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BIOMASS PRODUCTION AND NUTRIENT RECYCLING THROUGH LITTER FROM PIGEONPEA (*CAJANUS CAJAN* L. MILLSP.)

D. L. N. Rao* & H. S. Gill†

Central Soil Salinity Research Institute, Karnal-132001, Haryana, India

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Abstract

*In farm forestry trials for woody biomass production, pigeonpea (*Cajanus cajan *L. Millsp.) showed excellent adaptability to wide variations of inter-row or inter-plant spacings for stem as well as grain yields. The crucial factor determining biomass production was not spacing but planting density. Stem and grain yield increase beyond a density of ca. 20 000 plants/ha was minimal, so this is optimal. Average dry stem yields of 9·1 Mg ha^{-1} were obtained in a wide range of row spacings from 30 to 75 cm without diminishing the grain yields, which averaged 1·2 Mg ha^{-1}. At maturity, inter-row or inter-plant spacings did not significantly influence nutrient concentration in stem or seed. Litter production was 1·9 Mg ha^{-1} and the amounts of nutrients recycled in the growth season were (kg ha^{-1}) 39·5 N, 2·1 P, 7·3 K and 2·1 S.*

Key words: Pigeonpea, alkaline soil, farm forestry, firewood, nutrients, planting density, *Bradyrhizobium*, spacing trial.

Introduction

The biomass (especially firewood and fodder) shortage in developing countries has assumed serious proportions, necessitating urgent research into fast growing, multi-purpose, nitrogen-fixing shrubs for various farm forestry requirements. In the semi-arid tropics, pigeonpea is very widely cultivated for its grain; the woody stems are a valuable by-product for the rural homes, because they make excellent firewood. Suitable varieties have been bred and agronomic practices have been developed for enhanced grain production (Rao *et al.*, 1981), but not specifically for enhancing the woody-biomass component. There is no information on whether planting densities or geometry can be modified to increase woody biomass without sacrificing grain yield and quality, or placing a greater demand on the soil for nutrients. There is also no information on nutrient (N, P, K, S) recycling patterns through litter production. Keeping the above in view, we assessed the effects of varying the inter-row and inter-plant spacings of pigeonpea at a reclaimed alkali (sodic) site, in order to optimize woody biomass production.

*Author to whom correspondence should be addressed.
†Present address: Research Agronomist, Agricultural Research and Advisory Station, PO Box 300, Condobolin, NSW 2877, Australia.

METHODS

Location, soil and climate

The surface soil (0–15 cm) of the experimental site at the CSSRI farm, Karnal (29°N and 76°E), was a typic natrustalf, loam in texture, with sand 48%, silt 32% and clay 20%, and pH 8·5, electrical conductivity 0·24 dS m^{-1} (1:2 soil–water), organic C 0·42%, total N 0·07% and available N, P, K of 45, 8·2 and 40 mg kg^{-1}, respectively. No fertilizers were applied during the 2 years of experimentation. The average maximum temperature (°C) during the growing season of May to November ranged from 26·8 to 38·8 and the minimum from 11·7 to 26·3. Precipitation during the experimental period was 554 mm in 46 rainfall days in the first year; it was 570 mm in 34 days in the second year, out of which 290 mm was received in 14 rainfall days in the first 6 weeks after sowing.

Growth and biomass production

Pigeonpea, var. Pusa-84, was sown in rows in mid-May 1985 in furrows (N–S) in 6 × 6 m plots. The distance between rows was kept at 30, 45, 60 and 75 cm (A, B, C, D, Table 1) in the first year. After emergence, thinning was done to maintain a 30 cm distance between plants. The plant population varied from 11 111 in A to 44 444 plants ha^{-1} in D. The recommended spacing for grain production is 60 × 30 cm, i.e. 55 555 plants/ha (C). One set of treatments was uninoculated, whereas in the other the seeds were treated before sowing with a peat-based inoculant (obtained from Haryana Agricultural University, Hisar) of an efficient local

Table 1. Growth and biomass of pigeonpea as influenced by planting geometry

	Planting distance (cm) Rows	Plants	No. of plants/ha	Height (m)	Girth (mm)	Woody biomass (dry Mg ha^{-1})	Grain (Mg ha^{-1})
Year 1							
A	30	30	111 111	2·8	20·2	9·6	1·21
B	45	30	74 074	2·9	22·5	10·1	1·44
C	60	30	55 555	2·8	21·8	8·9	1·22
D	75	30	44 444	2·9	23·2	7·9	1·05
L.S.D. (P=0·5)				NS	NS	NS	NS
Year 2							
E	60	30	55 555	2·8	20·0	5·5	1·19
F	120	30	27 777	2·8	21·0	4·9	1·29
G	60	90	18 518	2·7	21·3	4·7	1·24
H	120	90	9259	2·5	21·3	2·5	0·74
L.S.D (P=0·05)				NS	0·8	2·1	NS

strain of *Bradyrhizobium*. The eight treatments were replicated four times in a randomized block design. At 1-month intervals, height, basal girth and dry weight of stem and leaves of five randomly selected plants in each plot were recorded. Two irrigations were applied (8 cm each) during summer before the onset of the monsoon rains, after which no irrigation was applied. One inter-row cultivation (hoeing) was done after the first irrigation. On maturity the plants were harvested in mid-November, 27 weeks after sowing. Height, basal girth and partitioning of biomass in the top, middle and bottom one-third portions were recorded. After removing the grains, the woody stems and branches were stacked and left in the field to dry for 2 months, after which biomass was recorded and its moisture content was determined.

Pigeonpea was found to be insensitive to variation in row spacings, so in the second year, 1986, in the same plots the effect of variation in plant spacings was studied. The recommended plant spacing of 30 cm and a wider plant spacing of 90 cm were combined with the recommended row spacing of 60 cm, as well as a wider spacing of 120 cm, in order to achieve a wide range of planting density from 55 555 to 9259 plants ha^{-1} (Treatments E, F, G, H, Table 1). Only one irrigation was applied. Biomass at maturity was measured as in the previous year.

Nutrient content

The concentrations of N, P, K and S were measured in the leaf and stem samples at 5, 9, 13 and 18 weeks after sowing during the first year. At maturity, in both years, the nutrient concentration was measured in the top, middle and bottom one-third portions of the stem and in the seed.

Litter fall and nutrient recycling

In the first year, from 14 weeks after sowing until harvest at 27 weeks, the leaf litter was collected in plastic trays (32 × 23 cm) at two random locations in each plot. Every 4 weeks the litter in the trays was removed, oven-dried and weighed. Nitrogen, P, K and S concentrations were determined at all stages.

RESULTS AND DISCUSSION

Growth and biomass production

There were no differences in growth among various row spacings in height, basal girth or biomass (g/plant) up to 18 weeks. The average values plotted in Fig. 1 show a linear increase in height and girth up to 18 weeks and slow-down thereafter; there was a rapid increase in stem biomass after 9 weeks. The ratio of stem to leaf was similar at various densities and averaged over row spacings was 0·7, 1·2, 4·3 and 3·8 at 5, 9, 13 and 18 weeks, respectively. After 18 weeks, plants at the lowest density (D) had a greater biomass in shoots (+30%) and leaves (+54%) compared to values at the highest density (A); obviously due to less competition. Such an increase was also noted by Hammerton (1971). However, the height and basal girth of plants at maturity among various planting densities was similar, showing that the above increase could be due to increases in girth elsewhere in the plant. The total dry stem and grain yields were similar at various plant densities (Table 1) and averaged 9·1 and 1·2 Mg ha^{-1}, respectively, in the first year. Inoculation with *Bradyrhizobium* did not produce a significant increase in biomass over the uninoculated control, due to a low population of rhizobia (2×10^5 cells/g of peat) in the culture and hence the low number of cells stuck on the seeds ($7{\cdot}5 \times 10^3$/seed) and high soil temperatures (43·2°C at 5 cm and 35·3°C at 15 cm depth), which all had an adverse effect on the establishment and functioning of rhizobial symbiosis with the plant. Hence data presented in Table 1 are the pooled data of uninoculated and inoculated treatments.

In the second year, stem yields were low, due to the adverse effect of a temporary water shortage on

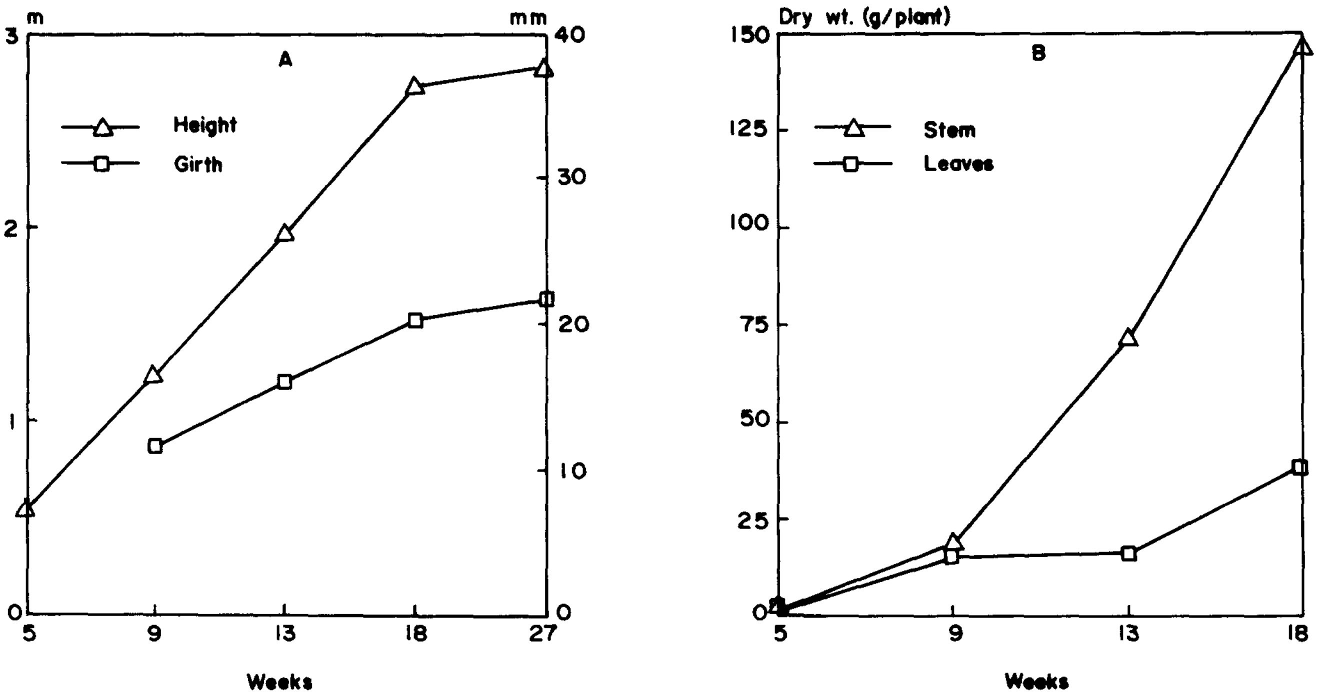

Fig. 1. Height and girth of pigeonpea (A) and biomass accumulation in stem and leaves (B) at different growth stages (average of spacings). Left axis relates to height, right axis to girth in A.

plant growth in the initial stages. Compared with a 30 cm distance between plants, which is normally recommended, increasing the row spacing from 60 to 120 cm produced a non-significant decrease in yield, confirming the first year's trend. Similarly, with the recommended inter-row distance of 60 cm, increasing the distance between plants from 30 to 90 cm did not significantly reduce stem or seed yield (Table 1). The first three row spacings were statistically at par and produced on average 5·0 Mg ha^{-1} of stem and 1·24 Mg ha^{-1} of seed. Since the recommended planting geometry of 60 × 30 cm was included for comparison in the second year as well, it is possible to conclude from the 2 years of experimentation that pigeonpea has an excellent adaptability to variation in inter-row distance (30–120 cm) or inter-plant (30–90 cm) distance. The crucial factor determining biomass production was not spacings but the plant population per hectare. Only at the lowest planting density, when inter-row and inter-plant distances were simultaneously increased, was an appreciable yield decline recorded, due to the low plant population of 9259/ha. So, planting densities can be lowered from the widely used ca. 55 000 plants/ha (Treatment E) to ca. 20 000 plants/ha (G) without sacrificing on grain or woody-stem yields. The results agree with Rao *et al.* (1981), who observed considerable plasticity in the response of pigeonpea to spacings either of the rows (30–120 cm) or plants (2·5–5·0 cm). Akinola and Whiteman (1974) reported that the seed yield or the total forage nitrogen yield increase beyond a planting density of 35 880 plants ha^{-1} was only minimal. Hammerton (1971) showed that with a planting density range of 4300–47 900 plants ha^{-1}, plant height and pod yield increased, although pod yield per plant decreased.

The dried-stem yields averaged 9·1 Mg ha^{-1} in the first year and represent an enormous potential for producing firewood. Comparable yields of 7–10 dry Mg ha^{-1} $^{-1}$ (ICRISAT, 1987) and 11·0 Mg ha^{-1} (Sen, 1958) have been reported by others. Wood distributions in the bottom, middle and top portions of the stem were 47, 31 and 22% in the first year; 36, 37 and 27% in the second year and did not vary much with spacing. The low moisture content of 16% in the air-dried wood, together with the high allocation of biomass (73–78% of the total) to the bottom two-thirds woody portion of the stem, accounts for the good firewood properties of pigeonpea.

Nutrient demand for biomass production

The various row spacings did not influence nutrient concentration in the leaves or stem, or nutrient uptake (Fig. 2 depicts averages of row spacings) during the early growth stages. The concentration of nutrients in stems declined throughout the early growth period of 5–18 weeks, N from 1·81% at 5 weeks to 0·54% at 18 weeks, P from 0·21 to 0·09%, K from 1·6 to 0·73% and S from 0·21 to 0·11%, due to dilution by growth. Leaf-N fell sharply from 4·72% at 5 weeks to 2·98% at 13 weeks and then increased to 3·72% at 18 weeks. Phosphorus and K (0·28 and 1·35%) were maintained at a steady level up to 18 weeks, whilst S declined from 0·39 to

0·29%. The net uptake of nutrients was higher in leaves up to 9 weeks (Fig. 2), after which it increased in the stem in respect of P, K and S, all of which showed a similar pattern of change. However, N uptake was higher in the leaves at all stages; it showed a decline during peak summer (9–13 weeks), which might indicate the adverse effect of high soil temperatures on symbiotic nitrogen fixation. It improved at later stages and was indicative of active nitrogen fixation during the favourable post-monsoon period. In general, the nutrient demand increased sharply after 9 weeks growth.

At maturity, row spacings did not influence nutrient concentration in the top, middle or bottom one-third portions of the stem or in the seed, and the average values are shown in Table 2. The concentration was lowest in the bottom portion of the stem due to woody tissues. Nutrient uptake in the first year is shown in Table 3. The values were generally in the ranges reported by others (Ahlawat, 1981; Sheldrake & Narayanan, 1979). Akinola and Whiteman (1974) also reported that seed N yields were unaffected by density of planting. In the second year, uptake was low in the stem because of reduced

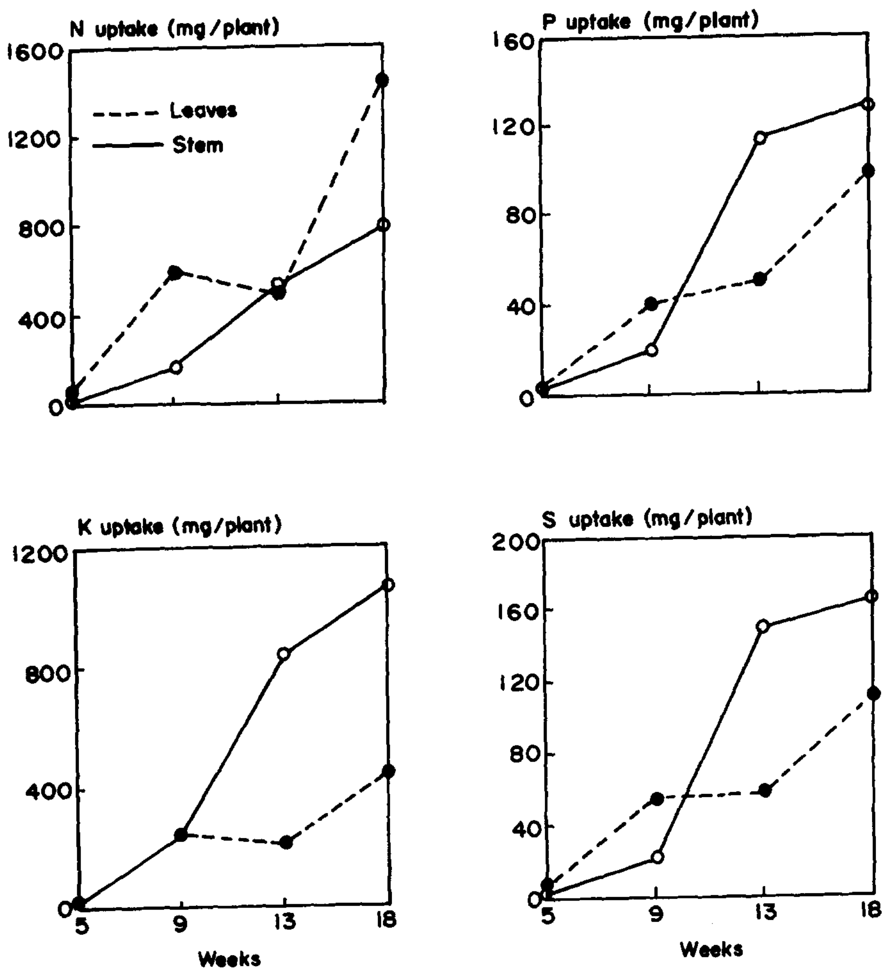

Fig. 2. Uptake of N, P, K and S in stem and leaves of Pigeonpea (average of spacings) at different growth stages.

Table 2. Nutrient concentration (%) in plant parts of pigeonpea at maturity in years 1 and 2 (average of spacings)

Plant part	N	P	K	S
Stem				
Top	0·84, 0·85	0·11, 0·08	0·58, 0·90	0·13, 0·20
Middle	0·69, 0·52	0·08, 0·07	0·56, 0·71	0·09, 0·13
Bottom	0·59, 0·43	0·09, 0·06	0·52, 0·68	0·09, 0·10
Seed	3·46, 3·20	0·39, 0·35	1·44, 1·76	0·41, 0·38

Table 3. Nutrient uptake (kg ha^{-1}) by pigeonpea as influenced by planting geometry

Planting geometry	Stem				Seed			
	N	P	K	S	N	P	K	S
Year 1								
A	66·2	8·7	53·4	9·8	42·9	4·8	17·5	5·0
B	69·7	9·2	56·2	10·3	50·3	5·6	20·7	6·0
C	57·3	8·1	49·5	9·0	42·0	4·8	17·6	5·1
D	57·3	7·2	44·0	8·0	35·5	4·1	15·2	4·4
L.S.D.(P=0·05)	NS	—	—	—	NS	—	—	—
Year 2								
E	35·0	4·2	45·2	7·9	38·5	4·3	21·2	3·9
F	25·9	3·1	32·7	5·6	39·8	4·3	21·8	5·0
G	27·2	3·0	36·3	6·2	40·0	4·3	21·5	5·8
H	14·2	1·9	18·6	3·6	24·6	2·7	13·6	2·3
L.S.D.(P=0·05)	11·5	NS	14·0	1·6	NS	NS	NS	NS

Table 4. Amount of litter fall and nutrients recycled by pigeonpea (average of row spacings)

	Weeks after sowing			Total
	14–18	18–22	22–27	
Litter DM (Mg ha^{-1})	0·62	0·91	0·38	1·9
Nutrients (kg ha^{-1})				
Nitrogen	9·6	20·0	9·9	39·5
Phosphorus	0·5	1·1	0·5	2·1
Potassium	2·0	3·4	1·9	7·3
Sulphur	0·6	1·0	0·5	2·1

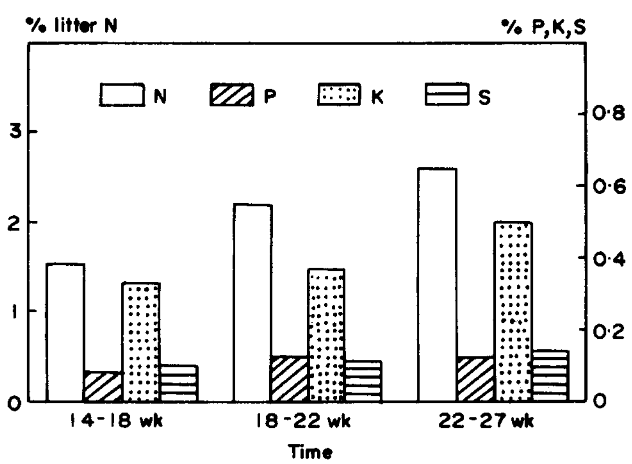

Fig. 3. Nutrient (N, P, K and S) concentration in litter of Pigeonpea (average of spacings) at different growth stages.

vegetative growth, but was unaffected in the seed. Protein contents (N × 6·25) of grains in treatments E and G were similar, around 20·2%. In conclusion, the same amount of woody biomass can be produced with ca. 20 000 plants/ha (G, Table 1)) as with ca. 55 000 plants/ha (E), but with a lower nutrient demand (Table 3) and no impairment of grain quality.

Litter production and nutrient recycling

The pattern of leaf fall showed a seasonal periodicity, but the amount recycled was not influenced by row spacings (Table 4). Litter fall began 3 months after planting, reached a peak in the second month (mid-September to mid-October) and totalled 1·9 Mg ha^{-1} in the 3 months after the beginning of leaf fall. Litter yields of 2·2 Mg ha^{-1} (Sheldrake & Narayanan, 1979) for a medium-duration variety and 7·2 Mg ha^{-1} (Sen, 1958) for a long-duration variety have been reported.

Nutrient concentration in litter was unaffected by row spacing at any of the stages, average seasonal values for N, P, K and S were 2·1, 0·11, 0·40 and 0·12%, respectively, but they exhibited a seasonal increase (Fig. 3), being about 50% higher in the third month than in the first. The amount of nutrient recycled reached a peak in the second month (Table 4). Sen (1958) reported 100 kg N ha^{-1} in litter, whereas Kumar Rao *et al.* (1981) reported 18 kg N ha^{-1}. In this study, the total N in the litter, stem and seed was 39·5, 62·6 and 42·7 kg ha^{-1}, totalling 144·8 kg. Thus 27% of the total N in the pigeonpea crop was returned to the soil. Hence, growing pigeonpea for firewood has the additional benefit of considerable enrichment of the soil with nutrients of direct benefit to subsequent crops grown in rotation.

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