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Growth, Light Interception and Radiation use Efficiency Response of Pigeon pea (*Cajanus cajan*) to Planting Density in Southern Ethiopia

¹Walelign Worku and ²Walelign Demisie

¹School of Plant and Horticultural Sciences, Hawassa University, Hawassa, Ethiopia, Canada

²Zhejiang University, Huajia Chi Campus, Hang Zhou, Postal Code 310029, China

Abstract: Planting density is a vital management tool that could be used to enhance productivity. A field experiment was conducted to examine the response of two pigeon pea varieties (ICPL 87091 and ICP 15027) to five planting densities (166666, 200000, 250000, 333333 and 500000 plants ha⁻¹). A split plot design with variety as main plot factor and planting density as sub plot factor was used. Samples were taken every two weeks until physiological maturity starting from 30 Days after Sowing (DAS). The upper two densities, 333333 and 500000 plants ha⁻¹, had greater Leaf Area Index (LAI) and fractional interception (f) during most of the growth period and attained full interception at 105 DAS. The remaining three densities had lower LAI and f and did not attain full interception. Cumulative Intercepted Photosynthetically Active Radiation (CIPAR), extinction coefficient (k) and Radiation Use Efficiency (RUE) increased with rising planting density though moderately for the later. There was a positive linear relationship between dry matter production per area and planting density. Dry matter was significantly correlated with LAI (r = 0.90), CIPAR (r = 0.98) and RUE (r = 0.88). The two varieties had similar productivity potential with similar leaf area indices, CIPAR, k and RUE values. The RUE values obtained were 1.81 g MJ⁻¹ PAR for variety ICPL 87091 and 1.86 g MJ⁻¹ PAR for variety ICP 15027. Because of pigeon pea's adaptation to drought, it will be useful to study its response to planting density under contrasting moisture levels.

Key words: Density, extinction coefficient, growth, light interception, radiation use efficiency

INTRODUCTION

Currently, pigeon pea ranks fifth among nine pulses in the world and is produced on 4.7 million ha of land with Asia, the leading producer, supplying 90% of world production followed by Africa with 9.3% (FAO, 2008). In Ethiopia, perennial pigeon pea is largely limited around homesteads and farm borders in the southern part of the country. However, due to the ever increasing uncertainty in amount and distribution of rain fall in the country, pigeon pea will be an important alternative crop because of its drought tolerance. Pigeon pea is a hardy, widely adapted and drought tolerant crop with a large temporal variation (90-300 days) for maturity allowing it to be grown in a range of environments and cropping systems (ICRISAT, 2010).

The review of Odeny (2007) indicated that the crop is under exploited in Africa compared to its potential. She also suggested that more than any other legume adapted to the region, pigeon pea uniquely combines optimal nutritional profiles, high tolerance to environmental stresses, high biomass productivity and nutrient and moisture contributions to the soil.

In spite of its large yield potential of up to 4.6 t ha⁻¹ (Kimani, 2001), its average productivity is one of the lowest, 0.84 t ha⁻¹ (FAO, 2008). One of the reasons is low research emphasis given to this crop compared to other more established pulses. Moreover, poor production practices such as low plant densities, low soil fertility, insufficient weeding and insufficient/inappropriate use of fungicides and herbicides are other constraints (Odeny, 2007).

Thus, in order to fully exploit and popularize the crop there is a need to conduct research aimed at understanding the crop better and identifying optimum agronomic practices in different prospective production areas. Diversification of pigeon pea into new production systems requires knowledge of its yield potential, production risks and returns in diverse climatic environments (Robertson *et al.*, 2001). Planting density and row spacing are powerful management tools whereby a grower can strongly influence early season light interception and crop growth (Ball *et al.*, 2000). Both cumulative intercepted radiation and radiation use efficiency can be modified by crop management factors.

For instance, Worku and Skjelvåg (2006) in common bean (*Phaseolus vulgaris*) found that 49 and 41% of the variation in productivity of common bean due to water stress was explained by differences in amount of intercepted radiation and radiation use efficiency, respectively. Also, Patel *et al.* (2000) from a sowing date study ascribed differences in pigeon pea dry matter production primarily in amount of intercepted light and to a lesser extent to radiation use efficiency. Bell *et al.* (1987) indicated that the increase in biological yield of peanut (*Arachis hypogaea*) with increasing density was primarily attributed to differences in the amount of light intercepted while no density effect was detected on radiation use efficiency.

Previous agronomic research on pigeon pea focused on intercropped pigeon pea. However, sole pigeon pea production may play an increasingly greater role due to its ability to grow in stressful environments. As suggested by Lemma *et al.* (2009) underutilized crops such as pigeon pea will be useful to sustain food production in the tropics and subtropics where amount and distribution of rainfall is more likely to be unfavorable due to climate change. There is a great potential for expansion of the crop in the semi-arid regions of Africa where it would also counteract the declining soil fertility (Hillocks *et al.*, 2000). Pigeon pea research in Ethiopia was started early in the 1970s though it never attained the status of other pulses due to interruption and change of focus. Recently interest was renewed on pigeon pea as one of the lowland pulse crops mandate by introducing short duration cultivars. Thus, as part of the research effort, this study was conducted to examine responses of pigeon pea in terms of growth, light interception and radiation use efficiency of potential pigeon pea varieties to different planting densities.

MATERIALS AND METHODS

Experimental site: The experiment was carried out during the 2006 cropping season at the research field of Hawassa Agricultural Research Center, southern Ethiopia. The site lies 7°04'N and 38°31'E and at an altitude of 1660 m.a.s.l. The soil is fluvisol type with a sandy clay loam texture. The soil had a pH of 6.75 and contained a total N of 0.056%, available phosphorus of 63.65 ppm and 1.76% organic carbon. The total annual rainfall for 2006 was 1198 mm of which the crop received 655 mm during its growing period. The growth period mean minimum and maximum temperatures were 14.0 and 25.7°C, respectively. Soil and weather conditions were in the suitable range for optimum pigeon pea production (Westphal, 1974). Weather records were obtained from National Meteorological Agency (NMA, 2006).

Treatments and experimental design: A total of 10 treatments were used from a factorial combination of two factors, five planting densities (166666, 200000, 250000, 333333 and 500000 plants ha⁻¹) and two pigeon pea varieties (ICPL 87091 and ICP 15027). The five densities were obtained by adjusting the inter-row spacing while keeping the intra-row spacing similar at 10 cm. The inter-row spacings for the five densities from the highest to the lowest were 60, 50, 40, 30 and 20 cm, respectively. A split plot design with three replications using planting density as sub plot factor and variety as main plot was used.

The two varieties differ in their morphological characters. Variety ICPL 87091 has determinate growth habit with erect plant type and with cream colored seed. The variety ICP 15027 has indeterminate growth habit with semi spreading growth habit and with reddish brown seeds. Both varieties are grouped under early maturity group with 120 days growth duration and were introduced from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Kenya.

Crop management: The land for the experiment was prepared in June 2006 and sowing of the experiment was done on 8th of July 2006. Phosphorus and nitrogen fertilizers were applied during sowing in the form of diammonium phosphate at 100 kg ha⁻¹ to give 18 kg N and 20 kg P ha⁻¹. Synthetic insecticide, lambda cyhalothrin (Karate[®] 17.5 EC) (Zeneca Ltd., Fernhurst, Haslemere, UK), was applied at the recommended rate of 1 L ha⁻¹ of the commercial formulation, containing 17.5 g a.i. Spray applications were done twice, at the start of flowering and 15 days after first spray. Three hand weeding were carried out at 30 days interval starting from 30 days after sowing (DAS). All other necessary cultural practices were accomplished manually as required, during the growing period.

Data collection: Days to emergence were recorded as the number of days from sowing to 50% emergence. Days to flowering were taken as the number of days from emergence to 50% first flower production. Days to maturity were recorded when 75% of the pods in a plot turned brown.

Samples of four plants from each plot were taken starting from 30 Days after Sowing (DAS) to determine plant height, leaf area, leaf area index and dry matter. Sampling continued for nine sequential harvests at two weeks interval up to physiological maturity. Leaf area was measured using area meter (LI-3000A Li-Cor, Lincoln, USA) at every sampling by stripping all the leaves. The LAI was computed as a ratio of leaf area of plants to ground area occupied by the sample plants. Dry matter

was determined by drying the above ground parts of the four sampled plants at 70°C for 48 h in a forced air ventilated oven.

Fraction of incoming PAR intercepted by the canopy was recorded by measuring ground cover at two weeks interval using grids of 120×40 cm, 100×40 cm, 80×40 cm, 60×40 cm and 40×40 cm divided in to 100 equal rectangles for spacings of 60×10, 50×10, 40×10, 30×10 and 20×10 cm, respectively. Every two weeks, the grids were put between rows and three measurements were taken at each plot by counting the number of rectangles more than half filled with green leaf. The fraction of intercepted PAR (f) by the canopy was determined assuming 1:1 relationship between percentage ground cover and percentage of intercepted radiation (Spitters, 1990; Tsegaye and Struik, 2003). Amount of incoming PAR intercepted at ith sampling date was calculated as:

$$IPAR_i = PAR_i \times GC_i$$

Where:

IPAR_i = Amount of incoming PAR intercepted at ith sampling date

PAR_i = Recorded PAR above the canopy at ith sampling date

GC_i = Ground cover of the crop at ith sampling date

The Cumulative Intercepted PAR (CIPAR) during the growth period was determined by summing up the fortnightly intercepted radiation as follows:

$$CIPAR = \sum_n [(IPAR_{n-1} + IPAR_n) / 2] (t_n - t_{n-1})$$

where, IPAR_{n-1} is IPAR at sampling time t_{n-1} and IPAR_n is IPAR at sampling time t_n.

Light quantity was continuously measured on site using a quantum sensor and a microvolt integrator (Delta-T Devices, England).

Canopy extinction coefficient (k) was determined from the slope of the regression line between ln (1-f) and Leaf

Area Index (LAI) (Squire, 1990). The radiation use efficiency was calculated as slope of the linear relationship, forced through the origin, between cumulative intercepted PAR and total dry matter (Muchow *et al.*, 1993).

Statistical analyses: Data were analyzed using the general linear model procedure of the SAS statistical software appropriate for the design. Means were separated using Fisher's Least Significant Difference (LSD) test at p<0.05. Pearson's simple correlation coefficients were used to analyze correlations between selected parameters using treatment mean values (n = 7).

RESULTS AND DISCUSSION

Planting density influenced most of the observed parameters including plant height, canopy size, radiation interception, radiation use efficiency, extinction coefficient and dry matter. Dry matter per plant, leaf area per plant and plant height decreased with rising planting density. On the other hand, the reverse was true for leaf area index, fractional interception, cumulative intercepted radiation, extinction coefficient, radiation use efficiency and dry matter per area. The indeterminate cultivar, ICP 15027, was longer in height and matured later than the determinate cultivar ICPL 87091. However, the two cultivars showed similar performance in interception and use of radiation and dry matter production.

Phenology: Planting density influenced neither days to flowering nor days to maturity (Table 1). On the other hand, days to maturity were extended to a maximum of 164 days though both varieties were expected to mature in 120 days. This happened because of extension of the rainy season which led to higher plant water status that might have delayed maturity and enhanced vegetative growth. For instance, well watered cowpea (*Vigna unguiculata*) plants had an extended growth duration compared to dry treatments (Lemma *et al.*, 2009). However, the observed

Table 1: The effect of planting density and variety on crop phenology, growth and cumulative intercepted PAR (CIPAR) of pigeon pea

Treatments	Days to flower	Days to mature	Plant height (cm)	Dry matter (g plant ⁻¹)	Dry matter (g m ⁻²)	CIPAR (MJ m ⁻²)
Density (plants ha⁻¹)						
166666	103.67	160.30	88.10 ^a	51.10 ^a	525.90 ^a	329.10 ^a
200000	103.83	161.30	88.00 ^a	46.00 ^{ab}	578.70 ^a	364.40 ^d
250000	103.67	161.30	87.40 ^{ab}	37.70 ^{bc}	657.70 ^b	405.10 ^e
333333	103.83	160.50	82.70 ^{bc}	36.90 ^c	721.20 ^c	444.10 ^f
500000	102.67	160.17	81.40 ^c	22.70 ^d	1010.70 ^d	538.30 ^f
LSD _{0.05}	ns	ns	5.19	8.33	62.52	17.76
Variety						
ICPL 87091	103.20	157.90 ^b	78.30 ^b	40.80	709.20	432.10
ICP 15027	103.80	163.50 ^a	92.70 ^a	37.00	688.40	400.30
LSD _{0.05}	ns	3.88	3.73	ns	ns	ns

Means with the same letter within columns are not significantly different at α≤0.05 level, ns: Not significant

30 to 36% increase in duration may not be ascribed entirely to moisture status. It could probably be attributed to the interplay of genotype and environmental factors. Crop duration in pigeon pea is determined by interactions between photoperiod, temperature and genotype (ICRISAT, 1991).

The two varieties required similar number of days to flower (103) but varied significantly for days to physiological maturity (Table 1). The determinate variety ICPL 87091 matured earlier (158 days) than the indeterminate variety ICP 15027 which took 164 days. The possible reason for the differences in maturity between the two varieties could be the variation in growth habit. The variation is only in the duration of the reproductive period in which the vegetative growth of the determinate is terminated after initiating flower buds while that of the indeterminate continued.

Plant height: Plant height decreased with increasing planting density, generally (Table 1). The longest plant height was measured from the lower densities (166666 and 200000 plants ha⁻¹), while the shortest plant height was recorded under the highest planting density (500000 plants ha⁻¹). This could be attributed to the increased competition for growth limiting factors at higher plant densities which might have resulted in reduced growth. Similarly, Roche *et al.* (2003) reported reduction of plant height with higher planting density in cotton. On the other hand, Saiful Islam *et al.* (2002) in pea (*Pisum sativum*) and Sener *et al.* (2004) in maize (*Zea mays*) observed an increase in height with rising density most probably as an adaptation mechanism to increased level of mutual shading. In this experiment, the level of shading may not have been severe enough to trigger this mechanism and override the competition effect.

The indeterminate variety ICP 15027 was taller than the determinate variety ICPL 87091 with their respective mean heights of 93 cm and 78 cm (Table 1). The difference in height arose due to differences in growth habit of the

two varieties. This result agreed with the findings of Egli *et al.* (1985) who reported that plant height of indeterminate varieties of soybean (*Glycine max*) to be higher than determinate ones. They suggested that the reason for the variation in height between the two growth habits was because most of the vegetative growth during flowering and pod set occurred on branches on determinate types while it was on the main stem with indeterminate types.

Leaf area per plant and leaf area index: Leaf area per plant declined with increasing planting density (Table 2). Maximum leaf area per plant was obtained at 120 DAS across all planting levels. At this date, the maximum leaf area per plant (1604 cm²) was observed at a plant density of 166666 plants ha⁻¹ while the minimum (863 cm²) was at the highest density (500000 plants ha⁻¹). The possible reason could be reduced resource availability for each plant with rising plant density limiting the amount of assimilates available for leaf development.

The determinate variety ICPL 87091 showed relatively higher leaf area per plant than the indeterminate variety ICP 15027 during most of the growth period though the differences were significant only at 30 and 135 DAS (Table 2). On the other hand, variety ICP 15027 showed a tendency of leaf area increment towards the later growth period during the last two samplings probably owing to its indeterminate nature. The maximum leaf area was obtained at 120 DAS in both varieties.

Leaf area indices increased with increasing density, generally (Fig. 1a). The highest density had the largest leaf area index consistently except the last two samplings where it was not different to the next highest density. The same trend was observed for the next density (333333). Narrowing of differences in LAI among densities towards the end may be attributed to higher rates of senescence of leaves due to shading from larger densities. Following the trends of leaf area per plant, maximum LAI was attained at 120 DAS for all densities considered. There was no

Table 2: Leaf area per plant of pigeon pea at different days after sowing (DAS) as affected by planting density and variety

Treatments	Leaf area at different DAS (cm ²)									
	30	45	60	75	90	105	120	135	150	
Density (plants ha⁻¹)										
166666	13 ^{ab}	28 ^a	208 ^a	492 ^a	787 ^a	1476 ^a	1604 ^a	1137 ^a	606 ^a	
200000	13 ^a	27 ^a	193 ^b	467 ^{ab}	696 ^b	1285 ^b	1412 ^b	917 ^b	552 ^b	
250000	12 ^{bc}	24 ^b	189 ^{bc}	439 ^b	631 ^c	1124 ^c	1191 ^c	798 ^c	471 ^c	
333333	11 ^c	22 ^b	188 ^{bc}	378 ^c	590 ^{cd}	964 ^d	1040 ^d	638 ^d	390 ^d	
500000	11 ^c	22 ^b	177 ^c	327 ^d	538 ^d	769 ^e	863 ^e	458 ^e	281 ^e	
LSD _{0.05}	1.1	2.5	13.0	40.8	62.2	126.7	114.0	92.0	41.1	
Variety										
ICPL87091	13 ^a	26	195	429	659	1201 ^a	1248	707 ^b	438	
ICP15027	12 ^b	24	187	412	637	1046 ^b	1196	872 ^a	480	
LSD _{0.05}	1.2	ns	ns	ns	ns	50.0	ns	113.7	ns	

Means with the same letter within columns are not significantly different at $\alpha \leq 0.05$ level, ns: Not significant

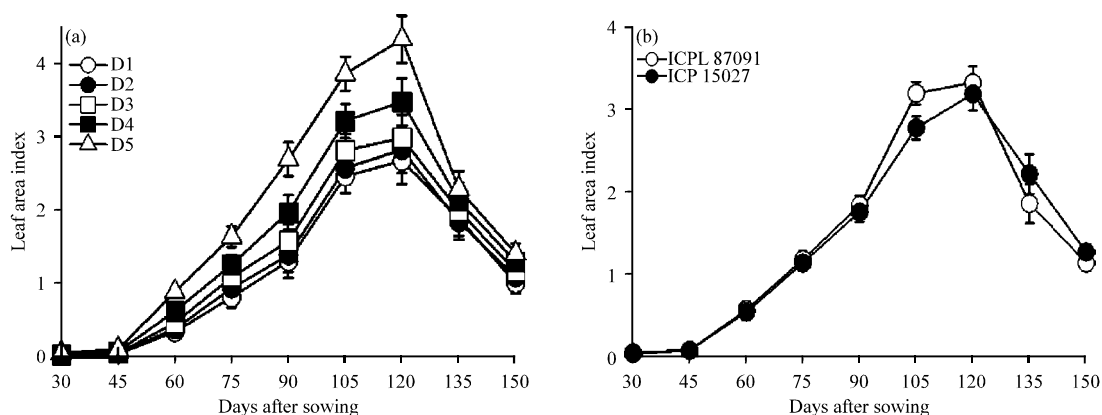


Fig. 1(a-b): Leaf area index of pigeon pea at different days after sowing as influenced by (a) Planting density and (b) Variety, D1: 166666, D2: 200000, D3: 250000, D4: 333333, D5: 500000 plants ha⁻¹

statistically significant difference between the two lowest densities at all samplings. Leaf area index increased slowly until 45 DAS and then exponentially until 105 DAS, irrespective of planting density. It leveled off and then declined starting from 120 DAS possibly due to senescence, abscission and ontogeny of leaves. In spite of decreasing leaf area per plant with rising planting density, LAI has showed an opposite trend because of greater leaf number contributions from the larger number of plants per area. As a result LAI increased with rising planting density.

Leaf area index of the two varieties showed no significant difference except at 105 and 135 DAS (Fig. 1b). The indeterminate variety ICP 15027 tended to produce higher leaf area indices at later growth periods owing to its indeterminate growth. Maximum leaf area indices were obtained at 120 DAS which was the pod setting stage, in both varieties and thereafter LAI of the varieties declined. This result agreed with the findings of Patel *et al.* (2000) who reported high LAI and light interception coinciding with the podding phase in pigeon pea. The maximum leaf area indices, averaged over densities, of the determinate and indeterminate varieties were 3.3 and 3.2, respectively. Canopy size could vary depending on growth classes. Patel *et al.* (2000) reported, in a favorable year, a maximum leaf area index of about three for a short duration cultivar while more than six was obtained for long duration indeterminate cultivars.

Radiation interception and radiation use efficiency:

Cumulative Intercepted Photosynthetically Active Radiation (CIPAR) increased with rising planting density (Table 1). The highest CIPAR (538 MJ m⁻²) was observed at the highest planting density (500000 plants ha⁻¹) while the smallest (329 MJ m⁻²) was from the lowest density

(166666 plants ha⁻¹) showing a 39% difference. The reason for increasing of CIPAR with rising planting density is due to higher fractional interception (f) arising from the greater leaf area indices under the higher densities. Increase in plant density increased f at each of the samplings (Fig. 2a). The highest density (500000 plants ha⁻¹) had consistently greater f during the entire growing period and reached full interception earlier, at 105 DAS. The next density also had greater f during most of the growing period and attained full interception at 105 DAS. The remaining three lower densities had smaller f and never attained full interception. Similar findings were reported by Rowden *et al.* (1981) at four densities except that all of the densities which, were between 2×10⁵ and 1×10⁶ plants ha⁻¹ attained full interception owing to the greater densities. In Australia, Jettner *et al.* (1998) working on faba bean (*Vicia faba*), observed that high sowing rates resulted in significantly earlier canopy closure, larger green area indices, more radiation absorption and dry matter accumulation particularly during the early vegetation stages than treatments where a low plant density was established. Moreover, Silim and Saxena (1992) in faba bean and Bell *et al.* (1987) in peanut, observed an increased intercepted radiation with rising planting density and ascribed variation in total dry matter among densities primarily to differences in intercepted radiation. Because of senescence, abscission and ontogeny of leaves, leaf area index declined at the last two samplings which, in turn decreased the fractional interception.

Differences in Cumulative Intercepted Photosynthetically Active Radiation (CIPAR) were not significant between the two varieties (Table 1) following a similar fractional interception (f) trend during the various growth phases (Fig. 2b). Fractional interception increased

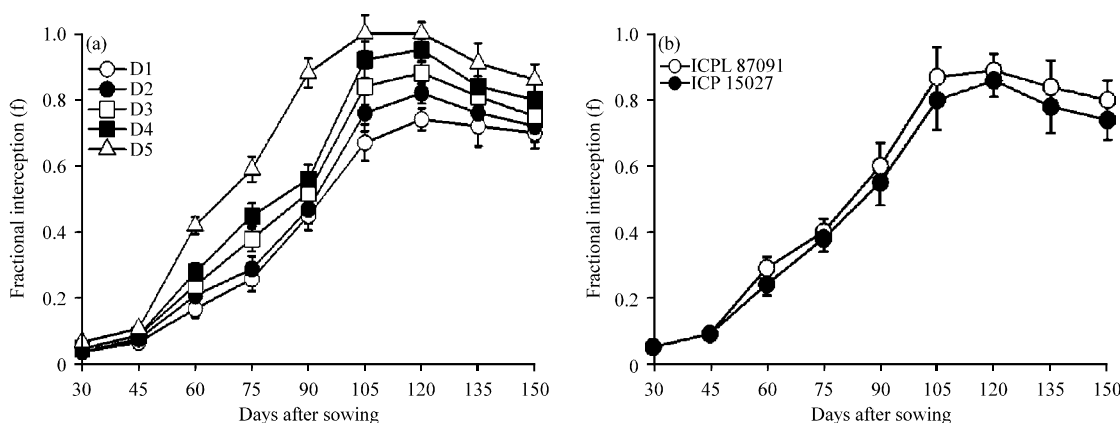


Fig. 2(a-b): Fractional interception (f) of pigeon pea at different days after sowing as influenced by (a) Planting density and (b) Variety, D1: 166666, D2: 200000, D3: 250000, D4: 333333, D5: 500000 plants ha⁻¹

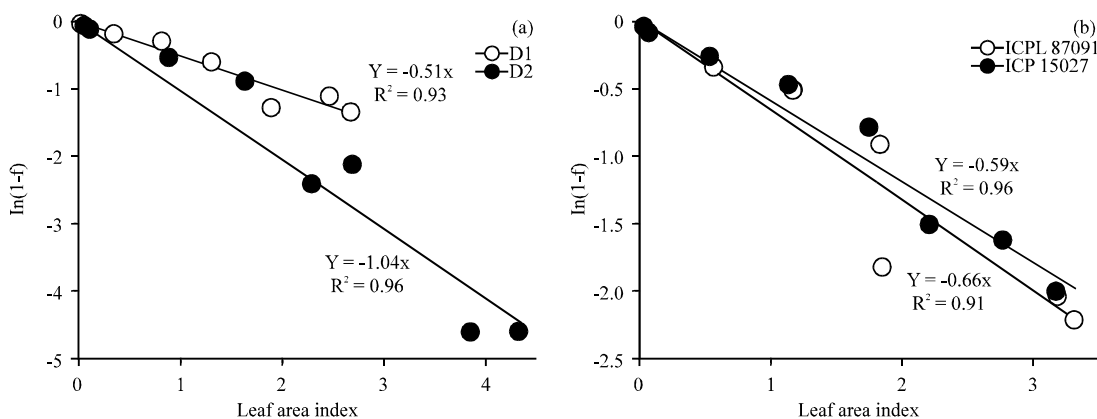


Fig. 3(a-b): Relationship between leaf area index and ln(1-f) at (a) Two densities and (b) Two varieties, D1: 166666 plants ha⁻¹, D2: 500000 plants ha⁻¹

exponentially between 45 and 105 DAS and then declined following the trends of the leaf area index. The similarity of fractional interception between the two varieties could be attributed to the similarity of their leaf area indices through most of the growing season and their comparable extinction coefficients (k) (Table 3). Because fractional interception (f) is influenced mainly by green leaf area duration and canopy extinction coefficient (k) (Thomson and Siddique, 1997).

The extinction coefficient (k) values increased with rising planting density which varied between 0.51±0.03 for the highest density and 1.03±0.07 for the lowest density (Table 3, Fig. 3a). There was an increasing tendency for horizontal leaf orientation as planting density raised. Gimenez *et al.* (1994) did not observe differences in k between two densities varying by 50% (57×10³ vs. 29×10³ plants ha⁻¹), in sunflower (*Helianthus annuus*). On the other hand, Squire (1990) suggested that a rise in density might cause leaves to have vertical

orientation thereby improving mean RUE. However, it is important to note that in spite of the high densities, the maximum leaf area index was not large (4.3) in this experiment leading to mild mutual shading. The reason for the increasingly horizontal orientation with rising density can not be clearly established.

The two varieties have shown a more or less similar k values (Table 3, Fig. 3b). The mean k values averaged over densities were 0.66±0.05 for ICPL 87091 and 0.59±0.03 for ICP 15027. These values are comparable with the findings of Nam *et al.* (1998) who reported that the k values among six pigeon pea genotypes ranged from 0.41 to 0.65 under irrigated conditions and to those of Patel *et al.* (2000) who reported k values of 0.65 and 0.66 for two short stature cultivars. Robertson *et al.* (2001) reported k values between 0.55 and 0.90 among nine genotypes representing three growth habit groups indicating the possibility of variability among genotypes.

Table 3: The effect of planting density and variety on canopy extinction coefficient ($k \pm SE$) and radiation use efficiency ($RUE \pm SE$) of pigeon pea

Treatments	Extinction coefficient (k)	(R^2) ^a	RUE ($g MJ^{-1} PAR$)	(R^2) ^a
Density (plants ha^{-1})				
166666	0.51±0.03	0.93	1.77±0.07	0.98
200000	0.59±0.04	0.94	1.77±0.07	0.97
250000	0.67±0.04	0.94	1.78±0.06	0.98
333333	0.76±0.06	0.91	1.80±0.07	0.98
500000	1.04±0.07	0.93	1.99±0.05	0.99
Variety				
ICPL 87091	0.66±0.05	0.91	1.81±0.07	0.98
ICP 15027	0.59±0.03	0.96	1.86±0.06	0.99

^aThe relationships are significant at $p \leq 0.001$

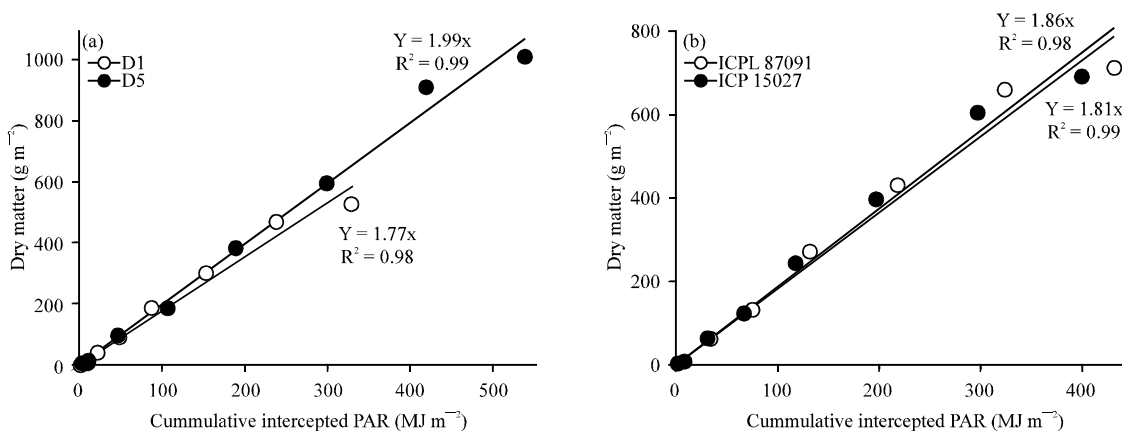


Fig. 4(a-b): Relationship between above ground total dry matter production and cumulative intercepted PAR (a) At two planting densities and (b) Two varieties, D1: 166666, D2: 500000 plants ha^{-1}

Radiation Use Efficiency (RUE) moderately increased with a rise in planting density (Table 3, Fig. 4a). The highest RUE ($1.99 g MJ^{-1} PAR$) was obtained at the highest planting density ($500000 plants ha^{-1}$) and the lowest ($1.77 g MJ^{-1} PAR$) was recorded at the smallest planting density ($166666 plants ha^{-1}$). Tsubo *et al.* (2003) observed that the higher the planting density the greater was the RUE in maize while no difference was observed for common bean. In peanut, Bell *et al.* (1987) did not find a response to planting density and indicated that differences in total biomass were ascribed to differences in amount of intercepted light. Also, Rosenthal *et al.* (1993) did not detect differences in RUE among densities in sorghum (*Sorghum bicolor*) ranging between 5×10^4 and $26 \times 10^4 plants ha^{-1}$. However, they did not detect significant difference in dry matter among the sorghum densities, either. On the other hand, RUE of sunflower was higher for plants grown under greater density ($57 \times 10^3 plants ha^{-1}$) and high nitrogen compared to low density ($29 \times 10^3 plants ha^{-1}$) while differences were minimal between densities under low nitrogen (Gimenez *et al.*, 1994). The detrimental effect of planting density on the N content of leaves may have been mitigated by the nitrogen fixing ability of pigeon pea, in

this study. Moreover, the trend in dry matter partitioning with rising planting density was in favor of the vegetative parts compared to reproductive structures and this may have contributed for the increased RUE observed in this experiment.

The determinate variety ICPL 87091 had RUE of $1.81 g MJ^{-1} PAR$ while the indeterminate variety ICP 15027 gave $1.86 g MJ^{-1} PAR$, showing similar efficiencies (Table 3, Fig. 4b). The RUE values obtained in this study were in the range reported by Nam *et al.* (1998) who found RUE of different pigeon pea genotypes varying from 1.70 to $2.19 g MJ^{-1} PAR$ under well watered conditions. However, the differences they reported were irrespective of growth habit with mean RUE of $1.91 g MJ^{-1} PAR$ for the indeterminate and $1.90 g MJ^{-1} PAR$ for the determinate. Also, Patel *et al.* (2000) obtained a mean pigeon pea RUE of $1.71 g MJ^{-1} PAR$ at optimum sowing date. Differences in RUE among genotypes may vary depending on the extent of the genetic variability existing among the genotypes. Similar to our results, Patel *et al.* (2000) in pigeon pea, Rosenthal *et al.* (1993) in sorghum and Silim and Saxena (1992) in faba bean did not find significant differences in RUE between genotypes. It seems that variation in RUE among genotypes is not

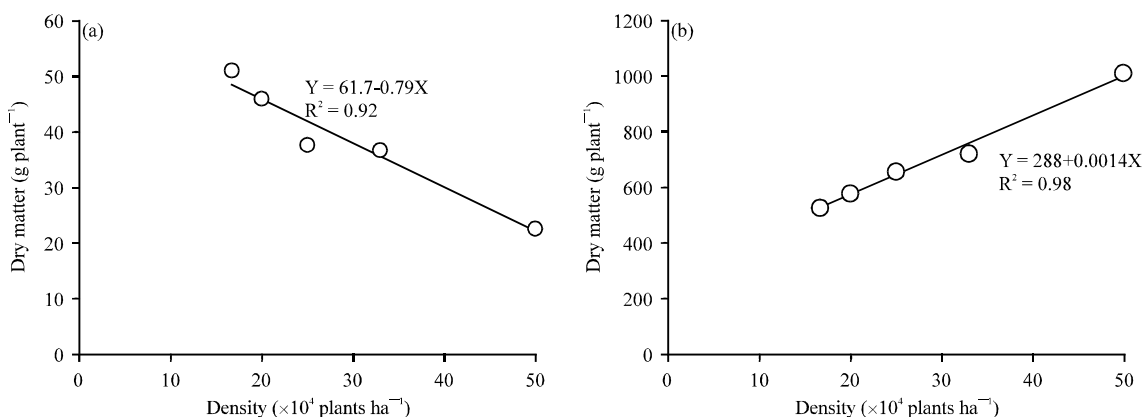


Fig. 5(a-b): Relationship between planting density and dry matter (a) Per plant and (b) Per area

extensive. Moreover, it is more likely to be detected among genotypes which show significant variation in productivity as is the case in Nam *et al.* (1998) among pigeon pea genotypes.

Dry matter: Increasing plant density significantly decreased dry matter per plant (Table 1) with a linear relationship (Fig. 5a). The lowest density (166666 plants ha⁻¹) produced the largest dry matter per plant (51 g) and the highest density (500000 plants ha⁻¹) gave the smallest dry matter per plant (23 g) (Table 1). On the other hand, dry matter per area increased with rising planting density (Table 1). There was also a linear relationship between dry matter per area and planting density (Fig. 5b). Thus, further increase in density should increase total biomass production by raising leaf area index and improving light interception. Greater dry matter was produced at increasing densities due to larger leaf area index, greater light interception and better RUE at these densities. Dry matter was positively correlated with LAI ($r = 0.90$), CIPAR ($r = 0.98$) and RUE ($r = 0.88$). Leaves determine dry matter production through their ability to intercept photosynthetically active radiation (Patel *et al.*, 2000). The increment of biomass with rising planting density is due to the increasing number of plants per unit area which had more than compensated for the decrease in biomass produced per plant. The two varieties produced similar amount of dry matter on per plant and per area basis. This could be attributed to absence of differences in their maximum leaf area indices, leaf area per plant, cumulative intercepted radiation and radiation use efficiency.

CONCLUSION

The experiment showed that planting density of pigeon pea can be used as an important management tool to improve leaf area index, light interception, radiation use

efficiency and hence productivity. As a drought tolerant crop, pigeon pea could be a strategic crop for drier environments. Thus, it will be worthwhile to investigate the response of the crop to planting density under contrasting moisture levels. The two varieties did not differ in growth, light interception and radiation use efficiency except small difference in growth duration. Thus, the varieties could be used interchangeably in the area. Maturity of pigeon pea may vary widely from location to location and further study on the influences of environmental and genotypic factors on the effect of maturity period needs to be addressed because it will be useful for the cropping calendar of the farmer.

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