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Limitations to seed yield in short-duration pigeonpea under water stress[1]

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Abstract

Yield components were determined for two short-duration pigeonpea [*Cajanus cajan* (L.) Millsp.] cultivars, ICPL 87 and ICPL 151, in response to terminal drought stress with three partial flower/pod removal or four foliar fertilization treatments applied from the time of full flowering. Flower/pod removal treatments comprised a control with no flower/pod removal, lower-plant flower and pod removal at full flowering and 18 days later (EL), allowing pods to develop only on the top-3 nodes of the main stem, and flower/pod removal 18 days after full flowering only (L). The EL and L treatments were applied to ICPL 87 and only the EL treatment to ICPL 151. Seed yield of the top-3 nodes was increased by the EL treatment for both cultivars under rainfed and irrigated conditions, but was not significantly affected by the L treatment. With flower/pod removal, increased yields of the top-3 nodes were due to increases in the pod density and/or the seed size, with little change in the number of seeds pod^{-1}. Foliar fertilization of cultivar ICPL 87 with solutions containing N, P, K and S in similar proportions to those found in developing seeds at 20 and 40 kg N ha^{-1}, had no significant effects on yield or yield components under either soil moisture condition. Factors within the plant during early reproductive growth appear to limit seed yield under both soil moisture conditions, and reproductive sink capacity and nutrient (N, P, K and S) supply, apparently, are not limiting. Such information on plant factors limiting yield under water stress conditions allows for a better understanding of drought resistance mechanism(s) for short-duration pigeonpea.

Key words: Cajanus; Foliar fertilization; Flower/pod removal; Pigeonpea; Yield components

1. Introduction

Intermittent drought periods can greatly reduce seed yields of short-duration pigeonpea [*Cajanus cajan* (L.) Millsp.] sown at the beginning of the rainy season in India (ICRISAT, 1988). In grain legumes, seed yield reductions under water stress are often largely due to lower pod density (Pandey et al., 1984; Muchow, 1985). In pigeonpea, abscission of fully expanded pods is rare and not significantly affected by water stress (Lopez et al., 1994a), suggesting that yield levels are determined fairly early during reproductive growth. The relative stability of other yield components (seeds pod^{-1} and seed size; Sheldrake, 1984) may actually limit yield compensation where water stress during early reproductive growth is followed by more favorable conditions. Reduced pod density under water stress and inflexibility of other yield components may result from limitations in the source or reproductive

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sink capacity, and/or competition from vegetative sinks. A better understanding of plant factors influencing yield components under water stress will allow a more directed approach at improving crop drought tolerance.

In pigeonpea cultivars of varying growth habits, the majority (up to 90%) of flowers abscise without setting pods, particularly those formed later (Sheldrake, 1984). This high abscission percentage for later-formed flowers declines when earlier formed flowers are removed, indicating that reproductive sink capacity may not be limiting at the time of pod set (Sheldrake, 1984). Also, the seed size (mg) for early- and later-formed pods is similar (Sheldrake and Narayanan, 1979a), suggesting that the source supply is not limiting during late reproductive growth. Studies involving partial removal of flowers, pods and/or leaves suggest that pod set in pigeonpea is determined by the capacity of the source (leaves) to supply assimilates (Sheldrake et al., 1979; Tayo, 1980, 1982; Pandey and Singh, 1981). The intra-plant competition for mineral nutrients during reproductive growth may also influence yield components, but variable results have been reported from foliar fertilization of pigeonpea (Del Valle, 1981; Tayo and Togun, 1984) and other grain legumes (Garcia and Hanway, 1976; Parker and Boswell, 1980; Elowad and Hall, 1987; Halevy et al., 1987). Most of these studies were carried out with adequate soil moisture and further information is required on the role of plant factors in controlling yield components under drought conditions.

Field experiments were conducted to examine the response of yield components to water stress with partial flower/pod removal or foliar fertilization during reproductive growth. In treatments with partial flower/pod removal, pods were allowed to develop only on the top-3 nodes of the main stem for two determinate, short-duration pigeonpea cultivars (ICPL 87 and ICPL 151). In a separate experiment, foliar fertilization treatments were applied to cultivar ICPL 87 during reproductive growth.

2. Materials and methods

2.1. Crop establishment

Two field experiments were conducted in close proximity on Alfisols (Udic Rhodustalf), at ICRISAT Center, Patancheru (17°N, 78°E; 500 m elevation) during the 1988 rainy season. The fields were surface tilled incorporating 100 kg ha^{-1} of diammonium phosphate, and ridges 0.6 m apart were established. Results of soil analyses and plant growth tests had indicated that any nutrient limitations to growth of pigeonpea would be unlikely on these soils. Sowing was done by hand on 22 June, with two rows (0.3 m apart) planted one on each side of ridges with a spacing of 0.1 m within rows (33 plants m^{-2}). Agronomic operations were carried out as necessary for adequate protection against pests, diseases, and weeds. Heavy rains under cloudy conditions during August and September resulted in complete abscission of first flush flowers in all plots, and experimental treatments commenced in October when full flowering was again established. After 30 September, there was no more rainfall for the remainder of crop growth, so that non-irrigated plots were subjected to terminal water stress.

2.2. Experiment 1

In experiment 1, the responses of yield components to irrigation and partial removal of flowers and pods during pod set and early pod development were investigated. A split-plot design with four replications was used and two soil-moisture (main-plot) treatments were applied:

a. rainfed – no irrigation;
b. irrigated – three furrow irrigations (55, 34 and 40 mm, respectively, were given at weekly intervals beginning 24 October).

In this study, two short-duration pigeonpea cultivars (ICPL 87 and ICPL 151) were used, and data for each cultivar analyzed separately because of unequal factor levels in the sub-plots. Each main-plot consisted of 14 rows (4 m long), and was separated from the other by a 2-m-wide buffer zone planted with ICPL 87. Three flower/pod removal (sub-plot) treatments were applied:

a. Control – no flower/pod removal;
b. Early + late (EL) – lower plant flower/pod removal at 118 days after sowing (DAS; flowering) and 136 DAS (podfill);
c. Late (L) – lower plant flower/pod removal at 136 DAS only.

In treated plots, flowers and pods on the lower part of each plant were removed, leaving pods to develop on the top-3 nodes of the main stem only. Each sub-plot consisted of two adjacent rows, and sub-plots were separated by two border rows. At 136 DAS, ICPL 151 had a low proportion of flowers and young pods among the reproductive structures because of the high synchronization of pod development, hence the L treatment was omitted for this cultivar, as it may have been too late to influence pod density and possibly the number of seeds pod^{-1}.

2.3. Experiment 2

In experiment 2, the responses of yield components of ICPL 87 to irrigation and foliar fertilization during pod-set and early pod development were investigated. The experimental design and soil moisture (main-plot) treatments were identical to those of experiment 1. Each main-plot consisted of 24 rows (4 m long) with a similar separation as that in experiment 1. Four foliar spray (sub-plot, consisting of four rows on two adjacent ridges, separated by two border rows) treatments were applied: (a) no foliar spray; (b) water; (c) N_{12} (12 g N l^{-1}); and (d) N_{24} (24 g N l^{-1}). The N_{12} and N_{24} solutions were similar to those used in earlier studies (Garcia and Hanway, 1976; Elowad and Hall, 1987), and contained N, P, K and S in similar proportions to those in developing pigeonpea seeds (Singh et al., 1984a,b; Table 1). All foliar sprays were applied between 1630 and 1800 h, using a hand-sprayer which delivered 140 ml min^{-1}, with 0.1% dimethyl sulfoxide as a wetting agent. They were applied on four occasions at weekly intervals beginning 12 October, with the total N applied at 20 and 40 kg ha^{-1} for the N_{12} and N_{24} solutions, respectively.

Table 1
Composition of the N_{24} nutrient spray solution[a] for foliar fertilization of pigeonpea (ICPL 87) during pod set and pod development

Nutrient source	Amount (g l^{-1})	Nutrient supplied (g l^{-1})			
		N	P	K	S
NH_4NO_3	60.3	20.5	0.0	0.0	0.0
KH_2PO_4	9.1	0.0	2.0	2.6	0.0
KNO_3	20.2	2.6	0.0	7.4	0.0
$(NH_4)_2SO_4$	4.2	0.9	0.0	0.0	1.0
Total		24.0	2.0	10.0	1.0

[a]The N_{12} solution was prepared by dilution of the N_{24} solution with an equal volume of deionised water.

2.4. Harvesting

Plots were harvested at 160 DAS, and net plot size was 1.8 m^2 for both experiments, with only the two middle rows harvested for sub-plots in experiment 2. In experiment 1, the top-3 nodes from each plot were first removed and pods were kept separate from those on the rest of the plant. Pods were sun-dried for 2 weeks and then oven-dried at 80°C to constant mass. The number of seeds pod^{-1} and seed size were determined from 100-pod subsamples. Pod number was determined gravimetrically using total pod mass and that of these 100-pod subsamples.

3. Results

3.1. Experiment 1

Seed yield of all nodes in control plants was increased by irrigation in both cultivars (Tables 2 and 3). For nodes other than the top-3 in control plants, seeds pod^{-1} and seed size were similar to those of the top-3 nodes (data not shown). The contribution of the top-3 nodes to total seed yield was 72% under rainfed and 66% under irrigated conditions (pooled s.e. = 2.0%) for ICPL 87, and 80% and 70% (pooled s.e. = 2.7%), respectively, for ICPL 151. For both cultivars, maturity (80% dry pods) was 142 days after sowing (DAS; pooled s.e. = 0.3) under rainfed conditions, and under irrigation, 5 days later for ICPL 87, but remained constant for ICPL 151. The EL treatment extended the time to maturity by 6 days under rainfed conditions and by 3 days under irrigated conditions for ICPL 87, and by 4 and 2 days, respectively, for ICPL 151.

Without flower/pod removal, seed yield of the top-3 nodes was increased by irrigation in ICPL 87, but not in ICPL 151 (Tables 2 and 3). The EL treatment increased seed yield in both cultivars, with a greater increase under rainfed conditions for ICPL 87, and under irrigated conditions for ICPL 151. Seed yield was not significantly affected by the L treatment under both soil moisture conditions (Table 2).

In the control, pod density (pods m^{-2}) was increased by irrigation for ICPL 87 but not significantly affected for ICPL 151 (Tables 2 and 3). The increase in pod density under the EL treatment was just signif-

Table 2
Effects of flower/pod removal[a] and soil moisture level on seed yield and yield components of the top-3 nodes for ICPL 87

	Rainfed			Irrigated			s.e.
	Control	Early + late	Late	Control	Early + late	Late	
Seed yield (kg ha^{-1})[b]	830	1220	720	1320	1620	1190	69 (72)[c]
Pods m^{-2}	260	330	220	390	400	330	25 (28)
Seeds pod^{-1}	4.0	4.3	3.9	4.2	4.4	4.0	0.14 (0.15)
Seed size (mg seed^{-1})	83	95	89	88	101	97	2.0 (2.3)

[a]Pods were allowed to develop only on the top-3 nodes of treated plants.
[b]All-node seed yield was 1160 kg ha^{-1} under rainfed and 2010 kg ha^{-1} under irrigated conditions for control plants (s.e. = 78).
[c]Values in parentheses represent s.e. for comparing means at the same soil moisture level.

Table 3
Effects of flower/pod removal[a] and soil moisture level on seed yield and yield components of the top-3 nodes for ICPL 151

	Rainfed		Irrigated		s.e.
	Control	Early + late	Control	Early + late	
Seed yield (kg ha^{-1})[b]	1110	1500	1220	2060	67 (77)[c]
Pods m^{-2}	290	330	300	440	11 (9)
Seeds pod^{-1}	4.3	4.7	4.4	4.4	0.11 (0.10)
Seed size (mg seed^{-1})	91	105	103	111	2.6 (2.1)

[a]Pods were allowed to develop only on the top-3 nodes of treated plants.
[b]All-node seed yield was 1390 kg ha^{-1} under rainfed and 1760 kg ha^{-1} under irrigated conditions for control plants (s.e. = 83).
[c]Values in parentheses represent s.e. for comparing means at the same soil moisture level.

Table 4
Effects of foliar fertilization[a] and soil moisture level during pod set and pod development on seed yield and yield components of ICPL 87

	Rainfed				Irrigated				s.e.
	None	Water	N_{12}	N_{24}	None	Water	N_{12}	N_{24}	
Seed yield (kg ha^{-1})	1300	1320	1400	1220	2020	1950	1980	1900	90 (97)[b]
Pods m^{-2}	450	440	430	420	560	560	570	550	36 (38)
Seeds pod^{-1}	3.9	4.0	4.1	3.9	4.3	4.1	4.1	4.2	0.13 (0.15)
Seed size (mg seed^{-1})	82	79	87	82	91	90	91	90	2.1 (2.1)

[a]N_{12} and N_{24} refer to N:P:K:S (24:2:10:1) solutions at 12 g (N) l^{-1} and 24 g (N) l^{-1}, with total N application of 20 kg ha^{-1} and 40 kg ha^{-1}, respectively.
[b]Values in parentheses represent s.e. for comparing means at the same soil moisture level.

icant under rainfed conditions and non-significant under irrigated conditions for ICPL 87, but was significant under both soil moisture conditions for ICPL 151. The L treatment did not significantly affect pod density of the top-3 nodes under either soil moisture conditions (Table 2).

For both cultivars, the number of seeds pod^{-1} (for pods produced in the top-3 nodes) was not significantly affected by irrigation, in the control or flower/pod removal treatments (Tables 2 and 3). In ICPL 87, both the EL and the L treatments had no significant effect on number of seeds pod^{-1} under rainfed or irrigated conditions (Table 2). For ICPL 151, the EL treatment marginally increased number of seeds pod^{-1} under rainfed but not under irrigated conditions (Table 3).

In the control, seed size (mg; for seeds produced in the top-3 nodes) was not significantly affected by irrigation for ICPL 87, but was greatly increased for ICPL 151 (Tables 2 and 3). For both cultivars, the EL treatment increased seed size under both rainfed and irrigated conditions. The L treatment did not affect seed size significantly under rainfed conditions, but increased it under irrigated conditions (Table 2).

3.2. Experiment 2

The N_{24} foliar spray treatment caused some leaf burn from the time of initial application. The time to maturity (80% dry pods) under each soil moisture condition was similar to that observed in experiment 1, with no effect of foliar fertilization treatments (data not shown). Seed yield and pod density were both increased by irrigation, irrespective of the applied foliar fertilization treatment (Table 4), but were not significantly affected by foliar fertilization sprays under either rainfed or irrigated conditions.

The number of seeds pod^{-1} was not significantly affected by either irrigation or foliar fertilization (Table 4). Seed size was increased by irrigation for all subplot treatments, except for the N_{12} foliar spray treatment. Foliar fertilization sprays did not significantly affect seed size under either rainfed or irrigated conditions.

4. Discussion

4.1. Effect of flower/pod removal

Seed yield and yield components were strongly affected by terminal water stress (rainfed conditions) and partial flower/pod removal, with the two cultivars showing different responses in some cases. The percentage of the total seed yield produced in the top-3 nodes was higher in ICPL 151 than in ICPL 87. Therefore, the effects of partial flower/pod removal treatments were stronger for ICPL 87, since a smaller proportion of the potential pod-load was allowed to develop for this cultivar. Similarly, the effect of partial flower/pod removal treatment was stronger under irrigated than under rainfed conditions. Comparable studies with pigeonpea involved complete (Sheldrake et al., 1979; Tayo, 1980) or partial flower/pod removal (Pandey and Singh, 1981), but yield components were determined for whole-plant seed yield. The present study has the advantage that yield components were determined in a section of the plant that was undisturbed by flower/pod removal.

The time to maturity was extended by irrigation for ICPL 87 and by partial flower/pod removal for both ICPL 87 and ICPL 151. For several grain legumes including pigeonpea, water deficit reduced the duration of flowering and pod-filling, with a resulting reduction in time to maturity (Muchow, 1985). Flower/pod removal increases pod set of later formed flowers, which leads to an extension in the time to maturity in pigeonpea (Sheldrake et al., 1979; Tayo, 1980; Pandey and Singh, 1981) and other grain legumes (Tayo, 1977; Pandey, 1983, 1984) consistent with the present observations. In soybean, removal of proximal pods reduces the probability of abscission of later-formed pods (Spollen et al., 1986; Wiebold, 1990), and delays leaf senescence and abscission (Crafts-Bradner and Egli, 1987), with a concomitant delay in time to maturity.

The greater reduction in seed yield of ICPL 87 under terminal drought stress compared to that of ICPL 151 is at variance with the general finding that ICPL 151 is more susceptible to drought (e.g. ICRISAT, 1988). However, in this study ICPL 151 may have escaped the terminal drought stress because of its earlier flowering and more synchronized pod development.

Seed yield of the top-3 nodes was increased by EL in both cultivars under rainfed and irrigated conditions. For ICPL 87, seed yield of the top-3 nodes was not significantly affected by the L treatment, indicating that seed yield was determined largely by internal plant factors during early reproductive growth. For pigeonpea and other legumes, whole-plant seed yield is not adversely affected by flower/pod removal during early reproductive growth, but is reduced by defoliation at the onset of flowering (Sheldrake et al., 1979; Tayo, 1980, 1982; Pandey and Singh, 1981; Pandey, 1983, 1984), suggesting that assimilate supply may be a limitation to seed yield. This is supported by the observation that non-structural carbohydrate (especially starch) content of vegetative tissues is increased by flower/pod removal in pigeonpea (Lopez, 1986) and soybean (Ciha and Brun, 1978; Crafts-Bradner and Egli, 1987), which can possibly explain the increased pod set of later formed flowers. However, simulation studies suggest that carbon availability within whole plants of pigeonpea at flowering is considerably in excess of that required for pod set (Rawson and Constable, 1981). Moreover, water stress during the late vegetative and early flowering stages increases the content of starch and sucrose in stems of short-duration pigeonpea (Lopez et al., 1994b), suggesting that the supply of assimilates is not a limitation to pod set under water stress conditions, although translocation to reproductive sinks may be impaired. Further studies are required to unequivocally establish whether assimilate supply has any direct role in controlling pod set. Apart from the possible involvement of mineral nutrients, an alternative explanation for the present results is that increasing concentration of substances produced by developing pods can inhibit further pod set (Huff and Dybing, 1980), since removal of these pods enhances pod set of later-formed flowers.

Changes in seed yield (top-3 nodes) with soil moisture and flower/pod removal treatments were generally reflected in variations in pod density for both cultivars, as reported elsewhere for pigeonpea and other grain legumes (Pandey et al., 1984; Muchow, 1985). Differences between ICPL 87 and ICPL 151 in the responses of pods m^{-2} to irrigation and flower/pod removal may be due to differences in the severity of the flower/pod removal treatments, and in the competitiveness of pod production versus that of other sinks. Highly significant increases in pods m^{-2} of the top-3 nodes for ICPL 151 with EL indicates less competition from other sinks during early reproductive growth compared to ICPL 87, consistent with the higher podding synchronization observed in ICPL 151. Vegetative parts can serve as strong sinks for assimilates when reproductive structures are removed in pigeonpea (Tayo, 1980) and soybean (Heitholt and Egli, 1985). More branches are formed in ICPL 87, and proportionally less pods occur in the top-3 nodes than in ICPL 151, especially when the first flush of flowers is lost as in the present study.

Irrigation and/or flower/pod removal had very little effect on seeds pod^{-1}, but increased the seed size for both cultivars. Pigeonpea shows a reduction in seed size under water stress in contrast to some other grain legumes (Muchow, 1985). In soybean, allowing one or two pods to develop at each node increases seeds pod^{-1} and seed size (Tayo, 1983), while removal of proximal pods on a raceme had variable effects on these parameters for distal pods (Spollen et al., 1986; Wiebold, 1990). The high stability of seeds pod^{-1} in these pigeonpea cultivars suggests that seed abortion is unaffected by the treatments in the present study. Increases in seed size with the EL or L treatments indicate that this yield component can compensate, to some extent, for reductions in other yield components which may occur earlier during reproductive growth due to water stress, or other environmental factors. Increases in seed size in response to irrigation or flower/pod removal were generally smaller with large increases in pod density than where increases were small, suggesting that there may be intra-plant competition among seeds for assimilates or some other associated factor. This competition appears to increase under water stress, leading to reduced seed size, especially for ICPL 151. Thus, under water stress, there was sufficient pod set in relation to the ability to fill pods, with the latter possibly determined by some associated plant factor at the time of pod set.

4.2. Effect of foliar fertilization

Although the N_{24} spray solution resulted in some leaf burn, time to maturity, seed yield and yield components of ICPL 87 were unaffected by foliar fertilization treatments under terminal water stress (rainfed) or irrigated conditions. The concentration of the N_{24} solution was lower than that of similar nutrient solutions which caused leaf burn in cowpea (Elowad and Hall, 1987), suggesting that cowpea may be more tolerant to foliar nutrient sprays than pigeonpea. Possibly, cowpea can make faster use of the foliar applied nutrients, thus less toxic concentrations remain to cause leaf burn. Unlike in cowpea (Elowad and Hall, 1987), foliar fertilization during reproductive growth did not extend photosynthesis or delay maturity in soybean (Boote et al., 1978), similar to observations for pigeonpea in the present experiment.

Whole-plant seed yield for ICPL 87 was not affected by foliar fertilization regardless of soil moisture conditions. Non-significant effects of foliar fertilization on seed yield may be due to the presence of adequate levels of the applied nutrients in the plant tissues under both soil moisture conditions. For several short-duration pigeonpea cultivars, drought during vegetative and flowering stages reduces the N, P and K levels in leaves, but not in stems (Lopez et al., 1994b), which can possibly buffer the nutrient supply for reproductive growth (Sheldrake and Narayanan, 1979b). In soybean, nutrient sprays that caused leaf burn increased N levels only in seeds, P levels only in leaves, and K levels are unchanged (Parker and Boswell, 1980). Although absorption and translocation of nutrients in the applied ratio may not always be achieved, utilization of foliar-applied nutrients may be reflected in increased yields. Foliar fertilization during reproductive growth has variable effects on the seed yield of pigeonpea and other grain legumes (Garcia and Hanway, 1976; Del Valle, 1981; Tayo, 1981; Tayo and Togun, 1984; Elowad and Hall, 1987), and responses probably depend on the availability of nutrients in the soil (Halevy et al., 1987). In pigeonpea (Tayo and Togun, 1984) and cowpea (Elowad and Hall, 1987), similar yield increases have been obtained regardless of whether fertilizers were applied to the foliage or the soil, suggesting that perhaps in deficient soils transport of nutrients from leaves is no more limiting to yield than transport from roots.

Foliar fertilization did not significantly affect pod density, seeds pod^{-1} or seed size of ICPL 87 under either rainfed or irrigated conditions. In situations where increased seed yields have been reported in response to foliar fertilization, increases in both pod density and seed size (Elowad and Hall, 1987) or in pod density only (Tayo, 1981) have been found for cowpea, and pod density and seeds pod^{-1} (Garcia and Hanway, 1976) for soybean. Foliar sprays (N, P, K, and S) at 4 weeks after sowing and at anthesis increased both pod density and seeds pod^{-1} in pigeonpea, with no change in seed size (Tayo and Togun, 1984). These results differ from the present observations, and may have been due to the foliar spray applied before reproductive growth (4 weeks after sowing) by Tayo and Togun (1984). In soybean, seed yield was increased by nitrogen fertilization of the soil during flowering but not during the grain-filling period (Brevedan et al., 1978). In the present study, foliar fertilization treatments commenced only after full flowering, and it is possible that application of nutrients at an earlier stage may increase yields largely through increased branching and pod density.

5. Conclusions

Plant factors during early reproductive growth appear to limit seed yield under both terminal drought stress and well-watered conditions. Application of foliar sprays of N, P, K and S nutrients failed to increase seed yield, while leaf burn was apparent at high nutrient concentration. Previous studies indicated that nutrients from such solutions can be utilized by pigeonpea leaves as indicated by increased yield under certain environmental conditions. Reduced seed size under water stress suggests that pod set is sufficient in relation to the capacity to fill pods as determined at the time of pod set. Thus, inadequate assimilate supply may be involved. To improve drought resistance of short-duration pigeonpea, efforts should be directed toward increasing pod density under drought conditions. Seed size can be allowed to vary above a given minimum value, so as to impart some ability for yield compensation if favorable soil moisture conditions follow a drought period during early reproductive growth.

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7. References

Boote, K.F., Gallaher, R.M., Robertson, W.K., Hinson, K. and Hammond, L.C., 1978. Effect of foliar fertilization on photosynthesis, leaf nutrition, and yield in soybeans. Agron. J., 70: 787–791.

Brevedan, R.E., Egli, D.B. and Leggett, J.E., 1978. Influence of N nutrition on flower and pod abortion and yield of soybean. Agron. J., 70: 81–84.

Ciha, A.J. and Brun, W.A., 1978. Effect of pod removal on nonstructural carbohydrate in soybean tissue. Crop Sci., 18: 773–776.

Crafts-Bradner, S.J. and Egli, D.B., 1987. Sink removal and leaf senescence in soybean. Plant Physiol., 85: 662–666.

Del Valle, R. Jr., 1981. Influence of nutrition and bioregulators on flower retention, pod set and yield of pigeon peas (*Cajanus cajan* (L.) Millsp.). J. Agric. Univ. Puerto Rico, 65: 346–352.

Elowad, H.O.A. and Hall, A.E., 1987. Influences of early and late nitrogen fertilization on yield and nitrogen fixation of cowpea under well-watered and dry field conditions. Field Crops Res., 15: 229–244.

Garcia, R.L. and Hanway, J.J., 1976. Foliar fertilization of soybeans during seed-filling period. Agron. J., 68: 653–657.

Halevy, J., Hartzook, A. and Markovitz, T., 1987. Foliar fertilization of high-yielding peanuts during the pod filling period. Fert. Res., 14: 153–160.

Heitholt, J.J. and Egli, D.B., 1985. Influence of deflowering on dry matter production of soybeans. Field Crops Res., 12: 163–173.

Huff, A. and Dybing, C.D., 1980. Factors affecting shedding of flowers in soybean (*Glycine max* (L.) Merril.). J. Exp. Bot., 31: 751–762.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), 1988. Annual report 1987. ICRISAT, Patancheru, A.P., India, pp. 183–184.

Lopez, F.B., 1986. Drought resistance studies in pigeonpea. Ph.D. Thesis, University of the West Indies, St. Augustine, Trinidad, pp. 207.

Lopez, F.B., Chauhan, Y.S. and Johansen, C., 1994a. Effects of drought stress timing on short-duration pigeonpea. II. Abscission and dry matter partitioning. Field Crops Res. (in prep.)

Lopez, F.B., Johansen, C. and Chauhan, Y.S., 1994b. Effects of drought stress timing on short-duration pigeonpea. V. Non-structural carbohydrates, and N, P, and K in leaves and stems. Field Crops Res. (in prep.)

Muchow, R.C., 1985. Phenology, seed yield and water use of grain legumes grown under different soil water regimes in a semi-arid tropical environment. Field Crops Res., 11: 81–97.

Pandey, R.K., 1983. Effect of leaf and flower removal on seed yield of lentil (*Lens esculenta* (L.)). J. Agric. Sci. Camb., 100: 493–503.

Pandey, R.K., 1984. Influence of source and sink removal on seed yield of chickpea (*Cicer arietinum* L.). Field Crops Res., 8: 159–168.

Pandey, R.K. and Singh, V.B., 1981. Influence of source and sink size on flower drop and seed yield of pigeon pea. Indian J. Agric. Sci., 51: 185–188.

Pandey, R.K., Herrera, W.A.T. and Pendleton, J.W., 1984. Drought response of grain legumes under irrigation gradient. I. Yield and yield components. Agron. J., 76: 549–553.

Parker, M.B. and Boswell, F.C., 1980. Foliage injury, nutrient uptake and yield of soybean as influenced by foliar fertilization. Agron. J., 72: 110–113.

Rawson, H.M. and Constable, G.A., 1981. Gas exchange of pigeonpea: a comparison with other crops and a model of carbon production and its distribution within the plant. In: Proceedings of the International Workshop on Pigeonpeas, Patancheru, A.P., India, December 1980, Vol. 1. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P., India, pp. 175–189.

Sheldrake, A.R., 1984. Pigeonpea. In: P.R. Goldsworthy and N.M. Fisher (Editors), The Physiology of Tropical Field Crops. John Wiley and Sons, New York, NY, pp. 385–417.

Sheldrake, A.R. and Narayanan, A., 1979a. Comparisons of earlier- and later-formed pods of pigeonpeas (*Cajanus cajan* (L). Millsp.). Ann. Bot., 43: 459–466.

Sheldrake, A.R. and Narayanan, A., 1979b. Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). J. Agric. Sci. Camb., 92: 513–526.

Sheldrake, A.R., Narayanan, A. and Venkataratnam, N., 1979. The effects of flower removal on the seed yield of pigeonpeas (*Cajanus cajan*). Ann. Appl. Biol., 91: 383–390.

Singh, U., Jain, K.C., Jambunathan, R. and Faris, D.G., 1984a. Nutritional quality of vegetable pigeonpeas (*Cajanus cajan* (L.) Millsp.). Mineral and trace elements. J. Food Sci., 49: 645–646.

Singh, U., Jain, K.C., Jambunathan, R. and Faris, D.G., 1984b. Nutritional quality of vegetable pigeonpeas [*Cajanus cajan* (L.) Millsp.]: Dry matter accumulation, carbohydrates and proteins. J. Food Sci., 49: 799–802.

Spollen, W.G., Wiebold, W.J. and Scott Glenn, D., 1986. Intraraceme competition in field-grown soybean. Agron. J., 78: 280–283.

Tayo, T.O., 1977. Effect of flower or pod removal on the performance of soybeans (*Glycine max* L.). J. Agric. Sci. Camb., 89: 229–234.

Tayo, T.O., 1980. Compensatory growth and yield of pigeonpea (*Cajanus cajan*) following pod removal at different stages of reproductive growth. J. Agric. Sci. Camb., 95: 487–491.

Tayo, T.O., 1981. Studies on the effects of foliar spray of nutrients on the performance of cowpeas (*Vigna unguiculata* (L.) Walp.). J. Agric. Sci. Camb., 96: 375–388.

Tayo, T.O., 1982. Growth, development and yield of pigeonpea (*Cajanus cajan* (L.) Millsp.) in the lowland tropics. 3. Effect of reduced assimilatory capacity. J. Agric. Sci. Camb., 98: 71–77.

Tayo, T.O., 1983. Effect of sink size on the pod and seed characteristics of soybeans (*Glycine max* (L.) Merr.) in the lowland tropics. J. Agric. Sci. Camb., 100: 285–292.

Tayo, T.O. and Togun, A.O., 1984. The response of pigeon pea (*Cajanus cajan*) to the application of fertilisers. Ann. Appl. Biol., 105: 293–302.

Wiebold, W.J., 1990. Rescue of soybean flowers destined to abscise. Agron. J., 82: 85–88.