

Internalized Soil Productivity Management Systems

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Introduction

A brief attempt is made to highlight the internalized traditional soil productivity management systems in crop production. Some background of the system is also provided along with nutrient dynamics, with emphasis on N. Wherever available, some mention on soil physical condition is brought out. The external inputs like silt and sand and use of small ruminants for penning are excluded in this presentation.

Mixed cropping

Earlier, diversity was the common feature in crop production system in rainfed areas. The crops are grown in irregular patterns either through broadcasting and/or mixing within row. This has been identified as mixed cropping (Freyman and Venkateswarlu 1977). Largely, mixed cropping is practised by smallholders. And it is meant to meet the household food and nutritional security. In fact, as many as nine crops (“navadhanyalu”) are used together in mixed cropping systems. Even vegetables, including leafy ones, are included. But all these systems are primarily to meet the household requirements of the tiller of the land.

In a detailed study Rao and Khan (2003) found mixed cropping is largely the domain of the smallholders and is practised by in the disadvantaged areas.

Region	Percent farmers practising mixed cropping only
Arid	31
Semiarid	17
Humid	59

Of the farmers who practice mixed cropping 60%, 75% and 58% are smallholders in arid, semiarid and humid regions. And food crops are essentially the components in the mixed cropping with smallholders (100%, 71% and 93% in arid, semiarid and humid regions. Even with large holders the food crops dominated, the respective values being 100%, 72% and 94%.

So they are subjective and need our attention to rationalise and maximise the mixed cropping systems. Andrews and Kassam (1975) also identified such systems as mixed intercropping systems. Francis (1989) in his review on multiple cropping system, pointed out the Nigerian experience of 13-crops mixture traditionally grown. The system is sustainable but low yielding. The technologies to improve such systems are lacking, says Francis. In Telangana, the farmers, particularly women, say the same through a song and its translated version is as follows.

“When we farm the land we grow 12 types of crops
We apply farm yard manure and plough the land
In *kharif* we sow mungbean
Along with it we grow a staple crop, the yellow sorghum
For better nutrition we mix with it the pigeonpea
We also add cowpea through one tyne seeding
We grow urdbean as well for improved nutrition
As a leafy vegetable we take up *Hibiscus*

In *rabi* season we grow white sorghum
To meet our festivity needs we take up chickpea in some rows
We grow some mustard to meet our need of condiments
We take safflower to have vegetable oil
As a special diet we also sow wheat
To eat along with wheat roti we also grow linseed”

Thus the farmers keep the soil protected and healthy and the soil, in turn, keeps the farmers healthy and engaged over extended time employment.

This mixed cropping has many benefits to the practising farmers (Parameswaran and Sivakumar 2001)

- Different rooting systems of base and component crops
- One crop may provide a favorable micro-climate for another
- N-fixing plants fertilize non-N-fixing plants
- Pest management / control may be easy
- Labour demands are spread out
- Labour requirements are less, more so for weeding
- More moisture is retained in the soil
- Returns are higher per unit area
- Provides mixed diet over extended harvesting period
- Risk in crop failure less
- Extended labour employment

Mixed cropping provides a continuous vegetal cover to the soil during the rainy season, thus preventing the beating action of the rains. Further there would be considerable leaf litter which acts as a mulch and reduces evaporative loss of soil moisture. It also ultimately adds nutrients to the soil, thus enriching its productivity. Even the weeds are not considered as villains by the farmers. They form the green fodder for the livestock or even is uncultivated foods for human consumption (Sateesh 2000).

Mixtures like sorghum, pearl millet, pigeonpea, cowpea, hibiscus and horsegram are common to meet food, feed, vegetable, fuel (pigeonpea). Sometimes Amaranthus and sunnhump are mixed to meet the fibre requirements. Sunnhump is also grown in black soils as a green manure crop for about 6 weeks in the rainy season and incorporated into the soil to grow *rabi* sorghum. Cowpea and in a few instances cucumber for the vegetable while hibiscus and amaranthus provide green leaf vegetable.

Akkidi system

It is traditional in southern Karnataka (red soils). This is mixed cropping of ragi with several other crops (Anonymous 1999). Ragi is the staple crop. *Kharif* sorghum and field bean (*Avare*) are mixed to provide fodder. Pigeonpea enriches the soil and provides the much needed fuel besides the pulse. Niger is a nutritious oilseed with protein as well. Cowpeas and blackgram protect the soil from the splash of the raindrops. Mustard is a trap crop reducing pest incidence. Row planting is common using local seed drill. Also ragi seed is, sometimes, broadcast. Some enterprising farmers apply 2-3 tractor loads of FYM/ha (Rs. 1000 / tractor load) and apply one bag of DAP (50 kg).

In high fertility soil, ragi is transplanted with every fourth row being cowpea, field bean or blackgram singly or in mixtures.

Niger is an interesting addition. It not only provides the oil and the protein, but through its root activity loosen the hard subsoil and the leaf litter acts as mulch-cum-manure. Such soils eventually got rejuvenated to better productivity. And this is what Sateesh (2000) also points in relation to the farmers of Medak district of Andhra Pradesh.

To sum up mixed cropping is a combination of cereals, pulses, oilseeds and vegetables meeting the daily needs of the smallholder, protecting the soil from erosion and enriching the soil with a great biodiversity. It not only provides food, but also provides fuel, fibre, fodder and thatching / fencing material. Further some of the associate crops (mustard) act as trap / decoy crops. Finally it provides the storehouse for various commodities, as they come to maturity at different periods in the calendar year.

Intercropping

Intercropping systems implies that two or more crops are grown together in set rows. Interest in cereal-legume intercropping is developing in both temperate and warm climates (Ofori and Stem 1987). Some of the advantages of intercropping appear to be :

- i. higher grain yields,
- ii. greater landuse efficiency,
- iii. improved soil fertility,
- iv. reduced fertiliser nitrogen requirements, and
- v. scope for developing energy-efficient and sustainable agriculture.

This is also known as row intercropping (Andrews and Kassam 1975).

Much of the research effort is in dealing with the row intercropping system. Line sowing allows crop-specific operations. It is our endeavour to go into more details of this system.

Perceptions on the system of intercropping

The perceptions on intercropping depend on the researchers and the practitioner.

The practitioner (farmer) aims at one or a combination of the following aspects :

- i. Food security
- ii. Income
- iii. Trap crop
- iv. Soil enrichment

The base crop which used to be the cereal was of the immediate concern of the farmer. Since his farm holding is limited he tries to produce many other crops (eg. legumes, oilseeds), vegetables and even fodder. Thus he likes to cover both food and nutritional security. This concept becomes more perceptible when women are the practising farmers.

The researcher considers, on the other hand, intercropping as a system for maximising productivity of the soils by efficient spatial and temporal use of resources (soil and rainfall). Evidently the researcher has no bias for a “base” crop. His urge would be how best to increase

- i. Productivity,
- ii. Sustainability, and
- iii. Monetary returns.

The increase in productivity comes through improved crop production technologies. Seed is the first change through use of HYB/HYV. Evidently the earlier systems and the growth rhythms there-of are bound to change. For instance the short duration sorghum/millet can provide more time and space for the pigeonpea. But if a *Phaseolus/Vigna* group of short pulse is taken up with these coarse cereals, the latter may be affected with a possible competition for water and nutrients at the critical physiological stages of these crops.

By use of external inputs like N, we may affect the efficiency of the legume component. It could be easy for a researcher to place nitrogen exclusively for the cereal crop. But it means more labour for the farmer. So more costs/ha.

The most commonly researched intercropping is cereal-legume system. And the legume provides all the necessary ingredients for sustainable crop production. Associating legume in fibre crops like cotton and oilseed crops like castor are well researched upon. But the extensive plant

protection measures take on the cotton/castor can lead to fair amounts of residues that might even affect human/animal health as these component crops are cleared earlier from the field.

Higher returns is one of the major thrusts of any researcher. But at what cost is the crucial question. With more than 75% farmers (in rainfed areas) being poorer, they cannot afford to take up high investment production system, more so in intercropping system. Through these systems many of the farmers seek food and nutritional security. How to reduce the costs of cultivation would, axiomatically, be the primary question that need be addressed by the researchers.

As mentioned earlier, mixed cropping provides enough leaf litter. In an excellent study Pratap Narain *et al* (1980) studied the leaf litter contribution in a sorghum + pigeonpea (1:1) intercropping in Kota (Rajasthan) abstracted details are given in Table-1.

Table-1: Contribution of leaf litter and N in sorghum + pigeonpea (1:1) intercropping

Treatment	Leaf litter (q/ha)	Total N (kg/ha)	Yield (q/ha)	
			Sorghum	Pigeonpea
NoPoKo	22.6	30.9	10.83	8.91
N ₂₅ PoKo	10.5	14.6	15.43	4.78
NoP ₄₀ Ko	27.1	37.3	10.94	7.834
N ₂₅ P ₄₀ Ko	18.33	24.5	15.43	4.98
NoP ₄₀ K ₃₀	25.2	34.9	8.81	9.30
N ₂₅ P ₄₀ K ₃₀	7.9	11.0	14.98	5.10

The data suggest leaf litter could effectively enhance pigeonpea productivity. Chemical N additions did enhance yield of sorghum but could not compensate the loss in yield of pigeonpea.

In another study Abdurahman *et al* (1998) found that the leaf litter in sorghum pigeonpea in a vertisol yielded 3.00 t/ha of leaves and left 2.40 t/ha of root mass, thus totally 5.4 t /ha of organic matter. The importance pigeonpea in the cropping systems is highlighted in such systems.

Traditional sequence cropping systems

The traditional double cropping systems in India are many. Two examples are given below.

Case study 1; Maghi sorghum in deep black soils of Khammam, Andhra Pradesh

Khammam district in Andhra Pradesh receives more than 1000 mm annual rainfall with an assured moisture supply period of 180-210 days. The soils here are predominantly deep and black. They are universally poor in nitrogen and high in potassium, while available phosphorus is adequate only at a medium level of production.

In rainfed areas sorghum, maize, greengram and groundnut are the important crops. One of the important indigenous methods here is the greengram-sorghum sequence cropping system. It occupies around 60,000 ha (Venkateswarlu 1999).

Features of sequence cropping

For the rainfed farmer of Khammam, sorghum, sown sometime in the second fortnight of August is the important staple crop.

Rainfall analysis indicates that the highest probability of the onset of monsoon is in the fortnight beginning 11th June and recedes with a good assurance by end October. This means that the total length of monsoon rains is about 20 weeks. Since the soils are deep and with the rains ending in the cooler part of the year, the crop growing season would be about 180-210 days. Evidently, a two crop sequence with 65-70 days variety of grain legume followed by a coarse grain crop of about 100 days is a distinct possibility.

Thus the farmer has been taking up greengram as a grain legume when he is able to sow the crop by early June. He then incorporates the haulms as a green manure for the following sorghum crop which is neither a typically *kharif* nor *rabi* crop. This is known as *Maghi jowar* (sorghum), generally sown in the third week of August.

In the process he not only capitalises on the nitrogen and other nutrients ploughed in through the greengram but also improves the physical environment of the soil.

When greengram haulms are used as green manure about 35-40 kg N / ha would be incorporated into the soil prior to taking up *maghi* sorghum. This is besides the other nutrients added through the system.

Addition of such small quantities of organic residues is the only way to take advantage of organic matter additions in improving the soil physical condition. Such incorporations were found to enhance soil aggregation in terms of mean weight diameter (mm) increases from 0.11 to 0.38 in such black soils. The infiltration also improved from 2.59 to 8.10 cm / ha.

Such a practice would lead to better recharge of the root profile with subsequent showers, and consequently better root proliferation. The yield of *Maghi* sorghum in this area has been rising, unlike many other districts in the state. As of now the average grain yields of greengram and sorghum are 0.45 and 1.1 t/ha, respectively.

Mid-season corrections

The rainfall, however, does not always follow the normal distribution pattern. On analysis, it is found that the duration of the rainy season could vary between a low of 14 weeks and a high of 28 weeks. Whenever the monsoon is delayed the farmer applies mid-season corrections.

When he sows greengram by the last week of June it may not mature fully for the timely sowing of *Maghi* sorghum. So he harvests greengram at physiological maturity and ploughs in the haulms as manure. In the event of a further delay in sowing, only the mature pods are picked and the haulms ploughed in. If, however, there is an even greater delay, the greengram is incorporated directly as green manure. In all cases, the farmer has two critical aims - firstly to sow his staple crop of sorghum on time, and secondly, to use greengram as a source of nutrition for the staple crop.

Case Study 2 : Rice based double cropping in north east India

Largely, rice crop is the important staple for north east India. This is because of the good rainfall (more than 1000 mm) received in the region. Farmers take up the rice crop in different physiographic situations in the slopy lands that are common in the region (Venkateswarlu and Vittal 1999). In the high moisture regime zones they take a second crop of a legume. The legumes include lentil, lathyrus and sometimes blackgram and greengram. Mostly these legumes are cultivated through *paira/utera* cultivation. The seed of legumes is mostly broadcast when the standing rice crop about 7-10 days prior to harvest. The *paira/utera* crop, thus, is a bonus as there is no fertilizer application or land preparation. Incidentally the association of a legume in the cropping sequence provides space for N-economy and even better response to N on the following rice crop.

The farmers in many areas harvest about 1/3 of the rice plants from above and leave the crop residues in the field. They harvest the legumes by hand and leave the residues. The livestock is allowed to graze these fields which in the process leave their excretions (urine and dung) on the fields. When the next monsoon starts in the coming year, the farmers plough the residues into the soil and pond the rainwater in the fields. Since anaerobic conditions exist during the process, the residues quickly decompose as anaerobic decomposition is a low energy process.

In this system the nutrients recycled, with particular reference to N would be as in Table-2.

Table-2: Nitrogen additions in rainfed rice

Source	N (kg/ha) (upland to lowland)
Crop residue	6 – 18
Atmospheric N	10 – 15
Livestock	10 – 15
Soil non-symbiotic N	4 – 5
Soil available N	20 – 30
<i>Bueshening</i> * (contribution of ploughed in weeds and excess rice seedlings)	30 – 45
Total	80 - 128

* Applicable in banded uplands, medium lands and lowlands.

Of this we can assume 65% as usable by the standing rice crop from atmospheric N, soil N and non-symbiotic N. About ½ of total N may be available from the other sources. The available N works out to 46-70 kg N / ha in areas practicing *bueshening* and 30 kg N / ha in unbanded uplands. It

works out to 46 – 70 kg N / ha. Assuring a response of 20 kg grain / kg N the base yield with the recycling system varies from about 600 kg in unbunded uplands and 900 – 1400 kg in banded uplands, medium lands and lowlands. And that is what the farmers obtain from their traditional farming.

Thus, the farming community in the region have been practising a very sustainable low input technology to obtain respectable yields of about 800-1200 kg of rice per ha.

In the above two examples the traditional wisdom of the farmer is clearly seen. As researchers we can only intervene to improve upon the system for enhanced productivity.

At the end we may recapitulate the N fixed by several of the grain legumes that are commonly grown by the farmers.

Table-3: Nitrogen fixed by grain legumes

Grain legume	Percent N derived from atmosphere – N
Chickpea	17-85
Pigeonpea	10-88
Groundnut	22-92
Cowpea	73-240
Soybean	17-124
Clusterbean	37-196
Lentil	35-77
Blackgram	119-140
Greengram	50-66

Traditional tree-based systems in agriculture

Trees had been a common component in arable lands. However due to mechanization and overuse, many of them have vanished from the farmers' fields. Still a few examples are available where tree-based farming is in vogue. Two such examples are presented hereunder.

a) Alder

Alder (*Alnus nepalensis*) is grown in Nagaland for enhancing the soil productivity for growing various crops. Alder grows well in attitudes between 1000 – 3000 m msl and in high rainfall areas of Nagaland (>1500mm). It is a non-leguminous tree which, however, fixes atmospheric N through Frankia to the tune of 50-100 kg/ha (Barrueco and Moiroud 1990).

Besides its role in improving soil fertility, alder is used for firewood, furniture and as poles in house construction. The foliage acts as a mulch. It provides shade to coffee plantations at lower altitudes and cardamom at higher elevation. The trunks of the roots are also laid across the slopes to slow down erosivity of the runoff water.

The alder trees vary in population in the arable lands. These trees are pollarded at 2-2.5 m above ground level. The twigs and stems are used for fuel. The leaves are left on the field and burnt along with the stubbles of the earlier crop to add nutrients to the soil and also to oxidize Fe²⁺ to Fe³⁺ (an irreversible reaction), thus reducing possible Fe²⁺ toxicity in the oxisols of Nagaland. Then arable cropping is practised growing different crops (as mixture) needed by the farmer. The pollarded trees coppice well and by the time the crops come to maturity full canopy develops.

b) Khejri

Khejri (Prosopis cineraria) is common in arid regions of NW India (west Rajasthan, Haryana, Gujarat, dry parts of Deccan). It is largely limited to rainfall below 500mm. Khejri is a leguminous and is small to moderate sized evergreen thorny tree. It partly sheds leaves from mid-October to mid-February. Thus considerable leaf litter accumulates under the trees and light will be unlimiting for crops grow along with them. Nagarajan and Sundaramoorthy, (2000) studied the microbial and organic C and N beneath and away from *Khejri* put to cultivation and left uncultivated. The results are given below in Table-4.

Table – 4: C and N additions under *Khejri* based agroforestry systems

Constituent	Cultivated		Uncultivated	
	Beneath	Away	Beneath	Away
Microbial biomass (μ g/g)	441	280	623	231
Organic carbon (g/kg)	2.48	1.90	3.12	1.92
Microbial N (μ g/g)	37	51	88	58
Organic carbon (g/kg)	0.38	0.20	0.46	0.25

It is clear that considerable C and N accumulate under the canopy for use by the crop plants.

In an earlier study Sundaramoorthy *et al* (1998) found, amongst various tree canopies the microfungus biomass in the under story soils (top few cm) would be more with *Prosopis cineraria* as compared to other trees.

Tree species	Fungal biomass (mg/g)
<i>Prosopis cineraria</i>	86
<i>Acacia tortilis</i>	62
<i>Azadirachta indica</i>	79
<i>Prosopis juliflora</i>	38

In another study on farmers fields, Aggarwal *et al* (1976) found more nutrients under *khejri* than under mesquite in the 0-15 cm soil.

Available nutrient (kg/ha)	<i>Khejri</i>	<i>Mesquite</i>
N	250	2103
P ₂ O ₅	22	10
K ₂ O	633	409

In the farmers fields under *khejri* canopy, the yield of barley was 999 kg/ha as against 537 kg/ha away from the canopy in Hisar district of Haryana under rainfed conditions (Kumar *et al* 1998). Such yield increases under *khejri* canopy were reported in the case of chickpea, pearl millet, mungbean and clusterbean.

Thus it is clear that *khejri* is the *kamadhenu* (well wisher) of the arid zone farmer providing sustainability in crop production.

c) ***Sesbanias***

Sesbanias as a plantation fixes upto 350 kg N / ha / year and the biomass could be upto 32 t/ha/year. The *S.rostrata* species nodulates from the stem also.

S.sesban and *S.grandiflora* find market as leaf fodder, edible flowers and leaves, fuel wood (calorific value of 4500 K cal/kg), charcoal, poles for house construction, small wood gums, medicine, pulp wood, etc. *S. bispinosa* is valued mainly as a source of green manure for *in situ* ploughing in crop fields. In addition to these direct benefits they confer several indirect benefits by improving the soil fertility status by way of N-fixation, providing shade, as wind breaks etc. Some *sesbanias* like *S.grandiflora* are preferred as shade plants in tea and coffee plantations.

Gliricidia

Gliricidia received an interesting coverage recently from Joshi (2002). He recalled the great M.S. Sivaramani's effort in encouraging gliricidia (*Gliricidia sepium*) as a green manure for rice in the erstwhile Madras Presidency in the early 20th century. He also persuaded the nearby Bombay Presidency and the Princely states of Travancore and Cochin by planting gliricidia on rice field bunds and lopping it for use as green manure to the rice crop. Bumper crops were obtained by its use without application of any fertilizers.

Gliricidia, however, was not accepted as a panacea to substitute chemical fertilizers, more so for other crops than rice by the then government(s) at centre and state level. Thus Sivaramam and gliricidia went into oblivion. Fortunately, in the recent past there is rekindled interest in this wonderful tree. Its leaves (green manure) are not only used for rice, but used even for rainfed crops. The Jute Research Station, Barrackpore indicated that a 5t gliricidia green manure equals 40 kg N / ha effect. Sharma (1998) of CRIDA, Hyderabad also showed that the yield of sorghum with gliricidia at 40 kg N / ha level were 690 kg / ha as against 530 kg/ha with urea N.

Green leaf manuring

a) **Story of Pongamia**

In Penugonda Mandal in one of the villages, the earlier generation of an irrigated farmer (large farm) was using the loppings of pongamia as green manure to his tankfed rice crop. The

landless and / or the poor were lopping pongamia trees from the adjoining hillocks and CPRs and carting the same for a price. About 125 bundles / ha were being applied. It was costing Rs. 675 / ha.

Pongamia is an excellent green manure. It analyzes for 3.69 % N. 2.41 % P₂O₅ and 2.42 % K₂O.

This process of green manuring came to a grinding halt when fertilizers (urea and DAP) appeared in the market. This was more so when the farming came into the hands of the son. He found it economical and easy to handle to apply urea and DAP which was applied at 100 kg N and 50 kg P₂O₅ / ha. The costs were then Rs. 350/ha.

Then came the grandson, a graduate in Agriculture. He was knowing the importance of organic manures and that too for a rice crop. And the costs of urea and DAP also increased by that time. 100 kg N + 50 kg P₂O₅ / ha cost him Rs. 1300/ha. Not only that. The responses to added fertilizers declined from about 20-25 kg/kg nutrient to just 8-10 kg of nutrient. With his knowledge acquired during his studies, he moved to 50% pongamia loppings and 50% fertilizers. The rice crop yields started showing up again. The soils became healthy. The responses bounced back to 18-20 kg / kg nutrient.

Now he intends to use of 100% pongamia loppings as manure to his rice crop. It may cost him more (Rs. 1875/ha now). But still he prefers as the response would be at least 20 kg/kg nutrient as against 10 kg/ka with chemicals.

b) *Beushening* leads to green manuring

Beushening in rainfed lowland rice (Chandra 1999) is an age-old practice in the shallow submerged low land rice in most of the eastern states. *Beushening* is criss-cross ploughing in a standing rice crop of 30-45 days after seeding when 10-15 cm depth of water stands in the field. This is followed by laddering and seedling re-distribution. Sometimes weeding is also taken up.

Thus *beushening* has four steps as seen below (Table-5)

Table -5: Effect of *beushening* operation on rice crop performance (farmers perception)

Effect	Benefit to crop
<i>Gara</i> * (ploughing)	
Loosen and soften soil	Improve water retention (<i>panirajiba</i>), aeration (<i>pabanbajiba</i>), root growth
Knock down plants	Improve nutrient uptake
Thin plants	Reduce insect pests
Root disturbance	Improve tillering and plant vigour
Uproot weeds	Improve tillering
	Reduce competition

<i>Khelua</i>* (seedling distribution)	
Space plants	Full ground cover
Raise plants out of mud	Keep plant from smothering
Remove weeds	Reduce competition
Thin plants	Improve tillering and plant vigour
Root disturbance	Improve tillering
Uproot weeds	Reduce competition
<i>Kalamahi</i>* (laddering)	
Incorporate weeds	Provide nutrients for rice plant
Control weeds	Reduce competition
Levelling	More uniform stand
Knock insects into water	Reduce insect pests
<i>Bachha and Khunchamariba</i>* (weeding and gap filling)	
Weeding	Reduce weed competition
Replant seedlings	Even ground cover

The weed population decreased considerably with *beushening*.

Treatment	Line sowing	Deep weigh (g/m ²)	
		<i>Beushening</i>	No <i>Beushening</i>
Hand weeding	90	62	92
No hand weeding	194	124	434

The grain yield under weeds control was more than *beushening*. However hand weeding is a difficult proposition in these areas as labour is the constraint.

The results suggest the merit of *beushening* when as much as 310 g / m² of weeds are buried as green manure. This is besides the additional rice seedlings ploughed in. The weeds and additional rice seedlings may add at least 45 kg N/ha taking 1.5% N as average content in the weed flora.

Under same treatments when the weeding also was taken up the yields were 3040, 2910 and 2750 respectively. It, thereby, shows weed control is needed for better yields. However, the additional yield with *beushening* even in hand weeded situations is due to root pruning of the rice seedlings. Thus in the absence of labour at least *beushening* leads to higher productivity.

Finally, we may conclude that *beushening* suppresses weeds, leads to root pruning and incorporates weeds and excess rice seedlings as green manure for the standing rice crop. Such a 'green-manuring' effect is welcome in lowland rice as its decomposition does not need high energy (being anaerobic). Also *beushening* saves demand on labour, an increasingly felt constraint in these areas.

Ley farming

Rao *et al* (1997) studied ley farming (with *Cenchrus ciliaris*) as an alternative farming system in the Indian arid zone. They found a six year lay in the arid zone would provide yields equivalent to 40 kg N/ha (Table 6).

Table-6: Production of pearl millet as influenced by ley farming

Grass ley	Grain yield (kg ha ⁻¹)		Stover yield (kg ha ⁻¹)	
	With stubble	No stubble	With stubble	No stubble
CCF ^a + no fertilizer		850		2200
CCF + fertilizer (20 kg N + 17.5 kg P/ha)		1015		2716
4-year ley	950	892	3090	2833
6-year ley	1292	1050	3920	3350
8-year ley	1450	1227	4467	3910
<u>Statistical significance</u> ^b				
Ley LSD		156		261
Stubble LSD		117		180
Ley X stubble LSD		N.S.		N.S.

^a CCF, conventionally cultivated field;

^b p = 0.05; N.S., non-significant

Note: Fertilizer N was applied through urea and P through single superphosphate

The increase in yield is attributed by Rao *et al* to the following

- Soil organic matter was more with ley farming (0.51 in control to 0.92 % in 6-year ley in 0-15 cm soil)
- VAM species (count/100 g soil) was more with ley farming (130 as against 390)
- Similar was the case with dehydrogenase, nitrogenase activity (1.7 and 3.9 times respectively over control)
- So was with nitrifying bacteria (10² / g soil) values being 4.2 for control and 7.9 for 6 year ley.
- The steady state infiltration rate (cm/min) was 0.14 and 0.16 with the control and 6-year ley while the saturated hydraulic conductivity in the field was 3.25 and 0.55 (Kfs x 10⁻² / sec). The data suggests retention of rainwater in the root profile.

Thus ley farming, practised, by a few farmers is allowing the soil to recoup and make it more living with improved organic matter and better microbial activity. Also the treatment retains rainwater in the root profile.

Phosphorus dynamics in arid ecosystem

In arid soils, the available phosphorus is low (~ 7.0 ppm). But organic P in soils is medium (~ 50 ppm). Tarafdar and Rao (1990, 1992 and 1995) in a series of experiments found that if the organic P that is critical in these arid soils. With the application of organic manures like cow dung and goat manure, the acid phosphatase, alkaline phosphatase and dehydrogenase activities increase, thereby releasing more P into available forms consequently the dry matter yields of legumes (cluster bean, mung bean, moth bean) as well as cereals (pearlmillet) increases by 20-50%. Even the grain yield of mung bean increased by 10-30 % with inoculation of the phosphatase producing fungi (*Aspergillus*

sp.) in pot studies. The grain of chickpea increased by 50-75% and that of wheat by 30-50% in controlled studies.

Tarafdar *et al* (1989) found the significant activity of fungal in tree lands as compared to croplands. On the other hand the actionmycetes activity was more in crop lands. IN any case the microbial activity was more with tree and crop based systems (Table-7).

Table-7: Microbial population of arid soil under different management systems

Sampling site	Population of micro-organisms per g of dry soil		
	Fungi (x 10 ³)	Bacteria (x 10 ³)	Actionmycetes (x 10 ³)
Crop land	9.3	28.0	30.6
Fallow land	6.3	18.6	6.3
Grassland	8.3	23.6	8.0
Tree land	21.3	20.3	15.3
LSD at 0.05 level	5.5	NS	15.2

Thus in arid ecosystem turnover of organic matter into the soil through the traditional agroforestry system (*khejri*-based) or by external addition of organics is needed to make the soil live better and make soil nutrients, particularly P, more available to crop plants.

Animal-soil-water-plant continuum: a case study

Now we propose to present a case example of Anima-soil-water-plant continuum in arid Rajasthan (Venkateswarlu 2004).

Setting

The livestock population in arid west Rajasthan is about 60 adult cattle units/Km² as on 1997. About 5.0% geographical area is under permanent pastures. As much as 60% area is estimated to be cultivated. Almost 1/3 area is classified as wastelands. And only 1.0% area is under forests.

Pastoralism

Pastoralism is an important rural activity. In fact the estimated income in rural families from livestock husbandry is 61% in 250 mm isohyet region while it is 35% in 250-350 mm and 20% in 350 mm regions. The estimates of fodder availability in the west Rajasthan indicate:

Fodder	Million tonnes
Minimum fodder needs	26.5
Available fodder* in normal years	14.1
Available fodder* in sub-normal years	10.5

* includes forages, stalks and top feed

Resource base

The soils are light in nature, holding less nutrients and about 50-200 mm water/metre depth. Of the land forms 58% are sand dunes. Active dunes exist beyond 250 mm isohyet. The wastelands are upto 33% of the geographical area. About 7.05 million hectares (Mha) are sand dunes 3-5 Mha are sand wastes while 1.0 Mha are open shrubs. About 0.2 Mha are salt infested. The common pool resources which used to be 11.3 Mha in 1956 came down to 7.6 Mha (as on 1983). The good quality commons have gone over to cultivation.

Continuous land degradation is the problem.

Fodder availability

The dry forage yield from grasslands is poor varying from 200 kg/ha in low rainfall regions to 875 kg/ha in 300-400 mm rainfall zones. The productivity of arable crops is also low being 100 kg to 150 kg/ha of grain legumes and 150 kg to 200 kg/ha of pearl millet. The productivity of both grasses and crops is low by poor native fertility and low rainfall.

In order to improve fodder availability, use of improved seed of grass (e.g. Marwar Anjan - *Cenchrus ciliaris* and Marwar Dhaman - *Cenchrus setigenus* at a relatively higher seed rate (6-10 kg/ha) or using pelleted the seed (2-3 kg/ha) before sowing are needed. Further, protection of the sown pastures by trenches or social fencing is needed. Then the productivity increases to 800-1800 kg/ha depending on the rainfall. Attempts to encourage 'cut & feed' method should be made. Concurrently the pastures have to be put with top feed tree species (e.g. *Prosopis cineraria*, *Hardwickia binata* and *Colospermum mopane*). With such improvements, the carrying capacity of the commons as well as waste lands would significantly improve, say by two-fold.

Soil productivity

The soil productivity in the region is recouped through

- i) the manure from livestock (particularly sheep and goat),
- ii) the leaf litter from multipurpose tree species (MPTs),
- iii) nitrate - N added through rain

The contribution of the above depends on many variables. They include farm size, livestock owned by the farmer, periods when the livestock is kept on the arable fields and/or held by the farmers by herding, transport losses, percent efficiency in storing number of MPTs (density) on the farm and the amount of rainfall. Some estimates suggest the total addition of nitrogen in the three agroecological sub-zones are as follows:

Agroecological sub-zone	Total N added (kg/ha)			
	Sheep/goat	Cattle	MPTs	Atmospheric
I (<250 mm rainfall)	3	4	5	6
II (250-350 mm rainfall)	3	6	10	8
III (>350 mm rainfall)	4	11	15	12

Taking 1/3rd of nitrogen coming through livestock and MPTs as the readily available N for crop plants, the available N would be about 10, 14, and 22 kg/ha in Zone I, II, and III respectively.

In fact the average yields of pearl millet in these 3 regions also reflects the presently available nitrogen in the system. The yields and estimated N uptake in the three subzones are:

Agroecological sub-zone	Av. yield (kg/ha) in normal years		Nitrogen uptake (kg/ha)
	Grain	Stover	
I	300	600	9
II	450	900	12
III	600	1200	17

Improvements of stover yields

In order to improve the yields of grain as well as straw it is important to use pearl millet varieties that have early maturity so as to avoid terminal stress. Such varieties also should produce more straw. Further at least 20 kg/ha of chemical nitrogen as an external input has to be encouraged. The response would be about 15kg grain and almost 50kg straw/kg N.

Livestock improvement

The sheep and goat in particular have to be improved local breeds so that they can withstand inadequate fodder but also insufficient water supplies besides enhanced salts and toxic elements like fluoride and nitrate.

Improvement of water bodies

This, then, also calls for improved water availability in the region. The existing surface runoff collecting systems like *Tankas* and *Nadis* have deteriorated. Reasons are many fold. Amongst others they include overgrazing and consequent soil erosion from the catchment areas leading to sedimentation, mining without proper protection of the catchment areas, over use of the existing water bodies and reduced attention to them due to introduction of protected water supply systems through taps. Water bodies are important in the region, more so where livestock farming is practised. The improved *Tankas* and better structuring of *Nadis* are steps in this direction.

Size of herds

A point frequently discussed is the size of the herd that the farmer maintains in this region. It is even upto 100 as far as sheep and goat are concerned. Agroecologically speaking the size of the herd, the farm size and the available commons are as follows:

Agro ecological sub-zone	Size of farms (ha)	Size of herd (Nos.)		Area of commons per farm family	Estimated fodder, forage & top feed (kg/family)*
		Sheep/goat	Cattle		
I	15.4	19	5	21.1	15,600 (45)
II	9.1	11	4	2.6	12,150 (41)
III	4.2	27	3.5	1.5	9,340 (66)

* The figures in parentheses indicate percent deficiency.

Note: Sheep/goat and cattle need 1.5 and 10 kg fodder/day

Present carrying capacity of the pasture lands is only 1.0 to 1.5 sheep/ha and even with the support of straw the farmer cannot maintain such large herds. Why then the farmer is herding larger number than the carrying capacity ? Answers are many. One is that he has no other alternative agricultural systems to fall back on for generating income. Second is the sheep/goat are very hardy and even if some die due to serious droughts still some are left for his sustenance.

Alternative agricultural systems

In other words, if the farmer has alternative agricultural systems he might be prepared to reduce the size of the herd. What are these alternatives ? At least one clear alternative is arid horticulture.

The most promising arid horticultural plant is *Ber* (*Zizyphus mauritiana*). It tolerates salinity up to 6 mmhos/cm. *Ber* plants need supplemental irrigation at the first dry season after planting. A circular catchment of 1.5 m radius along with mixing of 10 kg/pit of pond sediment helps in increasing moisture in the root profile, which in turn bring in 20.0 percent additional growth. The yield could also be improved by micro-catchment (54 m²/tree) technique wherein each plant would have access to more rainwater. The yield increases by about 40 percent. *Ber* plantation can be intercropped with grain legumes which could provide about 400 kg grain/ha. The fuel and fodder coming through pruning would be 1.0 to 1.5 t/ha and 750 days of goat grazing/ha are other benefits that accrue in this system.

References:

- Abdurahman, M.D., B. Seeling, T.J. Rego *et al* (1999) Organic matter inputs by selected cropping systems on a vertisol in the semiarid tropics of India. *Annals Arid zone*. 37, 363-371
- Aggarwal, R.K., J.P. Gupta, S.K. Saxena *et al* (1976) Studies on soil physico-chemical and ecological changes under twelve year old five desert tree species of western Rajasthan. *Indian Forester*, 102, 863-872
- Andrews, D.J. and A.H.Kassam (1975) Importance of multiple cropping in increasing world food supplies. In *Proc. Multiple Cropping Symposium*. ASA
- Anonymous (1999) Indigenous technical knowledge. UAS, Bangalore, pp 19
- Barrueco, C.R. and A. Moiroud (1990) Frankia. In *Biofertilizer Eds. L.L. Somani, S.P. Bhandari, S.N. Saxena et al.*, Scientific Publishers. Jodhpur. P 243-270
- Chandra, D. (1999) Beushening – a wonderful cultural operation of rainfed lowland rice in eastern India. *Indian Farming*, July 10-12.
- Francis, C.A (1989) Biological efficiencies in multiple - cropping system. *Adv. Agron.* 42, 1-42
- Freyman, S. and J.Venkateswarlu (1977) Intercropping on rainfed red soils of the Deccan Plateau, India. *Canadian J. Pl. Sci.* 57, 697-705
- Joshi, A.B. (2002) Greener revolution without chemical fertilizers: Mexico's Gliricidia – India's 'kalpavriksha'. *Asian Agri-History* 6(1), 43-62
- Kumar, A., M.S. Hooda and R. Bahadur (1998) Impact of multipurpose trees on productivity of barley in arid ecosystem. *Annals Arid Zone*. 37, 153-157
- Nagarajan, M and S. Sundaramoorthy (2000) Effect of *Prosopis cineraria* on microbial biomass and soil C; N in arid agroforestry systems in western Rajasthan, India. *Annals Arid Zone*. 39, 431-438
- Ofori, F and W.R.Stem (1987) Cereal-legume intercropping systems. *Adv. Agron.* 41, 41-90
- Parameswaran, P. and K.P. Shivkumar (2001) Sustainable development. Akshaya Vikas Founder Ed. E. Ranada. Vivekananda Kendra Prakasham, Chennai
- Rao, A.V, K.C. Singh and J.P. Gupta (1997) Ley farming – an alternate farming system for sustainability in the Indian arid zone, *Arid Soil Res. Rehabilitation*, 11:201-210
- Rao, A.V. and J.C. Tarafdar (1998) Significance of microorganisms in afforestation programs in arid zone. *Annals Arid Zone*. 37, 337-346
- Rao, J.V. and I.A. Khan (2003) Identification of Research gaps in Intercropping systems under rainfed conditions in India. NATP (ROPS 10) CRIDA, Hyderabad
- Sateesh, P.V. (2000) Crops of truth. Deccan Development Society, Pastapur-502220. Bookline, Hyderabad. pp 70
- Sharma, K.L. (1998) Final report on enhancing fertilizer use efficiency in conjunction with residue management in dryland crops and cropping systems. Indo-US project, CRIDA, Hyderabad centre

- Sundaramoorthy, S., A. Ramachandani and N. Jha (1998) Microfungal biomass in the under story soils of semiarid zone trees. *Annals Arid zone*. 37, 355-361
- Tarafdar, J.C. and A.V. Rao (1990) Effect of manures and fertilizers on dehydrogenase and phosphatases in the rhizosphere of arid crops. *Polish J. Soil Sc.* 23(2) 189-193
- Tarafdar, J.C. and A.V. Rao (1995) Contribution of *Aspergillus* strains to acquisition of phosphorus by wheat and chickpea grown in a loamy sand soil. *Applied Soil Ecology*. 3, 109-114
- Tarafdar, J.C., A.V. Rao and Praveen Kumar (1992) Effects of different phosphatase – producing fungi on growth and nutrition and mungbeans in an arid soil. *Biol.Fertil.Soils*. 13, 35-38
- Tarafdar, J.C., B.Kiran and A.V. Rao (1989) Phosphatase activity and distribution of phosphorus arid soil profiles under different land use patterns. *J. Arid Environments*. 16,29-34
- Venkateswarlu, J. (1999) *Maghi* sorghum in deep black soils of Khammam, Andhra Pradesh. *Leisa India*, 1 (2), 15
- Venkateswarlu, J. (2004) Rainfed agriculture in India: Research and Development scenario. ICAR, New Delhi. pp 508
- Venkateswarlu, J. and Vittal, K.P.R. (1999) Case studies on adoption of production technologies in rainfed rice, groundnut, *Rabi* sorghum, and pearl millet, CRIDA, Hyderabad, pp 72