-1}$), ESD* (0.45-0.55 mg $g^{-1}$) and ESD (0.37-0.47 mg $g^{-1}$) on fresh weight basis. A significant positive correlation was observed between seed yield and total chlorophyll content across the 20 pigeonpea genotypes (r=0.30**, n=60) and across the four soil-moisture environments (r=0.71**, n=12).

### 4.13 Leaf area index

The leaf area index (LAI) analysis for the four pigeonpea groups, viz., ESD*, SD, ESD and MD revealed highly significant differences in LAI due to soils at 45, 66, 93 and 105 days after sowing (DAS), due to treatment at 45, 55 and 105 DAS and due to genotypes throughout the crop growth (Appendices 4.6 and 4.7). A significant difference in LAI was also

**Table 4.20: Comparision of total chlorophyll content (mg $g^{-1}$) fresh weight for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 0.60 | 0.57 | 0.58 | 0.31 | 0.46 | 0.39 |
| ICPL 90004 | 0.61 | 0.60 | 0.60 | 0.52 | 0.44 | 0.49 |
| ICPL 90007 | 0.58 | 0.52 | 0.55 | 0.33 | 0.55 | 0.44 |
| ICPL 90011 | 0.51 | 0.44 | 0.48 | 0.38 | 0.43 | 0.41 |
| ICPL 91002 | 0.58 | 0.58 | 0.58 | 0.37 | 0.37 | 0.37 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 0.39 | 0.46 | 0.43 | 0.26 | 0.35 | 0.30 |
| ICPL 84023 | 0.54 | 0.47 | 0.50 | 0.42 | 0.46 | 0.44 |
| ICPL 85010 | 0.47 | 0.49 | 0.48 | 0.36 | 0.40 | 0.38 |
| ICPL 88032 | 0.43 | 0.56 | 0.50 | 0.39 | 0.44 | 0.42 |
| ICPL 88039 | 0.57 | 0.50 | 0.53 | 0.42 | 0.47 | 0.45 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 0.54 | 0.49 | 0.52 | 0.53 | 0.46 | 0.49 |
| ICPL 89008 | 0.46 | 0.55 | 0.50 | 0.47 | 0.56 | 0.51 |
| ICPL 88009 | 0.43 | 0.59 | 0.51 | 0.48 | 0.56 | 0.52 |
| ICPL 87 | 0.72 | 0.67 | 0.70 | 0.67 | 0.74 | 0.70 |
| ICPL 86012 | 0.57 | 0.56 | 0.56 | 0.62 | 0.52 | 0.57 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 0.56 | 0.59 | 0.58 | 0.48 | 0.57 | 0.53 |
| ICP 7035 | 0.60 | 0.61 | 0.61 | 0.50 | 0.61 | 0.55 |
| ICP 14199 | 0.55 | 0.65 | 0.60 | 0.51 | 0.51 | 0.51 |
| ICPL 227 | 0.68 | 0.59 | 0.63 | 0.50 | 0.54 | 0.52 |
| ICPL 87119 | 0.61 | 0.61 | 0.61 | 0.51 | 0.54 | 0.52 |
| Mean | 0.55 | 0.55 | 0.55 | 0.45 | 0.50 | 0.48 |
| SEm± | | | | | | |
| Soil | | | 0.014 ** | | | |
| Genotype | | | 0.027 ** | | | |
| Treatment | | | 0.009 * | | | |
| Soil x Genotype | | | 0.039 (0.038) | | | |
| Soil x Treatment | | | 0.016 (0.012) | | | |
| Treatment x Genotype | | | 0.038 | | | |
| Soil x Treatment x Genotype | | | 0.055 (0.054) | | | |
| CV % | | | 2.3 | | | |

Note: *, ** indicates significance at 5 and 1 % level respectively.
SE values in parentheses are used to compare at same levels of first factor.

observed due to soil x genotype interaction at 66 and 105 DAS, due to soil x treatment interaction at 45, 55, 93 and 105 DAS and due to soil x treatment x genotype interaction only at 66 DAS. In general on both soils LAI was low up to 55 DAS and then showed a sharp increase between 55 and 66 DAS. Maximum LAI was observed at 66 DAS for both ESD* and ESD, at 94 DAS for SD and at 135 DAS for MD genotypes.

As the most sensitive period for pigeonpea to excess soil moisture is during the pre-flowering stage, the leaf area development for all the four pigeonpea groups only between 45 and 55 DAS are presented in Tables 4.21 and 4.22 and Fig. 4.5 to 4.6 From the Tables 4.21 and 4.22 it is evident that in general, after 45 DAS mean LAI on Alfisol was 42 per cent higher than on Vertisol. After 55 DAS Alfisol recorded 11 per cent higher mean LAI than the Vertisol. At the end of the 45 DAS, difference between the two treatments were significant. On Alfisol, the rainfed treatment had 30 per cent more LAI while on Vertisol the irrigated treatment recorded 24 per cent more LAI. After 55 DAS, there was 25 per cent higher LAI in the rainfed treatment of Alfisol and 30 per cent higher LAI in the irrigated treatment of Vertisol. The increase in LAI from 45 to 55 DAS was 30 per cent in the rainfed treatment of Alfisol and 56 per cent in the irrigated treatment of Vertisol. Between the two soils the percentage increase in LAI from 45 to 55 DAS was 31 per cent on Alfisol and 55 per cent on Vertisol. For the five ESD* genotypes the increase in LAI between 45 DAS and 55 DAS ranged between 26 and 50 per cent on Alfisol and 36 to 58 per cent on Vertisol. Among the five ESD* genotypes, ICPL 90011 and ICPL 91002 had less than 50 per cent increase in LAI on Vertisol. The five SD genotypes had only 4 to 50 per cent increase in LAI on Alfisol while, the increase on Vertisol was about 51 to 60 per cent. All the SD genotypes had slow LA development on Vertisol (> 50 %) while the genotypes could regain higher LAI on Alfisol. The increase in LAI for the five ESD genotypes was between 12 and 38 per cent on Alfisol and 34 to 60 per cent on vertisol.

Among the five MD genotypes, the waterlogging susceptible MD genotype, ICP 7035 showed a decrease (7%) in LAI from 45 to 55 DAS on Alfisol, indicating that it was the most

**Table 4.21: Comparision of leaf area index (LAI) at 45 days after sowing (DAS) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parents, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in rainfed and irrigated teratments during Kharif 1994. ICRISAT Asia center.**

| Genotype | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD)* | | | | | | |
| ICPL 90002 | 0.64 | 0.45 | 0.55 | 0.35 | 0.39 | 0.37 |
| ICPL 90004 | 0.65 | 0.58 | 0.62 | 0.32 | 0.57 | 0.45 |
| ICPL 90007 | 0.89 | 0.42 | 0.66 | 0.46 | 0.61 | 0.54 |
| ICPL 90011 | 0.91 | 0.70 | 0.81 | 0.45 | 0.69 | 0.57 |
| ICPL 91002 | 0.80 | 0.52 | 0.66 | 0.26 | 0.43 | 0.35 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 0.99 | 0.67 | 0.83 | 0.58 | 0.58 | 0.58 |
| ICPL 84023 | 1.05 | 0.76 | 0.90 | 0.46 | 0.73 | 0.59 |
| ICPL 85010 | 1.02 | 0.77 | 0.89 | 0.39 | 0.45 | 0.42 |
| ICPL 88032 | 1.24 | 0.74 | 0.99 | 0.51 | 0.57 | 0.54 |
| ICPL 88039 | 1.19 | 0.93 | 1.06 | 0.43 | 0.78 | 0.61 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 1.01 | 0.74 | 0.88 | 0.47 | 0.47 | 0.47 |
| ICPL 89008 | 0.94 | 0.55 | 0.75 | 0.18 | 0.65 | 0.41 |
| ICPL 88009 | 0.66 | 0.66 | 0.66 | 0.37 | 0.38 | 0.38 |
| ICPL 87 | 0.86 | 0.77 | 0.82 | 0.49 | 0.69 | 0.59 |
| ICPL 86012 | 0.82 | 0.78 | 0.80 | 0.57 | 0.43 | 0.50 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 0.46 | 0.18 | 0.32 | 0.12 | 0.14 | 0.13 |
| ICP 7035 | 0.55 | 0.27 | 0.41 | 0.13 | 0.14 | 0.14 |
| ICP 14199 | 0.39 | 0.23 | 0.31 | 0.08 | 0.09 | 0.08 |
| ICPL 227 | 0.72 | 0.35 | 0.54 | 0.21 | 0.17 | 0.19 |
| ICPL 87119 | 0.46 | 0.38 | 0.42 | 0.18 | 0.21 | 0.20 |
| Mean | 0.81 | 0.57 | 0.69 | 0.35 | 0.46 | 0.40 |
| SEm± | | | | | | |
| Soil | 0.044 ** | | | | | |
| Treatment | 0.020 * | | | | | |
| Genotype | 0.048 ** | | | | | |
| Soil x Genotype | 0.080 (0.068) | | | | | |
| Soil x Treatment | 0.048 (0.028) ** | | | | | |
| Treatment x genotype | 0.069 (0.068) | | | | | |
| Soil x Treatment x genotype | 0.105 (0.098) | | | | | |
| CV% | 30.5 | | | | | |

Note : * , ** indicates significance at 1% and 5% level respectively.
SE values in parentheses are used to compare at the same levels of first factor.

**Table 4.22: Comparision of leaf area index (LAI) at 55 days after sowing (DAS) for five extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parents, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in rainfed and irrigated teratments during Kharif 1994. ICRISAT Asia center.**

| Genotype | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD)* | | | | | | |
| ICPL 90002 | 0.77 | 0.93 | 0.85 | 0.63 | 0.94 | 0.79 |
| ICPL 90004 | 1.11 | 1.07 | 1.09 | 0.69 | 1.2 | 0.94 |
| ICPL 90007 | 1.60 | 1.01 | 1.31 | 1.05 | 1.54 | 1.30 |
| ICPL 90011 | 1.12 | 1.05 | 1.09 | 0.93 | 1.29 | 1.11 |
| ICPL 91002 | 1.27 | 0.82 | 1.05 | 0.36 | 0.74 | 0.55 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 1.56 | 0.98 | 1.27 | 0.91 | 1.22 | 1.06 |
| ICPL 84023 | 1.37 | 1.02 | 1.20 | 0.78 | 1.01 | 0.89 |
| ICPL 85010 | 1.44 | 1.41 | 1.43 | 0.84 | 1.24 | 1.04 |
| ICPL 88032 | 1.41 | 0.85 | 1.13 | 0.92 | 1.39 | 1.15 |
| ICPL 88039 | 1.56 | 1.11 | 1.33 | 1.02 | 1.75 | 1.39 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 1.13 | 0.70 | 0.92 | 0.92 | 1.21 | 1.06 |
| ICPL 89008 | 1.31 | 0.80 | 1.06 | 0.50 | 1.24 | 0.87 |
| ICPL 88009 | 1.37 | 1.24 | 1.31 | 0.67 | 1.24 | 0.96 |
| ICPL 87 | 1.03 | 1.10 | 1.07 | 1.09 | 1.31 | 1.20 |
| ICPL 86012 | 1.34 | 0.73 | 1.03 | 1.21 | 1.20 | 1.20 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 0.41 | 0.45 | 0.43 | 0.42 | 0.13 | 0.27 |
| ICP 7035 | 0.34 | 0.42 | 0.38 | 0.35 | 0.63 | 0.49 |
| ICP 14199 | 0.82 | 0.38 | 0.60 | 0.21 | 0.26 | 0.23 |
| ICPL 227 | 1.01 | 0.69 | 0.85 | 0.62 | 0.75 | 0.68 |
| ICPL 87119 | 0.79 | 0.46 | 0.62 | 0.54 | 0.80 | 0.67 |
| Mean | 1.14 | 0.86 | 1.00 | 0.73 | 1.05 | 0.89 |
| SEm± | | | | | | |
| Soil | | | 0.067 | | | |
| Treatment | | | 0.057 | | | |
| Genotype | | | 0.085 ** | | | |
| Soil x Genotype | | | 0.135 (0.120) | | | |
| Soil x Treatment | | | 0.089 (0.081) ** | | | |
| Treatment x genotype | | | 0.130 (0.120) | | | |
| Soil x Treatment x genotype | | | 0.187 (0.184) | | | |
| CV% | | | 30.9 | | | |

Note : * , ** indicates significance at 1% and 5% level respectively.
SE values in parentheses are used to compare at the same levels of first factor.

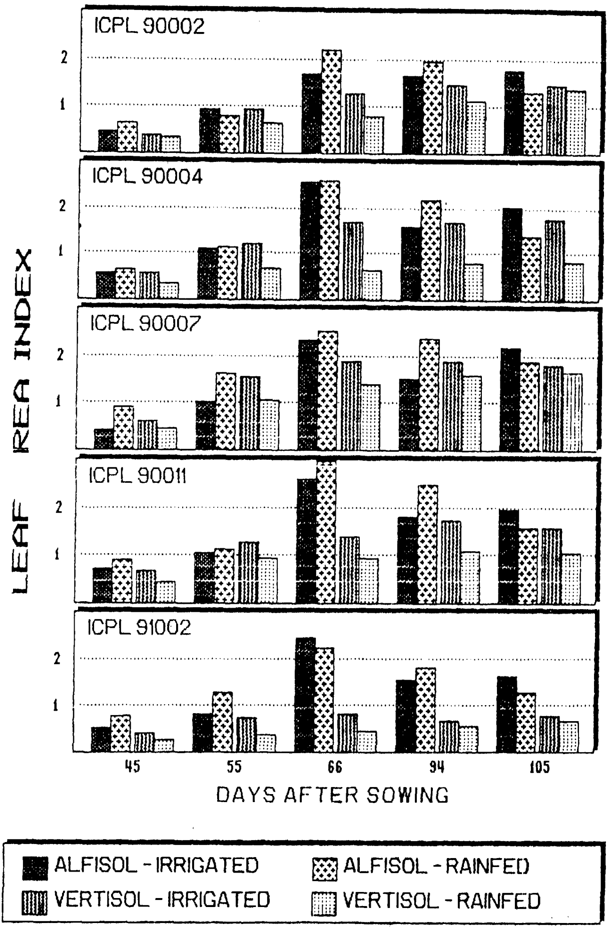



Fig 4.5: Leaf area index for the five extra-short-duration (ESD*) genotypes with ICP 7035 as on of the parents grown in Alfisol-rainfed, Alfisol-irrigated, Vertisol-rainfed and Vertisol-irrigated environments during Kharif 1994 growing season at IAC.

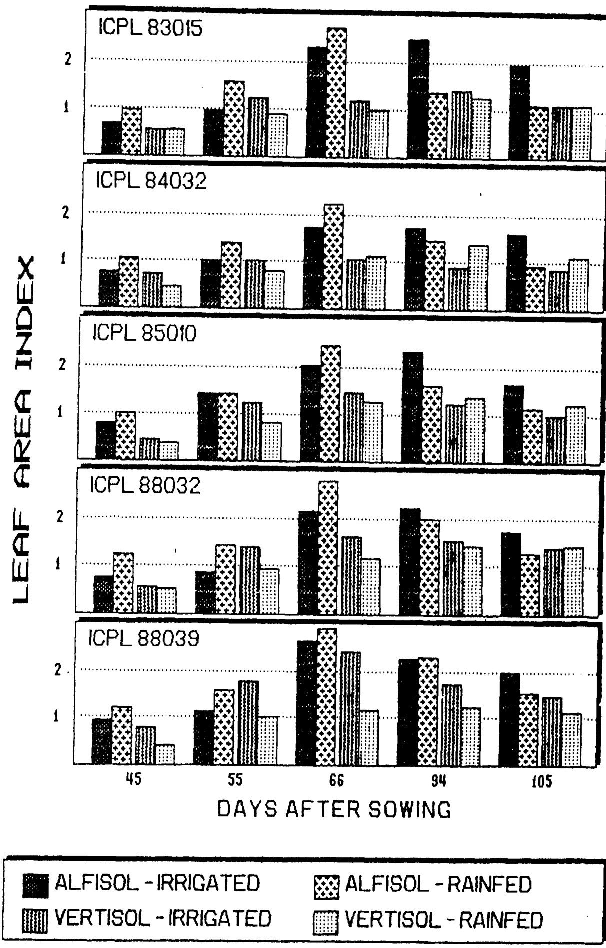



Fig 4.6: Leaf area index for the five extra-short-duration (ESD) genotypes grown in Alfisol-rainfed, Alfisol-irrigated, Vertisol-rainfed and Vertisol-irrigated environments during Kharif 1994 growing season at IAC.

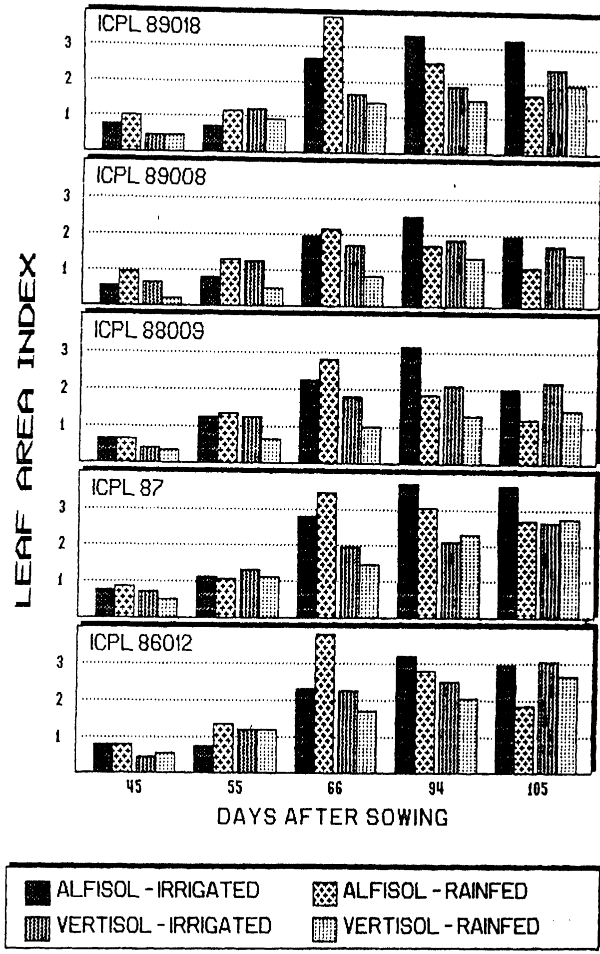



Fig 4.7: Leaf area index for the five short-duration (SD) genotypes grown in Alfisol-rainfed, Alfisol-irrigated, Vertisol-rainfed and Vertisol-irrigated environments during Kharif 1994 growing season at IAC.

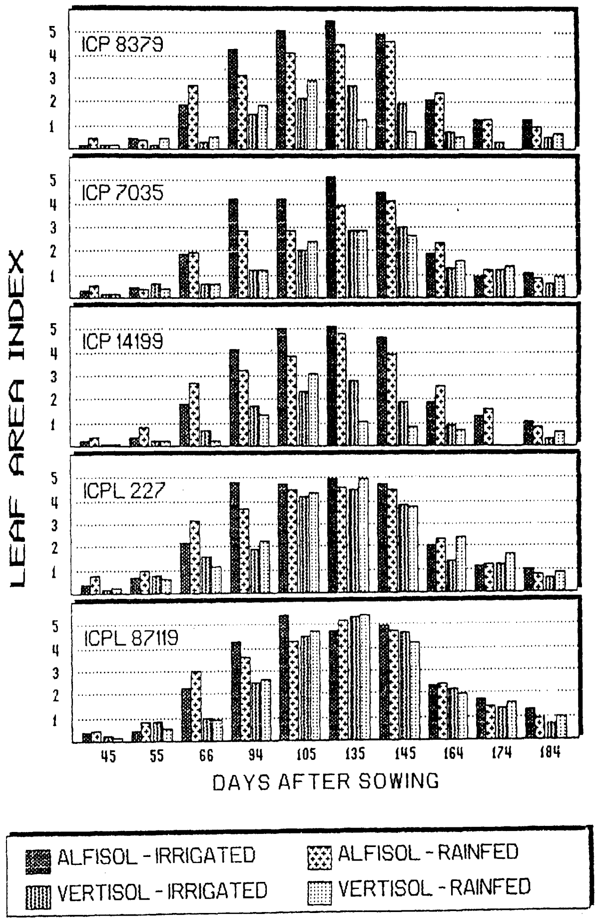



Fig 4.8: Leaf area index for the five medium-duration (MD) genotypes grown in Alfisol-rainfed, Alfisol-irrigated, Vertisol-rainfed, Vertisol-irrigated environments during Kharif 1994 growing season at IAC.

severely affected genotype among the 20 pigeonpea genotypes. On Vertisol, all the five MD genotypes showed more than 50 per cent increase in LAI between 45 and 55 DAS.

### 4.14 Dry matter abscision

Abscision of TDM was highly variable depending on the waterlogging stress and different genotypes (Appendix 4.8). A highly significant difference due to soils, genotypes and soil x genotype interaction was observed for abscised reproductive parts, abscised vegetative parts and for total abscised dry matter.

In general, the total dry matter abscised by plants on Alfisol was higher (45%) than the genotypes grown on Vertisol. While between the treatments, abscision rate was higher in the rainfed treatment (11.4%) than in the irrigated treatment (Tables 23 to 25). On Alfisol, the total dry matter (TDM) abscised under waterlogging stress had accounted 18-20 per cent of TDM for ESD*, 10-20 per cent of TDM for SD, 18-20 per cent of TDM for ESD and 31-43 per cent of TDM for MD genotypes (Fig. 4.9). Whereas on Vertisol, about 23-32 per cent of TDM was abscised for ESD*, 13-18 per cent of TDM for SD, 18-30 per cent of TDM for ESD and 24-26 per cent of TDM for MD genotypes. During the vegetative stage, the percentage contribution of abscised vegetative plant parts by the plants to the total abscised dry matter on Alfisol was 43-48 per cent for ESD*, 19-33 per cent for SD, 54-56 per cent for ESD and 15-19 per cent for MD genotypes. Similarly, the percentage contribution of abscised reproductive plant parts between flowering and maturity by the plants to the total abscised dry matter on Alfisol was 52-57 per cent for ESD*, 47-81 per cent for SD, 44-47 per cent for ESD and 81-85 per cent for MD genotypes. The per cent contribution of abscised vegetative plant parts to the total abscised dry matter on Vertisol was 27-32 per cent for ESD*, 31-36 per cent for SD, 32-35 per cent for ESD and 6.8-23 per cent for MD genotypes. While on Vertisol, about 68-73 per cent of total abscised dry matter was accounted for abscised reproductive parts for ESD*, 64-70 per cent for SD, 65-68 per cent for ESD and 77-93 per cent for MD genotypes. The variation in the total abscised dry matter among the four pigeonpea groups were in the ranking order of SD < ESD < ESD* < MD on Alfisol and SD < MD < ESD < ESD*

**Table 4.23: Comparision of abscised vegetative plant parts (g m$^{-2}$) during the crop growth for two extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, two extra-short-duration (ESD), two short-duration (SD) and two medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 46.4 | 59.7 | 53.1 | 50.7 | 43.7 | 47.2 |
| ICPL 91002 | 56.0 | 64.8 | 60.4 | 72.0 | 38.1 | 55.0 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 47.5 | 47.1 | 47.3 | 55.4 | 41.3 | 48.4 |
| ICPL 84023 | 47.2 | 32.8 | 40.0 | 23.0 | 31.3 | 27.1 |
| Short-duration (SD) | | | | | | |
| ICPL 87 | 65.6 | 46.1 | 55.9 | 74.7 | 58.4 | 66.5 |
| ICPL 86012 | 148.4 | 65.3 | 106.9 | 77.3 | 74.9 | 76.1 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 448.6 | 275.7 | 362.1 | 152.1 | 172.9 | 162.5 |
| ICP 7035 | 410.7 | 379.3 | 395.0 | 155.8 | 154.2 | 155.0 |
| Mean | 158.8 | 121.4 | 140.1 | 82.6 | 76.8 | 79.7 |
| SEm± | | | | | | |
| Soil | 8.63 ** | | | | | |
| Treatment | 11.84 | | | | | |
| Genotype | 10.93 ** | | | | | |
| Soil x Genotype | 16.83 (15.41) ** | | | | | |
| Soil x Treatment | 14.65 (16.75) | | | | | |
| Treatment x Genotype | 26.08 (33.49) | | | | | |
| Soil x Treatment x Genotype | 37.49 (47.37) | | | | | |
| CV % | 60.9 | | | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.24: Comparision of abscised reproductive plant parts (g $m^{-2}$) during the crop growth for two extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, two extra-short-duration (ESD), two short-duration (SD) and two medium-duration (MD) pigeonpea genotypes on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 44.8 | 54.8 | 49.8 | 15.1 | 20.5 | 17.8 |
| ICPL 91002 | 43.2 | 48.3 | 45.7 | 25.5 | 27.3 | 26.4 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 53.9 | 54.1 | 54.0 | 25.7 | 20.1 | 22.9 |
| ICPL 84023 | 44.6 | 57.0 | 50.8 | 16.3 | 12.7 | 14.5 |
| Short-duration (SD) | | | | | | |
| ICPL 87 | 27.3 | 26.9 | 27.1 | 27.2 | 31.3 | 29.2 |
| ICPL 86012 | 30.7 | 18.3 | 24.5 | 33.7 | 50.4 | 42.1 |
| Medium-duration (MD | | | | | | |
| ICP 8379 | 58.1 | 55.7 | 56.9 | 9.8 | 2.2 | 6.0 |
| ICP 7035 | 64.6 | 86.3 | 75.5 | 48.0 | 19.8 | 33.9 |
| Mean | 45.9 | 50.2 | 48.0 | 25.2 | 23.0 | 24.1 |
| SEm± | | | | | | |
| Soil | | | 1.71 ** | | | |
| Treatment | | | 2.88 | | | |
| Genotype | | | 5.39 ** | | | |
| Soil x Genotype | | | 7.33 (7.63) ** | | | |
| Soil x Treatment | | | 3.35 (4.07) | | | |
| Treatment x Genotype | | | 7.89 (8.14) | | | |
| Soil x Treatment x Genotype | | | 10.96 (11.15) | | | |
| CV % | | | 45.1 | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

**Table 4.25: Comparision of total abscised dry matter (g m$^{-2}$) during the crop growth for two extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, two extra-short-duration (ESD), two short-duration (SD) and two medium-duration (MD) pigeonpea genotypes grown on Alfisol and Vertisol in the rainfed and irrigated treatments. Kharif 1994, ICRISAT Asia center (IAC).**

| Genotypes | Alfisol | | | Vertisol | | |
|---|---|---|---|---|---|---|
| | Rainfed | Irrigated | Mean | Rainfed | Irrigated | Mean |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 91.2 | 114.6 | 102.9 | 65.7 | 64.2 | 64.9 |
| ICPL 91002 | 99.2 | 113.1 | 106.1 | 97.5 | 65.3 | 81.9 |
| Extra-short-duration (ESD) | | | | | | |
| ICPL 83015 | 101.5 | 101.1 | 101.3 | 81.1 | 61.5 | 71.3 |
| ICPL 84023 | 91.73 | 89.8 | 90.8 | 39.3 | 44.0 | 41.7 |
| Short-duration (SD) | | | | | | |
| ICPL 87 | 92.9 | 73.0 | 82.9 | 101.8 | 89.7 | 95.7 |
| ICPL 86012 | 179.1 | 83.6 | 131.4 | 111.0 | 125.4 | 118.2 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 506.7 | 376.4 | 441.6 | 161.9 | 175.1 | 168.5 |
| ICP 7035 | 475.3 | 465.1 | 470.2 | 203.8 | 173.7 | 188.8 |
| Mean | 204.7 | 177.09 | 190.9 | 107.8 | 99.9 | 103.8 |
| SEm± | | | | | | |
| Soil | | | 10.88 ** | | | |
| Treatment | | | 12.62 | | | |
| Genotype | | | 13.03 ** | | | |
| Soil x Genotype | | | 20.38 (18.43) ** | | | |
| Soi x Treatment | | | 16.66 (17.84) | | | |
| Treatment x Genotype | | | 28.39 (35.68) | | | |
| Soil x Treatment x Genotype | | | 41.09 (50.46) | | | |
| CV % | | | 48.4 | | | |

Note: * , ** indicates significance at 5% and 1% level respectively.
SE values in parentheses are used to compare at same levels of first factor.

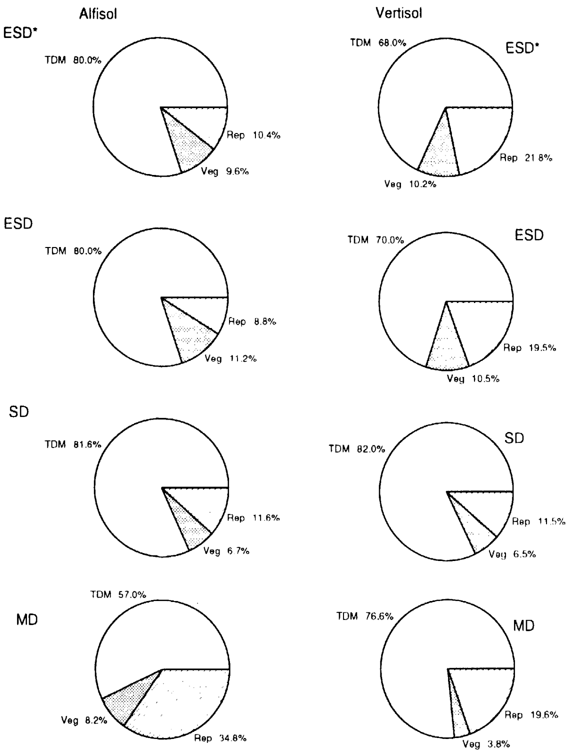



Fig 4.9: Contribution of abscised vegetative parts (Veg) and reproductive parts (Rep) to the total dry matter (TDM) of extra-short-duration(ESD*) with ICPL 7035 as one of the parents, short-duration (SD), extra-short-duration (ESD) and medium-duration (MD) genotypes grown in rainfed and irrigated treatments of Alfisol and Vertisol during kharif 1994 season at ICRISAT Asia Center (IAC).

on Vertisol.

## 4.15 Additive main effects and multiplicative interaction effects (AMMI) analysis

### 4.15.1 Seed yield

The percentage of variation allocated to the 20 pigeonpea genotypes (G), four soil-moisture environments (E) and the total G x E and further partitioned interaction effects in terms of significant first principal component axis (PCA 1) are presented in Appendix 4.9. The additive main effects and multiplicative interaction effects (AMMI) analysis for yield (t $ha^{-1}$) revealed that about 26 per cent variation was accounted due to genotypes (G), 66 per cent due to environment (E) and 8 per cent due to their G x E interaction. The significant PCA 1 accounted 81 per cent of the total G x E interaction. The probability for all sums of squares being significant (< 0.01). The AMMI biplot graph (Fig. 4.10) presents the main effects plus (on X axis) the PCA 1 score of the G x E interaction (on Y axis). The biplot graph had captured 92 per cent of the total variation in yield.

The mean yield (t $ha^{-1}$) and significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments viz., Alfisol-rainfed, Alfisol-irrigated, Vertisol-rainfed and Vertisol-irrigated environments are presented in the Table 4.26. From Table 4.26, it is evident that a positive PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments, while a negative PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments. Among the 20 pigeonpea genotypes, ICPL 90004, ICPL 90007, ICPL 91002 of ESD*, ICPL 89018 of SD, ICP 8379, ICP 7035 and ICP 14199 of MD genotypes had positive PCA 1 score. These genotypes showed positive interaction with Alfisol-rainfed and Alfisol-irrigated environments to produce yields higher than their respective means while they interacted negatively with Vertisol-rainfed and Vertisol-irrigated environments to produce yields lower than their respective means. In contrast, genotypes ICPL 90002, ICPL 90011 of ESD*, ICPL 89008, ICPL 88009, ICPL 87, ICPL 86012 of SD, ICPL 83015, ICPL 84032, ICPL 85010, ICPL 88032, ICPL 88039 of ESD and ICPL 227, ICPL 87119 of MD had negative PCA 1 score. These genotypes showed negative interaction

**Table 4.26: Additive main effects and multiplicative interaction effect (AMMI) table of unadjusted mean seed yield (t ha$^{-1}$), total dry matter at harvest (t ha$^{-1}$), and harvest index (%) of the five Extra-short-duration (ESD$^{*}$) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown in Alfisol-rainfed (AR), Alfisol-irrigated (AI), Vertisol-rainfed (VR) and Vertisol-irrigated (VI) environments. Kharif 1994, ICRISAT Asia center.**

| Genotype | Yield (t ha$^{-1}$) | | Total dry matter (t ha$^{-1}$) | | Harvest index (%) | |
|---|---|---|---|---|---|---|
| | Mean | PCA 1 | Mean | PCA 1 | Mean | PCA 1 |
| Extra-short-duration (ESD$^{*}$) | | | | | | |
| ICPL 90002 | 1.32 | -0.176 | 3.99 | -0.408 | 32.3 | -0.068 |
| ICPL 90004 | 1.30 | 0.249 | 4.18 | -0.091 | 30.8 | 0.223 |
| ICPL 90007 | 1.42 | 0.043 | 4.54 | -0.172 | 30.0 | 0.718 |
| ICPL 90011 | 1.34 | -0.085 | 4.26 | -0.055 | 30.1 | 0.286 |
| ICPL 91002 | 1.15 | 0.018 | 3.31 | -0.094 | 33.4 | -0.025 |
| Extra-Short-duration (ESD) | | | | | | |
| ICPL 83015 | 1.32 | -0.093 | 3.75 | -0.408 | 35.1 | -0.791 |
| ICPL 84032 | 1.16 | -0.086 | 3.68 | -0.248 | 30.7 | 0.294 |
| ICPL 85010 | 1.24 | -0.132 | 3.70 | -0.073 | 33.6 | -1.126 |
| ICPL 88032 | 1.27 | -0.188 | 3.92 | -0.319 | 31.9 | -0.189 |
| ICPL 88039 | 1.36 | -0.151 | 4.02 | -0.186 | 34.1 | -1.074 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 1.32 | 0.143 | 4.86 | -0.251 | 25.5 | 0.377 |
| ICPL 89008 | 1.32 | -0.164 | 3.88 | -0.224 | 36.7 | -2.116 |
| ICPL 88009 | 1.33 | -0.030 | 4.22 | -0.421 | 30.3 | 1.136 |
| ICPL 87 | 1.46 | -0.319 | 6.66 | -0.239 | 21.9 | -0.887 |
| ICPL 86012 | 1.19 | -0.037 | 6.13 | -0.855 | 19.5 | 1.461 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 1.15 | 0.844 | 6.62 | 1.995 | 11.6 | 2.135 |
| ICP 7035 | 1.50 | 0.035 | 6.89 | 0.502 | 20.9 | -0.537 |
| ICP 14199 | 1.09 | 0.659 | 6.05 | 1.319 | 12.3 | 2.529 |
| ICPL 227 | 2.68 | -0.373 | 10.2 | -0.439 | 26.0 | -0.991 |
| ICPL 87119 | 2.42 | -0.319 | 10.3 | -0.014 | 23.6 | -1.355 |
| Environment | | | | | | |
| AR | 1.83 | 0.930 | 6.48 | 1.775 | 30.5 | 2.576 |
| AI | 2.23 | 0.311 | 7.47 | 0.892 | 31.2 | 2.391 |
| VR | 0.86 | -0.587 | 3.86 | -1.660 | 23.3 | -1.478 |
| VI | 0.75 | -0.654 | 3.23 | -1.006 | 25.1 | -3.490 |

Grand mean 1.45 5.26 27.5

with Alfisol-rainfed and Alfisol-irrigated environments to produce yields lower than their respective means while they interacted positively with Vertisol-rainfed and Vertisol-irrigated environments to produce yields higher than their respective means.

The AMMI-biplot graph (Fig.4.10) for yield (t $ha^{-1}$) produced by the 20 pigeonpea genotypes as against the four soil-moisture environments revealed that all extra-short-duration (both ESD* and ESD) and SD genotypes with the exception of ICPL 87 formed a separate group with the waterlogging-susceptible MD genotype ICP 7035 near the origin. The SD genotype, ICPL 87 tended to be separated from this group, with a high negative PCA 1 score. The two MD genotypes ICP 8379 and ICP 14199 formed a separate group at the upper left side of biplot while the other two MD genotypes ICPL 87119 and ICP 227 formed separate group at the lower right side of AMMI-biplot. Genotypes ICPL 90007, ICPL 91002 of ESD*, ICPL 89008, ICPL 86012 of SD and ICP 7035 of MD had a very low or nearly zero PCA 1 scores.

Among the 20 pigeonpea genotypes, the wilt susceptible MD genotypes ICP 8379 and ICP 14199 produced the lowest mean yield and had highest positive PCA 1 score while, the wilt resistant MD genotypes ICPL 227 and ICPL 87119 produced the highest mean yield. The mean yield ranged between 1.15 and 1.42 t $ha^{-1}$ for ESD*, 1.2 and 1.46 t $ha^{-1}$ for SD, 1.2 and 1.36 t $ha^{-1}$ for ESD and 1.08 and 2.67 t $ha^{-1}$ for MD genotypes.

**4.15.2 Total dry matter (TDM) at harvest**

The additive main effects and multiplicative interaction effects (AMMI) analysis when used to quantify the effect of 20 pigeonpea genotypes (G), four soil-moisture environments (E), their G x E interaction for total dry matter (TDM) revealed that about 50 per cent variation was accounted due to genotypes (G), 39 per cent due to environments (E) and 11 per cent due to their G x E interaction (Appendix 4.9). The significant PCA 1 had accounted 82 per cent of the total G x E interaction. The probability for all sums of squares being significant was less than 0.01. The total variation in dry matter production for the 20 pigeonpea genotypes and four soil-moisture environments is 89 per cent.

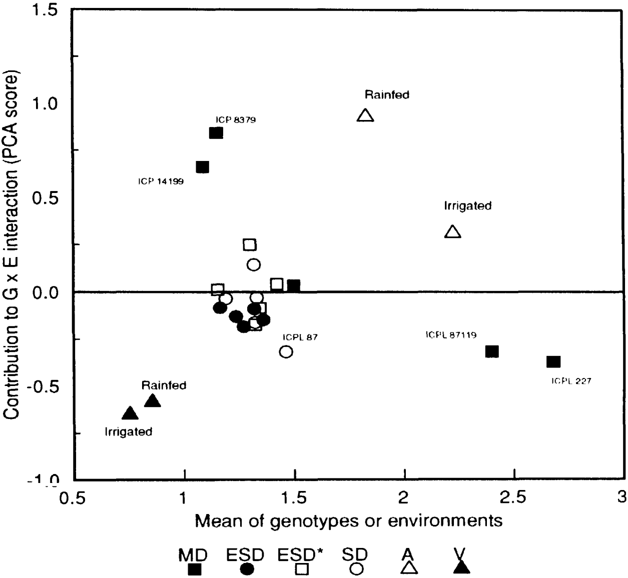



Fig.4.10: Additive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean yield (t ha ) of five extra-short-duration genotypes (ESD*, in open square) with ICP 7035 as one of the parents, five extra-short-duration (ESD, in solid circle), five short-duration (SD, in open circle) and five medium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of yield (t ha ); Y-axis).

The mean total dry matter (t $ha^{-1}$) and significant PCA 1 scores for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.26. From Table 4.26, it is evident that a positive PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments, while a negative PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments.

Among the 20 pigeonpea genotypes, ICPL 90002, ICPL 90004, ICPL 90007, ICPL 90011, ICPL 91002 of ESD*, ICPL 89018, ICPL 89008, ICPL 88009, ICPL 87, ICPL 86012 of SD, ICPL 83015, ICPL 84032, ICPL 85010, ICPL 88032, ICPL 88039 of ESD, ICPL 227, ICPL 87119 of MD had negative PCA 1 score. These genotypes showed negative interaction with Alfisol-rainfed and Alfisol-irrigated environments to produce dry matter lower than their respective means while they interacted positively with Vertisol-rainfed and Vertisol-irrigated to produce dry matter higher than their respective means. In contrast genotypes ICP 8379, ICP 7035 and ICP 14199 of MD had positive PCA 1 score. These genotypes interacted positively with Alfisol-rainfed and Alfisol-irrigated to produce dry matter higher than their respective means while they interacted negatively with Vertisol-rainfed and Vertisol-irrigated environments to produce dry matter lower than their respective means.

The AMMI-biplot graph (Fig.4.11) for total dry matter (t $ha^{-1}$) produced by the 20 pigeonpea genotypes in the four soil moisture environments revealed that all extra-short-duration (both ESD* and ESD) and SD with the exception of ICPL 87 and ICPL 86012 formed a separate group near the origin. The two SD genotypes ICPL 87 and ICPL 86012 tended to be separated from this group. Among the five MD genotypes, the wilt susceptible genotypes ICP 8379, ICP 14199 and ICP 7035 formed a separate group in the positive section while, the wilt resistant genotypes, ICPL 87119 and ICPL 227 formed a separate group in the negative section. Genotypes ICP 87119 (MD), ICPL 90004, ICPL 90011, ICPL 91002 all ESD*, ICPL 85010 of ESD had a very low or nearly zero PCA 1 scores. Among the 20 pigeonpea genotypes the wilt resistant MD genotypes ICPL 227 and ICPL 87119 produced the highest mean dry matter while ESD* genotype ICPL

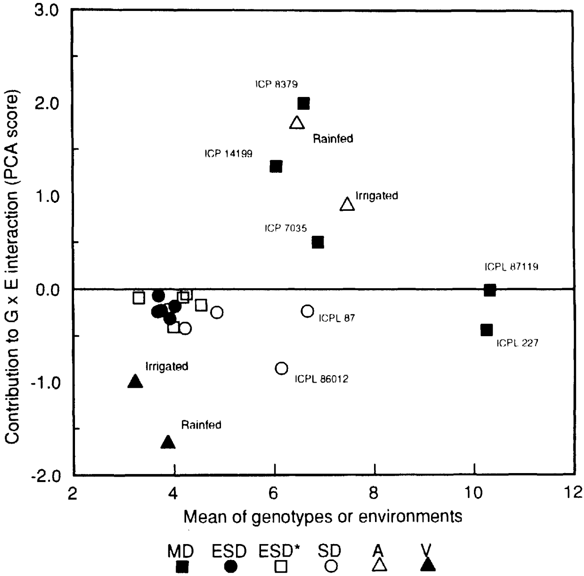



Fig.4.11: Additive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean total dry matter (t ha ) of five extra-short-duration genotypes (ESD*, in open square) with ICP 7035 as one of the parents, five extra-short-duration (ESD, in solid circle), five short-duration (SD, in open circle), five medium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of total dry matter (t ha ); Y-axis.

91002 produced the lowest mean dry matter. The total dry matter produced by the two SD genotypes ICPL 87 and ICPL 86012 was similar to that produced by the three wilt susceptible MD genotypes ICP 8379, ICP 7035 and ICP 14199. The mean total dry matter ranged between 3.3 and 4.5 t $ha^{-1}$ for ESD*, 3.9 and 6.66 t $ha^{-1}$ for SD, 3.7 and 4.0 t $ha^{-1}$ for ESD and, 6.05 and 10.3 t $ha^{-1}$ for MD genotypes.

**4.15.3 Harvest Index (HI)**

Additive main effects and multiplicative interaction effect (AMMI) analysis for harvest index (HI) had revealed that the total variation for 20 pigeonpea genotypes and four soil-moisture environments for harvest index is 73 per cent (Appendix 4.9). Of the 73 per cent variation due to treatment sum of squares, about 67 per cent variation was accounted due to genotypes (G), 16 per cent due to environments (E) and 17 per cent due to their G x E interaction. The significant first principal component axis (PCA 1) accounted 70 per cent of the total G x E interaction. The probability of all sum of squares being significant was less than 0.01 except for G x E interaction.

The mean harvest index (%) and significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.26. From Table 4.26, it is indicated that among the four soil-moisture environments, a positive PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments while, a negative PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments.

Among the 20 pigeonpea genotypes, ICPL 90004, ICPL 90007, ICPL 90011 of ESD*, ICPL 89018, ICPL 88009, ICPL 86012 of SD, ICPL 84032 of ESD, ICP 8379 and ICP 14199 of MD had positive PCA 1 and these genotypes showed positive G x E interaction with Alfisol-rainfed and Alfisol-irrigated environment to produce higher harvest index than their respective means while they interacted negatively with Vertisol-rainted and Vertisol-irrigated environment to produce lower harvest index than their respective means. In contrast genotypes ICPL 90002, ICPL 91002 of ESD*, ICPL 89008, ICPL 87 of SD, ICPL 83015, ICPL 85010, ICPL 88032, ICPL 88039 of ESD, ICP 7035, ICPL 227 and ICPL 87119 of MD had negative PCA 1 score. These genotypes showed negative G x E interaction with Alfisol-rainfed and Alfisol-irrigated environment to produce lower harvest index than their respective means while they interacted positively with Vertisol-rainfed and Vertisol-irrigated to produce higher harvest index than their respective means.

The AMMI-biplot graph (Fig.4.12) for the harvest index (%) produced by the 20 pigeonpea genotypes in the four soil-moisture environments revealed that the five ESD* genotypes formed a separate group along with ICPL 84032 and ICPL 85010 of ESD genotypes while the other three ESD genotypes ICPL 83015, ICPL 88032 and ICPL 88039 tended to form a separate group at the upper right side of Vertisol environment. The five SD genotypes did not form a separate group. The SD genotype, ICPL 88009 formed a separate group with ESD* genotypes while ICPL 87 formed separate group with the ICPL 227, ICPL 87119 and ICP 7035 MD genotypes in the Vertisol environment. The two MD genotypes, ICP 8379 and ICP 14199 formed a separate group at the upper left side in Alfisol environment. Genotype ICPL 89008 (SD) was seen far away on the lower right side in the Vertisol environment. Genotype ICPL 90002 and ICPL 91002 of ESD* genotypes showed very low or nearly zero PCA 1 scores.

Among the 20 pigeonpea genotypes the SD genotype ICPL 89008 had produced the highest harvest index while ICP 8379 (MD) produced the lowest. The mean harvest index (%) for the four pigeonpea groups ranged between 30 and 33.4 per cent for ESD*, 19.5 and 36.7 per cent for SD 30.7 and 35.2 per cent for ESD and 11.6 and 26.0 per cent for MD genotypes.

### 4.15.4 Days to 50 per cent flowering

The additive main effects and multiplicative interaction effects (AMMI) analysis for days to 50 per cent flowering revealed (Appendix 4.9) that about 97 per cent of total variation was accounted due to genotypes (G), 3 per cent due to environments (E) and with zero variation due to their G x E interaction (5% level of significance). The significant PCA 1 had accounted about 63 per cent of the total variation in G x E interaction. The probability

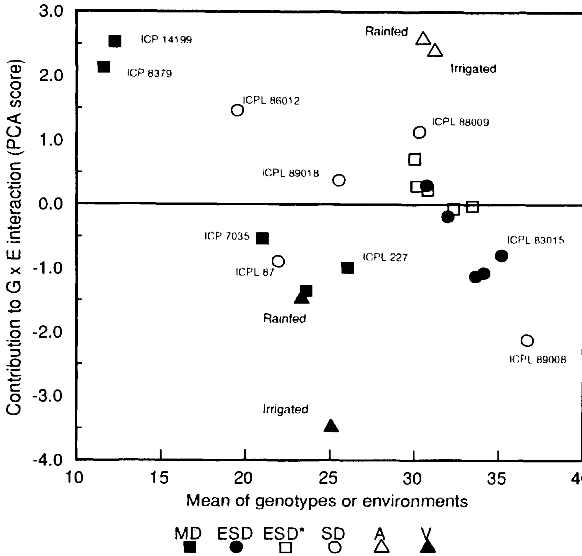



Fig.4.12: Additive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean harvest index (%) of five extra-short-duration (ESD*, in open square) with ICP 7035 as one of the parents, five extra-short-duration (ESD, in solid circle), five short-duration (SD, in open circle) and five medium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of harvest index (%); Y-axis).

of all sums of squares being significant was less than 0.01. As G x E interactions were not significant individual genotypes means, their PCA 1 and biplots scores are not presented.

### 4.15.5 Days to maturity

The percentage of total variation revealed by the AMMI statistical analysis is 99 per cent (Appendix 4.9). Of the 99 per cent total variation, about 94 per cent variation was accounted due to 20 pigeonpea genotypes (G), 4 per cent due to four soil-moisture environments (E) and 1 per cent due to their G x E interaction. Of the 1 per cent variation due to the G x E interaction, 90 per cent variation was accounted due to the significant PCA 1. The probability of all sums of squares being significant was less than 0.01.

The mean days to maturity (DTM) and the significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.27. From Table 4.27, it is evident that a positive PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environment while a negative PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments.

Among the 20 pigeonpea genotypes, ICPL 90002, ICPL 90004, ICPL 90007, ICPL 90011 and ICPL 91002 of ESD*, ICPL 89018 of SD, ICPL 83015, ICPL 85010, ICPL 88032, ICPL 88039 of ESD, ICP 8379, ICP 7035, ICP 14199, ICPL 227 and ICPL 87119 of MD genotypes had positive PCA 1 score. These genotypes showed positive G x E interaction with Alfisol-rainfed and Alfisol-irrigated environment indicating that they require less number of days to physiological maturity than their respective means. While, they interacted negatively with Vertisol-rainfed and Vertisol-irrigated environments indicating that they require more number of days to mature than their respective means. In contrast genotypes ICPL 89008, ICPL 88009, ICPL 87, ICPL 86012 of SD, ICPL 84032 of ESD, genotypes had negative PCA 1 scores. These genotypes showed a negative G x E interaction with Alfisol-rainfed and Alfisol-irrigated environment, indicating that they require more number of days to mature than their respective means while they interacted positively with Vertisol-rainfed and Vertisol-irrigated environment to indicate that they require less number

**Table 4.27 Additive main effects and multiplicative interaction effect (AMMI) table of unadjusted mean Days to mature and seedfill duration of the five Extra-short-duration (ESD*) genotypes with ICP 7035 as one of the parent, five extra-short-duration (ESD), five short-duration (SD) and five medium-duration (MD) pigeonpea genotypes grown in Alfisol-rainfed (AR), Alfisol-irrigated (AI), Vertisol-rainfed (VR) and Vertisol-irrigated (VI) environments. Kharif 1994, ICRISAT Asia center.**

| Genotype | Days to maturity | | Seedfill duration (days) | |
|---|---|---|---|---|
| | Mean | PCA1 | Mean | PCA 1 |
| Extra-short-duration (ESD*) | | | | |
| ICPL 90002 | 111 | 0.433 | 42 | 0.775 |
| ICPL 90004 | 111 | 0.286 | 44 | 0.152 |
| ICPL 90007 | 110 | 0.267 | 43 | 0.207 |
| ICPL 90011 | 111 | 0.486 | 41 | 0.144 |
| ICPL 91002 | 110 | 0.024 | 44 | 0.171 |
| Extra-Short-duration (ESD) | | | | |
| ICPL 83015 | 105 | 0.793 | 40 | 0.702 |
| ICPL 84032 | 107 | -0.154 | 45 | 0.567 |
| ICPL 85010 | 104 | 0.952 | 40 | 0.939 |
| ICPL 88032 | 109 | 0.330 | 40 | 0.757 |
| ICPL 88039 | 106 | 1.201 | 39 | 1.206 |
| Short-duration (SD) | | | | |
| ICPL 89018 | 116 | 1.079 | 42 | 0.919 |
| ICPL 89008 | 114 | -0.072 | 43 | 0.329 |
| ICPL 88009 | 113 | -0.638 | 43 | -0.141 |
| ICPL 87 | 133 | -3.843 | 56 | -3.956 |
| ICPL 86012 | 130 | -3.621 | 56 | -3.322 |
| Medium-duration (MD) | | | | |
| ICP 8379 | 185 | 0.725 | 55 | 0.614 |
| ICP 7035 | 187 | 0.638 | 55 | 0.379 |
| ICP 14199 | 187 | 0.077 | 56 | 0.132 |
| ICPL 227 | 186 | 0.492 | 59 | -0.205 |
| ICPL 87119 | 185 | 0.545 | 59 | -0.467 |
| Environment | | | | |
| AR | 122 | 3.334 | 42 | 3.293 |
| AI | 127 | 2.513 | 48 | 2.293 |
| VR | 137 | -2.699 | 50 | -2.271 |
| VI | 138 | -3.148 | 49 | -3.316 |

Grand mean 131 47

of days to mature than their respective means.

The AMMI-biplot graph (Fig.4.13) for days to maturity for all 20 pigeonpea genotypes revealed that all extra-short-duration genotypes (both ESD* and ESD) and SD with exception of ICPL 86012 and ICPL 87 formed a separate group near the origin. The two SD genotypes ICPL 87 and ICPL 86012 tended to be separate from this group and are seen at the lower half of the negative section. The five MD genotypes formed another separated group at the extreme right near the origin. Genotypes, ICPL 91002 (ESD), ICPL 89008 (SD) and ICP 14199 (MD) had very low or nearly zero PCA 1 scores. Among the five ESD* genotypes, ICPL 91002 was the earliest to mature while ICPL 90002 was the latest to mature. Similarly ICPL 88009 was the earliest while ICPL 87 was the latest to mature among the five SD genotypes. Genotype ICPL 85010 was the earliest while ICPL 88032 was the latest to mature among the five ESD genotypes. Whereas, ICP 8379 was the earliest while ICP 14199 was the latest to mature among the five MD genotypes. The mean days to mature for the four pigeonpea groups ranged between 109 and 110 days for ESD*, 113 and 133 for SD, 104 and 109 for ESD and. 184 and 186 for MD genotypes.

### 4.15.6 Seed fill duration

The AMMI analysis for seed fill duration revealed that 69 per cent of total variation was accounted due to genotypes (G), 11 per cent due to environments (E) and 20 per cent due to their G x E interaction (Appendix 4.9). The significant PCA 1 had accounted for about 85 per cent of the total variation in G x E interaction. The probability of all sums of squares was significant (<0.01). The percentage of total variation allocated to the 20 pigeonpea genotypes and four soil-moisture environments is 87 per cent.

The mean seedfill duration and the significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.27. From Table 4.27, it is indicated that a positive PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments while a negative PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments.

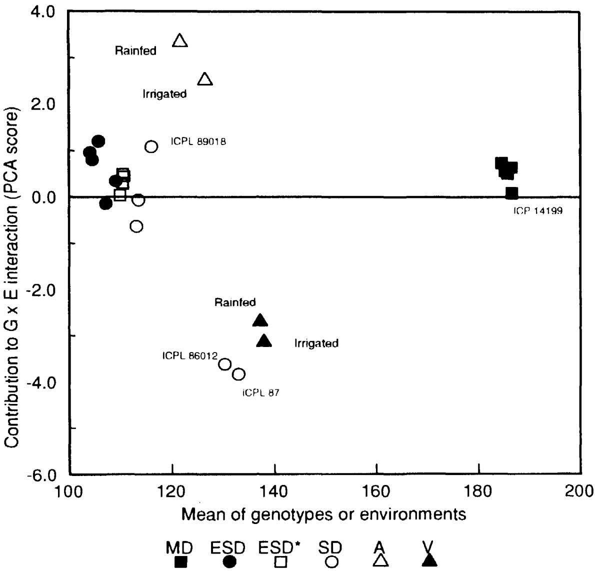



Fig.4.13: Additive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean days to maturity (days) of five extra-short-duration genotypes (ESD*, in open square) with ICP 7035 as one of the parents, five extra-short-duration (ESD, in solid circle), five short-duration (SD, in open circle) five medium-duration (MD,in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of days to maturity (days) ; Y-axis).

Among the 20 pigeonpea genotypes, ICPL 90002, ICPL 90004, ICPL 90007, ICPL 90011, ICPL 91002 of ESD*, ICPL 89018, ICPL 89008 of SD, ICPL 83015, ICPL 84032, ICPL 85010, ICPL 88032, ICPL 88039 of ESD, ICP 8379, ICP 7035 and ICP 14199 of MD genotypes had positive PCA 1 score. These genotypes showed a positive G x E interaction with Alfisol-rainfed and Alfisol-irrigated environment indicating that they took less number of days for seed filling than their respective means. While they interacted positively, to show that the number of days for seed filling were more than their respective means. In contrast, ICPL 88009, ICPL 87, ICPL 86012 of SD, ICPL 227 and ICPL 87119 of MD had negative PCA 1 score. These genotypes showed a positive interaction with Vertisol-rainfed and Vertisol-irrigated environment, indicating that they took less number of days for seed filling than their respective means. While, they interacted negatively with Alfisol-rainfed and Alfisol-irrigated environment, indicating that they took more number of days for seed filling than their respective means.

The AMMI-biplot (Fig.4.14) for the days to seed filling taken by the 20 pigeonpea genotypes in the four soil-moisture environment revealed that all extra-short-duration genotypes (both ESD* and ESD) along with the three SD genotypes, ICPL 89018, ICPL 89008 and ICPL 88009 had formed a separate group near the origin. While, the five MD genotypes tended to form a separate group at the extreme right of the biplot. The other two SD genotypes ICPL 87 and ICPL 86012 formed a separate group at the lower right side of the AMMI-biplot.

Among the 20 pigeonpea genotypes the ESD genotype ICPL 88039 had the fastest rate of seed filling while MD genotypes, ICPL 87119 had the slowest rate. The mean seed filling duration for the four pigeonpea groups ranged between 41 and 44 days for ESD*, 41 and 56 days for SD, 40 and 45 days for ESD and, 55 and 58 days for MD genotypes.

#### 4.15.7 Daily dry matter production (kg $ha^{-1}$ $day^{-1}$)

The AMMI analysis for daily dry matter production (kg $ha^{-1}$ $d^{-1}$) revealed that 16 per cent of total variation was accounted due to genotypes (G), 77 per cent due to environments

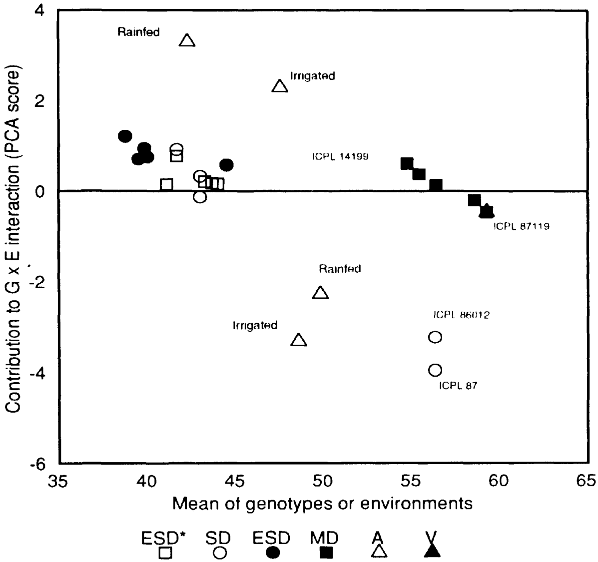



Fig.4.14: Addittive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean seedfill duration (days) of five extra-short-duration genotypes (ESD*, in open square) with ICP 7035 as one of the parents, five extra-short-duration (ESD, in solid circle), five short-duration (SD, in open circle) and five medium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of seedfill duration (days); Y-axis).

(E) and 7 per cent due to their G x E interaction. The significant PCA 1 had accounted about 46 per cent of the total variation in G x E interaction. The probability of all sums of squares was significant (<0.01). The percentage of total variation allocated to the 20 pigeonpea genotypes and four soil-moisture environments is 87 per cent (Appendix 4.9).

The mean daily dry matter production (kg $ha^{-1}$ $d^{-1}$) and the significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.28. From Table 4.28 it is indicated that a positive PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments while a negative PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments.

Among the 20 pigeonpea genotypes, ICPL 90002, ICPL 90007 of ESD*, ICPL 88009, ICPL 86012 of SD, ICPL 84032, ICPL 88032 of ESD, ICP 7035, ICPL 227 and ICPL 87119 of MD had positive PCA 1 score. These genotypes showed a negative G x E interaction with Alfisol-rainfed and Alfisol-irrigated environment producing lower amount of dry matter $day^{-1}$ than their respective means. While they interacted positively with Vertisol-rainfed and Vertisol-irrigated environment to produce higher amount of dry matter $day^{-1}$ than their respective means. In contrast, genotypes, ICPL 90004, ICPL 90011, ICPL 91002 of ESD*, ICPL 89018, ICPL 89008, ICPL 87 of SD, ICPL 83015, ICPL 85010, ICPL 88039 of ESD, ICP 8379 and ICP 14199 of MD genotypes had a negative PCA 1 score. These genotypes showed positive interaction with Alfisol-rainfed and Alfisol-irrigated environment producing higher amount of dry matter $day^{-1}$ than their respective means. While they interacted negatively with Vertisol rainfed and Vertisol-irrigated environment to produce lower amount of dry matter $day^{-1}$ than their respective means.

The AMMI-biplot (Fig. 4.15) for total dry matter produced $day^{-1}$ by the 20 pigeonpea genotypes in the four soil-moisture environments revealed that all extra-short- duration genotypes (both ESD* and ESD) along with two SD genotypes ICPL 89008 and ICPL 88009 and three wilt susceptible MD genotypes ICP 8379, ICP 7035 and ICP 14199 formed a separate group near the origin. While the three SD genotypes ICPL 89018, ICPL 87, ICPL

**Table 4.28 Additive main effects and multiplicative interaction effect (AMMI) table of unadjusted means for yield day$^{-1}$ (kg ha$^{-1}$ d$^{-1}$), total day$^{-1}$ dry matter and yield day$^{-1}$ of seedfill duration (kg ha$^{-1}$ d$^{-1}$) of the five ESD*, SD, ESD and MD pigeonpea genotypes grown in Alfisol-rainfed (AR), Alfisol-irrigated (AI), Vertisol-rainfed (VR) and Vertisol-irrigated (VI) environments. Kharif 1994, ICRISAT Asia center.**

| Genotype | Yield day$^{-1}$ | | Total biomass day$^{-1}$ | | Yield day$^{-1}$ seedfill duration | |
|---|---|---|---|---|---|---|
| | Mean | PCA 1 | Mean | PCA 1 | Mean | PCA 1 |
| Extra-short-duration (ESD*) | | | | | | |
| ICPL 90002 | 12.2 | 0.096 | 36.59 | 0.836 | 0.293 | 0.031 |
| ICPL 90004 | 12.2 | -1.384 | 38.72 | -0.967 | 0.287 | -0.207 |
| ICPL 90007 | 13.2 | -0.463 | 41.95 | 0.438 | 0.313 | -0.091 |
| ICPL 90011 | 12.5 | -0.825 | 39.35 | -1.017 | 0.312 | -0.157 |
| ICPL 91002 | 10.9 | -0.817 | 31.03 | -1.159 | 0.256 | -0.104 |
| Extra-Short-duration (ESD) | | | | | | |
| ICPL 83015 | 12.9 | -0.326 | 36.58 | -0.106 | 0.327 | -0.070 |
| ICPL 84032 | 11.3 | -0.260 | 35.24 | 0.066 | 0.258 | -0.016 |
| ICPL 85010 | 12.1 | -0.054 | 36.14 | -0.686 | 0.302 | -0.007 |
| ICPL 88032 | 11.9 | 0.235 | 36.58 | 0.898 | 0.298 | 0.031 |
| ICPL 88039 | 13.0 | 0.222 | 38.48 | -0.218 | 0.333 | 0.042 |
| Short-duration (SD) | | | | | | |
| ICPL 89018 | 11.5 | -0.800 | 42.33 | -2.424 | 0.276 | -0.096 |
| ICPL 89008 | 11.9 | 0.088 | 34.85 | -0.370 | 0.282 | 0.016 |
| ICPL 88009 | 12.2 | -0.427 | 38.04 | 0.737 | 0.294 | -0.118 |
| ICPL 87 | 11.6 | 0.400 | 52.43 | -1.287 | 0.238 | -0.026 |
| ICPL 86012 | 9.9 | -0.302 | 48.44 | 1.108 | 0.208 | -0.056 |
| Medium-duration (MD) | | | | | | |
| ICP 8379 | 6.9 | -0.039 | 41.422 | -1.049 | 0.121 | 0.068 |
| ICP 7035 | 8.1 | 1.009 | 37.28 | 0.567 | 0.150 | 0.213 |
| ICP 14199 | 6.5 | 0.106 | 38.91 | -0.032 | 0.083 | -0.008 |
| ICPL 227 | 14.5 | 1.746 | 55.34 | 2.809 | 0.250 | 0.276 |
| ICPL 87119 | 13.1 | 1.795 | 55.88 | 1.856 | 0.224 | 0.279 |
| Environment | | | | | | |
| AR | 15.4 | -1.507 | 52.06 | -1.749 | 0.377 | -0.314 |
| AI | 18.2 | -1.833 | 58.89 | -3.269 | 0.394 | -0.246 |
| VR | 6.6 | 0.983 | 29.24 | 1.672 | 0.135 | 0.209 |
| VI | 5.5 | 2.356 | 22.93 | 3.346 | 0.114 | 0.352 |
| Grand mean | 11.4 | | 40.80 | | 0.255 | |

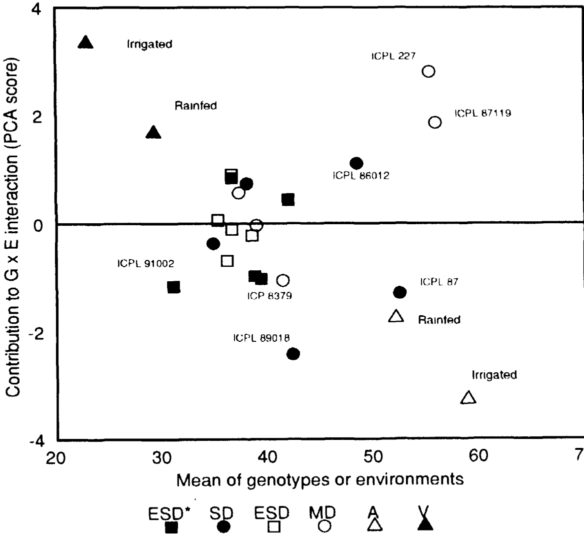



Fig.4.15: Additive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean biomass day (kg ha d ) of five extra-short-duration genotypes (ESD*, in open square) with ICP 7035 as one of the parents, five extr-short-duration (ESD, in solid circle), five short-duration (SD, in open circle) and five nedium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 score (square root of biomass day kg ha d ; Y-axis).

86012 and two MD genotypes ICPL 227 and ICPL 87119 tended to be separate from this group. Genotypes ICPL 84032 of ESD, ICPL 14199 of MD showed very low or nearly zero PCA 1 scores.

Among the 20 pigeonpea genotypes the per day dry matter production was highest in MD genotype ICPL 87119 while lower dry matter was produced by ESD* genotype ICPL 91002. The per day dry matter produced by the 20 pigeonpea genotypes was 52 kg $ha^{-1}$ $d^{-1}$ in Alfisol-rainfed, 58.9 kg $ha^{-1}$ $d^{-1}$ in Alfisol-irrigated, 29.2 kg $ha^{-1}$ $d^{-1}$ in Vertisol-rainfed and 22.9 kg $ha^{-1}$ $d^{-1}$ in Vertisol-irrigated environments. The mean daily dry matter production for the four pigeonpea groups ranged between 31 and 42 kg $ha^{-1}$ $d^{-1}$ for ESD*, 34 and 52 kg $ha^{-1}$ $d^{-1}$ for SD, 35 and 38 kg $ha^{-1}$ $d^{-1}$ for ESD and, 37 and 56 kg $ha^{-1}$ $d^{-1}$ for MD genotypes.

**4.15.8 Daily yield productivity (kg $ha^{-1}$ $day^{-1}$)**

The additive main effects and multiplicative interaction effects (AMMI) analysis for daily yield productivity revealed that 11 per cent of total variation was accounted due to genotypes (G), 82 per cent due to environments (E) and 7 per cent due to their G x E interaction. The significant PCA 1 had accounted about 75 per cent of the total variation in G x E interaction. The probability of all sums of squares was significant (<0.01). The percentage of total variation allocated to the 20 pigeonpea genotypes and four soil-moisture environments is 94 per cent (Appendix 4.9).

The mean daily yield productivity (kg $ha^{-1}$ $d^{-1}$) and the significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.28. From Table 4.28, it is clear that a positive PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environments, while a negative PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments.

Among the 20 pigeonpea genotypes, ICPL 90002 of ESD*, ICPL 89008, ICPL 87 of SD, ICPL 88032, ICPL 88039 of ESD, ICP 7035, ICP 14199, ICPL 227 and ICPL 87119 of MD had a positive PCA 1 score. These genotypes showed positive G x E interaction with Vertisol-rainfed and Vertisol-irrigated environment to produce higher daily yield productivity than their respective means while, they interacted negatively with Alfisol-rainfed and Alfisol-irrigated environment to produce lower yield productivity day$^{-1}$ than their respective means. In contrast, genotypes ICPL 90004, ICPL 90007, ICPL 90011, ICPL 91002 of ESD*, ICPL 89018, ICPL 88009, ICPL 86012 of SD, ICPL 83015, ICPL 84032, ICPL 85010 of ESD, and ICP 8379 of MD had a negative PCA 1 score. These genotypes showed positive G x E interaction with Alfisol-rainfed and Alfisol-irrigated environments to produce higher yield productivity day$^{-1}$ than their respective means while they showed a negative G x E interaction with Vertisol-rainfed and Vertisol-irrigated environments to produce lower yield productivity day$^{-1}$ than their respective means.

The AMMI-biplot graph (Fig. 4.16) for daily yield productivity (kg ha$^{-1}$ d$^{-1}$) produced by the 20 pigeonpea genotypes in four soil-moisture environments revealed that all short and extra-short duration (both ESD* and ESD) genotypes formed a separate group at the center of the biplot. The five MD genotypes tended to be separated from this group with high positive PCA 1 scores. Genotype ICPL 90002 of ESD*, ICPL 89008 of SD, ICPL 85010 of ESD and ICP 8379 of MD had very low or nearly zero PCA 1 scores.

Among the 20 pigeonpea genotypes, ICPL 227 (MD) had the highest daily yield productivity while ICPL 14199 of MD had the lowest. The per day dry matter produced by the 20 pigeonpea genotypes was 15.4 kg ha$^{-1}$ d$^{-1}$ in Alfisol-rainfed, 18.2 kg ha$^{-1}$ d$^{-1}$ in Alfisol-irrigated, 6.6 kg ha$^{-1}$ d$^{-1}$ in Vertisol-rainfed and 5.5 kg ha$^{-1}$ d$^{-1}$ in Vertisol-irrigated environments. The mean daily yield productivity produced by the four pigeonpea genotypes ranged between 11 and 13 kg ha$^{-1}$ d$^{-1}$ for ESD*, 10 and 12 kg ha$^{-1}$ d$^{-1}$ for SD, 11 and 13 kg ha$^{-1}$ d$^{-1}$ for ESD, and 6.5 and 13 kg ha$^{-1}$ d$^{-1}$ for MD genotypes.

### 4.15.9 Yield accumulated day$^{-1}$ of seed fill duration (kg ha$^{-1}$ d$^{-1}$)

The AMMI analysis for yield accumulated day$^{-1}$ of seed fill duration revealed that 19 per cent of total variation was accounted due to genotypes (G), 74 per cent due to environments (E) and 7 per cent due to their G x E interaction. The significant PCA 1 had accounted about 79 per cent of the total variation in G x E interaction. The probability of all

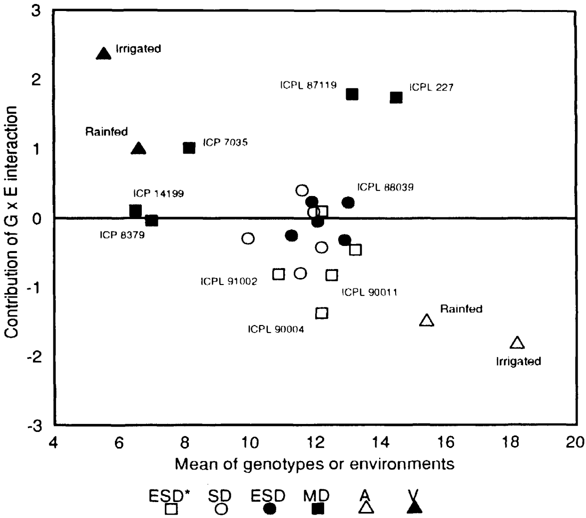



Fig.4.16: Additive main effects and multiplicative interaction effects (AMM) biplot of unadjusted mean yield day (kg ha d ) of five extra-short-duration genotypes (ESD*, in open square) with ICP 7035 as one the parents, five extra-short-duration (ESD, in solid circle), five short-dration (SD, in open circle) and five medium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of yield day kg ka d ; Y-axis).

sums of squares being significant was less than 0.01. The percentage of total variation allocated to the 20 pigeonpea genotypes and four soil-moisture environments is 94 per cent (Appendix 4.9).

The mean yield accumulated $day^{-1}$ of seed fill duration and the significant PCA 1 for the four pigeonpea groups and for the four soil-moisture environments are presented in the Table 4.28. From Table 4.28 it is evident that a positive PCA 1 scores were observed for Vertisol-rainfed and Vertisol-irrigated environment while negative PCA 1 scores were observed for Alfisol-rainfed and Alfisol-irrigated environments. Among the 20 pigeonpea genotypes, ICPL 90002 of ESD*, 89008 of SD, ICPL 88032, ICPL 88039 of ESD, ICP 8379, ICP 7035, ICPL 227 and ICPL 87119 of MD had positive PCA 1 scores. These genotypes showed a positive G x E interaction with Vertisol-rainfed and Vertisol-irrigated environments and showed higher rates of photosynthates accumulated $day^{-1}$ of seed fill duration, while they interacted negatively with Alfisol-rainfed and Alfisol-irrigated environments and showed lower rates of photosynthate accumulation $day^{-1}$ of seed fill duration than their respective means. In contrast, genotypes ICPL 90004, ICPL 90007, ICPL 90011, ICPL 91002 of ESD*, ICPL 89018, ICPL 88009, ICPL 87, ICPL 86012 of SD, ICPL 83015, ICPL 84032, ICPL 85010 of ESD, and ICPL 14199 of MD had negative PCA 1 scores. These genotypes showed a positive G x E interaction with Alfisol-rainfed and Alfisol-irrigated environments and showed higher rates of photosynthate accumulation $day^{-1}$ of seed fill duration than their respective means, while they showed negative G x E interaction with Vertisol-rainfed and Vertisol-irrigated environments indicating lower rate of photosynthate accumulation $day^{-1}$ of seed filling than their respective means.

The AMMI-biplot graph (Fig. 4.17) for yield accumulation $day^{-1}$ of seed fill duration indicated that all short- and extra-short-duration (both ESD* and ESD) genotypes formed a separate group near the center of the biplot. Whereas, the five MD genotypes tended to be separated from this group with high positive PCA 1 scores. Genotypes ICPL 90002, ICPL 90007 of ESD*, ICPL 89018, ICPL 89008, ICPL 87, ICPL 86012 of SD, ICPL 83015, ICPL

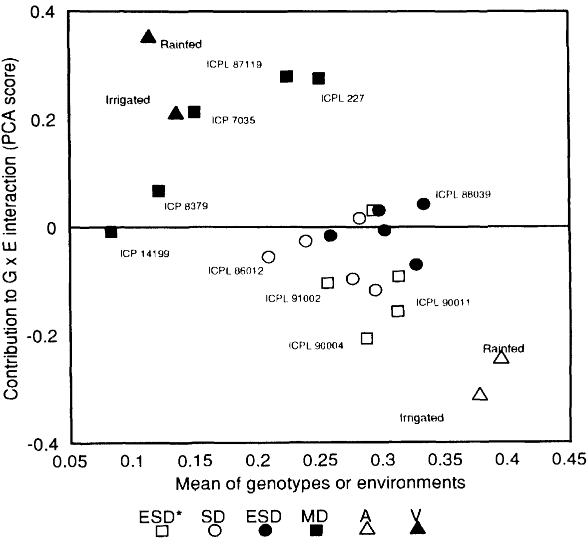



Fig. 4.17: Additive main effects and multiplicative interaction effects (AMMI) biplot of unadjusted mean yield day of seedfill duration (kg ha d ) of five extra-short-duration genotypes (ESD*, in open square), five extra-short-duration (ESD, in solid square), five short-duration (SD, in open circle) and five medium-duration (MD, in solid square) genotypes grown on Alfisol (A) and Vertisol (V), in rainfed and irrigated environments and PCA 1 scores (square root of yield day of seedfill duration kg ha d ; Y-axis).

84032, ICPL 85010, ICPL 88032, ICPL 88039 of ESD ICP 8379, ICP 14199 of MD had very low or nearly zero PCA scores. Among the 20 pigeonpea genotypes, ICPL 88039 had the highest yield accumulation day$^{-1}$ of seed filling while genotype, ICP 14199 had the lowest.

The mean yield accumulation day$^{-1}$ of seed filling for the four pigeonpea groups ranged between 0.25 and 0.31 kg ha$^{-1}$ d$^{-1}$ of seed filling for ESD*, 0.21 and 0.29 kg ha$^{-1}$ d$^{-1}$ of seed filling for SD, 0.26 to 0.33 kg ha$^{-1}$ d$^{-1}$ of seed filling for ESD and, 0.08 and 0.25 kg ha$^{-1}$ d$^{-1}$ of seed filling for MD genotypes. The yield accumulated day$^{-1}$ seedfill duration by the 20 pigeonpea genotypes was 0.38 kg ha$^{-1}$ d$^{-1}$ in Alfisol-rainfed, 0.39 kg ha$^{-1}$ d$^{-1}$ in Alfisol-irrigated, 0.14 kg ha$^{-1}$ d$^{-1}$ in Vertisol-rainfed and 0.11 kg ha$^{-1}$ d$^{-1}$ in Vertisol-irrigated environments.

# *DISCUSSION*

# CHAPTER V

# DISCUSSION

## 5.1 Main Effects of Soil type, Irrigation and Genotypes, and Their Interactions

In India, pigeonpea is generally sown at the onset of monsoon rains. medium-duration pigeonpea in the traditional intercropping cropping systems grows on current rainfall during the vegetative stage and on stored moisture during the reproductive stage. In contrast, the newly evolved extra-short- and short-duration genotypes complete their life cycle within the rainy season or soon after it. Thus depending on the local topography, soil factors which influence runoff, infiltration, storage and subsequent availability, and amount and distribution pattern of rainfall, and durations the crop is exposed to terminal drought, or is flooded or alternately experiences water deficits and excesses during rainy season (Krizek, 1981; Raper and Kramer,1983; Turner and Kramer, 1980). These stresses often affect the productivity of the crop (Reddy and Virmani, 1981; Lawn and Troedson, 1990). Waterlogging also predispose the pigeonpea to diseases such as *Phytophthora* Blight (Reddy et al., 1990; Singh and Chauhan, 1985; Drew and Lynch,1980; Stolzy,1974). Similarly drought can also enhance wilt incidence in pigeonpea. The stability of the crop production is determined a great deal by amount of rainfall, soil type and the duration of the genotype or variety.

In this study, an attempt was made to simulate some of the growing conditions pigeonpea experiences in the semi-arid environments of peninsular India. The inclusion of newly evolved extra-short-duration and short-duration and medium-duration pigeonpea genotypes provided an opportunity to study adaptation of pigeonpea to different soils in relation to differences in maturity as well as resistances to waterlogging and drought.

The total water supplied during the crop growth (rainfall plus irrigation) was approximately 600-900 mm on Alfisol and 690-830 mm on Vertisol (Table 4.2). This year, due to rains received in October (Appendix 4.1), development of drought stress on Alfisol was not severe as against the normal trend on these soils (Chauhan et al., 1992). Nevertheless, additional irrigations given served to examine if on Alfisols also excess water would be harmful as has been observed earlier by Okada et al.,(1991). However, only on Vertisol the additional irrigations appeared excessive (Table 3.2) and no negative effect of irrigation on crop growth was noted on Alfisol.

Alfisols have much smaller water holding capacity, and clay content (Rao and Willey, 1980). Their nutrient supplying capacity is also limited. In contrast, Vertisols have advantage of high water holding capacity and nutrient supplying capacity (Rao and Willey, 1980). Due to moisture as well as other limitations, average yield over several years medium-duration cultivars was always more on Vertisols than on Alfisols (Venkataratnam and Sheldrake, 1985). However, an opposite trend was observed in case of short-duration cultivars (Chauhan et al., 1987). In the present study overall crop yield was significantly more on Alfisol than on Vertisol (Table 4.8). This difference can not be attributed to differences in climatic factors as both fields are located close by. Yield advantage on Alfisol was substantial, up to 60 per cent in spite of a moisture deficit on this soil which was evident form a 18 per cent response to applied irrigation (Table 4.8). In other seasons when rainfall was less than normal and short, a much greater response to irrigation has been reported on Alfisol (Chauhan et al., 1992). Also the yields of short- and extra-short-duration genotypes have been found to be comparable or higher than medium-duration genotypes under rainfed conditions because the latter suffered from terminal stress (Chauhan et al., 1993). In such seasons, even on Vertisol a positive response to applied irrigation was reported. In this study the yield differences between the two soils were even greater in the irrigated treatment because the response to applied irrigation in yield was negative on Vertisol and positive on Alfisol. Clearly, the applied irrigations were in excess of water requirement on Vertisol and necessary for maximizing yield on Alfisol. This is evident from the reduced oxygen concentration on Vertisol (Fig. 4.4) which were in conformity with the

However, for the medium-duration genotypes such as ICP 7035, ICPL 87119 and ICPL 227, which maintained more than 80 per cent plant stand, it may have been adequate due to high plasticity of plants (Rao et al., 1981).

Harvest index, and yield component such as seeds pod$^{-1}$ and 100-seed weight were significant due to soil effects. The effect was most conspicuous for pods m$^{-2}$ (Table 4.9). The differences in 100-seed weight in the present study do not agree with the previous studies on pigeonpea where it was shown to be a very stable character (Sheldrake and Narayanan 1979, Sheldrake, 1984). Those observations were made by growing medium-duration genotypes. In the present study, extra-short- and short-duration genotypes were also included. This may suggest that 100-seed weight of pigeonpea, which was thought to be stable is also an unstable character and may need stabilization as it is not only an important yield contributor but also a quality parameter of considerable economic value. The effect of irrigation on 100 seed weight however, was not significant on any of the soils (Table 4.11).

Effect of soil type and irrigation was significant on *Helicoverpa* pod borer damage (Table 4.13). Even though this was attempted to be controlled on both soils, yet significantly more damage occurred on Vertisol. This is consistent with the observations made by Reed and Lateef, (1990). They found 62 per cent *Helicoverpa* damage on Vertisol as against 42 per cent on Alfisol. While very wet conditions on Vertisols might have reduced effective need-based spraying on Vertisols, differences in plant and pod growth could have also contributed to higher damage on this soil. One of the reasons why Vertisols had higher *Helicoverpa* attack could be that pods developed 31 per cent more slowly on Vertisol than on Alfisol. This would have allowed pod borer more time to attack the developing pods.

Genotypes of different maturity interacted with the soils and the irrigation treatments. Soil x genotype and irrigation x genotype interactions for time to flowering and maturity, 100-weight, yield, and total dry matter were highly significant (Appendix 4.2 and 4.3). A Significant soil x genotype interaction for both yield and dry matter were observed due to extra-short-, short-duration and also due to wilt susceptible medium-duration genotypes (ICP results of Okada et al., 1991; Drew and Lynch, 1980; Griffin, 1972; Stolzy, 1974). However, in the present study the oxygen concentration in Vertisol were higher than those observed by Okada et al., (1991). The primary reason for higher oxygen level in Vertisol was that the observations were taken at a fixed interval of time but not immediately after a rainfall event or excess irrigation treatment. The overall range of variation in yield of 1.7 to 3 t $ha^{-1}$ on Alfisol was much smaller than that of 0.05 to 2.3 t $ha^{-1}$ on Vertisol suggesting that under nonlimiting moisture conditions the realized yields are higher and more stable on Alfisol than on Vertisol. Yield of some medium-duration genotypes was higher than the short- or extra-short-duration genotypes on both Alfisol and Vertisol (Table 4.8). Genotype ICPL 227 (MD) gave over 3.2 t $ha^{-1}$ under irrigated conditions and up to 2.8 t $ha^{-1}$ under rainfed conditions on Alfisol suggesting that in the absence of severe water deficit and diseases such as wilt, the realized yields from some medium-duration genotypes can be very high. The yield advantage of ICPL 227 (wilt resistant MD genotype) over extra-short-duration genotypes was even greater on Vertisol. However, on Alfisol, short- and extra-short-duration genotypes also gave up to 2.4 t $ha^{-1}$ and a substantial response to irrigation due to lack of rainfall during their reproductive period (Fig. 4.1).

There was an advantage of irrigation in dry matter production on Alfisol compared to Vertisol (Table 4.7). On Alfisol, dry matter production increased with irrigation whereas it was higher in the rainfed treatment on Vertisol. The crop had a lower total chlorophyll content on Vertisol which was further reduced by supplemental irrigations. This is in agreement with the result of Talbot et al., (1987). The lower dry matter production on Vertisol was in spite of the fact that crop duration was up to one month longer. Obviously, there a was reduction in dry matter production on Vertisol on daily basis.

Some decrease in dry matter production on Vertisol was attributable to low plant stand (Table 4.3). While reduction in plant stand in short- and extra-short-duration genotypes on Vertisol was primarily due to wilting induced by waterlogging (Reddy et al., 1990) in ICP 8379 and ICP 14199 (MD) genotypes it was primarily due to the incidence of *Fusarium* wilt.


Plate 5.1 Response of pigeonpea genotypes to waterlogging grown on Alfisol during Kharif 1994 at ICRISAT Asia Center (IAC). Plant growth in Irrigated treatment (I) was superior to that of rainfed treatment (R).


Plate 5.2 Pigeonpea genotypes showing severe chlorosis and plant mortality caused due to waterlogging on Vertisol during Kharif 1994 at ICRISAT Asia Center (IAC). Severity was more pronounced in Irrigated treatment (I) than in rainfed treatment (R).

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8379 and ICP 14119) showing a greater sensitivity to Vertisol than the Alfisol. This suggests that these characters were influenced by moisture differences in soils and due to differential application of water. However, soil x genotype interactions only and not irrigation x genotypes were significant for plant survival, harvest index, pod borer damage suggesting that differences arising between the two soils that may not necessarily be due to differences in moisture availability.

On Alfisol, genotypes showing 100 per cent survival were ICPL 90004 (ESD*), ICPL 87 and ICPL 86012 (both SD), and ICPL 87119 (MD). However, on Vertisol, none of the genotypes showed 100 per cent survival (Table 4.4). Maximum survival on this soil was exhibited by ICPL 87 (SD) followed by ICPL 87119 (MD), ICPL 90004 (ESD*), ICPL 86012 (SD). Thus, genotypes showing high survival were the same on both soils. There was no indication that ESD* were more prone to mortality than other ESD and SD genotypes on Vertisol. Among extra-short-duration genotypes ICPL 88039 and among short-duration genotypes ICPL 89018 showed about 60 per cent survival on Vertisol whereas others had about 80 per cent survivality. Variation in plant survival correlated significantly with seed yield across genotypes ($r= 0.32^{*}$ ; n=60) and environments ($r=0.92^{**}$; n=12) indicating its importance as selection parameter for high and stable yield (Appendix 4.11).

Lower yield of pigeonpea on Vertisol especially under irrigated conditions may also be related to reduction in plant vigor and consequently growth (Chauhan, 1987; Hodgson, 1989). Indeed, total dry matter, chlorophyll contents, leaf area index correlated significantly with yield both across genotypes and environments (Appendix 4.11). Thus, genotypes with higher dry matter production and chlorophyll contents (which can be identified by foliage color) should be selected to improve adaptation to Vertisol in addition to higher survival. On Vertisol, ICPL 87 (SD) had distinctly superior chlorophyll a, b and total chlorophyll content than the other extra-short- and medium-duration genotypes (Tables 4.18 to 4.20). It also produced more dry matter in the Vertisol-irrigated treatment than any of the extra-short- and short-duration genotypes and was comparable to that of the medium-duration genotypes in spite of early maturity (Table 4.7). On Vertisol, not only was the pod formation reduced, but also seed size. Differences in harvest index among genotypes, however, did not correlate with yield variation among them (Appendix 4.11).

Contrary to the expectation, abscission of dry matter, both vegetative and reproductive was less on Alfisol than Vertisol than the irrigated treatment (Tables 4.23 to 4.25). This may be because the demand for remobilizing assimilate and nutrient reserves may be more on Alfisol due to heavier pod load. This suggests that waterlogging conditions on Vertisol may not induce large-scale abscission even though leaves may turn more chlorotic (Krizek, 1982; Scott, 1989) as indicated by reduction in chlorophyll contents (Chan and Hodgson, 1981; Hodgson, 1982; Hodgson and Chan, 1982).

Significant soil x genotypes and irrigation x genotypes interactions for times to flowering and maturity (Appendix 4.2) suggest that there is considerable phenological plasticity in pigeonpea which is unrelated to photoperiod and temperature. Muchow (1985) found little variation in flowering and maturity behavior of pigeonpea under drought stress. However, under excessive moisture conditions in Vertisol, its flowering and maturity showed considerable variation which was also related to genotype. Delayed flowering appears to be an adaptive mechanism as this seems to allow time for greater recovery, as was evident in ICPL 87 and ICPL 86012 (both SD). It is interesting to note that although time to flowering and maturity was positively related to yield across genotypes, it was negatively related to yield across environments (Appendix 4.11). On Alfisols, all genotypes flowered and matured earlier, yet they yielded more (Tables 4.5 and 4.6). This suggests that early maturity and high yield of pigeonpea crop in a given environment can be ensured by ensuring proper soil environment. This has implications for ensuring success of extra-short-and short-duration genotypes in double cropping in some environments. Chauhan et al., (1992) suggested that availability of phosphorus (P) nutrition can influence phenology in pigeonpea. It is not known if the delayed flowering and maturity on Vertisol is mediated by reduced uptake of nutrients such as P.

## 5.2 Yield System Analysis

Quantification of genotype x environment interactions and underlying physiological causes is of immense value to plant breeders and agronomists in their quest to maximize yield especially in stress environments. In the present study, AMMI analysis suggested that about 26 per cent of the variation in yield was caused by genotype, 66 per cent by environment interaction, and 8 per cent due to genotype x environment interaction (Appendix 4.9). Thus, there seems nearly 26 per cent variability in yield across environments which is amenable to improvement through a selection of genotype and 8 per cent through further selection of specifically adapted genotypes. Appreciably high variation accounted for by genotype itself suggests that identification of superior genotypes adapted to both soils and moisture environments is feasible. Screening of such genotypes and their early segregants in the early generations for yield can lead to appreciable improvement in yield. About 66 per cent improvement can be effected through agronomic improvement of the environment. This could include improvement in drainage, through planting configuration and slope of the field. Additional 8 per cent gains are expected if appropriate genotypes and improved agronomic measures are combined.

Biplot presentation of AMMI means (Fig. 4.10) clearly indicated the two soils represented different response patterns and similarly superiority of ICPL 227 and ICPL 87119 among medium-duration genotypes and ICPL 87 among the short-duration genotypes was distinct. Not only were their mean yields higher than the other genotypes in the group and across but also they had PCA 1 scores of similar negative sign as that of Vertisol environments indicating positive interaction for yield on this soil (Table 4.26). The difference in the interaction scores of positive and negative signs were discussed below.

The predicted grain yield of ICPL 227 by just comparing means would have been 3.56 t $ha^{-1}$ on Alfisol-irrigated environment (2.68 + 0.88 = 3.56; genotype mean plus the soil-environment mean deviation form the grand mean) and 2.10 t $ha^{-1}$ (2.68 - 0.58 = 2.10) on Vertisol-irrigated environment; resulting in a mean difference in the performance of 1.46

t $ha^{-1}$ in two environments. However, when interaction was taken into account, the difference between the predicted performance in two soils could be only 0.32 t $ha^{-1}$. The predicted mean yield for including the interaction effect was calculated from grand mean + (genotype mean - grand mean) + (environment mean - grand mean) + (PCA 1 score for genotype x PCA 1 score of environment for each environment (for e.g., Alfisol-irrigated 1.45 + (2.68 - 1.45) + (2.23 - 1.45) + (-0.373 x 0.311) = 3.576 t $ha^{-1}$ and for Vertisol irrigated 1.45 + (2.68 - 1.45) + (0.86-1.45)+ (-0.373 x -0.654) = 3.275 t $ha^{-1}$) (Zobel and Wallace, 1995). This example highlighted the value of considering interaction in the comparison of genotypic performance. The expected performance of all other genotypes in different environments can be compared in the similar manner.

Genotype ICP 7035 (MD) was grouped together with other extra-short- and short-duration genotypes. ICPL 14199, and ICP 8379 genotypes had similar positive sign PCA score as that of Alfisol indicating positive interaction on this soil and negative interaction with Vertisol (Table 4.26). We expected these genotypes to yield well on Vertisol due to their waterlogging resistance (ICRISAT Legumes Program Annual Report, 1992). However, these turned out to be wilt susceptible and hence their advantage could not be assessed (Table 4.4).

AMMI analysis made it easy to visualize the superior genotypes from a AMMI biplot. However, it was important to know what traits could have contributed to superior yield for initiating a selection and breeding program. Formation of yield is a complex process. Often underlying factor(s) which contributes to yield variation are not identified because the of the inherent complexity of doing so. Wallace and Masaya (1988) proposed that while yield is ultimately contributed by numerous biochemical and physiological processes, their integrated effect could be measured in major components of yield, i.e., total biomass, harvest index, and time needed to accumulate biomass over both during the vegetative period and reproductive period. In the present study, all the four major components of yield were measured. From these major components of yield additional components were derived in a yield system analysis approach proposed by Wallace et al., (1993a). The combinations of irrigation and soil were treated as individual environments. Among these components, the genotype x environments interactions were significant for all except for days to flowering (Appendix 4.9).

Of the several components of yield system analysis, total dry matter $ha^{-1}$, yield $day^{-1}$, seed-fill duration, yield accumulation $day^{-1}$ of seed fill duration correlated significantly with the yield (Appendix 4.11). Values of all these components were higher on Alfisol than on Vertisol. Tandem application of YSA-AMMI analysis identified larger negative and positive correlation among yield and the eight of the physiological genetic components of the process for its accumulation. Some of the largest negative correlation occurred between the HI and biomass (-0.54), days to flowering (-0.72), days to maturity (-0.75), seedfill duration (-0.74) and biomass $day^{-1}$ (-0.43) across the 20 pigeonpea genotypes. While across the four soil-moisture environments a large negative correlation was observed between HI and days to flowering (-0.84) and days to maturity (-0.79). The effect of soil was largely through production of dry matter rather than the increased abscission. Further visualization of these traits on AMMI biplots enabled identification of superior genotypes for each soil.

For dry matter production ICPL 227 and ICPL 87119 among medium-duration genotypes and ICPL 87 and ICPL 86012 among short-duration genotypes were superior on both soils (Table 4.26). These genotypes were also superior in dry matter production $day^{-1}$ basis. ICPL 86012 showed similar positive PCA 1 score as the Vertisol environments. Genotypes that have superior growth rate may cope with excess soil moisture better because it would accompany greater soil moisture use due to which water in the soil rhizosphere will decrease faster and allow air to diffuse rapidly.

For seedfill duration also ICPL 87, ICPL 86012 (both SD), ICPL 227 and ICPL 87119 (both MD) were superior. Seedfill duration of ICPL 86012 and ICPL 87 had similar negative PCA 1 as of Vertisol indicating positive interaction (Table 4.27). The extended seedfill duration may allow greater recovery. The delay in time to maturity on Vertisol was maximum in these two genotypes. For yield accumulation day$^{-1}$ of seedfill duration was also an important character with which yield across 20 genotypes correlated significantly (Appendix 4.11).

YSA-AMMI was successful in identifying genotypes that can optimize yields under stress condition/environments by quantifying the degree of adaptation to that particular environment being bred for. For example, for adaptation of genotypes to Vertisol environments which are more frequently subjected to waterlogging, genotypes such as ICPL 227 and ICPL 87119 with higher dry matter production are needed. Higher dry matter production can either be from longer duration or higher rate of accumulation of dry matter day$^{-1}$ . Genotypes that grow rapidly will be able to remove excess moisture from the soil expeditiously before it begins to severely harm the roots. However, under certain conditions genotypes that grow fast may also be prone more to waterlogging due to high evaporative demand vis-a-vis ability of their damaged roots to extract water (short- and extra-short-duration genotypes). Genotypes that grow longer have better ability to recover from waterlogging stress. Genotypes with higher grain yield accumulation day$^{-1}$ of seedfill duration or longer seedfill duration performed better on Vertisol. However, the same yield traits i.e., total dry matter day$^{-1}$, seedfill duration and yield day$^{-1}$ of seedfill duration were found to significantly correlated with yield on Alfisol also suggesting that the selection of genotypes with such traits will not result in lower yields in a waterlogging free environments.

# *SUMMARY*
# *&*
# *CONCLUSION*

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

Pigeonpea in the semi-arid tropical regions of India is mainly grown on Vertisols and Alfisols. The productivity of the crop on both soils is around 0.5 $t\ ha^{-1}$ while the potential yield is much higher. Low realization of yield is due to limitation imposed by various abiotic and biotic stress factors. These two soil types differ appreciably in soil moisture holding capacity. Vertisols have greater moisture supplying capacity and are prone to waterlogging because of the high clay content. Alfisol in contrast are more prone to intermittent and terminal drought due their low water holding capacity. One of the reasons for low yield on these soils could be that pigeonpea genotypes that are grown are poorly adapted to these soils in relation to maturity period mismatching the length of growing period determined by soil moisture availability, or due to susceptibility to one or more abiotic constraints encountered on these soils.

Matching the duration of the periods of soil moisture availability is one of the important strategies for maximizing crop productivity. In pigeonpea, genotypes of a wide range of maturity period varying from extra-short-duration (<100 days) to medium-duration (<180 days) are available for cultivation. Some of these possess some degree of resistance to waterlogging and drought. Their adaptation to Vertisols and Alfisols may vary depending on their duration and resistance to stress factors. In this study an attempt was made to understand the relative adaptation of these genotypes to Alfisols and Vertisols by simulating some of the growing conditions that pigeonpea experiences on these soils. The objectives of the study were to compare growth, dry matter production, yield and its components in extra-short-, short- and medium-duration pigeonpea genotypes grown on Alfisols and Vertisols under rainfed and simulated excess moisture environments; to quantify the effect of environment and their interactions; and to elucidate basis of G x E interactions.

The experiment was conducted on a Vertisol and Alfisol at the ICRISAT Asia Center during the crop growing season of 1994. The experiment on each soil was laid out in a split-

split plot design with rainfed and irrigated treatments as main plots and 20 pigeonpea genotypes, 10 extra-short- (including 5 having ICP 7035 as one of the parents), 5 short- and 5 medium-duration genotypes as sub-plots. The data were analyzed using analysis of variance procedure, regression statistics using GENSTAT software (GENSTAT Manual, 1983) and additive main effects and multiplicative interaction effects (AMMI) statistical method (Rhizostasitics 2.0, Cornell University, USA).

The total rainfall during the experimental period was higher than the long term average. Due to this the development of drought was only mild on Alfisol. On Vertisol, application of supplementary irrigation created waterlogging conditions. The total amount of water (rainfall + irrigation) supplied during the crop growth period was approximately 600-900 mm on Alfisol and 690-830 mm on Vertisol. With the advance of the rainy season, the oxygen concentration in the root zone of the saturated soils dropped sharply affecting the crop growth and functions on Vertisol. The crop appeared chlorotic, and grew poorly on Vertisol, especially in the irrigated treatment. Grain yield losses due to waterlogging were comparatively larger on Vertisol than on Alfisol. Pigeonpea grown on Alfisol showed an yield advantage of up to 60 per cent under similar environmental conditions. The response of yield to the applied irrigation was negative on Vertisol and positive on Alfisol. Under the non-limiting moisture conditions, the realized yields are higher and more stable on Alfisol than on Vertisol indicating that the overall range of variation in yields are much smaller on Alfisol than on Vertisol. Among the four pigeonpea groups tested, the grain yields of short- and extra-short- genotypes along with wilt susceptible medium-duration genotypes were significantly reduced on Vertisol compared to Alfisol. This was mainly due to high soil moisture content in the rhizosphere affecting the plant growth and dry matter production. The development of yield components was mainly restricted during both vegetative period as well as during the recovery period. Among the 20 pigeonpea genotypes, ICPL 227 and ICPL 87119 (MD) genotypes produced the highest yield while wilt susceptible medium-duration genotypes ICP 8379 and ICP 14199, which are tolerant to waterlogging produced the lowest. This suggests that waterlogging tolerance *per se* may not be of much help unless combined with resistance to important diseases. Most of the variation in seed yield observed in this study could be explained on the basis of variation in the total biomass produced by the genotype, which was significantly related with seed yield. A significant difference was observed due to genotype, soils and soil x genotype interaction with respect to harvest index, seeds $pod^{-1}$, pods $m^{-2}$ and hundred seed weight. Number of seeds $pod^{-1}$ were relatively more stable than other yield components. The extent of these changes in seed yield varied with the degree of excess soil moisture.

In general, the overall growth of pigeonpea genotypes was reduced on Vertisol due to reduction in plant stand, plant survival, LAI, dry matter and yield components like no of pods $m^{-2}$, seeds $pod^{-1}$ and harvest index. The severity of *Helicoverpa* and *Phytophthora* blight incidence was more on Vertisol than on Alfisol and increased with additional irrigation.

Yield system analysis (YSA) was used to compare the grain yields of 20 pigeonpea genotypes grown in four soil-moisture environment (80 treatment) with the aerial biomass production, days to seedfill, harvest index, yield, biomass $day^{-1}$ to harvest maturity and yield $day^{-1}$ of seedfill duration were calculated and also compared. An AMMI analysis was applied to all 240 levels (from three replications) for each of the nine traits.

The major conclusions of the study were :

1. During the rainy season, the soil profile of Vertisol was filled to saturation. Under this condition crop growth and development were restricted. The oxygen concentration of the saturated soils dropped sharply. This indicated that anaerobic conditions of the soil under excessive soil moisture had a similar effect as waterlogging condition.

2. Low soil oxygen concentration in the root zone of saturated soil affected root growth and root function of pigeonpea. The symptoms of chlorosis, poor crop growth and early leaf senescence were observed on Vertisol which were more pronounced in the irrigated treatment than rainfed treatment.

3. The chlorophyll content of all pigeonpea genotypes grown on Vertisol was lower than than that of the genotypes grown on Alfisol, and they were further reduced on Vertisol by irrigation.

4. Short- and extra-short-duration genotypes flowered and matured earlier on Alfisol than on Vertisol. These genotyes had larger harvest index but reduced biomass. While the medium-duration genotypes flowered and matured later with an enlarged biomass but reduced harvest index.

5. The effect of soil type and irrigation was significant on *Helicoverpa* pod borer damage. The incidence of pod borer damage was more on Vertisol (31%) than on Alfisol. Medium-duration genotypes when compared to short- and extra-short-duration were more tolerant to pod borer.

6. The decrease in dry matter production on Vertisol was attributable due to low plant stand on this soil. The low plant density in short- and extra-short-duration genotypes was primarily due to low plant survival induced by *Phytophthora* blight.

7. Grain yields of short- and extra-short-duration pigeonpea were significantly reduced on Vertisol (60%) than on Alfisol. Further, there was 18 per cent decrease in the yield due to additional irrigation. The response to additional irrigation was positive on Alfisol and negative on Vertisol.

8. Waterlogging during the vegetative phase mainly affected plant growth and dry matter production while waterlogging during reproductive phase caused loss of dry matter through leaf senescence and restricted development of yield components.

9. Among the yield components, the effect of soils was significant for seeds pod$^{-1}$, 100 seed weight and most conspicuous for pods m$^{-2}$. The effect of soil on harvest index was also significant. The effect of irrigation was however not significant for any of these yieled components on any of the soils.

10. There appeared to be a large difference in adaptation of genotypes to the different soils. Among the twenty genotypes tested ICPL 227 and ICPL 87119 (MD) were highly adapted to Vertisol; ICPL 87 and ICPL 86012 (SD) were moderately adapted to Vertisol while, ICP 8379 and ICP 14199 (MD) were least adapted to Vertisol due to wilt susceptibility.

11. Among the nine traits of yield system analysis, AMMI analysis revealed a significant genotype x environment interaction for all except days to 50 per cent flowering across the 20 pigeonpea genotypes in four soil-moisture environments.

12. Of the several components of YSA, biomass, days to flowering and maturity, yield day$^{-1}$, seed fill duration and yield day$^{-1}$ of seedfill were significantly correlated with yield across the 20 pigeonpea genotypes. The values of these components were higher on Alfisol than on Vertisol. Across the four soil-moisture environments, a significant positive correlation was observed between yield and biomass, harvest index, yield day$^{-1}$, biomass day$^{-1}$ and yield day$^{-1}$ of seedfill duration while a negative correlation was observed between yield and days to flowering, days to maturity and seedfill duration.

13. Tandem application of YSA-AMMI analysis identified larger negative and positive correlation among yield and eight of the physiological genetic components of the process for its accumulation. Some of the largest negative correlations occurred

between the HI and biomass (-0.54), days to flowering (-0.72) days to maturity (-0.75), seedfill duration (-0.74) and biomass $day^{-1}$ (-0.43) across the 20 pigeonpea genotypes. While across the four soil-moisture environments a large negative correlation was observed between HI and days to flowering (-0.84) and days to maturity (-0.79).

14. A negative correlation was observed between yield and days to flowering (-0.81) and days to maturity (-0.78) across the four soil-moisture environments while there was no correlation observed between yield and HI (0.003) across the 20 pigeonpea genotypes and a positive correlation (0.83) across the four soil-moisture environments.

15. Among the nine traits of YSA, total biomass $day^{-1}$, seedfill duration and yield $day^{-1}$ of seedfill duration were found to be the major yield contributing factors on both waterlogging and waterlogiing free environments.

16. The quantification by AMMI of the main and G x E interaction were interpretable from their relative vertical and horizontal positions on a biplot graph with just one point for each genotype and one for each environment. Therefore, holistic inclusion of all genotypic and environmental effects allowed visual interpretation of the relative effects due to the several factors causal of the large variation. In this study, much interpretation was achieved from 20 points for the genotypes plus four points from the soil-moisture environment, 24 being for fewer than direct comparison of the 80 treatment averages.

17. The interpretation derived from the 24 points can be used in conjunction with the 80 averages to further enhance the ability to select for superior adaptation and higher

yield.

18. YSA-AMMI provided a focus on the physiological-genetic components of the process of accumulating yield and sharpened the focus on the G x E interaction through its two way classification of the experiments treatments as either genotypes or environments.

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# *APPENDICES*

**Appendix 4.1 Meteorological data for the growing season in Kharif season 1994 at ICRISAT.**

| STD Week | RAIN mm | EVAP mm | T MAX °C | T MIN °C | RH07 % | RH14 % | WIND kphr | SUN hr |
|---|---|---|---|---|---|---|---|---|
| 25 | 19.4 | 44.9 | 31.3 | 23.2 | 83.4 | 52.9 | 18.2 | 2.0 |
| 26 | 18.0 | 50.5 | 32.3 | 23.1 | 85.0 | 53.3 | 17.4 | 3.5 |
| 27 | 49.6 | 36.5 | 29.6 | 22.1 | 91.1 | 61.9 | 16.4 | 3.9 |
| 28 | 24.6 | 22.1 | 27.5 | 22.1 | 90.9 | 81.1 | 21.6 | 0.5 |
| 29 | 19.4 | 42.4 | 30.7 | 22.8 | 87.4 | 62.9 | 19.0 | 2.5 |
| 30 | 40.3 | 29.6 | 29.6 | 22.5 | 90.4 | 72.3 | 13.8 | 2.5 |
| 31 | 9.3 | 29.8 | 29.1 | 22.6 | 87.0 | 67.0 | 13.2 | 0.5 |
| 32 | 37.0 | 38.6 | 29.9 | 22.3 | 86.1 | 58.3 | 12.2 | 3.7 |
| 33 | 54.2 | 27.6 | 29.1 | 21.9 | 92.3 | 68.7 | 11.7 | 2.5 |
| 34 | 88.4 | 27.9 | 29.6 | 22.1 | 92.9 | 74.4 | 10.3 | 3.9 |
| 35 | 17.5 | 27.6 | 27.8 | 21.8 | 89.9 | 78.3 | 16.1 | 1.9 |
| 36 | 12.5 | 32.9 | 30.0 | 21.6 | 90.4 | 59.1 | 14.8 | 3.5 |
| 37 | 11.0 | 38.7 | 30.9 | 21.9 | 92.0 | 55.9 | 7.8 | 8.5 |
| 38 | 36.0 | 30.6 | 29.5 | 19.7 | 88.6 | 58.7 | 9.1 | 6.4 |
| 39 | 6.0 | 33.9 | 31.5 | 19.8 | 87.9 | 45.1 | 5.1 | 7.5 |
| 40 | 163.6 | 19.1 | 29.4 | 21.6 | 95.3 | 67.6 | 8.9 | 3.4 |
| 41 | 0.0 | 26.4 | 30.0 | 20.2 | 95.9 | 53.0 | 6.5 | 6.8 |
| 42 | 3.4 | 30.7 | 29.6 | 21.0 | 93.9 | 54.1 | 7.5 | 6.4 |
| 43 | 56.5 | 29.7 | 29.1 | 20.5 | 94.9 | 62.9 | 5.7 | 7.9 |
| 44 | 31.6 | 27.4 | 25.7 | 19.0 | 93.6 | 70.6 | 10.6 | 3.8 |
| 45 | 2.0 | 27.4 | 27.4 | 18.2 | 96.3 | 63.3 | 7.7 | 6.3 |
| 46 | 0.0 | 30.6 | 28.4 | 17.4 | 96.7 | 52.0 | 6.4 | 7.7 |
| 47 | 0.0 | 31.2 | 27.4 | 12.6 | 93.3 | 40.9 | 6.6 | 8.5 |
| 48 | 0.0 | 31.7 | 27.9 | 11.6 | 96.4 | 38.6 | 5.1 | 9.7 |
| 49 | 0.0 | 27.1 | 27.0 | 11.1 | 96.0 | 33.1 | 5.2 | 9.8 |
| 50 | 0.0 | 27.6 | 28.5 | 10.6 | 91.6 | 30.3 | 5.2 | 10.3 |
| 51 | 0.0 | 27.9 | 26.7 | 9.6 | 91.6 | 32.7 | 6.1 | 10.0 |
| 52 | 0.0 | 31.0 | 25.9 | 9.3 | 91.3 | 32.3 | 6.4 | 9.1 |
| 1 | 0.0 | 27.5 | 26.9 | 13.3 | 87.6 | 35.4 | 9.6 | 8.6 |
| 2 | 11.4 | 24.1 | 26.0 | 15.1 | 94.4 | 55.0 | 8.4 | 7.5 |

Note: Rainfall and Evaporation data are totals and other data are mean value.

**Appendix 4.2: F values and significance levels of soils (S), treatment (T), genotypes (G) and interaction effects on plants m$^{-2}$, per cent pod borer damage, per cent plant survival and phenological studies (days to flowering and days to maturity) of five ESD*, five ESD, five SD and five MD pigeonpea genotypes grown in rainfed and irrigated treatment on Alfisol and Vertisol during 1994 rainy season at ICRISAT Asia center (IAC).**

| Variable | Source of Variation | | | | | | |
|---|---|---|---|---|---|---|---|
| | S | T | G | S x T | S x G | T x G | S x T x G |
| Plant m$^{-2}$ | 3.08 ns | 1.67 ns | 84.54 ** | 0.74 ns | 1.66 * | 0.96 ns | 0.89 ns |
| Per cent pod borer damage | 89.94 ** | 6.37 * | 5.58 ** | 1.57 ns | 1.85 * | 0.81 ns | 1.32 ns |
| Per cent plant survival | 867.74 ** | 1.02 ns | 23.60 ** | 0.07 ns | 8.29 ** | 0.46 ns | 1.03 ns |
| Days to flower | 385.83 ** | 2.89 ns | 1020.2 ** | 5.59 * | 2.82 ** | 1.46 ** | 0.98 ns |
| Days to maturity | 219.39 ** | 28.37 ** | 1235.7 ** | 14.19 ** | 18.53 ** | 0.88 ns | 1.55 ns |

**Appendix 4.3: F values and significance levels of soils (S), treatments (T), genotypes (G) and interaction effects on yield (t ha$^{-1}$), total dry matter (TDM) at harvest (t ha$^{-1}$) and yield componnets of five ESD*, five ESD, five SD and five MD pigeonpea genotypes grown in rainfed and irrigated treatment on Alfisol and Vertisol during 1994 rainy season at ICRISAT Asia center (IAC).**

| Variable | Source of Variation | | | | | | |
|---|---|---|---|---|---|---|---|
| | S | T | G | S x T | S x G | T x G | S x T x G |
| Yield | 1062.04** | 17.60 ** | 26.20 ** | 46.45 ** | 5.84 ** | 0.93 ns | 1.25 ns |
| TDM at harvest | 840.99** | 0.59 ns | 35.90 ** | 12.01 ** | 6.22 ** | 0.79 ns | 1.16 ns |
| Yield components | | | | | | | |
| Pods m$^{-2}$ | 90.12** | 0.29 ns | 7.58 ** | 9.41 ** | 5.21 ** | 0.92 ns | 0.39 ns |
| Seeds pod$^{-1}$ | 70.98** | 3.09 ns | 6.45 ** | 0.64 ns | 3.02 ** | 0.81 ns | 1.46 ns |
| 100 Seed mass | 19.04** | 0.46 ns | 49.52 ** | 0.02 ns | 2.57 ** | 1.63 * | 1.10 ns |
| Harvest index | 26.33** | 0.54 ns | 18.08 ** | 0.10 ns | 3.22 ** | 0.65 ns | 0.85 ns |

Note : * , ** indicates significance levels at 5 and 1% respectively.
ns : nonsignificance.

**Appendix 4.4: F values and significant levels of soils (S), treatment (T), genotypes (G) and interaction effects on chlorophyll A, chlorophyll B and total chlorophyll (mg $g^{-1}$) content of leaf tissue of five ESD*, five ESD, five SD and five MD pigeonpea genotypes grown in rainfed and irrigated treatment on Alfisol and Vertisol during 1994 rainy season at ICRISAT Asia center (IAC).**

| Variable | Source of Variation | | | | | | |
|---|---|---|---|---|---|---|---|
| | S | T | G | S x T | S x G | T x G | S x T x G |
| Chlorophyll A | 15.34 ** | 3.57 ns | 7.02 ** | 2.54 ns | 1.27 ns | 1.01 ns | 0.82 ns |
| Chlorophyll B | 12.48 ** | 21.43 ** | 5.92 ** | 3.06 ns | 1.47 ns | 0.88 ns | 1.23 ns |
| Total chlorophyll content | 14.92 ** | 5.13 * | 6.85 ** | 2.87 ns | 1.32 ns | 0.98 ns | 0.89 ns |

**Appendix 4.5: F values and significant levels of soils (S), treatment (T), genotypes (G) and interaction effect on yield $day^{-1}$ (YLD $d^{-1}$, in t $ha^{-1}$ $day^{-1}$), total biomass $day^{-1}$ (TDM $d^{-1}$, in t $ha^{-1}$ $day^{-1}$), seedfill duration (days) and yield $day^{-1}$ of seedfill duration ( yld $sfd^{-1}$ in t $ha^{-1}$ $d^{-1}$) of five ESD*, five ESD, five SD and five MD pigeonpea genotypes grown in rainfed and irrigated treatment on Alfisol and Vertisol during 1994 rainy season at ICRISAT Asia center (IAC).**

| Variable | Source of Variation | | | | | | |
|---|---|---|---|---|---|---|---|
| | S | T | G | S x T | S x G | T x G | S x T x G |
| YLD $d^{-1}$ | 2085.8 ** | 9.09 * | 12.09 ** | 109.65 ** | 6.43 ** | 2.74 ** | 0.97 ns |
| TDM $d^{-1}$ | 887.9 ** | 0.02 ns | 9.20 ** | 15.46 * | 1.69 * | 2.38 ** | 0.71 ns |
| Seed fill duration | 25.9 ** | 4.07 * | 41.18 ** | 10.74 ** | 10.30 ** | 1.22 ns | 0.99 ns |
| Yld $sfd^{-1}$ | 2950.3 ** | 0.015 ns | 9.66 ** | 13.10 ** | 2.49 ** | 2.65 ** | 0.53 ns |

Note: * , ** indicates significance levels at 5 and 1% respectively.
ns : nonsignificance.

**Appendix 4.6: F values and significant levels of soils (S), treatment (T), genotype (G) and interaction effects on leaf area index (LAI) at 45, 55, 66, 94, and 105 das for five ESD*, five ESD, five SD and five MD pigeonpea genotypes grown in rainfed and irrigated treatment on Alfisol and Vertisol during 1994 rainy season at ICRISAT Asia center (IAC).**

| Source of Variation | Days after sowing | | | | |
|---|---|---|---|---|---|
| | 45 | 55 | 66 | 94 | 105 |
| S | 21.86 ** | 1.25 ns | 20.74 ** | 182.37 ** | 9.88 ** |
| T | 5.75 * | 0.07 ns | 6.20 * | 0.32 ns | 154.38 ** |
| G | 15.51 ** | 12.20 ** | 15.47 ** | 6.27 ** | 63.58 ** |
| S x T | 39.61 ** | 13.61 ** | 0.86 ns | 25.78 ** | 113.35 ** |
| S x G | 1.07 ns | 1.40 ns | 4.52 ** | 1.51 ns | 4.66 ** |
| T x G | 0.86 ns | 0.90 ns | 1.10 ns | 1.10 ns | 0.91 ns |
| S x T x G | 1.34 ns | 1.32 ns | 2.25 ** | 0.75 ns | 1.33 ns |

**Appendix 4.7: F values and significant levels of soils (S), treatment (T), genotypes (G) and interaction effects on leaf area index (LAI) at 134, 145, 164, 173, and 184 das for five medium-duration pigeonpea genotypes grown in rainfed and irrigated treatment on Alfisol and Vertisol during 1994 rainy season at ICRISAT Asia center (IAC).**

| Source of Variation | Days after sowing | | | | |
|---|---|---|---|---|---|
| | 135 | 145 | 164 | 174 | 184 |
| S | 28.37 ** | 29.39 ** | 19.05 ** | 10.02 * | 3.01 ns |
| T | 12.06 ** | 4.42 ns | 1.17 ns | 0.29 ns | 0.19 ns |
| G | 17.39 ** | 21.73 ** | 5.58 ** | 8.99 ** | 1.76 ns |
| S x T | 0.05 ns | 0.33 ns | 0.20 ns | 0.01 ns | 0.62 ns |
| S x G | 13.48 ** | 16.25 ** | 5.17 ** | 11.02 ** | 1.55 ns |
| T x G | 1.59 ns | 0.92 ns | 1.15 ns | 0.46 ns | 0.06 ns |
| S x T x G | 1.63 ns | 0.38 ns | 1.08 ns | 0.69 ns | 0.08 ns |

Note: * , ** indicates significance levels at 5 and 1% respectively.
ns : nonsignificance.

**Appendix 4.8: F values and significant levels of soils (S), treatments (T), genotypes (G) and their interaction effects on abscised vegetative parts, reproductive parts and total plant parts of ESD*, ESD, SD and MD genotypes grown in rainfed and irrigated treatments on Alfisol and Vertisol during kharif 1994 at ICRISAT Asia center (IAC).**

| Variable | Source of variation | | | | | | |
|---|---|---|---|---|---|---|---|
| | S | T | G | S x T | S x G | T x G | S x T x G |
| Vegetative parts | 24.48 ** | 1.67 ns | 82.77 ** | 0.89 ns | 20.82 ** | 0.29 ns | 0.64 ns |
| Reproductive parts | 98.14 ** | 0.07 ns | 2.26 ** | 0.62 ns | 4.59 ** | 0.14 ns | 0.91 ns |
| Total abscised plant parts | 32.02 ** | 0.99 ns | 66.57 ** | 0.30 ns | 20.79 ** | 0.19 ns | 0.47 ns |

Note: * , ** indicates significance levels at 5 and 1% respectively.
ns: Non-significance.

**Appendix 4.9: Additive main effects and multiplicative interaction effects (AMMI) analysis table for yield (t ha$^{-1}$), total dry matter (t ha$^{-1}$) and harvest index, days to 50 per cent flowering and days to maturity of 20 pigeonpea genotypes grown in the rainfed and irrigated treatments on Alfisol and Vertisol during kharif 1994 at ICRISAT Asia center (IAC).**

| | | Yield (t ha$^{-1}$) | | | Total dry matter (t ha$^{-1}$) | | | Harvest index (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source | df | SS | %SS | Prob | SS | %SS | Prob | SS | %SS | Prob |
| Total | 238 | 154.8 | | | 2154.4 | | | 24111.2 | | |
| Treat | 79 | 142.8 | 96 | *** | 1924.1 | 89 | *** | 17656.6 | 73 | *** |
| Geno | 19 | 37.2 | 26 | *** | 59.1 | 50 | *** | 11837.4 | 67 | *** |
| Envi | 3 | 94.3 | 66 | *** | 64.9 | 39 | *** | 2772.3 | 16 | *** |
| G x E | 57 | 11.4 | 8 | *** | 18.1 | 11 | *** | 3046.9 | 17 | |
| PCA 1 | 18 | 9.2 | 81 | *** | 78.5 | 82 | *** | 2141.1 | 70 | *** |
| Residual | 39 | 2.2 | | | 9.6 | | | 905.9 | | |
| Error | 159 | 12.0 | | | 30.3 | | | 6454.6 | | |
| Grand mean | | 1.42 | | | 5.26 | | | 27.5 | | |

| | | Days to 50 flowering | | | Days to maturity | | | Days to seedfill duration | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source | df | SS | %SS | Prob | SS | %SS | Prob | SS | %SS | Prob |
| Total | 238 | 168987.1 | | | 269994.8 | | | 21181.4 | | |
| Treat | 79 | 167639.7 | 99 | *** | 268188.8 | 99 | *** | 18431.4 | 87 | *** |
| Geno | 19 | 161955.9 | 97 | *** | 252629.0 | 94 | *** | 12794.9 | 69 | *** |
| Envi | 3 | 4920.5 | 3 | *** | 11560.6 | 4 | *** | 1967.7 | 11 | *** |
| G x E | 57 | 763.3 | 0 | * | 3999.1 | 1 | *** | 3668.8 | 20 | *** |
| PCA 1 | 18 | 484.6 | 63 | *** | 3595.2 | 90 | *** | 3121.2 | 85 | *** |
| Residual | 39 | 278.8 | | | 403.9 | | | 547.6 | | |
| Error | 159 | 1347.0 | | | 180.6 | | | 2750.0 | | |
| Grand mean | | 83.69 | | | 130.88 | | | 47.05 | | |

**Appendix 4.10 AMMI analysis table for Daily productivity ( kg ha$^{-1}$ d$^{-1}$), Per day dry matter production (kg ha$^{-1}$ d$^{-1}$) and yield day$^{-1}$ of seedfill duration of 20 pigeonpea genotypes grown in the rainfed and irrigated treatments on Alfisol and Vertisol during kharif 1994 at ICRISAT Asia center.**

| | | Daily productivity (kg ha$^{-1}$ d$^{-1}$) | | | Per day dry matter production (kg ha$^{-1}$ d$^{-1}$) | | | Yield day$^{-1}$ of seedfill duration (kg ha$^{-1}$ d$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source | df | SS | %SS | Prob | SS | %SS | Prob | SS | %SS | Prob |
| Total | 238 | 9307.8 | | | 80643.3 | | | 5.94 | | |
| Treat | 79 | 8751.6 | 94 | *** | 70314.2 | 87 | *** | 5.59 | 94 | *** |
| Geno | 19 | 981.1 | 11 | *** | 10905.3 | 16 | *** | 1.07 | 19 | *** |
| Envi | 3 | 7178.7 | 82 | *** | 54432.5 | 77 | *** | 4.12 | 74 | *** |
| G x E | 57 | 591.7 | 7 | *** | 4976.5 | 7 | | 0.41 | 7 | *** |
| PCA 1 | 18 | 442.9 | 75 | *** | 2309.2 | 46 | * | 0.32 | 79 | |
| Residual | 39 | 148.8 | | | 2667.3 | | | 0.09 | | |
| Error | 159 | 556.2 | | | 10329.0 | | | 0.35 | | |
| Grand mean | | 11.42 | | | 40.78 | | | 0.26 | | |

**Appendix 4.11: Correlation matrix for the nine traits of yield system analysis and yield components across the 20 genotypes (a) and 4 soil moisture environments (b) for the 20 pigeonpea genotypes grown in rainfed and irrigated treatments of Alfisol and Vertisol during Kharif 1994 at ICRISAT Asia Center (IAC).**

a: Across the 20 genotypes (n=60). r values above 0.367 and 0.268 are significant at 1% and 5% respecively.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Yield (t ha$^{-1}$) | 1.000 | | | | | | | | | | | | | | |
| 2. Biomass (t ha$^{-1}$) | 0.813 | 1.000 | | | | | | | | | | | | | |
| 3. Harvest index (%) | 0.003 | -0.543 | 1.000 | | | | | | | | | | | | |
| 4. 100 seed weight (g) | 0.429 | 0.441 | -0.048 | 1.000 | | | | | | | | | | | |
| 5. Seed pod$^{-1}$ | 0.003 | -0.133 | 0.267 | 0.318 | 1.000 | | | | | | | | | | |
| 6. Pod m$^{-2}$ | 0.544 | 0.544 | -0.281 | -0.318 | -0.565 | 1.000 | | | | | | | | | |
| 7. Per cent pod borer | -0.462 | -0.579 | 0.363 | -0.240 | -0.276 | -0.323 | 1.000 | | | | | | | | |
| 8. Plant m$^{-2}$ | -0.404 | -0.658 | 0.561 | -0.406 | 0.129 | -0.363 | 0.479 | 1.000 | | | | | | | |
| 9. Plant survival (%) | 0.324 | -0.030 | 0.595 | 0.358 | 0.169 | -0.241 | 0.245 | 0.464 | 1.000 | | | | | | |
| 10. Days to flower | 0.467 | 0.790 | -0.719 | 0.392 | -0.131 | 0.449 | -0.614 | -0.924 | -0.504 | 1.000 | | | | | |
| 11. Days to mature | 0.482 | 0.829 | -0.754 | 0.388 | -0.185 | 0.473 | -0.599 | -0.903 | -0.463 | 0.990 | 1.000 | | | | |
| 12. Yield day$^{-1}$(kg ha$^{-1}$ d$^{-1}$) | 0.561 | 0.058 | 0.687 | 0.025 | 0.162 | 0.157 | 0.100 | 0.438 | 0.703 | -0.434 | -0.427 | 1.000 | | | |
| 13. Biomass day$^{-1}$(kg ha$^{-1}$ d$^{-1}$) | 0.715 | 0.863 | -0.426 | 0.216 | -0.143 | 0.489 | -0.380 | -0.247 | 0.153 | 0.436 | 0.503 | 0.283 | 1.000 | | |
| 14. Seedfill duration (days) | 0.464 | 0.836 | -0.745 | 0.347 | -0.324 | 0.459 | -0.454 | -0.678 | -0.219 | 0.791 | 0.869 | -0.325 | 0.658 | 1.000 | |
| 15. Yield day$^{-1}$ of seedfill duration (kg ha$^{-1}$ d$^{-1}$) | 0.857 | 0.506 | 0.307 | 0.184 | 0.125 | 0.464 | -0.269 | -0.106 | 0.367 | 0.152 | 0.134 | 0.797 | 0.528 | 0.046 | 1.000 |

b: Across the four soil-moisture environments (n=12). r values above 0.708 and 0.576 are significant at 1% and 5% respecively.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Yield (t ha$^{-1}$) | 1.000 | | | | | | | | | | | | | | |
| 2. Biomass (t ha$^{-1}$) | 0.986 | 1.000 | | | | | | | | | | | | | |
| 3. Harvest index (%) | 0.830 | 0.748 | 1.000 | | | | | | | | | | | | |
| 4. 100 seed weight (g) | 0.860 | 0.818 | 0.915 | 1.000 | | | | | | | | | | | |
| 5 Seed pod$^{-1}$ | 0.943 | 0.911 | 0.915 | 0.917 | 1.000 | | | | | | | | | | |
| 6. Pod m$^{-2}$ | 0.940 | 0.948 | 0.653 | 0.651 | 0.795 | 1.000 | | | | | | | | | |
| 7. Per cent pod borer | -0.969 | -0.939 | -0.879 | -0.844 | -0.970 | -0.885 | 1.000 | | | | | | | | |
| 8. Plant m$^{-2}$ | -0.343 | -0.256 | -0.616 | -0.544 | -0.510 | -0.123 | 0.382 | 1.000 | | | | | | | |
| 9. Plant survival (%) | 0.927 | 0.919 | 0.855 | 0.903 | 0.907 | 0.831 | -0.895 | -0.347 | 1.000 | | | | | | |
| 10. Days to flower | -0.809 | -0.844 | -0.484 | -0.523 | -0.666 | -0.892 | 0.749 | -0.082 | -0.729 | 1.000 | | | | | |
| 11. Days to mature | -0.781 | -0.795 | -0.684 | -0.733 | -0.762 | -0.711 | 0.765 | 0.229 | -0.887 | 0.773 | 1.000 | | | | |
| 12. Yield day$^{-1}$ (Kg ha$^{-1}$ d$^{-1}$) | 0.998 | 0.985 | 0.829 | 0.856 | 0.942 | 0.940 | -0.968 | -0.335 | 0.936 | -0.829 | -0.814 | 1.000 | | | |
| 13 Biomass day$^{-1}$(Kg ha$^{-1}$ d$^{-1}$) | 0.981 | 0.998 | 0.737 | 0.805 | 0.901 | 0.953 | -0.934 | -0.227 | 0.923 | -0.872 | -0.822 | 0.985 | 1.000 | | |
| 14. Seedfill duration (days) | -0.468 | -0.454 | -0.622 | -0.648 | -0.558 | -0.308 | 0.501 | 0.336 | -0.713 | 0.332 | 0.839 | -0.502 | -0.478 | 1.000 | |
| 15 Yield day$^{-1}$ of seedfill duration (Kg ha$^{-1}$ d$^{-1}$) | 0.989 | 0.979 | 0.837 | 0.871 | 0.941 | 0.922 | -0.961 | -0.334 | 0.961 | -0.821 | -0.862 | 0.995 | 0.982 | -0.585 | 1.000 |