Physiology of Growth, Development, and Yield of Chickpeas in India

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Crop physiology research on chickpea started only recently in India, and the information available on this pulse is therefore rather limited than on other crops, such as cereals and cotton. However, a number of papers have been published on some physiological aspects, including the effect of certain treatments on enzyme activities and the effect of growth regulators; in addition, a few papers have appeared on photosynthesis and translocation of assimilates. Saxena and Yadav (1975) reviewed previous work on the agronomy and physiology of chickpea; some growth and developmental aspects have also been discussed by Argikar (1970).

The purpose of this paper is to report ICRISAT research on crop growth processes, the physiology of yield, and the influence of environmental and cultural practices. Information is being sought for a better understanding of the complex phenomenon of yield determination.

In India, chickpea is grown as a winter crop from as far south as Karnataka (14°N) to as far north as Palampur (32°N). However, 53% of the chickpea production area is in the Indo-Gangetic plains of northern India, and 30% is in central India between latitudes 23° and 26°N; the rest of the chickpea-producing area is in peninsular India. Average yields in North India are around 800 kg/ha as compared to only 400 kg/ha in peninsular India. The crop is usually sown with the onset of cooler temperatures in October and November, utilizing moisture from the preceding monsoon rains in fields that were fallowed during the rainy season. When a rainy-season crop has been taken (in northern India), chickpea is planted after a presowing irrigation. Soil moisture is gradually depleted downward in the profile as crop growth proceeds. Toward the end of the growing season, the evaporative demand of the atmosphere is on the increase (Sheldrake and Saxena 1979a). Limited moisture availability finally terminates growth and forces the plants to mature. Thus, the period in which chickpea can be grown is limited, and is determined at a given location by climatic conditions. Climate is an important determinant of yield.

Data are collected on crop growth, development, and yield aspects at ICRISAT Center near Hyderabad (a short-growth duration location, representative of peninsular India) and at Hissar (a longer growth duration location, representative of northern parts of India).

Climatic Conditions at the Two Locations

Climatic conditions during the chickpea-growing period at Hissar and at ICRISAT Center are summarized in Figure 1. Minimum temperatures at Hissar decline from late October onward and remain low during December and January; the temperature starts rising again in late March. On the other hand, at ICRISAT Center, temperatures decline around the end of November or early December and start to increase again in mid-February. Open-pan evaporation during the growing period follows the same pattern. Thus, the fall of temperature with the onset of winter and the rise at the beginning of summer determines the duration of crop growth. This period is shorter in peninsular India than in the northern parts of India, and so are the growth durations.

Early-duration cultivars perform better than late-duration cultivars at ICRISAT Center, as they are better adapted to the short-growth duration conditions. The amount of rain received in the preceding rainy season as well as that received during the crop-growing period at ICRISAT Center is a little less than

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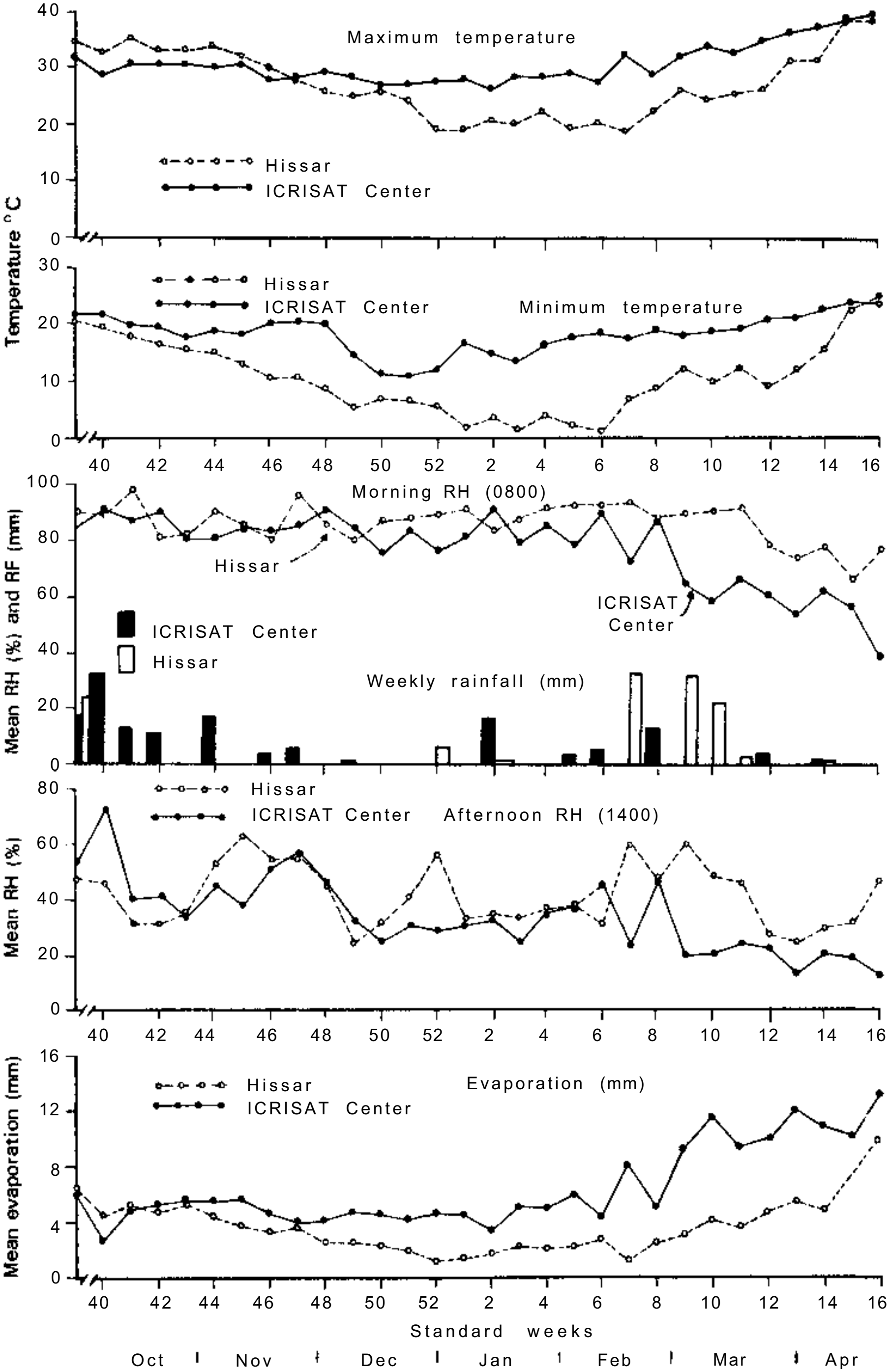

Figure 1. Weekly mean maximum and minimum temperature, rainfall, relative humidity in mornings and afternoons, and open pan evaporation throughout the monsoon season 1977-78 at Hissar and ICRISAT Center.

twice that received at Hissar (Table 1). The soils from both locations are low in available P and high in pH (Table 2). The soils at ICRISAT Center are Vertisols (fine, clayey, deep black cotton soils, typic chromustert); Entisols (sandy, typic cambarthids, alluvial) are found at Hissar. The cation-exchange capacity of the former is higher than that of the latter. The soils, fairly representative of the chickpea-growing areas of central and peninsular India, are rich in potash.

Table 1. Average monthly rainfall (mm) at Hissar and Hyderabad (average of 30 years, 1931-1960)[a].

Period	Hyderabad	Hissar
May-Sep	612.6	368.6
Oct	70.8	14.6
Nov	24.9	7.5
Dec	5.5	4.5
Jan	1.7	19.1
Feb	11.4	14.7
Mar	13.4	17.0
Apr	24.1	6.2
Oct-Apr	151.8	83.6

a. Climatological tables of observatories in India. India Meteorological Department.

Root Growth, Development of Leaf-Area Index, and Dry-Matter Accumulation

Sheldrake and Saxena (1979a) studied the root system of chickpea at ICRISAT Center by taking soil cores with a mechanical auger two times before and two times after flowering. They found that as the soil in the surface zone dried, there was little or no development of roots in this zone, but the roots continued to develop in deeper soil layers down to 120 cm; where there was enough water, development continued until harvest. Most of the nodules werefound to be confined to the 0-15 cm depth. Nodule mass increased during the vegetative period and declined in the later part of the reproductive period. Toward the end of the reproductive phase, more than half of the roots lay in the region below 45-60 cm.

Subramania Iyer and Saxena (1975) also described the rooting pattern in nine varieties of gram during pod development using P^{32}. The soils are rich in organic matter and have a relatively high water table. They reported that 50-65% of the root spread occurred in a radius of 7.5 cm around the plant. Root penetration was studied only up to a depth of 30 cm, which revealed that 40-50% of the extractable roots werefound in the top 10cm of the soil. Perhaps this is the case when moisture is not limiting in the surface layers.

Table 2. Soil characteristics at ICRISAT Center and at Hissar.

Location	Depth (cm)	pH	EC (mmhos/cm)	Available nutrients (ppm) N	P	K	CEC (me/100 g)
ICRISAT Center	0-15	8.0	0.45	52.0	2.0	163	40.9
	15-30	8.0	0.30	57.0	1.0	144	40.8
	30-45	8.1	0.30	49.0	Traces	128	40.8
	45-60	8.1	0.35	49.0	"	119	40.2
	60-75	8.0	0.40	48.0	1.0	169	NA
	75-90	8.2	0.35	41.0	Traces	145	NA
Hissar	0-15	8.1	0.23	87.1	7	203	8.1
	15-30	8.3	0.15	63.0	2.7	176	9.5
	30-60	8.3	0.13	63.0	2.7	149	10.6
	60-90	8.3	0.17	54.6	3.2	95	10.7

NA = Not available.

The dry-matter accumulation pattern in a short- (adapted to peninsular Indian conditions) and a long-duration cultivar grown at ICRISAT Center has been described by Sheldrake and Saxena (1979a). The pattern of dry-matter accumulation at Hissar is described here. Development of leaf area and addition of dry matter continued even after flowering in both cultivars (Fig. 2). Since chickpea is indeterminate, addition of dry matter in the vegetative structures continues even after the onset of reproductive growth. Pod number increased as dry matter and leaf area increased, but once the leaf area started to decline, there was no further increase in pod number.

There were big differences in flowering dates of the cultivars, both at ICRISAT Center and at Hissar. Pod set commenced with the onset of flowering at ICRISAT Center, but at Hissar the flowers on early cultivars and some on late cultivars did not bear fruit while temperatures were low. At Hissar, in both cultivars, pod set commenced at the same time (when temperatures were high enough), irrespective of the time of flower initiation.

At ICRISAT Center, senescence of the lower leaves generally begins before flowering in late cultivars and much after flowering in early cultivars. Data for 1974-75 are shown in Figure 3. At the time when senescence commenced, maximum and minimum temperatures had remained unchanged, but moisture was being progressively depleted from the upper soil profile. This suggests that soil moisture is an important factor in triggering senescence. Senescence occurred later in the border rows of plots, which had access to a better moisture supply; senescence is also delayed by irrigation.

At Hissar, both in early and late cultivars, considerable addition in leaf area occurred after 50% flowering, and the maximum leaf-area index was generally more than twice that at ICRISAT Center. Barring this exception, the

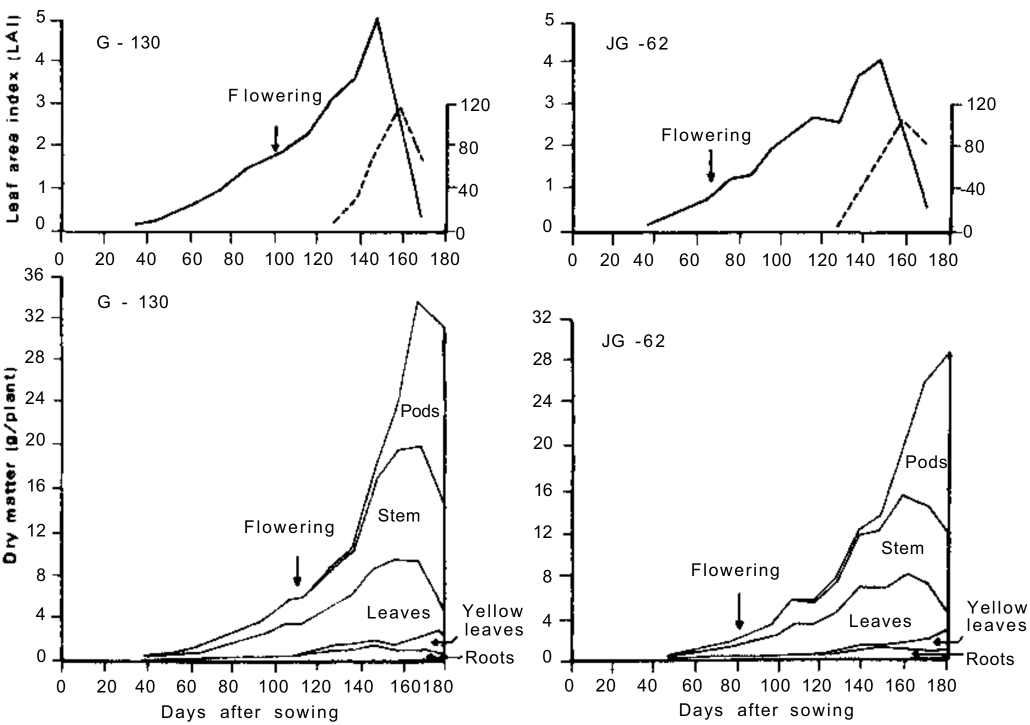

Figure 2. Development of leaf area, increase in pod number, and dry-matter partitioning overtime in two chickpea cultivars at Hissar (1977-78).

pattern of development of leaf area and its relation to pod development was similar at both locations.

The accumulation of dry matter at Hissar continued for a protracted period, owing to longer growth duration. In the early cultivar, JG-62, flowering commenced early in the season when temperatures were low and flowers produced during this period did not set pods. Even though the plant was physiologically in the reproductive growth stage, growth in the vegetative structures continued vigorously, and the node number at harvest was not much different from that of late cultivars.

The senescing pinnae drop off the plant, and at harvest only the rachis remains attached to the plant. A considerable part of total biological yield is sloughed off in the dropped pinnae, resulting in underestimates of total biological yield. The effect of this on harvest index (HI) is discussed later.

Pod Development

Pod development was studied in flowers tagged soon after they opened. Sampling of pods was done periodically until they matured at harvest. The pod wall was the first to develop, and more dry weight accumulated here than in the seeds during the first 15-17 days after anthesis. There was a rapid addition of dry matter in the seeds starting about the time growth of the pod wall ceased (Fig. 4). In the

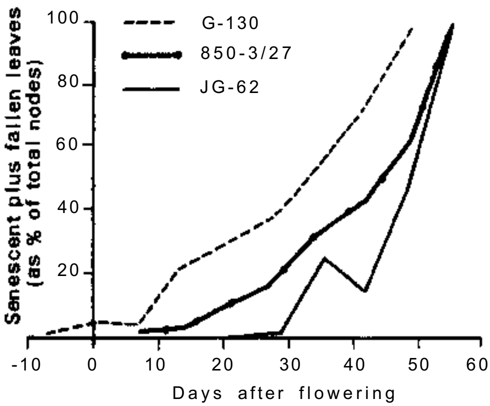

Figure 3. Time course of leaf senescence (1974-75).

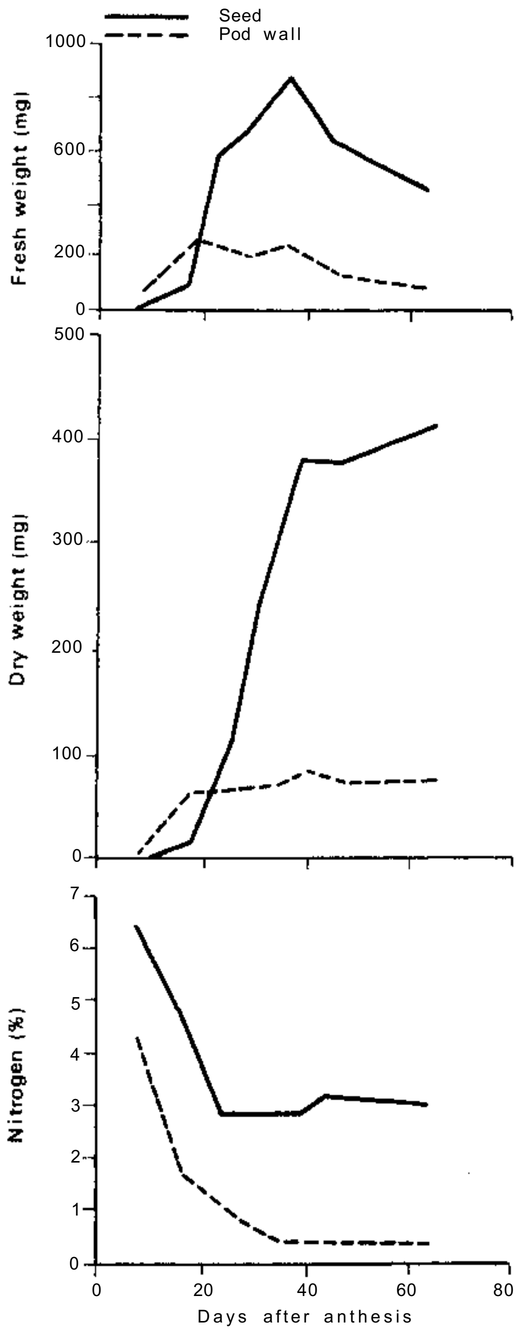

Figure 4. Fresh and dry weight and percent nitrogen of seed and pod wall of a developing pod in CV 850-3127 (1974-75).

early cultivars, which were suited to peninsular India, the addition of dry matter in the seed continued up to 35 to 40 days, whereas in cultivars of longer duration, which were subject to forced maturity, dry matter addition ceased after 25 to 30 days. This period may be considered as the time required for the individual pods to reach physiological maturity. Cultivars differed in rate of pod development and the time of maximum dry-matter accumulation. Pods of smaller-seeded cultivars tended to reach physiological maturity earlier.

In both the seed and pod wall, the percentage N was highest at first and declined with the growth of the pod. It remained unchanged after 24 days in the seed and after 31 days in the pod wall. Thus, during the period of most rapid growth of seeds, accumulations of dry matter and nitrogen take place in parallel.

Pods in chickpea are capable of photosynthesis. Kumari and Sinha (1972) reported variation in fruit-wall photosynthesis in Bengal gram; however, they made no assessment of the contribution to seed yield of fruit-wall photosynthesis.

Sinha (1974) suggested that selection of genotypes in which fruits come out of the plant canopy might be more useful in legumes because of greater photosynthetic activity in the pod walls. Such cultivars are known to occur in cowpea and mung bean. At ICRISAT Center, such cultivars have also been identified in chickpea.

Chickpea pods normally hang below the leaves and are consequently shaded. In a field experiment, pods were exposed to sunlight by hooking them onto the upper surface of the leaves to eliminate any possible limitation by light on their photosynthesis (Saxena and Sheldrake 1980a). No significant effect of pod exposure on yield was observed.

Sheldrake and Saxena (1979b) reported that at ICRISAT Center and at Hissar there was a decline in pod number per node, weight per pod, seed number per pod, and/or weight per seed in later-formed pods. The percentage of nitrogen in the seeds was the same in earlier- and later-formed pods at ICRISAT Center; at Hissar, the later-formed seeds contained a higher percentage of N. The decline in yield components suggests that pod filling was limited by the supply of assimilates or of nutrients. In one small-seeded cultivar, there was no decline in the number or weight of seeds in later-formed pods, indicating that yield was limited by sink size.

Analysis of Yield at Hissar and at Hyderabad

The growth duration at Hissar, as discussed earlier, is almost twice that at ICRISAT Center. Yield at Hissar is also about twice that at Hyderabad (Table 3). Differences in yield between early and late cultivars are quite evident at ICRISAT Center but are less pronounced at Hissar (Saxena and Sheldrake, unpublished data). The reason seems to be the less marked differences in growth duration of early and late cultivars at Hissar. Productivity per day, in total dry matter and to some extent in yield, was higher at Hissar than at Hyderabad. The response to longer growth duration was relatively more in total dry-matter production than in yield, and resulted in a lower harvest index at Hissar than at Hyderabad. The fall of pinnae, as mentioned earlier, results in underestimation of total biological yield and overestimation of harvest index. The fallen pinnae were collected in the field to correct the total biological yield at harvest. Harvest indices were calculated sepa-

Table 3. Differences In growth duration, growth, yield, and yield components of chickpea (average of two cultivars, 860-3/27 and JG-62) at ICRISAT Center and at Hissar (1977-78).

Character	ICRISAT Center (Hyderabad)	Hissar
Vegetative period (days)	49	76
Period of ineffective flowering (days)	0	48
Reproductive period (days)	41	48
Total growth duration (days)	90	172
Total nodes/plant (number)	167	346
Total dry matter (kg/ha)	2072	6176
Yield (kg/ha)	1166	2495
Harvest index (%)	50	40
Total dry matter (kg/day)	22	36
Yield (kg/day)	12	14

rately, using biological yield corrected and not corrected for pinnae fall (Table 4). On an average, the harvest index was overestimated by 10%, both in the desi and kabuli cultivars. The ranking of cultivars for harvest index changed only slightly, which suggests that the uncorrected harvest indices give a reasonably reliable indication of varietal differences.

High harvest index and high yield are two different things. The efficiency of partitioning of total dry matter into seeds was higher at ICRISAT Center; even then, the yield was about half that harvested at Hissar.

The harvest index (HI) thus seems to be greatly influenced by climatic conditions. At a given location, the high-yielding cultivars generally have higher harvest indices. Dahiya et al. (1976) suggested selection of early maturing, high-HI cultivars for North Indian locations. How these cultivars compare in yield with cultivars of later duration was not discussed in their paper. The harvest indices of around 50 for chickpea in peninsular India (Tables 3 and 4) are comparable with those reported for wheat and rice.

Uptake of Nitrogen and Phosphorus

The content of nitrogen is very high (about 5% of total dry matter) in the green leaves of chickpea; when the leaves senesce, the content drops to around 1%. Stems In early stages of growth contain about 1.5-1.8% nitrogen which drops to about 0.6-0.8% at harvest. The corresponding values for P in leaves in early stages and at harvest are 0.7 and 0.2%, whereas in stems they were around 0.5 and 0.3%, respectively. A considerable amount of nitrogen and phosphorus seems to be remobilized from older plant parts to seed and other younger tissues.

The amount of nitrogen and phosphorus in the above-ground parts and in the roots and nodules that could be recovered at ICRISAT Center and at Hissar are presented in Table 5.

Table 5. Seed yield, total dry matter, N, and P content at ICRISAT Center and at Hissar (kg/ha) of attached plant parts of chickpea. In neither location was N fertilizer supplied to the crop (1976-77).

Character	Hyderabad	Hissar
Seed yield	1500	3400
Total dry matter	2600	7000
N removed	58	143
P removed	5	10

Table 4. Effect of leaf fall on harvest Index (HI) and its ranking in chickpea cultivars (1975-76)[a].

Type	Cultivar	Harvest index (HI) Corrected	Harvest index (HI) Uncorrected	Mean	Increase (uncorrected/corrected)	Ranking Corrected	Ranking Uncorrected
		%					
Kabuli	Leb. local	34	44	39	29	6	5.5
	1-550	38	50	44	31	4	4
	K-16-3	34	42	38	23	6	7
	Rabat	29	41	35	41	8	8
	Mean	34	44	38	31		
Desi	BEG-482	34	44	39	29	6	5.5
	Chafa	53	61	57	15	1	1
	JG-62	46	54	50	17	2	3
	850-3/27	43	55	49	28	3	2
	Mean	44	53	48	22		

a. LSD (0.05); cultlvar means, 3.7; treatment means, 1.2; treatments within a cultivar, 3.5; cultlvar within a treatment, 4.4.

The total N removed at ICRISAT Center is less than half, and P removed is half that at Hissar, a relationship similar to dry-matter production and yield. Since nitrogen fertilizer was not supplied to the crops and the soils were low in available N, most of the nitrogen was presumably fixed by the nodules.

Source-Sink Relationships

The two important factors that determine yield are the photo-assimilate supply (source size and activity) and the storage capacity — i.e., number and size of pods (sink size). To evaluate which is a greater limitation to yield in chickpeas, shading, defoliation, and flower removal experiments were conducted.

Effect of Shading

Sheldrake and Saxena (1979a) reported the effects of shading with horizontal shades over the crop canopies during the reproductive period of growth at ICRISAT Center. When photosynthetically active radiation (PAR) was reduced by 50%, senescence was delayed and yield significantly increased up to 15%. This was ascribed to the fact that shading reduced the stresses that were accelerating the senescence process. It was assumed that, in spite of 50% PAR reduction, light intensity might still be near saturation. Further reduction in light intensity delayed senescence even more, but also reduced yield.

The studies on shading were extended to Hissar in the 1976 postrainy season using horizontal shades of cloth, which transmitted the following percentage of light through to the canopy:

Control (no shade) = 100%
Mosquito net cloth = 77% transmission
Thin cloth = 45% transmission
Thick cloth = 16% transmission

The shades were placed on the canopy when pod set commenced, rather that at flowering, because the crop virtually continues growing vegetatively until temperatures rise. Pod set, as it is determined by temperature, began in all cultivars at about the same time. Yield progressively declined with the increase in thickness of the shade (Table 6). There was a significant reduction in yield in all the cultivars, even with shades intercepting only 25% of the sunlight. Drastic reduction in total dry matter, harvest index, pods/m^2, and seeds per pod occurred at 84% light interception, i.e., 16% transmission (Tables 7, 8).

At Hissar, temperatures were not really very high at the time of pod set, when shading was started. Therefore, in the winter of 1977, shading at Hissar was delayed until the temperature began to rise. Even then, shading did not produce increases in yield and dry matter (Table 9), as was reported for ICRISAT Center, where reduction in yield occurred only under the thickest shade that transmitted only 16% sunlight. Senescence was delayed in all the shade treatments at Hissar, as was observed at ICRISAT Center.

Light becomes a limiting factor to dry-matter production and yield at Hissar, even at levels only 15% below full sunlight. This does not seem surprising in view of the high leaf area

Table 6. Effect of shading treatments on grain yield (kg/ha) of four chickpea cultivars at Hissar, postrainy season 1976-77.

Cultivar	Control	Mosquito net	Thin cloth	Thick cloth	Mean
P-173	3422	2479	2344	679	2231
850-3/27	3539	2848	2579	1229	2547
L-550	3879	3190	2701	1237	2752
G-130	3353	2356	1992	705	2102
LSD (0.05)			315.5		170.1
Mean	3548	2718	2404	960	2408
LSD (0.05)			126.1		
CV%			6.5		9.8

Table 7. Effect of shading treatments on total dry weight, harvest index and yield components of chickpea (means for 4 cultlvars), postralny season, Hissar, 1976-77.

Shading treatment	Total dry weight (kg/ha)	Harvest index (%)	Pod number/m^2	100-seed weight (g)
Control	7980	45	2547	19.2
Mosquito net	6590	42	2331	18.9
Thin cloth	6494	38	1789	17.9
Thick cloth	4067	24	984	19.6
LSD	754.1	5.2	749.0	1.39

Table 8. Effect of shading treatments on seed number per pod of 4 chickpea cultlvars at Hissar, postralny season, 1976-77.

	Seed number per pod				
Cultivar	Control	Mosquito net	Thin cloth	Thick cloth	Mean
P-173	1.19	0.98	0.99	0.82	0.99
850-3/27	0.79	0.87	0.89	0.84	0.85
L-550	1.07	0.87	1.24	0.94	1.03
G-130	1.25	1.21	1.02	0.95	1.11
LSD		0.229			1.107
Mean	1.07	0.98	1.03	0.88	0.99
LSD		0.150			
CV%		18.9			15.0

Table 9. Effect of shading treatments on total dry weight, yield, harvest Index and yield components, postralny season, Hissar, 1977—78.

Shading treatment	Total dry weight (kg/ha)	Yield (kg/ha)	Harvest index (%)	Seeds/ pod	100-seed weight (g)
Control	5550	1990	37.2	0.97	19.7
Mosquito net	5161	1956	38.8	1.00	19.0
Thin cloth	5393	1933	36.8	0.95	19.7
Thick cloth	4636	1112	24.7	0.86	14.7
LSD	444.5	238.2	0.06	0.15	1.59

index (LAI) values (around 5.0, Fig. 2) reached in this crop at Hissar, where mutual shading and light penetration in the canopy could be an important factor. On the other hand, at ICRISAT Center with a LAI of around 2.0 (35 days after flowering), the light transmission ratio was 40-50%.

Effect of Leaf Removal

Different degrees of partial defoliation were carried out at ICRISAT Center and at Hissar, starting at the time of flowering and continuing until harvest. There was practically no effect of 25, 33, or 50% defoliation, on total dry-matter production, but these treatments had a small effect on yield, although not in proportion to degree of defoliation. A 50% reduction in leaf area reduced yield only 20%, whereas 100% defoliation reduced yield by 70-80%. This suggests either that leaf area is not a primary factor in limiting yield or that the remaining leaves are able to compensate for the removal of leaves by an increased photosynthetic rate.

There is a possibility that such treatments modify the water balance of plants. To investigate this, the defoliation treatments were repeated with and without irrigation. Treatment effects were not modified by irrigation. Changes in plant water potential in response to defoliation were also monitored soon after defoliation and continued throughout the day. The water potential of defoliated and non-defoliated plants did not differ. These experiments suggest that the compensation was not because of changes in water status of plants after defoliation, but because of other factors.

The effects of defoliation were more severe at ICRISAT Center. Comparison of results at the two locations suggest that leaf area is not a serious constraint to total dry-matter production, but yield was relatively more sensitive than was total dry-matter production to defoliation.

Effect of Flower Removal

Flower removal experiments were conducted at ICRISAT Center and at Hissar to study the effect of altered sink size on dry matter production and its partitioning. Two kinds of experiments were conducted at the time of 50% flowering: (1) removal of all flowers for different periods of time; and (2) flower removal to different degrees (partial flower removal) until harvest.

Both flower removal treatments extended the growing period. The prevention of pod set by different flower removal treatments resulted in more growth of roots and nodules (tenfold increase in nodule weight) and delayed senescence of the plant.

Removal of flowers on some branches and not on others of the same plant resulted in delayed senescence of the branches on which pod set was prevented. This suggests that the stimulus or signal that initiates senescence is related to pod set and is localized within the plant. Such an observation is also reported in soybean (Lindoo and Nooden 1977).

There was no significant decline in yield when one-third of the flowers were removed throughout the growing period. Similarly, removal of all flowers for 14-28 days resulted in no significant reduction in total dry matter and yield. Both experiments on partial flower removal and flower removal for a specified period of time suggest that chickpea plants have some ability to compensate for the loss of potential sinks.

Extension of the growing period in response to flower removal provided one opportunity for yield compensation. Continued growth causes addition of flowering nodes, and more pods can be formed. Indeed, this activity was observed. The second means of compensation was the increase in the number of seeds per pod. The increase in seeds per pod was in a range of 24-26% of the plants in which flowers were removed, when compared to the controls. The third and final type of compensation involved increase in seed weight. The compensation in seed weight generally occurred in small-seeded cultivars, and was relatively small — ranging from 8-20%. In bold-seeded cultivars, the 100-seed weight declined in response to flower removal.

Response of Chickpea to Cultural Practices

Saxena and Yadav (1975) reviewed the work on agronomy in the International Workshop on Grain Legumes. Additional aspects are included in this paper.

Response to Irrigation

Saxena and Yadav (1975) summarized work on response to irrigation, suggesting a positive response to irrigation in areas where winter rainfall is negligible. We obtained positive responses to irrigation ranging between 3 and 94% on Vertisols and a threefold increase on an Alfisol at ICRISAT Center.

Response to Nitrogenous Fertilizer

Nitrogen is not generally applied to legumes, as it is symbiotically fixed by the plants. In the deep black soils at ICRISAT Center (Table 2), chickpea cv JG-62 (a high-yielding cultivar of that region) did not respond to nitrogenous fertilizer applications up to 100 kg N/ha nor to manuring with farmyard manure. Combined nitrogen at the rate of 100 kg N/ha reduced the nodule mass. Response to applied nitrogen was observed in greater vegetative growth and LAI development. This advantage was not reflected in total dry-matter production or yield at harvest. Sinha (1977) reported an increase in yield in some cultivars and a decrease in others when nitrogen was applied at the rate of 75 kg N/ha. Singh (1971) and Singh and Yadav(1971) reported an increase in yield of cickpea with nitrogen application at the rate of 22.5 kg N/ha on soils low in total nitrogen (0.042%). Singh et al. (1972) and Rathi and Singh (1976) also reported positive response to soil applied N at the rate of 30.2 and 20.0 kg N/ha, respectively.

No significant increase in yield in response to nitrogen application was reported by Manjhi and Chowdhury (1971) and Rao et al. (1973). The latter authors attributed it to low or total absence of rainfall during the crop season.

Response to Phosphatic Fertilizer

Saxena and Yadav (1975) summarized well the responses to phosphatic fertilizers reporting conspicuous responses to soil-applied P. At ICRISAT Center on deep black soil low in available P and high in pH (Table 1), no positive response to soil-applied P was obtained in broadcast application with and without irrigation or with placement. Though placement increased the yield, the increase was not statistically significant.

it was felt that interference in the uptake of soil-applied nutrients, especially under dryland conditions where the moisture in receding, may be a factor in the lack of response to soil-applied nutrients. We therefore investigated different methods of foliar fertilization.

The presence of a very acidic exudate prompted us to use rock phosphate or superphosphate as dust on chickpea foliage; P would then become available for growth of the plants. The experiment was conducted over 2 years, and there was a significant but small increase in one year and not in the other.

Response to foliar applications of N, P, and N + P in liquid solutions was also investigated. Interestingly, individually N and P and the two together in the spray increased yield significantly (21.6%). Singh et al. (1971) found that a three-fourth dose of the phosphorus applied as spray was equivalent to the full dose of P through the soil and concluded that P uptake efficiency in foliar applications was high. Srivastava and Singh (1975) did not find a response to foliarly applied P up to 60 kg P_2O_5/ha.

Intercropping of Chickpea Cultivars of Different Durations

Observations at ICRISAT Center indicate that considerable moisture is left behind in the soil profile, even after harvest. To make better utilization of moisture in the profile, intercropping of chickpea cultivars varying in growth duration (early, medium late, and late), either as alternate rows or as a mixture, was investigated at ICRISAT Center and at Hissar. No marked beneficial or detrimental effect of intercropping with cultivars of the same species was observed. However, when cultivars of varying duration were grown in alternate rows, there was a tendency for yield to be about 6% greater at ICRISAT Center and 4% greater at Hissar.

Effect of "Nipping" on Yield

In northern India and Pakistan, nipping of the young shoots during vegetative growth and grazing of the young plants by sheep in Rajasthan causes an increase in auxiliary branches, which sometimes leads to increased yields. The effect of nipping in shorter growth duration condition at ICRISAT Center (peninsular India) was investigated. Nipping treatments tended to reduce yield, but the reduction was not statistically significant.

Effect of Row Direction

Orientation of rows in some crops has been shown to increase yields, while in others it has no effect. Trials were conducted at ICRISAT Center and at Hissar to find the effect of east-west or north-south row directions on yield of chickpea. There was no effect on yield at either location.

Effect of Planting Geometry

Geometry of planting has been shown to influence the yield of many crops. Under conditions where water is limiting, square planting of dryland crops such as sunflower (Krishnamoorthy 1972) results in earlier development of moisture stress than does rectangular planting. This was investigated with chickpea at ICRISAT Center.

Three rectangularities were studied at two densities of population, 33 and 50 plants/m^2. At normal population densities (33 plants/m^2), square planting yielded less than rectangular planting. At higher population densities (50 plants/m^2), the difference between square and rectangular planting was statistically insignificancy although the square planting tended to produce higher yields.

Response to Plant Population

Response to increasing plant density was investigated at ICRISAT Center and at Hissar. Optimum plant population depended upon the location and choice of cultivar.

In general, yields of chickpea at both locations were fairly plastic over a range of plant densities. Total dry-matter production and yield did not reach a plateau at ICRISAT Center at population densities of less than 80 and 20 plants/m^2, respectively, compared to 20 and 4 plants/m^2 at Hissar.

The idea of increasing yield by increasing the plant density of nonbranching erect cultivars was also investigated and found to be not promising. Branching of a normal cultivar is automatically suppressed when it is grown at high population densities, and a normal branching type tailors itself into a nonbranching type.

Effect of Seed Size

In some crops, larger seeds have been shown to produce vigorous plants and high yield. This was investigated in chickpea. Narayanan et al. (in press) reported that there is a close relationship between the weight of seeds and seedlings in graded seeds of a given cultivar, which may result in better seedling vigor. The greater seedling vigor of larger seeds may be related to greater seed reserves. This could be of practical importance in overcoming problems of emergence from crusted soils.

Saxena et al. (in press) investigated the effect of graded seed size within a given cultivar on yield of chickpea at three locations in India. Large seed gave larger seedlings, but there was no significant effect on final yields.

Physiological Aspects of Yield Improvements

For directed efforts to improve yield levels through plant breeding, yield enhancing factors and genetic sources of these need to be identified. On the other hand, yield-reducing factors need to be identified and sources of tolerance found so they can be utilized by breeders to increase yields under growth-limiting conditions.

Double-Podded Character

In chickpea, the dominant component of yield is the number of pods produced per unit area. Where growth duration is short — as at ICRISAT Center (peninsular India) — there is a great limitation imposed on the production of pods and, consequently, on yield. Sheldrake et al. (1979) reported that the double-podded character (cultivars with more than one pod per node) can confer an advantage in yield, ranging between 6 and 11% under conditions in which the character is well expressed. The character is well expressed under normal short growth duration at ICRISAT Center and in late plantings at Hissar. The double-podded character can be exploited to make yield gains under such conditions.

Cultivaral Difference in Plasticity

Ability of cultivars to yield nearly the same at suboptimal populations as at normal plant population is a measure of plasticity of cultivars. Chickpea cultivars in general are very plastic, but cultivaral differences have been noted in yield reduction below a critical plant population (Saxena and Sheldrake, unpublished data). Those with reduced yield at low populations were considered to be nonplastic. The yielding ability of these nonplastic cultivars was similar to that of the plastic cultivars at normal plant populations. Plastic cultivars could be very important in stabilizing and improving yields in farmers' fields where the populations are often nonuniform and suboptimal. A simple screening procedure has been developed in which plants are grown at a suboptimal population and at the recommended normal population (actual populations depending upon the location). The ratio of suboptimal/normal population in yields indicates the plasticity of the cultivar.

Cultivaral Differences in Germination with Limited Water

Cultivaral differences in germination of chickpea with limited available water were noted in laboratory studies on soils brought to different moisture tensions and in osmotic solutions (Saxena and Sheldrake, unpublished data). Germination studies were also carried out under field conditions where emergence is influenced by variation in soil moisture, depth of sowing, soil compaction, and so on. Seed size within a cultivar seems to influence germination to some extent Under limited soil moisture conditions, small seed (within and between cultivars) had some advantage, which might be expected because of a larger surface/volume ratio and requirement of smaller amounts of water per seed. The reverse was observed when water was not limiting.

Cultivaral Differences in Susceptibility to Iron Chlorosis

Some of the chickpea cultivars exhibited iron chlorosis on Vertisols high in pH (Table 1) at ICRISAT Center. The symptoms are yellowing of the younger leaves with severe deficiency, reduction of size of younger leaves and dropping of pinnae. Agarwala et al. (1971) reported differences in cultivar reaction to iron deficiency in sand culture experiments.

In our studies, we found that iron chlorosis in the field can be easily corrected by a single spray of 0.5% $FeSO_4$ The recovery is very uniform, probably because of the presence of acid exudate on the foliage, which keeps the iron in an available and mobile form. The yield of nonsprayed susceptible cultivars was 41-44% lower than the sprayed cultivars (Saxena and Sheldrake 1980b). Expression of the symptoms appears to be under genetic control, and susceptible plants can be picked out and discarded from segregating populations.

Cultivaral Differences in Susceptibility to Salinity

Some of the chickpea-growing areas in India are saline. Though chickpea is more susceptible than wheat, barley, or other cereals to salinity, cultivar differences in response to salinity, as it affects germination and growth, were noticed in artificially salinized soil. Salinity tolerance at germination is important in ensuring plant stand, which also is an important factor in determining yield. Susceptibility to salinity may change depending upon the stage of plant development Brick chambers (above ground) have been constructed and are being used to grow chickpea at different salinity levels until harvest to identify cultivaral differences in yield.

Cultivaral Differences in Heat Tolerance

Early planting soon after the end of the rainy season should ensure better germination and plant stands, as the moisture supply is good. However, temperatures are higher at this time and have been reported to affect early growth (Sheldrake and Saxena 1979a). Numerous studies have shown reduced yields result from planting too early (Saxena and Yadav 1975). Plants planted early are also affected by disease. We investigated cultivaral differences in heat tolerance at ICRISAT Center by planting at the normal time (October) and in February when temperatures are rising. We planted late, when the season was dry, rather than early at the end of the rainy season, to avoid the effect of differential disease pressure from year to year. Relative growth rates (RGR) and net assimilation rates (NAR) were calculated. Significant differences among cultivars were noted both with respect to NAR and RGR, and there was a significant interaction between RGR sowing date (Table 10). The significant interaction between cultivar and sowing date suggests that some cultivars may be more heat tolerant than others. Bengal gram, Annigeri, 850-3/27, H-208, and Radhey are some of the cultivars that had high RGR values in the February planting.

Screening for Cultivaral Differences on Limited Water

By withholding irrigation, severe water stress

Table 10. Variance ratios for relative growth rate (RGR) and net assimilation rate (NAR) from heat stress trial at ICRISAT Center (1977-78).

Source of variation	RGR	NAR
Sowing dates	10.03	446 177.2
Cultivars	3.33**	4.98**
Interaction	3.33**	2.8

**Significant at 1% level.

can be created in Alfisols (red soils), which are poor in water holding capacity. A simple field screening technique was developed to compare relative yield performance of cultivars under stress and nonstress treatments. The three irrigation treatments included no irrigation, once a month irrigation and once every 15 days irrigation. Cultivars differed in their drought tolerance (avoidance and/or tolerance). A drought tolerance index (DTI) was calculated as follows:

DTI = nonirrigated yield/irrigated yield

On the basis of the drought tolerance index, drought tolerant cultivars were early, but not all early cultivars were drought tolerant. Drought tolerance index was positively correlated with yield of nonirrigated plants ($r = +0.40^{**}$, $n = 70$). Some degree of drought tolerance also appeared in cultivars of medium maturity. The ranking of cultivars in irrigated and nonirrigated treatments changed, suggesting that it may not be possible to select cultivars for nonirrigated conditions by growing them with irrigation.

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