PLANT POPULATION AND SPATIAL ARRANGEMENT EFFECTS IN MONOCROPS AND INTERCROPS IN RAINFED AREAS

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ABSTRACT

Knowledge on the effect of population changes and spatial arrangement in intercropping situation, unlike for pure crops, is very limited. The paper describes some aspects of total population pressure, proportional populations and relative space allocation, which are highly interrelated in intercropping. It is pointed out that unless their effects are quantified independent of one another, clear understanding of the basic relationships between various crops in mixtures can not be established. The response of crops, sorghum, pearl millet, ragi, sunflower, safflower etc., to changes in geometry of planting at constant population, such as wide row widths and pairing of rows, which may increase the scope for intercropping is discussed. Under moisture limiting conditions and no N fertilisation, doubling the row width of sorghum sole resulted in 15.8 - 93.2% higher yield depending on soil type. Widening the row width of base crop, without reducing its population, may allow an increase in the total population pressure of the system which may in turn give greater intercropping benefits. The advantages of grouping or pairing of rows in deficit moisture conditions as an yield improvement practice in sole crops and as a method to alleviate competition between the associated crops in mixtures is discussed with examples. Three crop intercropping with widely spaced pigeonpea showed 66% advantage compared to 45% in the case of two crop intercropping. Possible spatial arrangement of crops for intercropping and sequential cropping to suit broad ridge and furrow systems of cultivation is discussed.

For monocrops the different aspects of plant population and spatial arrangement are well understood. Plant population simply defines the number of plants per unit area, which in turn defines the area available for the individual plant. Within limits this plant number will usually have greater influence on yields than spatial arrangement. Spatial arrangement can be defined as the pattern of distribution of plants over the ground; this determines the shape of the area available to the individual plant. For crops regularly spaced in rows spatial arrangement is often defined as a degree of rectangularity, which is the ratio of the between row spacing to the within-row spacing. Thus for a crop on 60-cm rows and spaced at 30 cm within the row the rectangularity would be 2 : 1. In theory, the 'ideal' spatial arrangement is when any given plant is equidistant from all its immediate neighbours. As will be discussed later, however, this may not be the best arrangement in practice.

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For the intercropping situation, plant population and spatial arrangement aspects are more complex. With regard to plant number, both total population (i.e. all crops combined) and proportional population (i.e. of each crop) have to be distinguished. The main problem here is that, in terms of the plant population pressure exerted, a single plant of one species is not usually directly comparable with a single plant of another species. This can be overcome by regarding optimum populations as comparable. If the optimum population of any monocrop is taken as 100, proportional population can then be conveniently expressed on a simple relative basis. Thus an intercrop of alternate rows of two crops, where row width and within row spacings are the same as the monocrops, can be defined as 50 : 50. This indicates that the proportional population of each species is 50% and that the total population is therefore 100. Total population pressure of intercrops may, of course, be greater than 100 where a higher total population than either monocrop is established.

With regard to spatial arrangement of intercrops the degree of rectangularity of each crop will still be an important factor determining the efficiency with which resources are utilised. But two further factors can also be distinguished. Firstly, there are the proportional areas which are initially allocated to each crop. In row cropping this is usually determined by the number of rows allocated to each species. Often these proportional areas are directly related to proportional populations; e.g in the alternate row example above, proportional areas would also be 50:50. However, it is important to appreciate that this direct relationship does not have to apply and proportional populations of either, or both, species can be altered at constant row arrangement simply by altering within row spacing; conversely row arrangement can be altered without changing proportional populations.

The second factor is how the proportional areas of each species are arranged with respect to each other. This is often dependent on how "intimately" the species are mixed. For example an intercropping situation which has 50:50 proportional populations and 50:50 proportional areas can be arranged as a mixture within rows, as alternate rows, as alternate "double rows", as alternate "triple" rows etc.

All these populations and spatial arrangement factors are highly inter-dependent but at the same time they can each have distinct and separable effects. For the intercropping situation in particular it can be essential to distinguish between them if a full understanding of their relationship with crop yield is to be achieved. Some indication of the extent and nature of these effects is given below.

Plant Population:

The response of monocrops to increase in plant population is well known. Broadly speaking there are two types of relationship (Holiday, 1960) an "asymptotic" relationship which applies to vegetative yield (e.g. leaves, stems, roots etc.) and a "parabolic" relationship which applies to reproductive yield (e.g. grains, seeds, fruits etc). Current evidence suggests that these basic relationships hold good for the individual component crops in an intercropping situation (Osiru and Willey, 1972; Willey and Osiru, 1972; Herrera et al, 1975, Willey and Lackani, 1976; Baker and Yusuf, 1976). But perhaps the most important point is that if an intercropping situation is giving an appreciable yield advantage it may require a higher optimum for total population than either of the monocrop optima (Andrews, 1974; Willey and Osiru, 1972; Shelke, 1976). This is related to greater use of resources and is most easily illustrated for the intercropping situation where the component crops complement each other in time, e.g. an early and a late crop such as cereals and pigeonpea.

To get maximum yield out of this system the cereal must be at a sufficiently high population to make reasonably full use of early resources, and the pigeonpea must also be at a sufficiently high population to make resonable use of late resources. Thus whatever proportions of the two crops is eventually required by a farmer, the proportional populations should probably add up to more than the "100" monocrop populations. There has been an attempt to relate the optimum total population of intercrops to the time difference between component crops (Baker, 1974). However, this still requires a good deal of further study.

SPATIAL ARRANGEMENT.

Monocrops:

The theoretical 'ideal' spatial arrangement referred to earlier is often rather loosely regarded as 1 : 1 or 'square' planting. Although in practice this may be near enough, strictly speaking the 'ideal' arrangement is ' hexagonal' planting where each plant has six immediate neighbours arranged at the corners of a regular hexagon. But this ideal arrangement is feasible only in long-term perennial crops where the number of plants per unit area is low and establishment costs are spread over many seasons. For annual row crops where plant numbers are high the need for wide enough rows for inter-cultivation usually means that within-row distances are small and rectangularity is fairly acute. For annual crops such as cotton, castor or tobacco where plant numbers are not quite so high, 'square' planting could be preferred to allow intercultivation in both directions (AICRPDA, 1974-75).

As far as yield is concerned, the traditional view has been that as spatial arrangement moves farther from the ideal both optimum population and maximum yield decrease (Willey and Health, 1969). But recently, because of the recognised importance of intercropping, there has been considerable spatial manipulation of 'base' crops to try to facilitate the addition of intercrops.

For example the addition of an intercrop between normal rows of such narrow-row crops as ragi (30 cm), sorghum or pearl millet (45cm) can be difficult. Intercrops can, of course, be introduced by skipping rows of the base crop but if the latter is an important food crop its proportion in the system is undesirably reduced. To avoid this, two systems have been examined: one is the widening of rows to allow intercropping between all rows, the other is pairing of rows to allow intercropping between pairs of rows. In both systems the full population of the base crop is maintained.

Pearl millet yields have been found to be unaffected up to a row width of 75 cm (8.3 : 1 rectangularity) but decreased at 100 cm by 25% due to acute rectangularity of 16.6 : 1 (Pal and Kaushik, 1972; Gautam, 1975). In case of ragi, studies have shown that no appreciable yield reduction could be observed up to a row width of 55-65 cm. (Hegde and Havangi, 1975). Sunflower showed reduction in yields only when row width was widened beyond 67.5 cm at optimum population (Bhaskara Rao et el, 1975). The yield of safflower at 90 cm rows on deep black soil of Bellary was as good as in 45 cm rows. The rectangularity at these two row widths varied from 3:1 to 1.5:1 respectively (AICRPDA 1970-71); this may open avenues for intercropping with chickpea, sorghum etc. Studies held in various centres of the All India Coordinated Sorghum Project showed that, when maintained at normal populations, sorghum was little affected up to a row width of 90 cm in most of the varieties but it showed about 21% reduction when widened to 120 cm (Singh 1976). However, there may be marked varietal differences in response to rectangularity depending upon duration, height, spreading nature and optimum time of planting (Mahendra Sing et al, 1972, Anonymous, 1976; Krantz et al, 1976; Singh 1976).

In a moisture deficit situation as in *kharif* 1976, at reasonable fertility level and constant population, doubling the normal row width of sorghum (45 cm to 90 cm) did not result in any appreciable reduction in yields (Table 1). When no fertiliser was applied, wide rows recorded 93.2% higher yields in red soil and 15.8% in black soils perhaps for the reasons explained in the later section.

In other crops such as castor, pigeonpea etc. which facilitate inter-cropping even in normal rows (60-75cm), widening row width is equally important for achieving greater intercropping benefits. Castor yields have not declined in favourable and unfavourable seasons in as wide as 135-150 cm rows (Bhaskara Rao *et al*, 1975). The performance of medium maturing pigeonpeas was unaffected up to 135 cm rows (Anonymous, 1976) whereas those of medium to late and spreading types was unaffected up to 150 cm rows (Krantz *et al*, 1976). At normally practised population of 40,000 plants per ha rectangularity for these crops could vary between 0.81 to 17:1.

Considering 'paired' row planting it has been suggested that altering the planting pattern to give earlier competition can improve water use efficiency of dryland crops grown on conserved soil moisture (Blum, 1972). In two out of four trials on sorghum, changing from 100 cm equidistant rows to a configuration of 40-60 cm within a pair of rows and 160-140 cm between pairs resulted in a yield advantage of 13.2% (Table 2, Blum and Naveh, 1976). Similar studies conducted in AICRPDA have shown that pairing of rows was 14% more advantageous in case of sorghum, 22.6% with pearl millet and 38.5% in raya (Table 3). Paired row system in various other centres if not beneficial was not inferior to uniform rows. In Blum and Naveh's studies, paired or grouped row arrangement was observed to promote early competition in top as well as root growth leading to less profile moisture utilisation prior to the grain development stage. However, better moisture conditions prevailing in the inter-pair profile region in later growth stages, and good root growth under the paired rows, helped to produce higher grain number and grain size compared with the same moisture extracted under uniform rows.

It has been suggested that paired row pattern might reduce evapotranspiration through reduced leaf area index in early stages (Kitchie, 1972); it may also provide better opportunities to manage the wide inter-pair area through cultivation and mulching. The higher yields of sorghum at wider rows observed in Table 1 might have resulted from the same effect i.e. more plants within the row induced early competition and resulted in more efficient utilisation of limited moisture.

Intercropping:

Most of the basic investigations so far in intercropping have studied the effect of total population and relative populations but few studies have distinguished these from spatial arrangement effects (Willey et al, 1977). Strictly speaking, in the two examples presented in Table 4, the intercropping advantage was due to the combined effect of proportional population and the spatial arrangement (AICRPDA, 1973-74 and Gurmel Singh et al,1976). The effect of spatial arrangement at constant total and proportional populations in four intercropping systems is presented in Table 5. Alternate single rows 45 cm apart, giving a 50:50 population, produced a yield advantage of 13%. Grouping the rows to give one row of base crop and one row of intercrop 25 cm apart, and with 50 cm between groups (to suit a possible ridge and furrow situation) but without changing relative or total populations resulted in 31% advantage. Similarly, when pigeonpea was spaced at 67.5 cm and alternated with double rows of intercrops at 22.5 cm, again without changing populations, the average advantage was 37%.

The method of spatial adjustments within crops involved in mixtures could also be a means of shifting the balance of competition and increasing the total population pressure of the system. In double or triple row intercropping of sorghum within pigeonpea, grouping the rows of sorghum as close as possible has been attempted to provide more spatial advantage to pigeonpea (Shelke, 1976). Preliminary results indicated that grouping of sorghum rows as close as 20 cm or less has not appreciably reduced the sorghum yield while improving the growth of pigeonpea. When the rows of one of the component crops can be widened, the other component can be distributed over more rows at a constant proportional population. Thus the space allocated to the second crop is greater and rectangularity is improved. This may in turn allow higher populations of the second component for even greater advantages (Singh 1976). To what extent increasing population in intercropping can influence yield advantages is seen from Table 6. When pigeonpea at 67.5 cm was alternated with two rows of intercrops at 22.5 cm the system contained on the whole 67% relative population of pigeonpea and 133% relative population of intercrop compared to the 50:50 alternate rows at 45 cm. The average advantage from the former was 94% compared to 22% from alternate rows.

The complimentary advantage of growing two species together can perhaps be further extended to three or more crops. Especially when one species is a long duration one and requires wide rows, experimental evidence has shown greater advantage from 3 crop intercropping than 2 crop intercropping (Andrews, 1972; Baker, 1974, Hart, 1974 and Krantz et al, 1976); and perhaps 3 crop systems may prove more stable.

Experiments on both black and red soils were conducted at ICRISAT in 1975 and 1976 to evaluate pigeonpea containing 2 or 3 crop systems. Details are given below:

——150cm—— 25 cm P m m S m m P m m S m m P	P.Pea+mung+sorghum	) 3 crop systems, 1975
P M S M P M S M P	P.Pea+maize(C)+Sorghum	)
P s G s P s G s P	P.Pea+setaria+G.nut	) 3 crop systems, 1976
P s G G G s P s G ———225 cm——— 37.5 cm	P.Pea+setaria+G.nut	)
P S S S P S S S P	P.Pea+sorghum or setaria or G.nut	) 2 crop systems, in 1975 or 1976

In 1975, intercropping advantage was of the same magnitude (30-90%) on both soil types irrespective of the number of crops in the system, (Table 7). In 1976, three crop systems showed greater advantage on black soil compared to red soil primarily due to less moisture stress in the former and consequently higher setaria yield. Three crop intercropping showed maximum advantage (56-90%) in a good year, 1975, but showed as much benefit as 2 crop systems in an unfavourable season, 1976 (Table 8). Proper alignment of rows and extended temporal use of resources had realised the greatest complimentarity when the 3-crops were grown together. Widening row width of pigeonpea (PP) to 225 cm, whilst maintaining its population, helped to increase the population pressure of the three crop system to 183% of the component sole crops (Pigeonpea 100% + 33% Set. + 50% G.nut) compared to 175% (100% Pigeonpea + 75% Set/G.nut or 100% Pigeonpea + 50% Set. + 25% G.nut) in other systems. Similarly total population pressure for three crop systems of 1975 Pigeonpea + mung + sorghum and Pigeonpea + maize (cobs) + sorghum worked out 217% and 250% respectively compared to 150% in the case of two crop system, Pigeonpea + sorghum.

Planting pattern on broad ridge and furrows:

When planting and subsequent operations are largely carried out by hand, it may often be possible to get reasonably near the ideal spatial arrangement. However, when considering a watershed-based cropping systems approach in SAT, it may often be necessary to depart from the ideal because of restrictions imposed by various soil and water management practices or the use of bullock drawn equipment. The traditional ridge and furrow system (75 cm apart) often makes it difficult to achieve appropriate planting patterns for intercrop and sequential systems (Kampen and Krantz, 1976). Alternatively, broad ridge and furrows have been suggested and preliminary experiments have shown them to be promising. Broad ridges at 150 cm apart can provide at least a 100 cm planting bed that can satisfy spatial requirements more easily. Suggested cropping systems with details of planting patterns, some of which have been successfully adopted at ICRISAT are shown in Fig. 1 (Kampen and Krantz, 1976).

Any long duration crops like castor, avare (Dolichas lab lab) cassava etc., could take the place of P.pea at the centre of the bed and one row of intercrop (sorghum, maize, millet, setaria, ragi) on either side at 45 cm could be planted. But in the case of low growing and short duration crops two rows at 25 cm apart can be established on either side instead of one. Where sorghum ratooning is not an economical proposition (Fig.1) and sequential post-monsoon crops such as chickpea and safflower are to be established, sorghum stubbles and their regrowth pose operational problems and compete with establishing crops (Krantz et al, 1974). In such circumstances monsoon sorghum can be planted as two rows 90-100 cm apart on the bed so that interference of stubbles can be lessened while establishing post-monsoon crops between these rows. For maize too, though its stubble does not regrow, spacing at 100 cm apart, or two line at 60 cm in the centre, may facilitate easy establishment of sequential crops. Where supplemental irrigation is not required for post-monsoon crops e.g. like chickpea and safflower on deep black soils the furrow space could also be sown with the crop.

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Table 1 : Effect of row spacing and fertility level on the performance of sorghum and pigeonpea.

Crop/System	Row width cm.	Red soil q/ha 0	Red soil q/ha 60N	Black soil q/ha 0	Black soil q/ha 60N
Sorghum	45	8.9	29.6	15.2	35.2
	90	17.2	27.1	17.6	33.2
Pigeonpea	45	11.9	-	14.5	-
	90	12.5	-	13.8	-

Table 2 : Effect of spacing configuration on grain yield of sorghum, (Blum and Naveh, 1976).

Spacing Treatment cm	Bet Dagan 1971	Bet Dagan 1972	Bet Dagan 1973	Lakhish 1973
100 (Normal)	39.9	44.7	45.7	32.2
40 - 140	36.3	-	-	-
40 - 160	48.8*	49.1*	48.4	33.5
40 - 180	45.1	-	-	-
40 - 200	45.6	-	-	-
80 - 120	-	44.1	45.0	-
60 - 140	-	51.1*	48.9	33.9
20 - 180	-	40.2	44.4	-
150 (Normal)	-	-	-	34.2
60 - 240	-	-	-	36.9
80 - 220	-	-	-	35.1

*Significantly different from the normal (P = 0.05)

Table 3 : Effect of pairing (grouping) of rows on the performance of some rainfed crops (AICRPDA, 1971-72)

Crop/System	Centre	Uniform rows q/ha	Paired (Grouped) rows q/ha
Sorghum	Hyderabad	11.4	13.0
Pearl millet	Hyderabad	11.8	16.3
Pearl millet pure	Anand	18.2	21.9
Pearl millet intercrop	Anand	19.0	18.9
Pearl millet pure	Rajkot	18.7	22.7
Pearl millet intercrop	Rajkot	17.9	24.7
Raya, pure	Hissar	6.9	8.3
Raya, intercrop	Hissar	4.3	6.5

Table 4 : Effect of different relative proportions of crops in intercropping.

Proportional population (Sorghum-Pigeonpea, AICRPDA 1973-74) S : PP	Land equivalent ratio Sorghum	Land equivalent ratio Pigeonpea	Land equivalent ratio Total	Maize-Soybean Proportional population M : S	Land equivalent ratio M	Land equivalent ratio S	Land equivalent ratio Total
5 : 0	1	-	1	10 : 0	1	-	1.00
4 : 1	0.73	0.24	0.97	8 : 2	0.82	0.12	0.94
3 : 2	0.67	0.50	1.17	6 : 4	0.72	0.19	0.91
2 : 2	0.61	0.55	1.16	5 : 5	0.71	0.27	0.98
2 : 3	0.44	0.81	1.25	4 : 6	0.69	0.38	1.07
1 : 4	0.22	0.92	1.14	2 : 8	0.52	0.82	1.34
0 : 5	-	1	1	0 : 10	-	1.00	1.00

$$\text{Land Equivalent Ratio (LER)} = \frac{\text{Yield of crop A in intercrop}}{\text{Yield of crop A in monocrop}} + \frac{\text{Yield of crop B in intercrop}}{\text{Yield of crop B in monocrop}}$$

Table 5 : Effect of spatial arrangement at constant population on intercropping advantage (LER) in some pigeonpea based intercrop systems (Krantz *et al*, 1975).

Intercrop system	Alternate rows 45 cm	Grouped rows 25-50 cm	Alternate double rows of intercrop 22.5 cm
Pigeonpea Cowpea	1.08	1.26	1.40
Pigeonpea Setaria	1.07	1.33	1.48
Pigeonpea Pearl millet	1.28	1.22	1.37
Pigeonpea Sorghum	1.07	1.41	1.23
Mean	1.13	1.31	1.37

Mean of two soil types.

Table 6: Effect of two methods of planting pattern in some pigeonpea based intercropping systems (Krantz *et al*, 1974)

Intercrop system	Alternate rows 45 cm apart	Alternate double rows of intercrop 22.5 cm apart
Pigeonpea Mungbean	1.13	1.79
Pigeonpea Soybean	1.34	2.00
Pigeonpea Ragi	1.26	1.98
Pigeonpea Sunflower	1.18	2.08
Pigeonpea Pearl millet	1.17	1.84
Mean	1.22	1.94

Data are mean land equivalent ratios (LER) over two soil types.
Population pressure in alternate rows is 50 : 50, in alternate double rows is 67 : 133.

Table 7 : Yield and land equivalent ratios in Pigeonpea containing 2 crop and 3 crop intercropping systems, 1975 - 76.

Crop	Sole Crop q/ha	Pigeonpea + Sorghum Yield	LER	Pigeonpea + Mung + Sorghum Yield	LER	Pigeonpea + Maize + Sorghum Yield	LER
			Red Soil				
Pigeonpea	22.5	10.7	0.47	14.5	0.64	10.9	0.48
Mung	7.6	-	-	2.9	0.38	-	-
Sorghum (DM)	210.8	181.7	0.85	128.7	0.51	77.5	0.39
Maize (Cobs)	33,744	-	-	-	-	37,086	1.10
Total LER	-	-	1.33	-	1.63	-	1.97
			Black Soil				
Pigeonpea	28.2	15.1	0.53	16.3	0.57	14.0	0.49
Mung	14.3	-	-	5.7	0.39	-	-
Sorghum (DM)	307.6	229.1	0.74	165.4	0.53	119.1	0.38
Maize (Cobs)	34,577	-	-	-	-	32,919	0.95
Total LER	-	-	1.27	-	1.49	-	1.82
Mean of both soils.	-	-	1.30	-	1.56	-	1.90

DM - Total dry matter.

Table 8 : Yields and land equivalent ratios of Pigeonpea containing 2 crop and 3 crop intercropping systems 1976 - 1977.

Crop	yield q/ha	2 crop intercropping				3 crop interoropping			
		P.Pea +Set. 150 cm		P.Pea + G.nut 150 cm		P.Pea + Set + G.nut 150 cm		P.Pea + Set + G.nut 225 cm	
		Yield	LER	Yield	LER	Yield	LER	Yield	LER
Red Soil									
Pigeonpea	4.7	4.0	0.85	4.0	0.85	3.5	0.74	2.7	0.58
Setaria	24.7	18.6	0.75	-	-	14.2	0.57	9.7	0.39
Groundnut	14.1	-	-	9.7	0.68	2.4	0.17	3.8*	0.27
Total			1.60		1.53		1.48		1.24
Black Soil									
Pigeonpea	12.2	7.0	0.57	10.7	0.87	8.1	0.66	6.3	0.51
Setaria	17.7	19.7	1.11	-	-	18.4	1.04	14.8	0.83
Groundnut	5.4	-	-	2.2	0.41	0.7	0.13	2.5	0.46
Total			1.68		1.28		1.83		1.8
Mean of both soils			1.64		1.41		1.66		1.52

* Groundnut yield from 2 plots was low due to poor stand. Mean LER when calculated excluding effected plots works out to 1.59. Yield in q/ha.

FIG.1: SOME POSSIBLE CROPPING SYSTEMS ON BROAD RIDGES AND FURROWS