O'Loughlin CL and Pearce AJ, eds, Symposium on Effects of Forest Land use on Erosion and Slope Stability, pp 231–239. Environment and Policy Institute, East-West Center, University of Hawaii, Honolulu, USA
Wiersum KF (1985) Effects of various vegetation layers in an *Acacia auriculiformis* plantation on surface erosion in Java, Indonesia. In: El-Swafy, Moldenhaur and Lo A, eds, Soil Erosion and Conservation, pp 79–89. Soil Conserv. Soc. Am., Ankeny, Iowa, USA
Young A (1989) Agroforestry for Soil Conservation. CAB International, England

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Productivity of annual cropping and agroforestry systems on a shallow Alfisol in semi-arid India

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Abstract. An experiment was conducted at *ICRISAT* Center, Patancheru, India from June 1984 to April 1988 on a shallow Alfisol to determine whether the productivity of annual crop systems can be improved by adding perennial species such as *Leucaena leucocephala* managed as hedgerows. Except in the first year, crop yields were suppressed by *Leucaena* due to competition for moisture. The severity of competition was high in years of low rainfall and on long-duration crops such as castor and pigeonpea. Based on total biomass, sole *Leucaena* was most productive; even on the basis of land productivity requiring both *Leucaena* fodder and annual crops, alley cropping had little or no advantage over block planting of both components. Application of hedge prunings as green manure or mulch on top of 60 kg N and 30 kg P_2O_5 ha^{-1} to annual crops did not show any benefit during the experimental period, characterized by below average rainfall. Indications are that (i) alley cropping was beneficial in terms of soil and water conservation with less runoff and soil loss with 3 m alleys than with 5.4 m alleys, and (ii) root pruning or deep ploughing might be effective in reducing moisture competition.

Introduction

The potential length of the growing season on Alfisols and Vertic Inceptisols in semiarid India is generally longer than that of a single crop of 3 to 4 months, but shorter than that required for sequential systems with two short-season crops. Therefore, intercropping based on long-duration crops such as pigeonpea or castor is the most common annual cropping system on these soils [Reddy and Willey, 1985]. Even with these systems, the fraction of annual rainfall utilized by the crops (i.e. evapotranspiration) hardly exceeds 41% [El-Swaify et al., 1987] and the rest of the rainfall is lost as runoff (26%) or as deep percolation (33%). This is particularly true on shallow soils that have a hard concretionary iron stone 'murrum' layer 0.3 to 0.4 m below the soil surface that restricts root growth of annual crops. It is therefore assumed that the inclusion of a perennial species would increase total productivity by enhancing the uptake of water below the rooting depth of annual crops and by utilizing rainfall which occurs outside the annual cropping season. Furthermore, the addition of surface mulch from tree prunings could reduce the runoff when crop cover is low during the early part of the rainy season, and reduce soil evaporative losses.

Alley cropping (hedgerow intercropping) is a relatively new agroforestry system where closely planted tree hedges are pruned periodically for green manure or for fodder during the dry season. Pruning minimizes light competition to crops during the cropping period when incident radiation is generally low [Kang et al., 1990]. Diagnosis of traditional farming systems conducted in many parts of the tropics has identified low soil fertility as the major cause of poor yields and scarcity of green fodder, particularly during the dry season, as a constraint for livestock production [Hoekstra et al., 1985]. Alley cropping has been proposed as a potential technology to overcome these constraints, especially if the woody perennial chosen is a legume with high fodder value. This technology has been tested in humid and sub-humid environments using *Leucaena leucocephala* amongst other multipurpose trees [Kang et al., 1990], but its relevance for semi-arid India was not examined until recently [Singh et al., 1989b].

The experiment described here was one of a series of trials initiated in 1984 at ICRISAT Center, India to test the hypotheses that the addition of woody perennials to annual crop systems: (i) improves the overall productivity by exploiting the residual moisture and nutrients beyond the reach of annual crops, (ii) improves soil fertility and consequently crop yields by utilizing the prunings of the perennial as green manure and/or mulch, and (iii) reduces soil erosion by providing a protective soil cover.

Materials and methods

Site and experimental layout

The experiment was conducted at ICRISAT Center between June 1984 and April 1988 on a shallow Alfisol in contrast to two other trials initiated simultaneously, one on deep Alfisols [Rao et al., 1991] and another on Vertic Inceptisols [Rao et al., 1990]. The ICRISAT Center is located at 18°N, 78°E and 540 m elevation, Patancheru, Andhra Pradesh, India. It receives a mean annual rainfall of 765 mm, 80% of which occurs during June–October. The experimental site was a fairly flat area typical of the region (1–2% slope) with 0.40 to 0.45 m profile depth and a hard disintegrating 'murrum' below. It was cropped in the previous 5 years with sole castor and sorghum/pigeonpea intercrop in alternate years using moderate levels of fertilizers.

There were two sets of four treatments each, viz. a sole perennial, a sole annual crop and two alley cropping systems with the perennial rows spaced at 3 m and 5.4 m. The perennial was *Leucaena leucocephala* Lam. cv. Cunningham — a Peru type selected for forage. In one set, 'the fodder treatments' prunings from the *Leucaena* were taken out as fodder, while in the other the 'mulch treatments' they were either incorporated into the soil or used as mulch for soil fertility improvement. The eight treatments were replicated thrice in a randomized block design. Fodder removed from sole *Leucaena* of the first set of treatments was used for mulching the annual crop plot of the second set of treatments. *Leucaena* was planted in the sole system at 1.2 m × 0.25 m spacing, but in alley cropping it was established in paired rows at 0.6 m × 0.25 m within the pairs and 3 m or 5.4 m between pairs. The plot size varied across treatments: 6 × 11 m for sole *Leucaena* and annual crop systems, 10 × 11 m for the narrow-alley and 15.6 × 11 m for the wide-alley agroforestry systems. Crop and *Leucaena* yields were measured leaving sufficient border on all sides from net plots of 32 m^2 for sole *Leucaena* and annual crops, 73 m^2 in the narrow-alley system and 54 m^2 in the wide-alley system. The annual crop system was pearl millet (*Pennisetum glaucum* (L) Br.)/pigeonpea (*Cajanus cajan* L. Millsp) intercrop in the 1984 and 1986 cropping seasons, castor (*Ricinus communis*) in the 1985 and groundnut (*Arachis hypogea* L.) in the 1987 cropping season.

In order to identify probable causes of negative effects of hedges on crops, some additional treatments were superimposed in the 1987 rainy season in replication 3. Thick polythene barriers were installed between hedge and crops at 0.5 m from hedge and to 0.5 m depth to prevent root competition of hedges on the alley crop. To examine the effect of time of hedge pruning on the crop, the first pruning of the 1987 cropping season was carried out early (15 July, 1987) or late (15 August, 1987) on different hedges within a plot. These treatments were designed to quantify the magnitude of the above- and below-ground competition between *Leucaena* and groundnut.

Crop and tree management

Crops were sown every year normally in June/July after the rains had wetted at least the top 0.3 m (Table 1). *Leucaena* was established in September 1984, about two months after the annual crops were sown that year, by transplanting eight-week-old seedlings raised in polythene bags. The millet/pigeonpea intercrop was sown in an arrangement of 1 row pigeonpea: 2 rows millet at a constant 0.4 m row spacing. It was sown in a similar arrangement in alley cropping but with a 0.5 m gap between *Leucaena* and the first pearl millet row instead of 0.4 m. Castor in 1985 was sown at the same spacing as pearl millet/pigeonpea, but groundnut in 1987 was sown at 0.3 × 0.1 m spacing. These spacings correspond to the recommended populations for these crops in their sole systems, which means that in agroforestry 33% and 20% of the total area was lost to hedges with 3 m and 5.4 m alley spacings respectively. In the first year, 50 kg P_2O_5 ha^{-1} was incorporated into the soil before the crops were sown, and only pearl millet was top dressed with 60 kg N ha^{-1} after thinning. *Leucaena* was inoculated with the appropriate rhizobium culture and was not fertilized in the subsequent years. Castor in the second year and pearl millet/pigeonpea intercrop in the first and third years were fertilized at 60 kg N-30 kg P_2O_5 ha^{-1}, while groundnut in the final year was fertilized with 30 P_2O_5 ha^{-1}.

Table 1. Details of crops grown in different years during a study on Alfisols at ICRISAT Center, India.

Crops/Operations	Years			
	1984–85[a]	1985–86	1986–87	1987–88
Annual crops	Millet/Pigeonpea	Castor	Millet/Pigeonpea	Groundnut
Sowing date	July 16	June 19	June 23	June 18
Cultivars	BK560/ICP1-6	Aruna	BK560/ICP1-6	Kadiri 3
Density (plants ha^{-1})[b]	150,000/50,000	50,000	150,000/50,000	330,000
Duration of crops (days)	90/130	205	90/185	110
Number of *Leucaena* harvests[c]	Nil	4	4	3
Rainfall (mm) June–Oct.	591	477	538	596
Nov–May	70	140	84	360

[a] Agricultural year: rainy season June–October and dry period November–May.
[b] As sown in annual crop systems.
[c] *Leucaena leucocephala* cv. Cunningham was transplanted on 12–14 September, 1984 and finally removed on 7 April, 1988.

Leucaena required dusting with a mixture of Carbaryl and BHC to protect against leaf-eating caterpillars immediately after planting and spraying with Bavistin (1 g/l water) one month later in October. No other plant protection was given to either *Leucaena* or crops.

Leucaena was harvested for the first time in June 1985 at 0.75 m height and subsequently pruned at the same height. A total of eleven harvests were done during the course of the study, four in 1985/86, four in 1986/87, and three in 1987/88. The harvested material was separated into foliage and wood (stems of 5 mm diameter or more), both components were removed from the site in the fodder treatments but the foliage was either incorporated or left as mulch in the mulch treatments.

Measurements and data analysis

Crop and Leucaena *yields.* Grain and other crop products (stover/stalks/haulms) were recorded after the produce was thoroughly sun dried, threshed and weighed. At each *Leucaena* harvest, fresh weights of fodder and stems were recorded and dry weights estimated based on drying a few sub-samples at 80 °C. The productivity of the systems was assessed by calculating land equivalent ratios (LER) based on grain and fodder yields [Willey, 1979]. Yields of sole systems from non-mulched plots were used for this purpose but where relevant sole crops were not part of the study, yields as measured in nearby plots under similar management were used.

Runoff and soil loss. Rainfall amount and intensity were measured using two recording and two non-recording rain gauges located near the experimental area. Aluminum sheets were used for demarcating the boundary of plots and for estimating the catchment areas contributing to runoff and soil loss. Runoff and soil loss from all plots were measured using two-stage multi-slot divisors. Each divisor was calibrated separately for accurate estimation of runoff. After each rainfall the water levels in all containers of each multi-slot divisor were recorded to estimate runoff. After each storm, six runoff samples were collected from each multi-slot divisor system to estimate soil loss. At the inlet of each multi-slot divisor, a small metal screen was provided to avoid clogging the divisor pipes due to crop residues.

Economics. A simple economic analysis was performed based on prevailing market prices for all products and costs of variable inputs and operations. The net returns were the gross returns minus the variable costs. There is no market for *Leucaena* fodder, so its value was imputed based on fodders such as sunhemp and groundnut haulms, weighted according to the period of availability in a year. *Leucaena* fodder value (dry weight) was taken as Rs 750 t^{-1} during the rainy season and Rs 1500 t^{-1} in the dry season while its wood value was taken as Rs 100 t^{-1} throughout the year.

Results

Crop and Leucaena *yields*

Crop yields in 1984 were lower than those generally expected for the season (Table 2), primarily because crops were sown late in July, three weeks after the season had started. They suffered from moisture stress towards the later part of their growth cycle due to low rainfall as well as reduced growth period. Drought stress was more severe for the pigeonpea, which had little opportunity to compensate for earlier competition from pearl millet. Yields in alley-cropping systems were lower than in annual-crop system due to the area lost to *Leucaena*. Competition from *Leucaena* was minimal in the first year as the hedges were planted almost two months after the crops were sown.

The performance of sole castor was normal the following year but castor yields from alley cropping systems were considerably reduced (Table 2). Despite two prunings of *Leucaena* during the cropping season, castor yields were only 22% of the sole system in 3 m alleys and 42% in 5.4 m alleys, which indicates the degree of competition due to *Leucaena* hedgerows. Yields were similar in non-mulched and mulched plots.

In 1986, pearl millet in annual crop system yielded 1.8 to 2.1 t ha^{-1} but pigeonpea gave poor yields (Table 3). In 3 m alleys pigeonpea failed to produce grain, while in 5.4 m alleys it gave uneconomic yields. Pearl millet yields under alley cropping were 43% and 61% of yields of annual crop

Table 2. Crop yields (kg ha^{-1}) in sole and alley-cropping systems in the first two years (1984–85 and 1985–86) of a four year study on Alfisols at ICRISAT Center, India.

Treatment	1984–85				1985–86
	Pearl millet		Pigeonpea		Castor
	Grain	Fodder	Grain	Stalks[a]	Beans
Sole Cropping					
no mulch	955	1305	460	1175	1350
with mulch	725	1420	455	1150	1180
Alley cropping (3 m alleys)					
no mulch	535	910	310	850	300
with mulch	530	925	396	870	330
Alley cropping (5.4 m alleys)					
no mulch	640	1045	415	1010	570
with mulch	650	1065	385	1120	585
SE ±	29	60	40	89	76
CV (%)	7.6	9.3	17.0	15.0	18.3

[a]Includes pod husk.

Table 3. Crop yields (kg ha^{-1}) in sole and alley-cropping systems in the last two years (1986–87 and 1987–88) of a four-year study on Alfisols at ICRISAT Center, India.

Treatment	1986–87				1987–88	
	Pearl millet		Pigeonpea		Groundnut	
	Grain	Fodder	Grain	Stalks	Pods	Haulms
Annual crop						
no mulch	2135	2880	310	2900	1545	2475
with mulch	1800	3470	300	2820	1175	1900
Alley cropping (3 m alleys)						
no mulch	920	1030	—[a]	295	410	900
with mulch	1260	1935	—	335	280	590
Alley cropping (5.4 m alleys)						
no mulch	1305	1685	70	1175	730	1920
with mulch	1550	2240	65	1490	685	1805
SE ±	79	173	16	85	20	158
CV (%)	9.1	13.6	22.3	9.1	3.5	14.1

[a] Grain yield was negligible.

system in the narrow and wide alleys respectively. The green manure/mulch had a negligible effect on the sole pearl millet but it improved yields of pearl millet in alleys. Groundnut yields in the final year were only 26% and 47% of the sole groundnut system in the narrow and wide alleys respectively. Mulching significantly reduced groundnut yields in sole cropping and narrow alley system.

Sole *Leucaena* production from four harvests in the first harvest year (1985–86) totalled 5.68 t ha^{-1}, which increased to 7.03 t ha^{-1} in the subsequent year (Table 4). The biomass yield was even higher in the third year (1987–88) because of unusually good showers in the dry season totalling 7.16 t ha^{-1} from three harvests. The wood yield was negligible in 1985–86 and 3.09 t ha^{-1} in 1986–87. It was 5.65 t ha^{-1} in 1987–88 because of the inclusion of stem wood below 0.75 m at final harvest. In the first year *Leucaena* production under alley cropping was proportional to the area planted to *Leucaena*. In the subsequent two years, *Leucaena* yields were much higher than expected, at 73% and 57% of sole *Leucaena* in the narrow and wide alley systems respectively. Mulching caused small but consistent improvement in leucaena yields, which was proportional to the amount of mulch applied.

Land equivalent ratios

LERs were lower than 1.0 in the first year because of the relatively low productivity of *Leucaena*, which was planted late in the year. LERs were lower than 1.0 in the second year because the *Leucaena* contribution was unable to compensate for the yield reduction in the annual crop. By the third year, the two alley-cropping systems had higher productivity than sole annual cropping systems when LERs were higher than 1.0 for the non-mulched plots (Table 5). Even in this year, the relative advantages of agroforestry systems (24 to 36%) were only comparable to that of the pearl millet/pigeonpea intercropping system (37%). Moreover, there was hardly any advantage of agroforestry systems compared with the most appropriate block planting system with land apportioned to sole *Leucaena* and annual crops in

Table 4. Fodder and wood yield (dry weights, t ha^{-1}) of *Leucaena* in different years of a four-year study on Alfisols at ICRISAT Center, India.

Treatment	1985–86		1986–87		1987–88		Total	
	Fodder	Wood	Fodder	Wood	Fodder	Wood[a]	Fodder	Wood
Sole *Leucaena*								
no mulch	5.68	0.64	7.03	3.07	7.16	5.65	19.86	9.36
with mulch	6.02	0.68	7.62	3.22	8.75	6.09	22.39	9.99
Alley cropping (3 m alleys)								
no mulch	3.60	0.46	5.17	2.24	5.26	3.97	14.03	6.66
with mulch	3.70	0.50	6.36	2.59	6.98	5.39	17.04	8.48
Alley cropping (5.4 m alleys)								
no mulch	2.06	0.26	4.28	1.75	3.91	3.24	10.24	5.25
with mulch	2.15	0.30	4.42	1.78	4.27	3.41	10.84	5.49
SE ±	0.26	0.06	0.36	0.16	0.21	0.23	0.65	0.39
CV (%)	11.5	22.3	12.2	12.7	5.6	8.3	7.2	9.39

[a] Includes final stem yield at harvest.

equivalent ratios (LER) from sole and alley-cropping [illegible]ems in a four-year ols at ICRISAT Center, India.

Item	1984–85[a]	1985–86[b]	1986–87[c]	1987–88[b]
Annual crops systems				
no mulch	1.30	1.00	1.37	1.00
with mulch	1.12	0.87	1.20	0.76
Alley cropping (3 m alleys)				
no mulch	0.79	0.85	1.24	1.00
with mulch	0.90	0.24[d]	0.59[d]	0.18[d]
	—	(0.89)	(1.48)	(1.16)
Alley cropping (5.4 m alleys)				
no mulch	1.00	0.78	1.36	1.02
with mulch	0.97	0.43[d]	0.73[d]	0.44[d]
	—	(0.81)	(1.40)	(1.01)

Yields of sole crops used for LER calculation:

[a] Sole millet (1250 kg) and sole pigeonpea (850 kg) yields were measured in nearby experiments.

[b] Sole castor, sole groundnut, and sole leucaena yields were from non-mulched plots.

[c] Sole millet (2135 kg) and sole pigeonpea (830 kg) yields were measured in nearby experiments.

[d] LER of annual crop component only. Number in brackets is total LER including the *Leucaena* component, which was used as mulch.

$$\text{LER} = \frac{\text{Yield of Leucaena in alley cropping}}{\text{Yield of Leucaena in sole system}} + \frac{\text{Yield of crop in alley cropping}}{\text{Yield of crop in sole system}}$$

the same ratio as in alley cropping. In the final year, LERs were again close to 1.0, indicating no advantage of alley cropping over sole systems. Similar results were obtained when LERs were calculated on the basis of total biomass production. Total LERs in mulched plots were essentially the same as LERs of annual crop component because the tree products were not taken out of the systems, the LERs were very low as the annual crops did not benefit from the prunings of *Leucaena*.

Runoff and soil loss

The three years (1985–87) produced exceptionally low runoff and soil loss, averaging only 10% of that in typical years (Table 6). In 1987 when the runoff was highest, sole *Leucaena* reduced seasonal runoff by 79% and soil loss by 78% compared to sole annual crop. The two alley-cropping systems were more effective than the annual-cropping systems in controlling runoff and soil loss, particularly during the early part of the rainy season. Later on in the rainy season, differences between treatments in terms of runoff and soil loss were very small. The mulched plots had lower runoff and lower soil loss than non-mulched plots, with both the alley-cropping treatments showing similar trends. The performance of different treatments during two big storms also confirmed that sole *Leucaena* and the two alley-cropping systems were efficient in minimizing runoff and soil loss compared to annual-cropping systems (Fig. 1). However, these storms were relatively small compared with those observed in normal years.

Table 6. Effects of sole crops sole *Leucaena* and alley cropping systems on annual runoff and soil loss on shallow Alfisols at ICRISAT Center, India, 1987.

Treatment	Runoff[a] (mm)	Soil loss[a] ($t\ ha^{-1}$)
Unmulched		
Sole annual crop	44	0.45
Alley cropping (5.4 m alleys)	30	0.33
Alley cropping (3 m alleys)	20	0.22
Sole leucaena	9	0.10
SE ±	4.2	0.04
Mulched		
Sole annual crop	6	0.22
Alley cropping (5.4 m alleys)	3	0.10
Alley cropping (3 m alleys)	1	0.06
Sole leucaena	0	0.02
SE ±	0.3	0.02

[a] Mostly observed and some calculated values. Some of the values were calculated using a regression equation based on other observed events.

Table 7. Economic returns[a] (Rupees[b] ha^{-1}) from sole *Leucaena*, sole crops and alley cropping systems in a four-year study on Alfisols at ICRISAT, Center, India.

System	Year 1	Year 2	Year 3	Year 4	Total
Sole *Leucaena* (no mulch)	−4043	3717	6057	4475	10206
Annual crops					
no mulch	2649	1413	3988	5990	14060
with mulch[c]	−1714	−1620	1255	235	−1844
Alley cropping (3 m alleys)					
no mulch	−285	1938	4885	4436	10974
with mulch[c]	52	−1650	−567	−1755	−3918
Alley cropping (5.4 m alleys)					
no mulch	1045	1220	5689	5110	13164
with mulch[c]	1128	−890	1340	818	2396

[a] Gross values minus variable costs.

[b] US$1 = Rs 11–14 during the study period.

[c] Value of leucaena was not considered as it was put back into the soil. Its cost of production and spreading was taken into account.

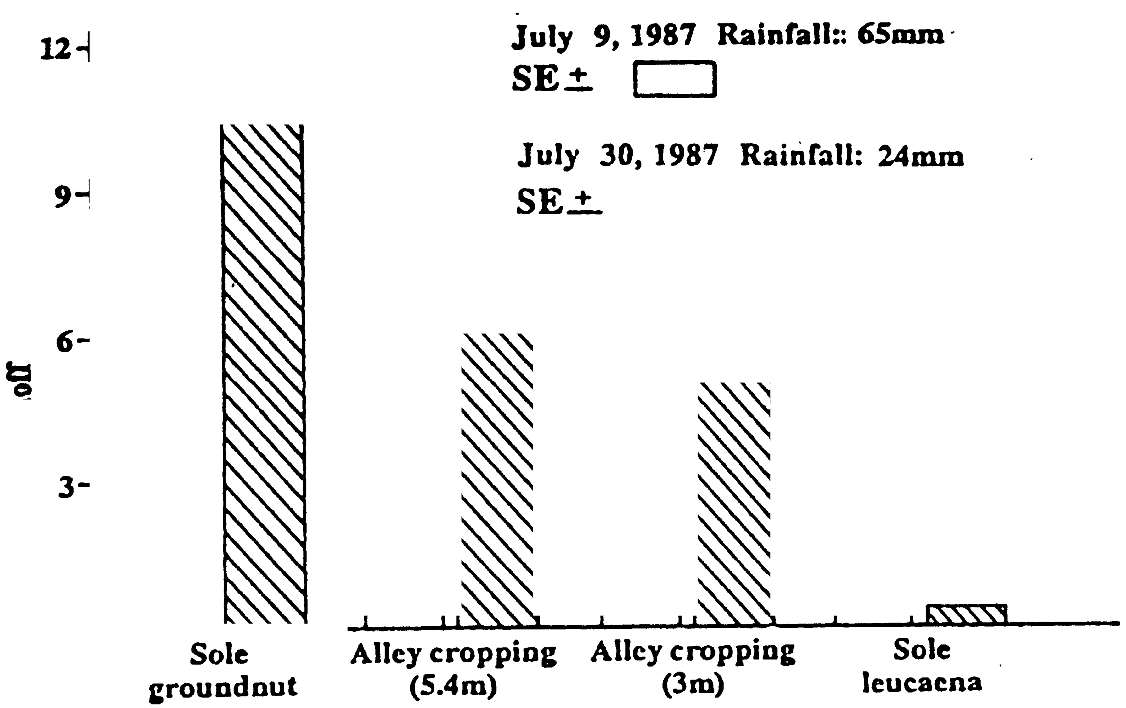

Fig. 1. Runoff from annual crop, sole *Leucaena*, and alley cropping systems during two storms at ICRISAT Center, rainy season 1987.

Economic returns

Returns from alley cropping in any given year were lower than from annual crops or sole *Leucaena*. The annual cropping system was most profitable in the first year when there was no *Leucaena* contribution in other systems and in the final year when the crop was high-value groundnut. Sole *Leucaena* was most profitable in dry years when moisture stress affected annual crop yields. Whatever the prices, it is unlikely that either of the alley-cropping systems will give better returns than the sole *Leucaena* or annual crops. Returns from alley cropping were also compared with those from block planting system in which the land was apportioned to sole leucaena and annual crops in the same proportion as they were grown in alley cropping.[1] For an example, the 3 m alley system in this study was compared against a system which had 33% land under sole leucaena and 67% under annual crops. On this basis, the 3 m alley system was 14% less remunerative than the corresponding block-planting while the 5.4 m alley system was only as good as the corresponding block-planting system. Returns from mulched plots were negative because mulch production involved additional expense, and not only the fodder value of the material was lost but also that it did not improve crop yields.

Discussion

The results of this study did not support the hypothesis that addition of perennial hedges to annual crops improves land productivity in semi-arid India. On the contrary, alley cropping was only as productive as or even less productive than sole cropping (or block-planting) systems. This was because *Leucaena* competed with crops for resources and was not productive enough to make up for the loss in crop yields. There were indications of competition between *Leucaena* and crops for below ground resources.

Installing a polythene barrier between hedge and crop rows in the final year increased groundnut yields by 3–4 fold (Table 8) compared to those under normal alley cropping without root barriers (Table 3). This was true even after discounting for yield increases due to the effect of the tillage associated with installing the barriers.

Since crops were fertilized annually and *Leucaena* fixes its own nitrogen, it could be inferred that the competition was primarily for soil water and not for nutrients. Similar results were observed by Singh et al. [1989a] in another study in a similar environment where placement of root barriers down to 50 cm increased crop yields up to sole-crop levels. Actively growing hedges might shade the alley crop, but a comparison of groundnut yields under early vs late hedge pruning suggested only a small advantage in favour of early pruning, indicating that competition for light was not a major factor in this environment.

Table 8. Effect of timing of hedgerow pruning on yield (kg ha^{-1}) of groundnut in alleys in final year (1987[a]) of a four-year study on Alfisols at ICRISAT Center, India.

System	*Leucaena* (dry weight)		Groundnut[b]	
	Fodder	Wood	Pods	Haulms
Alley cropping (3 m alleys)				
no mulch early	1785	645	1740	3455
late	2190	1520	1395	2745
with mulch early	2275	820	1115	2440
late	2700	1875	1060	1985
Alley cropping (5.4 m alleys)				
no mulch early	915	330	1240	3220
late	1535	1065	1115	2788
with mulch early	985	355	970	2620
late	1525	550	920	2395

[a] Early pruning was on 15 July and late pruning on 14 August in replication 3 only.
[b] Polythene barriers were installed to 0.5 m depth between hedge and crop rows to eliminate below-ground interactions following the method described by Singh et al. [1989a]. For a comparison of the effect of below-ground competition see groundnut yields (without barrier) in Table 3. Sole groundnut yield under complete digging was 2045 kg ha^{-1}.

Contrary to expectations, roots of *Leucaena* hedges were noted in the top 50 cm of the soil, and they spread laterally competing with crops for moisture [ICRISAT, 1986]. Observations at ICRAF's Field Station in Machakos, Kenya, indicated that pruning not only reduced the overall size of the root system but restricted it to a shallower soil depth compared with roots of unpruned trees. In this experiment in India, the competition for water was aggravated by the fact that the experimental period was characterised by sub-normal rainfall and, after the first year, the *Leucaena's* established root system conferred an advantage in exploiting the limited water from the beginning of season.

Crop yields were lower in this study than those recorded in contemporary studies conducted on deep Alfisols [Rao et al., 1991] and Vertic Inceptisols [Rao et al., 1990], suggesting limited water availability on shallow Alfisols. *Leucaena* yields were also lower for the same reason and also due to the lower productivity of cv. Cunningham compared to cv. K 8 used in the other trials. The evidence that alley cropping has no advantage over sole planting systems in all three soil types confirms that this technology is not very appropriate for areas in semi-arid tropical India receiving 500–700 mm annual rainfall. If the objective is to produce fresh fodder during the dry season, this can be achieved hy block planting of *Leucaena* in fodder banks.

Utilization of *Leucaena* prunings as green manure/mulch did not improve crop yields. In fact, the trampling associated with mulch application might have reduced groundnut yield in the final year. Assuming a moderate nutrient content of 3.5% N, 0.2% P, and 2.5% K in *Leucaena* prunings, the quantity of nutrients added to the soil from harvests in 1985–86, for example, was 130 Kg N, 7 kg P and 93 kg K ha^{-1} for 3 m alleys. In subsequent years, the amounts added were much higher because of higher *Leucaena* biomass harvests. Even assuming 50% losses, substantial nutrients were available to crops from prunings but, surprisingly the crops did not show any positive response. Given the low seasonal rainfall and competition for moisture from *Leucaena*, the crops' nutrient requirements were probably met by the 60 kg N and 30 kg P_2O_5 ha^{-1} added through fertilizer. The soil fertility improvement potential of alley cropping could not be judged from this trial; further studies are needed without fertilizer added to crops to test this potential.

Research on alley cropping in India has aimed at producing off-season fodder, often fertilizing crops at normal rates. Much of this work did not show any great advantage on the basis of biological productivity [Singh et al., 1989]. Results that showed an advantage of alley cropping were based on economic evaluation, which should be treated with caution because of the high value attributed to *Leucaena* inspite of the absence of regular market. Some studies lacked the necessary sole crop or *Leucaena* controls to test the system rigorously, while others based their evaluation on short-term trials. Long-term studies are needed, including perennial species other than *Leucaena*, to test the potential of alley cropping for maintaining crop yields without fertilizer.

The limited results on runoff and soil loss indicate that alley cropping has a definite role to play in soil conservation. Contour-aligned hedgerows were also found to control erosion in Nigeria [Lal, 1989] and in semi-arid Machakos on 10 to 14% slopes [Kiepe, ICRAF, personal communication]. By minimizing runoff, alley cropping could improve soil-water status for the benefit of plant growth and conserve soil for long-term fertility improvement. The soil-conservation potential of the system is improved by using the prunings as mulch wherever they are not required for external use. Since runoff and soil-loss reduction were proportional to the proportion of the perennial component in the system, alley spacing should be determined by the importance of potential runoff and soil-erosion problems.

Further studies are needed to examine the effects of management practices that minimize competition such as lower hedge cutting height, frequent hedge pruning, root pruning by deep ploughing close to hedge, and species other than *Leucaena*.

Note

1. Note that LER calculation of land productivity uses the same comparison.

References

El-Swaify SA, Sardar Singh and Pathak P (1987) Physical and conservation constraints and management components for SAT Alfisols. In: Proceedings of the Consultants' Workshop on the State of Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 1–3 December 1983. Pantancheru, India, ICRISAT

Hoekstra D, Huxley PA and Rocheleau D (1985) Diagnosis of land use systems and design of agroforestry interventions for drylands in Karnataka, India. Nairobi, ICRAF, 150 pp

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) (1986) Annual Report 1985. Patancheru, India, ICRISAT, 304 pp

Kang BT, Reynolds L and Attah-Krah AN (1990) Alley farming. Advances in Agronomy 43: 315–59

Lal R (1989) Agroforestry systems and soil surface management of a tropical Alfisol: 1. Soil moisture and crop yields. Agroforestry Systems 8: 7–30

Rao MR, Sharma MM and Ong CK (1990) A study of the potential of hedgerow intercropping in semi-arid India using a two-way systematic design. Agroforestry Systems 11: 243–58

Rao MR, Sharma MM and Ong CK (1991) A tree/crop interface design and its use for evaluating the potential of hedgerow intercropping. Agroforestry Systems 13: 143–158

Reddy MS and Willey RW (1985) Evaluation of alternate cropping systems for Alfisols of the Indian semi-arid tropics. Experimental Agriculture. 21: 271–280

Singh RP, Ong CK and Saharan N (1989a) Above ground and below ground interactions in alley cropping in semi-arid India. Agroforestry Systems 9: 259–274

Singh RP, Rick van den Beldt RJ, Hocking D and Korwar GR (1989b) Alley farming in the semi-arid regions of India. In: Alley Farming in the Humid and Sub-humid Tropics: Proceedings of an International Workshop held at Ibadan, Nigeria, 10–14 March 1986. Ottawa, IDRC, pp 108–122

Willey RW (1979) Intercropping — its importance and research needs. Part I. Competition and yield advantages. Field Crop Abstracts 32(1): 1–10