# Effectof Plant Density and Spatial Arrangement on Seed Yield of Cowpea (*Vigna unguiculata* (L.) Walp.)[1]

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*Abstract.* In spacing experiments at Ibadan, western Nigeria, cowpea cv. Prima, an erect, determinate and low branching type showed a consistently higher optimum density than 'Pale Green', semi upright, indeterminate and high branching type. Optimum spacing for 'Prima' ranged from 16 to 17 cm within rows and 34 to 40 cm between rows, representing a range in densities from 145 to 180 thousand plants per hectare. 'Pale Green' had optimum spacings of 19 to 20 cm within rows and 50 to 65 cm between rows, or densities from 70 to 105 thousand plants per hectare. The effect of varying either between-row or within-row spacing was consistently more pronounced in 'Pale Green' than in 'Prima'.

In 3 experiments where either the within-row spacing, the between-row spacing, or both were varied, there was a close linear relationship between the log of the yield per plant and the density. A factorial experiment, involving both within-row and between-row spacings, showed no significant interaction between these 2 factors. Apparently, varying the spacing between-rows affects yield for different reasons and to a greater extent than varying the spacing within rows.

In Africa, cowpea or southern pea, is the third most important grain legumes after peanut (*Arachis hypogaea* L.) and bambarra groundnut (*Voandzeia substerranea* L.) (17). Nigeria is the largest cowpea producer in Africa (8). On the basis of branching angle Ebong (5) recognized 3 basic growth habits of cowpea at flowering. These are erect (upright or bunch), semi-erect (semi-upright, semi-bunch or decumbent) and prostrate (climbing, scandent, or procumbent). Steele (18) reported that the cowpeas interplanted with cereals in northern Nigeria are generally prostrate and daylength sensitive, whereas those grown alone or interplanted with yams in southern Nigeria are predominantly upright and day-neutral.

Plant spacing (plant density) is important in obtaining maximum seed yield under given soil and climatic conditions. In some crops, spacing has an indirect effect on weed control (13),soil erosion (12), insect populations (1), and disease development (3). Many workers have conducted spacing experiments with cowpeas (6, 7, 10, 14, 15, 16, 19, 20), but most of them did not define the growth habit of the plants, making it difficult to make comparisons from their studies. Some workers who described the growth habits of the cultivars they used have shown that the response of cowpea to spacing and spatial arrangement is dependent on plant type. Jenkins and Hare (10) found that 1 to 6 plants per 30 cm of row and 2 plants per hill at 61 cm apart were best for the semi-bush 'Dixielee' and vining 'Brown Crowder; respectively, provided the distance between rows was kept at 107 cm. The runnerless, bunch, determinate type, 'Virginia 61-5' (19) and 'Princess Anne' (20), showed increases in green pod yield with decreases in row spacing if the distance between plants was maintained at 7.5-10 cm. Yield increase of 40% was obtained if the row spacing was reduced from 105 to 45 cm (18), and 74% if the row spacing was reduced from 90 cm to 15 cm (19).

A deterrent to comparing results reported for different spacing experiments, not only in cowpeas but in most other crops, is that often no simple mathematical relation between spacing and yield is reported. A direct linear relation holds when there is some density, roughly twice the optimum density, beyond which there is no marketable yield per plant as in the case in maize and broccoli (2). The log-linear relation holds where there is some usable yield even at high densities as with sugar beets (9) and most legume crops. Duncan (4) recommended this form of equation for most spacing data. Willey and Heath (20) have discussed the mathematical aspects of spacing experiments in detail.

Our objectives were to evaluate the response to varying within-row and between-row densities in cowpeas, and to study the interaction between these factors. Two cultivars with different plant habits were chosen to observe the effect of plant habit on the response patterns.

## Materials and Methods

Field experiments were conducted on Ibadan soil series at the International Institute of Tropical Agriculture, Ibadan, Nigeria. The chemical and physical properties of this soil were: pH 5.9–6.4, organic carbon 1.1–1.8%, CEC 4.5–6.9 meq/100g, total N 0.13–0.18%, sand 84%, silt 4%, and clay 12%. The soil was prepared by conventional methods of ploughing and harrowing, and fertilized with 40 kg N, 35 kg P and 50 kg K per ha just before planting. 'Prima', an erect, early, determinate and low branching type, and 'Pale Green', a large semi-upright, indeterminate and high branching type, were used. Plots were handweeded twice at 15 and 30 days after planting. Insects were controlled with weekly application of dimethoate before flowering, and a mixture of endosulfan and Gardona from flowering to final harvest. This insect control is not typical of Nigerian culture. The seeds were dusted with chloroneb just before planting in order to control seedling diseases. All missing hills were replanted with seedlings of the same age 3 to 6 days after emergence.

The rainfall pattern in Ibadan is essentially bimodal with a long rainy season (first season) from April to July and a short-rainy season (second season) from Late August to late October.

Throughout the following discussion, 240 cm was used as the unit distance, since this enabled us to express nearly all of the spacings as an integer number of rows or plants per unit.

The effect of between row spacing on cowpea seed yield was studied in the second rainy season, 1972, by varying the row density in 8 equal steps from 1 to 8 rows per 240 cm, and keeping within-row density constant at 16 plants per 240 cm. The experimental design was split plot with 3 replicates, cultivars as main plots and row densities as subplots.

The effect of within-row spacing on cowpea yield was investigated in the dry season 1972/73. Within-row densities were varied at 4, 8, 12, 16, 20 and 24 plants per 240 cm, and the between-row densities were maintained at 3.2 rows per 240 cm by planting the cowpea on ridges 75 cm apart. The experimental design was again a split plot, but with 4 replicates. Furrow irrigation was applied at weekly intervals.

In the first rainy season, 1973, both within and between-row spacings were varied simultaneously. The experimental design was split-split-plot with 3 replicates, cultivars as main plots, between-row spacings as subplots and within-row spacing as sub-subplots. The spacing treatments were factorial combinations of between-row

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densities of 2, 4, 6 and 8 rows per 240 cm and within-row densities of 8, 16 and 24 plants per 240 cm.

The effect of spatial arrangement on cowpea yield was evaluated in the second rainy season, 1973, by maintaining a constant plant density of 1 plant per 900 $cm^2$ or 111,111 plants per ha. Four plant arrangements with different ratios of between-and and within-row densities were used. These, in terms of rows and plants per 240 cm, were: 8 × 8, 4 × 16, 2.67 × 24 and 2 × 32. The experimental design was a split plot with 3 replicates, cultivars as main plots and spacing as subplots.

## Results and Discussion

Experiment 1 was the only experiment in which 'Prima' out-yielded 'Pale Green', for in the other tests rainfall was of sufficient duration to favor the indeterminate cultivar. The second rainy season in 1972 was unusually short. The rains stopped 45 days after planting, or about a week after the first flowering of both cultivars giving the determinate 'Prima' a decided advantage over the indeterminate 'Pale Green'. Another factor favoring 'Prima' over 'Pale Green' in this experiment was the high constant within-row density of 16 plants per 240 cm (15 cm spacing). Later tests showed that this was much closer to the optimum for 'Prima' than to that for 'Pale Green'.

Both the yields per plant and their logarithms were analyzed for linear correlation with between-row density. Both analyses gave a highly significant linear correlation, but in view of the results with other experiments and on the basis of past experience, it was decided to use the log-density relation (Fig. 1). In other words, since it is known that cowpeas will produce some yield even at high densities, it is preferable to fit a function that approaches zero asymptotically. Fitting such a function gave the following equations:

$$\text{For 'Prima' Ln (yield/plant)} = 2.96 - 0.153\ B$$

$$\text{For 'Pale Green' Ln (yield/plant)} = 2.90 - 0.220\ B$$

where Ln is the natural logarithm and B is the number of rows per 240 cm.

Observed and predicted values for Ln (yield/plant) were closely related (Table 1) as indicated by significantly high coefficients of linear correlation for 'Prima' and 'Pale Green' (0.99 and 0.98, respectively). Total seed yield of 'Prima' increased with a decrease in row spacing and levelled off at row spacing of 40 cm, while seed yield of 'Pale Green' reached a maximum between 48 and 60 cm and then declined with further increase in row spacing (Fig. 2).

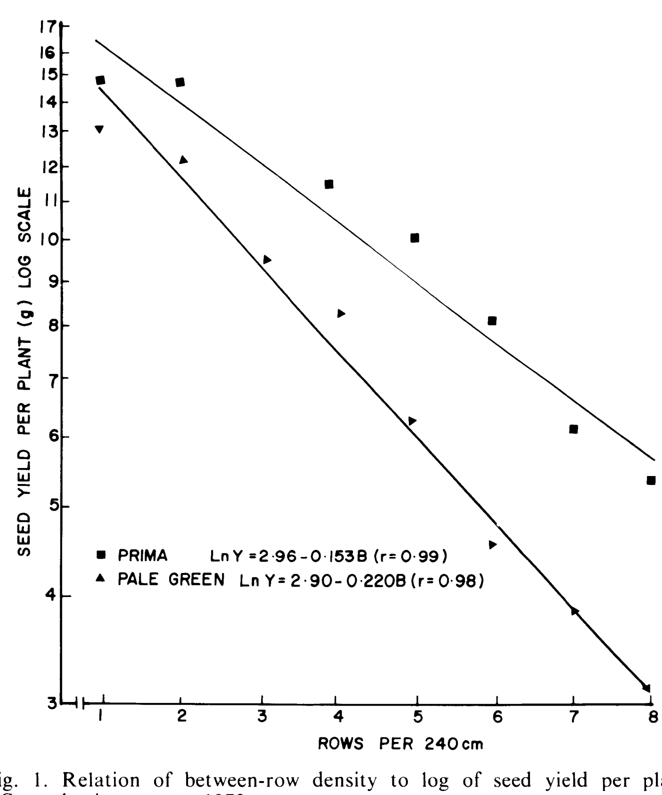


Fig. 1. Relation of between-row density to log of seed yield per plant. Second rainy season, 1972.

Table 1. Effect of between-row density on seed yield of 2 cowpea cultivars. Within-row density constant at 16 plants/240 cm. Second season, 1972.

| Between-row density (rows/240 cm) | Seed yield (kg/ha)[z] | Yield per plant (g) | Ln (yield/plant) Observed | Ln (yield/plant) Predicted | Predicted total seed yield (kg/ha) |
|---|---|---|---|---|---|
| | | Prima | | | |
| 1 | 408g | 14.7 | 2.69 | 2.81 | 460 |
| 2 | 816def | 14.7 | 2.69 | 2.66 | 789 |
| 3 | 1017cd | 12.2 | 2.50 | 2.50 | 1016 |
| 4 | 1259abc | 11.3 | 2.43 | 2.35 | 1164 |
| 5 | 1384a | 10.0 | 2.30 | 2.20 | 1249 |
| 6 | 1351ab | 8.1 | 2.10 | 2.05 | 1286 |
| 7 | 1161abc | 6.0 | 1.81 | 1.89 | 1288 |
| 8 | 1189abc | 5.4 | 1.68 | 1.74 | 1264 |
| | | Pale Green | | | |
| 1 | 364g | 13.1 | 2.58 | 2.68 | 403 |
| 2 | 679f | 12.1 | 2.50 | 2.46 | 646 |
| 3 | 778ef | 9.3 | 2.24 | 2.24 | 778 |
| 4 | 927de | 8.3 | 2.12 | 2.02 | 832 |
| 5 | 875def | 6.3 | 1.84 | 1.80 | 835 |
| 6 | 753ef | 4.5 | 1.51 | 1.58 | 804 |
| 7 | 742ef | 3.8 | 1.34 | 1.36 | 752 |
| 8 | 676f | 3.0 | 1.12 | 1.14 | 690 |

[z] Means followed by the same letter are not significantly different by Duncan's multiple range test at 5%.

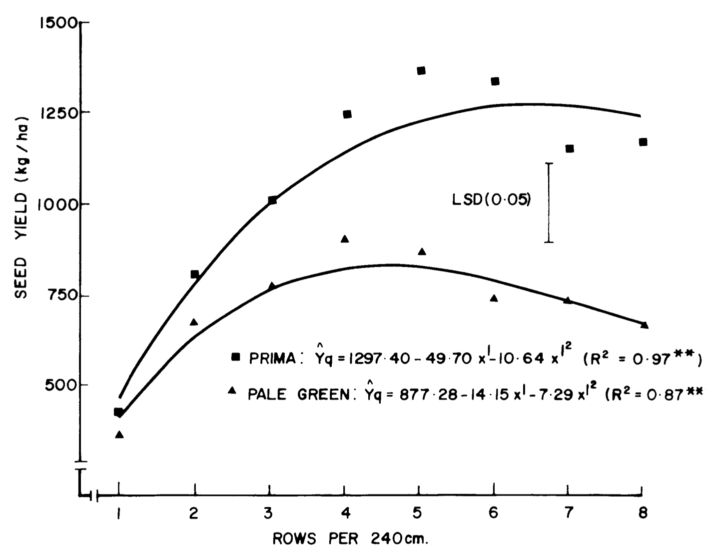


Fig. 2. Curves representing the relation between total seed yield per ha and between-row density. Second rainy season, 1972.

Since total yield in kg/ha is density in thousands of plants/ha times/yield/plant in g, equations for predicting total yield were obtained by adding the natural log of the density to the above equations. Furthermore, D (density in thousands of plants/ha) = W (plants/240 cm) × B (rows/240 cm)/0.576 and in this experiment, W was maintained at 16. Therefore the equations for total yield could be expressed entirely in terms of B:

$$\text{Ln yield of 'Prima'} = 6.284 - 0.153\ B + \text{Ln } B$$

$$\text{Ln yield of 'Pale Green'} = 6.224 - 0.220\ B + \text{Ln } B$$

Table 2. Effect of within-row density on seed yield of 2 cowpea cultivars. Between-row density constant at 3.2 rows/240 cm. Dry season, 1972/73.

| Within-row density (plants/ 240 cm) | Seed yield (kg/ha)[z] | Yield per plant (g) | Ln (yield/plant) Observed | Predicted[y] | Predicted total seed yield (kg/ha)[y] |
|---|---|---|---|---|---|
| | | Prima | | | |
| 4 | 722d | 32.49 | 3.48 | 3.27 | 586 |
| 8 | 769cd | 17.30 | 2.85 | 3.01 | 900 |
| 12 | 953cd | 14.30 | 2.66 | 2.74 | 1035 |
| 16 | 939cd | 10.56 | 2.36 | 2.48 | 1058 |
| 20 | 1092c | 9.83 | 2.29 | 2.21 | 1014 |
| 24 | 1008cd | 7.56 | 2.02 | 1.95 | 933 |
| | | Pale Green | | | |
| 4 | 1544b | 69.48 | 4.24 | 4.04 | 1267 |
| 8 | 1836ab | 41.31 | 3.72 | 3.73 | 1848 |
| 12 | 1613b | 24.20 | 3.19 | 3.41 | 2022 |
| 16 | 1655b | 18.62 | 2.92 | 3.10 | 1967 |
| 20 | 1902a | 17.12 | 2.84 | 2.78 | 1794 |
| 24 | 1822ab | 13.66 | 2.61 | 2.47 | 1570 |

[z] Means followed by the same letter are not significantly different by Duncan's multiple range test test at 5%.
[y] Based on equations:

'Prima' Ln (yield/pt.) = 3.54 − 0.066 W
LN (yield) = 5.25 − 0.066 W + Ln W

'Pale Green' Ln (yield/pt.) = 4.36 − 0.079 W
Ln (yield) = 6.07 − 0.079 W + Ln W

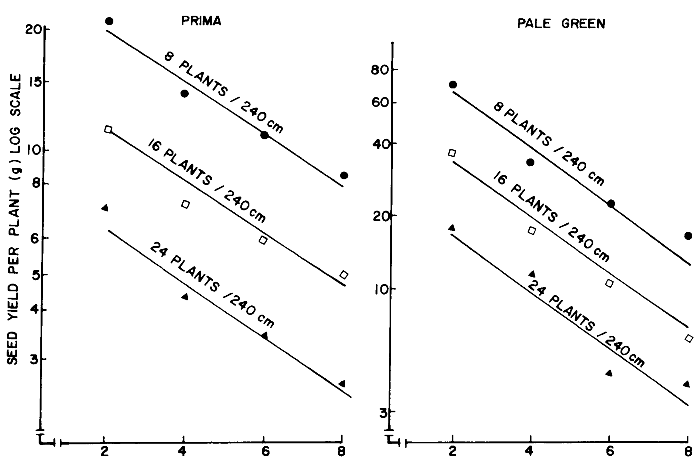


Fig. 3. Relation of between-row density to log of seed yield per plant at 3 within-row densities in 'Prima' and 'Pale Green'. First rainy season, 1973.

The use of natural logs in these equations has the advantage of simple rendering of determination of optimum density or spacing. Expressing the equation in general terms.

$$Y = a - bB + \ln B$$

and equating the first derivatives to zero gives.

$$dY/dB = -b + 1/B$$

so that $B = 1/b$ is the value of B which theoretically should give the maximum yield. In terms of spacing, since $B = 240/\text{spacing}$, the optimum spacing is simply 240 b. Thus for 'Prima', the optimum between-row density was $1/0.153 = 6.54$ and optimum spacing $0.153 \times 240 = 36.7$ cm. The corresponding values for 'Pale Green' were 4.55 and 52.8 cm.

In Experiment 2, conducted with irrigation during the dry season, 'Pale Green' outyielded 'Prima' by about 90% (Table 2). In both cultivars, the linear correlation between the logs of yield/plant and density was higher than that between yield/plant and density. The theoretical optimum density within-rows for 'Prima' was 15.1 plants/240 cm or 15.9 cm spacing. For 'Pale Green', the optimum was 12.7 plants/240 cm or 18.9 cm spacing.

Experiment 3 suffered from a short early season drought just before flowering. Although 'Pale Green' recovered 'Prima' plants remained stunted and relatively small up to harvest. This experiment, being a factorial experiment, made it possible not only to make comparisons with the results of the preceding 2 experiments, but also to study the interaction between the 2 factors. The most striking result was the almost complete absence of such an interaction as shown by parallel lines in Fig. 3. This seems to indicate that the total area available to each plant is not the most important factor influencing yield per plant. If this were so, then the optimum within-row density would be high when the between-row density was low and vice versa. Such a situation would result in a high interaction between the 2 factors. Our data strongly supports the conclusion that within the range of densities studied, the effects of within-row and between-row densities were independent. A possible explanation is that within rows, plant competition for soil moisture and nutrients is the important factor that causes a decrease in yield per plant with increase in density. On the other hand, such competition may be relatively unimportant when between-row densities are varied. The effect may be due, instead, to changes in the efficiency of various practices. Weeding and insecticide spraying were more difficult in closely spaced than widely spaced rows. This difference became more pronounced as the season progressed, and was more important in the indeterminate 'Pale

Table 3. Effect of within and between-row densities on seed yield in cowpeas. First rainy season, 1973.

| Density/240 cm Between-rows | Within-rows | Seed yield (kg/ha)[z] | Yield/ plant (g) | Ln (yield/plant) Observed | Predicted | Predicted total seed yield (kg/ha) |
|---|---|---|---|---|---|---|
| | | | Prima | | | |
| 2 | 8 | 611c | 22.0 | 3.09 | 3.01 | 564 |
| 4 | 8 | 744abc | 13.4 | 2.60 | 2.69 | 817 |
| 6 | 8 | 920abc | 11.0 | 2.40 | 2.38 | 900 |
| 8 | 8 | 982ab | 8.8 | 2.17 | 2.07 | 881 |
| 2 | 16 | 639bc | 11.5 | 2.44 | 2.44 | 639 |
| 4 | 16 | 765abc | 6.9 | 1.93 | 2.13 | 935 |
| 6 | 16 | 972ab | 5.8 | 1.76 | 1.81 | 1018 |
| 8 | 16 | 1016a | 4.6 | 1.53 | 1.50 | 998 |
| 2 | 24 | 640bc | 7.7 | 2.04 | 1.88 | 547 |
| 4 | 24 | 731abc | 4.4 | 1.48 | 1.56 | 793 |
| 6 | 24 | 886abc | 3.5 | 1.25 | 1.25 | 873 |
| 8 | 24 | 876abc | 2.6 | .96 | .94 | 853 |
| | | | Pale Green | | | |
| 2 | 8 | 2049a | 73.8 | 4.30 | 4.24 | 1927 |
| 4 | 8 | 1819ab | 32.7 | 3.49 | 3.71 | 2269 |
| 6 | 8 | 1981a | 23.8 | 3.17 | 3.17 | 1985 |
| 8 | 8 | 2048a | 18.4 | 2.91 | 2.64 | 1556 |
| 2 | 16 | 2107a | 37.9 | 3.63 | 3.52 | 1878 |
| 4 | 16 | 1864a | 16.8 | 2.82 | 2.99 | 2211 |
| 6 | 16 | 1731abc | 10.4 | 2.34 | 2.45 | 1933 |
| 8 | 16 | 1289de | 5.8 | 1.78 | 1.92 | 1516 |
| 2 | 24 | 1473bcd | 17.7 | 2.87 | 2.80 | 1371 |
| 4 | 24 | 2040a | 12.2 | 2.50 | 2.27 | 1613 |
| 6 | 24 | 982e | 3.9 | 1.36 | 1.73 | 1410 |
| 8 | 24 | 1392de | 4.2 | 1.44 | 1.20 | 1107 |

[z] Means followed by the same letter within the same cultivar are not significantly different by Duncan's multiple range test at 5%.

Table 4. Effect of spatial arrangement on the seed yield of 'Prima' and 'Pale Green.' Late rainy season, 1973.

| Spacing (cm) | Seed yield (kg/ha)[z] | |
|---|---|---|
| | Prima | Pale Green |
| 30 × 30 | 1054b | 1671a |
| 15 × 60 | 1089b | 1466a |
| 10 × 90 | 1036b | 1429a |
| 7.5 × 120 | 689c | 1152b |

[z] Means followed by the same letter are not significantly different at the 5% level.

Green' than in the determinate 'Prima'. Seeds, particularly those of 'Pale Green', harvested from experiments 1 and 3 consistently showed more insect damage at close spacings than at wide spacings. It should be stressed, however, that the lack of interaction of between-row and within-row may not be a general rule in cowpeas, but rather as a peculiarity of the season in which the experiments were conducted.

The optimum spacings calculated from Table 3 were strikingly similar to those obtained in the previous 2 experiments in spite of the wide differences in growing conditions and mean total yields. In 'Prima' the optimum between- and within-row spacings were 37.6 and 17.0 cm respectively, while in experiments 1 and 2 the corresponding figures were 37.0 and 15.9. In 'Pale Green' the optimum spacings calculated from experiment 3 were 64.1 and 21.6 while the other 2 experiments gave values of 53.0 and 18.9.

From the equations involving both B and W it is possible to calculate the theoretical optimum ratio of between-row to within-row spacings at a fixed density. This is simply the ratio of the coefficients of B and W. In 'Prima' this ratio was 2.2:1 and in 'Pale Green' it was 3:1, emphasizing the fact that between-row spacing was a more critical factor in the indeterminate 'Pale Green' than in the determinate 'Prima'.

Experiment 4 was designed to test the effect of varying the ratio of between-row to within-row spacing, keeping the total density in plants/hectare constant. Actually the number of treatment levels was too small to permit a critical analysis. However, the results confirmed what could be predicted from Experiment 3, namely, that there is considerable leeway in ratios on either side of the optimum, which will have little effect on the total yield, and it is only extreme deviations from the optimum that will have a serious deleterious effect on yield. Thus it was only the extreme ratios of 16:1 for between-row to within-row spacings that showed a significant reduction in yield in both cultivars (Table 4).

Conclusions: a highly significant linear correlation existed between the log of the yield per plant and the population density. Between-row and within-row densities were virtually independent in their effects, and the former had the greater effect. The optimum density both between and within-rows was lower (wider spacing) for the indeterminate 'Pale Green' than for the determinate 'Prima'.

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