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EVALUATION OF ALTERNATE CROPPING SYSTEMS FOR ALFISOLS OF THE INDIAN SEMI-ARID TROPICS†

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SUMMARY

A three-year experiment examined the possibility of increasing the cropping intensity of a medium-deep Alfisol (red soil) by using sequential, relay, ratoon or intercropping systems. It was found that a short-season mungbean (*Vigna radiata*) crop could be taken before the commonly-grown castor crop but that castor yields were reduced by the delayed sowing. If the castor was sown after the harvest of mungbean in a sequential system the profits were less than from a sole castor system. Relay-sowing the castor 20 days before the harvest of mungbean gave 9 $US ha^{-1} greater profit than sole castor, but this is probably not enough to justify the more intensive double crop system. On the other hand a reasonable yield of horsegram (*Macrotyloma uniflorum*) could be produced after an early pearl millet crop, giving a worthwhile extra profit of 21 $US ha^{-1} compared with sole pearl millet. Ratooning the sorghum gave ratoon yields that averaged only 14% of the first crop, so this system was not considered suitable for these lighter Alfisols.

Intercropping systems of pearl millet/groundnut, sorghum/pigeonpea and groundnut/pigeonpea gave average yield increases of 24, 47 and 46%, respectively, compared with both component crops grown separately. Compared with growing only the higher value sole crop, increases in profits were 16, 82 and 120 $US ha^{-1} for the same three systems, respectively. It is concluded that intercropping systems provide the best opportunity for increasing cropping intensity on medium-deep Alfisols.

Alfisols (red soils) are the third most important soil order in the world, covering 13.1% of the total land area (Burnigh, 1982). In India alone, where they are shallow to medium in depth, the Alfisols occupy 59.6 million hectares. Clay content increases with depth and the subsoil is usually compact and interspersed with murram (El-Swaify *et al.*, 1983). Water holding capacity is small, varying from 50 to 150 mm according to depth. Thus there is little residual soil moisture for crop growth after the end of the rains and in semi-arid areas there are frequent within-season droughts.

In the Indian semi-arid tropics (SAT) the common Alfisol crops are sorghum, pearl millet, groundnut, pigeonpea and castor; these may be grown either as sole crops or in various intercropping systems. The traditional cereal varieties tend to be fairly long season, maturing after the end of the rains and making at least some use of residual soil moisture. As the staple food crops, cereals are often the dominant component of intercropping combinations. Groundnut is commonly a sole crop but is also found intercropped with

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wide rows of pigeonpea or millet. Pigeonpea is almost invariably intercropped and as a long-season, deep-rooting crop it has the special advantage of utilizing residual moisture, and producing some additional yield, after the harvest of earlier intercrops; but it is usually sparsely sown, so as not to compete too much with the earlier crops, and its yields are low. Castor has a similar role to pigeonpea, especially on shallow soils, but because of its importance as a cash crop it is also commonly grown as a sole crop. Typical yields of unfertilized traditional varieties quoted from on-farm studies are: sorghum 300-500 kg ha^{-1}, millet 300-450 kg ha^{-1}, groundnut 400-600 kg ha^{-1}, pigeonpea 200-300 kg ha^{-1} and castor 300-550 kg ha^{-1} (Rastogi *et al.*, 1982; Sanghi and Rao, 1982).

Under rainfed conditions on the Alfisols, there is usually thought to be little opportunity for producing much more than the equivalent of a single crop. This paper describes a three-year study which examined the scope for raising cropping intensity either with various 'double' crop systems that incorporate earlier maturing genotypes, or with improved intercropping systems.

MATERIALS AND METHODS

Experimental site

Experiments were conducted at the ICRISAT Centre, about 25 km northwest of Hyderabad (17° N, 500 m elevation), from 1978 to 1981 on medium deep Alfisols which have the physical and chemical characteristics shown in Table 1. These soils are low in nitrogen and available phosphorus but high in potassium.

Climatic conditions

The rainy season is approximately from mid-June to the end of September and on average 86% of the annual total rain falls during this period. Rainfall is very erratic, with an annual coefficient of variation of 26% (Virmani, 1979); data for the last eight years have shown a variation in total from 320 mm (1972) to 1400 mm (1971). Rainfall was 1202 mm in 1978-79, 833 mm in

Table 1. *Physical and chemical characteristics of a medium deep Alfisol at the ICRISAT Centre*

	Mechanical composition											
Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Field capacity (θW)	Wilting point (θW)	pH 1:2.5	Bulk density (g cc^{-1})	Cation exchange (me 100 g^{-1})	Organic carbon (%)	Total P (%)	K (me 100 g^{-1})
0–18	37.0	27.5	6.0	29.6	18.1	9.4	6.7	1.57	10.0	0.20	0.0130	0.4
18–35	30.5	15.3	7.2	47.2	21.9	13.9	5.8	1.72	16.4	0.32	0.0110	0.6
35–62	29.5	15.3	8.9	47.0	24.8	17.4	6.1	1.65	18.8	0.35	0.0086	0.6
62–105	25.8	11.5	7.4	55.2	23.6	16.2	6.4	1.75	19.8	0.29	0.0089	0.4
105–145	34.8	15.8	9.1	40.6	18.7	11.5	6.6	1.83	22.2	0.14	0.0140	0.3

Source: Sardar Singh and B. A. Krantz (1976) – unpublished data.

1979-80 and 751 mm in 1980-81. In the particularly wet season of 1978-79 a record amount of rain (517 mm) fell in August. During the 1980-81 season, the rains receded very early, in mid-September. Further details of rainfall distribution and temperature regimes are shown in Fig. 1 and have been described previously by Reddy and Willey (1982).

Treatments

Four broad types of cropping system were examined: sequential, relay, ratoon and intercropping (see Reddy and Willey, 1982). Details of crop varieties, maturity periods and spacings are given in Table 2 and specific treatments in each year in Table 3. Castor, groundnut, sorghum and pearl millet are

Table 2. *Varieties, days to maturity and spacings of different sole crops and intercrops grown on Alfisols at the ICRISAT Centre during 1978-81*

Crop	Variety	Days to maturity	Row to row spacing (cm)	Within-row spacing (cm)
		Sole crops		
Castor	Aruna	150	60	28
Sorghum	CSH 6	95	45	12
Millet	BK 560	85	30	15
Pigeonpea	ICP 1	190	60	28
Groundnut	Robut 33-1	110	30	10
Mungbean	S8	70	30	10
Horsegram	Local	90	30	10
		Intercrops		
1 row millet	BK 560	85	30	15
3 rows groundnut	Robut 33-1	110		10
2 rows sorghum	CSH 6	95	45	8
1 row pigeonpea	ICP 1	190		12
1 row pigeonpea	ICP 1	190	22.5	12
5 rows groundnut	Robut 33-1	110		13

Table 3. *Seed yields (t ha^{-1}) from various cropping systems on Alfisols at the ICRISAT Centre*

Cropping system	1978-79	1979-80	1980-81	Mean
Sole castor	1.46	1.14	1.04	1.21
Sole groundnut	1.24	1.17	1.17	1.19
Sole sorghum	2.52	2.24	2.83	2.53
Sole pearl millet	1.94	2.10	1.87	1.97
Sole pigeonpea	–	1.22	1.01	1.12
Sorghum/pigeonpea intercrop (2:1)	2.17/0.42	1.68/0.83	2.39/0.63	2.08/0.63
Millet/groundnut intercrop (1:3)	0.85/0.87	1.06/0.88	1.29/0.75	1.07/0.83
Pigeonpea/groundnut intercrop (1:5)	–	0.84/0.84	0.77/0.93	0.81/0.88
Mungbean + relay castor	0.63 + 0.88	0.60 + 0.74	0.57 + 0.29	0.60 + 0.64
Mungbean + sequential castor	0.59 + 0.67	0.57 + 0.61	–	0.58 + 0.64
Millet + relay horsegram	1.87 + 0.59	2.10 + 0.54	–	1.98 + 0.56
Millet + sequential horsegram	1.94 + 0.62	–	1.87 + 0.38	1.91 + 0.50
Sorghum + ratoon sorghum	2.52 + 0.50	–	2.83 + 0.24	2.67 + 0.37

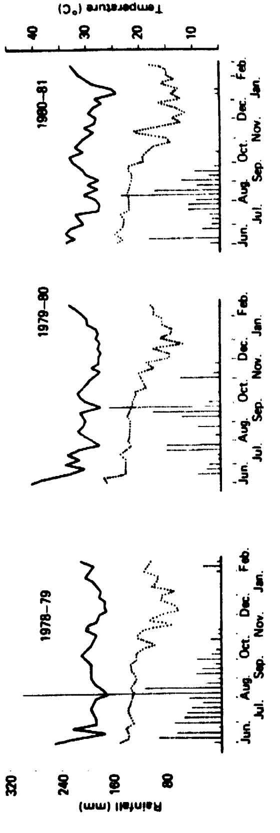

Fig. 1. ll dis mm) and temperature regime (——maximum, ... minimum °C) during the experiment.

commonly grown as sole crops and were thus included as such in all three years of the experiment. For sorghum and pearl millet the yields of first crops in ratoon and sequential systems, respectively, were taken as the measure of productivity in sole crop systems; in 1979 the yield of pearl millet in a pearl millet and relay horsegram system was taken as the sole crop pearl millet yield. Because pigeonpea is almost invariably grown as an intercrop, a sole pigeonpea treatment was not included in the first year but thereafter it was included for comparative purposes.

Two combinations were tried as sequential systems (where the second crop is sown after the harvest of the first) and as relay systems (where the second crop is sown about three weeks before the harvest of the first): the very hardy horsegram was sown after an early-maturing pearl millet, and a very early mungbean was grown before the traditionally late-sown castor. An early sorghum hybrid was tried in a ratooning system (where the stubble of the first crop is allowed to re-grow to produce a second 'ratoon' crop); although sorghum ratooning is well recognized as a means of producing a low cost second crop on deep soils with good residual moisture supply, no information was available for Alfisols. Unfortunately not all the sequential, relay and ratoon treatments could be accommodated in the last two years (see Table 3).

Two intercropping combinations, sorghum/pigeonpea and pearl millet/groundnut, were examined in all three years; both these combinations had been found promising in more detailed intercropping studies at ICRISAT. Sorghum/pigeonpea is one of the most common 'temporal' combinations in India, the sorghum occupying the rainy season and the pigeonpea making much of its growth on the residual soil moisture left after the sorghum harvest. In this treatment the sorghum was an early hybrid and the arrangement was 2 rows sorghum:1 row pigeonpea, with each crop at its full sole crop population; the objective was to maintain a good yield of sorghum, the main crop in the system, while producing a much larger yield of pigeonpea than is achieved from the sparse pigeonpea populations used in local farming practice. The pearl millet/groundnut was grown as a simple replacement treatment in a 1 row pearl millet:3 rows groundnut arrangement where the within-row spacing for each crop was the same as its sole crop; with this combination the aim was to maintain a good yield of groundnut, an important cash crop, while also producing a worthwhile yield of pearl millet. After the first year, an intercrop of pigeonpea/groundnut was included in a 1 row pigeonpea:5 rows groundnut arrangement; this had additive populations, as with the sorghum/pigeonpea, in order to produce a good yield of each crop. For all three intercropping combinations both components were sown simultaneously.

Experimental design and analysis

In each year the experiment was laid out in a randomized block design with three replicates. Yields were not statistically analysed because of the very different types and amounts of yield produced by the different crops involved. However, gross and net returns were analysed and maximum CVs for any one year were 7.9 and 11.4%, respectively. (Net returns were estimated by deducting actual experimental inputs for seed, fertilizer and pesticide costs but the small plots did not allow estimates of land preparation and labour costs).

Returns were based only on seed yields because of difficulties in valuing some of the crop by-products (e.g. groundnut haulms for fodder and pigeonpea stalks for fuel). This underestimation of total crop value would be greatest for the sorghum crop where straw can add up to 15–20% on gross returns.

Routine procedures

Crop cultivars were the same in all years (Table 2). The early maturing crops of mungbean, pearl millet, sorghum and groundnut matured about 70, 85, 95 and 110 days after sowing, respectively. The late maturing crops of castor and pigeonpea matured in about 150 and 190 days, respectively. First crops were sown during the last week of June each year, just after the onset of the rains. In all three years initial establishment of all crops was satisfactory.

The experiments were conducted in small-scale plots of about 48.6 m^2 gross area and 18.9 m^2 harvest area. Fertilizer was applied by hand and placed below the soil surface along the side of the crop rows. All sole crops (including both first and second crops of relay and sequential systems) received 18 kg N and 46 kg P_2O_5 ha^{-1} as basal fertilizer, and the cereal and castor crops were top dressed with 62 kg N ha^{-1}. The sorghum ratoon crop was only given a top-dressing of 40 kg N ha^{-1}. The intercrop plots received the basal fertilizer dressing at the same level as the sole plots. Sorghum in the sorghum/pigeonpea intercrop received a higher N top-dressing per row to give the same overall rate per unit area as the sole sorghum because of the objective of producing a high proportional sorghum yield. Pearl millet in the pearl millet/groundnut intercrop received a N top-dressing at the same rate per row as the sole crop, that is per unit area the intercrop received only one quarter of the N top-dressing of the sole crop. All crops were hand weeded twice during the rainy season and once during the post-rainy season for the late maturing crops and the relay, sequential and ratoon crops. Plant protection measures were used as necessary to control sorghum shootfly (*Atherigona soccata*), castor semilooper (*Achoea janata*), pigeonpea pod borer (*Heliothis armigera*) and groundnut thrips (*Frankliniella schultzei*).

RESULTS AND DISCUSSION

Yields for each year are presented in Table 3. For all five crops the sole crop yields were considerably more than typical farm yields, probably because of the improved genotypes and fertilizer application. Sole crop yields were consistent across years, the maximum variation being a castor yield 20% below the mean in 1978–79.

In the double-crop systems where mungbean was grown before castor, mungbean yield ranged from 570 to 634 kg ha^{-1}, which is very good for this short season crop. However, because later sowing caused greater end-of-season drought stress, especially in drier years, castor yields in the double-crop systems were less than the sole crop, and the sequential castor crop yielded less than the relay crop. In the double-crop systems where horsegram followed pearl millet, yields of horsegram were good in the first two years but low in 1980, suggesting an effect of the early cessation of the rains. In the only year when sequential and relay horsegram could be compared (1978–79) there was no difference between these two systems, though this was admittedly a heavy rainfall year. For the ratoon sorghum crop yields were only 20 and 8% of the first crop in 1978–79 and 1980–81, respectively; shootfly attack on the ratoon growth was particularly severe in both years, but lack of sufficient residual soil moisture was probably another major factor, as indicated by the virtual failure of the crop in 1980.

In the pearl millet/groundnut intercropping system, the groundnut yield averaged 70% of the sole crop, over the three years. Thus despite the fact that it was partially shaded by the pearl millet, the groundnut produced a yield only slightly smaller than the 75% yield 'expected' from its sown proportion. On the other hand, the millet produced an average yield of 54% of the sole crop, more than twice the 25% expected from its sown proportion. This increase over the expected pearl millet yield must have occurred because of an increase in yield per plant, a response that has been attributed elsewhere both to an increase in tillering and head number and to a greater yield from the main stem (Reddy and Willey, 1981). Pearl millet is obviously more competitive than groundnut in this combination and the pearl millet plants were presumably responding to what was effectively a low population of pearl millet. Combining the two crops, this intercropping combination gave a 24% yield advantage, possibly because of more efficient use of intercepted light (Reddy and Willey, 1981) and moisture (Varasoot 1982).

The sorghum/pigeonpea intercropping combination averaged 82% sorghum and (for the two years in which sole pigeonpea was included) 65% pigeonpea, an advantage of approximately 47% over the three years. Compared with traditional farming practice, which appears to try to preserve a 'full' yield of the staple cereal, there was a sacrifice of 20% in sorghum yield. However, this allowed a very considerable increase in pigeonpea yield. Moreover, because an improved sorghum genotype was used, the 82% sorghum yield of 2080 kg ha^{-1} was still several times greater than traditional sole crop yields. This sorghum/pigeonpea combination has been examined in more detail on both Vertisols (deep black soils) and Alfisols (Natarajan and Willey, 1981; 1985) and it has been concluded that yield advantages are not due to more efficient use of resources (i.e. more growth per unit of resource used) but to a complementary use of resources over time. Essentially, the sorghum ensures good use of early resources and the pigeonpea good use of later resources. A similar type of temporal complementarity no doubt occurred in the groundnut/pigeonpea intercrop, which produced 74% groundnut and 72% pigeonpea, an average of a 46% advantage in the two years in which it was tried. Compared with the sorghum/pigeonpea combination groundnut was obviously a little less competitive than sorghum, resulting in a slightly lower proportional yield of groundnut but a slightly higher proportional yield of pigeonpea.

The profitability of these different systems is shown in Fig. 2. Sole crops of groundnut, pigeonpea and castor averaged good returns, mainly by virtue of their large unit value. Sole sorghum was also quite good on average because of its large yield; sole millet averaged rather less than sole sorghum because of a smaller yield and, in 1980–81, a lower price. The mungbean and sequential castor system had no advantage over sole castor, with less profit in 1978–79 and a similar profit in 1979–80. The mungbean and relay castor was a slightly better system than the sequential one but it was only more profitable than sole castor in 1979–80, and over the three years it gave on average only an extra 9 $US ha^{-1}. It is unlikely that this return would be sufficient to encourage a farmer to try the more intensive double crop system. Moreover, the crop most at risk is the potentially more profitable castor, as shown by its poor yield in 1980–81. Horsegram grown after pearl millet gave a reasonable additional profit compared with sole pearl millet in all three years, averaging an extra 21 $US ha^{-1}. Where pearl millet is the preferred cereal this system could be useful, providing an opportunity for some additional profit without jeopardizing the main crop.

In most instances the intercropping systems were more profitable than any of the sole crops; the exception was the pearl millet/groundnut combination, which did not quite exceed the best sole crops in 1978–79 and 1980–81, essentially because of the relatively small value of its pearl millet component. If these intercropping systems are compared with the same yield proportions of their two components grown as sole crops, the increases in profitability work out at 70 $US ha^{-1} for sorghum/pigeonpea, 31 $US ha^{-1} for pearl millet/groundnut, and 142 $US ha^{-1} for groundnut/pigeonpea. (In percentage terms these increases are exactly the same as those given for yield, i.e. 47, 24 and 46%, respectively). As indicated earlier, however, it may often be more relevant to compare intercropping returns with the main component grown as a sole crop. On this basis sorghum/pigeonpea gave an increased profitability of 82 $US ha^{-1} (46%) compared with sole sorghum. Similarly, pearl millet/groundnut gave 16 $US ha^{-1} (8%) more than sole groundnut, though an important feature of this combination is that it produces a reasonable yield of the pearl millet food crop in addition to a good cash crop of groundnut. Groundnut is also traditionally the main crop of the groundnut/pigeonpea combination, though in recent years pigeonpea has become a high

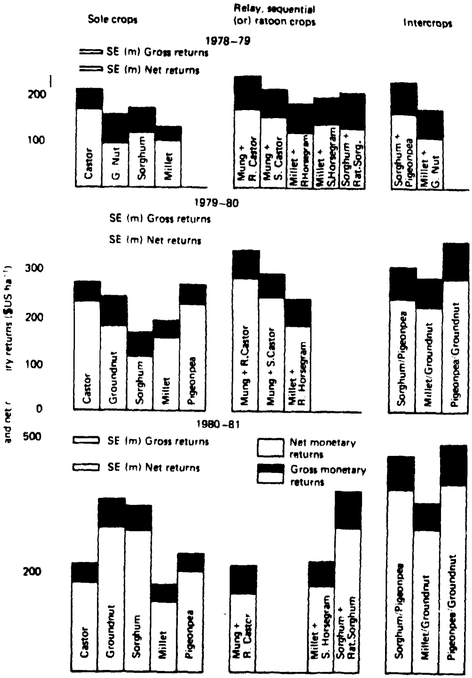

Fig. 2. Gross and net monetary returns from various cropping systems grown on Alfisols at the ICRISAT Centre (1978-1981). R-Relay, S-Sequential, G-Nut-Groundnut, P-Pea-Pigeonpea, Sorg-Sorghum and Rat-Ratoon. Prevailing market prices (rupees 100 kg^{-1}, 1 $US = 12 rupees) one month after harvest of the respective crops, used for calculating gross returns for 1978-79, 1979-80 and 1980-81, were respectively, castor 170, 285 and 265; groundnut 150, 250 and 375; sorghum 80, 90 and 150; millet 80, 110 and 116; pigeonpea 230, 260 and 297; mungbean 200, 330 and 342; horsegram 100, 102 and 177.

value crop; this combination averaged 147 $US ha^{-1} (76%) more than sole groundnut and 120 $US ha^{-1} (54%) more than sole pigeonpea.

In general therefore, compared with sole crops the intercropping systems gave a greater increase in profitability than the relay or sequential systems. The intercropping systems also offer greater stability because they do not run the same risks of a poor yielding second crop. Even on a deep Vertisol, where sequential cropping is far less risky, a maize/pigeonpea intercropping system gave more stable returns than a maize and sequential chickpea system (Reddy and Willey, 1982). It has also been shown that the probability of net returns falling below any given 'disaster' level is much less for a sorghum/pigeonpea intercrop than for its constituent sole crops (Rao and Willey, 1980). These stability aspects could not be measured in the present experiments but it was very evident that in 1980–81, when the rains ended early, the sequential and relay systems offered little or no advantage over the sole crops, whereas the intercropping systems were particularly good.

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