A MODIFIED MODEL FOR PLANT COMPETITION UNDER VARYING PLANT GEOMETRY

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ABSTRACT

Earlier work suggests a close link between plant competition and pattern of planting. A new approach has been made to compare the competition effect in varied plant geometry. For this, the model proposed by Goodall and Berry, has been modified to include all the surrounding plants, and the competition effect is assumed to vary inversely as the distance between plants. The competition effect computed under varied plant geometry has been discussed. These theoretical considerations suggest equidistant planting in triangular pattern to yield less competition of individual plants. The competition effect under square planting was not consistently lower. The effect of rectangular shape. *i.e.*, the ratio of the sides of the rectangle, affected the net competition. Rectangular pattern obtained by 1:2 ratio of the sides of the rectangle yielded lower competition, compared to the square pattern itself. Also the modified model, appeared to be more flexible and realistic in practical situations, compared to Goodall's model.

PLANNING pattern or what is known as plant geometry is relatively a new concept in Agronomy. The main objective is to minimise the competition among plants, by varying the planting pattern. Generally, planting in rectangular fashion is in vogue, but several workers have tried different methods of planting for varied purposes. Square planting, a particular case of rectangular planting was preferred by Donald[3] and Robinson and Modson[8]. According to them, these yielded higher than the conventional rectangular planting, when the direction of rows had no effect. But rectangular planting was preferred because of ease of intercultivation. Shubeck and Young[9] opined that planting in diamond shape-pattern was profitable.

Goodall[4] was the first to postulate a model for plant competition. He assumed competition effect to be proportional to the distance between the plants and suggested a logarithmic relation, *i.e.*, between log of weight of the individual plant and the log of the distance between plants. He further assumed a linear additive effect of the neighbours. Goodall also opined that photosynthesis reduction and the competition effect should increase inversely as a power of the distance (of the neighbours), ranging between the first and third power, according to the relative importance of below ground portion and above ground portion competition. Berry[1] modified the model proposed by Goodall to include the rectangularity of planting.

The purpose of this article is to find out the theoretical competition effect in varying plant geometry.

METHODOLOGY

To find out the competition effect, a single plant is considered, following Goodall[4]. Goodall postulated a model. $W = ad_1^{b_1} d_2^{b_2}$, where W = dry weight of the plant, a = constant, b_1, b_2 = regression coefficients, d_1 and d_2 = distance between rows and within a row.

But Bleasadale and Nelder[2] observed that the mode depicting the relation of plant yield and density, was of a logistic type, wherein a final constant yield exists. As such, Berry[1], assuming a simple reciprocal equation, between plant yield and density, gave the following model, taking the plant rectangularity also into consideration.

$$\frac{1}{W^0} = a + b\left[\frac{1}{d_1} + \frac{1}{d_2}\right] + \frac{c}{d_1 d_2}$$

Here d_1, d_2 are the sides of rectangular and $d_1 \times d_2$ is the area per plant, b and c are the regression coefficients.

Here, for a particular situation wherein the different patterns are tried, keeping the area per plant constant the third term will be the same. Only the second term varies, depending on the planting pattern. As such, this term which brings in the variation, is considered for finding the differential effect of competition. Also the competition effect is assumed to be proportional to the inverse of the distance between plants. Goodall observed that it may vary inversely anywhere from single to third power of the distance. But in the absence of any biological menaing for assuming any higher power, the simple distance is considered, in computing the competition effect.

Further, Goodall considered only the inter- and intra-distance of the neighbouring plants, but here all the plants surrounding in the first rhizosphere has been considered for assessing competition effect. This will assume importance, especially in varied planting patterns. And thus totally all the 8 plants surrounding the plant in rectangular and square patterns, and 6 plants in triangular pattern is considered for finding out the competition effect. Further, the competition effect is assumed to be the same, with respect to direction of rows.

The competition effect and algebra of the same is shown below :

Rectangular Planting

Consider a plant 'A', surrounded by B, C on the same row and D, E vertically opposite, along either side and F, G, H and I diagonally, in different rows.

If the distance between AB or AC is d_1 and the distance AD, AE be d_2, then the distance between AF, the diagonal is

$$\sqrt{d_1^2 + d_2^2}$$

Similarly, AH, AG and AI. Assuming linear additive effect of competition from all the 8 plants, the competition will comprise of 2 plants within row, 2 plants vertically opposite on either side of the plant and four plants diagonally placed. Further, assuming inverse linear relationship, the differential competition due to varying planting pattern is proportional to

$$\frac{2}{d_1} + \frac{2}{d_2} + \frac{4}{\sqrt{d_1^2 + d_2^2}}$$

or differential competition is

$$b\left[\frac{2}{d_1} + \frac{2}{d_2} + \frac{4}{\sqrt{d_1^2 + d_2^2}}\right]$$

where b is the partial regression coefficient in the model suggested by Berry[1].

Square Planting

Square planting is a particular case of rectangular planting, and here $d_1 = d_2 = d$ (say), so

the differential competition is

$$b\left[\frac{4}{d} + \frac{4}{\sqrt{2d^2}}\right] = \frac{6 \cdot 84b}{d}.$$

where b is the partial regression coefficient.

Triangular Planting

In triangular planting, the distance between plants in the same row, and the distance between rows will be constant. So, if we consider the differential competition for plant A, on the same row, distance AB, AC $= d$.

The distance AD, AE, AF and AG $=$

$$\sqrt{d^2 + (0 \cdot 50d)^2} = 1 \cdot 118\, d.$$

So competition

$$\propto\left[\frac{2}{d} + \frac{4}{1 \cdot 118\, d}\right] \propto \frac{1}{d}\,(2 + 3 \cdot 58) \text{ or } \frac{5 \cdot 58}{d} = \frac{5 \cdot 58}{d}\, b$$

where b is the same partial regression coefficient in Berry's model.

To illustrate one example, sorghum crop is grown with plant density of 2·67 lakh per hectare under varied planting pattern as shown below. The differential plant competition due to varied planting pattern (second term in Berry's Model), is computed as follows :

Planting pattern	Rectangular	Square	Triangular
Spacing (in cm)	(i) 7·5 × 50	19·4 × 19·4	19·4 cm (bet. plants and bet. rows)
	(ii) 10·0 × 37·5		
	(iii) 12·5 × 30·0		
	(iv) 15·0 × 25·0		

Then, the plant competition in rectangular pattern will be proportional to

$$\frac{2}{7 \cdot 5} + \frac{2}{50 \cdot 0} + \frac{4}{\sqrt{(7 \cdot 5)^2 + (50)^2}}$$

as per methodology, explained previously.

That is competition $= b\,(0 \cdot 3857)$, similarly for other rectangular patterns, it is shown in Table I.

TABLE I

Differential competition effect in sorghum, due to varying planting pattern (g/plant/unit area)

	L/B	Competition effect due to distance
1. *Plant density of 1·33 lakh/ha.*		
(a) Rectangular pattern		
(i) 12·5 × 60	4·800	0·2586
(ii) 15.10 × 50·0	3·333	0·2499
(iii) 20·0 × 37·5	1·875	0·2474
(iv) 25·0 × 30·0	1·200	0·2491
(b) Square pattern		
27·4 × 27·4		0·2492
(c) Triangular pattern (27·4 cm between rows and between plants in a row)		0·2036
2. *Plant density of 2·67 lakh/ha.*		
(a) Rectangular pattern	L/B	Competition effect due to distance
(i) 7·5 × 50	6·667	0·3857
(ii) 10·0 × 37·5	3·750	0·3564
(iii) 12·5 × 30·0	2·400	0·3498
(iv) 15·0 × 25·0	1·667	0·3505
3. *Square pattern* 19·4 × 19·4		0·3520
(c) Triangular pattern (19·4 cm between rows and between plants in a row)		0·2863

For the square pattern of planting, the competition will be proportional to

$$\frac{4}{19\cdot 4} + \frac{4}{\sqrt{2x(19\cdot 4)^2}},$$

because $d_1 = d_2 = 19\cdot 4$, *i.e.*, competition $= (0\cdot 3520)\,b$. For the triangular planting :

Competition

$$\alpha \frac{2}{d} + \frac{4}{\sqrt{d^2 + (0\cdot 5d)^2}}$$

$$\alpha \frac{2}{19\cdot 4} + \frac{4}{\sqrt{(10\cdot 4)^2 + (0\cdot 25)(19\cdot 4)^2}}$$

$$\alpha \frac{2}{19\cdot 4} + \frac{4}{21\cdot 69} \text{ or } 0\cdot 2875$$

$$= b\,(0\cdot 2875).$$

RESULTS AND DISCUSSION

Results of differential competition effect is tabulated in Tables I and II for sorghum and finger millet, respectively, for two different plant densities, under varied plant geometry.

TABLE II

Differential competition effect in finger millet, due to varying planting pattern (g/plant/unit area)

1. *Plant density of 2·5 lakh/ha*

(a) Rectangular pattern	(L/B)	Competition effect due to distance
(i) 8 × 50	6·25	0·3690
(ii) 10 × 40	4·00	0·3470
(iii) 12·5 × 32	2·56	0·3389
(iv) 16 × 25	1·56	0·3398
(b) Square pattern (20 × 20)		0·3414
(c) Triangular pattern (20 cm between rows and between plants in a row)		0·2789

2. *Plant density of 4·4 lakh/ha*

(a) Rectangular pattern	(Ratio of the side)	Competition effect due to distance
(i) 7·5 × 30·0	4·00	0·4628
(ii) 9 × 25·0	2·78	0·4527
(iii) 10 × 22·5	2·25	0·4514
(b) Square pattern (15 × 15)		0·4553
(c) Triangular pattern (15 cm between rows and between plants in a row)		0·3778

From this, it is clear that triangular planting creates less competition, if the plants in the first circle surrounding each plant is considered. As in triangular planting only 6 plants compete directly, whereas in either the rectangular or the square planting 8 plants compete. But if the spacing is too close, then even the plants in the subsequent second circle of each plant may compete, and then these plants also should be considered. Even in that case, the triangular planting will have an edge over the traditional planting. Also if the competition effect is considered as some higher power of the distance between plants, then in that situation the competition effect between any two arrangements becomes more marked or distinct, and these will not alter the results much. Thus it appears, that triangular planting has marked advantages compared to traditional planting, in terms of the competition effect.

The comparison of competition effect between rectangular and square planting has always been a controversial one. Several workers including Goodall[4] have opined that competition effect will be low, in square planting. Donald[3] quoted several workers to emphasise that square planting will yield higher yield ; but admitted that this was not wholly consistent. This was true only when direction of rows is immaterial for competition effect. But Holliday[5] found some advantage in slight variation from rectangular planting. Goodall while suggesting a model for plant competition considered only the adjacent plants on either side, and thus his model always gave the superiority of square planting to rectangular planting. But in computing the competition effect, diagonal plants also should be considered. While comparing planting patterns, in rectangular planting, a plant more distant than the diagonal one in square planting, is considered for finding out the competition, but the nearer plant, *viz.*, diagonal plant is not considered in square planting. This anomaly can be overcome only by considering all the 8 plants surrounding each plant in both the patterns. Hence, as per the methodology explained the inverse of the distances of all the 8 plants were considered for finding out the competition effect. Hypothetically this method of finding competition effect was followed for two crops, *viz.*, sorghum and finger millet, for two population levels, under different planting pattern. Here for different planting patterns, the area was kept constant, and the intra and inter-distance of plants was varied and the competition effect was computed theoretically. The results are tabulated in Tables I and II.

The competition effect was compared at two plant population levels. The competition effect was more at higher density of plant population, compared at lower density. Also the differential effect of competition due to planting patterns was more pronounced at higher density, than at lower density. This clearly shows that this mode of explaining competition effect, is in conjunction with the reality of the situation, basically.

As expected, in triangular planting the competition effect was theoretically lower than either the rectangular or square planting. But the differential effect of plant competition between square planting and rectangular planting was not consistent in both the crops. *Hypothetically, different rectangular* shapes were created, by varying the sides of the rectangle, but keeping the area consttant. The effect of rectangular shape, *viz.*, the ratio of length to breadth of rectangle was found to be important. Whenever the ratio was very high, square planting yields less competition, but when the ratio was marginally greater than two, the competition effect was the lower in rectangular planting. Again when the ratio ranged between 1 to 1·5, the competition effect in rectangular pattern increased. Thus, these theoretical considerations suggest that there exist a optimal range of ratios of the rectangular sides, beyond which zone on either side the rectangular pattern will yield more competition of individual plants. And this ratio suggested from these *investigations was found to be somewhere* around 2 to 2·5, at which the rectangular pattern of planting will yield slightly less competition effect of individual plants.

The theoretical results, obtained from the assumption of the inverse relationship of competition effect with distance and the additive effect of competition, seems to explain practical results obtained in some experiments. For example, triangular planting has yielded more than the conventional planting pattern in finger millet crop in an experiment conducted in summer *1976 with three genotypes of differing plant* types (Subramaniam, personal communication).

Also in some genotypes, in Sorghum, triangular planting has yielded more than the conventional planting[7].

Shubeck and Young[9] found increased yield by 9 bushels/ha when planted in diamond shape, (compared to the conventional rectangular *shape, in maize*). But systematic and sophisticated studies with refined techniques are required to investigate on these aspects.

Thus, it appears that from this modified approach of computing competition effect, equi-distant spacing in triangular pattern of planting seems to have marked advantages over conventional planting. And in the comparison of rectangular and square patterns, it appears rectangular pattern varying moderately from square pattern to yield better results than the square pattern. Also it appears the results obtained *from the trials conducted on planting patterns*, conform more with this new theoretical approach, compared to the model considering adjacent plants only. Further, this concept developed is more flexible and comprehensive, in that, it can be used to compare the effect of different patterns of planting.

However in all these models the competition effect is assumed to be two-dimensional, while, in practice, it is three-dimensional, involving the other factors —volume of the soil, plant canopy and plant roots. Inclusion of that factor involves investigation with *highly sophisticated techniques under highly controlled* conditions, which is not in the perview of the present study.

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