Dynamics of Soil Fertility Management Practices in Semi-Arid Regions: A Case Study of AP

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The overuse of chemical fertilisers in India for nutrient management in farming over the last few decades has led to several problems affecting the health of soil, the environment and farmers themselves. Farmers in semi-arid regions actively manage fertility and other soil properties through a wide range of practices that are based on local resources and knowledge. Empirical data reveals farmers' soil fertility management options are being undermined by government policies that give more priority to chemical fertiliser-based strategies. It is argued that equal importance should be accorded to farmers using organic and farmers using inorganic methods. By doing so, we not only maintain the soil in a healthy condition but also support the livelihoods of millions, especially small and marginal farmers.

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Introduction

In India more than 70% of the population directly or indirectly depends on farming. Indian agriculture is often discussed in relation to the green revolution and its mixed record of successes and failures. The technology gains of the green revolution in productivity and food security are widely associated with irrigated regions, where the benefits of improved seeds and increased use of inorganic fertilisers can be realised. Yet what most Indian farmers (more than 60%) practise is rain-fed agriculture, an entirely different way of farming than that in irrigated areas. There are now widespread problems related to the use of chemical fertilisers, mismanagement of surface water and overexploitation of groundwater, the most important source for irrigation (*Economic Survey* 2008). The potential for expanding irrigated agriculture is decreasing as it becomes more expensive or risky to further exploit water resources. It has been realised that even if the full irrigation potential of the country were to become operative, 50% of the net sown area would continue to be rain-fed. Hence, rain-fed agriculture is still high on India's development agenda. Its contribution is vital to the food security and livelihoods of the poorest farming families and communities, who have no access to irrigated land. Moreover, dryland agriculture holds the key for future food security because the green revolution has reached its saturation point in enhancing land productivity. It has also been shown that returns on investment in rain-fed agriculture are greater than those in irrigated agriculture (Fan and Hazell 2000).

In semi-arid regions,[1] dryland farmers have developed cropping practices ranging from summer ploughing to crop rotations that are suited to the harsh agroclimatic conditions they have to deal with (Pionetti and Reddy 2002). These practices are derived from their deep understanding about the interactions between climate, soil, crops and insects, and enable the regeneration of soil and the optimal use of scarce moisture. As a major source of organic manure, livestock is crucial to the stability of dryland agriculture and farmers also depend on them for income (Reddy 2001; Sagari 2004). It is estimated that by 2025 India will use about 30 million tonnes of plant nutrients per annum, 8.1 million tonnes of which will be organic manure. Soil fertility management (SFM) not only affects those who own or cultivate agricultural land but also the landless poor, especially women, who often gather, process, and transport organic manure, and are employed to put it into use in fields. Cattle owners trade animal waste both for use in fields and as a valuable source of fuel. Shepherds barter manure of their sheep and goats for the right to graze on particular plots of land (Adolph and Butterworth 2002). Through these multiple dimensions, SFM is key to the sustainable livelihood of rural people in the semi-arid tropical regions of India.

Based on fieldwork done in Andhra Pradesh (AP), this study examines the in-depth knowledge on SFM methods that local farmers possess, and the cultural and socio-economic network that has evolved around these practices. It also looks at how policy interventions threaten this knowledge base and the sustainable practices it supports.

This paper addresses the following main research questions.
(1) What kind of SFM strategies do farmers in semi-arid regions adopt to address the risks inherent in rain-fed farming?
(2) How do these practices ensure the efficiency and sustainability of agriculture in dryland areas?
(3) What is the impact of agricultural policies pertaining to SFM on farmers in semi-arid areas?

Keeping the above research questions in mind, a thorough review of the relevant literature was carried out. To fill some of the gaps in the existing literature, this paper focuses on the following objectives:
(1) To identify and record the SFM strategies adopted by different size-classes of farmers (large, medium, and small) in dryland regions.
(2) To examine the ecological, economic, social and livelihood significance of SFM practices.
(3) To contribute to the overall policy discourse on SFM in semi-arid regions.

Study Area, Data Collection and Methodology

AP was the state chosen for the study. More than 80% of those involved in agriculture here are small and marginal farmers and landless labourers, who together own a mere 35% (3.5 million hectares) of the total 10 million hectares of cultivated land. The state has the distinction of having very diversified livestock resources in seven agro-climatic zones, each with different production systems. In AP, agriculture has undergone many changes over the past two to three decades. The increasing intervention of the state in agriculture, and the green and yellow revolutions, have prompted changes throughout the state's semi-arid regions, especially in landownership, cropping patterns, irrigation, credit and extension services, productivity, marketing, and prices. In addition, the use of fertilisers is high in AP. In 2004-05, as much as 11.57, 5.39 and 2.92 lakh tonnes of nitrogen (N), phosphorus (P) and potassium (K) were respectively used by the state's farmers. In the same year, the total NPK consumption per hectare was 158.80 kilograms (CMIE 2006) against India's 88.11 kg/ha (Fertiliser Association of India 2006). All this has a huge bearing on the SFM practices of farmers, particularly in semi-arid regions. It was against this background that AP was selected for the study on SFM practices in semi-arid regions and their socio-economic, ecological and livelihood dimensions.

The selected districts were Mahbubnagar, Anantapur and Prakasam, each from a region – Telangana, Rayalaseema and Coastal Andhra – having different socio-economic and ecological characteristics. These semi-arid districts have the least percentage of net irrigated area in their regions and average annual rainfall ranging from 500 to 900 mm. Two mandals were then selected from each district, one with the least percentage of net irrigated area and the other with the highest net irrigated area. Though both mandals fall in the semi-arid category, this was done to observe the dynamics of SFM in irrigated and dryland conditions. Two villages, one each from the selected two mandals of each district, were chosen on the basis of the same criteria (Table 1). This helps one gain a holistic perspective on SFM at the village level, both in irrigated and dryland conditions.

In each village, 60 farmers were picked, 20 from each size-class (large, medium and small). Thus a total of 360 farmers covering the three districts were personally interviewed, using a structured schedule. The study used both qualitative and quantitative methods for understanding the farmers' SFM practices and the conditions under which they adopt them. It employed an ex post facto research design coupled with case studies, and participatory rural appraisal (PRA) methods such as timelines, trends analyses, resource mapping, soil mapping, matrix ranking, seasonality analysis and focus group discussions. Secondary data on rainfall, net irrigated area and demographic features of the district were collected from the Bureau of Economics and Statistics, the Centre for Monitoring Indian Economy (CMIE), and *Economic Survey* and *Fertiliser News* reports. Fertiliser recommendations were obtained from the package of practices suggested by the Acharya N G Ranga Agricultural University in Hyderabad, AP's capital.

The data analysis was done in two ways – one, comparing farmers of different size-classes; and two, comparing the better irrigated and less irrigated villages. The results of the study are discussed at two levels – one at the household level and the other at the plot level. The data gathered was analysed using different statistical tools. Averages, frequency and percentages were used to analyse the various aspects related to SFM. The Battese and Coelli model (1988) for estimating stochastic frontier production was used for the paddy, groundnut and sunflower crops. This approach was used to calculate the average technical efficiency of paddy, groundnut and sunflower cultivation with regard to

Table 1: Study Area in Andhra Pradesh

District	Mandal	Village	Number of Sample Households
Telangana region			
Mahbubnagar	Peddakothapalli (3.16% net irrigated area and 625 mm rainfall)	Maredudinne (0.50% net irrigated area)	60
	Chinnachintakunta (91.57% net irrigated area and 565 mm of rainfall)	Dhupalle (89.20% net irrigated area)	60
Rayalaseema region			
Anantapur	Puttaparthi (0.36% net irrigated area and 609 mm rainfall)	Brahmanpalle (10.16% net irrigated Area)	60
	Tadipatri (39.30 net irrigated area and 667 mm rainfall)	Chinnapolamada (29% net irrigated area)	60
Coastal Andhra region			
Prakasam	Korisepadu (9.33% net irrigated area and 865 mm rainfall)	Ravinuthala (0.48% net irrigated area)	60
	Darsi (75.12% net irrigated area and 733 mm)	Darsi (82.06% net irrigated area)	60

Source: Chief Planning Office of the selected districts.

size-classes, the fertility level of soil as perceived by farmers, the number of SFM methods and types of soils. However, in this paper we focus only on the technical efficiency of paddy and groundnut and their relation to different SFM methods.

Analytical Method

This section aims to analyse the SFM practices adopted by the sample farmers. While doing so, the study is subjected to a three-way analysis. First, each practice adopted by the sample farmers is described, along with the costs involved. Second, the SFM practices recommended by the agricultural university are looked into. Third, the gulf and variations between the recommendations of the agricultural university and the actual SFM practices of the farmers across size-classes are compared. In this section, farmers' practices are assessed with reference to size-classes and irrigated and unirrigated villages. Villages with the least net irrigated area were considered unirrigated. The frontier production function was used for paddy and groundnut to arrive at the technical efficiency of different SFM practices. Farmers' fertility-enhancing practices are discussed against the backdrop of the package of practices suggested by scientists of the agricultural university for the selected crops in the *Agricultural Almanac* (*Vyavasaya Panchangam* in Telugu).

Farmers' Practices

The farmers actively manage soil fertility and other properties through a wide range of practices. These include farm yard manure (FYM), sheep penning, tank silt application, oil cakes, cultivation of legumes, crop rotation, intercropping, mixed cropping and chemical fertilisers. These practices are based on their long experience and a rich knowledge of locally specific conditions; despite constraints, such practices are alive and vibrant (Butterworth et al 2003). To get an idea of how various methods were applied and in what proportion, an attempt was made to examine the SFM practices across different size-classes of farmers and the status of irrigation in the villages. There were 664 fields among the 360 sample households, covering all size-classes, in the six villages. Of these, 79 plots were fallow (current as well as permanent). Information from the remaining 585 plots is presented in Table 2.

It is important to note that multiple practices were followed in some plots. In a few plots, two or three practices were followed at a given time for a given crop. Hence, the percentages were calculated for each practice with respect to the area of the total number of sample plots in each size-class. As more than one SFM practice was adopted in some sample plots, the total of percentages exceeds 100.

Looking at the mean column in Table 2, it is evident that the combination of FYM and chemical fertilisers (1,792.65 acres) was predominant across all size-classes of farmers, followed by intercropping/mixed cropping (1,089.75 acres), and legume cultivation (927.25 acres). FYM application has been one of the principal means of replenishing soil losses in dryland regions. A unique feature of FYM is that it supplies humus (which can never be substituted by inorganic fertilisers). This humus is a major source of food for micro-organisms in the soil and is essential for their well-being and development. The physical properties of the soil like porosity, water stable aggregates, water-holding capacity, infiltration rate and hydraulic conductivity are significantly added to by the conjunctive use of organic manure and inorganic fertilisers (Reddy Uma 1999). It was found that only chemical fertilisers were used in 412.75 acres, and of this area, no SFM practice was followed in 135.5 acres. It was surprising to note that the practice of applying only FYM was not seen in any size-class in all the villages studied. This was largely due to the lack of sufficient quantities of organic manure because of a fall in the livestock population, which, in turn, had been caused by a shortage of fodder and water in summer. It was interesting to find that the practice of sheep penning still existed and most of the farmers were enthusiastic about it. Shepherds were the source of the best quality FYM (Butterworth et al 2003).

Table 2: Size-Class-wise Adoption of SFM Practices in Sample Plots during the Kharif 2005-06 (percentages)

SFM practice	Large Farmers (N=245)	Medium Farmers (N=183)	Small Farmers (N=157)	Mean of all (N=585)
Not followed any practice	1.63(57)	4.37(42)	10.19(36.5)	5.40(135.5)
FYM + chemical fertilisers	77.14(1127.65)	63.93(435)	57.96(230)	66.34(1792.65)
Only chemical fertilisers	15.51(214)	24.84(147.75)	17.83(51)	19.39(412.75)
Sheep penning	2.86(44)	0.0	5.10(22.5)	2.65(66.5)
Sheep penning + chemical fertilisers	0.0	0.0	0.64(2)	0.21(2)
Tank silt	0.0	0.0	0.64(3)	0.21(3)
Neem cake	6.12(95)	5.46(43.5)	0.64(0.5)	4.07(139)
Castor cake	6.94(99.5)	2.73(22.5)	5.10(15)	4.92(137)
Legume cultivation	45.71(606.75)	33.88(228.5)	23.57(92)	34.39(927.25)
Inter/mixed cropping	40.41(619.25)	38.80(316)	40.13(154.5)	39.78(1089.75)
Others	00.0	00.0	1.27(3)	0.42(3)

Figures in parentheses indicate the actual acres in which the practice was used. More than one practice is adopted in a given season in a given plot and the above table is based on multiple responses.
Source: Based on a primary survey.

Organic fertilisers such as neem cakes were being used for paddy to increase the efficiency of nitrogen uptake as well as enhance resistance to pest attacks. Castor cakes were being used along with it, largely for horticultural crops in Anantapur district. Farmers said in focus group discussions that these organic cakes were more suited to orchard crops than chemical fertilisers because they served several purposes such as adding to soil fertility, reducing pest incidence, increasing the water-holding capacity of the soil, producing fruit of a good colour and shape, and prolonging shelf life, which helped to transport it to distant places. It was surprising that vermicompost, which had become popular of late in some pockets of AP, was not used even in a single plot. This seemed to indicate that the idea had not spread widely enough. Efforts must be made to promote vermicomposting alongside establishing a number of units doing it so as to make compost that is much higher in nutrients accessible to more small and marginal farmers. The study's empirical data clearly pointed out that farmers attached great significance to the practice of legume cultivation.

Contrary to the popular belief that farmers mostly rely on chemical fertilisers, this study brings out that farmers across all size-classes use several other methods of SFM, including organic fertilisers. According to them, this is done keeping in view the long-term sustainability of the soil. From Table 2, it is evident that FYM plus chemical fertilisers was the preferred combination among most of the sample farmers across all size-classes. This shows that farmers clearly understand the prominent role FYM and other organic manures play in the long-term sustainability of the soil and crop yields. At the same time, there is considerable diversity in farmers' conditions and SFM strategies as there is no blanket solution for improving soil fertility (Hilhorst and Muchena 2000).

Organic vs Inorganic Inputs

An analysis was done to understand how the sample farmers were distributed with regard to the use of organic and inorganic inputs (Tables 3 and 4). For this, the total amounts spent by them on organic manures and inorganic fertilisers in 2004-05 and 2005-06 were considered. Different ratios of both were taken into account for an easier and better understanding of how money was being invested on organic and inorganic fertilisers and by what percentage of farmers. The analysis did not include cultural practices such as crop rotation and inter/mixed cropping as no separate investment is needed for these apart from the seed cost, which the farmer has to anyway bear for raising a crop.

The distribution of the sample farmers revealed that only 16.94% exclusively used chemical fertilisers in their plots. There was no one exclusively using only organic manures. But more than 32.50% of the farmers spent more than 50% of their total investment on soil fertility on organic manures/practices. This is a positive sign for the emerging organic market. This large group of farmers can be encouraged to become totally organic and take advantage of the growing organic market and the facilities extended by the government to encourage organic agriculture. Among the size-classes, 46.67% of small farmers invested more than 50% of their money on organic manures/practices. They were followed by medium (31.67%) and large farmers (19.17%). In unirrigated villages, 33.88% of the sample farmers spent 50% or more on organic fertilisers compared to 31.10% in irrigated villages.

Recommended Practices vs Farmers' Practices

In the earlier sections, various SFM practices adopted by the sample farmers were discussed, irrespective of the crops they were growing. In this section, an attempt is made to understand their practices with reference to the agricultural university's recommendations regarding SFM for the selected crops. Of the total crops being cultivated by the farmers, only those which had good distribution (a minimum of 30 sample farmers) were selected for analysis. Paddy, maize, sunflower, castor, and groundnuts (irrigated and rain-fed) grown during the kharif 2005-06 were selected for comparing farmers' practices against the recommended practices. However, we are restricting our discussion to only paddy and groundnuts in this paper. It is well known that not only major nutrients such as nitrogen, phosphorus and potassium but also micronutrients play a critical role in crop growth and yield. But, in this analysis and discussion, we restrict ourselves to NPK and FYM.

SFM in Paddy

Acharya N G Ranga Agricultural University has divided AP into nine agro-climatic zones on the basis of physiography, soil types, crops and cropping patterns. It is interesting to note that it recommends packages of practices only for paddy in each of the zones. SFM suggestions are also made separately for each zone. Paddy has been one of the major food crops grown under irrigated conditions in AP. But there is no specific recommendation made for the use of FYM for paddy though FYM recommendations are made for other crops (groundnuts, sunflower and castor). The reason could be the scientists assuming that farmers invariably use all available manure from their compost pits for paddy, thus making it not really essential to make a mention of it. But one cannot ignore the enormous importance of FYM in maintaining soil health and soil life. So, it is necessary to specifically recommend FYM dosages for all the crops in the state.

Farmers across all size-classes in Darsi (both a mandal and village) of Prakasam district applied two and half to three times the recommended dosages of nitrogen and phosphorus-supplying fertilisers per acre (Table 5, p 60). This was because they cultivated three crops a year, which made it necessary to replenish the soil either with FYM or inorganic fertilisers. The availability of FYM is limited, encouraging the excessive application of nitrogen and phosphorus fertilisers. Coastal farmers are proactive in gaining information related to agriculture and private companies are active in this region. The farmers are motivated to use more chemical fertilisers through advertisements that claim they give higher yields. But their application of potassium-supplying fertilisers is less than recommended. This could be due to the good

Table 3: Size-Class-wise Distribution of Farmers according to the Ratio of Amount Used for Organic and Inorganic Fertilisers in 2004-05 and 2005-06 (percentages)

Size-Class	OF:CF 0:100	OF:CF 10:90	OF:CF 20:80	OF:CF 30:70	OF:CF 40:60	OF:CF50:50	OF:CF 60:40	OF:CF 70:30	OF:CF 80:20	OF:CF 90:10	Total
LF	5.83(7)	15.83(19)	23.34(28)	17.50(21)	18.33(22)	5.0(6)	7.5(9)	6.67(8)	0(0.00)	0(0.00)	100.0(120)
MF	20.0(24)	5.83(7)	12.5(15)	20.83(25)	9.17(11)	10.0(12)	9.17(11)	5.0(6)	3.33(4)	4.17(5)	100.0(120)
SF	25.0(30)	4.17(5)	7.5(9)	8.33(10)	8.33(10)	8.33(10)	9.17(11)	14.17(17)	10.0(12)	5.0(6)	100.0(120)
All	16.94(61)	8.61(31)	14.45(52)	15.56(56)	11.94(43)	7.78(28)	8.61(31)	8.61(31)	4.44(16)	3.06(11)	100.0(360)

OF = Organic Fertilisers; CF = Chemical Fertilisers; LF, MF, SF = Large, Medium, Small Farmers. Figures in parentheses are the actual number of farmers.
Source: Based on a primary survey.

Table 4: Distribution of Farmers in Irrigated and Unirrigated Villages according to Amount Used for Organic and Inorganic Fertilisers in 2004-05 and 2005-06

Village	OF: CF 0:100	OF: CF 10: 90	OF: CF 20:80	OF: CF 30:70	OF: CF 40:60	OF: CF 50:50	OF: CF 60:40	OF: CF 70:30	OF: CF 80:20	OF: CF 90:10	Total
Irrigated	10.56 (19)	8.89 (16)	15.0 (27)	21.67 (39)	12.78 (23)	10.0 (18)	9.44 (17)	8.89 (16)	1.66 (3)	1.11 (2)	100.0(180)
Unirrigated	23.33(42)	8.33(15)	13.89(25)	9.44(17)	11.11(20)	6.11(11)	7.22(13)	8.33(15)	7.22(13)	5.0(9)	100.0(180)
All	16.94(61)	8.61(31)	14.45(52)	15.56(56)	11.94(43)	7.78(28)	8.61(31)	8.61(31)	4.44(16)	3.06(11)	100.0(360)

OF = Organic Fertilisers and CF= Chemical Fertilisers. Figures in parentheses are the actual number of farmers.
Source: Based on a primary survey.

Table 5: SFM Inputs Used Per Acre for Paddy during the Kharif 2005-06

Particulars	LF	MF	SF	Recommended Nutrient Dosage by Agricultural University	Recommended Yield in Kg/Acre	Yield Obtained in Kg/Acre
Darsi (Prakasam)						
FYM in kg	980.00	1,744.53	1,919.13	No specification	2,800	2,031.16
Nitrogen in kg	84.91	81.68	75.86	24-32		
Phosphorus in kg	52.62	52.625	48.51	16		
Potassium in kg	9.34	9.43	8.93	12-16		
Chinnapolamada (Anantapur)						
FYM in kg	332.50	875.00	2,705.00	No specification	2,500	1,100
Nitrogen in kg	18.50	21.5	17.8	64		
Phosphorus in kg	17	15.00	12.60	32		
Potassium in kg	17	12.50	9.70	32		
Brahmanpalle (Anantapur)						
FYM in kg	879.90	1,164.37	1,531.25	No specification	2,500	1,022.17
Nitrogen in kg	21.09	21.50	18.5	64		
Phosphorus in kg	18.36	18.50	16.75	32		
Potassium in kg	16.54	16.5	12.50	32		
Dhupalle (Mahbubnagar)						
FYM in kg	2,061.94	1,948.81	1,184.33	No specification	2,500	1,991.02
Nitrogen in kg	76.77	71.75	61.80	40-48		
Phosphorus in kg	42.27	37.50	27.26	24		
Potassium in kg	21.83	21.31	20.08	16		
Maredudinne (Mahbubnagar)						
FYM in kg	1,075.00	0	541.66	No specification	2,500	1,219.44
Nitrogen in kg	20	21	21.66	40-48		
Phosphorus in kg	16.4	16	17.33	24		
Potassium in kg	16.8	15	17.33	16		

LF, MF, SF = Large, Medium, Small Farmers. No paddy was grown under irrigated conditions in Ravinuthala village of Prakasam.
Source: Based on a primary survey.

quantities of native potassium in the soil of Darsi mandal (Table 7, p 61) and Prakasam district (Table 6) as a whole. Among size-classes, large farmers applied higher quantities of NPK nutrients, followed by medium and small farmers. FYM was applied in larger quantities per acre by small farmers (1,919 kg), followed by medium (1,744 kg) and large farmers (980 kg). This was because small and medium farmers had less land and were more dependent on livestock, which gave them some manure.

Excessive use of inorganic fertilisers over long periods of time is a cause of concern as it leads to gradual degradation of the soil, even if there is access to assured irrigation. This is more so in cases where inorganic fertilisers are not combined with good quantities of organic manures. Depletion of organic matter in the soil leads to deterioration of its structure, reduced water and nutrient-holding capacity and a decline in microbiological activity (Wommer et al 1994; Reddy Ratna 1999).

In Ravinuthala village, there was no paddy crop at all. In Chinnapolamada of Anantapur district, farmers used one-third less nitrogen and 50% less phosphorus and potassium than the recommended amount. This was due to a lack of sufficient water – higher dosages of fertilisers in moisture-stress conditions could have a negative effect on the yield. The fertility index in Tables 6 and 7 indicates that the soils in the districts and mandals studied have a medium to high content of native phosphorus and potassium. This could be one of the reasons for the lesser use of phosphorus and potassium than recommended. Another reason could be that the recommendations made by the scientists did not hold good for the conditions under which the sample farmers worked.

In Chinnapolamada, medium farmers applied the highest dose (21.5 kg) of nitrogen, followed by large (18.50 kg) and small farmers (17.8 kg). This could be attributed to the effort of medium farmers to maximise profit from the land available to them. FYM use per acre by small farmers in this village was the highest (2,705 kg/acre) among all the villages studied, whereas medium and large farmers here applied 875 kg and 332 kg, respectively. This was quite low and the probable reason could have been fewer livestock maintained by these groups due to lack of fodder and water. However, small farmers still managed to hold onto their livestock because it helped them earn a livelihood.

In the village of Brahmanpalle of Anantapur district, the situation was almost similar to that of Chinnapolamada but with slightly higher doses. FYM was applied in higher quantities by small farmers (1,531.25 kg), followed by medium (1,164.37 kg) and large farmers (879.90 kg). The reason was more livestock with small farmers, who also looked after their animals better.

In Dhupalle village of Mahbubnagar district, the quantities of NPK applied were one and half to two times higher than the university's recommendation. A significant observation made in this village was that farmers across all size-classes were applying higher doses of even potassium (in other villages, it was less than recommended). The reason could have been the medium fertility index of potassium in its mandal, Chinnachintakunta (Table 7). Another reason was the extensive cultivation of paddy in this village, which began with a new lift irrigation scheme, and the cultivation of two crops a year. The application of complex fertilisers, which also contribute potassium, could have added to this. Moreover, the variety being cultivated was long-duration BPT-5204, which requires fertilisers for a longer period than short-duration varieties. Contrary to other villages, in Dhupalle, large farmers applied slightly higher quantities of FYM (2,061.94 kg) per acre, followed by medium (1,948.81 kg) and small farmers (1,184.33 kg). The reason for this was the availability of FYM due to a good number of livestock and also the capacity to pay for it.

It can be observed from Table 5 that the actual yields obtained by farmers were less than the recommended yield for that agro-climatic zone. Yields were less, both in the case of those villages where NPK nutrients were applied in excess and those where they

Table 6: Fertility Index for Macronutrients (NPK) in the Study Districts during 2005-06

District	Fertility Index		
	Nitrogen	Phosphorus	Potassium
Prakasam	1.10	1.88	2.75
Anantapur	1.18	2.78	2.81
Mahbubnagar	1.61	1.78	1.85

Fertility Index rating: 0 – 1.66 = Low, 1.67 – 2.33 = Medium, > 2.33 = High.
Source: Soil Testing Laboratories, Department of Agriculture, Government of Andhra Pradesh.

Table 7: Categorisation of Soils in Mandals Studied based on the Fertility Index in 2005-06

District	Name of Mandal	Fertility Index		
		Nitrogen	Phosphorus	Potassium
Prakasam	Darsi	1.08 (Low)	1.89(Medium)	2.65(High)
	Korisepadu	1.21(Low)	1.95(Medium)	2.50(High)
Anantapur	Tadipatri	1.37(Low)	2.93(High)	2.90(High)
	Puttaparthi	1.07(Low)	2.46(High)	2.84(High)
Mahbubnagar	Chinnachintakunta	1.81(Medium)	1.86(Medium)	186(Medium)
	Peddakothapalli	**	**	**

** Information is not available for this mandal.
Fertility Index rating: 0 – 1.66 = Low, 1.67 – 2.33 = Medium, > 2.33 = High.
Source: Soil Testing Laboratories, Department of Agriculture, Government of Andhra Pradesh.

Table 8: SFM Inputs Used Per Acre of Groundnut Crop under Rain-fed Conditions during 2005-06

Particulars	LF	MF	SF	Recommended Nutrient Dosage by Agricultural University	Recommended Yield in Kg/Acre	Yield Obtained in Kg/Acre
FYM in kg	498.22	786.48	1,053.65	4,000-5,000	480-600	387.24
Nitrogen in kg	18.05	15.68	10.57	12		
Phosphorus in kg	22.62	21.34	20.03	16		
Potassium in kg	5.72	5.41	4.46	20		
Gypsum in kg	12.14	0.00	0.00	200		

Source: Based on a primary survey.

were applied in lower quantities than recommended. A possible reason could be that the recommendations are based on data obtained from research designs 10-15 years old, which is not in line with present conditions. However, it indicates that excess quantities of chemical fertilisers are being applied in the coastal village of Darsi, which may eventually lead to soil degradation. In the case of the other villages, the farmers add smaller quantities of nutrients because experience has proved that it is the optimum they can apply in the given situation and larger inputs may not increase yields anymore. On the other hand, it could lead to soil degradation.

SFM for Rain-fed Groundnut

The quantities of nitrogen and phosphorus being applied were higher than the university's recommendation (Table 8). Only 25% of the recommended dosage of potassium was applied across all size-classes. This was due to native potassium in the soil (Table 6), especially in Anantapur district where groundnut is predominantly grown under rain-fed conditions.

Gypsum was not being applied by small and medium farmers. Large farmers were using only 12.14 kg gypsum per acre against the recommended 200 kg/acre. This was due to difficulties in accessing the subsidised gypsum supplied by the government. The process of procuring subsidised gypsum from the Agricultural Department was very complicated and not something small and marginal farmers could tackle. All categories of farmers were applying much less FYM for rain-fed groundnuts than recommended. The reason was that they tended to concentrate on the application of nutrients in irrigated plots to get a better and assured income. Groundnut yields were quite low because of inadequate FYM and gypsum, combined with the incidence of pests.

SFM and Technical Efficiency

Production function is the average function. Each and every farmer's practice is much more important than the average production of all farmers. Hence, it is essential to calculate the technical efficiency index of each farmer – which determines yield – taking the input bundle into account. It also helps us find out whether an increase in the technical efficiency index is because of SFM practices or some other practices adopted by these farmers. In this way, a technical efficiency analysis enables us to undertake a more detailed investigation.

The frontier production function estimates the maximum feasible or potential output that can be produced by a farm with a given level of inputs and technology.

Consider the frontier production function

$$y_{it} = f(x_{it}, \beta) + e_{it} \qquad \ldots (1)$$

$$\text{and } e_{it} = v_{it} - u_i \qquad \ldots (2)$$

where y_{it} denotes the appropriate function of the production for the *ith* sample firm
(i = 1,2, .. N) in the *tth* time period (t=1,2, .. T).

x_{it} is a (1 x k) vector of appropriate functions of the inputs associated with the *ith* sample firm in the *tth* period.

β is a (k x 1) vector of the coefficients for the associated independent variables in the production function.

v_{it} is a random variable assumed to be independent and identically distributed (iid) as $N(0, \sigma_v^2)$ and independent of u_i random variable.

u_i is a firm-specific technical efficiency-related variable and non-negative defined by the truncation (at zero) of $N(\mu, \sigma_u^2)$.

It is assumed that the random variables v_{it} and u_i are distributed independently of the input variables in the model. The density function for u_i is defined by

$$fu_i(u) = \frac{\exp[-\tfrac{1}{2}(u-\mu)^2/\sigma_u^2]}{\sqrt{2\Pi}\,\sigma_u[1-\phi(-\mu/\sigma_u)]}, \; u > 0$$

By the convolution formula, the joint density function of e_i, that is, $(v_{it} - u_i)$ can be written as

$$F_{ei}(e_i) = \frac{[1-\phi(Z) \,.\, M \,.\, N]}{[(2\pi)^T(\sigma_v^2 + T\sigma_u^2)]^{1/2}\sigma_v^{T-1}[1-\phi(-\mu/\sigma_u)]}$$

$$\text{where } Z = \frac{\sigma_u^2 T \ddot{e}_i - \sigma_v^2\mu}{\sigma_u\sigma_v\sqrt{(\sigma_v^2 + T\sigma_u^2)}}$$

$$\ddot{e}_i = \frac{1}{T}\sum_{t=1}^{T} e_{it}$$

$$M = \exp[-\tfrac{1}{2}\Sigma(e_{it} + \mu)^2/\sigma_v^2]$$

$$N = \exp\left[\frac{\sigma_u^2 T^2(\ddot{e}_i + \mu)^2}{2\sigma_v^2(\sigma_v^2 + T\sigma_u^2)}\right]$$

and ϕ (.) denotes the distribution function of the standard normal random variable. The density function of Y_i is written as

$$f_y(y) = \frac{[1-\phi(Z)]\exp\left[\frac{-\Sigma(e_{it}+\mu)^2}{2(1-\mu)\sigma^2}\right]\exp\left[\frac{T^2\gamma(\ddot{e}_i+\mu)^2}{2(1-\gamma)\sigma^2(1+(T-1)\gamma)}\right]}{\{(2\pi)^T\sigma^2[1+(T-1)\gamma]\}^{1/2}[\sigma^2(1-\gamma)]^{T-1/2}[1-\phi(-\mu\sqrt{\gamma\sigma})]}$$

$$\text{where } \sigma^2 = \sigma_u^2 + \sigma_v^2$$

$$\gamma = \sigma_u^2/\sigma^2$$

The distribution of the non-negative firm effect is u_i, which is the generalisation of the half-normal distribution in which $\mu = 0$. The log-likelihood function for the model is given by

$$\ln L_i = (-NT/2) \ln (2\pi) - (N (T-1)/2) \ln [(1-\gamma) \sigma^2] - (N/2) \ln \{\sigma^2 [1 + (T-1) \gamma]\} - N \ln [1-\phi(-\mu/\sqrt{\gamma\sigma})] + \Sigma^N \ln [1 - \phi (Z)] - (2(1-\gamma) \sigma^2)^{-1} \Sigma^N \Sigma^T (e_{it}+\mu)^2 + T^2 \mu \Sigma^N (\ddot{e}_i + \mu)^2 \{2 (1-\gamma) [1 + (T-1) \gamma] \sigma^2\}^{-1}$$

$$\text{where } Z = \frac{(T \ddot{e}_i + \mu) \gamma - \mu}{\sqrt{\{\gamma (1-\mu) [1 + (T-1) \gamma]\}} \sigma^2}$$

Further a joint test on the significance of the random variable u_i in the frontier function is obtained from the generalised likelihood ratio. If the random variable is absent from the model (that is, $\mu = \gamma^2 = 0$), then the Ordinary Least Squares (OLS) estimators of the remaining parameters of the production function are maximum likelihood (ML) estimates. Thus, the negative of twice the logarithm of the generalised likelihood ratio has approximately chi square (χ^2) distribution with parameter equal to the number of restrictions. That is, if $\mu = 0$, it follows the χ^2 distribution with a parameter equal to one.

Table 9 presents the results of tests of significance conducted for paddy. In frontier regression analysis it could be seen that independent variables such as FYM, total organic manures, nitrogen, phosphorus, other nutrients and human labour were positively significant at 1% level, whereas bullock labour was positively significant at 5% level. This means that with every one rupee increase on independent variables such as FYM, organic manures, human labour and bullock labour, there was an increase in yield of 0.019 kg, 0.024 kg, 0.647 kg and 0.115 kg respectively. Similarly, with an increase in every kg of independent variables such as N, P and other nutrients, there was an increase in yield of 0.222 kg, 0.221 kg and 0.028 respectively. The probable reasons for the increase could have been the addition of more nutrients or a synergetic effect as well as human and bullock labour taking up timely agricultural operations. Seed was negatively significant. With an increase in every kg of seed, there was a decrease of 1.11 kg in yield. When the seed rate goes up, the plant population per acre increases, intensifying the competition for nutrients, moisture, sunlight and air, which leads to a lesser yield.

Table 9: Frontier Production Function Results for Paddy

Independent Variable	Yield in Paddy Frontier Regression (Half Normal)
Seed in kg	-1.1173** (0.2273)
FYM in Rs	0.0196** (0.0056)
Total organic manures in Rs	0.0240** (0.0065)
Nitrogen (N) in kg	0.2226** (0.0522)
Phosphorus (P) in kg	0.2217** (0.0460)
Potassium (K) in kg	0.0515 (0.0333)
Other nutrients in Rs	0.0281** (0.0076)
Pesticides in Rs	-0.0806* (0.0329)
Human labour in Rs	0.6479** (0.0845)
Bullock labour in Rs	0.1151* (0.0540)
R2/sigma-squared	0.0199** (0.0025)
Gamma	0.9479** (0.0228)
Log likelihood function	202.8354
LR test of the one-sided error	27.0134
Number of observations	190

** 1% level of significance.
* 5% level of significance.
Figures in parentheses indicate standard errors.

In the case of groundnuts, the model showed neither positive nor negative significance for any independent variable. This meant that there could be other variables such as rainfall and climate, which could have an impact on the yield, but these factors are not within the scope of this analysis.

Technical Efficiency

After the regression analysis using the frontier production function, the average technical efficiency, or TE, was calculated for paddy and groundnut. This was done using all inputs, including fertility-enhancing organic inputs.

TE is the ratio of the actual output represented in original units to the potential output measured in original units that is obtained when the firm is technically efficient (U=0). Thus the TE of the *ith* firm, is defined by

$$TE_i = \frac{E (Y_{it}^*/U_i , x_{it} , t = 1,2 \ldots)}{E (Y_{it}^*/U_i = 0 , x_{it} , t = 1,2 \ldots)}$$

where Y_{it}^* denotes the production in original units for the *ith* firm in the *tth* time period.

If the frontier production function (1) – (2) defined the logarithm of the production, then the measures of firm-specific technical efficiencies are calculated from the conditional distribution of U_i, given the joint distribution of E_{it}. The conditional distribution of U_i, given $\ddot{E}_{it}$

$$TE_i = \exp(-U_i/E_i) = \frac{1 - \phi [\sigma^* - (M_i^*/\sigma^*)]}{1 - \phi (- M_i^*/\sigma^*)} . \exp (-M^* + ½ \sigma^{2*})$$

where ϕ (.) is the standard normal distribution function

$$M_i^* = (-\sigma_u^2 \ddot{E}_i + T^{-1} \mu \sigma_v^2) (\sigma_u^2 + T^{-1} \sigma_v^2)-1$$

$$\ddot{E}_i = T^{-1} \sum_{t=1}^{T} E_{it}$$

$$\sigma^{2*} = \sigma_u^2 \sigma_v^2 (\sigma_v^2 + T\sigma_u^2)^{-1}$$

The details of the results of this analysis with respect to paddy and groundnuts are discussed below.

SFM Methods and Average Technical Efficiency

After assessing the crop-wise cost of cultivation and technical efficiency, an effort was made to see which methods were most effective for paddy, groundnuts and sunflower. For this purpose, the major SFM practices, excluding cultural practices like mixed cropping and legume crop cultivation, were considered for analysis. That is, only the practices that were input-based were analysed. For paddy, a combination of sheep penning and neem cake application realised the highest technical efficiency (0.92%). This emphasises the argument that policymakers and agricultural scientists should look at some of the traditional practices as well as ones that have been recently picking up such as application of neem cake. There is a need to support such strong useful practices in various ways so that farmers can enhance the fertility of their soil. It was also seen that a combination of FYM and chemical fertilisers had a technical efficiency of 0.90%, and the use of only chemical fertilisers ranked third with 0.89%. The least technical efficiency was seen in castor cake application.

In the case of the groundnut crop, the highest (0.88%) average technical efficiency was seen in the practice of combining FYM and chemical fertilisers. This was the practice being followed by a large number of the sample farmers. The least technical efficiency was seen in the case of neem cake application (0.79%). However, it must be noted that the number of farmers using this practice in groundnut cultivation is low.

Table 10: Average Technical Efficiency in Different SFM Practices

SFM practices	Paddy	Groundnut
Chemical + FYM	0.90	0.88
Only chemical fertilisers	0.89	0.87
Sheep penning	0.92	**
Neem cake	0.92	0.79
Castor cake	0.85	0.87

** The practice was not used for this crop in 2005-06.
Source: Based on a primary survey.

Conclusions

Soil is critical to agriculture, food security and livelihoods. With a large proportion of India's population being dependent on small-scale, rain-fed agriculture, sustainable management of soil is a high priority. This study points to the many techniques that farmers in India's semi-arid regions have developed to maintain and enhance the fertility of their soil. We can see that farmers' SFM options are being undermined by government policies that give more weight to chemical fertiliser-based strategies. These include promoting packages of practices that include chemical fertiliser-responsive seeds, extending credit for buying them, not recognising the benefits of a mixed cropping system, and subsidising chemical fertilisers rather than organic inputs. Policies that encourage fertiliser and irrigation subsidies may discourage soil conservation and encourage depletion of groundwater (Lutz et al 1994; Reddy 2001). Hence this study makes the following recommendations.

- Subsidies and credit policies should allow farmers to buy whatever form of fertilising input they require.
- Policies are needed that encourage and support low external input and labour-intensive practices such as sheep penning, composting, vermicomposting, tank silt application, or incorporating green manure crops.
- Appropriate credit programmes have to be developed that enable farmers to obtain crop loans for mixed farming systems, including organic inputs such as FYM.
- Local animal breeds are important to livelihoods. Sustainable agriculture should be conserved in the places that it exists by strengthening integrated farming and indigenous systems of land use. Livestock plays a key role in nutrient cycles and the maintenance of soil fertility.
- All agricultural development projects, especially those focusing on soil, should focus on increasing supplies of organic matter to farmers that nourish organisms in the soil.

NOTES

1 Semi-arid refers to a climatic classification of typically dry areas with rainfall ranging from 500 to 950 mm and an evaporation rate in excess of rainfall for a greater part of the year.

2 γ is the ratio of individual variation to total variation in output. That is, $\gamma=\sigma^2_u/(\sigma^2_v+\sigma^2_u)$.

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