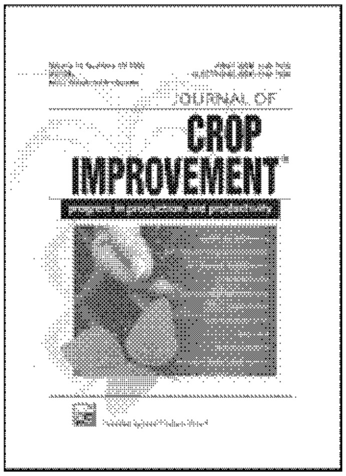

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Sustainable Management of Dryland Alfisols (Red Soils) in South India

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A community based cooperative research project was implemented on farmers' fields on some dryland Alfisols in Tamil Nadu, India, to demonstrate and validate improved dry-farming technologies, such as: 1) soil and water conservation and water harvesting; 2) cropping systems, including intercropping and double cropping; 3) recycling of processed agricultural wastes and byproducts; and 4) low-cost drip irrigation. Disc plowing to 30 cm depth during summer and contour bunding enhanced soil moisture storage in the profile, and facilitated harvesting of runoff water into a community pond. Under the bimodal rainfall pattern in the region, among the medium- and long-duration varieties of pigeon pea, short-duration varieties of blackgram and greengram evaluated, long-duration variety of pigeon pea was the most suited to this region. The pigeon pea variety 'VBN2', blackgram variety 'VBN3', and greengram variety 'VBN2' produced the maximum grain yields. Increasing the land equivalent ratio (LER) by intercropping of pigeon pea with pulses and oilseeds enhanced agronomic productivity. Pigeon pea + groundnut was the best intercropping system. Pigeon pea + lablab and pigeon pea + groundnut

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intercropping system produced the highest yields. In years with normal rainfall, green manuring with sunnhemp and raising a pulse crop, horsegram, increased soil fertility. Application of compost enriched with rock phosphate (produced by using locally available crop residues of cotton, pigeon pea, sugarcane, and raw pressmud) significantly enhanced the yield of pigeon pea, groundnut, onion, and okra in these degraded Alfisols with high phosphate fixation capacity. Tied ridging and mulching with groundnut residues produced the maximum yield of cowpea even in seasons with below normal rainfall. Tied ridging produced the highest net returns from pigeon pea + greengram intercropping system. A low-cost, zero-energy drip-irrigation system produced the highest yield of 23.2 Mg/ha of tomato, with a saving in water of 73.8% compared with the control. Introduction of arid horticulture with amla, sapota, and mango, and water management through pitcher-pot irrigation and mulching with coconut husk as a means of diversification of land use management, provided employment during the off-season and enhanced household income.

KEYWORDS rainfed agriculture, water conservation, Alfisols, participatory research, intercropping, tied ridges, enriched compost

INTRODUCTION

About 58% of the 142 Mha of arable land in India depends entirely on the rains received during the southwest and northeast monsoons of South Asia. The soils of the dryland regions of India comprise: 1) Sierozems (Aridisols); 2) sub-montane soils (Mollisols, Inceptisols, and Entisols); 3) Alluviums (Inceptisols, Alfisols, and Entisols); 4) red soils (Alfisols); 5) black soils (Vertisols); and 6) Laterites (Oxisols) (Swindale, 1982; Venkateswarlu, 1987). Genesis and properties of the soils of India are discussed by Murthy et al. (1981).

Crop yields under dryland conditions are low and highly variable. The Green Revolution of the 1960s and 1970s occurred on irrigated soils of the Indo-Gangetic Basin. In contrast, Alfisols of southern India have numerous constraints to adopting intensive cropping and enhancing crop yields. Effectiveness of highly variable and erratic monsoons is extremely low because of high intensity that generates a large volume of surface runoff and high temperatures that cause severe losses by evaporation. Consequently, crops suffer from frequent and severe drought stress at critical stages of growth. Adverse impacts of drought stress are exacerbated by the severe problem of soil degradation. Alfisols have inherently low soil fertility characterized by low nutrient reserves (e.g., N, P, K, Ca, Mg, Zn, Cu), low soil organic matter

(SOM) content, low available water capacity (AWC), and consequently low microbial biomass C. With predominantly coarse texture and scanty vegetation cover, crops suffer from supra-optimal soil temperatures exceeding 50°C in the top 0 to 5 cm layer. Adverse impacts of high soil temperatures and recurring drought stress are accentuated by the root-restrictive ground layer at shallow depth of 30 to 40 cm. Thus, alleviating these soil-related constraints by improving soil quality, conserving water in the root zone, moderating soil temperature, improving soil fertility, and enhancing SOM content are essential to increasing agronomic production. Agronomic benefits of improving soil quality can be realized only through adoption of improved cultivation and cropping systems. In this regard, the importance of intercropping and legume-based rotations cannot be overemphasized. The strategy is to enhance agronomic production per unit land area, per unit time, and per unit input of water and other off-farm resources.

Thus, a community-based project was initiated by the M.S. Swaminathan Research Foundation (MSSRF), Chennai, India, and the Ohio State University, Columbus, Ohio, to promote adoption of proven soil- and crop-management practices to enhance local food security and improve environmental quality on rainfed Alfisols in southern India (MSSRF, 2006). The specific objectives of the project were to:

1. Test, validate, and extend adoption of management options to alleviate soil-related constraints through a participatory research approach;
2. Enhance production diversification by introducing legumes/pulses, vegetables, livestock, agro-forestry, and aquaculture through on-farm demonstration and validation;
3. Develop and introduce management practices for efficient utilization of soil, water, and organic resources that would lead to sustainable high productivity; and
4. Restore degraded soils, enhance water recharge and soil organic carbon (SOC) concentration.

SITE

Field demonstrations were established at Ariyamuthupatti village in Kudumianmalai Panchayat in Pudukottai district of Tamil Nadu, India (Figure 1). The population is entirely dependent on agriculture, and predominant soils of the district comprise degraded, infertile red soils (Alfisols- Vayalogam series) under semi-arid climate. The district is located between 8° 30′ to 10° 40′ N latitude and 78° 24′ to 79° 40′ E longitude in East Central Tamil Nadu, India, and falls in the 8.3 agro-eco sub-region of India (Natarajan et al., 1997; Velayutham et al., 1999). The district has a bimodal rainfall distribution, with an average annual rainfall of 685 mm.

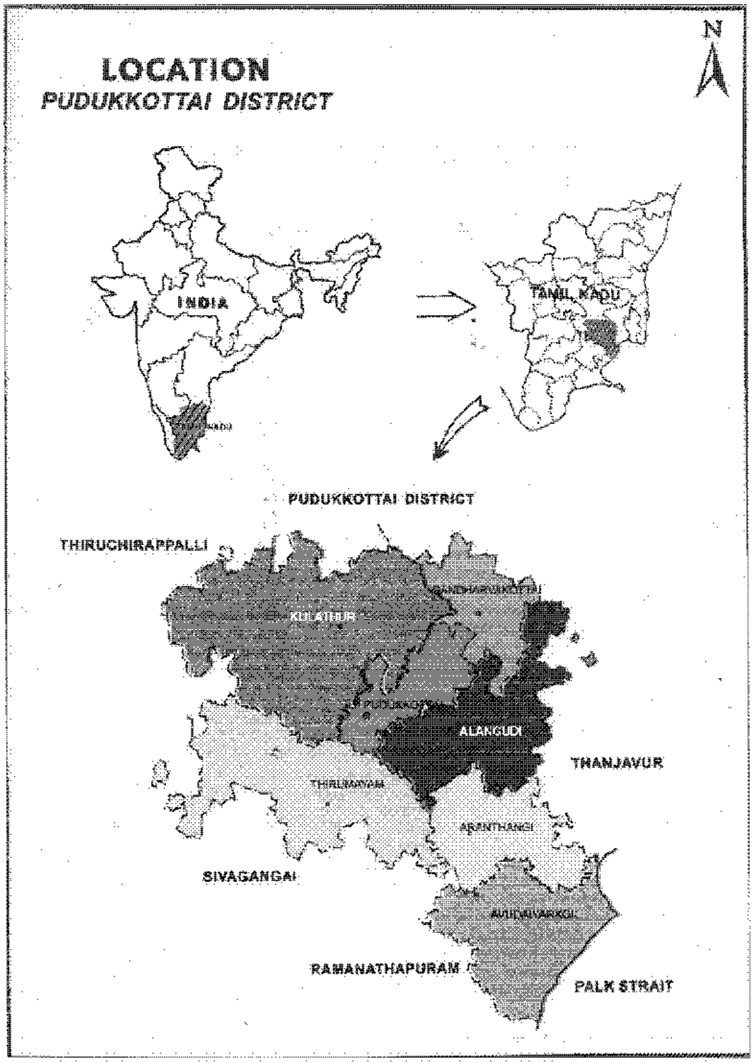

FIGURE 1 Location of the project site.

About 40% of rainfall is received during southwest monsoon season (July-September), 44% during northeast monsoon (October-December), 7% during winter (January-February), and 9% in summer (March-June).

Based on the participatory rural appraisal approach (Pretty, 1994; Velayutham, Ramamuthy, & Venugopalan, 2002) and interaction with the farmers, an on-farm work plan for five years (2001–05) was developed. It consisted of: (i) crop diversification; (ii) improved crop varieties; (iii) enriched compost made from locally available crop residues and organic wastes; (iv) soil and water conservation, water harvesting, and micro-irrigation techniques; and (v) agriculturally based income-generating activities.

Demonstrations were also conducted at Pudupatti village, near Kannivadi, in Dindigul district. It lies between 10° 3′ and 10° 48′ N latitude and 77° 15′ and 78° 20′ E longitude. Predominant soils of the study site also represent Alfisols (red soils). The soil of the project site belongs to Irugur series. These soils are used for intensive cultivation of vegetables by surface irrigation methods. Accelerated erosion by water runoff and shallow soil depth are the major soil-related problems. The soil is sandy clay in texture with pH of 7.5 and SOC concentration of 0.58% in the 0–15 cm depth. The demonstrations were focused on drip irrigation.

WATER MANAGEMENT TECHNOLOGY

At the start of the project, most of the rainfed soils in Ariyamuthupatti village had been uncultivated and left fallow for the past two decades. The farmers were reluctant to undertake high risks of crop failure involved in cultivating these soils under dry farming conditions. Consequently, the village water pond (locally called 'tank') was uncared for several years and had been silted up by sedimentation because of uncontrolled and accelerated soil erosion. The pond was overgrown with weeds and shrubs (e.g., *Prosopis spp.).*

Farmland area of 5.1 ha leased from the community was chosen as the experimental-cum-demonstration farm. Initial soil analysis was done to establish baseline soil properties (Jackson, 1975). The data in Table 1 show a low level of plant available nutrients of only 146 kg/ha of NPK, and a low cation exchange capacity of 4.6 C mol (t)/kg of soil. The SOC concentration

TABLE 1 Nutrient Status (0–20 cm) of the Soil at Ariyamuthupatti Village Site Just Before Sowing in 2001

Parameter	Value	Remarks
Available nitrogen (kg/ha)	52	Low
Available phosphorus (kg/ha)	14	Medium
Available potassium (kg/ha)	80	Low
Soil organic carbon (%)	0.26	Low
Extractable calcium (cmol/kg soil)	2.26	Low
Extractable magnesium (cmol/kg soil)	1.10	Low
Extractable sodium (cmol/kg soil)	0.34	Low
Cation exchange capacity (cmol/kg soil)	4.65	Low
Base saturation (%)	82.15	High
Exchangeable sodium (%)	7.3	Low
†DTPA extractable zinc (ppm)	0.44	Low
DTPA extractable iron (ppm)	10.03	High
DTPA extractable copper (ppm)	0.62	Low
DTPA extractable manganese (ppm)	9.79	High

†DTPA = diethylene triamine pentaacetic acid.

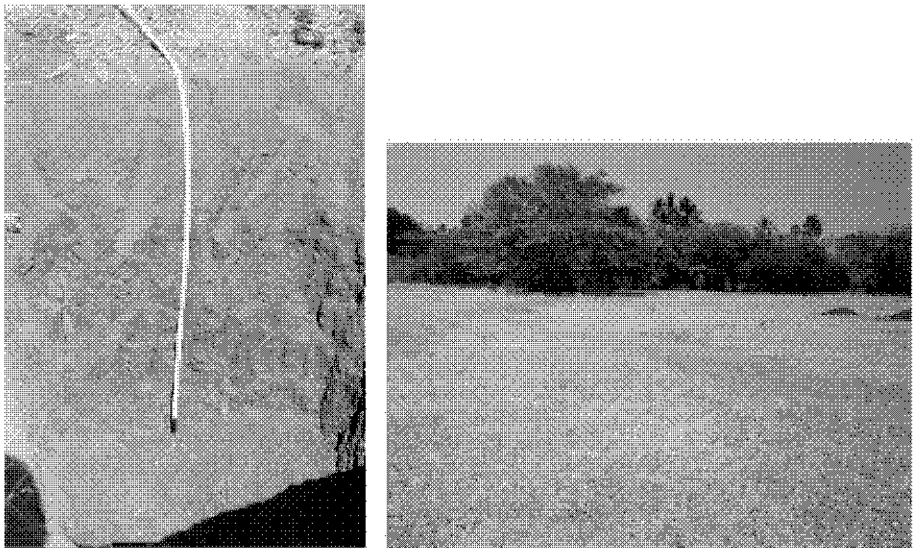

FIGURE 2 Soil profile at Ariyamuthupatti, site at the start of the project.

(0.26%) was below the critical level of 1.1% for soils of the tropics (Aune & Lal, 1998). The effective rooting depth is shallow, because the soil is underlain by a thick gravelly horizon (Figure 2). The surface soil has low AWC, and is prone to crusting, moderate to severe erosion, and acidification. The soils have a high fixation capacity of P because of the presence of iron and aluminum hydroxides.

Improved dry-farming technologies evaluated were: 1) soil and water conservation techniques and water harvesting; 2) cropping systems, including intercropping and double cropping; 3) recycling of processed agricultural wastes and byproducts; and 4) drip irrigation.

WATER HARVESTING

Seedbed preparation during summer was done by disc plowing to about 20 cm depth. Bunds were erected across the slope around individual fields for diverting the excess rainwater into the channels. These channels, about 0.5 m deep with strengthened bunds and installed on the contour, were connected to a main waterway. The latter with a gentle gradient and a depth of 0.75 to 1.0 m, drained into the village pond. The pond was excavated to more than 1 m depth by farmers for storing the excess runoff water carried off from the fields through a network of channels and waterways (Figure 3). Periodic desilting and deepening of the pond was done by the village community throughout the study period. In addition to serving as a water reservoir, the tank also recharged the groundwater in its vicinity.

FIGURE 3 Water harvesting—rain water stored in Ariyamuthupatti tank after desilting and deepening.

CROPS AND CROPPING SYSTEMS

Improved varieties of pigeon pea (*Cajanus cajan* L.) tested involved those of varying growth duration. These included medium-duration (135 days) or MD varieties (APK 1, CO 5, and VBN 1), and long-duration (165–180) or LD varieties (VBN 2, LRG 30, and ICPL 87119). The data in Table 2 show that LD varieties were better suited for this eco-region with a bimodal rainfall pattern than MD varieties. Furthermore, among LD varieties, the highest grain yield of 263 kg/ha was obtained with the VBN2 variety. Four varieties of black gram (*Vigna mungo* L. Hepper; VBN 2, VBN 3, CO6, T 9) and three varieties of greengram

TABLE 2 Performance of Pigeon Pea Varieties of Different Growth Duration

Parameter	APK 1	Co 5	VBN 1	VBN 2	ICPL 87119
Duration (days)	126	160	121	183	178
Days to 50% flowering	70	80	70	152	127
No. of pods/plant	14	25	18	66	81
No. grains/pod	5	4	4	4	4
No. of plants/m2	33	33	33	28	28
100 grain weight (g)	6.5	8	6.7	7.3	11.4
Dry matter production (Mg/ha)	3.0	3.0	2.5	7.0	5.0
Grain yield (kg/ha)	–	140	–	263	198

(*Vigna radiata* L. R. Wilczek; VBN 2, CO 6, K 851), with crop duration range of 65-70 days, were also tested for their performance. Variety VBN 2 of greengram and VBN 3 of blackgram performed relatively well in these soils and yielded 188 and 180 kg/ha, respectively. The prolonged dry spell in August coincided with the grain-filling stage and resulted in low yields.

INTERCROPPING WITH PIGEON PEA

The LD pigeon pea variety (VBN 2) was tested for its productivity in an intercropping system (Figure 4). Both groundnut (*Arachi hypogaea* L.; TMV 3) and cowpea (*Vigna unguiculata* L.; VBN 1) were grown as intercrops. Pigeon pea was sown at a row-to-row spacing of 1.0 m. In between the rows of pigeon pea, three rows of cowpea and groundnut were sown at a spacing of 30 × 10 cm. The data in Table 3 indicate that intercropping of pigeon pea is climatically adaptable (Velayutham, 1999) and economically advantageous for this region. Pigeon pea + groundnut was the best intercropping system in net income (Rs. 4145/ha).

DOUBLE CROPPING

Double cropping, or sequential cropping, was evaluated by disc plowing during the summer to 30 cm depth. In addition, water harvesting using

FIGURE 4 Red gram + green gram intercropping under mulching moisture conservation.

TABLE 3 Agronomic Performance of Intercropping of Pigeon Pea (Var. VBN2) with Cowpea and Groundnut

			Intercrop	
Parameter	Monoculture	Main crop	Cowpea	Groundnut
Population (plants/m^2)	28	28	72	78
Duration (days)	183	187	65	98
Days to 50% flowering	152	151	41	41
No. of pods/plant	66	40	9	11
No. of grains/pod	4	4	11	2
100 grain weight (g)	7.2	7.2	13.5	36
Dry matter production (Mg/ha)	6.0	5.5	3.1	3.2
Grain yield (kg/ha)	263	109	23.5	313
Net income (Rs./ha)	1315	545	235	3600

Net income (Rs./ha): pigeon pea (pure) – 1315; pigeon pea + cowpea – 780; pigeon pea + groundnut – 4915.

TABLE 4 Agronomic Yields and Economic Returns of a Range of Crops and Cropping Systems

First crop (July–Sept.)	Second crop (Oct.–Feb.)	Yield of first crop (kg/hg)	Yield of second crop (kg/ha)	Net income (Rs./ha)
Pigeon pea (LD) (pure crop)	Contd.	263	–	1315
Pigeon pea (LD) + black gram	Red gram (contd.)	198	107	4158
Pigeon pea (LD) + cowpea	Red gram (contd.)	109	123	1780
Pigeon pea (LD) + groundnut	Red gram (contd.)	109	313	4145
Pigeon pea (LD) + lablab	Red gram (contd.)	198	248	4712
Pigeon pea (MD)	Red gram (contd.)	140	–	1120
Black gram	Horse gram	180	63	3620
Green gram	–	188	–	3478
Cowpea	Bengal gram	27	64	1457
Groundnut	Cluster bean & Radish	244	257	3643
Sesame	Horse gram	121	165	1638
Varagu (Kodo Millet)	Varagu (contd.)	634	–	2219
Finger millet	–	594	–	2673

Note: LD = long duration; MD = medium duration.

diversion channels and waterways and supplemental irrigation were also used. Enriched pressmud was used to improve soil fertility. Compost was used in conjunction with foliar application of di-ammonium phosphate. Integrated pest management (IPM) was adopted against the pod borer in pigeon pea. The data in Table 4 on yields of different cropping systems shows that agronomic productivity can be greatly enhanced in ecosystems with a bimodal rainfall pattern by growing two sequential crops under rainfed conditions. Pigeon pea + lablab (*Lablab purpureus* L.) and pigeon pea + groundnut intercropping systems produced the highest grain yields, even under conditions of uneven rainfall distribution. Among the double-cropping systems, groundnut followed by cluster bean (*Cyamopsis tetragonolobo* L. Taubert) and radish (*Raphanus sativus* L.) produced the highest monetary returns. In comparison with the monoculture of pigeon pea, the minor millets varagu or Kodo millet (*Paspalum scrobiculatum* L.) and finger millet (*Eleusine coracana* L. Gaertn) also performed well, indicating the potential prospect of including these nutritious minor millets in cropping systems for advancing crop diversification, food and nutrition security.

SUMMER PLOWING

Summer plowing to ~30 cm depth enhanced soil-water reserves during the S-W monsoon of 2004, primarily by breaking the crust and improving water infiltration rate. With intense rains received in July '04, farmers included groundnut in the cropping system. Although there was a continuous dry spell for 52 days, the crop survived because of the moisture conserved through summer plowing, resulting in an average yield of 1.67 Mg/ha of pod. In some plots where summer plowing was not done, the groundnut crop sown in July suffered from severe drought stress at the critical stages of flowering, peg formation, and pod filling. The average groundnut yield was 600 kg pods/ha, or 36% of the yield obtained with summer plowing. Vittal, Vijayalakshmi, and Rao (1983) reported the beneficial effects of deep tillage on dryland crop production in red soils of India. The importance of summer plowing is now widely accepted by the farmers of the district, and it forms an important component of the best management practices (BMPs) for dry farming in the region.

GREEN MANURING

Sunnhemp (*Crotalaria juncea* L.) was raised as a green manure crop, and green biomass of 8.5 Mg/ha was incorporated at 45 days after sowing. Horsegram (*Macrotyloma uniflorum* L. Verde; Var. Paiyur 1) was sown after green manuring. While the yield of horsegram was low due to the prolonged dry spell (Table 5), which occurred during the grain-formation stage, the dry-matter production and post-harvest soil-fertility parameters indicate its numerous advantages and the possibility of introducing green manuring within the cropping cycle, particularly in seasons with normal rains. Thus, intercropping, double cropping, and green manuring are important BMPs for production of additional biomass from the same land. Biomass return to

TABLE 5 Effect of Using Sunnhemp as Green Manure on Horsegram Yield and Soil Fertility Measured after the Crop Harvest

Parameter	With green manuring	Without green manuring
Dry matter production of horse gram (kg/ha)	1100	1000
Grain yield of horse gram (kg/ha)	75	62.5
Post-harvest soil nitrogen (kg/ha)	165	133
Post-harvest soil phosphorus (kg/ha)	22.5	21.5
Post-harvest soil potassium (kg/ha)	206	175
Post-harvest soil organic carbon (%)	0.41	0.30

Initial soil analysis: Av. N – 93 kg/ha; Av. P – 18 kg/ha; Av. K – 218 kg/ha; Organic carbon – 0.28%.

the soil is essential to enhancing SOC sequestration (Lal, 2004) and reversing the degradation trends.

SOIL FERTILITY MANAGEMENT BY USING COMPOST

Farmers, in particular women, participated in the training program for the production of enriched compost using locally available crop residues of cotton (*Gossypium hirsutum* L.), pigeon pea, sugarcane (*Saccharum officinarum* L.), and raw pressmud obtained as a byproduct from the nearby sugar-refining factory. These materials were wetted and mixed with animal dung. Rock phosphate at 25 kg/Mg of the material, zinc sulfate at 2.5 kg/Mg, *Trichoderma viride* at 5.0 kg/Mg, and phosphobacteria at 200 g/Mg were added to the residues, mixed and formed into heaps of 3 × 1.5 × 1 m dimensions. The moisture content of the heap was maintained at about 60% by sprinkling water periodically. The heap was turned over twice at 30 and 45 days, and well-decomposed compost was ready for field application by 60 days after the start of the composting process.

The enriched compost was mixed with the appropriate inoculum of rhizobium or azospirillum (depending on the crop) and applied at the rate of 2.5 Mg/ha. Increase in crop yield by compost was 10% in pigeon pea, 58% in groundnut, 500% in onions (*Allium cepa* L.), and 12% in okra (*Abelmoschus esculentus* L. Moench; Table 6). The strategy of using integrated nutrient management (INM) practices is important for these depleted

TABLE 6 Effect of Enriched Compost Application on Yield Crops Grown at Two Sites (kg/ha)

Ariyamuthupetti				Kannivadi			
Crop	Without compost	With compost	% Increase	Crop	Without compost	With compost	% Increase
Pigeon pea	83	93	10.0	Onion	500	3000	500
Groundnut	302	478	58.0	Okra	15000	17620	12.0

and degraded Alfisols of southern India. Farmers are now practicing the production of enriched compost as a component of BMPs for INM strategies.

SOIL AND WATER CONSERVATION AND WATER HARVESTING

Four techniques of soil conservation and mulching and three of INM were laid out in a strip-plot design with cowpea as a test crop in 2002 and 2003 seasons. Total amount of rainfall received during winter 2002 and 2003 crop period was 162 and 132 mm, respectively, with distribution of seven rainy days in both years. Ridges, furrows, and tied ridges were formed immediately after the first monsoon rains (Figure 5). Crop-residue mulch was applied at the rate of 2.5 Mg/ha about 15 days after sowing. The crop yield figures and the derived resource indices are given in Tables 7 and 8.

The efficiency indices, such as production efficiency (PE) and economic efficiency (EE), were computed by the following formula (Singh et al., 2005):

$$PE(\%) = \{(Y^{IS} - Y^{TS}) / Y^{TS}\} \times 100$$

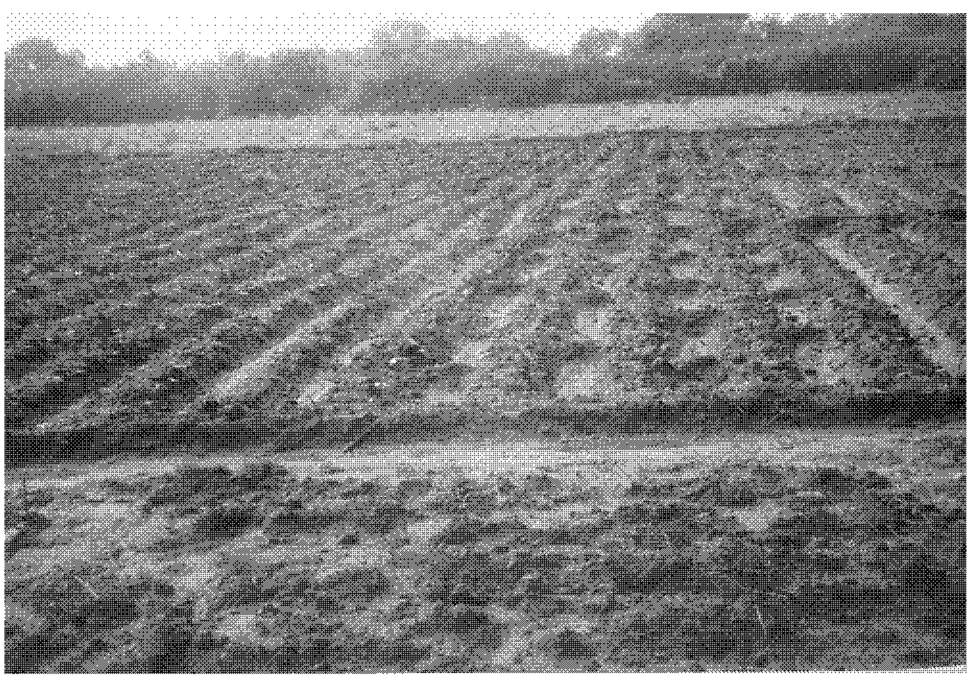

FIGURE 5 Tied ridges.

TABLE 7 Effect of *in situ* Rainwater Harvesting on Sustainable Indicators of Rainfed Cowpea

Moisture conservation	Total biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Total factor productivity	Production efficiency (%)	Energy productivity (kg MJ^{-1})	Energy efficiency
Winter, 2002						
Farmer's practice	2652.5^{b}	572.2^{c}	0.127	–	0.77	12.60
Ridges & furrows (R&F)	2897.8^{ab}	662.8^{ab}	0.134	15.83	0.78	12.75
Compartmental bunding (CB)	2775.5^{b}	627.8^{b}	0.132	9.71	0.78	12.78
R&F + mulching	3008.8^{a}	715.9^{a}	0.143	25.11	0.81	13.20
CB + mulching	2917.3^{a}	688.9^{b}	0.143	20.39	0.81	13.18
Winter, 2003						
Farmer's practice	956.3^{c}	169.7^{c}	0.066	–	0.37	5.96
Ridges & furrows (R&F)	1117.0^{b}	208.5^{b}	0.072	22.86	0.40	6.53
Tied ridge (TR)	1151.8^{b}	223.2^{b}	0.072	31.52	0.40	6.58
R&F + mulching	1345.2^{a}	279.0^{a}	0.088	64.40	0.46	7.48
TR + mulching	1406.6^{a}	297.4^{a}	0.089	75.25	0.47	7.70

Means within column followed by the same letter are not significantly different (l.s.d at P = 0.05).

TABLE 8 Effect of Land and Nutrient Management on Cowpea Yield and Efficiency Indices (2003)

Treatments	Grain yield (kg/ha)	Production efficiency (%)	Economic efficiency (%)	Rainfall use efficiency (kg/ha/mm)	Solar radiation use efficiency (g/cal)	Energy efficiency
Moisture (M)						
Farmers' practice	169.7	–	–	1.3	0.51	6.0
Ridges & furrows (R&F)	208.5	22.86	924	1.6	0.59	6.5
Tied ridge (TR)	223.2	31.52	1024	1.7	0.61	6.6
R&F + mulching	279.0	64.40	4024	2.1	0.71	7.5
TR + mulching	297.4	75.25	4468	2.3	0.74	7.7
CD (P = 0.05)	29.1	–	–	–	–	–
Nutrient (N)						
Farmers' practice	156.6	–	–	1.2	0.46	7.1
Rec. NPK	237.9	51.91	1526	1.8	0.65	6.5
50% NPK + 50% Enriched compost	284.5	81.67	4665	2.2	0.72	7.1
Enriched compost	263.2	68.07	2921	2.0	0.69	6.7
CD (P = 0.05)	20.3	–	–	–	–	–

where Y^{IS} is grain yield in intervention system and management, and Y^{TS} is grain yield in traditional system and management.

$$EE\ (\%) = \{(NR^{IS} - NR^{TS}) / NR^{TS}\} \times 100$$

where NR^{IS} is net returns in intervention system and management and NR^{TS} is net returns in traditional system and management.

Energy efficiency was computed by evaluating the input and output of energy for each treatment (Dazhong & Pimentel, 1984). Rainfall-use efficiency (RUE) was calculated by dividing the yield by total quantity of rainfall obtained during the cropping period. Solar radiation-use efficiency (SRUE) for the cropping period was computed as per the procedure of Hayashi (1966) and expressed in g cal^{-1}

$$SRUE = \frac{\text{Dry matter production}\,(gm^{-2}) \times 4000}{\text{Total incident energy} \times 0.45\,(\text{Cal}\,m^{-2})}$$

The data in Table 7 and Table 8 show that tied ridges significantly improved cowpea performance through increasing soil-water reserves in the root zone. In addition, mulching with groundnut crop residues reduced soil evaporation and increased crop yield. Among the INM treatments, application of enriched compost produced the highest yield. During the second year, tied ridges replaced the compartmental bunding treatment, and ordinary compost application was replaced by application of 50% of inorganic fertilizer and 50% of enriched compost.

Significantly more grain yield of cowpea was obtained under ridges and furrows with mulching (715.9 kg/ha) and tied ridges with mulching (297.4 kg/ha) during 2002 and 2003, respectively, over farmers' practice. Ridges and furrows with mulching had higher PE (25.11%), EE (13.2), RUE (4.4 kg/ha/mm), and SRUE (1.61 g/cal) during 2002 than other treatments. Tied ridges with mulching were superior to farmers' practice and ridges and furrows with mulching in PE (75.25%), EE (7.7), RUE (2.3 kg/ha/mm), and SRUE (0.74 g/cal) during 2003. Among nutrient-management practices, application of enriched compost during 2002 and integration of 50% inorganic fertilizers and 50% enriched compost during 2003 produced significantly higher grain yield (730.7 and 284.5 kg/ha) and at higher resource-use efficiencies. Application of enriched compost improved PE (30.46 and 68.07%), EE (12.5 and 6.7), RUE (4.5 and 2.0 kg/ha/mm) and SRUE (1.67 and 0.69 g/cal) during 2002 and 2003, respectively, more than inorganic fertilizer application and farmers' practice of no-nutrient application. The advantage of tied ridges over farmer's practice in producing higher yield, even during seasons of sub-normal rainfall (2003), is significant (Ramesh & Devasenapathy, 2005, 2007a).

Field observations during the cropping seasons showed (Ramesh, Devasenapathy, & Sabarinathan, 2006) that root growth (length, volume, and dry weight) and nodulation characteristics (numbers and dry weight) increased with the practices of soil moisture conservation (e.g., ridges and furrows, and tied ridges with mulching).

The data in Table 9 indicate that the highest yield of pigeon pea was obtained with tied ridges and mulching among soil-conservation treatments, and with application of enriched compost among the INM treatments. Soil moisture content (0–30 cm depth) was the highest throughout the growing season under tied ridges with mulching (Figure 6). Improved grain yield (475.5 kg/ha), PE (8.9 kg/ha-cm), and EE (15.63) were obtained with tied ridges with mulching. In soil-management treatments, application of enriched compost significantly influenced grain yield (471.2 kg/ha) and nutrient uptake. The highest net returns of Rs 5731/ha from pigeon pea + green gram intercropping was obtained with the BMPs comprising tied ridges and mulching. In accordance with the increase in agronomic yields, improvements in the post-harvest available soil NPK and SOC concentration were also observed with mulching in ridges and furrows and tied-ridges treatments as given in Table 10 (Ramesh & Devasenapathy, 2007b). Selvaraju and colleagues (1999) reported that tied ridging and application of manures in combination with N and P fertilizer improved soil-water storage and yield of crops compared with sowing on the flat bed in rainfed Alfisols and related soils of the semi-arid tropics.

TABLE 9 Effect of Land and Nutrient Management on Pigeon Pea Yield and Efficiency Indices (2003)

Treatments	Grain productivity (kg/ha)	Water productivity (kg/ha/cm)	Energy efficiency
Moisture (M)			
Farmers' practice	292.3	5.5	11.38
Ridges & furrows (R&F)	353.6	6.6	12.23
Tied ridges (TR)	393.7	7.4	13.45
R&F + mulching	454.5	8.5	15.18
TR + mulching	475.4	8.9	15.63
CD (P = 0.05)	42.6		
Nutrient (N)			
Farmers' practice	271.2	5.1	14.0
Rec. NPK	391.2	7.4	12.5
50% NPK + 50% enriched compost	442.0	8.3	13.6
Enriched compost	471.2	8.9	14.2
CD (P = 0.05)	21.0		

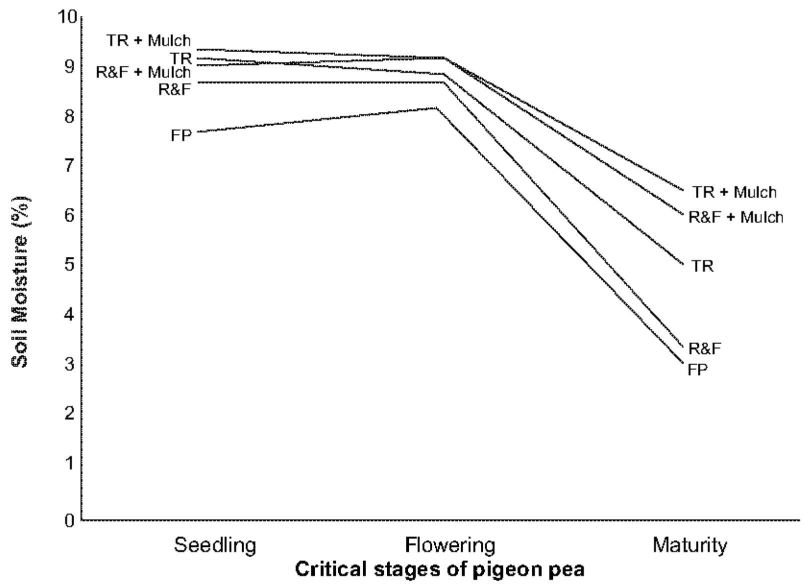

FIGURE 6 Effects of soil management treatments on soil moisture content at different phenological stages of crop growth.

GRAVITATIONAL DRIP IRRIGATION SYSTEM USING LOCAL MATERIALS

A ground-level, zero-energy, drip-irrigation system was installed in a farmer's field at the Ariyamuthupatti and Kannivadi sites (Figure 7). The system involved installation of a PVC tank of 800-liter capacity at an elevation of about 1 m. The tank was connected with a drip irrigation system. Drip line was laid in alternate rows of the crop, with 1 lph dripper spaced at 30 cm. The tank was filled from the nearby borewell once a day, and tomatoes were transplanted during the dry season. Yield of fresh tomatoes of 23.2 Mg/ha was obtained with 73.8% saving in water.

At Kannivadi site, the plots receiving drip irrigation yielded 15.2 Mg green chillies (*Capsicum annum* L.) per ha compared with the production of 9.4 Mg/ha for plots with surface irrigation, an increase of 61%. The green chillies from the drip irrigation plots were larger, longer, and shinier than those from surface-irrigated treatments, and fetched a higher price in the market.

ARID HORTICULTURE

Adopting rainfed horticulture is an important strategy for providing another income stream for farmers. In cooperation with the state-funded wasteland

TABLE 10 Effect of In Situ Soil Moisture Conservation and Nutrient Management Practices on Post-Harvest Available NPK (kg ha^{-1}) in Cowpea and Pigeon Pea

	Cowpea (2002)					Cowpea (2003)				Pigeon pea (2003)		
Treatments	Org. C	N	P	K	Treatments	Org. C	N	P	K	N	P	K
Moisture (M)					Moisture (M)							
Farmers' Practice	0.28	184	13.8	28.9	Farmers' Practice	0.20	170	12.8	36.4	155	16.9	44.8
Ridges & Furrows (R&F)	0.28	193	16.2	32.7	Ridges & Furrows (R&F)	0.22	181	14.8	50.4	162	18.9	52.2
Compart. Bunding (CB)	0.29	206	17.3	31.7	Tied Ridge (TR)	0.23	173	13.3	40.5	178	21.4	56.8
R&F + Mulching	0.32	235	21.2	49.4	R&F + Mulching	0.26	192	17.5	64.0	205	25.2	69.9
CB + Mulching	0.30	221	22.9	57.8	TR + Mulching	0.27	193	15.9	68.0	219	26.8	78.3
SEd	0.02	12.1	2.3	7.4	SEd	0.02	9.20	0.90	3.40	17.7	1.2	6.4
CD (P = 0.05)	0.04	28.1	5.2	17.1	CD (P = 0.05)	0.03	21.2	2.00	7.80	40.8	2.8	14.8
Nutrient (N)					Nutrient (N)							
Farmers' Practice	0.25	182	9.9	20.9	Farmers' Practice	0.22	158.9	9.6	36.6	145.5	14.5	35.1
Rec. NPK	0.27	199	13.7	29.9	Rec. NPK	0.23	182.0	11.3	45.0	162.4	21.1	44.8
Raw compost	0.33	210	20.1	44.1	50% NPK+50% Enriched compost	0.24	189.6	17.6	57.7	207.1	24.2	73.8
Enriched compost	0.32	242	29.3	65.6	Enriched compost	0.25	198.2	20.8	68.0	221.1	27.6	87.8
SEd	0.01	5.9	1.0	3.6	SEd	0.01	9.75	0.76	2.90	14.5	1.1	2.8
CD (P = 0.05)	0.03	14.5	2.4	8.7	CD (P = 0.05)	0.02	23.90	1.86	7.00	35.4	2.7	6.8

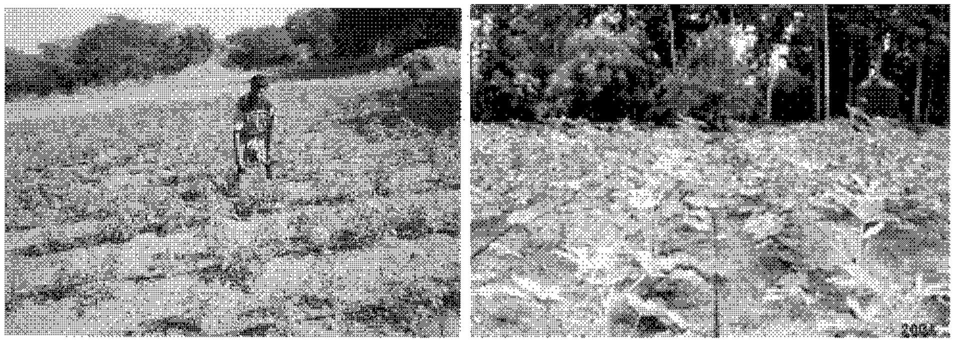

FIGURE 7 Tomato grown with gravitational drip, okra under gravitational drip.

development project, seedlings of amla (*Phyllanthus emblic* L.), sapota (*Manilkara zapota* L.), and mango (*Mangifera indica* L.) were planted on 35 acres (14 ha) of uncultivated wasteland in the village (Figure 8). The farmers were advised to use pitcher-pot irrigation (Figure 9), and mulching with coconut husk and crop residues (Figure 8 and Figure 10) around the saplings for initial establishment and better growth of the seedlings during the summer period. This has been a successful undertaking, and a popular practice with the community.

FIGURE 8 Coconut husk for moisture conservation—crop residues of cowpea on the background.

FIGURE 9 Pitcher irrigation to sapota.

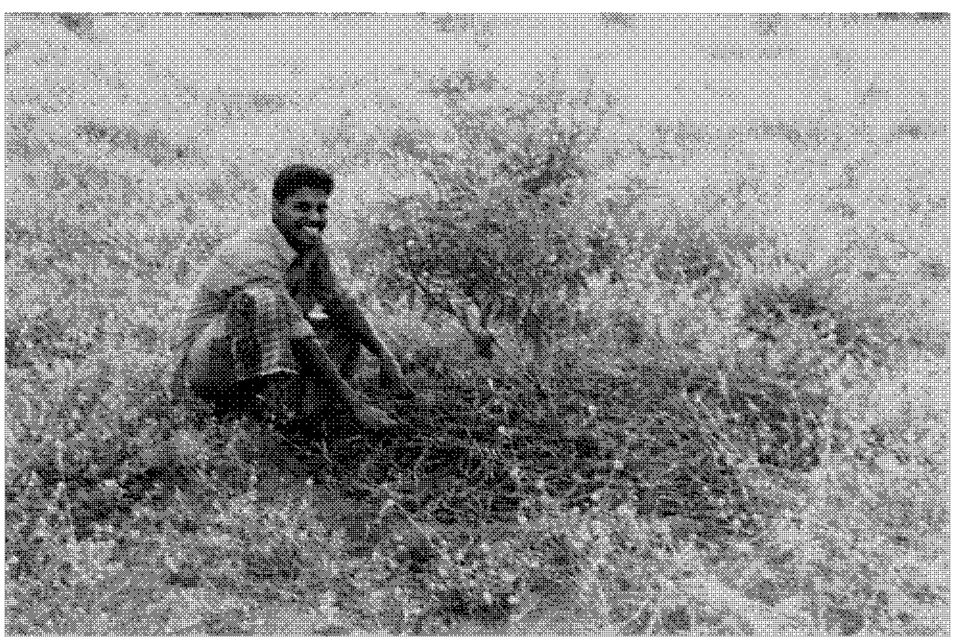

FIGURE 10 Mulching with crop residue (groundnut) to a sapota sapling.

SOIL TESTING

A soil-testing campaign was organized in the project area with the assistance of a soil-testing laboratory in Kudumianmalai. The services of the mobile soil-testing laboratory were also availed. Based on the soil-test analyses of individual farms, 'soil-health cards' were printed and distributed to the farmers (Figure 11) Specific training sessions were organized for the

FIGURE 11 Soil health card distributed to the participating farmers.

method of soil-sample collection, soil-test interpretation, and the use of soil-health card. Participating farmers appreciated the usefulness of these cards for periodic monitoring of soil health with the adoption of BMPs and recommended cropping systems.

SOCIAL MOBILIZATION AND INCOME-GENERATING ACTIVITIES

Self-help groups were formed to create other livelihood opportunities and to generate off-season and off-farm income. The women self-help group formed comprised Mangayi Amman Self Help Group with 16 founding members and Akilandeswari Self Help Group with 12 founding members. Members were invited to the MSSRF centers at Kannivadi and Pondicherry to observe the functioning of the self-help groups in these centers and to interact with them in starting micro-finance-assisted micro-enterprise. The self-help group members mastered the technique of producing *Trichogramma parasitoid* and supplied the cards to sugarcane cultivators through a buy-back arrangement with the EID Parry Sugar Factory, located at Aranthangi, 30 km from project site (Figure 12). This arrangement was extremely effective in the biological control of sugarcane internode borer. This micro-enterprise and preparation of enriched compost (Figure 13) has considerably improved

FIGURE 12 Sub-collector (training) keenly watching the *Trichogramma parasitoid* production process.

FIGURE 13 Compost enrichment.

the employment and income-generating capacity of the participating women.

Arrangements were also made for the construction of a "smokeless stove" in 26 households, through the available government scheme. Because of this, the accumulation of smoke inside the house is averted and respiratory and wheezing problems are much reduced among women in rural households.

CONCLUSIONS

A community-based participatory operational research project on Alfisols (red soils) of Tamil Nadu in the semi-arid region of India benefited the farming community by adopting rainfed agriculture and best management practices of dry-farming technologies. The technologies adopted comprised: 1) scheduling suitable crops and varieties, and standardizing intercropping and double-cropping systems based on rainfall patterns in a region normally used for monocropping of coarse cereals; 2) land configuration for water harvesting and soil- and water-conservation practices for alleviating drought stress; 3) INM to improve soil fertility and IPM practices; and 4) introduction of arid horticulture and drip irrigation.

These on-farm demonstrations indicated the beneficial impacts on soil quality and agronomic production of the BMPs comprising the following components: 1) disc plowing during summer; 2) establishing tied ridges with mulch; 3) application of pressmud compost enriched with rock phosphate; 4) intercropping of pigeon pea as main crop and other pulses and groundnut as intercrop; 5) double cropping with sunnhemp and pulses; 6) diversification of cropping with nutritious minor millets; 7) drip irrigation for high-value vegetable crops; 8) agriculture-centered, income-generating activities for self-help groups of farm women; 9) utility of soil testing and use of a 'soil-health card' for monitoring soil productivity and sustainable agriculture; and 10) introduction of arid horticulture. The approach used in the project provides a community-based interactive participatory operational research model, with an intrinsic value of large-scale social mobilization and extension domain for adoption of improved dry-farming technology.

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