THE EFFECT OF ENVIRONMENTAL FACTORS ON GROWTH, POD-SET AND YIELD OF SHORT DURATION PIGEONPEA (*Cajanus cajan* (L.) Millsp.)

By

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DECLARATION OF ORIGINALITY

The work reported in this thesis is my original research work unless as otherwise acknowledged and has not been submitted for a degree in this or any other university.

Signed:

Date: 28.3.89

This thesis has been submitted for examination with our approval as university supervisors.

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ABSTRACT

Four experiments were conducted to investigate effects of temperature, humidity, soil water deficits, photoperiod and sowing date on growth, pod-set and yield of different varieties of pigeonpeas. The varieties were chosen to include determinate (ICPL4, ICPL87, ICPL151) and indeterminate (ICPL81, UPAS120) types.

Temperature and photoperiod treatments imposed from flower initiation to harvest in a naturally lit glasshouse had no effect on shoot and root dry weights, but the pod number and grain yield were reduced except in one genotype when the day temperature was increased from 30^{o} to 40^{o}C. Variation in day/night temperatures showed that low night temperature delayed flowering and inhibited pod-set. Pod-set occurred at $30/15^{o}$C and $30/25^{o}$C day/night temperature in ICPL4 and ICPL81 but no pod-set was observed at $30/5^{o}$ in all the genotypes and at $30/15^{o}$ in ICPL87. High day temperature under growth chamber conditions caused complete flower abscission regardless of the night temperature and high leaf shedding occurred which influenced the biomass production.

High humidity and increased soil moisture increased leaf area for ICPL87 but reduced that for ICPL81. At high humidity the shoot dry weight decreased for ICPL81 at high soil moisture but an increase was observed for ICPL87. The flower number declined at high humidity and increased soil

moisture for ICPL87 but was not affected for ICPL81. High humidity reduced the number of pods, percentage pod-set and grain yield regardless of the moisture regime.

Delayed sowing at this site is characterised by declining day-length, temperature, as well as rainfall. The results of the sowing date experiment showed that delayed sowing led to a decline in leaf area and shoot dry weight at flowering as well as at maturity. Late sowing reduced the number of flowers, pods, branches, and percentage pod-set which led to a decline in grain yield.

The following conclusions may be made from the results of this work:

1. Increased day temperature reduced the grain yield as a result of greater flower abscission and pod abortion. Both day and night temperature are important for growth after flowering and pod-set in the genotypes studied.

2. 'Severe' water stress can limit the yield of these genotypes and the indeterminate genotype tolerated the water-limited situation better than the determinate.

3. A major effect of the date of sowing at this location and the genotypes used is the reduction in plant size due to reduced branching and stem size.

INTRODUCTION

1.1 General

In many developing countries, population pressures have resulted in a shift towards utilising marginal lands. A changing weather pattern in recent years, especially failure of the rains to come in time has led to serious droughts in several African countries (Palutikof, 1985). The unpredictable environmental conditions which may lead to crop failure make the farmers reluctant to use high inputs. For example, in eastern Kenya in the low potential lands of Embu and Meru, one out of three harvests in general will be poor or will fail completely (Wiggins, 1981).

Pigeonpea is reputed to do well under the unfavourable conditions of the marginal areas. This outstanding ability is attributed to its deep rooting nature which confers on it some level of drought tolerance to survive protracted water stress (Sheldrake et al. 1979; Whiteman et al. 1985).

The origin of pigeonpea is presently established to be India (Van der Maesen, 1980a,b). The eastern ghats of India is the probable place of origin with the African region developing later as a secondary centre of diversity. Pigeonpea belongs to the genus Cajanus of sub-tribe cajaninae, tribe Phaseoloeae of the Leguminosae family. There are several ways in which pigeonpea is utilised (Whiteman and Norton, 1981; Allen and Allen, 1981; Kay, 1979). It is a major source of protein in the vegetarian diets.

In India the dried grain is utilised in a split form referred to as "dhal" (Pandey, 1981). In parts of East Africa the dried grains are consumed whole by boiling in a mixture with maize and in the West Indies the green mature seeds are usually canned or frozen (Morton et al. 1980).

1.2 **Research Justification**

It is becoming increasingly clear that matching crop phenology with environment is advantageous in situations of environmental stresses (Lawn, 1981). Barlaug (1972) contended that the sustained scientific studies on production, management and utilisation of pigeonpea had been limited in the past. Recently, (Summerfield, personal communication, 1987) pointed out that there is wide recognition of the substantial productivity improvements that have been achieved within the cereals, but the grain legumes remain the "slow runners". The yield of pigeonpea in India is estimated at 692 kg per hectare (Whiteman et al. 1985). The figures quoted for pigeonpea in most cases do not indicate whether it was for short, medium or long duration types. The yields of these three groups differ remarkably, especially those of the short duration versus the long duration cultivars.

Environmental factors influence the growth and development of pigeonpea to a great extent (Turnbull, 1986). The effects of temperature are mediated through fundamental influences on water movement, uptake and transport of mineral ions, transpiration and translocation and ultimately cytoplasmic function (Wareing and Phillips, 1981). The adaptation of traditional cultivars of a crop is usually linked to differential responses to photoperiod which in turn are associated with seasonality and latitude. Water stress affects all aspects of plant growth (Simpson, 1981). Lawn (1980) has pointed out that pulses are most sensitive to water stress during the late flowering and early pod-filling stages. The effect of water stress may be modified by humidity (Tibbits, 1979). The cultivation of pigeonpea is spreading to coastal areas of peninsular India as well as coastal areas of Kenya (Kimani, 1985; ICRISAT, 1986). The humidity in these areas is higher than further inland where the crop is presently cultivated (Dennet, 1984).

O'Leary (1975) has reviewed much of the earlier work on the effect of humidity. The environmental factors are influenced by sowing date and pigeonpea plant phenology and dry matter partitioning can be greatly altered by planting date (Turnbull, 1986; Chauhan et al. 1987). The observations on the morphology and flowering behaviour of cultivar NPP 670 at various sites in Kenya underscores the need to further understand the behaviour of pigeonpea in different environments (Kimani, 1985). He observed that the height of this cultivar when grown at Kikambala (4°S, 16 m) near Mombasa was 1.6 m, further inland at Kibwezi (1.8°S, 1000 m) it was 1.4 m and at a higher altitude on the Field Station Farm of the Department of Crop Science, Faculty of Agriculture of the University of Nairobi at Kabete (1°S, 1820 m), the cultivar grows to a height of 0.5 m. Flowering at the lower altitude is delayed. These observations are also true for ICRISAT short duration genotypes when they are grown during rainy season at Patancheru and at a lower altitude but higher latitude at Hisar (Chauhan et al. 1987).

In crops whose economic yield is grain, the fruit number per plant is quite important (Sinha, 1977). This is related to plant size and duration of the crop (Akinola et al. 1977), Keatinge et al. 1981). Akinola et al. (1975) concluded that the number of fruit bearing branches and the length of the stem over which inflorescences are produced are clearly related to fruit number per plant and are affected by crop density, time of sowing and climatic factors. A large number of pigeonpea flowers abort (Pandey, 1981). It has been suggested that pigeonpeas develop only sufficient fruits that individual plants are capable of filling completely (Sheldrake, 1979). This intrinsic "self-regulating" mechanism (Sheldrake, 1979) is yet to be clearly understood and maybe environmental stresses contribute to it. There is need to understand the effects of environmental stresses on pod-set in pigeonpea. This will lead to -

a) Choice of the most suitable growing season.

b) Choice of the most suitable genotype.

c) More efficient use of scarce agronomic resources available to the farmer in the marginal areas.

1.3 Statement of Experimental Objectives

The differences observed in the growth and development of pigeonpea at different sites imply that quite different physiological limits will exist in material adapted to different places (Onim, 1981). In recent years emphasis in improvement of pigeonpea is being laid on developing short-duration genotypes in order to fit them into relay-cropping system in peninsular India (ICRISAT, 1986; Sinha, 1980). Information is required on the environmental limitations that may exist for these new plant types.

The study was carried out:-

a) To investigate the effects of temperature, photoperiod, humidity, and water stress during the reproductive stage on the partitioning of dry matter under controlled environments.

b) To evaluate the effect of sowing date on growth, pod-set, and yield.

c) To determine if any genotypic differences exist in the response to the above factors.

2. LITERATURE REVIEW

In grain legumes the pod number is an important component of yield. The implications of reduced pod set on yield are therefore clear since the final yield is determined largely by the number of pods formed. Many of the grain legumes bear many flowers but only a few end up as pods (Sinha, 1977). It is not clear why abscission of flowers and young pods occurs. Several explanations have been put forward (Sinha, 1977; Sheldrake, 1979; Rawson et al. 1980; Brun and Betts, 1984; Warrag et al. 1984). Some workers have stated that reproductive abscission is hormonally mediated (Heindel et al. 1984; Huff et al. 1980; Tamas et al. 1979). However others attribute it to the availability of photoassimilates (Sreeter et al. 1978; Rawson et al. 1980; Brun and Betts, 1982; Brun and Betts, 1984). Apparently no single hypothesis can suffice and it could be that this reproductive abortion is mediated through a combination of factors (Sheldrake, 1984). Sinha (1977) listed several factors that could be responsible for this phenomenon. The following review attempts to highlight the effects of four environmental factors and their role in determining reproductive development and yield.

For any given location there exists an optimum planting date. This provides the crop with the optimum conditions for growth and development so that reasonable yields can be realised. The date of planting therefore combines the effects of the various environmental factors and as such is an important aspect to consider in understanding the adaptation of new genotypes to a

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2.1 Effects of Temperature

Temperature is among the most important environmental factors affecting plant growth. It influences almost all growth processes and often determines where and when each plant is most successfully grown (Badizadegan, 1977). Some of the plant processes that are influenced by temperature are water movement and the uptake and transport of mineral ions, photosynthesis, transpiration and ultimately cytoplasmic function (Wareing and Phillips, 1981). Details of effects of temperature on several other plant processes are discussed in basic text books (Leopold, 1975; Salisbury and Ross, 1979).

Marowitch *et al*. (1985) studied the influence of temperature on photosynthesis and translocation rates in *Phaseolus vulgaris* and *Glycine max*. They reported that reducing the temperature to 5°C from the optimum 15°C reduced photosynthesis to a greater percentage in *Phaseolus* than in soybean. The effect on translocation was mainly on the rate at which the available translocate was transferred to the sink and the removal of the translocate from the conducting elements of the sink. Bjorkman (1980) reviewed the effects of temperature on photosynthesis.

Summerfield *et al*. (1980) reviewed literature on the effect of temperature on diverse aspects of growth and development in pulses. Several studies on soybean (Thomas and Raper, 1977), pigeonpea (McPherson *et al*. 1985), and cowpea (Littleton *et al*. 1979) have further demonstrated the importance of temperature on the growth and development of grain legumes.

The effect of temperature is realised quite early in the life of the plant. The maturity of seed and its subsequent ability to germinate is affected by high temperature during seed filling (Keigley and Mullen, 1986). They reported a consistent decline in germination and vigour in soybean as days of high temperature accumulated throughout the seed-filling period. The average seed weight reduced while the percentage of small seeds increased with high temperature.

Warrag and Hall (1983, 1984) investigated the response of cowpea to temperature during the reproductive phase. In screening a large number of lines for heat tolerance at flowering, they reported that high night temperature induced flower abscission. At 33/22°C temperature, development of cowpea appeared normal, although all the flowers abscised within 48 hours after anthesis. They attributed this to male sterility resulting from abnormal pollen development and anther indehiscence. This failure of anthers to dehisce has also been observed in soybean (Warrag el al. 1983; Summerfield et al. 1979). Under field conditions, Nielsen and Hall, (1985) observed complete abscission of flowers in six cowpea strains during hot weather, but a consequent decrease in night temperature led to pod set. The duration of pod fill and mean dry weights of cowpea are reduced due to warm air temperature (Roberts, 1980). Turk et al. (1980) stated that even under conditions of frequent irrigation seed yields and pod number per unit area were negatively correlated with hot weather during the month of flowering.

Controlled environment studies have contributed widely to the understanding of the effects of temperature on growth and development of cowpea. High day temperature is associated with flower abscission (Huxley and Summerfield, 1976; Stewart et al. 1980). In their studies on the effect of temperature on cowpea Stewart et al. (1980) reported decreased seed yields, fewer pods and reproductive nodes, enhanced peduncle abortion and earlier senescence at 33/19°C day/night temperature as compared to 27/19°C day/night temperature. Minchin et al. (1976) investigated the effects of diurnal variation in temperature that occurs in the greenhouse. They reported that the combination of high soil temperature and large variation in day/night soil temperature during flowering inhibited reproduction. They observed a high level of peduncle abscission and a very high proportion of abnormal male sterile flowers which also exhibited a high level of abscission. Grantz et al. (1982) concluded that for cowpea the reproductive stage is the one most affected by warm night temperature and therefore reduction in yield can be solely attributed to flower abscission.

In black gram and green gram, Lawn (1979) reported that genotypes of temperate or sub-tropical origin may be more responsive to day temperature and those of tropical origin more responsive to night temperature. Summerfield (1979) reported earlier flowering in chickpea as a result of warmer day and or night temperature. Recent studies on heat tolerance of chickpea during the reproductive stage indicate that high temperature curtails growth and reduces yield significantly (Summerfield et al. 1984). Saxena and Sheldrake (1980) made the observation that in chickpea the length of the reproductive period is determined by temperature and that no pod-set could occur at 5°C. Earlier flowering was observed in chickpea in warm environment (33/18°C) day/night temperature than in cool environment (22/10°C) day/night temperature (Roberts et al. 1980). An analysis of weather data from sixty-two location years in Oregon (USA) showed that the yields of pea were negatively correlated with the thermal sum above a temperature of 26.5°C during blooming and fruit filling (Pumphrey et al. 1979). They calculated that 13 kg^{-1} ha of yield was lost for each degree-day above 26.5°C. Williams et al. (1977) reported that increase in pod temperature promoted transport of photosynthate in pea. Van Schaik and Probst (1958) concluded from controlled environment and field experiments that high temperature appeared to increase pod shedding in soybean. Thomas and Raper (1977) reported that final plant height in soybean was determined by temperature, with plants grown at higher temperature being tallest. Lower temperatures and short photoperiods reduced the intensity of seed-fill in soybean (Thomas and Raper, 1976). In *Phaseolus vulgaris*, Andrews et al. (1981) reported that reduced yields could occur as a result of low temperature on the growth of late flowering branches. Holi et al. (1976) observed that the number of racemes in pea depends on the genotypes as well as the ambient temperature. Observations on the line "Verano" of the pasture legume *Stylosanthes* showed that the interval between the blooming of successive flowers on a single spike is negatively related to temperature (Argel and Humphreys, 1973).

The rate of increase in pod weight in groundnut has been observed to be higher at higher temperature (Cox, 1979). Using the cultivar Florigiant with day/night temperature combinations of 34/30°C, 18/14°C, and 34/30°C, 22/18°C, it was found that the rate of increase in individual pod weights and total fruit weights was greatest at 23.5°C.

Bond et al. (1980) reported that in faba beans pollen life was limited to a day at a high temperature of 30°C as compared to several days when the temperature was reduced to 15°C. In pigeonpea, like most other legumes flowers are shed to a large extent (Sheldrake, 1979). Studies on the effect of temperature on pigeonpea have mainly centred on early growth and development (e.g. McPherson et al. 1985; Turnbull, 1980, 1986). The events before flowering such as the development of sufficient canopy no doubt have an important bearing on the final yield, but a better understanding of the effects of temperature during flowering and pod formation is of particular importance in the semi-arid tropics. The pigeonpea plants usually start their reproductive development after a slow early growth (Sheldrake, 1984; Brakke and Gardner, 1987), which at times coincides with unfavourable weather conditions. Earlier studies (Akinola and Whiteman, 1985; Sheldrake and Narayanan, 1979) suggest that the overall growth rate of pigeonpea is influenced by temperature, with slower rates for winter crops. McPherson et al. (1985) tested eleven cultivars of pigeonpea that represented the different maturity groups under controlled environment. They observed a substantial effect of temperature on the duration from sowing to flower bud initiation and from sowing to flowering. The shortest duration or most rapid rate of development usually occurred in the 24/24°C treatment, with longer durations at both higher and lower mean temperature. However, a common mean with differing day/night temperature combination produced quite different results. By subjecting the data to discrete rate analysis, they reported that the rate of development from sowing to flower bud initiation changed by more than 50% in all cultivars over the range 16-32°C, while that from sowing to flowering was maximum from 20 to 28°C. The cultivars of different maturity groups did not differ in the rates of development from flower bud initiation to flowering at any given temperature. Detailed investigations on the role of temperature in early vegetative growth have recently been reported (Turnbull, 1986). Temperature determined vegetative growth and floral development in the early maturity lines QPL-2, QPL-3, Prabhat, and Hunt. These studies revealed that an increase of mean daily temperature from 16 to 32°C increased vegetative growth with the extreme inhibiting floral initiation. Genotypic differences were observed in rates of floral induction with QPL-2, QPL-3, and Prabhat having greatest floral induction rates in the range 20-24°C while Hunt had a higher range (24-28°C). Floral abortion increased and pod set decreased with high day temperature (35°C) irrespective of the night temperature, while the pod dry weight increased as night temperature increased regardless of the day temperature. In earlier studies Turnbull et al. (1980) reported that floral initiation occurred earliest under 24/16°C day/night temperature in a 16h photoperiod.

Ariyanayagam (1981) observed after testing six cultivars of pigeonpea under increasing night temperature from 18.3°C to 28.9°C that there was delayed flowering in some of the cultivars while others were unaffected.

The effect of temperature on reproductive development is variable as stated in the foregoing review. It is unclear whether it is day temperature or night temperature that exerts a greater influence. Some workers have stated that it is night temperature *per se* (Lawn, 1979; Littleton, 1979; Huxley *et al*. 1974; Littleton *et al*. 1979) in field trials and Summerfield *et al*. (1983) suggested that mean diurnal temperature is more important. McPherson *et al*. (1985) pointed out that response to different diurnal temperature regimes was not necessitated by thermoperiodism as suggested by Lawn (1979).

The poor yield of pigeonpea maturing during the summer months in India is said to be partly due to the high temperatures prevailing during pollination (Sharma *et al*. 1980). Several studies at ICRISAT center have identified some genotypes that set sufficient pods during the summer months (Chauhan Y.S, personal communication, 1987). This will likely enhance the cultivation of pigeonpea in areas that have ample irrigation during summer.

2.2 Effects of Water Stress

The rainfall pattern in the semi-arid tropics is characterised by alternate spells of drought and abundant water (Elston and Bunting, 1980). Crops in these regions are therefore subjected to water stress to varying extents and at various stages of their life cycles. The marginal lands of Kenya fall into water availability zones V and VI (Woodhead, 1970). Pigeonpea production is mainly concentrated in the transition zone that constitutes the semi-arid and arid lands. The rainfall pattern is bimodal, with the rainy season from March to May being referred to as the long rains and that from October to December being referred to as the short rains. The crop is sown in either rainy season and usually harvested after six or ten months depending on the maturity group. Hence water stress is realised in the intervening months that have no rainfall.

Kramer (1980) defined water stress as a phenomenon brought about by a shortage of water disturbing the normal function of the plant. McIntyre (1987a) stated that basically water plays three roles in plant development. These are:

i) to mediate the response of the plant to environmental factors.

ii) to provide a mechanism for the integration of plant development.

iii) to integrate growth and metabolic activity at the cellular level.

A number of reviews have been made on plant-water relations and plant response to water stress (e.g.Levitt, 1972; Hsiao, 1973; Begg and Turner, 1976; Teare and Peet, 1983; Parsons, 1983; Turner and Kramer, 1980; Simpson, 1981).

These reviews generally indicate that metabolic and physiological processes in the plant are impaired by water stress. Crop plants respond to water stress in diverse ways which vary from species to species and are modified by the environment. Turner (1978) suggested that plant response mechanisms should be classified as follows: drought escape, dehydration tolerance and dehydration avoidance. This classification has been modified by Kramer (1980) to remove some ambiguity in the use of terms when referring to mechanisms of plant response to water stress. He suggested use of the word "avoidance" instead of escape. Therefore this modified classification gives only two categories: drought avoidance and drought tolerance (dehydration postponement and dehydration tolerance). Flower (1985) pointed out that survival of plants in water-limited environments may depend on their ability to combine these response mechanism. Parsons (1982) discussed plant response under two headings: leaf shedding, leaf angle changes and root factors were grouped as morphological changes. Seven other response mechanisms - leaf cuticular wax, osmotic adjustment, leaf enlargement, stomatal behaviour, photosynthesis, translocation and proline accumulation were discussed under physiological changes. He concluded that nearly all metabolic processes in the plant are affected by water stress if the stress is severe and of long duration.

Similar conclusions were made by Hsiao (1973) that any parameter of crop growth was subject to change by water stress as long as the stress was severe and long enough.

Turner (1982) suggested that crops for water-limited environments should have their phenological development synchronised with water availability.

Legumes

Sherrif and Muchow (1984) stated that the effect of water deficits in crop production is mediated through its impact on duration of the crop cycle and canopy development. Monteith (1977) observed that the economic yield of a crop is dependent on the total amount of solar radiation intercepted and its conversion into dry matter as well as the efficiency of partitioning biological yield to economic yield. Therefore a shortened crop duration or limited canopy development will affect economic yield.

In legumes several forms of developmental plasticity have been identified (Turk et al, 1980; Lawn, 1982; Angus and Moncur, 1977; D'Souza and Coulson, 1988; Coulson, 1987). Paraheliotropic leaf movement which minimises the amount of solar radiation absorbed is well developed in legumes (Begg, 1980; Forseth and Ehleringer, 1982; Fisher and Ludlow, 1983; Seymour and Hsiao, 1986; Shackel and Hall, 1979). Osmotic adjustment has been studied in several legumes (Flower, 1985, 1986; Turner, 1978; Cortes and Sinclair, 1986; Nelson et al. 1980). It is a fairly useful mechanism under water-limited conditions. However, recent studies show that its contribution to economic yield in pigeonpea is not substantial (Flower, 1985). Muchow (1985a) compared several grain legumes grown under different soil water regimes and concluded that water deficits had little effect on the date of flowering, but the duration of flowering and pod filling was reduced and time to maturity hastened. In another study Muchow (1985b) reported that for plants undergoing progressive stress from seedling stage until maturity, the reduction in light interception was more important than the efficiency of conversion of photosynthetically active radiation to above ground dry matter. He concluded that the observed differences between these cultivars and species could be attributed to differences in water extraction patterns and efficiency and not phenological differences *per se*. Sinclair and Ludlow (1986) compared four grain legume species with regard to the influence of soil water supply on the plant water balance. They reported differences in dehydration tolerance between these legumes.

An added advantage of the legumes is their ability to fix atmospheric nitrogen and therefore improve the soil for the succeeding crop (Kumar rao *et al*. 1980). Water stress has been shown to greatly affect the nodulation process (Bonetti and Saite, 1984; Wien *et al*. 1979).

Several investigations have been made on the response of cowpea to water deficit at different stages of development (Lawn, 1982a,b; Silim, 1982; Turk *et al*. 1980; Harvey, 1980; Hall *et al*. 1979). Lawn (1982a,b) compared the response of soybean, black gram, green gram and cowpea to water stress. In cowpea it was observed that water stress restricted growth and hastened maturity. Severe stress delayed development indefinitely. Relieving the stress later in the cycle led to a new flush of flowers. Therefore, cowpea exhibited developmental plasticity. Lawn (1982a) suggested that cowpea showed dehydration avoidance by stomatal regulation so that leaf conductances to water were reduced. Hall et al. (1979) referred to cowpea as a water saver because of stomatal closure at comparatively high leaf water potential before substantial water loss could occur. This observation has also been reported elsewhere (Bates and Hall, 1982; Shackel and Hall, 1983; Turner and Schulze, 1984). Silim (1982) reported that stress during the vegetative phase did not affect the time to flowering but the duration of the flowering phase was curtailed leading to fewer flowers and pods. Flowers and fruit abortion was also observed. Harvey (1980) reached a similar conclusion that the critical period in terms of effect on yield was at anthesis. Turk et al. (1980) investigated the response of cowpea to water stress at different stages of development. Water stress occurring during the vegetative phase did not make any difference between the yield of stressed and non-stressed treatments. However, differences in yield were observed between these treatments when stress occurred during flowering. Steele et al. (1985) have suggested that cowpea genotypes for water-limited environments should be sufficiently early maturing to escape severe drought stress.

In comparison to other grain legumes the response of soybean to water stress has been well investigated (Constable and Hearn, 1978; Sivakumar and Shaw, 1978; Ashley and Ethridge, 1978;

Carlson _et al_. 1979; Sionit and Kramer, 1979; Villalobos-Rodriguez and Shibles, 1985; Korte _et al_. 1983; Neyshabouri and Hatfield, 1986).

Villalobos-Rodriguez and Shibles (1985) reported that indeterminate genotypes of soybean recovered from water stress better than the determinate types. They imposed stress of 15 days duration before flowering, during full bloom, and early podding stage in a field experiment and concluded that recovery from water stress by producing more pods was more important for final yield than amount and duration of the assimilating surface. Korte _et al_. (1981) after comparing three irrigation treatments imposed on eight cultivars of soybean concluded that irrigation during the pod elongation was the most beneficial to increasing the yield. The reproductive stage is the most sensitive to water stress in soybean (Ashley and Ethridge, 1978; Sionit and Kramer, 1977). Reduction in yield was reported when stress was imposed at the seed-filling stage (Constable and Hearn, 1978). They further stated that the reduction in yield could have partly been accounted for by the rapid senescence of leaves as a result of the stress. Neyshabouri and Shibles (1985) stated that yield in a plant may be determined primarily by the plant's ability to retain pods and fill them rather than by having the leaf area for carbohydrate production. They reached this conclusion after comparing semi-determinate and determinate cultivars. The determinate cultivar retained more pods relative to the flowers produced as compared to the indeterminate cultivar. Leaf area reduction during drought stress has been reported (Ramseur _et al_. 1985; Scott and

Batchelor, 1979; Sivakumar and Shaw, 1978). The maintenance of high leaf water potential under water stress by leaf re-orientation has been reported in soybean (Meyer and Walker, 1981). Sivakumar and Shaw observed that at -1 to -1.2 MPa leaf growth completely stopped. Itoh and Kumura (1986) reported that under well-watered conditions the leaf area/root weight ratios were low. They further observed that stress of a short period led to a decrease in leaf area, relative growth rates and net assimilation rate. When stress was of a longer duration the leaf area, relative growth rate, net assimilation rate and dry matter accumulation to the stem increased. In conclusion they stated that readjustment due to stress resulted from acclimation of the photosynthetic function of the leaves and leaf expanding process. Momen (1979) reported reduction in plant height as a result of short periods of water stress. Brief periods of drought stress during vegetative or reproductive growth significantly reduced the rate of shoot growth (Huck et al. 1983). He stated that the yearly variation in the yield of soybean could be due to the fact that water stress occurs at different stages each time. It has been suggested that mild stresses at the beginning of the vegetative stage may condition the plant to cope with stress better than when these occur in the later stages (Hoogenboom et al. 1987a). They observed that plants irrigated throughout the vegetative phase were susceptible to drought when canopy size increased as compared to those subjected to stress earlier. They concluded that accumulated growth in terms of total leaf area, number of nodes, final internode length and main stem height was comparable between the irrigated and non-irrigated treatments as rainfall in the later stages nullified the treatment effects. Root characteristics in response to water stress have been studied (Hoogenboom et al. 1987b; Garaj and Wilthem, 1983; Robertson et al. 1980; Mayaki et al. 1976). Total root growth of soybean may not be affected by stress but the root length distribution may differ (Hoogenboom et al. 1987b). They concluded that the high root growth rates observed during water stress conditions are due to plants partitioning a greater part of the available photosynthate into the roots. Roots grew more during flowering and pod development stages but ceased after seed filling had begun.

The scheduling of irrigation according to developmental stages has been shown to change the yield of chickpea to varying extents. Singh et al. (1987) reported that withholding water at the flower initiation stage reduced yield by 33% relative to that of the irrigated crop. They also observed that the reduction in the number of pods per plant reduced the harvest index by about 23% and that irrigation at pod set appreciably increased the yield.

Beans respond well to irrigation at the time of flower initiation and early pod filling (Adams et al. 1985). They stated that leaf flagging, stomatal closure, and shedding of leaves, flowers and young fruits occurred when plants were stressed.

Ike (1986) reported that in groundnut reduced biomass occurred when stress was imposed at the early flowering stage as compared to applying the stress at pod formation stage. Rao (1986) reached a similar conclusion and further observed that the total number of pods per unit area decreased while kernel weight increased under stressed conditions. Williams (1979) observed that water stress hastened maturity of groundnuts because the last initiated fruits did not develop. Boote et al. (1982) stated that moisture stress effect was more pronounced when it occurred at a time of complete canopy closure, fruit filling and formation.

Premature abscission of flowers and fruits occurs when lupins undergo water stress (Buddiscombe, 1975). In faba beans irrigation applied after many ovules have been 1 and sinks established can lead to substantial yield increase (Bond et al. 1980). Mung bean and black gram have been shown to have considerable developmental plasticity (Lawn, 1982). He observed that when water stress occurred, the period to flowering did not change but that from flowering to maturity was curtailed.

Pigeonpea is reputed to be drought tolerant due to its deep rooting system (Akinola et al. 1975; Keatinge and Hughes, 1981; Sheldrake and Narayanan, 1979; Natarajan and Willey, 1980). Probably it is for this reason that little attention has been paid to the water requirements of this crop. However, recent studies are a pointer towards an emerging need to understand better the physiological basis of pigeonpea response to water deficits (Muchow, 1985a,b; Flower, 1986; Lopez, 1986; Lopez et al. 1987, 1988). Sinclair (1986) studied response to water stress by pigeonpea and three other legumes. He observed that pigeonpea showed the greatest dehydration tolerance. Muchow

(1985a) reported genotypic differences between two pigeonpea cultivars while comparing four grain legume species. The striking observation in this study was that under conditions of sufficient moisture, pigeonpea yielded as much as soybean, cowpea and green gram. However, under water stressed conditions the greatest reduction was observed in one of the pigeonpea cultivars. He concluded that the low yield in pigeonpea was due to its low water use efficiency for dry matter above the ground as well as for seed yield. The cultivar realising the lowest yield had the deepest root system in response to water stress. Lopez (1986) suggested that improving the water use efficiency could improve yield in pigeonpea. In another study Muchow (1985b) reported that cultivar Royes, which in an earlier study had responded greatest to stress, did not show any reduction in leaf area, height or dry matter when observed at a later phase.

The stomata of pigeonpea have been reported to be sensitive to water stress (Lopez, 1986). He observed that the closure of stomata led to reduced gas exchange. Water stress also reduced leaf area and paraheliotropy was observed under these conditions. Lopez _et al_. (1987) investigated the effect of water stress on photosynthetic process in pigeonpea and cowpea. Their results revealed that pigeonpea withstood low leaf water potentials better than cowpea. Under stress, pigeonpea photosynthesis was undamaged while that of cowpea had stopped at comparatively greater potentials. It has recently been pointed out that pigeonpea tolerates drought by conserving water and as such leaf diffusive conductance decreases with developing water stress (Lopez _et al_. 1988). Flower (1985) studied the role of osmotic adjustment with the objective of understanding the nature and extent of drought tolerance in pigeonpea. He reported that leaves of pigeonpea had ample ability to adjust osmotically by accumulating solutes. He suggested that this adjustment could delay the onset of lethal low water potentials and thereby retention of leaves that could substantially contribute to recovery when the stress was released. He also observed that osmotic adjustment could contribute to flower retention by delaying the production of abscisic acid until the water potential dropped drastically. Whereas osmotic adjustment contributed appreciably to the plant's ability to respond to water stress, the observation that growth and photosynthesis are not influenced makes the contribution of this important survival mechanism to agronomic improvement of pigeonpea open to question (Flower, 1985). Nyabundi (1980) subjected an early determinate cultivar and an indeterminate cultivar to three water regimes and reported a significant reduction in yield due to stress. The early determinate cultivar yielded better under stress conditions. He also observed that leaf orientation was a mechanism of avoiding high radiation loads. Severe water stress led to leaf shedding. Due to the nature of the stress that pigeonpea is subjected to in the semi-arid areas of Kenya, it has been suggested that an appropriate plant type for this situation should characteristically be a perennial with deep roots and osmotic adjustment (Nyabundi, 1986). The utilisation of soil moisture is stated to improve if pigeonpea is planted on ridges (Tayo, 1985). Studies being carried out at ICRISAT centre seem to suggest the same (Okada K. personal communication, 1988).

2.3 **Effects of Humidity**

Literature on this subject is limited and also tends to deal with isolated plant parts or processes rather than the whole plant response. Tibbitts (1979) stated that little attention has been paid to the effects of humidity on plant growth and development due to its less dramatic effects as compared to effects of other factors such as radiation, temperature, soil moisture and mineral nutrition. Several studies (Waldron and Terry, 1987; Hsiao and McIntyre, 1984; Hoffman et al. 1971; Gale et al. 1970) and reviews (Tibbitts, 1979; O'Leary, 1975) suggest that humidity has a role to play in plant growth and development. The fluctuation in humidity between the dry and wet periods in the semi-arid tropics is likely to influence growth and development of crops. Literature on this factor in relation to growth and development of grain legumes is scarce. Investigations have been diverse and have ranged from crops to weeds (Hsiao and McIntyre, 1984; McIntyre, 1981; McIntyre and Boyer, 1984).

An outstanding effect of humidity on the plant is its influence on transpiration and other related processes, such as stomatal opening, leaf temperature, translocation of nutrients, photosynthesis and water potential (Tibbitts, 1979). The rate of transpiration is determined by the vapour pressure deficit between the moist leaf surface and the air (Tibbitts, 1979). Water loss from the leaf is increased by increase in vapour pressure deficit resulting from decrease in humidity. Rawson et *al*. (1977) reported that at low vapour pressure deficits the water loss per unit of leaf surface is proportional to changes in humidity. At high vapour pressure deficits the closing of stomata alters this relationship as the transpiration process decreases (Swalls and O'Leary, 1975; Drake *et al*. 1970). Stomatal opening is an important plant process. Several factors are responsible for the regulation of opening and closing of stomata. The plant exerts control over increased evaporative demand through reduction in stomatal opening to maintain a water balance (Kramer, 1980). Sheriff (1977) suggested that stomatal closure comes about as a result of large differences in vapour pressure deficits between the guard cells and the air. This view is also supported by Lange *et al*. (1971) who stated that the stomatal aperture changes quickly in response to increased transpiration by the guard cells. The process of photosynthesis is also affected by humidity (Tibbitts, 1979). He pointed out that differences in dry matter accumulation at different relative humidities are a result of differences in turgor which then alters leaf area of the plants. Some of the plant nutrients move in the transpiration stream. It has been observed that calcium deficiencies in fruit can occur at high humidities due to reduced transpiration (Tromp and Oele, 1972). Leaf temperature is determined by effectiveness of transpirational cooling (Tibbitts, 1979). Carlson *et al*. (1972) showed a correlation between leaf temperature and atmospheric temperature in soybean.

The response of crop plants to humidity is unclear. It appears that the effects of either low or high humidity differ from crop to crop. In the review by O'Leary (1975) several crops were mentioned as having responded to high humidity with increased vegetative growth while in others there was no change or a reduction occurred. Reduction in vegetative growth would lead to a reduced leaf area thereby limiting availability of photosynthate. Some recent studies have indicated that humidity affects plant growth and development. Nagarajah and Schulze (1983) investigated the responses of *Vigna unguiculata* to changes in humidity. They reported that dry air caused a significant reduction in whole plant biomass. McIntyre and Boyer (1984) reported increased rate of elongation of the hypocotyl of sunflower. They attributed this to a reduction in transpiration rate and consequent increase in the water potential of the growing cells. The growth of apical sprouts of potato increased when either water was added to cut ends of the tuber or humidity was increased (McIntyre and Quick, 1984). They also suggested that increased humidity counteracted the inhibitory effects of light. Lateral buds at the basal nodes developed due to increase in humidity in peas (McIntyre, 1971) and sunflower (McIntyre, 1977). Shoot-induced inhibition of the development of root buds was released when humidity increased (Hsiao and McIntyre, 1984). Hunter *et al* (1985) investigated the effect of humidity on growth and development of *Cirsium arvense* (Canada thistle) and reported that increasing humidity increased stem height, shoot dry weight and root dry weight.

Sharma and Green (1980) stated that damp cloudy weather does not favour fertilisation in pigeonpea. This suggests that high humidity could have an effect on the reproductive stage of pigeonpeas. Similar observations have been made for soybean (Gai _et al_. 1986). They reported that differences in success of crossing in soybean between locations in North and South China are as a result of differences in humidity in the two regions during flowering of the crop. It is important to understand effects of humidity during the reproductive stage in grain legumes.

2.4 Effects of Planting Date

The date of planting is critical because of the need to avoid unfavourable conditions that could subject the crop to stresses. For most farming systems optimum sowing dates have been established by experimentation over various years. In the semi-arid areas the onset of rainfall may be an important determining factor in the choice of the date of planting. Temperature and day length may also determine the date of planting for grain legumes that require low temperature during growth and development e.g. chickpea. Several studies have revealed that delayed planting usually lowers yield and reduces biomass production in legumes (Akinola and Whiteman 1974; Lawn, 1979; Hammerton, 1976; Bell, 1986; Haloi, 1986; Beatty et al. 1982; McVetty et al. 1986). The effect of sowing earlier than the optimum date is not within the scope of this review because it is limited or rarely practised for rainfed crops where irrigation is not available.

Kvien et al. 1987 while investigating the influence of population, planting date and water availability on growth and development of peanuts reported that the effect of population on yield depended on the planting date. They observed that yield and grade declined with delayed planting. The differences in pod-set and maturity were stated to have accounted for the decline in yield. Canopy development was slower and vegetative dry matter declined with late sowing when groundnuts were grown under irrigation in a monsoonal environment (Bell, 1986). He observed an increase in leaf to stem ratio with delayed planting, and concluded that late planting altered partitioning of dry matter between leaf and stem. He also suggested that planting date influenced pod numbers more than pod yield with later sowings having larger pod weights to compensate for the low pod numbers. Mouldoon (1985) stated that the lower pod production rate observed in percent with delayed planting could be due to reduced shoot growth. Laurence (1983) reported that delayed planting led to increase in kernel size in groundnut.

Lawn (1979) compared several Vigna spp. in their response to sowing date. Growth was reduced with delayed sowing. Seed yield and harvest index also declined with delayed sowing. McVetty et al. (1986) reported that harvest index and total dry matter in faba bean declined with delayed planting. The duration from planting to maturity declined with delayed planting in soybean (Parker et al. 1981), though plant height and seed quality increased. Seed quality was also insignificantly affected by delayed planting in the studies of Beatty et al. (1982). They reported a decline in yields and seed weight of soybean. Beaver et al. (1980) reported similar observations but differences were observed between indeterminate and determinate plant types. They reported that reduction in yield of determinate soybean cultivars did not occur until at later sowing dates but indeterminate cultivars showed a progressive decline in yield with each successive date of planting. Late planting increased seed weight of soybean though no consistent yield reduction was observed due to late planting (Heatherly, 1986).

Planting date assumes importance in pigeonpea since most of the medium and long duration genotypes being used are photoperiod sensitive. In India the end of the monsoon season also marks the advent of the short days accompanied with decreasing temperature. Short duration genotypes are fairly photoperiod insensitive (Turnbull, 1986) and as such may be sown later than one would expect if day-length was the only limiting factor. Earlier studies (Akinola and Whiteman, 1975; Hammerton, 1976) showed that day length sensitive cultivars must be planted according to the photoperiodic cycle in order to obtain reasonable yields. Reduction in length of vegetative phase occurs when photoperiod sensitive cultivars are grown during short days (Faroda and Singh, 1980), branch number as well as total dry matter yield (Dhingra _et al_. 1980, Akinola and Whiteman, 1975). The reduction in grain yield is dependent on the degree of photoperiod sensitivity. The extremely sensitive types show a marked yield decline with delayed planting (Akinola and Whiteman, 1975; Dhingra _et al_. 1980) while the insensitive types show a negligible response to sowing date (Wallis _et al_. 1980). Delayed planting has been observed to shorten the crop duration (Narayanan and Sheldrake, 1979). They reported that pigeonpea planted during the cool post-rainy season had a higher harvest index as compared to the normal season crop.

2.5 **Effects of Photoperiod**

Day-length varies with seasons and latitude. The grain legumes, like many other plant families display specific responses to day-length (Turnbull, 1986; Summerfield et al. 1988). Depending on the photoperiod requirement for flowering, plants have been divided into three basic categories (Wareing and Phillips, 1981; Vince-Prue, 1981). Plants which require short days before they come into flowering are referred to as short-day plants while those which require long days are classified as long-day. Day-neutrals (photoperiod-insensitive) are those that do not fall into either category and as such flower regardless of the photoperiod. This classification is favoured by several workers (Lawn, 1981; Vince-Prue, 1975; Turnbull, 1986) but recently (Summerfield et al. 1987a, 1988) have modified this classification. This modified classification suggests that short- day plants can often flower in relatively long days and vice versa for long- day plants. There is another group referred to as short-long-day plants which flower when short days are followed by long days. Photoperiod is mainly considered for its influence on flowering but it may also influence vegetative growth (Vince-Prue, 1975). Photoperiodism was first reported by Tournois (1914) and later by Garner and Allard (1920). The mechanism of plant perception of photoperiod is still a subject of much discussion, though it is generally agreed that phytochrome plays a role. The earlier view had been that the phytochrome pigment exists in two convertible forms (Vince-Prue, 1975). It was held that this conversion process determined whether a plant was short-day or long-day. The present view (Salisbury, 1981; Lumsden and Vince-Prue, 1984; Hughes et al. 1984) is that change in spectral quality may not be the signal to identify day and night but rather the value of irradiance could be the signal. The various diverse influences of photoperiodism and plant responses are well reviewed (Evans, 1969; Vince-Prue, 1975, 1981; Zeevart, 1976).

The initiation of phasic changes in grain legumes is influenced by photoperiod (Summerfield and Roberts, 1985). As a group, grain legumes are quite sensitive to photo-thermal conditions so that duration of the vegetative phase varies depending on location and date of planting (Summerfield and Roberts, 1987b). Summer grain legumes are all quantitative short-day species (Aggrawal and Poelhman, 1977; McPherson and Warrington, 1980). It has been suggested that grain legumes which give a short-day response are of tropical or sub-tropical origin while those responding to long day-length are of temperate origin (Adams and Pipoly, 1980; Lawn, 1982; Summerfield et al. 1988).

The investigation of Thomas and Raper (1976) of photoperiodic control of seed fill in soybean revealed that shoot dry weight, and leaf area decreased while pod weight increased with increasing number of consecutive short days. Shibles (1980) gave an illustrative example of the adjustment in yield of soybean due to photoperiod. Late planting of a full season cultivar instead of a short season cultivar gave better yield. He concluded that under the circumstances of late planting, the full season cultivar will still develop sufficient source size to maximise yield as compared to a short season cultivar. Inouye and Shanmugasundaram (1985) reported that pod number per plant and grain yield of soybean were higher under long day condition than under short day conditions in forty eight cultivars tested. The yield differences as a fraction of short days or long days was smallest among indeterminate photoperiod insensitive cultivars and highest in the quantitative short day cultivars. Thomas and Raper (1976) suggested that seed-fill in soybean was influenced by photoperiod. Plants that were exposed to 3 short-day photoperiods after flowering had increased dry matter accumulation. They concluded that intensity of seed-fill and duration of seed set to maturity was determined by photoperiod. In other investigations, Thomas and Raper (1978) reported that long-day photoperiods prolonged pod fill independent of the temperature, but dry matter accumulation was observed to be greater at low temperature ($22/18^{o}C$ day/night temperature) in long-day than short-day photoperiods. The optimum day-length requirement may be different for different soybean cultivars. Criswell and Hume (1972) observed that late maturing cultivars had a lower optimum day length requirement than early cultivars. These genotypic differences were also observed by Major et al. (1975), later maturing cultivars being more sensitive to day-length in the flowering period. Lawn et al. 1973) observed delayed maturity at long day-lengths in soybean which had earlier been regarded as being insensitive to photoperiod. The number of reproductive sites in soybean depends on number of main stem nodes, 1 branches, and the number of nodes present on these 1 branches (Thomas and Raper, 1977). Increasing short days from 0 to 10 increased main stem node number but no change was observed with further increase in short days.

Photoperiods before and after flowering were associated with reduced branch number, total branch length and branch node number in soybean (Board and Settimi, 1986). Shanmugasundaram (1978) observed that long photoperiod led to increased number of flowers which eventually resulted in higher number of pods per plant. Some of the earlier work suggested that long day-lengths increased flowering period in soybean (Van Schaik and Probst, 1958). They reported that long photoperiods accompanied with high temperature caused flower and pod shedding. There have been several reviews on flower initiation in soybeans (e.g.Summerfield and Roberts, 1985; Hume et al. 1985).

The yields of photoperiod sensitive cultivars of Phaseolus bean are more than those of photoperiod insensitive cultivars under warm tropical condition (CIAT, 1977). The explanation for this is that sensitive cultivars tend to be sufficiently large when flowers appear and as such are able to produce higher yields. It has been suggested by Brown (1984) that if vegetative growth is completed before plants attain the size for maximum photosynthesis, grain yield is reduced. The duration to flowering and reproductive maturity in chickpea was altered depending on sowing date, latitude, and altitude (Summerfield and Roberts, 1985). The role of photoperiod in this response in conjunction with temperature is evident. Summerfield et al. (1987) have discussed the interactive as well as sole effects of photoperiod and temperature on flowering in chickpea. Recent studies point to the fact that some earlier studies that attributed certain plant responses to photoperiod could in fact be due to temperature (Roberts et al. 1988; Ellis et al. 1988a, b; Summerfield et al. 1988 for *Vicia faba, Lens culinaris*, and mung bean).

Pigeonpea is classified as a short day plant although recently day-neutral genotypes have been found (Akinola and Whiteman, 1974; Turnbull et al. 1981; Rowden et al. 1981; Turnbull, 1986). Pigeonpea cultivars differ widely in time from planting to flowering at different latitudes (Sharma, 1981) and within one cultivar at different altitudes (Kimani, 1985). The results obtained by Sharma (1981) showed the effect of photoperiod on days to flowering in which plants grown at Hyderabad flowered in a mean of 118 days while those grown in Kenya attained the same phase in 65 days. Several studies indicate that longer duration cultivars require shorter day-lengths than earlier cultivars (Akinola and Whiteman, 1974; ICRISAT, 1976). Turnbull (1986) observed that extra early cultivars flowered in continuous illumination suggesting that they could be regarded as day-neutrals. Narayanan and Sheldrake (1979) reported that long duration cultivars responded more to decreasing day-lengths than early types. An intensive investigation of floral initiation, floral bud development and flowering as influenced by photoperiod and temperature has been recently reported (Turnbull, 1986). For the genotypes used, vegetative growth was unaffected by photoperiod in the first 3 weeks after emergence.

Thereafter growth increased in 16h relative to 12h photoperiods. Under 16h photoperiod the plants were taller, had more nodes on the main stem and carried more flowers at harvest. The increased number of flowers did not result in a higher pod number. The percentage pod set or flower abortion did not differ between 8, 10 and 12h photoperiods.

The studies of McPherson et al. (1985) on rate of development of pigeonpea as affected by temperature and day-length showed that later-maturing types are more sensitive to day-length. The rate of development from planting to flower bud initiation was reduced by between 8 and 60 per cent by 14h photoperiod, and higher at 12h than at 10h. They observed similar response on rate, of development between planting and flowering.

Spence and Williams (1972) suggested the practical implications of understanding plant response to photoperiod. Modification in plant morphology resulting from manipulation of time of planting has been observed (Byth et al. 1981; Lawn, 1981; Wallis et al. 1981) in pigeonpea. Practical application in chickpea has been reported (Sethi et al. 1981).

THE EXPERIMENTS

EXPERIMENT 1

3.1. EFFECT OF TEMPERATURE AND PHOTOPERIOD ON PARTITIONING OF DRY MATTER IN VEGETATIVE AND REPRODUCTIVE STRUCTURES IN SHORT DURATION PIGEONPEA.

3.1.1 Introduction

Temperature and photoperiod have been considered to be important in determining the relative rates of growth of both vegetative and reproductive organs in grain legumes (Summerfield et al. 1980). Recent studies (e.g.Turnbull, 1986) suggest that temperature and photoperiod influence the duration of the pre- and post-flowering stages of development in pigeonpea.

Pigeonpea has a very low harvest index. Studies under field conditions at Patancheru have shown that delayed sowing in September - October increases the harvest index (ICRISAT, 1983). At Patancheru, as for most parts of peninsular India, the day length decreases from 12.98 hours in June to 11.01 hours in December (appendix I). The mean daily temperature also decreases remarkably. For example, in 1987, the mean monthly maximum temperature decreased from 35.6°C at the end of June to 26.9°C by end of December. Likewise the mean monthly minimum temperature decreased from 24.5 to 14.2°C over the same period of time (Appendix II). There are differences in morphology and yield which are partly a result of altered partitioning when the late sown plants are compared with the crop sown on optimum date in June (Sheldrake, 1985; Chauhan et al. 1987). This may be related to the differences in temperature and photoperiod as observed elsewhere (Turnbull, 1986). The foregoing literature review (Chapter II) has pointed out the effects of temperature and photoperiod on the specific plant processes and yield components. It has been recognised that the effect of temperature on the formation of new leaves will determine the size of canopy available for light interception.

Day-length is an important environmental factor because of photoperiodism in plants (Dennet, 1984). It also determines the amount of time during which a crop can intercept solar radiation. Locational and seasonal adaptability may be associated with day length.

Seasonal variation and interaction between photoperiod and temperature, are some of the major environmental factors that regulate the rate and duration of vegetative growth and the realisation of the consequent yield potential (Turnbull, 1986). These are influenced not only by latitude but also altitude. These two factors can be used to predict the times of phenological features such as onset of flower initiation, appearance of first flower, duration of flowering, and physiological maturity (Summerfield et al. 1988). Several studies in other crops have shown that temperature at flowering determined the yield (Warrag et al. 1983; Summerfield et al. 1979 in soybean; Huxley et al. 1976 in cowpea).

Objectives

The objectives of this experiment were:

1. To determine whether partitioning of dry matter into grain was altered by different day temperatures and photoperiods.

2. To determine whether some of the early duration genotypes differed in their response to these factors.

3. To relate the information obtained in the first objective to the adaptation of pigeonpea grown during the summer season (April-May) in peninsular India.

3.1.2 Materials and Methods

3.1.2.1 Treatments

Three short duration determinate genotypes (ICPL4, ICPL87, ICPL151) and one indeterminate genotype (UPAS120) were selected for this study and 216 pots were used. Temperature and photoperiod were imposed when at least two plants per pot had initiated flower buds. Half the pots were allocated to the 40°C day temperature and the remaining half to 30°C treatment. The night temperature in both treatments was maintained at 20°C. Within each temperature treatment the pots were further divided into three groups for photoperiod treatments. The photoperiods used were normal day length (12.5h), 13.5h and 15h. Longer day lengths were created by using four 200 watt incandescent bulbs suspended a metre above the canopy for each photoperiod. The distance between bulbs was one metre. Hourly mean air temperature was recorded on a Campbell's scientific automatic data logger (model CR 7).

3.1.2.2 Design and Layout

The experiment was conducted at ICRISAT, Patancheru, India, between January and March, 1987, in a naturally lit glasshouse which admitted about 50% of the natural irradiance.

A completely randomised design was adopted. Each genotype was sown in plastic pots of 23 cm diameter containing 7 kg of air dry soil which had been passed through a 5 mm mesh wire sieve. The soil was a sandy clay loam, defined according to USDA taxonomy as a fine hypothermic udic rhodustalf. Fertilizer (1.162 g single superphosphate was incorporated into the soil to give 80 mg phosphorus and 60 mg sulphur kg^{1} of air dry soil. Twenty seeds which had been inoculated with Rhizobium (IC 3195) were sown per pot. For determining the field capacity, three pots filled with similar soil were well watered, covered with aluminium foil and left standing on the glasshouse benches for 96 hours. Six soil samples were taken from each pot. The samples were weighed immediately and then placed in a hot air circulation oven. These samples were dried to constant weight and from these weights the original moisture content which represents the moisture at field capacity was calculated. Soil moisture was maintained at field capacity by daily weighing and adding calculated quantities of water to the pots. Polythene beads (125 g) were spread on the soil surface to reduce surface evaporation. The pots were randomised once a week. Thinning was done in two stages, fifteen days after sowing and when the temperature was recorded on a Campbell's scientific automatic data logger (model CR 7).

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3.1.2.3 **Measurements**

Sampling at 50% flower bud initiation

Twelve pots of each genotype were sampled when two plants in each pot reached the flower bud initiation stage. The plants were cut at the base of the stem and the shoot separated into leaves and stems. Leaf area was determined using an automatic leaf area metre. Leaf samples were dried in a hot air circulation oven (Unitherm Drying oven, Russel-Lindsay Engineering Ltd, Birmingham, England) at 80°C for three days. The stems were dried at 80°C in the same oven for five days. Roots were recovered using a water jet and a sieve. These were also dried at 80°C in the oven for three days. The shoot and root dry weights were measured using an electronic balance (Mettler P 160; Mettler PC 16-32, Mettler Instruments, Zurich Switzerland).

During the course of the experiment the following observations were taken; plant height at weekly intervals, daily tagging of open flowers and counting aborted pods and abscised flowers.

Sampling at maturity

Plants from five pots for each treatment were harvested when most of the pods had lost the green colour. Leaves were separated for leaf area measurement while the stems were dried in the oven as at the earlier sampling dates. Pods were removed and dried in the oven at 40°C for three days. The following measurements were taken at harvest; final plant height, shoot dry weight, root dry weight, pod number per plant, grain yield per plant, grains per pod, and branch number.

The data was analysed using the Genstat statistical package provided by the Institute's Computer Services.

RESULTS

The genotypes did not show any differences in leaf area or shoot dry weight at the imposition of treatments. In all the genotypes the plants attained a minimum of 9 nodes before flower bud initiation could occur.

The leaf area at harvesting was influenced by temperature and day-length (Fig.1). Increasing the temperature produced different responses in the genotypes studied. High temperature at 12.5h and 15h day-lengths increased leaf area in all the determinate genotypes but at the middle day-length (13.5h), high temperature did not affect the leaf area significantly. The leaf area of the indeterminate genotype remained almost the same over the different treatments except at 12.5h where high temperature reduced the leaf area.

The shoot dry weight response was almost similar to that of the leaf area(Fig.2). High day temperature increased shoot dry weight in all the determinate genotypes at 12.5h and 15h day-lengths especially for ICPL87 AND ICPL151. In contrast to the leaf area response, the shoot dry weight for UPAS120 increased at high temperature at 13.5 day-length. These differences in shoot dry weight of the genotypes were related to the differences in plant height (Fig.3) as well as relative stem sizes. Effect of temperature on number of branches per plant was not clear (Fig.4)

The effects of temperature and day-length on the root dry weight (Fig.5) did not show a consistent similarity among the determinate genotypes as was observed for the shoot dry weight.

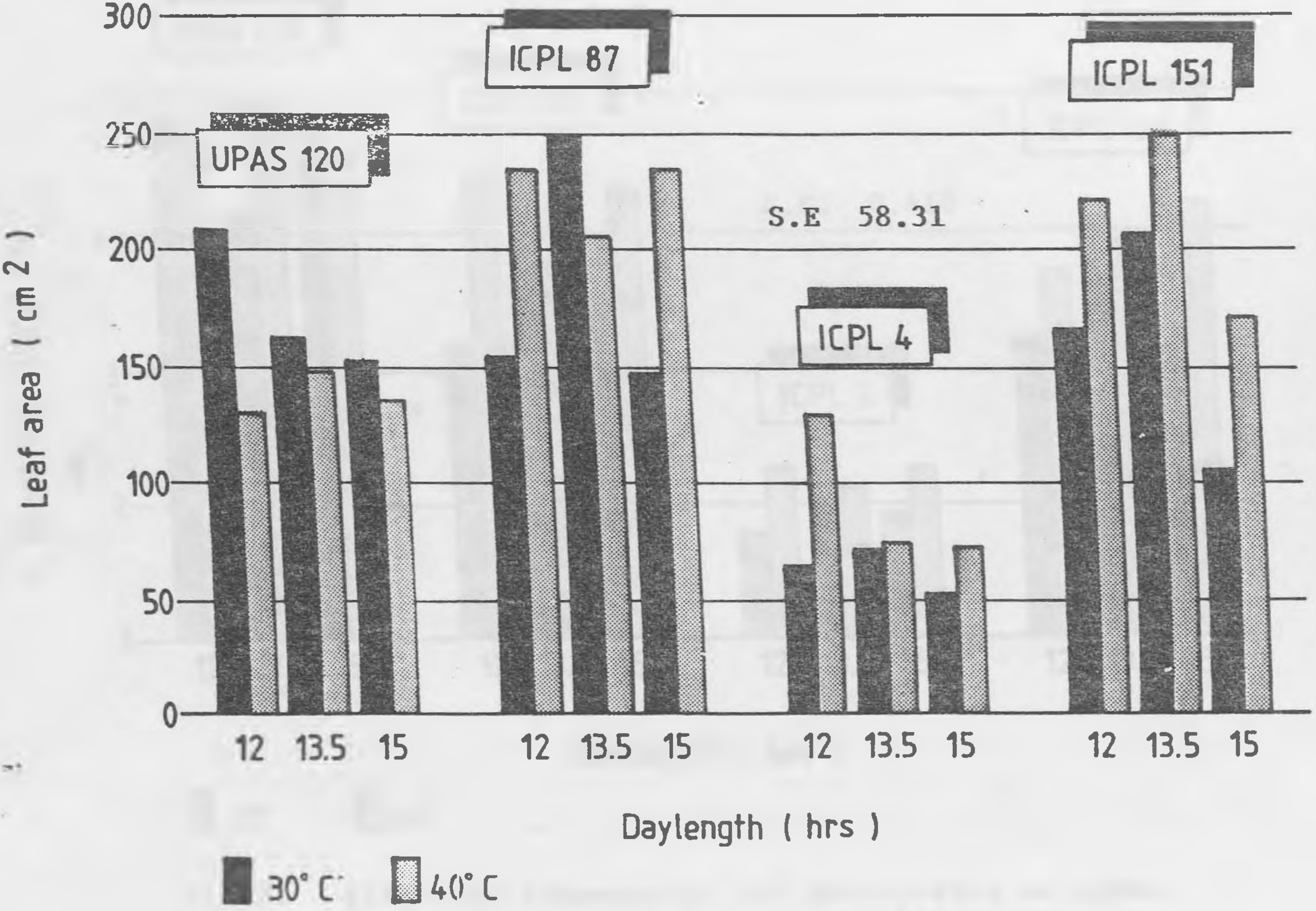

Fig.1. Effect of temperature and photoperiod on leaf area per plant at harvesting.

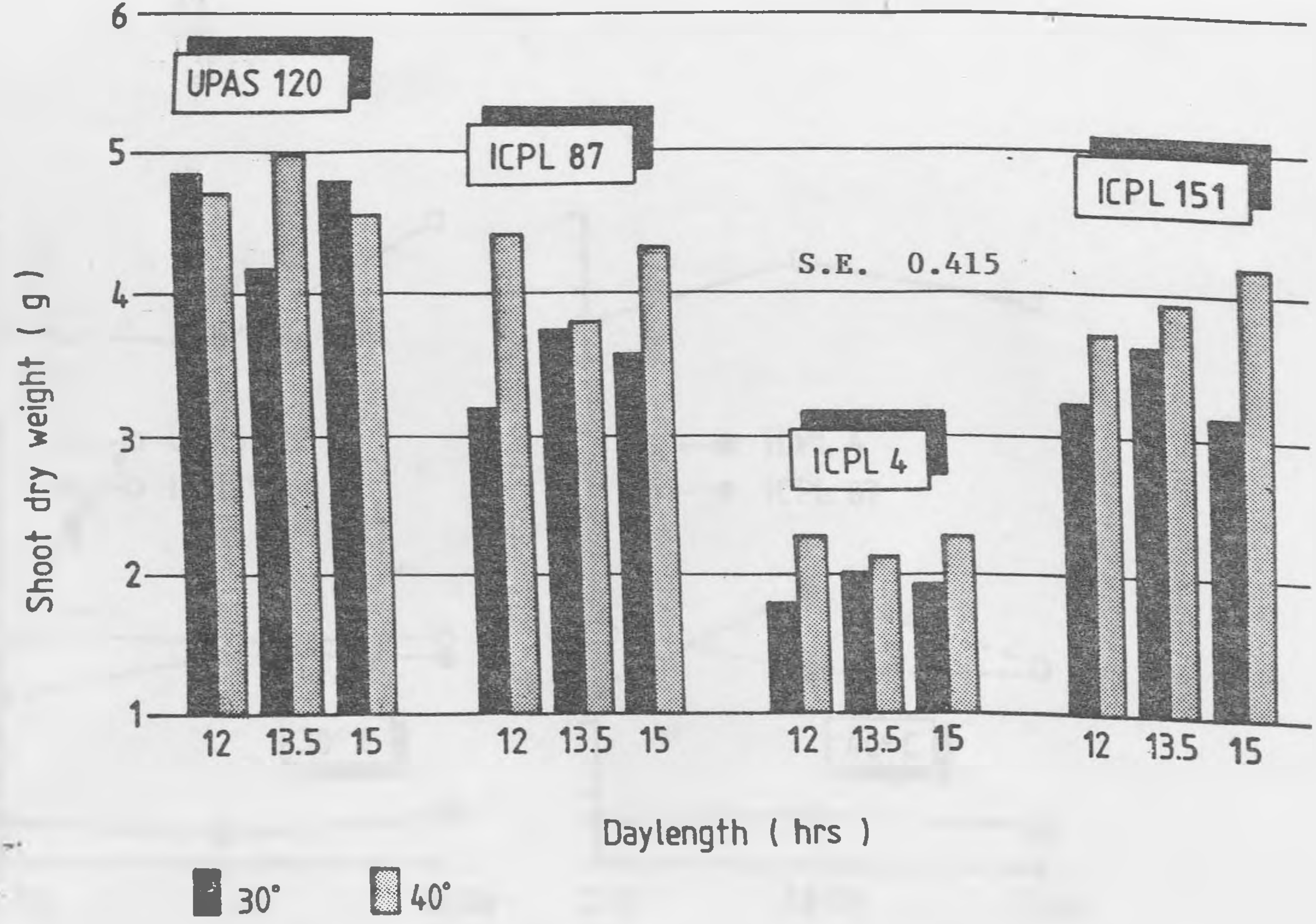

Fig.2. Effect of temperature and photoperiod on shoot dry weight per plant at harvesting.

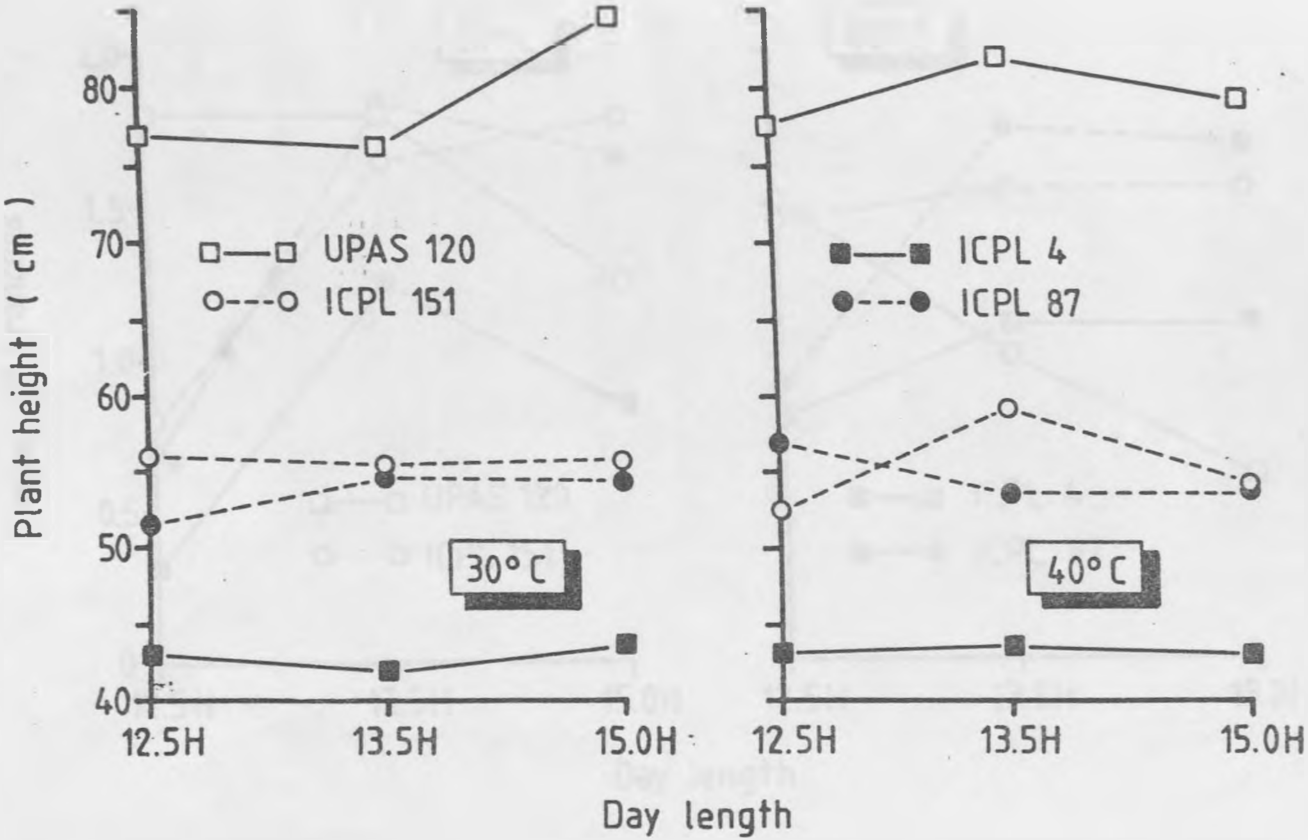

Fig.3. Final plant height of the four genotypes.
S.E 5.65

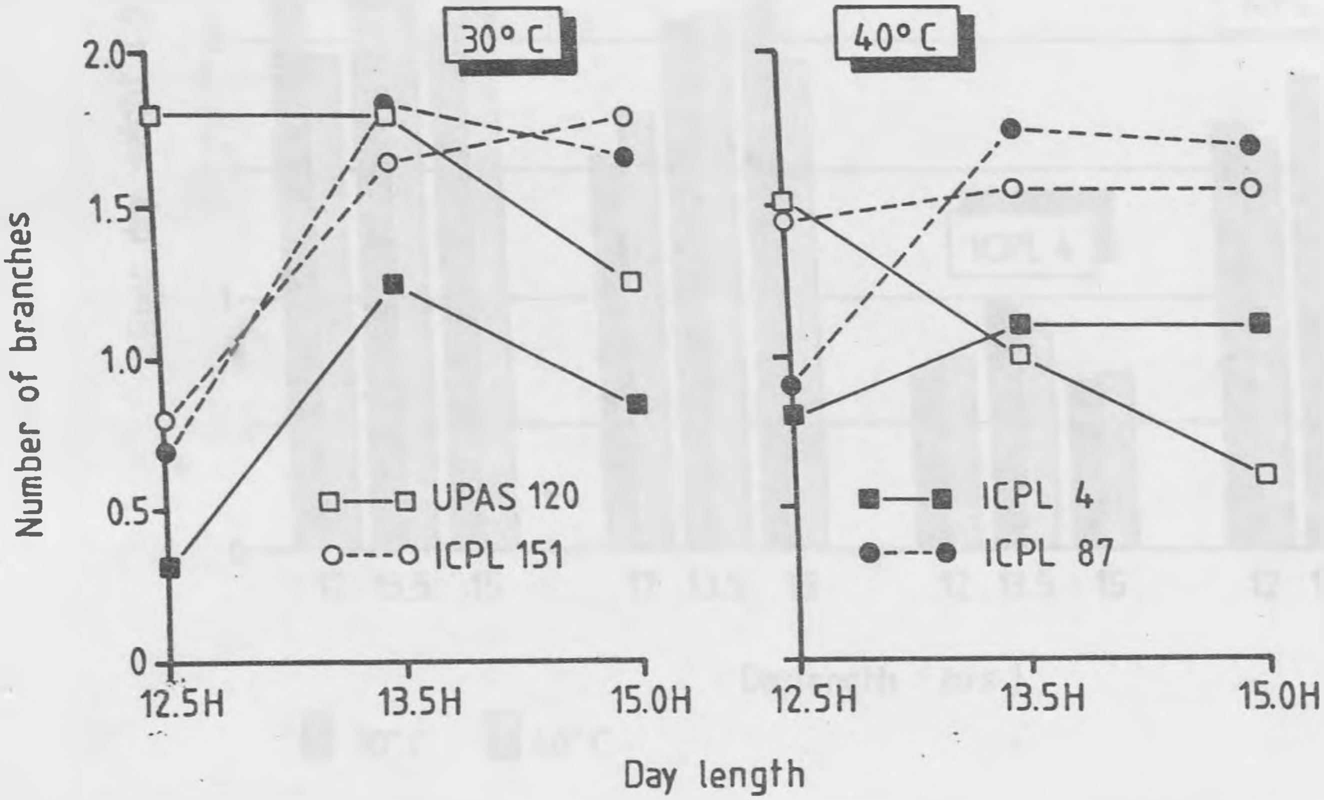

Fig. 4 Number of branches per plant at harvesting.
S.E 0.62

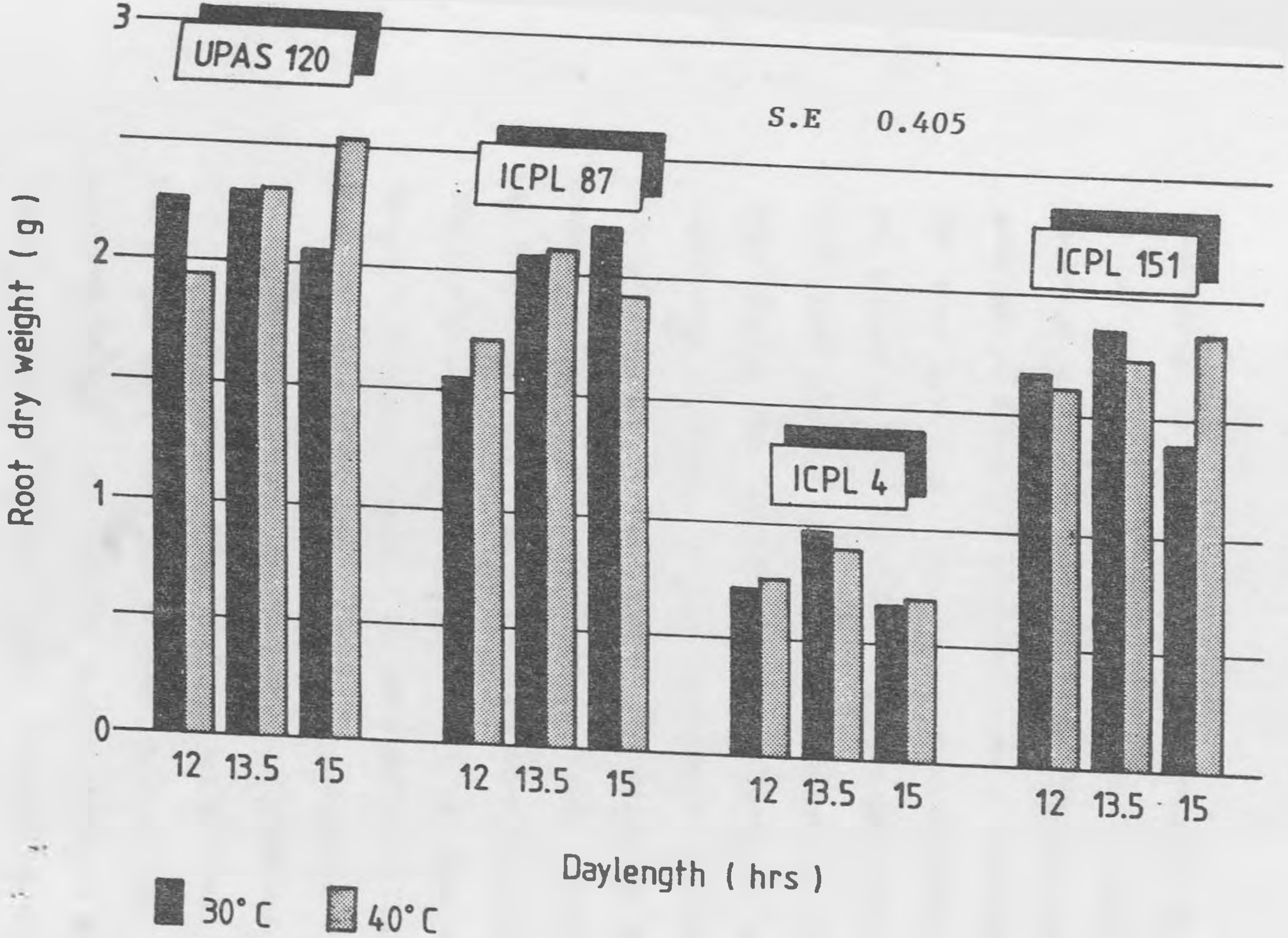

Fig. 5. Effect of temperature and photoperiod on root dry weight per plant at harvesting.

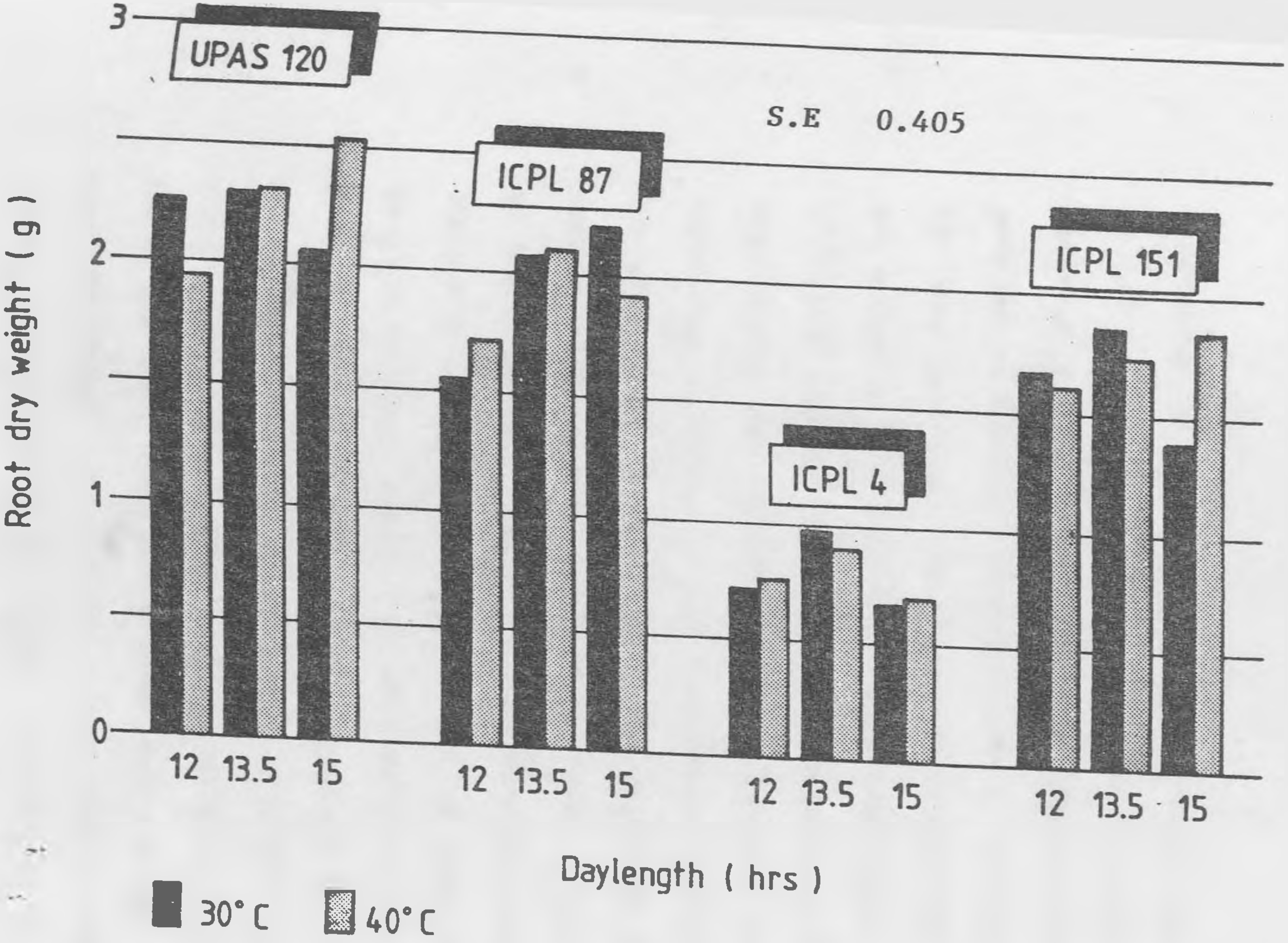

Fig. 5. Effect of temperature and photoperiod on root dry weight per plant at harvesting.

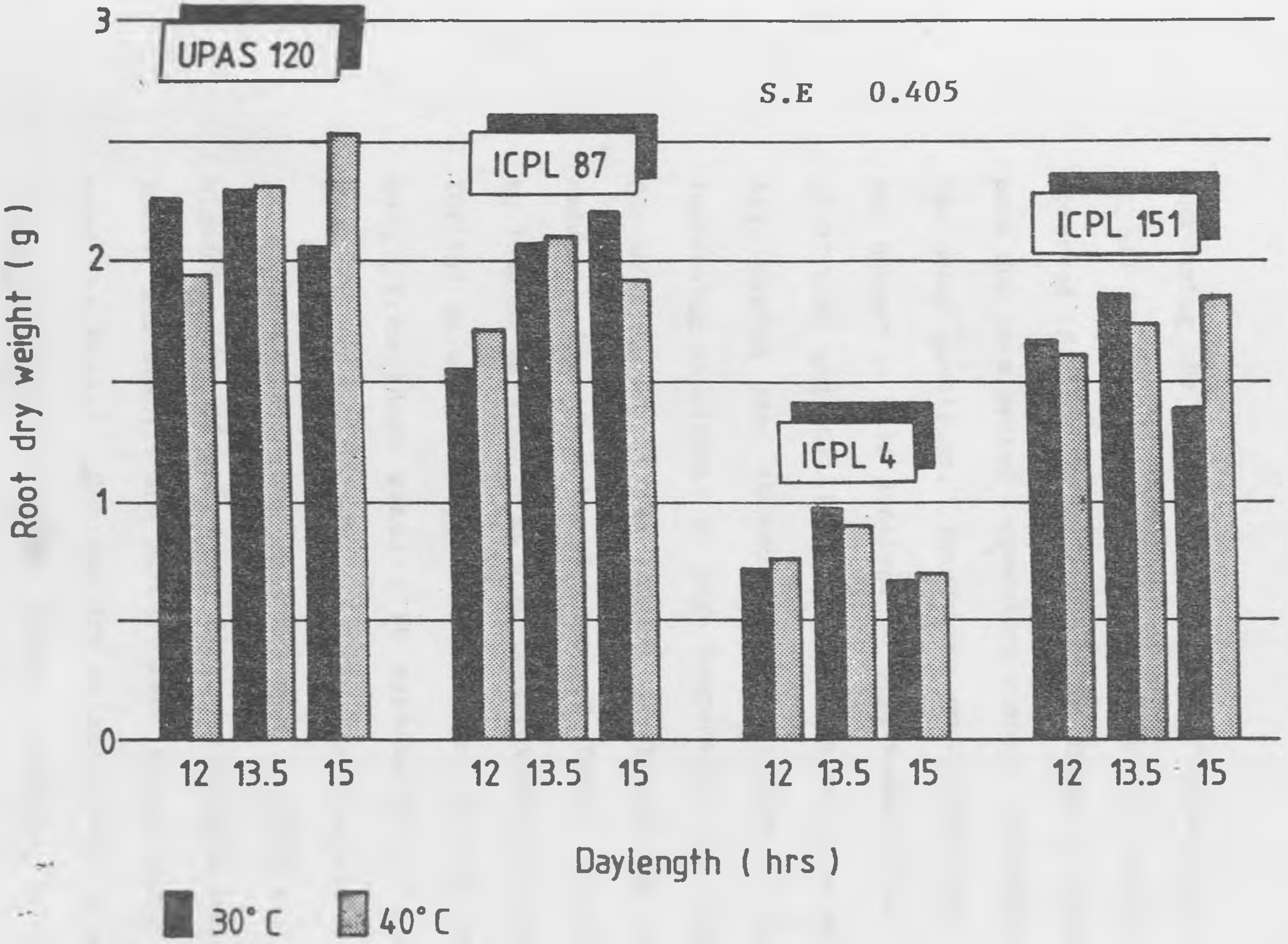

Fig. 5. Effect of temperature and photoperiod on root dry weight per plant at harvesting.

High temperature appeared to increase root dry weight in UPAS120 and ICPL151 only at 15h with the temperature and day-length making little difference in root dry weights of the remaining genotypes.

Increasing the temperature at 12.5h reduced the number of pods in all the genotypes except for ICPL4 in which no change was observed (Fig.6). The response of ICPL4 in terms of number of pods due to elevated temperature clearly contrasted with that of the other genotypes. Increasing day-length upto 15h increased pod number in this genotype at high temperature. The response of ICPL151 and ICPL87 to increased temperature at the range of day-lengths used showed that the number of pods declined. Increasing day-length at high temperature increased pod number for UPAS120 but at the longest day-length the pod number was reduced. Therefore the response of ICPL87, ICPL151 and UPAS120 to longest day-length at high temperature was similar, although ICPL151 gave a slightly higher number of pods than the other two. From these results it appears that UPAS120 is more sensitive to high temperature for pod production since at the low temperature its response and that of ICPL4 were similar. The highest number of pods over all the daylengths was obtained for ICPL4, and UPAS120 and ICPL151 were intermediate, while ICPL87 gave the lowest. The pod dry weight showed a similar trend (Fig.7) to that for the pod number. However, it should be noted that though the number of pods was high for ICPL4, the pods are small and as such the pod dry weights were ranked differently.

The grain yield was reduced at high day temperature (Fig.8).

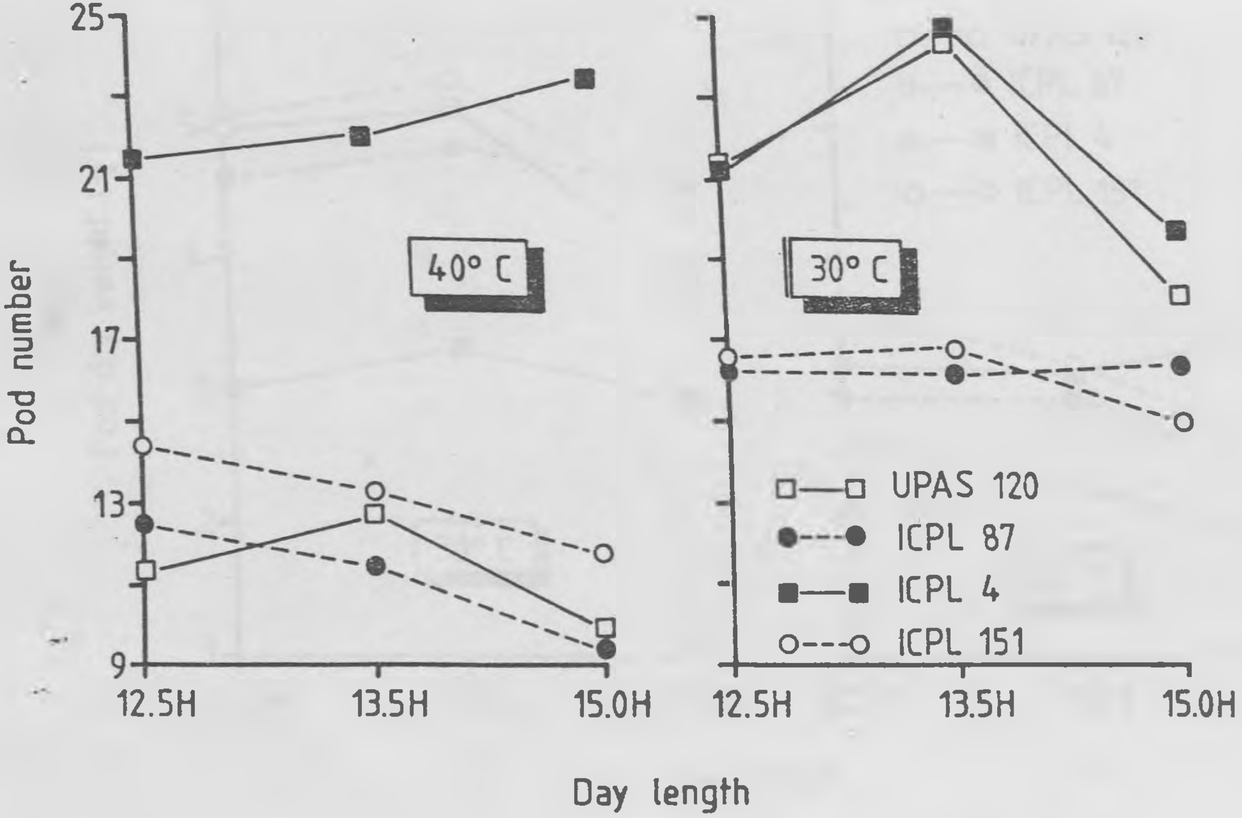

Fig.6. Effect of temperature and photoperiod on pod number per plant.

S.E 2.878

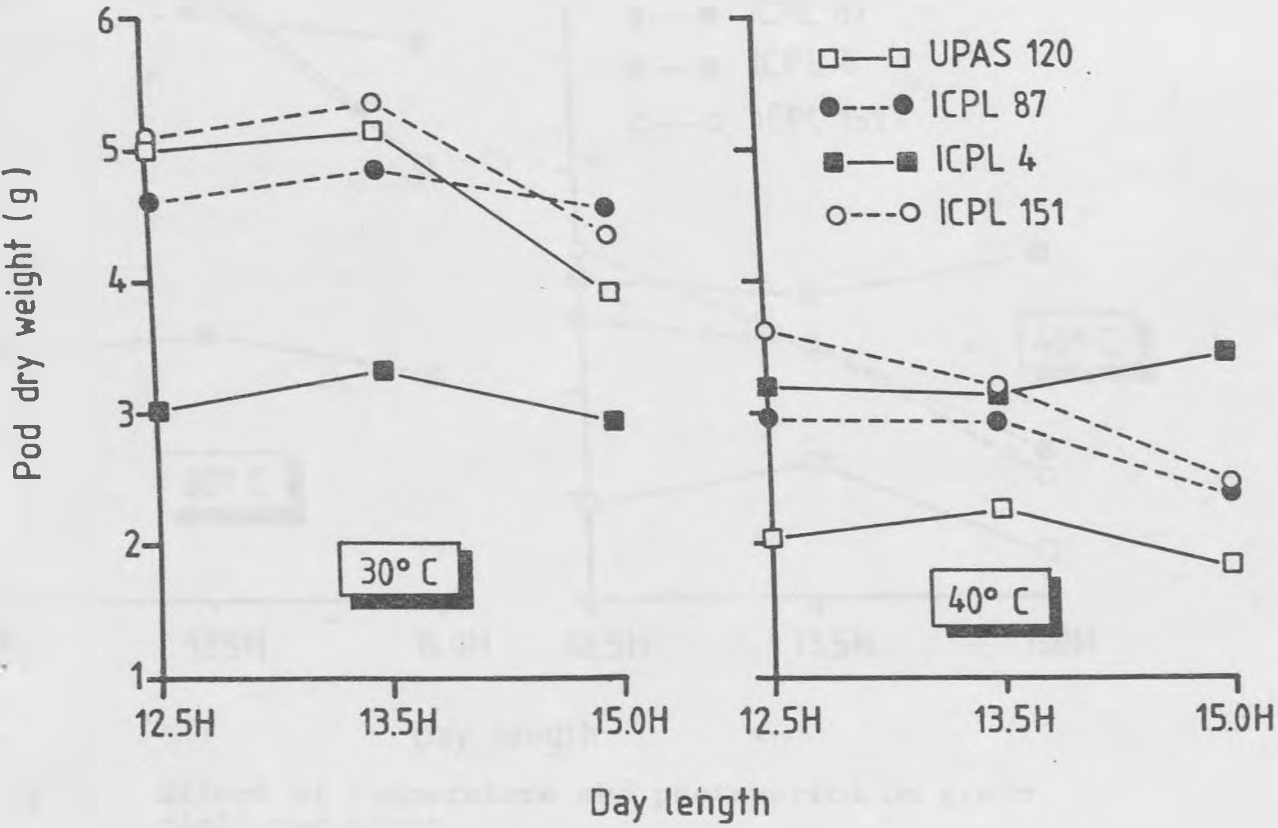

Fig.7. Effect of temperature and photoperiod on pod try weight per plant.

S.E 0.663

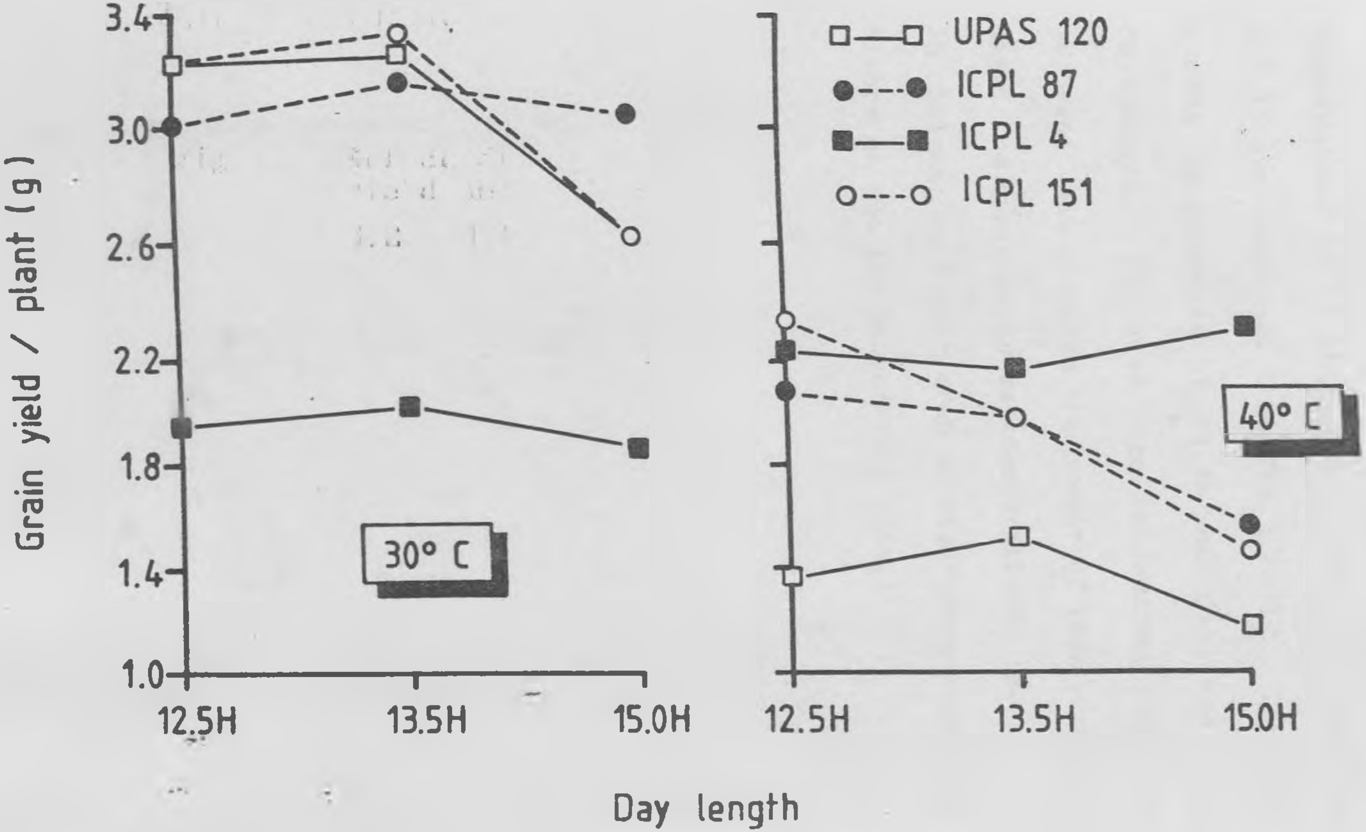

Fig.8. Effect of temperature and photoperiod on grain yield per plant.

S.E 0.495

This reduction was as a result of the reduced number of pods. The longest day-length gave the lowest yield at both low and high temperature. At low day temperature increasing the day-length to 13.5h increased grain yield in all the genotypes and a further increase in day-length to 15h reduced grain yield in all genotypes. Increasing the day-length at the high temperature to 13.5h did not affect the yield for ICPL4 and ICPL87 and decreased that for ICPL151. The yield for UPAS120 showed an increase at 13.5h and declined with increase in day-length. The seed size determined the yield and it was observed that although the number of pods produced for ICPL4 was high, the grain yield was comparatively low.

In contrast to flower drop at high temperature, pod abortion was higher at the low temperature (Tab.1)

Table 1. Daily flower drop and pod abortion due to temperature and photoperiod.

	TEMPERATURE			
	30^oC		40^oC	
Days after flowering	No. of flowers	No. of pods	No. of flowers	No. of pods
1	3	0	12	0
2	5	0	26	0
3	12	0	51	0
4	34	2	57	0
5	51	12	96	0
6	77	16	116	0
7	86	10	106	5
8	91	15	95	8
9	51	21	126	3
10	66	23	138	6
11	77	16	131	8
12	65	31	154	12
13	56	26	161	9
14	60	24	122	7
15	58	27	107	11
16	51	20	113	6
17	38	11	95	4
18	26	17	76	7
19	33	13	57	11
20	21	19	64	11
21	28	11	42	4
22	16	7	35	3
23	10	8	38	6
24	13	3	23	9
25	11	5	31	2

DISCUSSION

These results indicate that the effect of temperature or photoperiod can be modified by each other. Several studies have underscored this fact (e.g. Summerfield et al. 1987, 1988; El-Madina and Hall, 1986). The effect of day-length on biomass production was evident in this study but temperature exerted a greater effect. The differences in leaf area at harvesting were mainly due to the rates of senescence for the genotypes and leaf retention was better in ICPL87 and 151 while heavy leaf shedding occurred in ICPL4. In general the leaf area for the indeterminate genotype (UPAS 120) declined at higher temperature more than in the determinates suggesting a greater sensitivity in this genotype to increased temperature.

High temperature reduced the pod number largely as a result of higher flower drop. The number of flowers that dropped at higher temperature per day was about twice that collected at the low temperature. This effect of high temperature is a well established phenomenon (Turnbull, 1986; Van Schaik and Probst, 1958; Warrag and Hall, 1984). The high flower drop at high temperature has been attributed to failure of the anthers to dehisce (Summerfield et al., 1979). Anther indéhiscence as well as abnormal pollen development leading to male sterility has been observed in cowpea as a result of high temperature (Warrag and Hall, 1983, 1984). However, Van Schaik and Probst (1958) reported that abscission of flowers is due to failure of pollination before any pod or seed development while failure of fertilisation or any subsequent developmental process of the seed may cause abscission of pods. In Maize, Herrero and Johnson

(1980) reported that high temperature (38^{o}C) reduced anther development and pollen viability in otherwise healthy tassels.

In contrast to flower drop at high temperature, pod abortion was higher at the low temperature. This indicates that at the high temperature flower abscission reduced the number of pods thereby leading to a low pod load. The converse was true at low temperature. This observation emphasises the fact that the regulation of flower retention was interfered with by high temperature. However, what limited pod retention at low temperature was not clear. It has been pointed out in a hydrodynamical model (Sheldrake, 1979) that the pigeonpea plant retains only as many pods as it can supply with carbohydrates, nitrogen or other nutrients. A similar theory was proposed for boll retention in cotton (Eaton, 1955). Recent studies (e.g. Rawson et al, 1980) suggest that for pigeonpea there is no limitation of assimilates at the reproductive stage. In general the various theories fall in two categories; either hormonal or nutrient limitation. Extensive studies in cotton have led to the conclusion that deficiency of photosynthate and water deficits increase the boll abscission rates because they modify hormonal balance in the young bolls and their abscission zone (Guinn, and Brummett, 1987; Guinn, 1974, Guinn, 1982; Guinn 1976). In this study it was observed that the pigeonpea pods abscised within the first five days of pod formation. A majority of the pods that were not abscised within this period continued to maturity. This suggests that abortion is related with age or timing. It has been suggested that abortion occurs early so that wastage of nutrients is minimised (Lloyd, 1980;

Stephenson, 1981). Several workers have suggested that abortion may be due to nutrient deficiency and that progressive increase in sink size limits yield (Stephenson, 1980; Binnie and Clifford 1981; Lee and Bazzaz, 1982). But Rawson and Evans (1970), and Tamas et al., (1979) argued that at the early stage at which abortion is usually observed the competition for assimilates is not considerable enough to cause abortion. They suggest that hormonal interactions between reproductive organs may be more important. Data gathered in this study was not sufficient to clearly assign the response to a given single factor. However involvement of endogenous substances as well as limitation of photosynthate is suggested. Abortion of pods occurred before a given stage was reached (within the first five days) which could indicate a role of endogenous substances. But the fact that pod abortion was higher at low temperature where flower abscission had been low and led to a higher pod load could imply that photosynthates were limiting. On the other hand if earlier formed pods inhibited the growth of later-formed pods as suggested elsewhere (Sheldrake, 1984), then this effect should have been fairly uniform at both temperatures unless it indicates that the magnitude of inhibition is related to the number of pods available.

The increased yield observed for ICPL4 under high temperature shows that this genotype may have a higher temperature requirement for flowering and pod-set than the other genotypes. The low yield recorded in this genotype as compared to the other genotypes was attributed to its small seed although it had a high pod number.

EXPERIMENT II

3.2 RESPONSE OF TWO SHORT DURATION PIGEONPEA GENOTYPES TO WATER REGIMES AND RELATIVE HUMIDITY DURING THE REPRODUCTIVE PHASE.

3.2.1 Introduction

Plants respond to water stress in a variety of ways. Several workers e.g. (Ludlow, 1980; Turner, 1979; Simpson, 1981; Teare and Peet, 1983) have discussed the various mechanisms by which plants respond to water stress. The effect of water deficits on crop yield is determined primarily by the degree and duration of such deficits (Sionit and Kramer, 1977). In determinate species this may not appreciably delay flowering, but yield reduction will occur due to reduction in leaf area (Rawson and Turner, 1982). In general, a plant organ is most sensitive to stress during the period of rapid growth (Simpson, 1981). Lawn (1980) reported that pulses are most sensitive to water stress during the late flowering and early pod-filling stages. Pigeonpea grows slowly in the early stages (Sheldrake, 1984) and in the marginal areas this usually is the time of sufficient rainfall. Flowering may coincide with the receding rains or the dry spells. This sort of situation will undoubtedly affect the yield of the crop.

Low atmospheric vapour pressure may exaggerate the effects of water stress. It determines the saturation vapour pressure deficits and as such influences transpiration. High humidity even with sufficient soil moisture will affect the leaf temperature since the cooling effects of transpiration may not be realised (Tibbits, 1979). Pod set is affected in some plants but a generalisation is still not possible (O'leary, 1975).

This experiment was carried out in order to understand the response of two pigeonpea genotypes (ICPL81 and ICPL87) to water stress and humidity after flowering.

3.2.2 **Materials and Methods**

3.2.2.1 Glasshouse Culture

The experiment was conducted between April and June 1987,at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), situated at Patancheru, India, on latitude 17°N and longitude 78°E at an altitude of about 500 metres. The plants were raised in a naturally lit glasshouse which admitted 50% of the natural irradiance until flowering.

A completely randomised design was used. Each genotype was sown in plastic pots of 23 cm diameter containing 7 kilograms of air dry soil which had been passed through a 5 mm mesh wire sieve. The soil was sandy clay loam, defined according to the USDA (1975) taxonomy as a fine hypothermic udic rhodustalf. Single superphosphate (1.1625 g) was incorporated into the soil to give 80 mg phosphorus and 60 mg sulphur per kilogram of air dry soil. Twenty seeds were sown at 3 cm depth per pot and were inoculated with rhizobium (IC 3195). Soil moisture was maintained at field capacity by daily weighing and adding calculated amounts of water. Polythene beads (125 g) were spread on the soil surface in each pot to reduce evaporation. The pots were randomised once a week. Thinning was done in two stages, fifteen days after sowing and when the first trifoliate leaf was fully expanded. Four plants were retained in each pot. The temperature of the glasshouse was thermostatically controlled and maintained at 30/20°C day and night by evaporative cooling. Plants were transferred into the growth chamber at the flowering stage.

3.2.2.2 Treatments

The treatments were imposed using two identical walk-in growth chambers (Conviron, model CG 1011, Controlled Environment Ltd. Winnipeg, Manitoba Canada). The light rack consisted of 12 fluorescent tubes (VHO cool light Sylvania, 96, USA) and 20 incandescent bulbs of 50 watts each (Sylvania, USA). The photosynthetic photon flux density at the canopy which was 30cm from the light source was 260 umol s m^{-2} (the PPFD was measured using a L1-188B integrating Quantum/Radiometer/Photometer, Li-Cor Inc. Lincoln, Nebraska, USA). Half the pots were assigned to one chamber maintained at 75% humidity day and night, and the remaining half to the second chamber programmed for 35% humidity. In each chamber four pots of each genotype were subjected to different water regimes. The soil moisture treatments were 10%, 14%, 18% and 22% on weight basis of water and air dry soil. The field capacity for this soil was 20%. Pots were weighed every morning using an electronic balance to adjust the soil moisture to the required levels and shifted once a week.

3.2.2.3 **Measurements**

Weekly measurements of plant height were done. Flowering dates and flowering duration were also recorded. All the plants were harvested when most of the pods had lost their green coloration. They were cut at the soil surface and separated into leaves, stem, and pods. Leaf area was measured using an automatic leaf area metre. Measurements of transpiration, stomatal conductance and leaf temperature were done three times a week after treatment imposition at midday using a steady state porometer with a data logger. The first fully expanded trifoliate leaf from the apex was the one on which the measurements were done.

Roots were recovered using a water jet and a 3 mm sieve. Leaf and root samples were dried at 80°C for three days while the stems were similarly dried for five days. The dry weights were measured using an electronic balance (Mettler PC 16-32, Mettler Instruments, Zurich, Switzerland), after drying to constant weight. Percent pod-set was determined by counting of the floral scars on the inflorescence and the number of pods per plant.

RESULTS

The leaf area was mainly influenced by the water regimes and a significant response to humidity was observed (Fig.1). Increasing the soil moisture increased the leaf area regardless of the level of humidity. High humidity increased leaf area for ICPL87 at all water regimes. Although a decline was observed when soil moisture was increased from 10 to 14% at high humidity. The indeterminate genotype behaved differently. Plants at 75% humidity had lower leaf area under low soil moisture conditions (10%) but at higher soil moisture levels there was no significant difference.

Increasing the soil moisture increased the dry weight of leaves, stems and total shoot in ICPL87 (Fig.2-4). These parameters were also favoured by the higher humidity level in ICPL87. In ICPL81, however, watering level and humidity had no significant effect on leaf dry weight. Humidity also did not have consistent effect on stem weight and total shoot weight in this genotype but increasing water level produced an overall increase in these parameters even though the effect was less marked than in the case of ICPL87.

The two genotypes differed in height at the end of the experiment, and the indeterminate genotype attained greater height than the determinate one (Fig.5). The other treatments did not result in any significant differences in plant height.

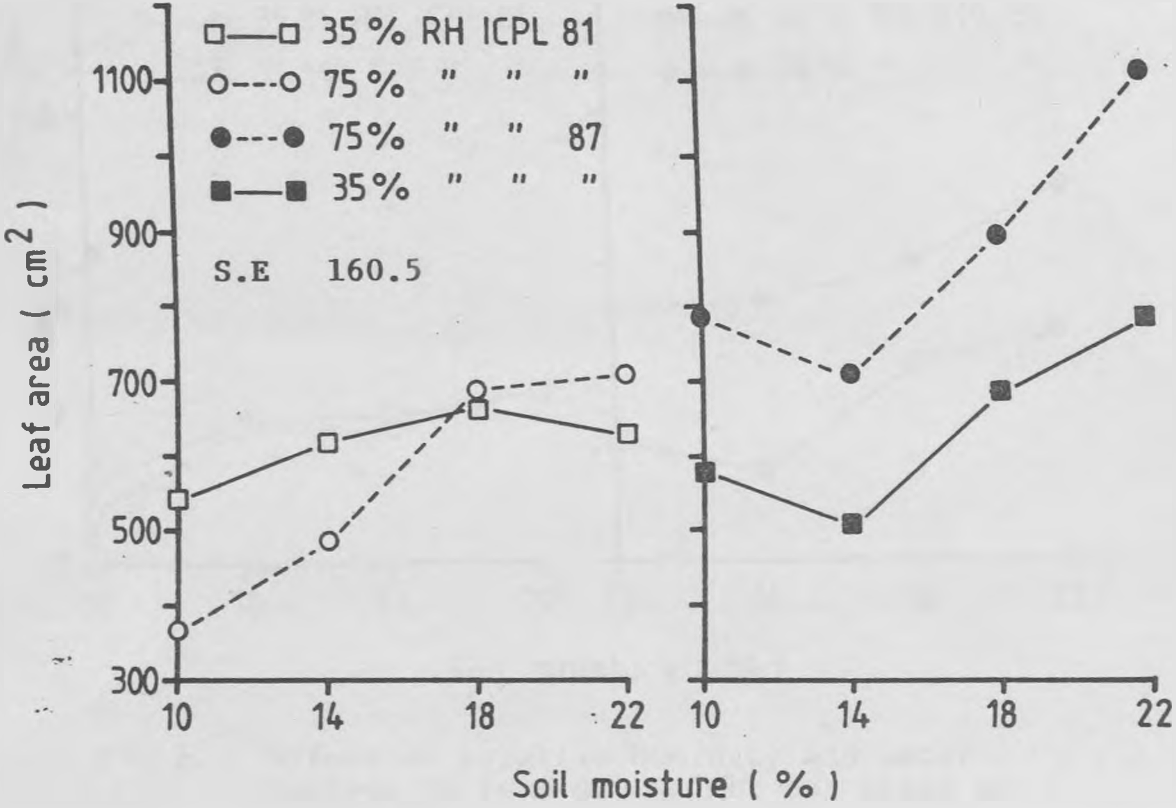

Fig.1. Effect of relative humidity and water regimes on leaf area per plant at harvesting.

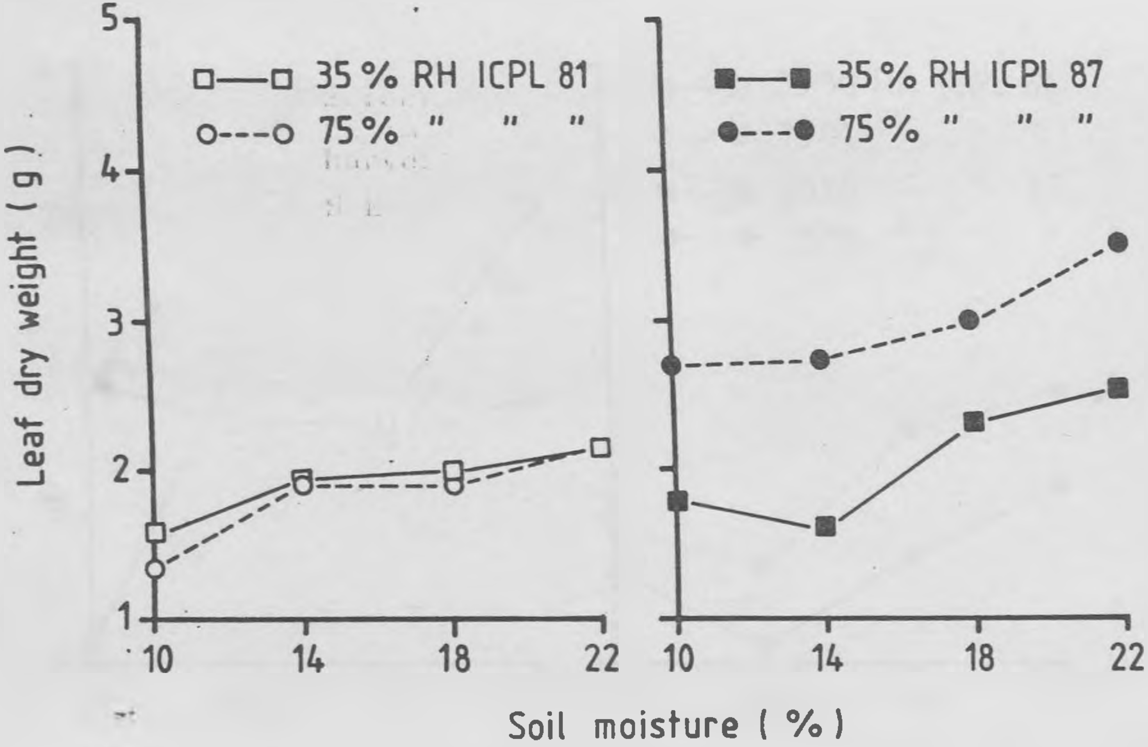

Fig.2. Effect of relative humidity and water regimes on leaf dry weight per plant at harvesting.

S.E 0.474

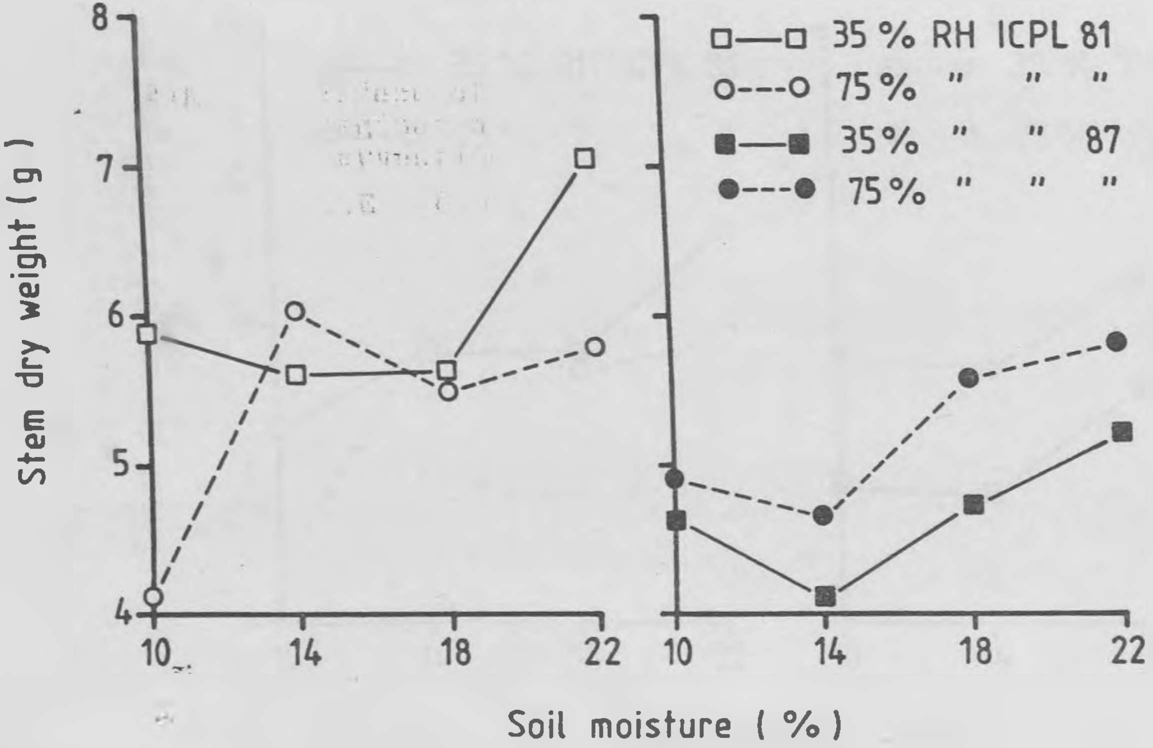

Fig.3. Effect of relative humidity and water regimes on stem dry weight per plant at harvesting.

S.E 0.904

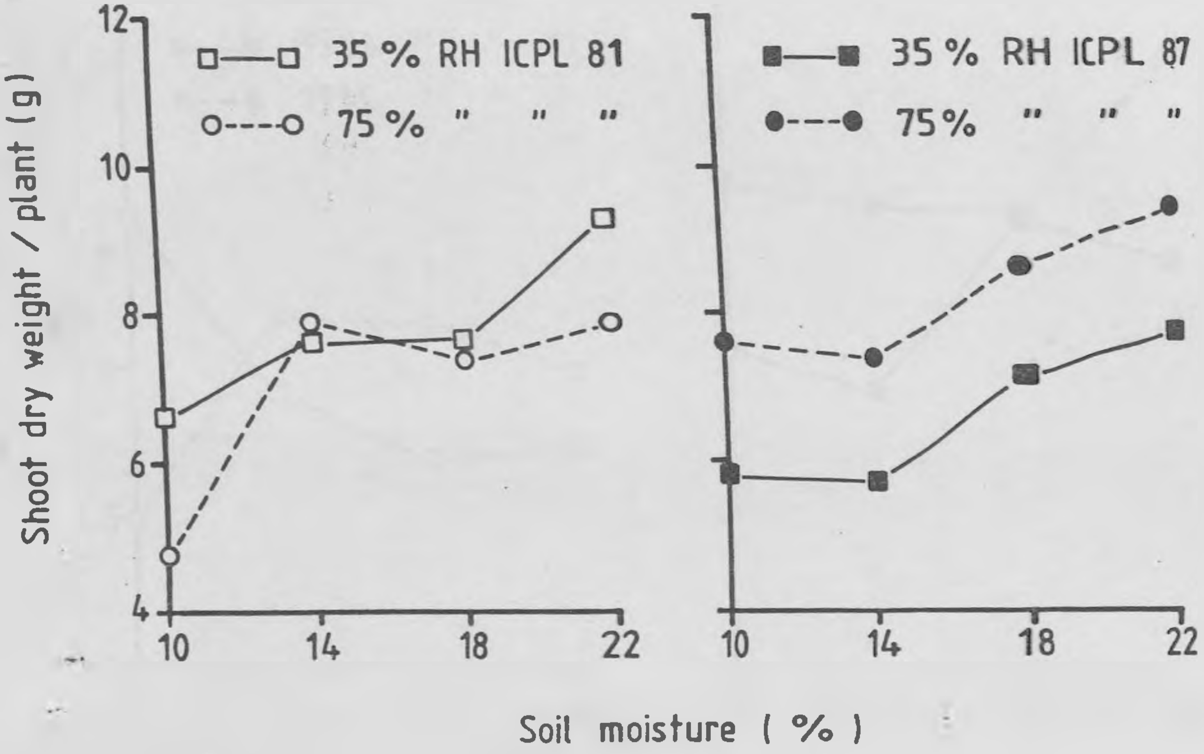

Fig.4. Effect of relative humidity and water regimes on shoot dry weight per plant at harvesting.

S.E 1.261

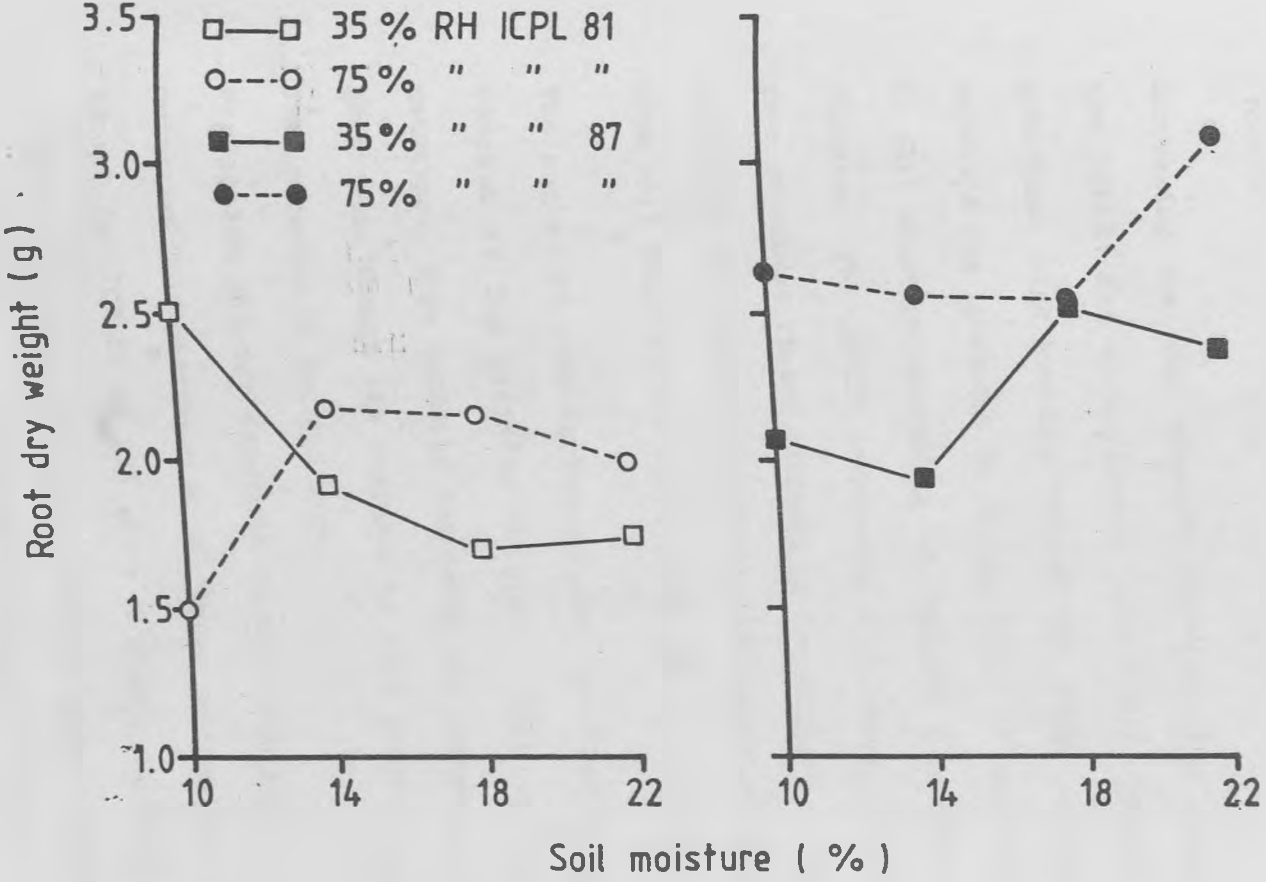

Fig.5. Effect of relative humidity and water regimes on root dry weight per plant at harvesting.

S.E 0.541

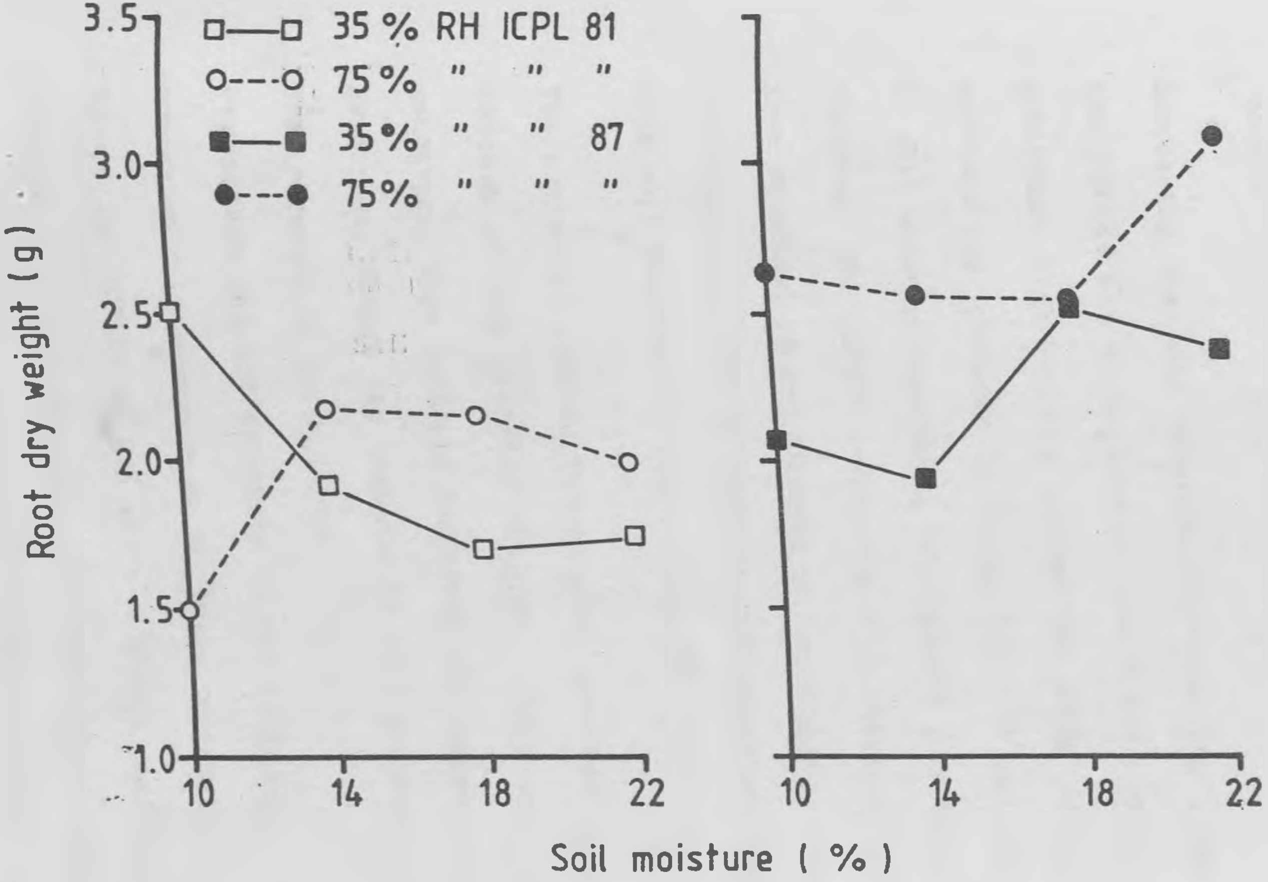

Fig.5. Effect of relative humidity and water regimes on root dry weight per plant at harvesting.

S.E 0.541

The response to high humidity and increasing soil moisture in terms of root dry weight (Fig.6) differed from that obtained for shoot dry weight. Although no significant effect of these treatments was observed, it was noted that high humidity tended to increase root dry weight for ICPL81 at 14, 18 and 22% water regimes.

Increasing the soil moisture increased the number of flowers and ICPL81 had more flowers than ICPL87 (Fig.7). In both genotypes, high humidity reduced the number of flowers as soil moisture was increased to 18 and 22%. At the two lower levels of soil moisture increasing the humidity increased the number of flowers. For ICPL81 increasing soil moisture at low humidity gave an almost linear increase in the number of flowers, but for ICPL87 at this level of humidity the number of flowers increased when soil moisture was raised from 14% onwards.

The number of pods increased with increase in soil moisture content at low humidity (Fig.8). This was true for both genotypes. High humidity decreased the number of pods for both genotypes, though the response to soil moisture was similar to that observed at low humidity.

Percentage pod-set depended on the humidity. High humidity decreased this parameter at all water regimes for both genotypes except for ICPL81 at 22% where a slight increase was observed (Fig.9). At high humidity increasing pod moisture caused a linear increase in percentage pod-set for ICPL87, while at this level of humidity increasing soil moisture beyond 14% caused a decline in the pod-set percentage for ICPL81.

Atmospheric humidity and water regimes influenced the grain

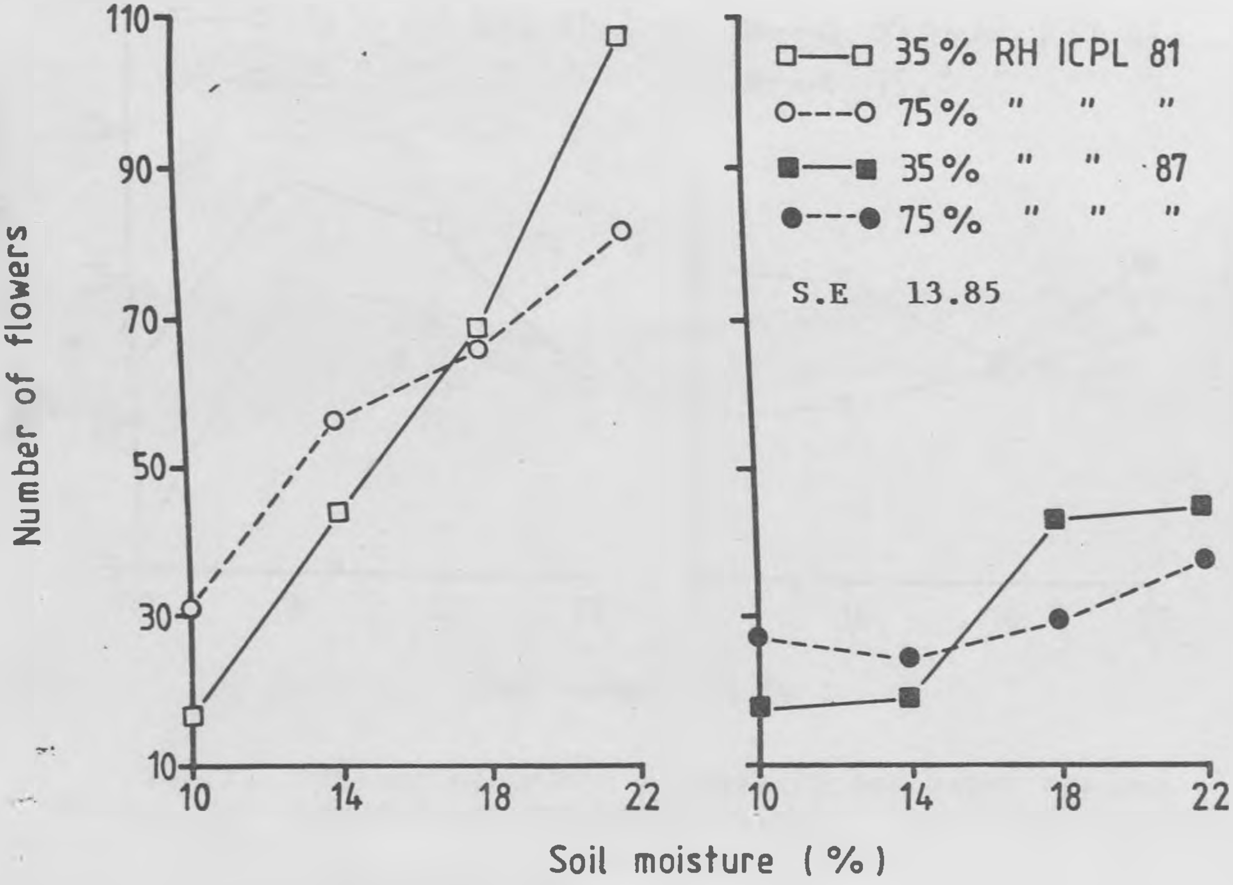

Fig.6. Effect of relative humidity and water regimes on total number of flowers.

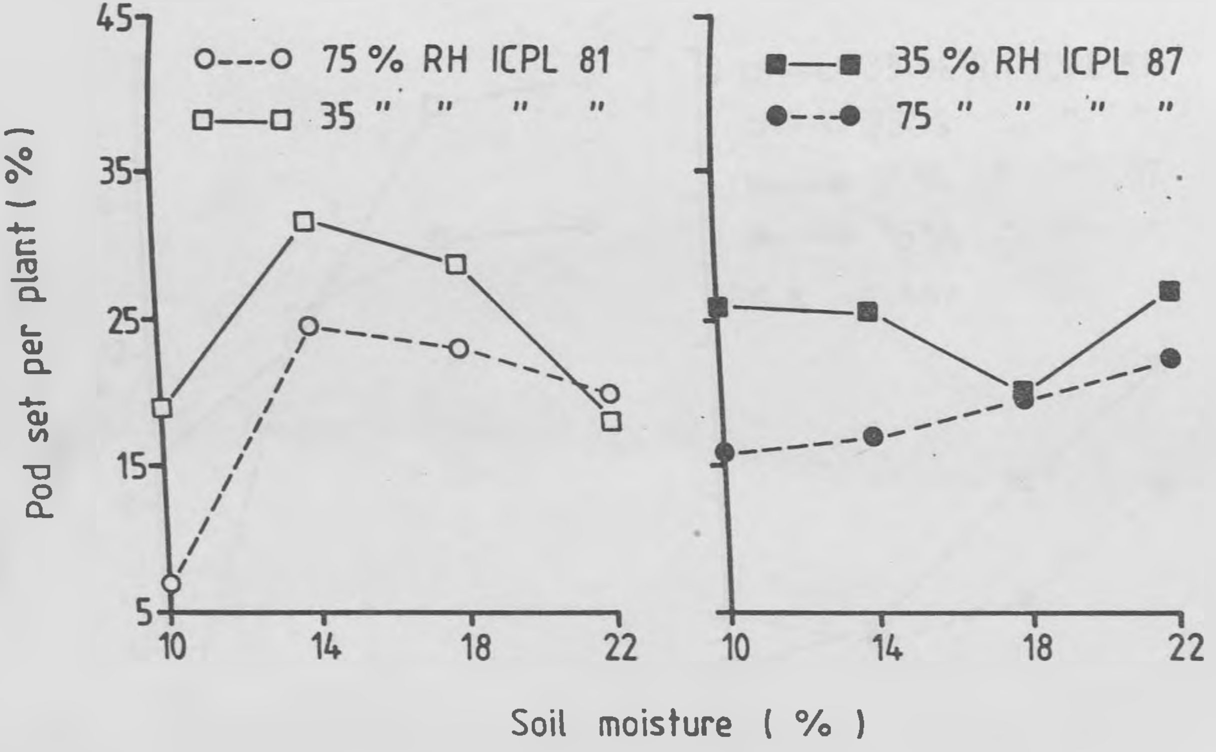

Fig.7. Effect of relative humidity and water regimes on pod-set percentage.

S.E 9.88

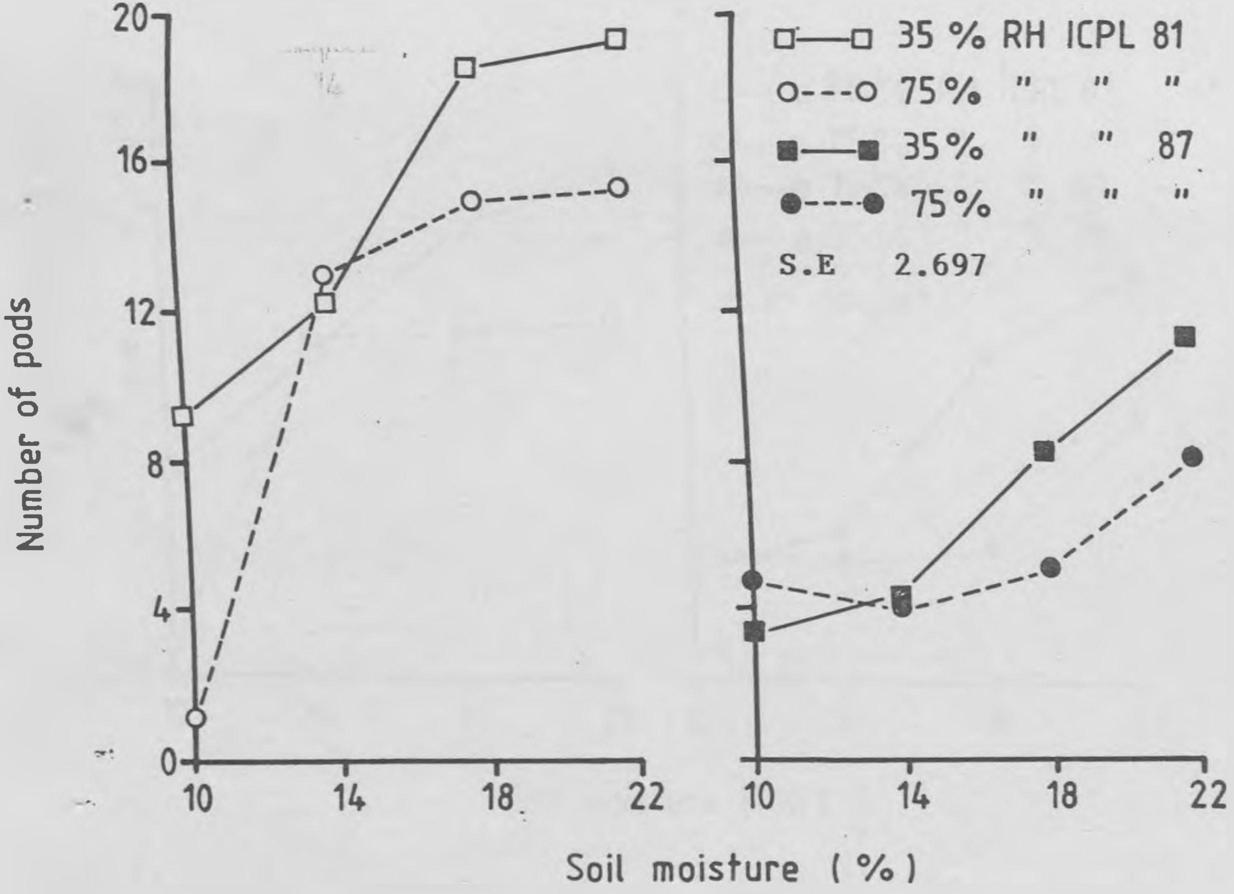

Fig.8. Effect of relative humidity and water regimes on pod number per plant.

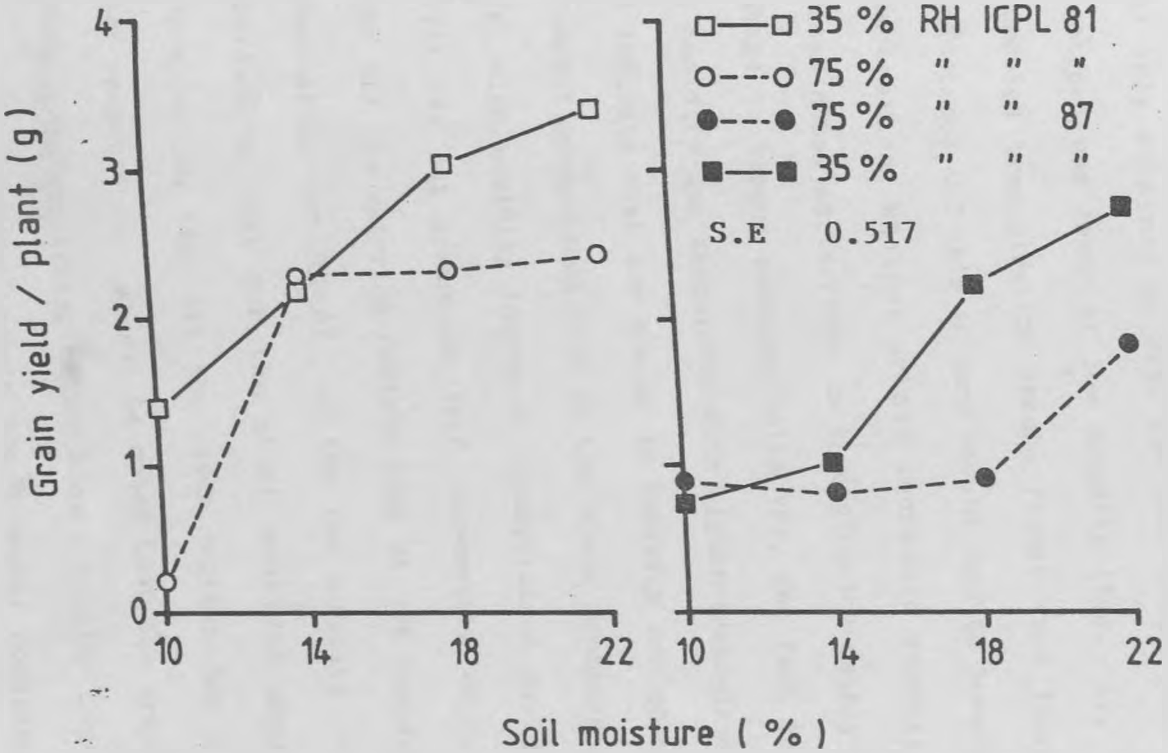

Fig.9. Effect of relative humidity and water regimes on grain yielf per plant.

yield (Fig.10). Increasing soil moisture increased grain yield in both genotypes at the low humidity. At high humidity increasing soil moisture increased grain yield for ICPL81 with the greatest increase observed when soil moisture was raised from 10 to 14%. Increasing soil moisture had little effect on the yield for ICPL87. There was little difference in yield at 10, 14, and 18% soil moisture. A significant increase in yield was only obtained at 22%. The leaf temperature for both the genotypes was lower at low humidity (Fig. 11). Theoretically increased transpiration should result from increased stomatal conductance and this in turn should lead to lowering of the leaf temperature. Whether or not increased stomatal conductance brings about an increase in transpiration mainly depends on the change in vapour pressure(delta VP). The fact that an increase in humidity was associated with higher transpiration would seem to indicate that the change in humidity had more effect on the stomatal conductance than on the vapour pressure gradient to the air. High humidity increased transpiration for ICPL81 but this still did not lower the leaf temperature which remained high over all the watering regimes than at 35% humidity . The leaf temperature for ICPL87 at the low humidity followed a trend similar to that for the other genotype whereby increased transpiration over all the water regimes led to a decline in leaf temperature. It can be noted that the graphs for stomatal conductance and transpiration show a similar trend (Figs.12,13). Increased humidity lowered the stomatal conductance for ICPL87 at low soil moisture and increased that for ICPL81 at all the soil moisture levels.

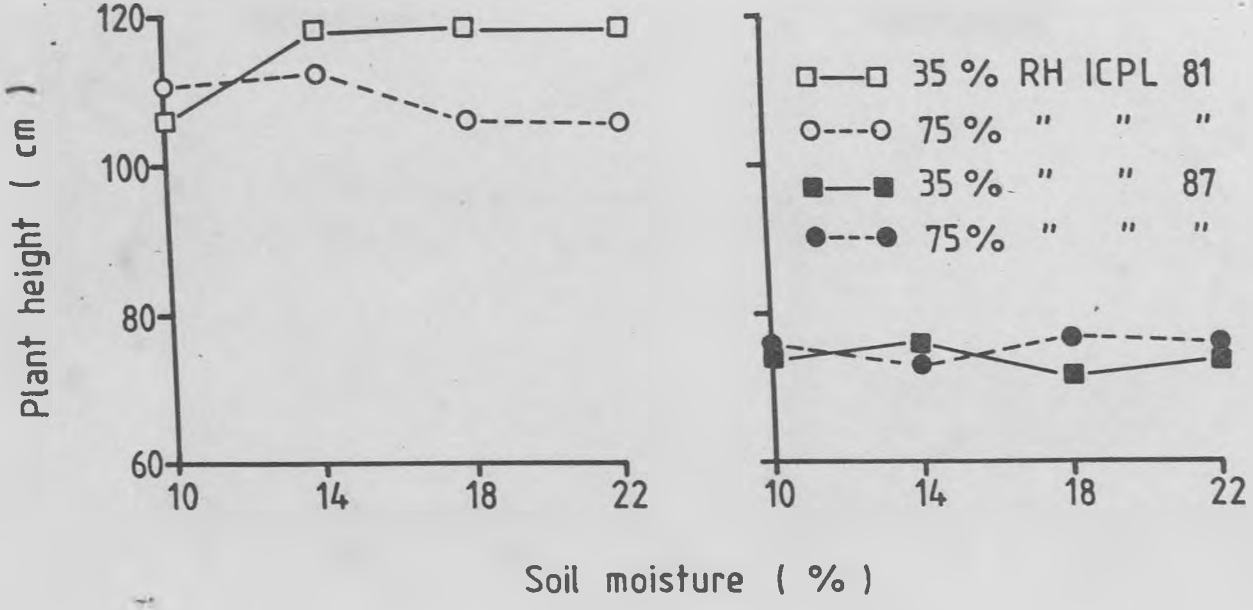

Fig.10. Effect of relative humidity and water regimes on plant height at harvesting.

S.E 6.688

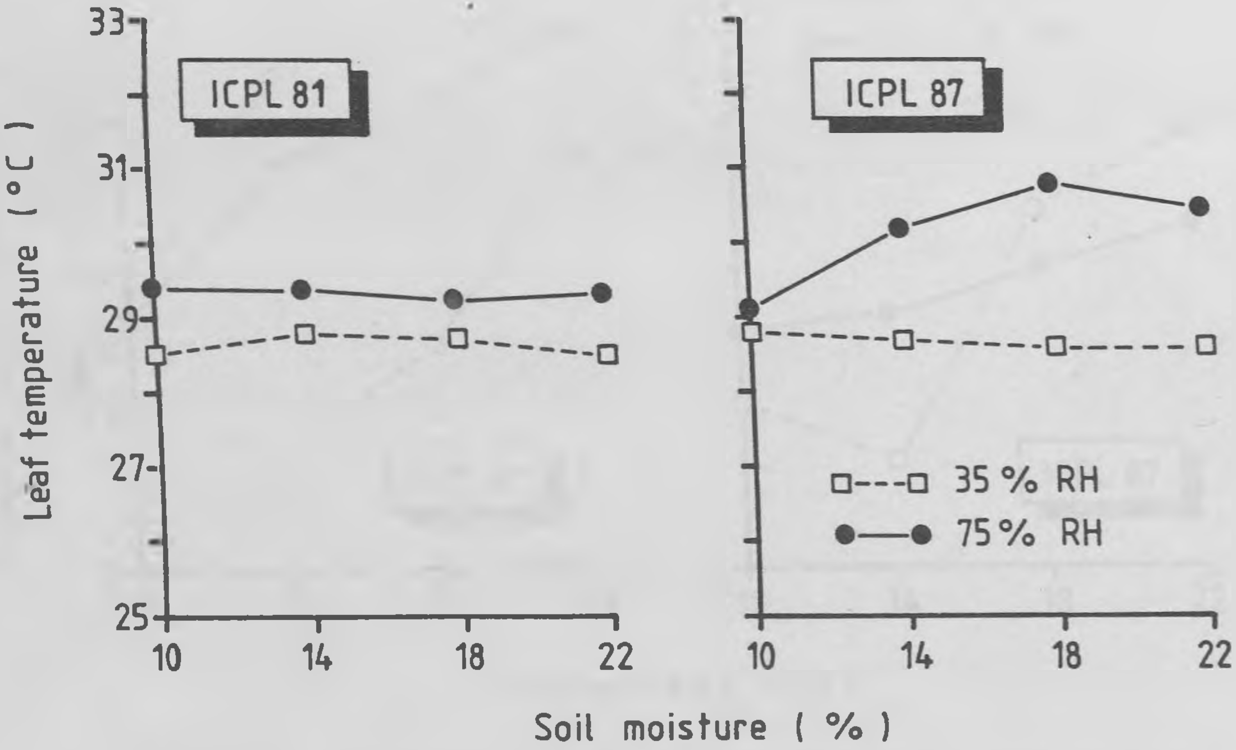

Fig.11. Effect of relative humidity and water regimes on leaf temperature.

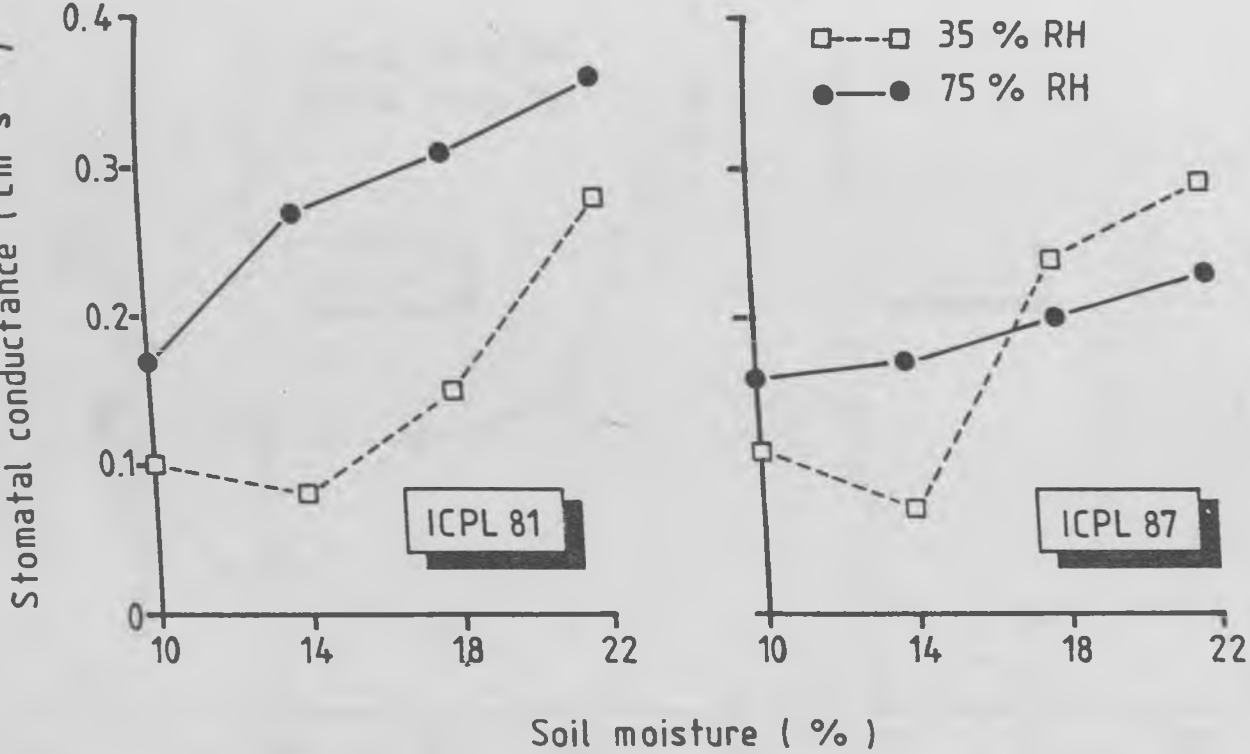

Fig.12. Effect of relative humidity and water regimes on stomatal conductance.

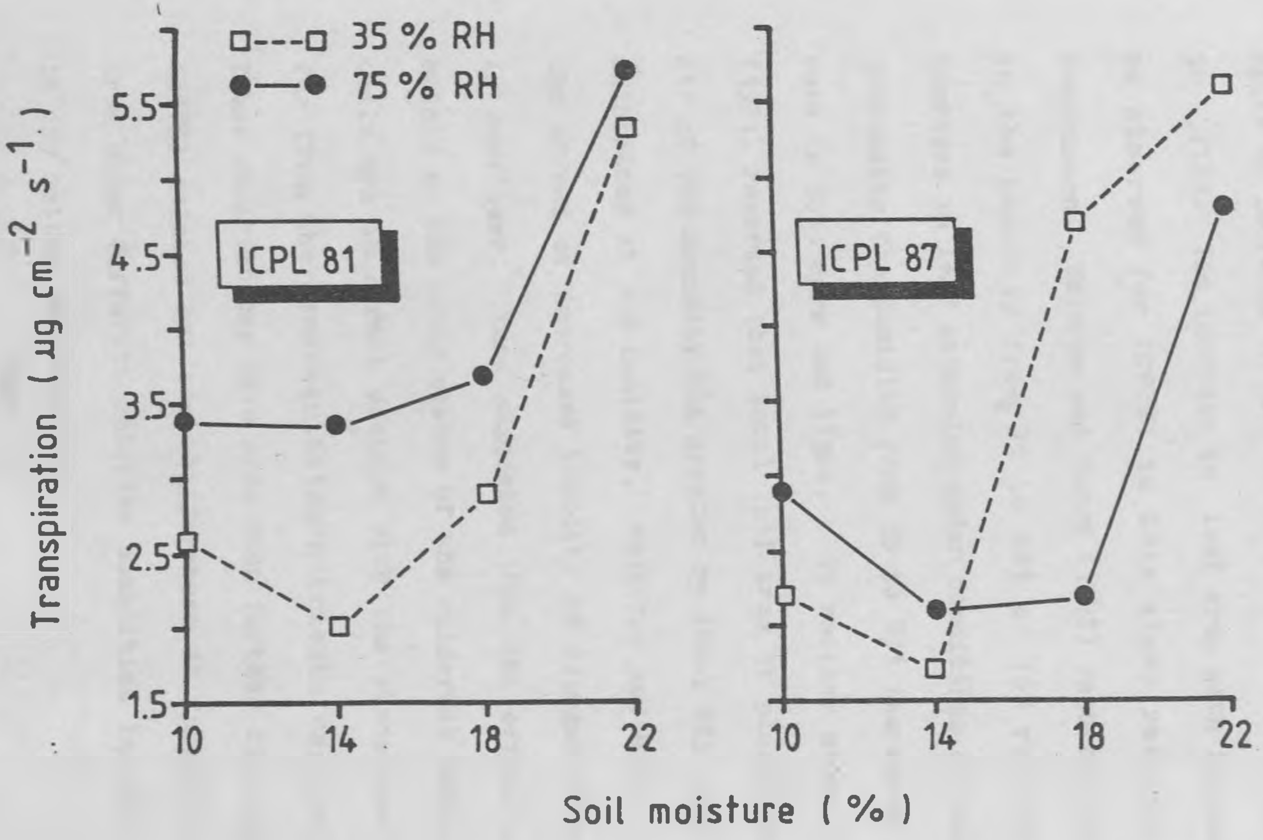

Fig.13: Effect of relative humidity and water regimes on transpiration.

DISCUSSION

These results suggest that ICPL87 was more responsive to increased humidity than ICPL81 in terms of dry matter production since an increase in leaf area and shoot dry weight was observed in ICPL87. The increase in leaf area with increasing humidity, as observed for ICPL87 in this study seems to be a common phenomenon. Waldron and Terry (1987) reported that an increase in the humidity from 35 to 65% or 75% resulted in a rapid increase in leaf extension under conditions of continuous light. Increasing the humidity from 35 to 85% increased leaf extension rate in both dark and light. In another study, Hoffman et al. (1971) reported that total leaf area of plants grown in ambient air of 90% humidity was greater by about 40% than that of plants maintained at 65% humidity. McIntyre and Boyer (1984) compared the effect of increased humidity on elongation and leaf growth in sunflower. They suggested that the effect of humidity was mainly on the water status of the epidermal cells. The epidermal cells are in direct contact with the atmosphere and are also far from the osmoregulating nutrients carried in the stele. These observations have also been further discussed and Tibbitts (1985) pointed out that differences in turgor altered the leaf area under different relative humidities leading to differences in dry matter accumulation.

The increase in leaf area with increase in soil moisture is a well established phenomenon (Hsiao, 1973; Bradford and Hsiao, 1982) which has for a long time been related to reduced turgor under water deficit conditions. Some recent work (Michelena and Boyer, 1982) suggests that expansive growth may not be related to turgor under different watering regimes. Van Volkenburgh and Boyer (1985) reported data which suggest that water stress may depress leaf expansion mainly by inhibiting bulk cell wall extensibility. The effect of water stress has been reported in soybean (Ramseur et al. 1985; Scott and Batchelor, 1979; Sivakumar and Shaw, 1978), and leaf shedding under water stress has been reported in pigeonpea (Nyabundi, 1980). The reduction in leaf area for light interception is regarded to be more important under water stress than the efficiency of photosynthetically active radiation to above ground dry matter (Muchow, 1985).

The decline in the grain yield at the higher humidity resulted from the reduction in the number of pods. In this study the total number of flowers was not significantly affected by the high humidity. The results of Sengupta and Roy (1979) showed that under field conditions at Berhampore, West Bengal, India, the percentage pod-set in chickpea increased from 2.28 to 42.92% when the humidity declined from 78.3 to 41.6%. Earlier studies (e.g. Mukherjee, 1961) attributed the effect of humidity on pod-set as being due to anther indehiscence. However, in other studies (Sengupta and Roy, 1979) it was found that pod-set still declined even though pollination had been done by hand after mechanical breaking of the anther sacs. They concluded that the failure to set pods was due to the effect of humidity on the germination of the pollen grains on the stigma. Singh and Auckland (1975) reported 19.7 to 23.1% success in chickpea crossing at ICRISAT, Patancheru, India, when the atmospheric humidity was 59.8%. In addition they stated that more pod-set was obtained when flowers were pollinated in the afternoon.

Similar results of the relationship between successful crossing and humidity have been reported by Gai et al., 1985 in soybean. They observed that the differences in the success of crossing in locations in northern and southern China were due to differences in humidity at these sites and that areas with low humidity had higher success. From these observations elsewhere, it is probable that in this study either anther indehiscence or failure of pollen germination could have caused the decline in the number of pods. The response to increased soil moisture for total flower number, pod number, and grain yield is consistent with other studies. Turk et al., (1980) while investigating the response of cowpea to water stress at different stages concluded that stress at flowering reduced the yield. Constable and Hearn (1978) stated that the leaf senescence resulting from water stress could affect the yield, although the results of Villalobos-Rodriguez and Shibles (1980) showed that formation of more pods after recovering from stress was more important than the duration of the assimilating surface. Low yield in pigeonpea has been attributed, among other factors, to its low water use efficiency for dry matter above the ground as well as for seed yield. The differences in yield between the two genotypes may be attributed to the differences in the number of pods (see Figs. 8and 9).

High humidity may increase flower abscission through its effect on increasing the leaf temperature. Theoretically increased humidity will reduce vapour pressure deficit between the leaf and the air and thus depress transpiration. High temperature has been reported to stimulate flower abscission in legumes (Turnbull, 1986; Warrag and Hall, 1983,1984). In this experiment the determinate genotype exhibited higher transpiration at 35% humidity. This was also accompanied by a higher stomatal conductance and lower leaf temperature at high soil moisture levels. At low soil moisture levels, transpiration and stomatal conductance were higher at 75% than 35% humidity. This may be attributed to improved plant water status and hence increased vigour. Increased abscission at high humidity may thus be attributed to the higher leaf temperature in this genotype. For ICPL81 however, lower vapour pressure deficit caused only a small and insignificant decrease in leaf temperature. Transpiration and stomatal conductance were higher at 75% than 35% humidity. These varietal differences may be attributed to differences in stomatal response to vapour pressure deficit and leaf water deficits (Flower, 1986).

In the hot, humid coastal areas of Kenya, a number of pigeonpea genotypes have been observed to grow taller and often exhibit delayed flowering than in the less humid hinterland areas. In this study,e higher level of humidity produced higher leaf area and shoot dry weight particularly for ICPL87. However, the 1 were only introduced at flowering period when vegetative growth had largely stopped. It would be interesting to monitor effects of humidity on vegetative growth and plant phenological development in situations which expose the plant to varying levels of humidity throughout the vegetative and reproductive phases.

EXPERIMENT III

3.3 EFFECTS OF VARIATION IN DAY AND NIGHT TEMPERATURE ON POD-SET IN THREE PIGEONPEA GENOTYPES DURING THE REPRODUCTIVE PHASE.

3.3.1 Introduction

Temperature is among the most important environmental factors affecting plant growth. It influences almost all growth processes and often determines where and when each crop plant is most successfully grown (Badizadegan, 1977)

Pigeonpea has become an important grain legume in Kenya as well as in other countries of East Africa. The development of short-duration pigeonpea genotypes has given rise to need for a reappraisal of the present understanding of pigeonpea adaptation. Earlier studies indicated that environmental factors affect growth and reproductive development of this crop (Chauhan et al., 1987; McPherson et al.. 1985; Turnbull, 1986; Akinola and Whiteman, 1985; Lopez, 1986). Investigations on the effect of day and night temperature response in several grain legumes suggest existence of differences in behaviour. Lawn (1979) pointed out that in green and black gram, genotypes of temperate or sub-tropical origin may be more responsive to day temperature while those of tropical origin respond to night temperature. This led to the suggestion that probably thermoperiodism existed in the grain legumes (Lawn, 1982). However, recent studies have ruled out existence of such a phenomenon (McPherson et al., 1985). Studies of Hadley et al.,

(1985) supported the view that it could be the mean diurnal temperature that is important, rather than either day or night temperature per se. Temperature-induced male sterility has been reported in faba beans (Bond et al., 1980) and in phaseolus vulgaris (Coulson, 1984). Several investigations have shown that the temperature during the reproductive stage could effect yield (Warrag and Hall, 1983, 1984; Stewart et al., 1982; Huxley and Summerfield, 1978). Exploitation of the yield potential of the new plant types will require a better understanding of the limitation that these plants are likely to encounter in different environments. Pigeonpea usually starts its reproductive development after a slow early growth (Sheldrake, 1984). Detailed studies on the role of temperature in early reproductive growth have recently been reported (Turnbull, 1986). In these studies it was reported that floral abortion increased and pod set decreased with high day temperature (35^{o}C).

This experiment was carried out to understand the response of the short duration genotypes to varying day and night temperature during reproductive phase. Genotypic differences needed to be investigated to establish the difference in ability for better adaptation in peninsular India and pigeonpea growing areas of Kenya and high altitude regions that experience low temperatures.

3.3.2 Materials and Methods

3.3.2.1 Glasshouse Culture

The experiment was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), situated at Patancheru, India on latitude 17°N and longitude 78°E at an altitude of 500 metres. The plants were grown in a naturally lit glasshouse which admitted 50% of the natural irradiance until flower bud initiation.

A completely randomised design was used. Each genotype was sown in plastic pots of 23 cm diameter containing 7 kg of air dry soil which had been passed through a 5mm mesh wire sieve. The soil was a sandy clay loam, defined according to USDA (1975) taxonomy as a fine hypothermic udic rhodustalf. Single superphosphate (1.162 g) was incorporated into the soil to give 80 mg phosphorus and 60 mg sulphur per kilogram of air dry soil. Twenty seeds were sown at 3 cm depth per pot and were inoculated with Rhizobium (IC 3195). Soil moisture was maintained at field capacity by daily weighing and adding calculated amounts of water. Polythene beads (125 g) were spread on the soil surface in each pot to minimise evaporation. The pots were randomised once a week. Thinning was done in two stages, fifteen days after sowing and when the first trifoliate leaf was fully expanded. Four plants were finally retained in each pot. The temperature of the glasshouse was thermostatically controlled and maintained at 30/20°C day/night temperatureby evaporative cooling until treatment imposition.

3.3.2.2 Treatments

The plants were shifted into two similarly constructed walk-in growth chambers (Conviron, Model CG 1011, Controlled Environment Ltd., Winnipeg, Manitoba, Canada) at 50% flower bud initiation. The light arrangement consisted of two racks of lights running lengthwise in each chamber. These could be moved up or down using a pulley system. Each light rack consisted of 12 fluorescent tubes (VHO cool light, 96, Sylvania, USA), and 20 incandescent bulbs of 50 watts each (Sylvania, USA). The photosynthetic photon flux density (PPFD) at the canopy which was 30 cm from the light source was 260 umol s^{-1} m^{-2} (the PPFD was measured using a Li-188B integrating Quantum/Radiometer/Photometer, Li-Cor, inc., Lincoln, Nebraska, USA). Relative humidity was maintained at 50% throughout the course of the experiment. The two chambers were programmed for 40°C and 30°C day temperature in either chamber and 25°C and 15°C night temperature. This gave a combination of 40/25°C and 30/15°C day/night temperature. The other treatment combinations were obtained by shifting some of the pots every evening to the cold room (5°C) and exchanging between the chambers.

Therefore, 40/5°C and 30/5°C day/night temperature treatments were obtained by shifting to the cold room and 40/15°C and 30/25°C day/night temperature by exchanging between the chambers. Half the number of pots was assigned to either chamber during the day. The pots were laid out in two rows under each lighting system. The pots were rotated twice a week.

Two determinate (ICPL4, ICPL87) and an indeterminate (ICPL81) short duration pigeonpea genotypes were selected for study.

3.3.2.3 **Measurements**

Weekly measurements of plant height were done. Flowering dates and flower duration were also recorded. Plant analysis was done at first flush maturity. Plants were harvested when most of the pods had lost their green colour. The plants were cut at the base of the stem. The shoot was separated into leaves, stem, and pods. Leaf area was measured with an automatic leaf area meter. Roots were recovered using a water jet and a sieve. Leaf and root samples were dried at 80°C for three days while the stems were similarly dried for five days. The dry weights were measured using a Mettler balance (Mettler PC 16-32, Mettler Instruments, Zurich, Switzerland).

Qualitative scoring was done to determine pod-set at harvesting.

RESULTS

The genotypes differed in leaf area at the time the treatments were imposed and ICPL4 had the greatest leaf area while ICPL87 had the least (Tab.1). There were no significant differences in leaf, stem and root dry weights at this stage.

Growth analysis at the end of the experiment showed that day temperature reduced the leaf area and shoot and root dry weights in all the genotypes. At low day temperature the greatest leaf area was obtained at 15°C night temperature in all the genotypes (Fig.1). Increasing night temperature at the high day temperature increased leaf area for ICPL4. The leaf area for ICPL81 at high day temperature at 15° and 25°C night temperatures was not significantly higher than at 5°C. The response of ICPL87 at high day temperature was similar to that at the low day temperature whereby both lowest and highest night temperatures decreased the leaf area. However, the differences between the genotypes at the high temperature over the whole range of night temperatures was not as marked as at low day temperature.

The shoot dry weight was influenced by both treatments of temperature, (Fig.2). High day temperature decreased the shoot dry weight to about 41% of that obtained at the low day temperature. Increasing the night temperature to 15°C at the low day temperature increased the shoot dry weight in all the genotypes. A further increase to 25°C decreased the shoot dry weight for ICPL4 and ICPL81 while for ICPL87 the shoot dry weight continued to increase. The middle night temperature

Table 1. The leaf area, leaf, shoot, and root dry weights before treatment imposition.

	Genotype				
	ICPL4	ICPL81	ICPL87	S.E	C.V
Leaf area	562a	559a	475b	61.8	11.6
Leaf dry wt.	1.91a	2.01a	1.98a	0.25	13.1
Shoot dry wt.	3.72a	4.01a	3.63a	0.36	9.6
Root dry wt.	1.35a	1.34a	1.37a	0.24	17.5

* Means bearing similar script are not significantly different using Duncan's Multiple Range test at 1%.

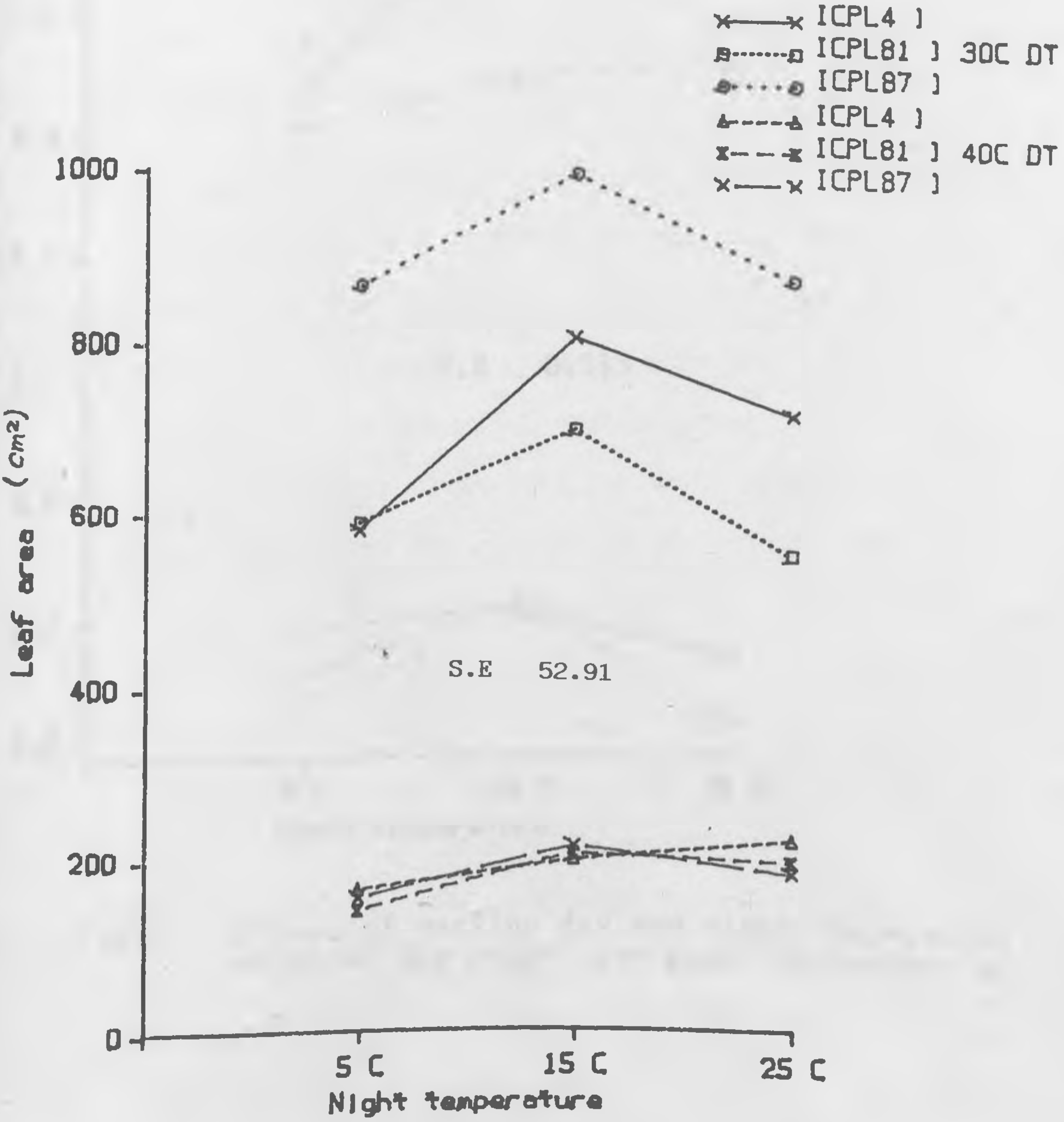

Fig.1. Effect of varying day and night temperature on leaf area per plant at harvesting.

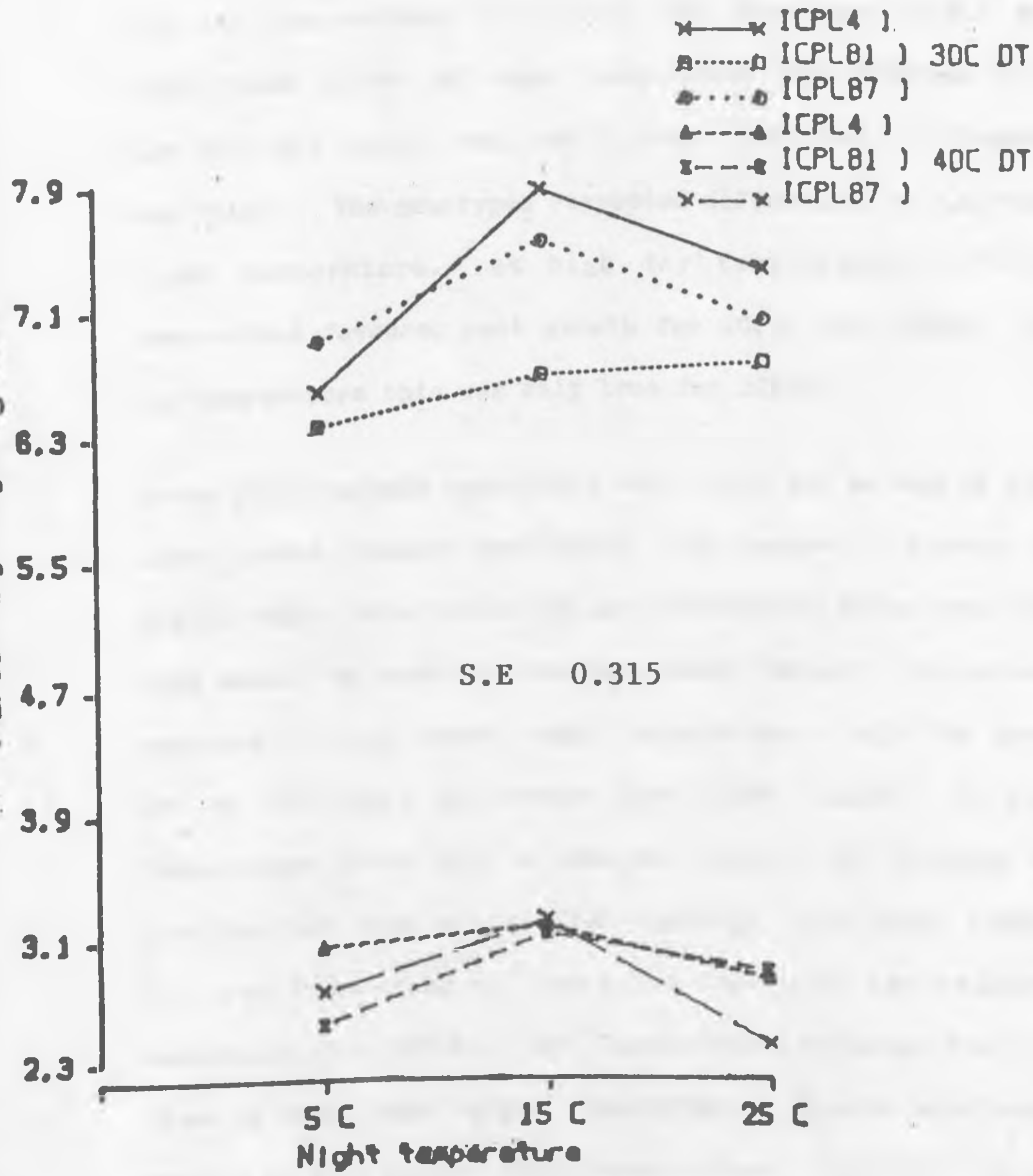

Fig.2. Effect of varying day and night temperature on shoot dry weight per plant at harvesting.

(15°C) was the best for shoot development as an increase was observed at this night temperature. At 5°C night temperature and high day temperature the genotypes differed to some extent with ICPL81 being the most affected.

The day temperature influenced the root dry weight but no significant effect of night temperature was observed (fig.3). The root dry weight declined by about 35% when day temperature was raised. The genotypes responded differently to the range of night temperature. At high day temperature, 25°C night temperature favoured root growth for ICPL4 and ICPL87. At low day temperature this was only true for ICPL4.

Grain yield in this experiment was fairly low as may be expected under growth chamber conditions. The number of flowers at the lowest night temperature was not determined since counting was done mainly to calculate the percentage pod-set. No pod-set was recorded at this lowest night temperature in all the genotypes and at 15°C night temperature for ICPL87 (Tab.2). At high day temperature there was no pod-set because the flowers usually abscised two days or so after opening. Low night temperature delayed flowering at both low and high day temperature especially for ICPL87. But flowers were retained for a longer time at the lowest night temperature. Flower abscission was higher at the highest night temperature (30/25°C) in all the genotypes. For ICPL4 and ICPL81 flowering started at 30/15, then 30/25 and finally at 30/5°C. The high night temperature treatment (30/25°C) was the first to flower for ICPL87 while the other two treatments flowered at about the same time. Pod formation was enhanced at the highest night temperature. The

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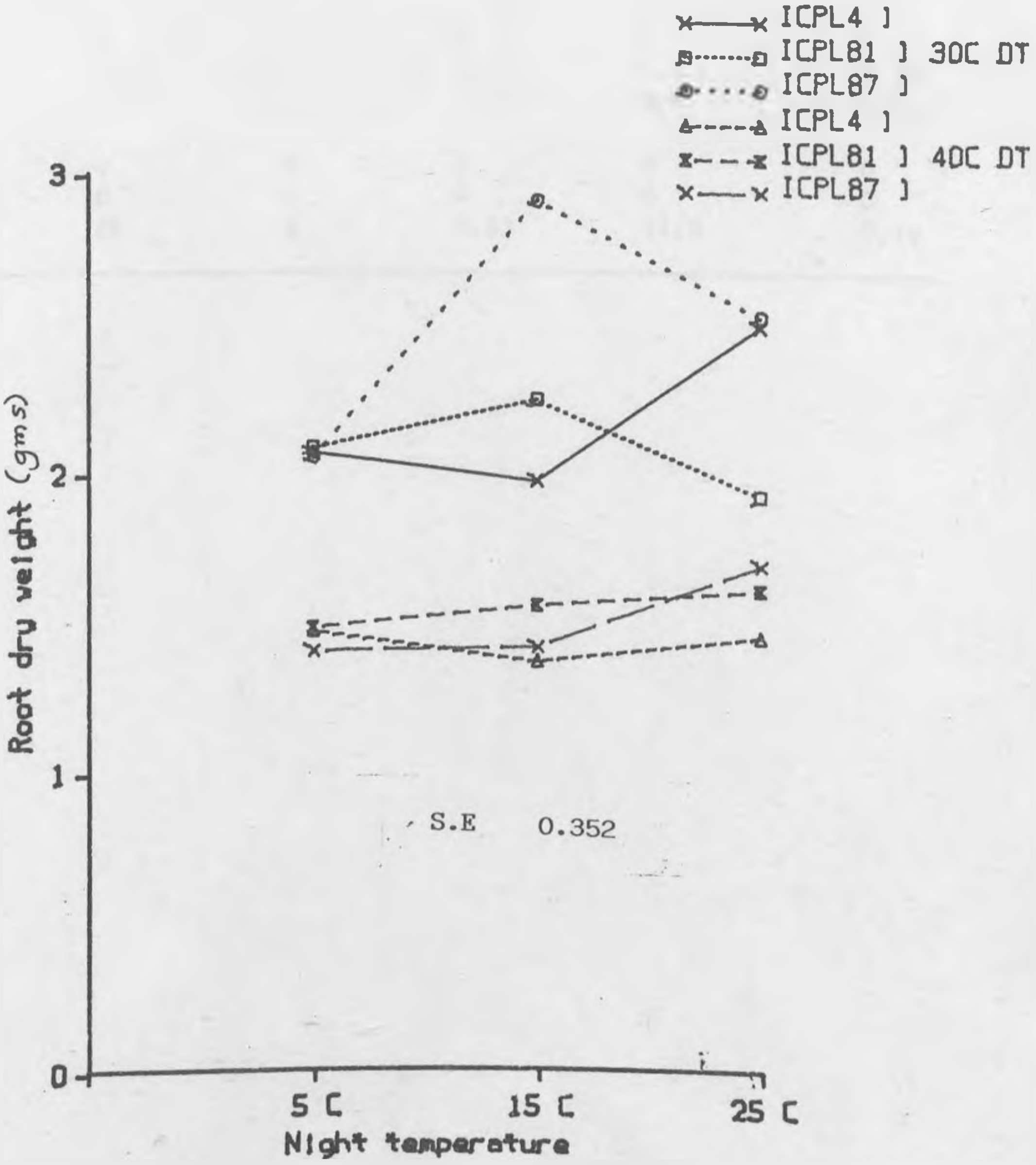

Fig.3. Effect of varying day and night temperature on root dry weight per plant at harvesting.

Table 2. The effect of varying day and night temperature on flower, pod number, % pod-set, pod dry weight and grain yield.

	No. of Flowers	No. of Pods	Pod dry weight	% Pod-set	Grain Yield (g)
ICPL4					
5C	0	0	0	0	0
15C	85	6	0.20	7.0	0.11
25C	82	5	0.38	6.0	0.14
ICPL81					
5C	0	0	0	0	0
15C	120	7	1.14	5.6	0.76
25C	112	5	1.11	4.0	0.74
ICPL87					
5C	0	0	0	0	0
15C	0	0	0	0	0
25C	26	3	0.33	11.0	0.19

middle night temperature (15°C) gave mostly single-seeded pods as compared to 25°C for ICPL4. Increasing night temperature at the low day temperature decreased the number of flowers and pods as well as the pod-set percentage for ICPL81.

DISCUSSION

The effect of day temperature on leaf area was associated with leaf abscission. High day temperature caused extensive leaf shedding. Newly formed leaves did not expand sufficiently before they shed. Rawson and Dunstone (1986) observed that high temperature resulted in smaller leaves in sunflower and attributed this to short growth periods because of accelerated initial expansion rates. There was epinastic bending of leaves under high day temperature in this study suggesting that high day temperature damaged the pulvini or interfered with hormonal functioning. The epinastic bending of the leaves reduced the leaf area available for light interception. It was observed that the leaves of plants under high day temperature treatment did not assume the vertical "sleeping" position when the lights went off. The failure of the leaves to orientate indicates that the high temperature probably interfered with the circadian rhythm. Vince-Prue (1975) stated that the measurement of time in short day plants is based on an endogenous circadian rhythm of sensitivity to light. Rapid re-growth and branch formation was observed under high day and night temperature, this being probably the result of high temperature interference with apical dominance. High day temperature has been observed to result in larger sized plants of pigeonpea (Turnbull, 1986). At the lowest night temperature the leaves turned greenish-yellow. Smartt (1979) observed that low temperature could interfere with chlorophyll formation and probably that is why the leaves at low night temperature were not as green as those at 30/15 and 30/25°C. The reduction in leaf dry weight followed a pattern similar to that of leaf area indicating that the final leaf dry weight was determined by the extent of senescence. Abscission was high at the high day temperature and this led to the low leaf dry weights. The results of the interaction of day and night temperature in determining the leaf area indicates that the response to day temperature could be modified by the night temperature though this was not translated into the leaf dry weight. High day temperature is reported to reduce photosynthesis (Marowitch, 1985). Therefore apart from the major factor of leaf senescence, high temperature may have reduced photosynthesis. In any case the decline in the leaf area could have limited the area available for light interception leading to a limitation in the availability of assimilates. This may have led to a reduction in the accumulation of dry matter both in the shoot and roots as evidenced by the reduction in the dry weights of these parts due to high temperature.

Failure to set pods at low night temperature has been observed in chickpea (Saxena and Sheldrake, 1979). Flowering at the lowest temperature was delayed in all the genotypes in this study but more so in ICPL87. The flower number at 30/15 and 30/25^{o} day/night temperature were almost similar for ICPL4 and ICPL81. At the low night temperature the flowers were not counted since there was no pod-set because counting was done mainly for determining the pod-set percentage. Flower abscission was slightly higher at the highest night temperature. It has been reported that high day temperature causes flower abscission in pigeonpea (Turnbull, 1986), soybean (Warrag and

Hall, 1983; Nielsen et al., 1985 Stewart et al., 1980). Mechanisms underlying this phenomenon are said to include anther indehiscence, abnormal pollen development and reduced pollen life. High temperature-induced male sterility has been reported in soybean (Warrag and Hall, 1983; Summerfield et al., 1979). In faba beans pollen life at 30°C was only for a day as compared to several days when the temperature was reduced to 15°C (Bond et al., 1980). Warrag and Hall (1984) hypothesised that in cowpea exposed to high night temperature the failure to set pods resulted from the development of small pollen grains which could not exert sufficient pressure to dehisce the anthers. They also noted that high night temperature caused the degeneration of the cytoplasm in the tetrads within days of release from the microspore mother cell sac. Abscised flowers at the lowest night and low day temperature were dissected in this study and it was observed that the ovaries were normal. Studies on chickpea have shown the sensitivity of pollen development to low temperature. Savitri and Ganapathy (1980) reported that pollen germination and pollen tube growth were hampered by low temperature. They dissected the aborted flowers and found that no embryos had been formed while in the flowers that had set pods their were embryos suggesting that fertilisation had not occurred in the aborted flowers. . The range of night temperatures used here suggests that the optimum temperature for shoot and root growth as well as pod-set is 15° for ICPL81 and ICPL4. The optimum for ICPL87 is higher (25°C) suggesting that ICPL87 is more sensitive to low night temperature or conversely more tolerant to high night temperature.

EXPERIMENT IV

3.4 EFFECT OF DATE OF SOWING ON POD-SET AND DRY MATTER PARTITIONING IN FIELD-GROWN SHORT DURATION PIGEONPEA.

3.4.1 Introduction

In regions of the world which experience annual variations in day-length and temperature, partitioning of dry matter in pigeonpea is altered (Sheldrake and Narayanan, 1979; Akinola and Whiteman, 1974). They observed that as sowing was delayed from the optimum date, the later sown plants experienced decreasing day length and temperature. It has been stated that the amount of dry matter produced is dependent on the amount of intercepted solar radiation and the efficiency of its conversion (Monteith, 1977). A longer day length would mean more time for interception of solar radiation. The date of planting often determines the availability of sufficient soil moisture to the crop during critical stages of growth and development. Pigeonpea cultivars that are photoperiod-sensitive need to be planted in accordance with the day length cycle if maximum yields are to be realised. Wallis et al. (1975) observed that in south eastern Queensland when flowering took place during late January and February, low pod yields were obtained.

The effect of planting date is related with the other important environmental factors i.e. temperature, humidity, water stress, and photoperiod. Therefore, the effects of sowing date are a result of the interaction of these factors.

The controlled environment studies (Experiments I, II and III) had shown the effects of these four environmental factors and therefore, a field experiment was carried out to observe the response of the short duration genotypes used in earlier studies.

3.4.2 Materials and Methods

3.4.2.1 Trial Site

The site used for the experiment was situated at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. The centre is situated on latitude 17°N, longitude 78°E at an altitude of 500 M. The soil was a well drained Alfisol (Sandy clay loam) described according to USDA taxonomy as a fine hypothermic udic rhodustalf. The Alfisols are light with an available water holding capacity of 60-100 mm. (ICRISAT, 1986). The rain season starts in June and runs into October. This is the main season for pigeonpea cultivation in most parts of India. Before sowing a basal dose of 100 kg Diammonium phosphate to give 18 kg N and 20 kg P per hectare was applied. Ridges of 60 cm width were made in an East West direction. The meteorological observatory was about 250 m from the site.

3.4.2.2 Treatments

Three sowing dates (June 25, July 28, and August 28) were chosen to represent optimum sowing date and two late sowing dates. Three short duration determinate genotypes (ICPL4, ICPL87, ICPL151) and one indeterminate (ICPL81) were selected for the study.

3.4.2.3 Design and Layout

A split-plot randomised complete block design with three replications was used. The main plots (sowing dates) were 1.8 metres wide and 19 metres. The sub-plots measured 4 metres long and 1.8 metres wide and were separated by a 1 metre width path. The seeds were sown in furrows opened on either side of the ridges. This gave a spacing of 30 cm between the rows. The intra-row spacing was 10 cm. Six rows were sown for each genotype with two outer rows on each side acting as guard rows.

The unsown areas were kept weed free by regular hand weeding. Furrow irrigations were given depending on lack of rainfall. Thinning was done three weeks after sowing.

3.4.2.4 Measurements

Six plants were taken from each one of the inner two guard rows at flowering for growth analysis. The plants were cut at the base of the stem. Leaves were separated for determining leaf area. The leaf area was determined using an automatic leaf area meter (Delta T, Burwell, Cambridge, England). The dry weights were recorded after drying the leaf samples in a hot air circulation oven at 80 C for three days, and the stem samples at 80 C for five days.

Weekly measurements of plant height were done. Days to flower bud initiation, flowering, and pod maturation were recorded. The plants were harvested when a majority of the pods had dried up. The leaf area, leaf dry weight, and stem dry weight were study.

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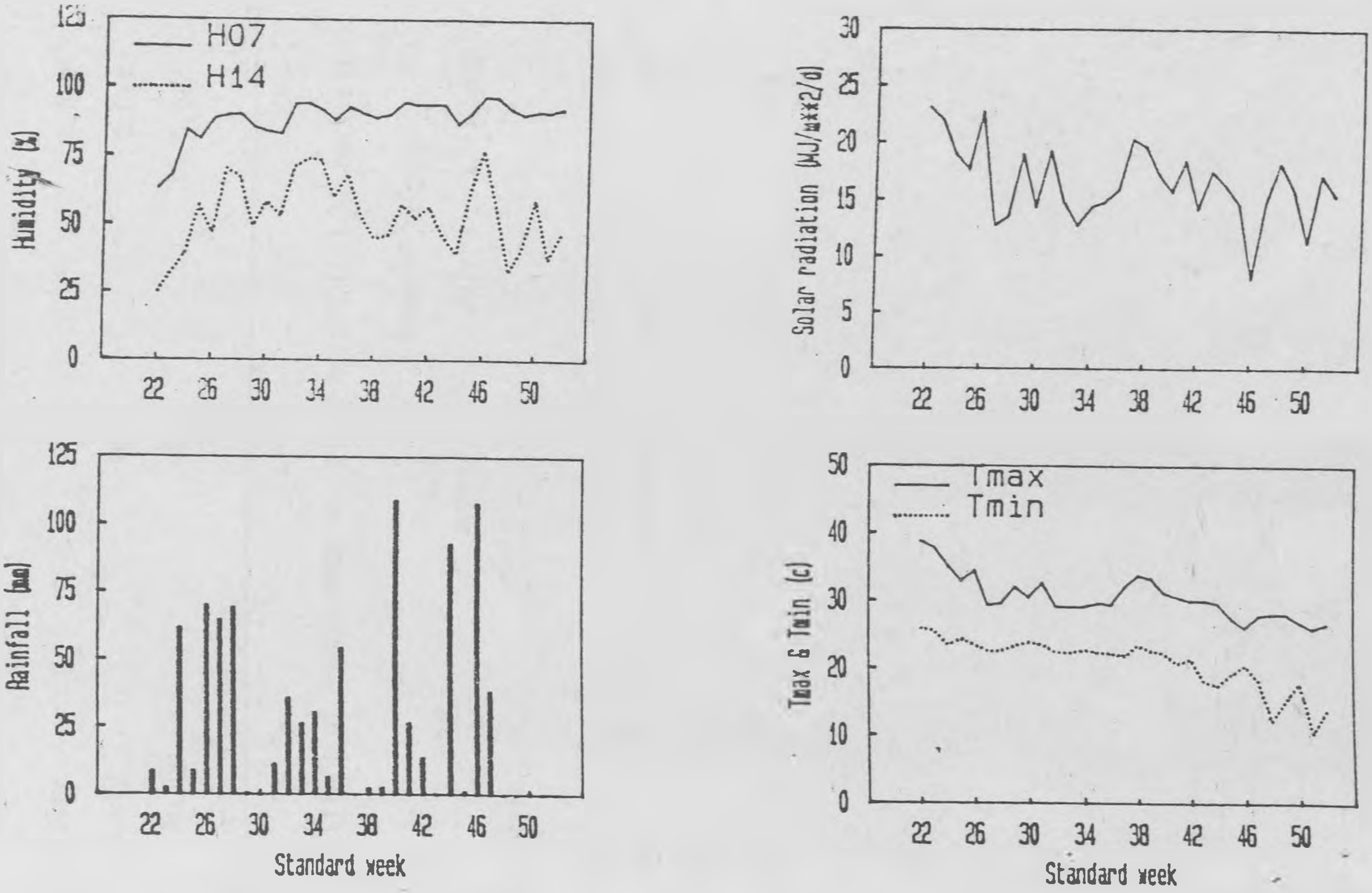
RESULTS

The rainfall, humidity, solar radiation, and minimum and maximum temperature are shown in Fig.1. The daily means as well as totals for the rainfall are given in appendix II. TThe number of days to flowering were not different, the rate towards this phase increased at late sowing (Tab.1)

At flowering, delayed sowing was found to depress leaf area, total shoot biomass and the biomass of leaves and stems (Fig.2). The determinate genotype did not differ in these parameters at the June sowing while the indeterminate genotype exhibited higher. At the later dates of sowing no genotypic differences were observed in these growth aspects.

The final leaf area was determined by the leaf retention ability of the different genotypes, but the differences were less marked than at the flowering stage (Fig.3c). The greatest leaf area retained at maturity over all the dates was obtained for ICPL87 while the lowest was recorded for ICPL151. At July sowing date, the final leaf area for ICPL4 and ICPL87 were similar and higher than that for ICPL81 and ICPL151 which were also similar. Late sowing led to a decline in leaf area for ICPL81 and ICPL151 at all dates of planting while for ICPL4 and ICPL81 an increase was observed at August sowing as compared to July date.

The final shoot dry weight consisted of the stem and leaf dry weights and this declined with delayed sowing (Fig.3a,b). Apart from ICPL4, the other genotypes showed a progressive decline in shoot dry weight. For ICPL4 the shoot dry weight declined drastically when sowing was delayed beyond July.



Station Patancheru Data base : 1.6.'87 - 31.12.'87

Fig. 1 The Weather data for the growing season

Table 1 a. Effect of date of sowing on days to flowering.

Date of sowing	Days to flowering (f)	(I/f)
June	55	0.018
July	46	0.021
August	45	0.022

1 b. Effect of sowing date on plant height (cm) at harvesting.

		Date of sowing	
	June	July	August
Genotype			
ICPL 4	75.43	75.33	63.38
ICPL 81	86.31	96.38	93.16
ICPL 87	63.77	67.22	67.16
ICPL 151	70.0	75.27	71.8

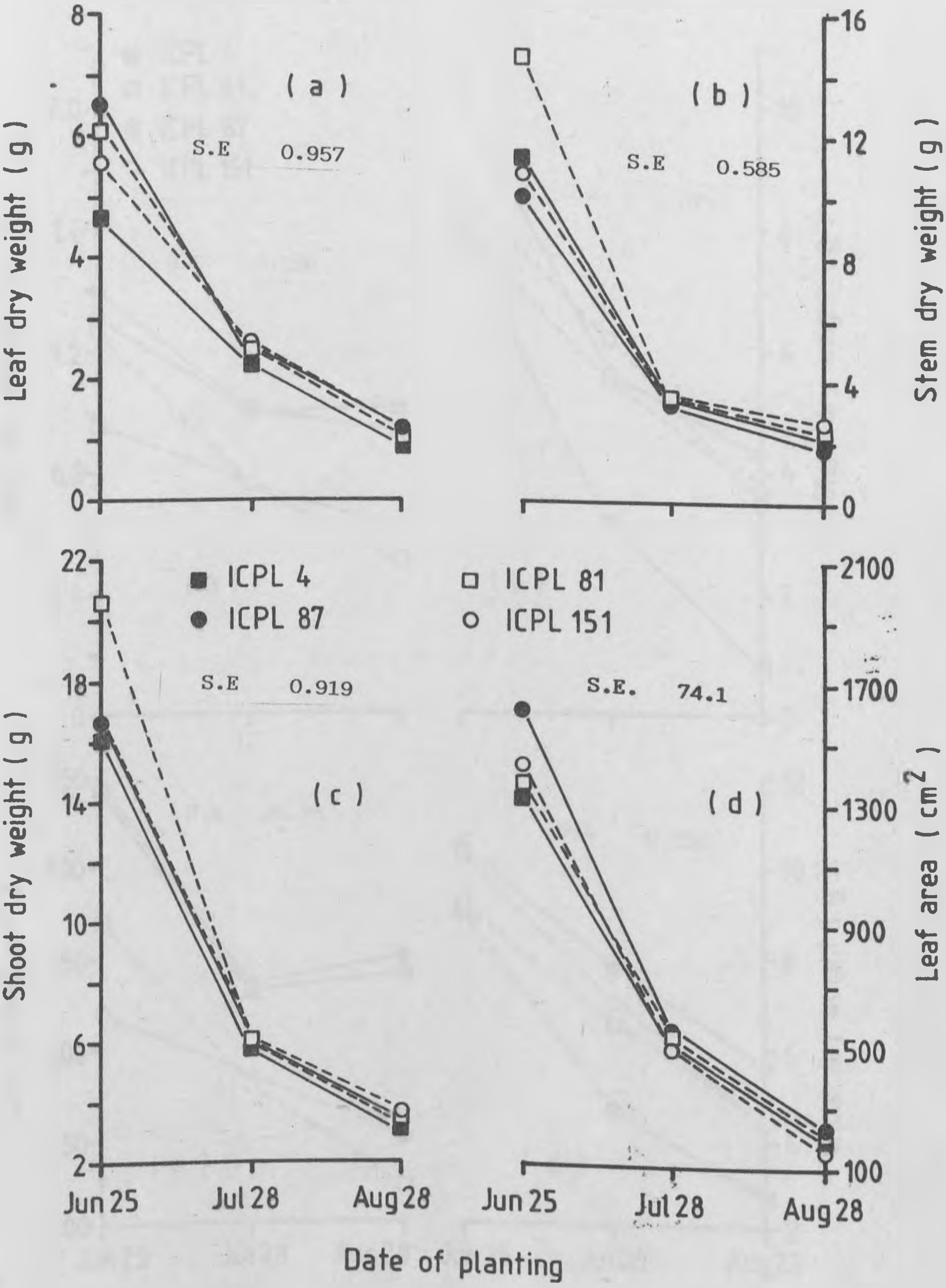


Fig.2. Effect of sowing date on leaf area, dry weights of leaf, stem, and shoot at flowering.

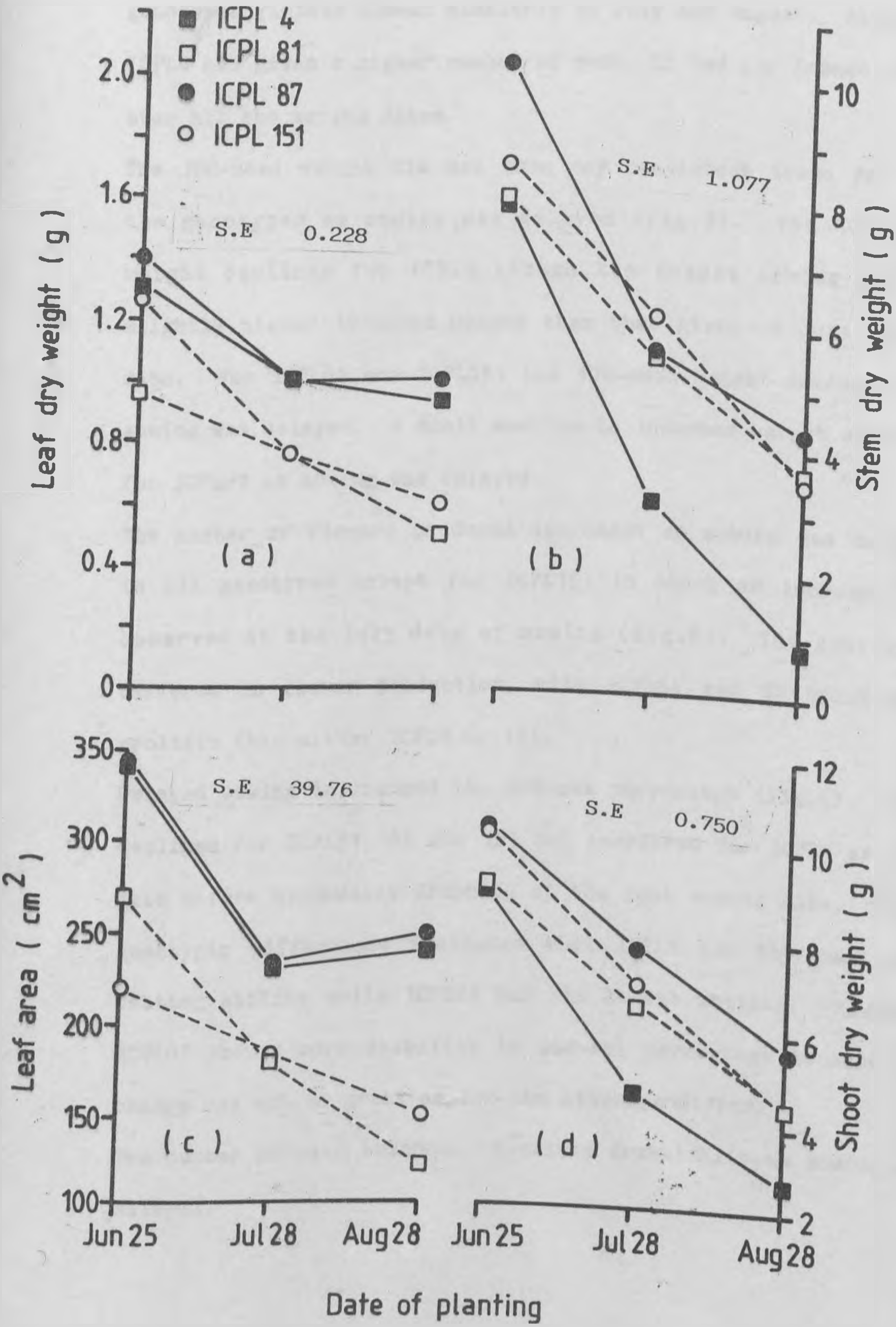


Fig.3. Effect of sowing date on leaf area, dry weights of leaf, stem, and shoot at harvesting.

The date of sowing influenced the number of pods and delayed sowing reduced the pod number (Fig.4). The lowest number of pods was obtained for ICPL151 at all the sowing dates.

The grain yield was reduced by delayed sowing (Fig.4). All the genotypes yielded almost similarly at July and August. Although ICPL4 had given a higher number of pods, it had the lowest yield over all the sowing dates.

The 100-seed weight did not show any consistent trend for all the genotypes as sowing was delayed (fig.5). The 100-seed weight declined for ICPL4 though the August sowing gave a slightly higher 100-seed weight than that given at July sowing date. For ICPL81 and ICPL151 the 100-seed weight increased as sowing was delayed. A small decline in 100-seed weight occurred for ICPL87 as sowing was delayed.

The number of flowers produced decreased as sowing was delayed in all genotypes except for ICPL151 in which an increase was observed at the July date of sowing (Fig.6). The genotypes differed in flower production, with ICPL81 and 87 being more prolific than either ICPL4 or 151.

Delayed sowing influenced the pod-set percentage (Fig.6). This declined for ICPL81, 87 and 151 but increased for ICPL4 at July date before eventually dropping at the last sowing date. These genotypic differences indicated that ICPL4 had the best pod-setting ability while ICPL87 had the lowest ability. However, ICPL87 showed more stability in pod-set percentage because the change was not as great as for the other genotypes.

The number of main branches declined drastically as sowing was delayed.

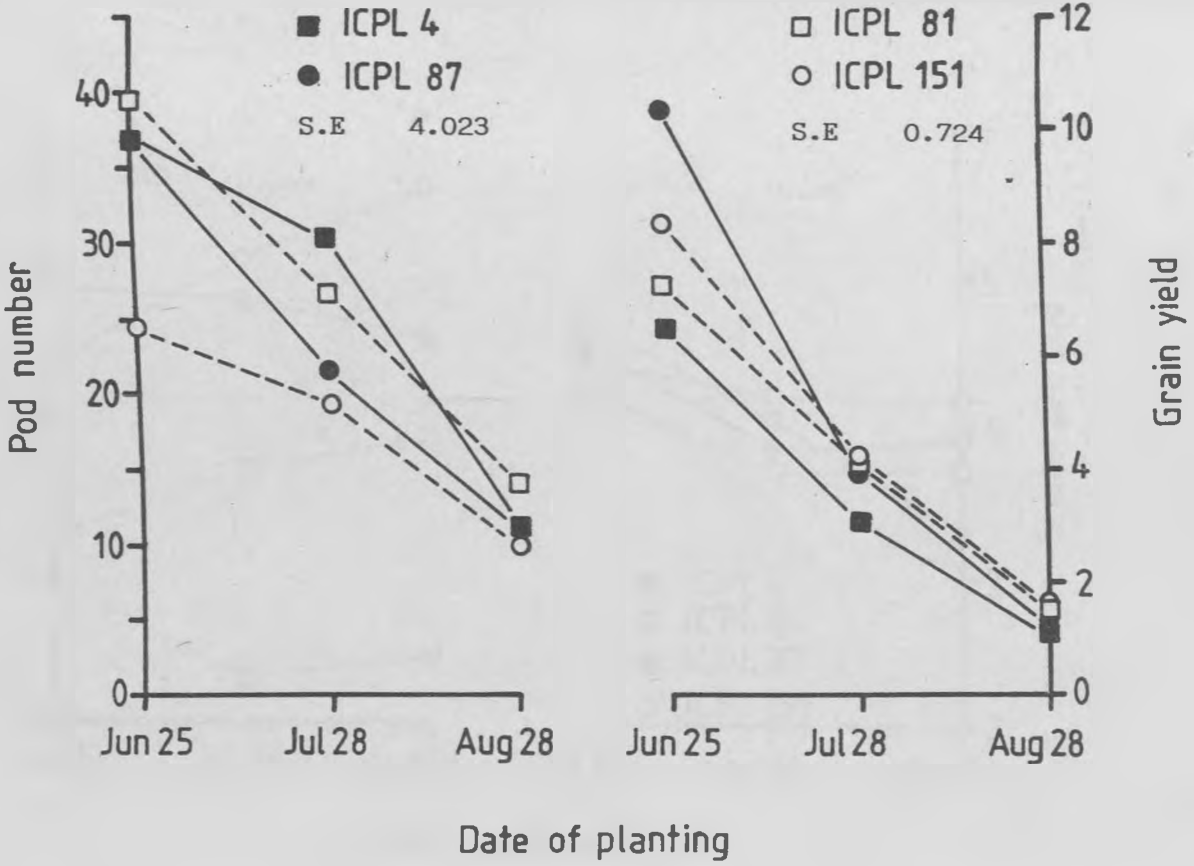


Fig.4. Effect of sowing date on number of pods and grain yield per plant.

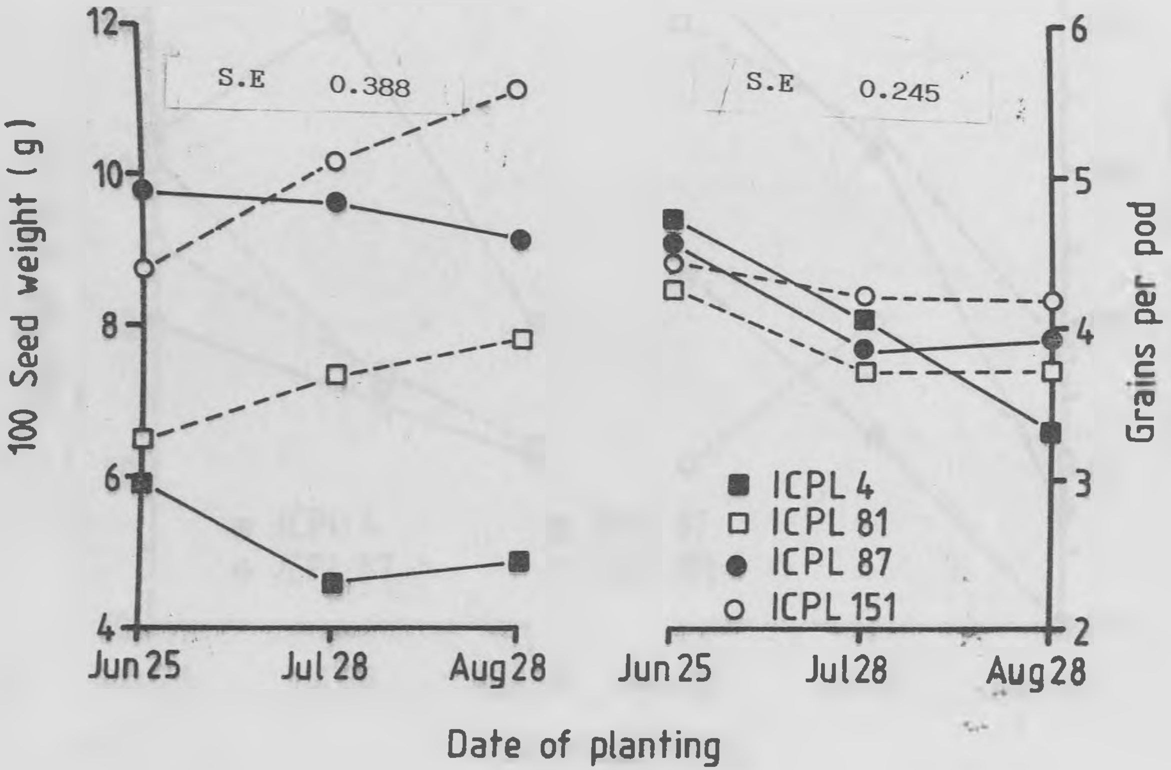


Fig.5. Effect of sowing date on 100seed weight and grains per pod per plant.

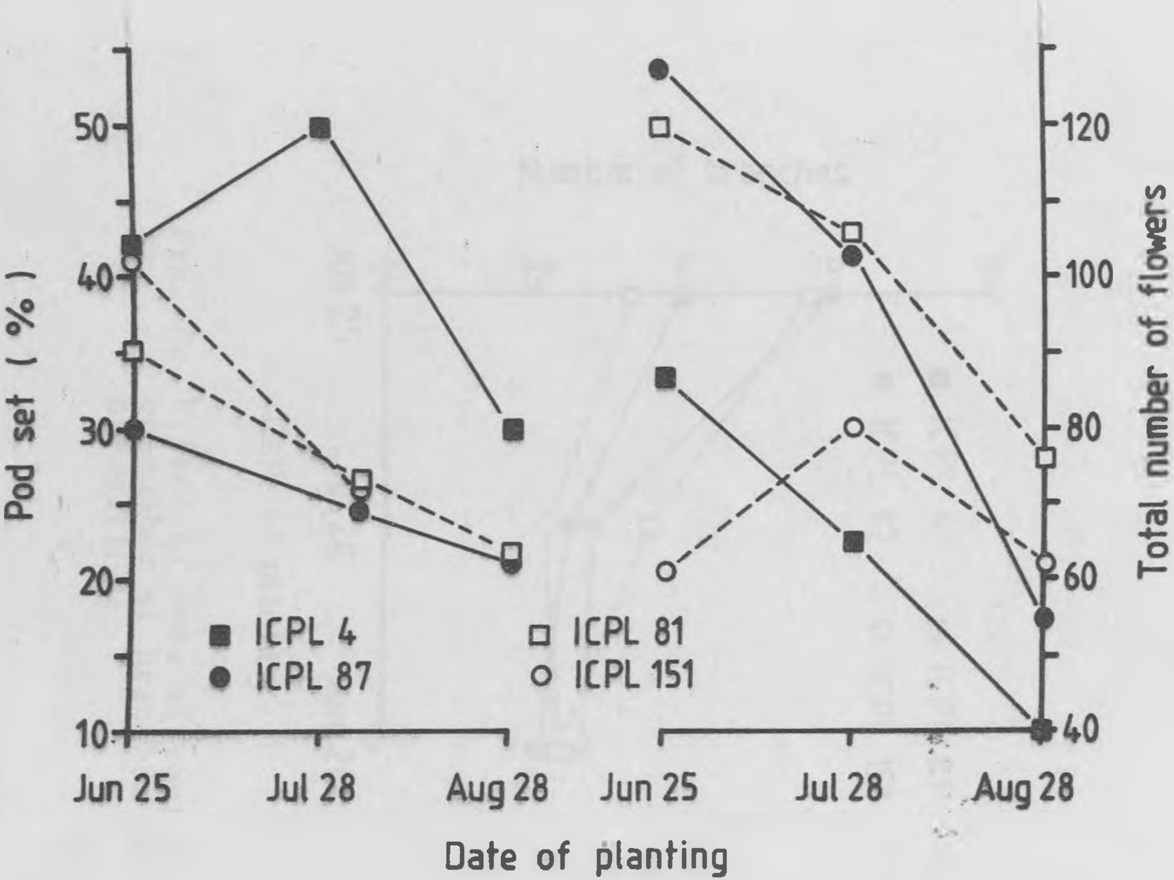


Fig.6. Effect of sowing date on total number of flowers and podset percentage per plant.

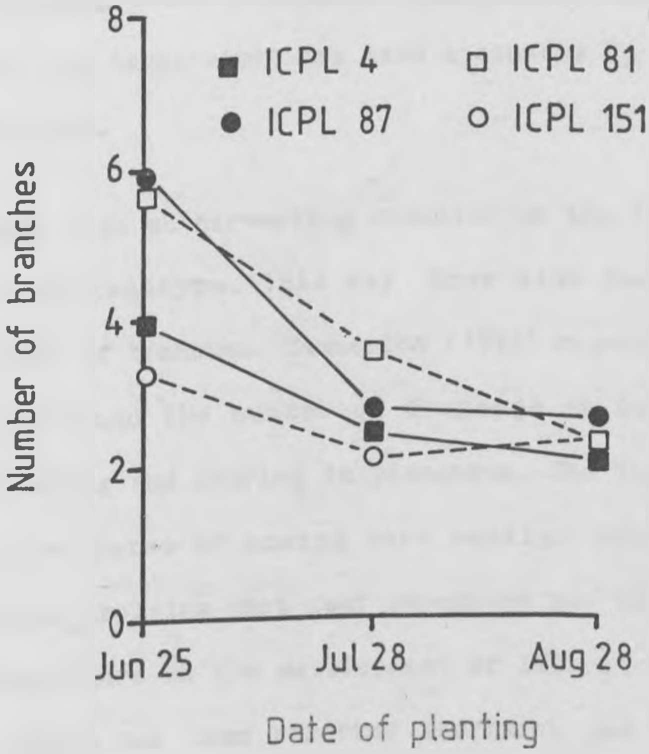


Fig. 7. Effect of date of sowing on number of branches at harvesting.

DISCUSSION

The days to flowering were not significantly different for the various dates of sowing . Chauhan et al. (1987) made similar observations at this site but using only two dates of sowing. However, in this study it was observed that ICPL4 tended to flower earlier at the last date of sowing. It is probably this earlier flowering that led to the decrease in plant height for this genotype at the August sowing. The weather data shows a declining trend in minimum temperature after standard week 38. This low temperature may have accounted for some of the response observed.

Leaf area at harvesting depended on the leaf retention ability of the genotype. This may have also depended in part on the number of branches. Hammerton (1971) reported that planting date determined the number of branches as well as the height at flowering and bearing in pigeonpea. The leaves of plants at the latter dates of sowing were smaller than those for the June sowing implying that leaf expansion was affected. The effect of temperature on the development of lateral branches in Phaseolus vulgaris has been reported (Hardwick and Andrews, 1980). They reported that low temperature reduced the development of the lateral branches. Narayanan and Sheldrake (1979) suggested that the short duration pigeonpea genotypes are less well adapted to cooler temperatures because they have been developed under warmer conditions. The reduced plant size observed in the studies here is in agreement with other observations that post-rainy pigeonpeas have a higher harvest index due to the reducedp lant size (Sheldrake, 1980). Similar observations have been reported (Chauhan *et al*., 1987) that dry matter production reduced with delayed planting in short duration pigeonpea. McPherson *et al*. (1985) stated that shorter crop growth duration contributed to the lower growth and dry matter production. Owing to the responsiveness of pigeonpea growth to high temperature (McPherson et al., 1985; Sheldrake, 1984), lower temperature during rainy season might have also contributed to the decreased dry matter production. Lawn (1979), used the Arrhenius equation to explain changes in dry matter accumulation rate over sowing dates in *Vigna*. He concluded that ultimately the sum total of growth is both directly and indirectly a function of temperature. He stated further that the pattern of development in short day plants, i.e. the rate of development during both the sowing to flowering and flowering to maturity phases were negatively associated with longer day-length and positively associated with warmer temperatures. High temperature (30°C) has been reported to increase growth of pigeonpea plants (Turnbull, 1986). In this study the declining maximum as well as minimum temperature may have accounted for the reduction in plant size. Parvez and Gardner found that in soybean lines with a juvenile trait, branching could enhance leaf area, node and raceme numbers as well as reproductive potential. They reported a decline in branch number with delayed sowing. Tanner and Hume (1978) reported reduced plant height and total vegetative plant size in soybean due to late planting. The decline in stem diameter in this study was evidenced by the reduced stem dry weight as sowing was delayed. Apparently delayed sowing enhanced senescence in ICPL4. The limited leaf area appreciably reduced the area available for light interception and consequently photosynthesis. Since stem reserves may be useful for re-translocation, a low stem dry weight may not provide sufficient reserves. This could have affected growth after flowering as the leaf area started decreasing. The reduced stem size in ICPL4 hindered rejuvenation after first flush maturity and thus making this genotype behave like an annual plant. Probably this character could be important since it has been hypothesised that pigeonpea produces more flowers than necessary due to in-built perennial tendency (Sheldrake, 1984). Exploitation of this annual tendency and the observed high pod-setting ability may improve the yield in pigeonpea. However, the leaf retention in this genotype (ICPL4) is relatively poor as compared to other determinate genotype like ICPL87 (Chauhan et al., 1987). The decline in the day-length over the growing period is given (Appendix 1). An earlier experiment (Expt. 1) showed that the effect of day-length was not marked in this genotypes after flowering. It is probable that day-length may have affected early vegetative growth but this effect must have been over-shadowed by the temperature effects. Vince-Prue (1975) pointed out that the major effect of day-length is on the flowering process and since in this study the time to flowering was not very different for the majority of the genotypes then the effect of day-length may be ruled out. Sharma (1978) found that significant effect of day-length.

The decline in the number of pods per plant accounted for the decline in yield when sowing was delayed. Several studies (e.g. Akinola and Whiteman, 1974; Lawn, 1979; Chauhan et al., 1987) have reported a decrease in yield with delayed planting. Akinola and Whiteman (1974) also observed that early maturing pigeonpea plants had a lower percentage pod-set during the cool months than late maturing plants due to temperature. The contribution of the low number of branches and hence fewer floral sites at the later dates also accounted for the reduction in grain yield. Akinola and Whiteman (1974) reported that the yield for subsequent sowing dates depended on the secondary and primary branches and further stated that since the number of pod producing branches and yield were associated, it indicated that yield was influenced by the number of available floral sites.

In this study the grain yield at the last two dates of sowing was unrealistically low as a result of Heliothis infestation in spite of the heavy plant protection schedule (Appendix III).

GENERAL DISCUSSION

The environmental factors tested here affect the growth, development and yield of the genotypes investigated. Temperature appears to markedly account for yield reduction under fairly optimum conditions. The effect of temperature on the rate of new leaf formation and senescence, bud and flower abscission indicates that the cultivation of these genotypes during the summer months under high temperature may not realise reasonable yields.

Extremely high day temperature reduces biomass production. The reduction in yield observed here resulted mainly from flower drop and early pod abscission. At high day temperature flowers dropped off at about twice the quantity observed at low temperature. This observations have been established in other studies (Turnbull, 1986; Warrag and Hall, 1983, 1984; Summerfield et al. 1987, 1988). However, at low day temperature the young pods abscised in larger measure than at high temperature. This tends to imply that any pods that were formed could set. A large pod load due to less flower drop at the low day temperature could therefore have accounted for the higher pod abortion. The abortion of flowers and pods under fairly normal conditions has received much attention but it is not well understood whether this is hormonally - mediated or simply a limitation of photosynthate (Sheldrake, 1984; Sinha, 1977; Guinn and Brummet, 1987; Rawson et al. 1980). When day and night temperature were varied, it was still observed that high day or night temperature affected pod-set. Although no anatomical studies were done to find out the exact cause of failure to set pods at low night temperature, this has been observed in other legumes (e.g. Saxena and Sheldrake, 1980). The failure to set pods may have been due to slow pollen tube development or non-viability of pollen. High day temperature may have led to anther indehiscence and abnormal pollen development as observed elsewhere (Warrag and Hall, 1984 ; Van Schaik and Probst, 1958).

The response of pigeonpea at the stage investigations commenced confirms earlier observations on its drought tolerance (Nyabundi, 1980 ; Flower, 1985). Although yield reduction was observed probably due to limited leaf area and as such insufficient canopy to utilise the available radiation, growth and development were not stopped. The observations also suggested that the second harvest yield for ICPL87 may be reduced to a great extent if the stress is not released after first flush maturity. This is a determinate genotype which has a large leaf area in terms of leaf size as well as a reduced leaf senescence habit. Earlier observations on the effect of humidity have indicated that anther indehiscence can occur under high humidity (Gai et al 1985; Sengupta and Roy, 1979).

But the actual role that humidity may play to lead to this is not clear.

The plant is subjected to several stresses under field conditions. In the Indian sub-continent, temperature and day-length are closely related. A declining day-length is associated with decreasing minimum as well as maximum temperatures. Under the Kenyan conditions recent studies (Coulson C. L., personal communication, 1988) indicate that the differences in day-length in different regions over the growing seasons may be more significant than previously thought. In most field experiments this coupling of day-length and temperature has led to difficulty in ascertaining the effects due to either factor (McPherson, <u>et al.</u>, 1985). The greenhouse experiments carried out here on investigating the effect of photoperiod suggest that for the genotypes used here, the response to photoperiod is not significant. As pointed out in earlier studies (Turnbull, 1986; Turnbull and Ellis, 1987), the response to photoperiod under artificial conditions needs careful interpretation. A response to a given source of extended lighting may not be a universal response, therefore, the results obtained here depend on the source of light used.

Temperature and humidity are modified by the altitude (Dennet, 1980). The observation that the time of flowering is longer at coastal locations in Kenya may be as a result of the prevailing temperature. In general if the temperature is unsuitable for flowering to occur then the plants remain in vegetative growth thereby attaining greater size. High humidity at coastal locations may aid soil moisture status while the relatively drier air up-country may aggravate the water stress effects.

These studies have established that the decline in yield for short duration pigeonpea due to late sowing resulted from the reduction in branch number. The reduced number of branches reduced the number of potential floral sites and hence the observed decline in the number of flowers. In one of the genotypes a drastic reduction in stem diameter was observed indicating that probably the reduced branching also affected the formation of sufficient canopy for the production of enough assimilates that could be stored in the stem.

CONCLUSION

The process of abscission of flower buds, flowers and young pods is aggravated by adverse temperature or water stress. The duration from flower bud initiation to flowering and subsequent pod-set is determined by the night temperature. This may be related to rate of development of the buds as observed elsewhere (Turnbull, 1986). Branch development and re-growth are affected by night temperature and this could be a major reason why the plants sown at the later dates in the field developed fewer branches. Day-length does not appear to be important for these genotypes after flower bud initiation for the range of day-length used here. Relative humidity was important for pod-set and for these genotypes a fairly low humidity of about 50% is optimum.

The results of the controlled environment and greenhouse may not be exactly comparable to those of the field experiment due to the limitation in radiation under controlled environment and therefore constant day or night temperature may give a slightly different plant response.

Further Investigation

The relationship between humidity and temperature was not well established in these studies and hence a thorough investigation covering both vegetative and reproductive phases of plant growth could enhance the understanding of plant response to these factors. Anatomical studies to find out the actual cause of failure to set pods at low night temperature, high day temperature, and high humidity need to be done. Though these studies were mainly concerned with effects during the reproductive stage, it may be worthwhile to study the effects of temperature and humidity throughout the growth period.

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APPENDIX I

*LENGTH OF DAY (HOURS) AT VARIOUS LATITUDES

Month	11^0 N (Coimbatore	17^0 N (Hyderabad & Mahabaleswar)	24^0 N (Sehore)	29^0 N (Pantnagar & Hissar)
January	11.44	11.10	10.70	10.37
February	11.57	11.47	11.22	11.03
March	11.95	11.91	11.88	11.85
April	12.25	12.38	12.57	12.71
May	12.51	12.79	13.15	13.45
June	12.60	12.98	13.47	13.81
July	12.57	12.91	13.33	13.66
August	12.37	12.57	12.84	13.05
September	12.08	12.13	12.19	12.23
October	11.77	11.65	11.49	11.36
November	11.51	11.23	10.88	10.60
December	11.40	11.01	10.54	10.20

* Taken from the tabulated information supplied by Dr. Gordon Yaciuk.

JULIAN DAY CALENDAR

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Feb	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365

Add 1 to red values during leap years.

APPENDIX II

WEATHER DATA FOR 1974-1987 RECORDED AT METEOROLOGICAL OBSEVATORY

TA FOR A GIVEN DAY REFER TO WEATHER FOR THE PAST 24 HOURS ENDING AT 8.00
AT DAY

ATA FOR THE MONTH..... 6 YEAR...... 1987

Y	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kmhr	SUNSHINE hr	SOLAR (MJ m**
	0.0	11.0	39.2	26.6	55.0	25.0	10.2	9.5	22.2
	0.0	14.2	40.4	27.5	62.0	22.0	15.3	10.2	23.
	0.0	14.1	40.5	27.5	67.0	22.0	20.6	9.9	23.
	0.0	12.6	36.8	26.5	65.0	45.0	24.2	5.4	17.7
	0.0	14.1	40.6	26.	72.0	21.0	22.4	10.6	25.4
	0.0	14.8	38.4	25.0	70.0	30.0	22.6	11.3	25.8
	0.0	15.0	38.0	24.5	67.0	31.0	24.6	11.7	25.2
	0.0	14.4	37.5	25.0	64.0	34.	22.6	10.8	22.7
	0.0	15.9	36.4	26.5	58.0	37.0	27.6	9.9	22.4
	2.4	9.0	36.0	24.0	84.0	32.	18.7	4.9	16.0
	0.0	10.9	35.4	24.6	84.0	34.0	20.3	5.1	18.9
	5.	9.	36.0	23.0	84.0	35.0	18.7	2.3	15.8
	2.2	9.3	35.8	23.5	87.0	37.0	18.6	6.8	20.6
	0.0	11.7	35.0	24.0	77.0	38.0	24.8	7.7	21.4
	12.	9.	36.0	23.5	84.0	39.0	18.4	7.8	20.2
	9.0	.6	34.5	22.9	87.0	45.0	23.1	7.9	17.7
	36.0	3.8	33.0	23.4	88.	47.0	17.7	7.3	18.
	4.	2.4	27.5	22.6	98.0	80.0	17.6	0.5	8.
	4.6	4.0	28.6	22.0	88.0	95.0	18.6	0.7	10.
	0.0	8.6	33.5	24.6	80.0	57.0	16.2	9.7	23.6
	0.0	9.6	36.	24.9	75.0	37.0	15.1	8.	21.5
	0.0	10.	36.	25.6	69.	37.	17.5	10.4	23.
	0.0	5.	31.2	25.4	80.0	52.0	12.5	1.4	12.4
	0.0	[illegible]	35.8	24.5	7	38.0	8.7	8.5	22.9
	→ 17.0	10.0	35.5	22.5	9	42.0	11.3	9.7	23.5
	0.0	.5	34.4	25.0	84.	45.0	5.9	10.1	24.4
	3.5	.0	35.9	24.5	89.0	41.0	5.6	10.9	24.6
	29.4	10.1	34.4	21.5	87.0	47.0	10.7	10.3	23.5
	16.0	8.4	34.5	23.0	90.0	47.0	13.5	9.1	21.9
	4.0	7.3	33.0	23.5	97.0	55.0	15.4	8.8	21.
N	142.7	299.4	35.6	24.5	78.7	41.6	17.3	7.9	20.6

ASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS.NOT MEANS

APPENDIX II

WEATHER DATA FOR 1974-1987 RECORDED AT METEOROLOGICAL OBSEVATORY

DATA FOR A GIVEN DAY REFER TO WEATHER FOR THE PAST 24 HOURS ENDING AT 8.00 A.M. THAT DA

DATA FOR THE MONTH..... 7 YEAR...... 1987

DAY	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD (MJ/m**2/D)
1	0.0	8.0	32.8	24.0	82.0	50.0	21.6	8.3	19.9
2	0.0	8.1	32.5	24.0	81.0	50.0	21.3	4.4	19.4
3	14.2	8.1	32.0	23.2	90.0	51.0	22.8	4.1	17.2
4	15.4	6.8	30.8	22.1	93.0	60.0	15.8	4.7	16.4
5	6.0	2.8	29.0	22.0	93.0	80.0	16.8	0.1	9.4
6	12.0	2.4	25.5	21.5	91.0	93.0	16.4	0.0	6.5
7	15.0	4.0	26.4	21.5	90.0	84.0	18.2	0.0	8.7
8	2.0	4.1	28.5	23.0	92.0	75.0	23.1	0.3	11.4
9	61.0	0.0	28.0	20.6	97.0	90.0	21.6	0.0	7.4
10	5.4	2.2	25.9	23.2	93.0	86.0	20.6	0.0	5.8
11	0.0	3.8	27.8	23.5	92.0	76.0	17.4	0.1	10.9
12	0.0	4.7	29.4	22.5	88.0	60.0	15.1	1.4	13.1
13	0.0	8.0	32.0	23.5	87.0	52.0	19.7	7.5	20.9
14	1.8	6.0	31.4	22.5	90.0	58.0	15.8	5.6	16.8
15	1.0	6.9	32.5	22.5	85.0	50.0	14.0	10.2	20.2
16	0.5	8.7	33.[illegible]	22.8	84.0	47.0	17.3	10.5	23.2
17	0.0	8.2	32.5	23.0	88.0	46.0	20.3	10.2	20.[illegible]
18	0.0	8.7	32.5	23.1	84.0	45.0	15.7	9.9	22.0
19	0.0	9.3	33.5	23.5	87.0	39.0	17.5	10.2	21.7
20	0.0	6.0	30.5	23.5	89.0	55.0	17.8	1.5	14.7
21	0.0	7.0	32.2	23.4	87.0	58.0	15.3	6.9	19.7
22	0.0	5.0	29.5	24.5	79.0	56.0	12.8	2.2	10.9
23	0.0	3.3	28.6	23.5	87.0	67.0	10.0	0.0	8.4
24	0.0	4.0	29.2	24.2	86.0	68.0	11.1	1.8	12.5
25	0.0	6.7	29.7	24.5	79.0	62.0	12.7	7.2	21.0
26	0.4	6.3	32.2	23.8	85.0	45.0	14.0	2.7	16.0
27	0.0	4.5	30.7	23.0	81.0	58.0	10.6	0.3	10.8
28	→ 0.0	6.7	32.4	24.3	85.0	47.0	10.9	9.3	20.8
29	0.0	3.3	30.0	23.0	84.0	62.0	6.5	0.6	10.8
30	9.2	5.0	32.5	22.5	89.0	62.0	6.4	4.5	15.2
31	0.0	6.4	32.5	23.5	81.0	59.0	8.9	9.0	21.3
MEAN	143.9	175.0	30.5	23.1	87.1	61.0	15.7	4.3	15.3

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS,NOT MEANS

APPENDIX II

WEATHER DATA FOR 1974-1987 RECORDED AT METEOROLOGICAL OBSEVATORY

FOR A GIVEN DAY REFER TO WEATHER FOR THE PAST 24 HOURS ENDING AT 8.00 A.M DAY

FOR THE MONTH..... 8 YEAR...... 1987

RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD (MJ/m**2/D)
9.0	8.3	33.4	23.2	84.0	44.0	13.3	9.4	23.5
0.0	6.0	32.0	24.0	81.0	52.0	12.1	2.7	16.5
0.0	7.3	33.5	24.8	70.0	48.0	10.5	10.6	21.6
0.0	7.0	32.8	24.2	87.0	48.0	10.0	8.9	21.4
2.0	5.3	31.4	21.6	90.0	58.0	8.9	4.1	15.8
3.4	4.2	29.0	22.0	97.0	63.0	8.6	2.9	14.3
9.0	3.1	28.7	21.6	98.0	69.0	8.5	1.2	11.7
8.6	2.8	27.5	21.5	98.0	75.0	9.2	1.6	10.5
6.0	3.9	27.5	22.0	95.0	73.0	8.3	2.6	14.2
7.0	4.0	29.0	22.6	89.0	90.0	8.7	7.0	16.9
1.6	5.0	30.5	22.5	93.0	70.0	9.0	8.7	18.4
0.0	4.8	30.6	23.7	90.0	61.0	9.1	6.6	17.8
9.0	4.8	30.1	22.7	92.0	61.0	9.5	5.1	15.5
9.0	3.0	28.2	20.6	98.0	74.0	5.9	0.0	10.5
4.0	2.5	27.5	22.5	98.0	82.0	6.0	1.1	10.3
3.0	2.7	28.0	22.5	95.0	82.0	4.9	1.0	10.8
0.4	3.4	29.5	22.5	97.0	75.0	4.4	5.6	15.0
0.0	3.8	29.5	23.5	90.0	71.0	7.2	3.6	13.1
0.8	4.0	30.0	22.0	90.0	75.0	10.6	5.1	13.9
0.6	3.9	28.6	22.6	88.0	74.0	13.4	3.2	13.7
16.2	3.0	27.5	21.6	95.0	73.0	14.8	0.6	11.0
9.6	7.0	29.1	22.5	92.0	83.0	12.7	7.7	16.7
0.0	5.0	29.5	23.0	93.0	70.0	12.8	8.7	18.4
0.8	4.6	29.7	23.0	92.0	78.0	13.2	1.6	13.3
3.2	4.1	29.2	23.0	90.0	69.0	15.1	1.6	13.6
0.0	4.8	29.7	23.0	92.0	68.0	15.3	4.9	14.2
0.6	5.6	29.7	23.0	88.0	60.0	19.8	3.8	12.4
1.4	4.3	28.0	22.5	93.0	63.0	14.7	0.0	8.5
0.0	4.8	28.0	22.5	88.0	68.0	14.1	1.1	9.0
0.0	4.0	29.0	22.0	88.0	58.0	12.4	0.7	14.7
1.8	7.1	32.0	21.5	88.0	56.0	10.9	10.5	22.7
98.0	144.1	29.6	22.6	90.9	67.5	10.8	4.3	14.8

E NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS.NOT MEANS

APPENDIX II

WEATHER DATA FOR 1974-1987 RECORDED AT METEOROLOGICAL OBSEVATORY
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DATA FOR A GIVEN DAY REFER TO WEATHER FOR THE PAST 24 HOURS ENDING AT 8.C
THAT DAY

DATA FOR THE MONTH..... 9 YEAR...... 1987

DAY	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOL (MJ /m*
1	1.0	6.5	31.5	22.7	85.0	52.0	9.0	10.0	21.
2	1.7	5.2	29.0	22.0	87.0	64.0	14.2	2.8	15.
3	41.4	4.6	28.6	22.0	95.0	66.0	9.1	0.2	11.
4	13.0	3.3	26.8	22.0	95.0	93.0	9.9	0.9	9.
5	0.0	2.2	27.0	22.6	88.0	77.0	6.7	0.0	8.
6	0.0	4.2	30.0	21.8	95.0	68.0	6.2	2.2	18.
7	0.0	4.6	30.9	22.4	90.0	62.0	5.4	8.2	20.
8	0.0	6.2	30.9	22.2	92.0	57.0	7.3	9.9	22.
9	0.0	6.0	31.0	22.0	97.0	56.0	7.8	9.5	21.
10	0.0	5.6	31.0	22.8	88.0	59.0	9.5	6.2	19.
11	0.0	5.3	30.2	21.5	93.0	60.0	10.1	6.6	15.
12	0.0	6.2	31.4	21.7	93.0	52.0	8.8	10.9	22.
13	0.0	6.0	32.0	21.2	92.0	50.0	6.2	10.9	21.
14	0.0	5.3	33.0	20.0	87.0	50.0	5.7	9.2	20.
15	0.0	6.0	33.7	22.8	90.0	45.0	6.4	9.6	21.
16	0.0	6.0	33.0	22.5	92.0	53.0	6.7	9.3	22.
17	0.0	5.6	34.0	24.0	88.0	39.0	5.4	8.3	20.
18	2.4	5.9	33.4	23.0	92.0	44.0	5.9	8.9	19.
19	0.0	4.9	33.2	23.2	92.0	51.0	2.4	10.7	20.
20	0.0	7.0	34.5	22.0	88.0	42.0	6.0	9.3	21.
21	0.0	6.8	34.5	24.5	89.0	37.0	6.1	9.7	23.
22	0.0	6.0	33.0	24.0	80.0	50.0	6.8	5.8	15.
23	0.0	6.0	33.0	23.1	93.0	51.0	7.5	4.5	17.
24	0.0	5.4	32.6	22.4	93.0	48.0	5.7	6.3	15.
25	2.6	4.4	33.2	22.2	95.0	43.0	4.2	5.5	14.
26	0.0	5.3	33.4	23.2	92.0	50.0	4.6	8.1	19.
27	0.0	4.4	32.5	23.6	87.0	66.0	4.1	6.7	16.
28	0.0	5.2	33.8	22.9	89.0	40.0	4.6	7.2	18.
29	0.0	4.3	33.4	23.0	92.0	36.0	2.9	4.7	15.
30	0.0	6.7	33.5	21.0	85.0	39.0	5.1	9.5	20.
MEAN	62.1	161.1	31.9	22.5	90.5	53.3	6.7	7.1	18.

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS,NOT MEANS

APPENDIX II

DATA FOR THE MONTH..... 10 YEAR...... 1987

DAY	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD (MJ/m**2/D)
1	0.0	7.2	34.0	23.0	88.0	40.0	9.5	8.8	20.2
2	12.0	5.7	31.0	22.5	95.0	51.0	12.8	5.4	14.5
3	6.2	4.2	31.5	21.2	98.0	59.0	6.2	7.1	16.3
4	18.0	4.0	30.0	22.6	93.0	64.0	3.7	3.3	12.4
5	13.5	4.3	30.0	22.5	95.0	64.0	5.1	5.3	15.4
6	39.2	6.6	30.5	22.0	98.0	60.0	5.8	7.2	16.5
7	20.0	4.7	30.4	21.5	97.0	64.0	4.3	5.6	14.8
8	26.6	4.1	29.5	22.0	98.0	65.0	2.8	6.0	13.8
9	0.0	2.7	27.5	22.5	98.0	76.0	3.1	4.9	14.4
10	0.0	4.2	30.0	21.5	97.0	57.0	4.0	9.6	16.3
11	0.0	5.6	31.0	20.2	95.0	46.0	4.9	10.4	22.1
12	0.0	5.0	32.0	20.0	88.0	36.0	5.1	10.1	20.9
13	0.0	5.2	31.5	19.5	93.0	42.0	5.3	9.6	20.8
14	0.0	5.5	31.0	19.0	88.0	43.0	6.4	10.4	20.8
15	0.0	6.1	32.0	19.5	93.0	33.0	6.2	10.2	20.9
16	0.0	5.7	31.2	22.6	86.0	37.0	12.0	4.5	14.8
17	13.6	1.0	23.5	22.0	93.0	95.0	21.1	0.0	2.1
18	0.0	4.0	30.0	22.5	97.0	59.0	15.4	7.3	14.6
19	0.0	4.2	30.5	22.0	93.0	62.0	8.7	9.3	16.8
20	0.0	3.0	31.0	21.5	98.0	61.0	3.8	6.0	13.7
21	0.0	3.8	31.0	20.0	97.0	49.0	5.3	8.2	16.7
22	0.0	5.0	30.5	21.5	97.0	61.0	6.4	10.3	19.7
23	0.0	3.6	30.0	21.0	95.0	59.0	6.6	5.7	16.0
24	0.0	3.0	29.6	19.6	96.0	53.0	3.0	6.0	13.3
25	0.0	5.0	30.5	17.5	93.0	39.0	4.9	9.5	17.1
26	0.0	4.2	29.5	17.2	94.0	45.0	4.6	7.9	14.7
27	0.0	5.4	29.5	15.5	92.0	35.0	5.9	11.2	21.5
28	0.0	5.4	29.6	14.9	92.0	27.0	5.2	11.8	21.1
29	0.0	4.8	29.6	15.5	90.0	35.0	4.2	11.1	21.5
30	0.0	4.8	30.4	17.4	94.0	40.0	4.8	10.7	19.5
31	0.0	4.3	30.5	18.4	87.0	37.0	4.3	10.3	19.1
MEAN	149.1	142.5	30.7	20.3	93.8	51.4	6.5	7.8	16.8

PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS,NOT MEANS

APPENDIX II

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###### WEATHER DATA FOR 1974-1988 RECORDED AT METEOROLOGICAL OBSEVATORY #########

DATA FOR A GIVEN DAY REFER TO WEATHER FOR THE PAST 24 HOURS ENDING AT 8.00 A.M. THAT DAY


 DATA FOR THE MONTH.....  11   YEAR......  1987
------------------------------------------------------------------------------------
DAY        RAIN   EVAP   TMAX   TMIN   RH07   RH14   WIND  SUNSHINE    SOLRAD
            mm     mm      C      C      %      %    kphr     hr    (MJ/m**2/D)
------------------------------------------------------------------------------------
  1        0.0    5.7   29.0   15.0   86.0   41.0    4.4    9.4         16.7
  2        0.0    5.5   30.0   14.5   90.0   28.0    7.9    8.6         17.1
  3        0.0    7.3   30.5   21.2   62.0   28.0   18.0    6.4         14.7
  4       92.8    2.0   26.5   20.5   98.0   64.0   22.7    0.0          6.1
  5        0.0    1.4   25.0   21.8   97.0   87.0   14.4    0.1          6.7
  6        0.3    1.4   27.0   21.1   97.0   81.0    5.2    2.8         10.0
  7        0.0    3.6   29.2   20.0   96.0   60.0    4.5    8.7         17.6
  8        0.0    5.6   29.5   18.2   87.0   52.0    6.2   10.6         17.9
  9        0.0    4.8   28.0   15.5   81.0   43.0    8.4   10.6         19.3
 10        0.0    4.4   26.8   17.0   87.0   42.0    4.7    9.1         19.8
 11        0.8    1.8   25.6   21.0   93.0   68.0    3.4    3.9         10.8
 12        0.0    2.8   28.0   18.5   94.0   59.0    5.8    1.9          9.5
 13       34.4    5.0   27.0   18.3   98.0   44.0   13.3    4.7         13.4
 14       37.6    0.4   20.8   19.6   98.0   98.0   13.3    0.0          1.8
 15        1.0    1.0   23.6   21.4   98.0   90.0    8.0    0.0          5.9
 16        0.0    1.6   26.5   21.5   97.0   80.0    5.9    2.1          9.2
 17        0.0    1.8   27.8   22.5   97.0   73.0    4.9    1.9          8.7
 18       35.2    3.3   27.6   21.7   97.0   98.0    7.6    1.6          7.7
 19       38.1    5.5   28.5   20.5   97.0   62.0    7.1    6.2         13.5
 20        0.0    3.6   29.4   21.6   97.0   67.0    3.2    7.8         15.3
 21        0.0    3.1   28.5   22.0   97.0   65.0    2.9    4.7         12.8
 22        0.0    5.0   26.3   17.5   98.0   67.0    3.3    0.5          8.7
 23        0.0    4.2   27.0   15.0   94.0   39.0    4.8    9.4         18.2
 24        0.0    4.4   28.0   14.5   94.0   52.0    2.8    9.9         17.6
 25        0.0    3.4   27.5   16.0   98.0   42.0    2.9   10.2         17.7
 26        0.0    4.1   28.0   13.0   94.0   51.0    4.4   10.2         17.6
 27        0.0    4.6   29.0   14.8   94.0   26.0    5.7   10.6         19.6
 28        0.0    4.7   28.5   12.5   91.0   32.0    5.6   10.5         18.0
 29        0.0    4.8   28.1   12.0   87.0   30.0    6.2   10.7         18.5
 30        0.0    4.7   28.0   11.4   91.0   30.0    6.1   10.2         18.7
------------------------------------------------------------------------------------
MEAN     240.0  109.4   27.5   18.0   92.8   56.6    7.1    6.1         13.6
------------------------------------------------------------------------------------
PLEASE NOTE THAT RAINFALL AND EVAPORATION DATA ARE TOTALS,NOT MEANS
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APPENDIX II

DATA FOR THE MONTH..... 12 YEAR...... 1987

DAY	RAIN mm	EVAP mm	TMAX C	TMIN C	RH07 %	RH14 %	WIND kphr	SUNSHINE hr	SOLRAD (MJ/m**2/D)
1	0.0	4.2	27.0	10.0	95.0	29.0	5.1	10.5	17.8
2	0.0	4.5	27.8	12.5	94.0	28.0	6.0	10.6	18.1
3	0.0	4.3	28.0	11.5	93.0	31.0	5.6	10.4	17.2
4	0.0	3.7	27.8	16.0	82.0	32.0	4.1	10.4	17.9
5	0.0	4.0	28.8	17.7	93.0	45.0	5.0	4.0	12.4
6	0.0	4.7	29.0	19.5	94.0	47.0	6.6	8.6	16.1
7	0.0	4.0	28.0	12.5	94.0	51.0	6.3	9.3	14.2
8	0.0	3.8	27.5	13.4	94.0	41.0	5.3	10.1	16.7
9	0.0	3.9	27.5	16.5	81.0	42.0	5.9	9.9	16.3
10	0.6	2.2	26.5	21.0	96.0	59.0	12.9	4.1	9.9
11	0.2	1.2	24.6	21.0	95.0	85.0	13.5	0.6	4.8
12	0.0	3.0	27.0	19.0	96.0	61.0	11.9	4.1	11.5
13	0.0	3.2	27.5	18.5	96.0	54.0	7.0	6.2	12.9
14	0.0	2.7	28.0	20.5	91.0	60.0	7.8	4.6	10.8
15	0.0	2.7	27.2	13.5	94.0	55.0	4.0	5.3	10.6
16	0.0	4.5	26.5	11.5	73.0	42.0	5.9	10.6	17.7
17	0.0	4.4	25.5	9.5	93.0	35.0	6.1	10.4	18.2
18	0.0	3.4	25.3	9.3	95.0	39.0	4.1	9.6	16.9
19	0.0	3.8	26.0	7.5	95.0	35.0	6.5	9.1	16.5
20	0.0	5.2	25.0	8.2	88.0	25.0	7.3	10.5	18.2
21	0.0	4.8	25.0	9.0	88.0	30.0	6.2	10.6	17.8
22	0.0	4.4	27.0	14.7	82.0	42.0	6.4	10.4	17.0
23	0.0	3.6	27.0	15.5	96.0	53.0	7.1	9.3	16.1
24	0.0	3.6	27.5	15.5	96.0	55.0	6.8	6.5	13.5
25	0.0	3.0	27.5	18.0	96.0	57.0	7.1	8.4	14.0
26	0.0	5.0	27.2	18.0	85.0	53.0	10.9	8.0	14.4
27	0.0	4.4	26.6	12.5	83.0	39.0	8.2	10.2	16.4
28	0.0	4.0	25.0	11.0	98.0	49.0	[illegible]	9.7	15.1
29	0.0	4.0	25.2	11.0	93.0	39.0	5.7	9.7	16.1
30	0.0	4.1	27.5	13.0	96.0	39.0	5.0	10.3	16.9
31	0.0	3.8	26.8	12.0	95.0	43.0	5.8	10.2	16.6
MEAN	0.8	118.1	26.9	14.2	91.6	45.0	6.8	8.5	15.1

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APPENDIX III

Dates of spraying and Chemicals used.

Date	Chemical
23.9.87	FENVALERATE (0.1%)
30.9.87	THIODON (0.17%)
21.10.87	THIODON (0.1%)
31.10.87	NUVACRON 40 EC (0.1%)
10.11.87	FENVALERATE (0.09%)
23.1.87	CARBARYL 50% WP (0.14%)
17.12.87	EKALUX 25 EC (0.12%)
8.1.88	EKALUX 25 EC (0.12%)