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CHICKPEA, PIGEONPEA, AND GROUNDNUT

N. P. Saxena, M. Natarajan, and M. S. Reddy

Of the grain legumes, chickpea, pigeonpea, and groundnut are some of the most important crops in the semiarid tropics. Groundnut has received considerable research attention in developed and developing countries but chickpea and pigeonpea have been neglected crops until recently. Even now they receive little attention. Therefore, information relating to the physiological aspects of growth and yield of these two crops is fragmentary. This paper reviews work on the growth, development, and yield of these three crops in relation to management and environmental factors.

CHICKPEA

Cicer arietinum L. (*Leguminosae*, Papilionoideae, tribe Vicieae) is commonly known as chickpea, gram, Bengal gram, garbanzo, or pois chiche. Chickpea is distinguished in the Indian subcontinent as desi (generally brown seed coat) and kabuli (generally white seed coat). Kabulis are preferred and are better adapted to East Asian regions, including the Indian subcontinent. Ninety percent of the world's chickpea area is in the Indian subcontinent - 79% in India and 11% in Pakistan (Anonymous 1977).

Chickpea is essentially a subtropical crop adapted to warm dry conditions. Excessive moisture, cloudy weather, and high humidity reduce flowering, pod set, and yield. A diurnal sequence of cool nights and warm days is optimum for crop growth and yield. It is quantitatively a long day length plant but it flowers in all photoperiods. Chickpea responds to rhizobium inoculation on virgin soils and, occasionally, on soils where it has been grown previously. It is particularly important in the Indian subcontinent between lat. 10° N and 35° N, where it is grown on the residual moisture of heavy, well-drained deep soils during the postmonsoon dry season. It grows as an irrigated crop during the dry season in Ethiopia and during spring and summer in the Mediterranean regions. It was recently introduced to Africa, Australia, and the Americas.

Plant physiologist and agronomists, International Crops Research Institute for the Semiarid Tropics (ICRISAT), Patancheru PO 502324, A.P. India.

In this paper the growth and yield of chickpea are illustrated by studies carried out in two contrasting environments: International Crops Research Institute for the Semiarid Tropics (ICRISAT) Center, Hyderabad (17° 32'N, 78° 16'E, altitude 542 m), and Hissar (29° 10'N, 75° 44'E, altitude 221 m). At Hyderabad the crop is grown on deep Vertisols, with pH values of 8.0-8.3, medium in available N, and low in available P. Winters are mild and growth is terminated by regularly rising temperatures and increasing atmospheric evaporative demand in late February. At Hissar the crop is grown on Entisols with a pH of 8.2 and medium availability of nitrogen and phosphorus. Precipitation is 300 mm in the rainy season plus another 80 mm during the crop growth period. Winters are long with lower long temperatures. Open pan evaporation is low during the crop growth period and the temperature rises later, resulting in a longer growth duration.

Photosynthetic rate

In common with other legumes, chickpea is classified as a C-3 plant (Sinha 1977). There is at least one report on a crassulacean acid metabolism (CAM)-like behavior in chickpea (Santakumari et al 1979).

Leaf photosynthetic rates in chickpea cultivars vary between 15 and 40 mg CO_2/dm^2 per hour. This rate compares favorably with photosynthetic rates in other C-3 crops such as wheat, cotton, and barley, but is poorer than in C-4 plants such as maize, sorghum, and millet. The photosynthetic rates in chickpea are better than those in soybean, lentil, drybean, cowpea, and red clover (Sinha 1977, van der Maesen 1972).

Large differences in relative rates of photosynthesis exist between chickpea cultivars. Pandey et al (1976) reported a difference of 124% between cultivars with the highest and lowest photosynthetic rates. A similar difference (1:14.5) was reported by Shantakumari and Sinha (1972). Cultivars of diverse geographic origin exhibited large differences in photosynthetic efficiency ranging between 200 and 400 μg CO_2/cm^2 per hour (van der Maesen 1972).

CO_2 fixation by leaves decreased from flowering to pod formation. Cultivars that had the highest photosynthetic rate at flowering had the lowest rate during pod filling (Shantakumari and Sinha 1972). Nitrogen applied in the form of 1% KNO_3 solution during pod development enhanced the rate of photosynthesis (Sinha 1973).

Both pods and stems contribute to total photosynthesis in chickpea (Pandey et al 1976, Khanna and Sinha 1973). Pod walls remain green for a considerable period and, because they are photosynthetically active, may contribute to grain yield. Differences in pod photosynthesis exist among cultivars; the ratio of lowest to highest was reported as 1:8.5 (Shantakumari and Sinha 1972). Chickpea pods normally subtend below the leaves and consequently are shaded. In field experiments pods were hooked on the adaxial leaf surface to expose them to greater illumination. The absence of increases in seed yield (Saxena and Sheldrake 1980) indicated that the light intensity requirement for maximum pod wall photosynthesis may be low.

Cultivars differed in photosynthetic rate with increasing illumination (Shantakumari and Sinha 1972), but leaves of most of the cultivars reached maximum photosynthetic rates at a light intensity of 0.5 cal/cm^2 per minute. Leaf photosynthetic rates were highest in 2-week-old leaves (van der Maesen 1972).

Prasad et al (1978) reported a significant positive correlation (0.56) between photosynthesis and grain yield but no other evidence of a relation between leaf photosynthetic rate and grain yield.

The translocation of photosynthates to the nodules generally stops at flowering and nodule disintegration begins (Shantakumari et al 1975). Roots always receive more photosynthates than the nodules. Under irrigation the translocation of photosynthates to roots and nodules is higher. The use of labeled carbon ^{14}C indicated that photosynthates are translocated to all plant parts including unfed branches (Shantakumari et al 1975). The developing pod receives most of the photosynthates from its subtending leaf (Pandey et al 1978). When there is no axillary pod the photosynthates are diverted to other actively growing sites such as the lower pods, which serve as strong sinks. During pod development, when stems are also growing fast, competition for photoassimilates may occur between these two sinks. Lower leaves supply 36% of their photoassimilates to stems and developing pods (Pandey et al 1978).

In general, the translocation of preflowering photoassimilates accumulated in stems to developing seeds is small in chickpea. Only 22-27% of the total photoassimilates in seeds are accounted for when estimates are from defoliation studies (Pandey et al, unpubl., quoted by R. J. Summerfield et al 1979) and around 7-20% when the relative loss in stem weight and gain in seed weight provide the basis for estimates (Saxena and Sheldrake, unpubl.).

Crop growth rate, leaf area index, leaf area duration, and dry matter production

The rate and duration of growth of chickpea are greatly influenced by climatic conditions, especially temperature, which strongly influences the adaptation of cultivars in different regions. In India, the adaptation of early cultivars at Hyderabad (where winters are short) and late cultivars at Hissar (where winters are long) is an example (Saxena and Sheldrake 1979). The growth and development patterns of cultivars adapted to these contrasting environments are illustrated by the changes in the crop growth rate (CGR), leaf area index (LAI), and dry matter accumulation of G-130 (Hissar) and JG-62 (Hyderabad) in 1977-78 under conditions of a gradually receding soil-moisture profile (Fig. 1).

CGR values in the early stages are higher at Hyderabad than at Hissar. At 50 days after sowing (DS), the CGR at Hyderabad was 9.0 g/m^2 per day compared with 2.0 g/m^2 per day at Hissar. Thereafter at Hissar the CGR increased exponentially until 150-160 DS, shortly after flowering and during pod set. During this period maximum CGR ranged from 20 to 34 g dry matter/m^2 per day. Then the crop abruptly stopped growing as the plants prematurely senesced because of the sudden rise in temperature, which normally occurs at this time of the year. A similar CGR (20 g dry matter/m^2 per day), sustained for a shorter period because of increasing temperatures, is reported for these environments by others (Sinha 1977).

In contrast, at Hyderabad the CGR increases gradually, reaches a maximum of 8-14 g dry matter/m^2 per day and then declines as gradually at later growth stages — a pattern somewhat similar to that observed at Pantnagar, India (Prasad et al 1978), where maximum values ranged from 8 to 12 g dry matter/m^2 per day. The CGR values in irrigated chickpea at ICRISAT Center are as high as 20 g dry matter/m² per day, approaching the values in northern Indian environments such as at Hissar.

LAI followed a pattern close to that of CGR at both locations. At Hissar, 140-150 DS during the exponential phase of LAI increase, a sudden rise in temperatures normally occurs and the active leaf area abruptly declines from 6 to almost zero. In crops that received no presowing irrigation, maximum LAI values were between 3 and 4. At Hyderabad, the maximum LAI was between 1 and 2 at peak CGR values and only rarely exceeded 2. LAI values of 2-3 were recorded in irrigated chickpea.

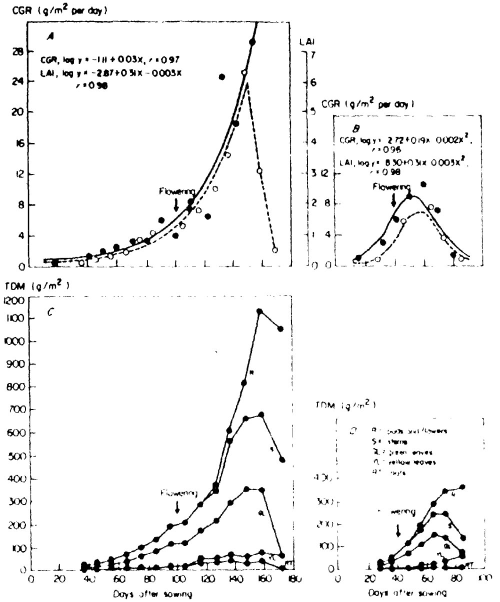
The accumulation and distribution of dry matter are also shown in Figure 1. In early growth stages the accumulation of dry matter at a given time was slower at Hissar than at Hyderabad. At Hyderabad the crop accumulates almost all of its dry matter by 85 DS and senesces, whereas at Hissar it accumulates only a fraction of the total dry matter at harvest. At both locations most of the dry matter accumulation in leaves, stems, or roots occurs after flowering, reflecting the indeterminate nature of the crop in which vegetative growth continues along with reproductive growth. Pod number increases simultaneously with LAI, but once the leaf area starts to decline there is no further increase in pod number (Sheldrake and Saxena 1979, Saxena and Sheldrake 1979). The addition of dry matter continues for a protracted period at Hissar because cooler temperatures prolong growth. Under such environmental conditions even the growth duration of early cultivars is extended because the flowers produced during the cool season do not set pods and the crop continues to grow vegetatively (Saxena, unpubl.). The period of ineffective flowering was around 60 days in early cultivars and was short in late cultivars (Table 1). At harvest, therefore, the total node numbers in early and late cultivars are similar. The rate of increase in dry matter during the linear phase of growth differs significantly between cultivars at Hyderabad (66.3-197 mg dry weight/day per plant) and is positively correlated with grain yield. At Hissar, cultivars do not differ significantly (350-450 mg dry weight/day per plant) and there is a negative trend in the relation to grain yield (-0.23) (Saxena and Krishnamurthy, unpubl.).

Green leaf area duration (LAD) showed trends similar to those described for rate of increase in dry matter. At Hyderabad, it ranged between 29 and 62.7 days and although it correlated positively with grain yield, the relation was not very close (r = 0.53*). In contrast, at Hissar, the LAD was very high and was positively correlated with average growth rates (0.79*) but was negatively correlated with grain yield (-0.63*).

Yield, yield components, and harvest index

In chickpea, average yields vary widely, from 0.2 t/ha in Jordan to 1.7 t/ha in Egypt (Anonymous 1977). Average yields in India ranged from 0.4 to 0.8 t/ha.

Growth duration at Hissar is twice as great as at ICRISAT Center and so are the yields per hectare (Table 1). Under well-managed experiments, yields as high as 4 t/ha are obtained in Hissar and 3 t/ha with irrigation at Hyderabad. The potential yields of this crop are high. At ICRISAT Center, early-duration cultivars are better adapted and yield more than the late cultivars, which perform very poorly. At Hissar, the late cultivars yield more, but the early cultivars also give relatively higher



1. Crop growth rate (CGR), leaf area index (LAI), and dry matter accumulation (TDM) of 2 chickpea cultivars: G-130 grown at Hissar (A, C) and JG 62 grown at Hyderabad (B, D).

Table 1. Growth duration, total dry matter, yield, and yield components of chickpea at International Crops Research Institute for Semi Arid Tropics, Hyderabad, and Hissar, India.

Character[a]	Hyderabad	Hissar
Total growth duration (days)	75-100	165-180
Vegetative period (days)	35-50	60-100
Period of ineffective flowering (days)	–	30 60
Duration of podding (days)	40-50	45 50
Nodes (no./plant)	150-180	300 400
TDM (t/ha)	2.0-2.6	5.5-6.8
TDM (kg/ha per day)	20-30	30-40
Yield (t/ha)	.95-1.4	2.2-3.0
Yield (kg/ha per day)	10-20	15-20
Harvest index (%)	40-60	35-40

[a]TDM = total dry matter.

yields than at ICRISAT Center because growth duration is extended. The per-day productivity of dry matter is higher at Hissar than at ICRISAT Center, but the per-day yield is similar (Table 1). The duration of podding ranges from 40 to 50 days. Extending podding duration by 30 to 35 days with irrigation increases chickpea yields at Hyderabad. Podding duration at Hissar cannot be extended with current cultivars because cool temperatures during early flowering inhibit pod set and high temperatures in late reproductive stages of growth cause premature senescence. It may be possible to extend the duration of podding at Hissar by the selection of cultivars that tolerate low and high temperatures during these crucial growth stages.

In chickpea, the number of pods per plant has the highest correlation with yield. Pod number per plant is closely correlated with the number of secondary branches (Gowda and Pandya 1975; Sandhu and Singh 1972; Saxena and Sheldrake, unpubl.). Grain yield has a low positive correlation with 100-grain weight but is negatively correlated with the number of grains per pod. The 100-grain weight has highly significant negative correlations with seeds per pod and pods per plant (Gowda and Pandya 1975).

Harvest index (HI) values are higher at Hyderabad than at Hissar (Table 2) because of greater vegetative growth at Hissar. Also at Hissar, the HI is higher in late sown crops, which produce less dry matter and yield than crops sown at the normal time. Pinnae fall begins fairly early in the season, especially at Hyderabad. This results in inaccurate computation of the HI. At Hyderabad the HI is overestimated by 10% due to pinnae fall (Saxena and Sheldrake 1979), but the cultivar ranking for HI does not change even if the HI values used have been corrected for pinnae fall. HI values observed with a number of cultivars ranged from 20 to 47%, the highest being from the best adapted local cultivar (Dahiya et al 1976, Lal 1976).

Response to irrigation

Chickpea can draw water from depths of 150–180 cm (Sardar et al unpubl.; Sandhu et al 1978) and grow and yield well without supplemental irrigation provided:

- there is adequate soil moisture in the profile at seeding in regions where the temperatures remain low for a fairly long time after planting, and
- open pan evaporation is low and humidity is high, such as at Hissar in India.

On a deep Vertisol at ICRISAT Center where crop growth duration is short, the yields of the best adapted chickpea Annigeri were doubled by frequent irrigation with the soil water profile fully saturated at planting (depth of the profile, 187 cm; water-holding capacity, 840 mm; available water, 230 mm) (Table 2). The long-term average precipitation in the rainy season is around 700 mm for this region and winter rains add another 150 mm. Chickpea responded to irrigation because in the surface soil layer, where most of the roots were concentrated, moisture was depleted rapidly (Gupta and Agarwal 1977). The irrigated plant maintained a higher leaf water potential, greater LAI, longer LAD, and the crop growth duration was extended by about 35 days. The average net assimilation rates of the irrigated plants were high during the first 52 days. Both pods per plant and seeds per pod increased and contributed to yield (Table 2). The response in total dry matter was greater than that in yield and so the HI is lower in the irrigated treatment. Leaves of the nonirrigated plants showed no rolling of the pinnae or drooping of the compound leaf. The

Table 2. Effect of irrigation on yield, total dry matter, harvest index, and yield components of Annigeri on a deep Vertisol at International Crops Research Institute for Semi-Arid Tropics, Hyderabad, India, 1978-79.

Treatment[a]	Yield (t/ha)	Total dry matter (t/ha)	Harvest index (%)	Pods (no./plant)	Seeds (no./pod)	100-seed weight (g)
Nonirrigated	1.3	2.3	59.3	35.4	1.12	17.2
Irrigated 2 times - 31, 43 DS	2.1	3.6	59.8	44.6	1.20	16.2
Irrigated 4 times - 31, 43, 65, and 92 DS	3.0	6.0	50.8	63.7	1.32	15.1
LSD (0.05)	0.59	2.0		21.1	0.07	1.59
CV (%)	20.7	18.7	15.2	19.5	2.5	4.3

[a]DS = days after sowing

nonirrigated plants had fewer leaves with smaller pinnae, fewer internodes, and fewer branches.

At Hissar, on an Entisol with 220 mm stored soil moisture from the 320 cm preplanting rains and 80 mm rainfall during crop growth period, a heavy presowing irrigation reduced yields by 9-12% (Saxena and Sheldrake, unpubl.). The excessive vegetative growth encouraged lodging. The LAI values in irrigated chickpea ranged from 7 to 8, compared with 3 to 4 in the nonirrigated crop. At Ludhiana in northern India, an irrigation during podfill increased yield when early crop growth was well supported by conserved moisture; irrigation also encouraged excessive growth in those experiments (Sandhu et al 1978).

Responses to supplemental irrigation in chickpea occurred in the absence of enough stored water in the soil profile or where winter rains were negligible or absent. Two irrigations, one during vegetative growth and the other during podfill, generally gave the best yield response (Saxena and Yadav 1975, Sharma et al 1974) at a number of locations in India. The highest yield increase in northern India was 32%.

The average water use by chickpea crops at Dehradun, India, ranged from 110 to 210 mm as the yields varied from 0.9 to 1.8 t/ha (Singh and Bhushan 1979-80). The water-use efficiency was around 8.6 kg grain/mm per ha. Application of P_2O_5 increased the water-use efficiency. At ICRISAT Center, water-use efficiencies of rainfed chickpea and of those receiving irrigation only during the early stages of growth (31 and 43 DS) were around 8.1 kg grain/mm per ha, whereas that of a crop receiving frequent irrigation (31, 43, 65, and 92 DS) was 7.8 kg grain/mm per ha (Sardar Singh and Saxena, unpubl.). Nonirrigated chickpea extracted water from a depth of 142 cm and fully irrigated chickpea from a relatively shallow depth of 127 mm.

Photoperiod response

Chickpea is grown at a wide range of latitudes at which photoperiods vary as well as planting time. It is under increasing photoperiods in the Mediterranean region, under decreasing photoperiods in India and Pakistan, and under constant photoperiods in Ethiopia (van der Maesen 1972). Chickpea has been variously described as long-day length plants (Nanda and Chinoy 1960a, b; Eshel 1968; Pandey et al 1977), quantitative long-day length plants (Sandhu and Hodges 1971, and van der

Maesen 1972), and short-day length plants (Bhardwaj 1975). Cultivars that are early to late in flowering and maturity under normal field conditions all flower more rapidly in longer (15-hour) days. Temperature can modify the photoperiod response. Cooler temperatures with short days delay flowering further whereas warmer days with longer photoperiods hasten flowering. These two opposing effects can exactly offset each other (Summerfield et al 1979). The response of chickpea to longer photoperiods is being used in the ICRISAT breeding programs for accelerated generation turnover to speed advancement of breeding material (Sethi et al, unpubl.).

Potential yields of chickpea, though fairly high, are not realized in farmers' fields because of constraints such as water, salinity, and nutrient deficiencies. The yield potential can be further increased by breeding cultivars tolerant of salinity and drought, developing input (water and nutrient)-responsive cultivars, and extending the podding duration by identifying cultivars tolerant of cooler temperatures.

PIGEONPEA

Cajanus cajan (L.) Millsp (*Leguminosae*, Papilionoideae, tribe Phaseoleae), commonly known as pigeonpea and redgram, is a grain legume of considerable importance in India and is grown in many other tropical countries from 30° N to 30° S.

Most of the improved and local cultivars of pigeonpea are short-day length plants, but day neutral and intermediate forms also exist. Flowering periods are often long and second flushes are common.

Pigeonpea is tolerant of drought, but sensitive to waterlogging. It grows well on all kinds of well drained soils. Wet weather during vegetative growth followed by dry conditions during reproductive growth favors high yields. Pigeonpea also grows well in humid areas.

Leaf photosynthetic rate

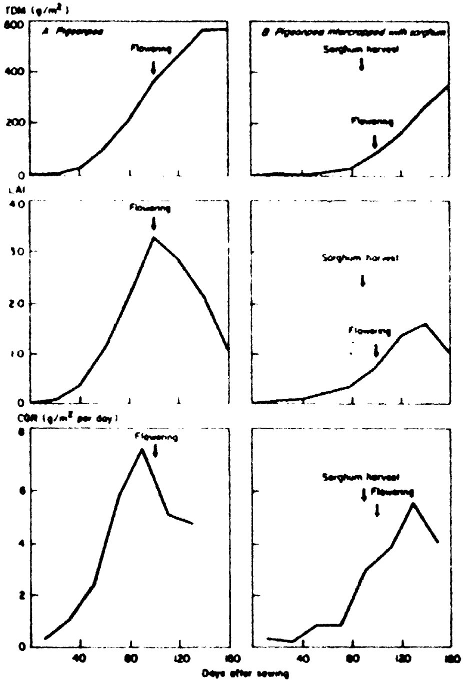
Like all food legumes, pigeonpea is a C-3 plant. Low amounts of phosphoenol pyruvate carboxylase (PEP) enzyme (activity ranging from 0.04 to 0.11 μmol CO_2. dm^2 per minute) have been reported but it is doubtful whether such low levels of activity can be involved in photosynthesis (Sinha 1977). No direct measurement of absolute photosynthetic rate of pigeonpea leaves is available, but genotypic differences in the relative rates of photosynthesis of pigeonpea leaves measured by ^{14}C fixation have been reported (Pandey et al 1976). In 12 genotypes tested, the relative photosynthetic rates varied from 100 to 126%.

Without direct measurement of leaf photosynthesis, net assimilation rate (NAR) is the best measure of photosynthetic efficiency. For a medium-duration cultivar (ICP-1) at ICRISAT Center, NAR was about 75 g/m² per week at the time of flower bud initiation (Sheldrake and Narayanan 1979).

Crop growth rate

A typical growth pattern of a medium duration cultivar (ICP-1) grown on a medium-deep Vertisol at ICRISAT Center over 3 years is illustrated in Figure 2. Dry matter production and CGR in the earlier stage of growth were very slow. The peak

CGR of 7.65 g/m² per day was attained between 80 and 100 DS. The CGR values in later stages of growth were underestimated because no correction was made for the fallen leaves and other organs. Although the pods continued to fill beyond 140 days and new flowers and buds were formed, they were not reflected in total dry matter because of the continuous loss of dry matter by leaf fall. Sheldrake and Narayanan (1979) estimated that the fallen material constituted 25% of total dry matter production of 8.4 t/ha for this cultivar grown on a Vertisol.



2. Crop growth rate (CGR), leaf area index (LAI), and total dry matter (TDM) of medium-duration pigeonpea. ICP-1 grown alone (A) and intercropped (B) with sorghum on medium-deep Vertisol at International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India (M. Natarajan, unpubl.)

Work in Australia with longer growth duration pigeonpea showed three distinct growth phases: an initial lag phase up to day 84, a very rapid growth phase lasting until day 168, and a final slow phase of dry matter accumulation. In this study the maximum CGR for one of three accessions reached as high as 18 g/m^2 per day (Wallis et al 1975).

Differences in maximum CGR have been reported for different cultivars. At ICRISAT Center, early cultivars T-21 and Pusa ageti had a maximum CGR of 6.8 and 5.1 g/m^2 per day whereas the medium duration cultivars ST-1, ICP-1, and HY-3C produced 8.9, 13.7, and 7.5 g/m^2 per day (Sheldrake and Narayanan 1979). The slow growth rate during the first 2 months is typical of all cultivars. That may be a disadvantage in a pure crop but not in a mixed crop. Pigeonpea is generally intercropped in India (Pathak 1970), West Indies (Ariyanayagam 1975), and Africa (Acland 1971) with a variety of other crops such as cereals, low-growing legumes, and root crops, but notably with the cereals sorghum, maize, and millet. The effect of these associated crops on the growth and development of pigeonpea is discussed later.

Dry matter production

Dry matter yield as high as 23 t/ha has been reported from Australia for a long-duration pigeonpea UQ1 (Akinola and Whiteman 1974b). When pigeonpea was grown in the normal season at ICRISAT Center, the aboveground dry matter production generally ranged between 6 and 8 t/ha for medium-duration cultivars and between 3 and 5 t/ha for early cultivars (Sheldrake and Narayanan 1979; ICRISAT unpubl. data). The dry matter production of the determinate and indeterminate cultivars in each of the three growth duration classes was studied. The indeterminate types outyielded the determinate types in all cases (ICRISAT 1978).

Because of pigeonpea's photoperiod sensitivity, its dry matter production is greatly influenced by the time of planting. Akinola and Whiteman (1974a) observed a range of photoperiod responses over a broad group of accessions, but the maximum dry matter yield of all the accessions declined with a delay in sowing beyond September. At ICRISAT, when cultivars belonging to early-, medium-, and later-duration classes were planted in October instead of the normal planting time in July, plants flowered earlier and were shorter (0.5-1 m) than normal (1.5-2.5 m) (ICRISAT 1978). In Puerto Rico, when the normal April-May planting time of indeterminate cultivars was delayed to September-October, the plants also flowered earlier and were appreciably shorter (Abrams and Julia 1973).

Dry matter production has been studied in relation to population density. Akinola and Whiteman (1974b) found that the dry matter yield-density relation described a parabolic curve over a wide range of plant population densities. Increasing plant production favored vegetative growth, particularly of the stem, and reduced seed yields. Thus, the optimum density for dry matter production (107,639 plants/ha) was much higher than that for seed yield (17,940 plants/ha). For a medium duration cultivar (ICP-1) tested at ICRISAT Center with population densities ranging from 15,000 to 130,000 plants/ha, dry matter accumulation increased up to the highest population density. Seed yield response to a population density of about 100,000 plants/ha remained low and then decreased (ICRISAT unpubl. data).

Partition of dry matter and harvest index

In pigeonpea, dry matter accumulation in the vegetative structures continues unabated after the onset of reproductive growth. At ICRISAT Center dry weight of the stem increased after flower bud initiation, reflecting continued production of new branches and continued thickening of existing stems (Narayanan and Sheldrake 1976). The early cultivars produced 73-86% of their total stem dry weight after flower bud initiation and the medium-duration cultivars about 35-55%. Production of secondary branches continued during the reproductive phase in all the cultivars.

During the initial slow growth phase, the leaf fraction constituted a greater portion of the dry matter than the stem, but thereafter decreased progressively. The stem, however, continued to be the major constituent of the total dry matter until harvest.

Pigeonpea has one of the poorest HI values among the grain legumes. At ICRISAT Center, mean HI values of 34% for the early cultivars and 24% for medium-duration cultivars have been recorded (Sheldrake and Narayanan 1979). These values, however, overestimated the partitioning efficiency of the crop because the enormous loss of dry matter through leaf fall was not considered in the calculations. The mean HI for the medium cultivars was reduced from 24 to 17% when correction for leaf fall was made. In Trinidad, the HI of pigeonpea has been reported to range between 12 and 30% for early- and medium-duration cultivars (Ariyanayagam 1975).

Cultivar differences in HI may be influenced by the relative duration of the vegetative phase and by the dry matter partitioned into seeds in the reproductive phase. The higher HI of early cultivars might be due in part to the relatively higher portion of their whole growth period that was occupied by the reproductive phase (Narayanan and Sheldrake 1976). Further studies at ICRISAT Center revealed that HI did not differ appreciably between determinate and indeterminate cultivars in early and medium groups, but in the late-maturity group the mean HI was higher in determinate cultivars (31.5%) than in indeterminate cultivars (19.2%) (Venkataratnam and Green 1979).

As in most food legumes, HI in pigeonpea is strongly influenced by environment and can be manipulated agronomically by planting density, irrigation, and fertilization. Striking changes in HI caused by intercropping and change in the time of planting were also reported.

As mentioned earlier, pigeonpea is grown mostly in association with other crops and this can greatly change the growth and development pattern of the crop. Figure 2 compares the dry matter accumulation pattern in a medium-duration pigeonpea cultivar (ICP-1) grown alone or in an intercrop system at the same population density. Sorghum, the other component in the system, severely depressed the growth of the intercropped pigeonpea and the growth rate of the intercropped pigeonpea did not exceed 0.8 g/m^2 per day until the sorghum was harvested. After the sorghum harvest the pigeonpea CGR rose sharply, peaking at 5.5 g/m^2 per day between 120 and 140 DS. Intercropped pigeonpea was shown to have great compensating ability after the harvest of sorghum (Natarajan and Willey 1980a). The dry matter production of intercropped pigeonpea at the time of sorghum harvest (85 DS) was only 14.5% that of pigeonpea grown alone. Three months later, at maturity, the total dry matter yield of intercropped pigeonpea was 41% of the maximum that pigeonpea alone produced. Nevertheless, the HI of intercropped pigeonpea was 31.6% compared with 18.8% for pigeonpea grown alone. This was due not to a change in the partitioning efficiency of the intercropped pigeonpea per se but to the greater dry matter production that occurred after the crop had entered the reproductive phase. Intercropping pigeonpea with less aggressive, low-growing legumes such as groundnut is practiced to some extent in India and these intercrops may have less effect on pigeonpea growth.

Pigeonpea is normally planted in India in June–July when the day length is maximum. Late plantings, which produce smaller plants with less vegetative growth, result in high HI (ICRISAT 1978). Thus, with high plant populations to compensate for the smaller plant size, pigeonpea has good potential as a winter crop in areas of India where winter temperatures are not too low (Narayanan and Sheldrake 1979).

Economic yield and yield components

At ICRISAT Center pigeonpea seed yield normally ranges between 1 and 2 t/ha for a medium-duration cultivar, depending upon the rainfall and soil type. It is approximately 6–12 kg/ha per day in the normal crop season. Yield can be much higher. Under favorable growing conditions, dry seed yields of 1.6–2.5 t/ha can be realized and an exceptional yield of 5 t/ha was reported from India (Rachie and Roberts 1974). Akinola and Whiteman (1972) reported the highest annual dry seed yield of 7.6 t/ha, based on 2 major harvests from a single planting of UQ 50 — a per-plant yield of 2.5 kg with plants spaced at 1.83 × 1.83 m. Wallis et al (1979) reported that a photoperiod-insensitive, short-duration variety (112 days to first harvest) had a yield potential of [illegible] t/ha or 2[illegible] kg/ha per day.

A strong association found between total annual seed yield and the total number of pod-producing branches per plant suggested that seed yield was influenced by the number of sites available for pod production (Akinola and Whiteman 1974a). There was no significant direct relation between seed yield and other yield components such as number of seeds per pod, weight of 100 seeds, and ratio of seed weight to pod weight. Work at ICRISAT Center and in Puerto Rico also indicated that grain yield differences in pigeonpea resulting from agronomic manipulation were largely manifested through differences in the pod number and pod-bearing branches per plant rather than in the seed number per pod and 100-grain weight (ICRISAT, unpubl. data; Abrams and Julia 1973).

Canopy development and light use

Canopy development in pigeonpea is very slow. A typical leaf area development pattern for a medium-duration cultivar showed that after the first 30 days of growth, LAI was barely 0.5 (Fig. 2). Therefore, a large portion of the incident sunlight reaches the ground unintercepted. A crop of the same cultivar intercepted as little as 10% of the total incoming radiation (Natarajan and Willey 1980b) 1 month after sowing. A peak interception level of 77% was reached at about 100 DS.

Figure 2 shows that the maximum LAI of 3.28 nearly coincided with the attainment of peak CGR. Although this maximum LAI is typical of a medium-duration cultivar, higher values have been reported under more favorable conditions (Sheldrake and Narayanan 1979). Leaf area development in pigeonpea is influenced by such factors as variety, fertility, density, and moisture availability Keatinge and Hughes (1980) reported peak LAI values ranging from 0.34 to 12.5 in 24 situations resulting from site, variety, and moisture level combinations. Maximum LAI values ranging from 13 to 16 have been reported from Australia for 4 pigeonpea cultivars (Wallis et al 1975).

Rachie and Roberts (1974) suggested that the erect *Cajanus* plant, with comparatively small lanceolate leaves, should have higher photosynthetic efficiency than other legumes. They believed that LAI values of 7.0 and higher should be considered optimum compared with LAI values of 3.0 and 4.0 for other large-leaved legumes. This opinion was contradicted by Hughes et al (1980) because the values were higher than for other tropical legumes and higher than those normally achieved by the pigeonpea varieties in their trials. Studies at ICRISAT with early and medium-duration cultivars also showed that the maximum LAI values were mostly below 4.0 when pigeonpea was grown at optimum population density and exceeded 4.0 only when the season was abnormally wet The maximum LAI was normally achieved after flower bud initiation and nearly coincided with the time of maximum CGR (Sheldrake and Narayanan 1979, Natarajan and Willey 1980a).

Pigeonpea intercepts about 95% of the incident radiation when the LAI is about 4.4 (Hughes et al 1980; Natarajan and Willey, unpubl.), and virtually all the light at LAI values greater than 6.0 (Wallis et al 1975).

Pigeonpea, besides being slow in canopy development, inefficiently uses intercepted radiation for dry matter production. A mean intercepted light use efficiency of 0.91% and 1.08% for the period up to maximum dry matter accumulation was obtained with a short duration pigeonpea at Trinidad (Hughes et al 1980) and a medium duration cultivar at ICRISAT Center (Natarajan and Willey 1979). The relation between the accumulated dry matter and accumulated intercepted radiation was approximately linear in both studies, at least during vegetative growth.

Response to major climatic factors

Temperature. A temperature range of 25 to 30° C is optimal for pigeonpea, but it can survive temperatures up to 45° C if soil moisture is adequate (Sinha 197?). Pigeonpea is extremely sensitive to frost but it can survive, though with poor growth rates, when temperature goes as low as 5-10° C. Pigeonpea cultivars differ in degree of cold tolerance (Chi-Chu Wang 1979).

Water. Pigeonpea has a deep taproot system and is highly drought resistant (Gooding 1962). Root development is extensive and deep, enabling the plant to tap moisture and nutrients at greater depths than the more herbaceous tropical grain legumes. Once established, pigeonpea grows exceptionally well on residual moisture. On upland soils in southern Nigeria the crop grows vigorously and fruits profusely 75 days after rains stop (Rachie and Roberts 1974). In India, where the crop is almost entirely rainfed, the medium- and long-duration cultivars flower at the end of the rainy season and grow for long periods on residual soil moisture. Notwithstanding its high drought tolerance, pigeonpea responded to irrigation in dry seasons (Saxena and Yadav 1975, Keatinge and Hughes 1980).

Day length. Most pigeonpeas are photoperiod sensitive and are quantitative short-day plants (Wallis et al 1979). But a range of photoperiod responses has been found by investigators working with a broad group of genotypes. Early-maturing types did not seem to show a typical short-day reaction as did the medium types (ICRISAT 1975). Akinola and Whiteman (1974a), in an experiment with two early- and two late-maturing cultivars, showed that the late-maturing cultivars were quantitative short-day types, one of the early-maturing cultivars was day-neutral or nearly day-neutral with a quantitative response to low temperature, and the other was intermediate. Four photoperiod response groups were identified among 21 cultivars tested by monthly planting (ICRISAT 1976). Interactions between the photoperiod responses of pigeonpea and climatic factors such as temperature were found at ICRISAT (ICRISAT 1976) and in Australia (Akinola and Whiteman 1974a).

Perennial character. Gooding (1962) described pigeonpea as a short-lived perennial that is often cultivated as an annual. This is especially so in India where pigeonpea is normally cut and harvested when the pods mature. If the plants are left standing, the reproductive phase is followed by a second flush of growth and flowering (Sheldrake and Narayanan 1979). The second crop is produced during the hot dry season when the fields cannot be used for any other crop; the well-established root system of the pigeonpea exploits water that is still available in the soil (ICRISAT 1977).

According to Sheldrake and Narayanan (1979), the perennial nature of pigeonpea means that during the reproductive phase, sufficient assimilants and other nutrients must be retained for the survival and continued growth of the vegetative structures. They think that the plants set fewer pods than they can fill because the pods do not set when the assimilants supply falls below a threshold. The feasibility of exploiting the perennial nature of pigeonpea to produce more than one crop from a single planting has been demonstrated at ICRISAT and the University of Queensland, Australia (ICRISAT 1977, 1978; Sharma et al 1978; Sheldrake and Narayanan 1979; Wallis et al 1979).

Two physiological factors seem to limit the seed yield in pigeonpea:

1) a prolonged phase of slow growth in the early growth stages, and

2) poor partitioning of dry matter into seed.

Farmers use the first limitation to their advantage by intercropping pigeonpea with fast growing, [illegible] crops. The second limitation is more important and further study is needed to understand the physiological constraints that govern it.

GROUNDNUT

Arachis hypogaea L. (*Leguminosae*, Papilionoideae, tribe Aeschynomeneae) commonly known as groundnut, peanut, earthnut, or monkeynut, is usually grown as an annual crop. Groundnut is of South American origin, most likely from Eastern Bolivia, and is now grown throughout the tropics and subtropics to 40 N and S lat where rainfall during the growing season exceeds 500 mm. It is very important in semiarid tropics where about 2/3 of the world's groundnut is produced. Groundnut performs well in the dry temperature range between 24 and 33°C but can survive up to 45°C if adequate soil moisture is maintained. The most suitable soils for ground nut are well-drained, light, sandy loams. Groundnut does not tolerate waterlogging and harvesting is difficult in heavy soils because the soil sticks to the pods. Groundnut is generally considered a day-neutral plant although some work suggests that the sensitivity of growth parameters to day length is modified by temperature (Wynne et al 1973). However, normal day length is not a critical factor influencing yields. Provided that the correct strain of Rhizobium is present in the soil or the seeds are inoculated with it before they are sown, root nodules are abundant on the main and lateral roots. The nodules are globular and never lobed.

Photosynthetic rate

Groundnut has the C-3 photosynthetic pathway, but the observed rates of photosynthesis at high light intensities are comparable with those of C-4 plants. There is no evidence of light saturation in this crop as in other C-3 species at relatively low light levels (Pallas and Samish 1974, Hesketh and Moss 1963).

Photosynthetic response of groundnut helps to explain its adaptation to the wide range of light conditions in humid, semihumid, and arid regions. Its high rate of photosynthesis at any light level indicates that it is one of the more efficient species in converting solar energy to fixed carbon. Genotypic variation in photosynthetic rate ranging from 16 to 30 mg CO_2/dm^2 per hour at a given light intensity seems to exist (Pallas 1973). Leaf photosynthetic rates in groundnut genotypes varied between 24 and 37 mg CO_2/dm^2 per hour (Bhagsari and Brown 1976a). Photosynthetic rate was positively, though weakly, correlated with percentage nitrogen and chlorophyll content of leaves. Stomatal frequency and photosynthetic rates were negatively correlated. A significant correlation was obtained (r = +0.79) between the rate of translocation and photosynthesis for 9 groundnut genotypes studied (Bhagsari and Brown 1976b).

The highest apparent photosynthesis (AP) was observed for leaf 3, the youngest fully expanded leaf on the branch, and the lowest AP for leaf 8. Leaf 5 exhibited an intermediate AP rate (Henning et al 1979). AP decreased with plant age; the decrease was 21% from day 80 to 110 and 58% from day 110 to 140. Leaves in the [illegible] of the groundnut plant contribute most during pod filling and the [illegible] capacity of all leaves decreases during this period. There [illegible] photosynthesis (Pn) for 4 out of the 5 genotypes tested when [illegible] concentration was increased from 50 to 600 ppm (Bhagsari and Brown 1976c). Net photosynthesis of leaves of all the five genotypes was not closely related to boundary layer resistance nor leaf characteristics including chlorophyll content, stomatal frequency, leaf nitrogen content, or specific leaf weight.

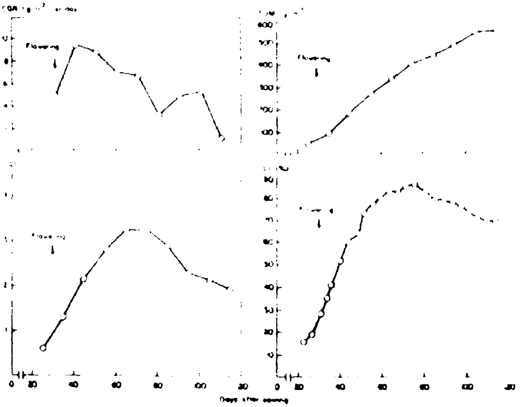
The indeterminate nature of groundnut permits stem growth to absorb any surplus photosynthate, thus photosynthate utilization is not considered a good measure of photosynthetic rate (Williams et al 1976). Cool temperature restricts vegetative growth and reduces photosynthesis. In warmer conditions, the development of the reproductive sinks does not appear to alter photosynthesis (Williams et al 1975a).

Khan and Akosu (1971) used ^{14}C to trace carbon transport in groundnut during the vegetative growth stage. Developing leaves accumulated most of the carbon while fully expanded leaves exported most of their carbon to developing apices of young leaves and roots. Immediately following peg formation, the developing pods become the main sinks. At this stage assimilates are translocated mainly from the leaves of a branch to pods of the same branch.

Crop growth rate and dry matter production

Maximum CGR of groundnut are similar to those of other C-3 crop species (Enyi 1977, Williams et al 1975). Maximum CGR values ranging from 13 to 20 g dry matter/m² per day were obtained for four groundnut cultivars in Rhodesia (Williams et al 1975b). Samaru 61, a groundnut of about 125 days duration, grown at Samaru, Nigeria, produced 845 g dry matter/m². The maximum CGR value was 20.7 g dry matter/m² per day at about 60 DS (Kassam et al 1975). Dodoma Edible, another groundnut of about 125 days duration when grown in Morogoro, Tanzania, produced 1,550 g total dry matter/m², a mean CGR of 12.5 g dry matter/m² per day (Enyi 1977). The CGR of 5 groundnut cultivars grown in Florida, USA, did not differ significantly; their pooled CGR was 19.1 g dry matter/m² per day (Duncan et al 1978).

At ICRISAT Robut 33-1, a groundnut of about 115-day duration, produced 568 g total dry matter/m². The maximum CGR was 9.5 g dry matter/m² per day (Fig. 3). In this cultivar flower initiation occurs at about 30 DS and abundant flowering continues until 70 DS. Initial CGR increased rapidly, reached a maximum at about 35 DS, and then gradually declined. This pattern was complicated to some extent by



3. Crop growth rate (CGR), leaf area index (LAI), total dry matter (TDM), and percent light interception (LI) in groundnut Robut 33-1 on a medium-deep Alfisol at ICRISAT, Hyderabad, India (M. S. Reddy, unpubl.)

leaf losses of unknown magnitude that lowered apparent CGR values late in the season. CGR also declined because of vegetative growth rate reductions. The rate at which the kernel component continued to contribute to CGR appeared unaffected by the decline in the leaf area.

A close and positive relation between CGR and grain yield ($GY = 34.37\,CGR - 306.93$, and $r = 0.982$) was reported by Enyi (1977). The relation between the CGR and LAI was linear, CGR increased with increasing LAI between LAI of 1 and 4.2 ($CGR = 43.86\,LAI - 9.75$, and $r = 0.881$). Williams et al (1975a) found a poor relation between the yield and CGR, total dry matter, or LAI presumably because of variable growth distribution between vegetative and reproductive components.

Duncan et al (1978) concluded that selection for higher yield in groundnut has not resulted in corresponding increases in CGR. A large part of the yield differences in groundnut cultivars with nearly the same CGR values is associated with differences in partitioning of daily photosynthate to fruits. The duration of the transition from vegetative to reproductive growth, and the proportion of growth going to reproductive components vary considerably with temperature and variety (Williams et al 1975a,b). The distribution of assimilates between vegetative and reproductive components is important because any change in this distribution that favors reproductive growth under the same growth conditions may result in greater total pod growth rate and, therefore, higher yields. This greater pod growth rate should also allow a greater pod initiation rate, and decrease the losses of yield and quality that usually occur as a result of the indeterminate pod production pattern.

Leaf area index

The LAI of Robut 33-1 increased gradually, reached a maximum of 3.3 at around 65-75 DS, and then declined gradually to 2.0 at harvest (Fig. 3). Maximum LAI values ranging from 4.5 to 6.2 were achieved with 4 groundnut cultivars in Rhodesia (Williams et al 1975b). The development of leaf area differed considerably and appeared to be independent of branching habit. Kassam et al (1975) observed a maximum LAI of 5.5 at about 70 DS in Samaru 61 (125 days duration) grown at Samaru, Nigeria. The LAI decreased to 1.5 at harvest. Duncan et al (1978) reported that the LAI continued to increase to more than 7.0 in some cultivars, but because light interception appeared complete at about LAI 3.0, further increase in LAI was assumed to have no measurable effect on CGR. Dodoma Edible, grown at Morogoro, Tanzania, attained a maximum LAI of 5.6 about 80 DS and decreased to 0.6 LAI at harvest (Enyi 1977). There was a positive and linear relation between LAD and grain yield ($GY = 33.97\,D - 458.03$, and $r = 0.853$).

Florigiant groundnut in growth chambers has larger leaf area for the 34/30° C and 30/26° C day/night temperatures than for the 26/22°, 28/22°, and 18/14° C (Cox 1979). The optimum average temperature for the maximum leaf was about 30° C — slightly higher than that of flowering and about 2° C above that for dry weight accumulation.

Yield and other yield components

Groundnut pod yield per unit area depends on the number of pods per unit area and weight per pod. The number of pods depends on the number of pegs and pods produced within the time available for filling. The pod growth rate and development to mature kernel depends on the supply of carbon and on temperature. Pod yield in groundnut is also affected by variety, spacing, fertilizer, soil moisture, and soil type.

Groundnut yields are reasonably high considering the conditions under which the crop is grown. Worldwide average yields are 0.9 t unshelled nuts/ha and are as high as 5.5 t/ha for the United States. Yields exceeding 9.6 t/ha have been obtained (Rachie and Roberts 1974, Hilderbrand and Smartt 1980). The shelling percentage is about 80% for early-maturing, bunch types compared with 60-75% for spreading cultivars.

Robut 33-1 at ICRISAT produced 2.21 t dry pods/ha (Table 3). Samaru 61 at Samaru, Nigeria, produced 1.6 t kernel/ha at the rate of 2.6 g/m^2 per day, the HI was 62.5% (Kassam et al 1975). Dodoma Edible at Morogoro, Tanzania, produced seed yield up to 2.72 t/ha (Enyi 1977). Pod yields ranging from 2.47 to 5.38 t/ha for 4 Florida cultivars in the US were reported by Duncan et al (1978). Groundnut's great ability to recover from adverse conditions such as drought and waterlogging gives the crop considerable performance stability.

Temperature response

The effect of temperature on groundnut flowering and fruiting has been studied by several workers (Wood 1968, Cox 1979, Carlson et al 1975, Wynne et al 1973). Wood (1968) subjected a Spanish type, at early flowering, to 12 days of varying temperatures. Fruit production was greatest for plants held at a constant day/night temperature of 25°C. Plants were exposed to 30/25°C day/night temperature regime before and after the 12-day treatment. The total dry matter accumulation of the Makulu Red cultivar grown in Rhodesia increased with increasing mean temperatures over a range from 17.9 to 23.3°C, but the yield of kernels was greatest at 20.1°C (Williams et al 1975). In phytotron studies, maximum dry matter accumulation of NC4 groundnut was achieved at 28°C during early growth, whereas older plants had maximum dry matter accumulation at 32°C (Carlson et al 1975). Cox (1979) conducted two studies in growth chambers to evaluate the effects of temperature on the vegetative and reproductive growth phases of the Florigiant cultivar. Day/night temperature regimes ranged from 34/30° to 18/14°C in the first study and from 34/30° to 22/18°C in the second. Early growth, determined by accumulation of top dry weight, was optimum at a weighted mean temperature of 27.5°C, essentially no growth occurred at 15.5°C. Rate of increase in pod weight, individual pod weight, and total fruit weight were greatest at 23.5°C. During early growth, the optimum temperatures for leaf area development and for flowering were above 28°C. In later stages the optimum temperature for flowering decreased to about 26°C.

Photoperiodism and day length response

Flowering induction in groundnut is generally independent of photoperiod and cannot be regulated by photoperiodic treatment. Tatenyi (1957) reported that groundnut is photoperiod sensitive, but only during the first 6 days after germination. The growth of groundnut plants of both subspecies of *A. hypogaea* responded to the effect of day length (Wynne et al 1973). Plants grown under short days (9 hours) produced pegs but only 31.2% of the flowers produced pegs when the plants

Table 3 Growth duration, yield, and yield components of Robut 33-1 groundnut cultivar grown on a medium-deep Alfisol at International Crops Research Institute for Semi-Arid Tropics, Hyderabad, India (av of 3 seasons).[a]

Days to initial flowering
Initial flowering to pod formation (days)
Pod development and maturity (days)
Total growth duration (days)
Total dry matter (t/ha)
Pod yield (t/ha)
Total dry matter (kg/ha per day)
Pod yield (kg/ha per day)
Harvest index (%)
Shelling percentage

[a] M. S. Reddy, unpubl.

were grown under long days. Three groundnut lines and three F_1 hybrids grown under a 9-hour day were smaller but produced more fruit than when they were grown under a long day treatment (9 hours of light plus a 3-hour interruption of the dark period). Most hybrids showed greater heterotic response for fruit yield under short days than under long days (Wynne and Emery 1974).

Solar radiation

Light interception in Robut 33-1 at ICRISAT was measured by tube solarimeters throughout the growing season. Interception increased gradually and reached a maximum of 87% by about 75 DS and declined gradually to 70% at harvest (Fig. 3). The total light energy intercepted by this crop was 29.04 kcal/cm² and 1.9 mg of dry matter per kilocalorie was produced (Reddy and Willey 1979). Seasonal energy conversion of groundnut grown at Samaru, Nigeria, was 0.6% of the total incoming radiation (Kassam et al. 1975).

Solar radiation during early growth is an important yield determinant. Plants that were shaded to 80% reduction in direct solar radiation from emergence to beginning of flowering (4 weeks) had slower leaf development and lower CGR and reproductive development. At ICRISAT, artificial shade (70% reduction in solar radiation) 55 DS until final harvest did not produce any noticeable reduction in total dry matter or leaf area development; however, the study was conducted during the summer dry season when solar radiation values are especially high.

Water relations

Little research has been conducted on the water relations of groundnut, but the crop appears comparatively resistant to drought and is able to extract soil moisture under extreme conditions. In the sandy soils of Senegal, yields are reduced when soil moisture reaches 70% of its retention capacity. The permanent wilting point is estimated at 40% of that level (Dancette 1970). Moisture deficiency has a direct effect on yields, particularly when it occurs during flowering. Water requirements for groundnut grown on dry lands have been estimated as 500-600 mm/season. During the first months of growth, daily requirements increase from 1.5 to 4 mm/day, reach 5-7 mm/day during peak growth, decrease to 4 mm by the 1st month of the

Table 4. Effect of moisture stress on yield, total dry matter, harvest index, and other yield components of Robut 33-1 on a medium-deep Alfisol at International Crops Research Institute for Semi-Arid Tropics, Hyderabad, India, 1980 summer.[a]

Treatment	Pod yield (t/ha)	Total dry matter (t/ha)	Harvest index (%)	Pods (no./plant)	100-kernel weight (g)
No stress (irrigated every 10 days)	2.7	5.9	45	16.2	35.92
Stress (irrigated every 20 days)	0.8	2.4	34	6.5	13.28

[a]M. S. Reddy, unpubl.

vegetative cycle, and finally drop to 2 mm daily during ripening (Ochs and Wormer 1959, Mantez and Goldin 1964). Crop water use of 120-day Samaru 61 in the Northern Guinea Savanna was reported at about 440 mm, corresponding to a crop water efficiency of about 520 g water/g total dry matter (Kassam et al 1975).

Robut 33-1, grown on a medium-deep Alfisol at ICRISAT during 1980 summer, produced 2.7 t dry pods/ha when the crop was irrigated every 10 days compared with 0.8 t dry pods/ha from a stressed crop irrigated every 20 days (Table 4). During the 1978 rainy season crop water use of Robut 33-1 was 368 mm, corresponding to a crop water-use efficiency of 134 kg dry matter ha per cm water (Ready and Willey 1980).

Florunner groundnut, when subjected to a 70-day drought by rainfall-controlled shelters (from 36 to 105 days in a 140 day crop), produced only 1.4 t pod yield/ha compared with 5.2 t/ha in the no-drought treatment (Stansell and Pallas 1979). It seems that water stress does not reduce photosynthesis in groundnut as drastically as it does in some other crops (Klepper 1973). Transpiration rates of groundnut plants drought-stressed to wilting were 66% of maximum, and stomata were only partially open (Wormer and Ochs 1959). Diffusive resistance, determined with a porometer or from transpiration rates, varied between 0.5 and 2.5 seconds/cm for control plants, while the diffusive resistance of stressed plants reached maximum values of 18-20 seconds/cm. Under a given degree of water stress, as indicated by relative leaf water content, leaf diffusive resistance and net photosynthesis were similar in five groundnut genotypes tested (Bhagsari et al 1976).

Yields in the semiarid tropics are lower (about 0.9 t/ha) than the yields (about 3 t/ha) in the developed world. The reasons for these large disparities in yields include pests, diseases, unreliable rainfall, and poor agronomic practices. Yields can be further improved by breeding for disease resistance because diseases are the greatest yield reducers. The crying need of the semiarid tropics farmers is for high-yielding varieties tolerant of various stress situations.

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