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Sustainable Development of Rainfed Agriculture

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Abstract: On identifying the rainfed districts in the country with less than 30% dependable irrigation, it was found that as many as 326 of the 631 districts studied were rainfed. Various indicators were studied from the latest data as available between rainfed and irrigated districts under arid, semi-arid and humid climatic regimes. These included biotic pressure, landuse, soil erosion and groundwater exploitation. After presenting the state-of-the-art of these two ecoregions, an attempt was made to present the possibilities for sustainable agriculture in rainfed ecosystems. The Government of India opted for Integrated Watershed Management Program (IWMP) as the growth engine for sustainable development in rainfed areas. The importance of smallholders, women and the role of edaphic factors are presented. Land degradation and the role of soil organic matter in sustaining the health of soils with focus on the importance of flora and fauna in soils are discussed. Finally the effect of IWMP on some of the selected indicators is presented, followed by the emerging issues and the way forward for sustainable agriculture in rainfed areas are highlighted.

Key words: Smallholders, women in agriculture, land husbandry, soil health, soil biota.

India has about 142 Mha area under cultivation, of which crops are grown only with the rains in about 83 Mha (Anonymous, 2012a). A question frequently raised is "What is Rainfed Agriculture (RFA)?" While RFA utilizes rainwater as the source, it does not exclude harvesting the surface and sub-surface runoff, storing and reusing. In other words in areas that are supported with additional water besides the rains, but that which has been harvested and reused also should be a part of RFA. If this is agreed the irrigation provided by surface reservoirs which are not fed from the canals/ rivers, but are evolved as (Rainwater Harvesting Structures (RWHS) only and by wells in non-command areas should become a part of RFA.

The RFA has different agro-climatic zones from arid to humid through semi-arid and dry subhumid regions. By and large as rainfall increases, the ecology in terms of vegetation and soils would be superior exclusive of specific situations as in Koraput, Bolangir and Kalahandi (KBK) districts west Odisha and the hilly districts of Jharkhand and Chhattisgarh, where the tribals of different ethnic groups make a living. Besides *Jhum* cultivation, these areas stand denuded of vegetal cover due to intensive and greedy contractors and that too more frequently with the connivance of the related Government establishments. And with the high, more frequently intense, rains the denuded soils loose their fertile surface soil and stand degraded. Consequently they hold less water for the traditional crops like rice to survive, resulting in poor returns. Thus even high rainfall tribal districts are now an ecologically disadvantaged zone besides being economically poor. Such lands require all our attention. Keeping in view these issues, an exercise was taken up to identify the rainfed districts in our country. Prior to this exercise, the guidelines provided by Hanumantha Rao Committee (1994) need consideration. The committee kept 30% dependable/assured irrigation as the cut-off between rainfed and irrigated districts.

The district-wise data were collected on the area irrigated by canals (major and medium irrigation) tanks and wells (minor irrigation). The areas under canals and wells in command areas were taken as dependable/assured irrigated. The areas under tanks and other wells in non-command areas were adjusted in relation to agroclimatic situations to arrive at dependable/ assured irrigated areas as given below:

Moisture index	Dependable/Assured irrigated area
- 66 to -50	Canal and Command Area wells + 25% of tanks and wells
-49.9 to 0.0	Canal and Command Area wells + 50% of tanks and wells
0.0 to 99.9	Canal and Command Area wells + 75% of tanks and wells
< 100	Canal and Command Area wells + 100% of tanks and wells

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The districts under rainfed and irrigated farming are depicted in Fig. 1. In all the following picture emerges:

Ecosystems	No. of districts	Net irrigated area (Mha)	Net sown area (Mha)
Rainfed (<30 of dependable irrigation)	326	11.20	76.50
Irrigated (>30% of dependable irrigation)	305	34.41	63.72
Total	631	45.60	140.22

After identifying the rainfed and >30% assured irrigated districts selected indicators were examined between these two ecosystems. These include biotic pressure, landuse, land holdings, soil erosion, groundwater depletion and crop production.

Biotic Pressure

The human and livestock densities are provided in Table 1 and 2. The human population density is based on 2011 census. It is evident that the density was more in irrigated districts (558 km^{-2}) as against 258 km^{-2} in rainfed areas. Coming to agroclimatic zones, the population density increased with increasing moisture index from arid to humid zones in irrigated districts while it was parabolic in rainfed districts with increase in semi-arid zones with decline on either side. Evidently in the arid areas (disadvantaged areas) the population could be expected to be low.

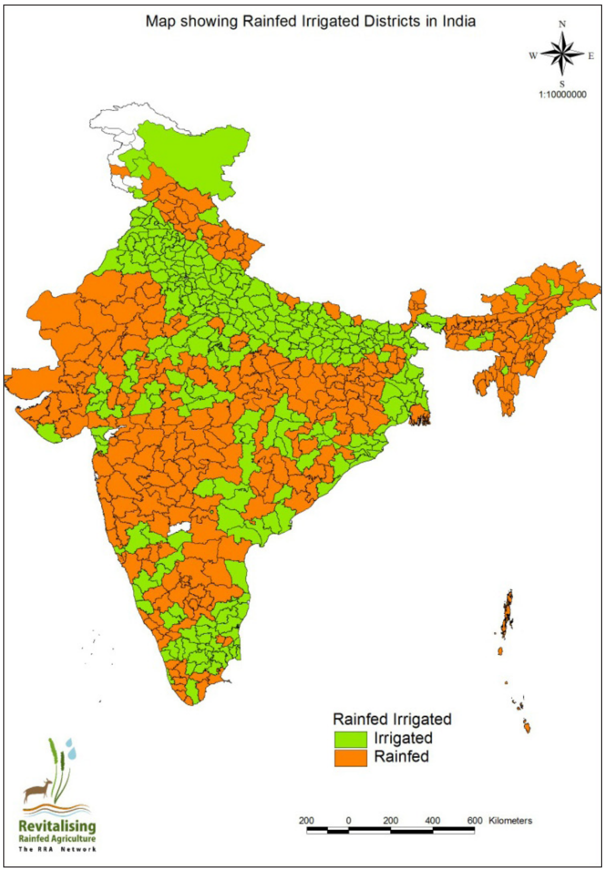

Fig. 1. Rainfed and irrigated districts in India.

Coming to livestock density (18th Census), all the livestock was estimated as Adult Cattle Units (ACUs). As with human populations, ACUs were more in irrigated districts (148 km^{-2}) as against 88 km^{-2} in the case of rainfed districts. The data also suggest that livestock husbandry was an excellent ancillary occupation. In fact, over the years (1971-72 to 2002-03) there were fluctuations in the composition as well as numbers amongst

Table 1. Human and livestock density

Density	Rainfed				Irrigated			
	Arid	Semi-arid	Humid	All	Arid	Semi-arid	Humid	All
Human Population WRT TGA (No. km^{-2})								
Number of districts	13	104	209	326	18	130	157	305
Mean	123	282	277	258	213	559	613	558
Minimum	17	2	1	1	3	10	13	3
Maximum	361	1335	4646	4646	2442	6155	9258	6155
ACU WRT TGA (No. km^{-2})								
Number of districts	13	100	200	313	16	117	154	287
Mean	56	100	88	88	85	159	149	148
Minimum	18	1	1	1	2	6	1	1
Maximum	145	314	303	314	611	4991	404	4991

WRT: With reference to; TGA = Total geographic area; ACZ = Agroclimatic zone; ACU: Adult cattle unit.

Table 2. Livestock dynamics vis-a-vis different farmers

Class of farmer		Number per 100 households			
		1971-72	1981-82	1991-92	2002-03
Landless	In-milk bovines	16	7	6	1
	Ovines	45	37	20	4
	Poultry	56	39	49	17
Marginal	In-milk bovines	33	28	41	40
	Ovines	68	98	81	84
	Poultry	102	171	190	164
Small	In-milk bovines	64	48	69	63
	Ovines	102	120	115	90
	Poultry	137	179	223	191
Semi-medium	In-milk bovines	92	74	80	84
	Ovines	160	147	131	99
	Poultry	127	206	247	136
Medium	In-milk bovines	142	106	102	126
	Ovines	281	240	166	162
	Poultry	129	180	141	278
Large	In-milk bovines	225	153	130	208
	Ovines	256	505	375	424
	Poultry	118	311	174	457
All	In-milk bovines	54	37	46	36
	Ovines	99	105	85	64
	Poultry	101	144	166	123

Source: NSSO Report 59 on livestock ownership.

different categories of the farmers (Table 2). Poultry was on an increase with all the farmers over the years, more so with large farmers. In-milk bovines were gradually on the rise with marginal farmers.

Landuse

The net sown area (NSA), net irrigated area (NIA) and culturable wastelands were examined (Table 3).

Table 3. Different land uses

Land use	Rainfed				Irrigated			
	Arid	Semi-arid	Humid	All	Arid	Semi-arid	Humid	All
% of Net Sown Area WRT TGA								
Number of districts	13	103	207	323	17	130	154	301
Mean	45	54	27	40	81	56	49	54
Minimum	14	14	1	1	49	1	1	1
Maximum	84	111	82	111	98	659	98	659
% of Net Irrigated Area WRT NSA								
Number of districts	13	104	203	320	18	129	154	301
Mean	16	23	17	20	62	51	54	53
Minimum	6	4			40	19	28	19
Maximum	47	100	47	100	100	100	96	100
% of Culturable Waste Land WRT NSA								
Number of districts	13	101	189	303	9	111	138	258
Mean	45	6	11	14	3	5	5	5

Table 4. Percentage of smallholders in farming

Year	Per cent smallholders				Per cent operational area			
	Total	Marginal	Small	Ratio	Total	Marginal	Small	Ratio
1960-61	61.7	39.1	22.6	1.73	19.2	6.9	12.3	0.56
1981-82	68.2	45.8	22.4	2.04	28.1	11.5	16.6	0.69
1991-92	75.3	56.0	19.3	2.90	34.3	15.6	18.7	0.83
2002-03	80.6	52.8	17.8	3.53	43.5	22.6	20.0	1.08
2010-11	84.9	67.0	17.9	3.74	44.4	22.3	22.1	1.01

Source: Department of Agriculture and Cooperation (Agriculture Census 2010 is provisional).

The NSA as per cent of the total geographical area (TGA) was 40% in rainfed and 54% in irrigated districts. Agroclimatologically in rainfed areas only 27% of humid area was cultivated, while it was double (54%) in semi-arid regions. On the other hand the NIA was highest (81%) in arid irrigated districts, being 56% and 49% in semi-arid and humid areas, respectively. The high per cent in arid areas was from Punjab and Haryana.

The NIA as per cent of NSA was only 20% in rainfed, but 53% in irrigated districts. As with NSA, similar scenario was observed with NIA in these two ecosystems.

Culturable wasteland was 14% of NSA in rainfed districts, while it only 5% in the case of irrigated districts, maximum of 45% being arid rainfed areas and again minimum of 3% being in arid irrigated areas.

Landholdings

Before getting at the rainfed vs. irrigated districts with reference to land holdings we have to realize that the per cent small and marginal holders (SMF) are on the rise (from 1960-61 to 2010-11) (Table 4).

The data on small and marginal farmers (SMF) in rainfed and irrigated districts are presented in (Table 5).

While the overall per cent of SMF is 73 and 79 in rainfed and irrigated districts, respectively, the per cent is much lower in arid ecosystem, being 37% in rainfed and 57% in irrigated ecosystems. In both ecosystems the SMF are on the rise with enhanced Moisture Index (M.I.), maximum being 84% in humid irrigated areas.

In the case of area owned by the SMF, in the rainfed region 43% area is owned by them as against 51% in irrigated areas. Agroecologically same scenario prevails with minimum area owned by them is 13% in arid rainfed districts and maximum being 59% in humid districts.

Soil Erosion

The overall soil erosion as per cent of TGA is given in Table 6. The soil erosion was more or less same, hovering around one-third area in both the ecosystems. However, ecologically the per cent soil erosion is lowest (17) in arid irrigated districts (e.g. Punjab and

Table 5. Per cent number and area of holdings with SMF

	Rainfed				Irrigated			
	Arid	Semi-arid	Humid	All	Arid	Semi-arid	Humid	All
% Number of holdings with small and marginal farmers								
Number of districts	13	77	170	260	17	120	126	263
Mean	37	70	77	73	57	77	84	79
Min	6	27	1	1	8	11	14	8
Max	69	98	100	100	92	98	100	100
% Area under holdings with small and marginal farmers								
Number of districts	13	77	170	260	17	120	126	263
Mean	13	36	49	43	21	47	59	51
Min	1	6			1	2	3	1
Max	34	83	99	99	62	84	97	97

Source: Department of Agriculture and Cooperation (Agriculture Census 2010 is provisional).

Table 6. Soil erosion status

% of Soil Erosion WRT TGA	Rainfed				Irrigated			
	Arid	Semi-arid	Humid	All	Arid	Semi-arid	Humid	All
Number of districts	12	87	140	239	9	108	111	228
Mean	57	35	26	34	17	40	22	30
Min	2	1	1	1	1	1	1	1
Max	97	99	92	99	40	100	94	100

Source: NBSS&LUP (2010).

Haryana) and highest (57%) in arid rainfed districts (inclusive wind erosion in arid west Rajasthan).

Groundwater Exploitation

This is a global phenomenon. India is no exception, more so southern Deccan plateau and the NW part of the country. The groundwater exploitation was examined in rainfed vs irrigated districts. Data were available in 126 rainfed and 162 irrigated districts (Table 7).

It is clear that the groundwater exploitation was safe in 66% rainfed and 53% irrigated districts. It is in safe limits of about two third of the districts in humid regions in both the ecosystems. It is a point of concern that the exploitation is more (47%) in irrigated districts as compared to 33% in rainfed areas.

Crop Production

The average yield of selected food crops along with cropping intensity (C.I.) and fetilizer use are given in Table 9.

Table 7. Groundwater status

% of GW discharge WRT GW recharge	Rainfed				Irrigated			
	Arid	Semi-arid	Humid	All	Arid	Semi-arid	Humid	All
Number of districts	8	60	58	126	14	66	82	162
Mean	132	74	37	61	114	91	59	77
Min	76	14	12	12	51	16	14	14
Max	200	187	197	200	179	209	254	254

Source: Central Groundwater Board (2011)

While the groundwater exploitation was more in irrigated districts (77%), it was only 61% in rainfed districts. It is only in humid areas of both rained and irrigated areas that the exploitation is less than the permissible 65%. All the more, the exploitation is very high in arid rainfed (132%) as well as irrigated (114%) districts. The data on criticality was also reviewed (Table 8).

In general, the yields of selected food crops were more in irrigated districts except with sorghum. In arid rainfed districts yields of chickpea and pearl millet were much less as with sorghum in arid irrigated districts. The data suggest that the farmer invests more in the irrigated districts in crops of their choice with enhanced cropping intensity and increased fertilizer use.

Table 8. Groundwater development stage

		Safe	Semi-critical	Critical	Over exploited
Irrigated	Arid	3	2	1	8
	Semi-arid	27	11	3	25
	Humid	56	15	3	8
	Total	86	28	7	41
Rainfed	Arid	-	1	2	5
	Semi-arid	31	14	3	12
	Humid	52	3	1	2
	Total	83	18	6	19

Source: Central Groundwater Board (2011).

Table 9. Average yield of selected crops (q ha^{-1})

Crop	All districts							
	Rainfed				Irrigated			
	Arid	Semi-arid	Humid	All	Arid	Semi-arid	Humid	All
Rice	27	17	14	15	33	27	21	23
Wheat	24	17	14	17	39	31	25	30
Sorghum	4	8	10	8	3	9	10	8
Pearl millet	3	6	7	6	9	7	8	8
Chickpea	5	9	8	7	13	14	11	13
C.I.	1.16	1.24	1.30	1.25	1.69	1.50	1.53	1.53
Fertilizer use NPK (kg ha^{-1})	23	93	75	72	156	184	159	170

Source: District-wise data (2005-10) from Kesava Rao, ICRISAT.

To conclude, rainfed areas occupy 67.5% of the net sown area. Districts with >30% dependable irrigation are 305 out of 631 districts. The summarized data on indicators between these two ecosystems is presented in Table 10.

Sustainable Rainfed Agriculture

One of the goals of the Government of India is to achieve inclusive growth for socio-economic development (SD) on a sustainable basis. The SD implies taking care of the disadvantaged who, in fact, are a majority in the rainfed ecosystem.

Table 10. Details of the indicators between rainfed and irrigated districts

Indicators	Rainfed districts	Irrigated districts
Biotic pressure		
- Human population (No/km^2)	258	558
- ACUs (No/km^2)	88	148
Landuse		
- NSA (% TGA)	40	54
- NIA (% NSA)	20	53
- Culturable wastelands (% NSA)	14	5
- Smallholders (%)	73	79
- Soil erosion (% TGA)	34	30
- Groundwater exploitation (%)	61	77
Crop production		
- Fertilizer consumption (NPK in kg ha^{-1})	72	170
- C.I.	1.25	1.53
- Yield of crops (q ha^{-1})		
* Rice	15	23
* Sorghum	8	8
* Pigeonpea	6	8

The Government of India took integrated area development of rainfed regions on watershed basis (IWMP) as the growth engine for enhancing the productivity of rainfed ecosystems. Watershed development is to harmonize the water, soil, forest and pasture resources in a way that conserves these resources while raising the agricultural production both by conserving moisture in the soil and by increasing irrigation through tank and aquifer-based water harvesting (Bhattacharya, 2008). This initiative enhances rural employment; reduces migration; increases irrigation, yield, biomass, cropping intensity, health, social development and enhances other economic activities. Also it is adaptive to climate change.

Rainfed Agriculture (RFA)

Rainfed agriculture has several problems unlike irrigated agriculture (IA). Among them, the first is the high spatial variability. Second is the dependency of RFA on local rains which are highly variable. The climate change (CC) is further accentuating the problem. Third is the production technology itself which has largely been drawn from the irrigated agriculture (IA) systems. Fourth is the preponderance of the poor in such ecosystems who are economically disadvantaged. Fifth is the smallholdings (SMF) that are more under RFA. Sixth is the mindset that RFA excludes any external water. And the last (seventh) is treating such lands as bottomless pits and extracting crops without any additions or with little addition of inputs leading to impoverished soils both in SOM and productivity. The last could be due to the incapacity of the predominantly poor farmers to invest on needed inputs which are to be obtained from external sources.

Some issues on sustainable production in rainfed areas are presented hereunder.

Smallholders

We all agree that small is beautiful as it is easily manageable and replicable. Vandana Shiva (2014) further suggested small is really beautiful as the smallholders are the future key for the abundance.

Coming to inclusive growth, tapping agricultural and rural based opportunities is a critical component of this endeavour. It is known that yield improving technology and expanding into high value commodities and non-farm goods and services are the keys leading to employment and income generation.

The SMF cultivate 44% of NSA in the country and contribute 51% to the national kitty (Mahendra Dev, 2012). While there is enough data to show that SMF are as good as large and medium farmers (LMF) in crop production, particularly in production of food crops, Ramesh Chand *et al.* (2011) and Mahendra Dev (2012) showed that the income and consumption per household are negative for SMF largely because of the size of the holding. Consequently both the authors called for income generation through non-farm activities/employment.

In one of our studies, involving 947 watersheds with 75 farmers in each watershed, the yields of cereals, pulses and oilseeds in semi-arid and arid regions between SMF and LMF were examined. Details are given in (Table 11).

The data suggest that,

- With the implementation of the Integrated Watershed Development Program (IWMP), the yields of the commodities increased significantly
- The increase was more in cereals than in pulses and oilseeds
- The SMF have discernible thrust on cereals (food crops) over LMF

When we examine the reasons, the first thrust of SMF would be on the daily needs. Even though their lands are, by and large, poorer in quality, the cereals (mostly C_4 crops except rice and wheat) stand harsh conditions. With enhanced external inputs (more so the nutrients), the SMF are able to get better yields in cereals. On the other hand the energy rich pulses and oilseeds (C_3 crops) need better environments which the LMF have. Thus the LMF are more benefitted with these commodities.

Globally and now nationally the smallholders have been recognized to have a role in sustainable development and inclusive growth. In a rapidly changing society where 2000 farmers are lost every day from agriculture (Ghosh, 2013), unless attention is paid to the SMF, there would be a serious problem of ecological refugees from rural to urban areas. We are losing about 4.9 ha crop land per minute through various degradation processes (Bai *et al.,* 2008). It is the smallholder that is the most affected. Thus smallholder farming in less-favoured areas (LFAs) need be considered on priority if sustainable development is the aim.

Vandana Shiva (2014) called small is really beautiful as the SMF only can be the source for abundance in foodgrain production. Thus, she called for all out support to them. Sharma (2004) and others from ASEAN Nations called for strengthening agricultural support systems for small farmers. AMEF Chairman Dwarakinath (2000) demanded for an exclusive extension system for the smallholders. Jha of NCAEP (2001) pleaded for a separate R&D for them. Bharat Krishik Samaj (Jakhar, 2012) called for better inputs (irrigation, fertilizer, pesticide, implements and agricultural machinery) to them for achieving food security and poverty alleviation. The Prime Minister (August 2005) and President of India (2013) focused on

Table 11. Yield of (kg ha^{-1}) crops with watersheds

Crops	Semi-arid				Arid			
	SMF		LMF		SMF		LMF	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Cereals	2630	3130	2380	2800	1340	1530	1130	1330
Pulses	1680	2220	1770	2460	730	830	740	820
Oilseeds	1040	1440	1500	1990	1040	1160	990	1270

smallholder and rainfed farming for sustaining food security. The international agencies (IFPRI, World Bank, FAO, DFID, IFAD, etc.) suggested equity and sustainable development by attending to the smallholders.

Role of Women in Production Systems

Women-headed households are on the rise standing at 41.9 million by 2001. Women farmers produce less as they have less access to inputs compared to men. If equal input access is assured, women farmers would be as efficient as men. The inputs include land and other agricultural assets like seed, water, credit, market and training on technologies. Globally it is estimated that if this discrimination is eliminated and women given greater voice in decision-making at all levels, the productivity would enhance by 20-30%. In the process the number of hungry people can be reduced by 12 to 17% (FAO, 2005a).

In any case, the cost of food has to come down and ecological access to food must be ensured by making habitats self-sufficient in foodgrain production. And women have a major role to play in achieving these objectives.

Women consider natural resources beyond agricultural uses. For them domestic water and energy for cooking and fodder needs are important. It should be realized that 60% of the rural energy needs come from the biomass. Insofar as crop production is concerned their primary focus is on foodgrains (Chitnis, 2013). In livestock farming, coming to dairying 75 million are women, while men are only 15 million. In homestead farming/kitchen gardening their occupation varies from backyard poultry to horticulture through related activities like vermicomposting. A community based development through Self Help Groups (SHGs) will help in improving and upscaling such activities and ensuring good profits through rural as well outward marketing.

There are 6.0 million SHGs (as in 2010), of whom 80% are women-based groups with 97 million beneficiaries. These groups can be used (as experienced by some of the civil societies) for upscaling doable technologies in NRM, crop and livestock production. Providing equitable access to subsidized inputs to women is needed. GoI asked the commercial banks to provide 5.0% of the credit to women farmers. In the bank - SHG linkages, over 24 million households are benefited, of whom 90% are women (Gangadhara, 2012).

Even in watershed programs, women are involved in the National Resource Management (NRM) as well production systems. By improving National Resources (NRs), the time to fetch drinking water, fuel and fodder is saved upto 18% and it can be safely utilized for other non-farm activities to earn additional income per household. Then the food security, healthcare and education at household level will improve.

Groundwater Exploitation

A little water can go a long way in improving rainfed production systems. It can be upgraded by improving soil moisture, soil conservation, and where feasible providing supplemental irrigation. These technologies hold under-exploited potential for quickly alleviating people from poverty. They increase water productivity.

In poorly managed land, the share of plant available water would be as low as 40-50% of rainfall. On severely degraded land, as little as 5% of the total rainfall may be used productively. So the needed correction is to retrieve the degraded lands to improve water as well as crop productivity. In better managed soils, it was found that a 5.0 cm irrigation improves yields of cereals by 200 kg ha^{-1} while with energy-rich pulses and oilseed increment is 100 kg ha^{-1} All India Coordinated Research Project on Dryland Agriculture (AICRPDA).

However, in the watershed programmes, the water harvesting through surface water bodies (check dams, percolation tanks, farm ponds, sunken ponds, KT weirs) is carried out without any scientific norms. For instance, the suggestion had been "harvest runoff upto 30% leaving the rest for sustenance of the hydrological systems (e.g. inflows into traditional water bodies including tanks)". In the process two things are happening. First the excessive runoff harvesting is, no doubt, enhancing groundwater recharge and the persons who can invest more are tapping this water at the cost of the poor, particularly in the hard rock areas. Second, the traditional surface water bodies are receiving lesser inflows (surface as well as sub-surface). The net result is there is hardly any overall benefit in term of increase in irrigated area (Batchelor *et al.*,

Table 12. Irrigated status (%)

Class	Wholly irrigated		Partly irrigated		Unirrigated	
	No	Areas	No	Areas	No	Areas
Marginal	71.1	20.6	47.1	11.0	59.7	17.5
Small	16.2	21.9	22.5	17.4	20.9	21.8
Semi-medium	8.5	21.9	17.9	26.0	12.5	24.6
Medium	3.7	19.7	10.6	31.2	5.7	22.5
Large	0.5	7.9	1.9	14.3	1.3	13.5

Source: Anonymous (2012a).

Table 13. Sources of irrigation (%)

Class	Canal	Tank	Well	Tube well	Others	All
Marginal	25.2	42.0	13.9	26.6	30.0	25.0
Small	20.1	24.7	20.9	21.0	22.8	21.0
Semi-medium	21.4	18.8	27.2	22.6	21.8	22.8
Medium	22.8	10.9	27.9	21.2	17.7	22.1
Large	10.5	3.6	10.2	8.6	7.6	9.1

Source: Anonymous (2012a).

2000). The rich individuals are largely benefited with increased investments by digging deeper bore wells. With shrinkage in command areas, the tail-enders (who are generally the poor) stand losers. Even inland fishing area shrinks adversely affecting the lives of the fishers to some extent. The share of irrigation sources by different classes of farmers as in 2011 is provided in Tables 12 and 13.

In other words, even SMF have a good share of irrigation water. In fact only 39% area of SMF remains unirrigated. However their wells/ tube wells are generally shallow and with overexploitation by one and all, it is the SMF that are first to have dysfunctional wells as the others have deeper wells/tube wells. In fact with the subsidies on power, it is the LMF that go for deeper tubewells depriving the SMF of the precious groundwater, as they can invest in digging shallow wells/tube wells only.

Landuse

That the smallholders are on the rise and there is increased number of marginal farmers alongwith data on NSA and NIA have already been presented. What is more relevant is the edaphic factors (specially texture and depth) *vis-a-vis* land use by the farmers. Some are presented hereunder.

Farmers mostly look at the edaphic factors in crop choice and management levels. Soil depth and texture are the two major factors considered by them. Some examples are discussed here.

Soil Depth and Production Systems

Yavatmal (Maharashtra)

In the catena chosen there are 3 divisions - upper, middle and lower reaches. The soils are largely Vertisols. Their depth increases as we move down the slope. The predominant cropping systems have been cotton and sorghum grown in the kharif season (Joshi *et al.*, 1996). The yields of these crops vary depending on the soil type, which is largely reflected in the depth of the soil:

Crop	Yield (kg ha^{-1})	
	Good soils	Poor soils
Sorghum	100 - 400	50 - 150
Cotton *	100 - 200	30 - 60

* Seed cotton.

The farmers accordingly use the production inputs in these soils (Table 14).

Thus the resource allocation has been adopted to suit the production capacity of the soil type.

Post-monsoon rabi sorghum area

Largely, rabi sorghum is grown in deep or medium black soils as a post-rainy crop. These areas receive about 700 mm or less rainfall with unassured precipitation during June-July,

Table 14. Soil type and use of production inputs

Input	Good soil	Poor soil
Tillage	Normal	More passes to loosen the soil
FYM (cartloads ha^{-1})	5	None
Fertilizer (18-18-10) (kg ha^{-1}) (complex)	125	50
Seed	Cotton improved and hybrid	Cotton local and improved
	Hybrid sorghum	Hybrid sorghum
Pesticide	2-4 sprays on cotton	-

but assured rainfall during late August and September. There had not been a major break through in the varietal picture and even today almost the entire area under rabi sorghum is with the local *Maldandi* variety, the improved version of which is M-35-1. This variety is said to require a minimum of 140 mm soil water and is said to extract upto 180 mm to complete its life cycle.

Earlier data (Walker and Subba Rao, 1982) had proved beyond doubt that the grain as well as straw yield in 38 observations was 171 and 746 kg ha^{-1}, respectively. On the other hand, in deep black soils in 95 observations these were found to be 375 and 988 kg ha^{-1}, respectively. Even the coefficient of variation was found to be much less as the soil depth increases. All these data prove that for a good and stable rabi sorghum, we need deep black soils. In fact, in a field survey it was found that in Hanugundh *taluq* of Bijapur District, the average good yields in deep black soils touch 2 t ha^{-1} in the farmers' fields. In this *taluq*, the soils are largely deep and hence the result. The farmers also apply external inputs like chemical fertilizers in this *taluq* (Venkateswarlu and Vittal, 1999).

Table 15. Productivity potential of different crops vs soil depth and texture

Soil depth	Crop production potential *		
	Cotton	Sorghum	Wheat
Very shallow (<20 cm) loamy sand	L	M	Marginal
Shallow (20-30 cm) gravelly sandy clay loam	M	H	M
Shallow (30-50 cm) gravelly sandy clay loam	M	H	M
Deep (50-90 cm) clay loam	H	VH	VH
Very deep (100-150 cm) silty clay	VH	VH	VH
Very deep (>150 cm) silty clay	VH	VH	VH

*VH = Very high; H = High; M = Medium; L = Low
Source: Gajbhiye (1993)

Further, Gajbhiye (1993) examined the existing yield potential of number of crops in different soil types (Table 15).

Effect of soil depth *per se* was also studied in these black soils (Table 16). All the data sets indicate the two edaphic factors - depth and texture - affect the yield of crops in the Vertisols.

Table 16. Effect of soil depth on yield of crops in the black soils

Soil depth (cm)	Yield of crops (q ha^{-1})		
	Cotton	Sorghum	Pigeonpea
> 100	8.6	27.5	5.4
50-100	7.1	25.8	5.1
25-50	5.8	17.6	4.4
< 25	5.2	11.3	3.0

Source: Dent (1993).

Coming to crop management the details are given in Table 17.

Soil Texture and Crop Management

Arid soils of west Rajasthan

Kolarkar (Pers. Commn.) pointed out that the farmers of Jodhpur District (Rajasthan) choose their crops depending on the texture of soil (Table 18). Here the soils are fairly deep.

East India (rainfed rice area)

The familiar catenae in east India growing rainfed rice have uplands, medium lands and low lands. The soils are largely lateritic soils. The difference in the physiographic locations is texture, being light in uplands and heavier in low lands. Moisture regime would progressively improve from uplands to low lands. Rice is the main crop in the region. The yield levels have been:

Catenary location	Yield of rice (kg ha^{-1})
Upland	60.0
Medium land	90.0
Low land	170.0

Table 17. Production inputs in different soil depths for rabi sorghum

Management practice	Deep soils	Medium soils	Shallow soils
Variety	*Maldandi*	*Maldandi*	*Maldandi*
Land preparation	2 tractor ploughings and harrowings	2 ploughings with bullocks and harrowings	2 ploughings with bullocks and harrowings
Seeding	One or two bowl seed drills	One or two bowl seed drills	One bowl seed drill
FYM (t ha^{-1})	10-12	5-12	5-6
Fertilizer (kg ha^{-1})	Basal: 100-150 (urea) or 125 (*Suphala* 15-15-15)	50 kg (urea)	-
	Top dressing: 100 (urea)	-	-
Crop rotation	Sorghum + safflower - pigeonpea or sorghum - pigeonpea/ sunflower/groundnut	Sorghum - pigeonpea or sole sorghum	Sole sorghum; rarely sorghum - pigeonpea

Table 18. Soil texture and crop choice in arid soils

Texture	Crop choice
Heavy	Monsoon fallow followed by wheat/mustard
Medium	Pearl millet, sorghum, sesame
Light to medium	Pearl millet
Duny sands	Pearl millet, moth bean
Light (with hard pan)	Clusterbean

The existing practices in rice production in uplands and lowlands (Chandna, 1999; Venkateswarlu and Vittal, 1999) are as presented in Table 19.

is a lynchpin in securing soil for the world. So basically by increasing the carbon content in the soils we can contribute to lots of global problems like food security, energy security, climate change mitigation and biodiversity protection, said Mercer. Causative factors include intense farming and now the climate change, besides others. Once the soil loses its carbon, producing more abundant yields become much more difficult because of the lack of nutrients in the production base (UNESCAP, 2009). In fact 1/4th of the world population is affected with the global degradation. Area estimated works out to be 20% of the cultivated area, 30% of forest area and 10% of grasslands (FAO, 2008). Globally 78% of the degraded lands are in humid area.

Table 19. Farming practices for rainfed rice grown in different zones of the catena

Production system	Uplands		Medium lands	Lowlands
	Unbunded	Bunded		
Sowing	Broadcasting (100-120 kg ha^{-1})	Broadcast/line sowing (60-80 kg ha^{-1})	Broadcast/ Line sowing and transplanting (random dibble)	Transplanting (random dibble)
Fertilizers	FYM	FYM + 50 kg DAP	FYM + 20-10-10	FYM + 36-16-16
Weeding	Hand weeding	**Bueshening* after 4-5 weeks in standing water	* *Bueshening* after 4-5 weeks in standing water	Hand weeding or use of tyre harrow
Yield (t ha^{-1})	0.4	0.7	0.9	1.7

**Bueshening* is done in fields where seeds are broadcast.

Thus the two important edaphic factors that have a bearing on productivity of crops are depth and texture.

Land Degradation

Soil degradation poses risk to earth's future. It is a more serious threat to human health than climate change (Mercer, 2012). But it is rarely discussed in the media and by governments. There is a need to realize that soil carbon itself is a lynchpin in securing soil for the world.

The next stages in agricultural development will need to be much more about conserving the natural resources, recycling carbon and ensure soils retain vital nutrients. Also there is a need to protect the biodiversity, the lifeline of the smallholders and regenerate the natural resources of soil and water (UNESCAP, 2009).

Paradigm Shift in Soil Conservation

Retrieving degraded lands, which are largely result of soil erosion, calls for a paradigm shift from the traditional soil conservation through mechanical structures to land husbandry. Here we like to quote the doyen in soil conservation, Hudson (1992). He said "Current changes include even the term soil conservation will probably fade away to be replaced by land husbandry because that better describes the fundamentals of the new approach. The idea of the care of crops and their management and improvement has for years been called crop husbandry. Animal husbandry has described the care and management of livestock. Soil conservation was appropriate when we were mainly concerned with increasing knowledge and awareness of soil degradation and learning how to decrease the process. But that was mainly a defensive strategy and what we now seek is a positive approach where care and improvement of the land resource comes first and control of erosion as a result of good land husbandry".

Soil Health

Soil health is defined as the capacity of soil to function as a living system. Healthy soil maintains diverse communities of soil organisms that help control plant diseases, insects and weed pests, from beneficial symbiotic association with plant roots, recycle essential plant nutrients, improve soil structures with positive repercussions for soil and nutrient holding capacity and ultimately improve production (Collette *et al.,* 2011).

From an ecosystem perspective a healthy soil does not pollute the environment, rather it contributes to mitigate climate change by maintaining or increasing its carbon content. Functional interactions of soil biota with organic and inorganic components, air and water determine a soil's potential to store and release nutrients to plants to sustain their growth.

Thus "soil health is the capacity of a soil to function". Soil health is reflected through how well is the soil functioning to infiltrate water and recycle nutrient to water and feed growing plants. Soil is controlled by macroscopic and microscopic flora and fauna. They need food (being heterotrophic) to survive and help in making the soil functional (USDA, 2010). Soil life adds life. A living soil enriches soil. In order to make the soil live effectively, the needs are water, food (organic matter), air and favourable pH and temperature. The below ground biodiversity provides ecosystem goods and services to crop plants (Johri, 2006).

The SOM generally, contains some fresh residues (<10%), decomposing organic matter (33-50%) and stabilized organic matter (33-50%) and living organisms (~5%). It is the stabilized organic matter that forms the humus component in the soil. It holds water 4-6 times its weight and its cation exchange capacity (nutrient holding capacity) is 250-400 me per 100 g soil. It decomposes slowly @ 2.5% per annum. A 15 cm soil with 1.0% SOM contains 1000 kg N, 100 kg P and 5 kg S ha^{-1} (Krishnamoorthy and Venktaeswarlu, 1976).

A teaspoon of living soil contains more of these organisms than the population on the earth. Some details of the flora and fauna are provided in Table 20.

Thus soil biodiversity underpins a multitude of ecosystem functions and processes that are essential both for sustainable food production and to manage the agroecosystems beyond farming. It arrests the current alarming state and trend in degradation of agricultural soils.

Soil biodiversity is a key determinant of land productivity and farming, which is presently facing significant sustainability challenges. Improved management of soil biodiversity in agro-ecosystems offers solutions for sustainable farming and food security, whilst simultaneously increasing carbon storage (C-sequestration), improving water cycling and reducing off-farm pollution (Dias and Coates, 2012).

The soil biodiversity regulates three major bio-geochemical cycles on earth, namely nutrient, carbon and water cycling which are essential for food, energy and water security. Additional important functions of soil include

- Regulating pests and diseases
- Supporting pollinators
- Reducing chemical pollution

Thus soil biodiversity can be used as a direct intervention in the production systems. For example

Table 20. Flora and fauna in soils

Soil Biota	Examples	Functions
Macrofauna	Earthworms	• Major decomposer of dead and decomposing organic matter and derive nutrition from bacteria and fungi leading to recycling of nutrients • Generate tonnes of casts each year, drastically improving structures • Stimulate microbial activity • Mix and aggregate soil • Increase infiltration • Improve water holding capacity • Provide channels for root growth • Improve water quality
	Nematodes	• Many help in controlling diseases and recycle nutrients • Help in dispersal of microbes • Omnivores feeding on roots of plants (plant parasites)
	Arthropods (e.g. insects, springtails beetles)	• Shred organic matter • Stimulate microbial activity • Enhance soil aggregation • Mineralize plant nutrients in bacteria and fungi • Burrow improving water infiltration • Control pests
Macroflora	Fungi	• Nutrient cycling through their hyphae (VAM) • Water dynamics • Disease suppression • Decompose organic matter
	Bacteria	• Decomposer - Decompose and breakdown pesticides and pollutants - Retain nutrients in their bodies • Mutualists - N-fixing, nitrifying, denitrifying • Obtain energy from components of N, S, Fe or H instead of carbon compounds
	Actinonycetes	• Degrade recalcitrant compounds
	Protozoa	• Mineralize nutrients making them available for use by plants and other soil organisms and thus help in nutrient recycling

Source: USDA (2010).

- Inoculation with soil beneficial organisms, such as nitrogen fixing bacteria, mycorrhiza, and earthworms

Such interventions enhance/improve

- Plant nutrient uptake
- Heavy metal tolerance
- Soil structure and porosity, and reduce pest damage (FAO, 2002)

As most of these soil biota are heterotrophic external energy through organic matter is needed. To reiterate the need and importance of agriculture soil biodiversity, the following may be kept in view:

- Soil biodiversity received much less attention than desired
- Soil biodiversity is worth trillions of dollars (Gnacadja, 2010)
- Of about 100 crop species that provide 90% of food for 146 countries. 71 are bee-pollinated. If we loose these "keystones" species, whole edifice will collapse (FAO, 2005a)
- Over 80% of the plant species can act as host to VAM fungi
- VAM is the corner stone of a second green resolution (Roy-Bollue and Hijri, 2011)
- Ants, termites and earthworms are ecosystem engineers

- Preservation of biodiversity protects drylands (Zanu, 2010).

In the process, the synergy between soil-water-crop-livestock can be revitalized, which is so important in reducing production costs and provide sustained income (Sergaldin, 1999; Kurien, 2001).

In summary, the biota in the living soil help in nutrient cycling, soil carbon sequestration, improving soil physical conditions, assisting in plant nutrient and water acquisition, fixation and mobilization of nutrients, enhance plant health and enable biotic and abiotic stress tolerance.

A living soil provides nutritious food of high quality. It enables drought tolerance and provides resilience. It also helps in lowering pollution.

Since most of the beneficial biota are heterotrophic, they need to be provided with energy through organic matter. Presently the SOM stock in the arable area is quite poor. This is all the more so where farmers moved to chemical agriculture leaving the traditional systems. We need to have a revisit to the these earlier practices for revival with suitable/ possible adaptations. Let us also realize that available potential of organic nutrients 110.75 Mts. But we are tapping only 3.75 Mts (Singh, 2012). These are estimates based on bulky organics. But if we take traditional systems also into account there is a plenty of scope to go non-chemical in crop production.

Soil is a living system. A teaspoonful of soil would contain a billion of the micro-flora and fauna. There are several types of microorganisms habitating in the soils. Some are autotrophic which draw upon atmosphere for their carbon supplies. On the other hand there are quite a large number of useful organisms that are heterotrophic deriving their energy from organic sources. And it is these useful heterotrophic organisms that need organic matter in the soil as their source of energy (Broadbent, 1957).

Further, organic matter also drives several other chemical processes and physical properties (Fan *et al.,* 2005). Thus SOM contributes considerably to increasing soil stability and resilience that are so important in food supply stability (Niggli *et al.,* 2007). Pimentel *et al.* (2005) argue that enhanced SOM leads to better aggregate stability and biologically more active soils, increasing water retention. In fact, they reported 28 to 34% high maize yields in the Rodale experiments in the organically managed plots in years of drought. This is what the author used to see in Anantapur District during 1955-56 in the farm fields where mixed cropping had been the practice contributing more and more leaf litter on to the soil. Even runoff and nutrient losses would be reduced (Niggli *et al.,* 2007; Thorup-Kristensen, 2007). However the level of SOM that can be maintained in soil depends on its texture, the way it is managed and the climate. thus SOM is always in equilibrium with the environment (Broadbent, 1957).

The Impact of Watersheds

As said earlier, keeping these scientific principles as the background, Government of India opted for area development on watershed basis (IWMP). The impact of watershed development on various indicators are presented in Table 21. These data are summarized over the year of the integrated watershed development programs.

More salient results of the impact of implementing the watershed programmes by different agencies (GOs, NGOs, Researchers) in different agroclimatic regions (arid, semi-arid and humid) covering different states are as follows:

- Over the years (1994 through 2011) there was considerable improvement in the reduction of soil erosion and runoff
- Use of groundwater had been the major source for sustainability of production systems and even with considerable extraction and use there was rise in groundwater table beyond one meter in all the studies
- Improvement of wastelands by vegetation or by conversion into cultivable lands was perceptible. So was the case with increase in irrigated areas
- There was shift to commercial crops in this decade
- Even though there was a special focus on milk production, in general, there was further

Table 21. Evaluation of watersheds in India with J. Venkateswarlu as Consultant

Details/Project	Impact of watershed management practices on sustainable of land productivity and socio-economic status (NATP study, 2004)	Impact assessment of watershed projects (MoRD, GoI 2010)	Impact of investments in watershed projects (MoRD, GoI - 2012)
(a) Size of the sample			
• Period of completion of the watersheds	1994-1997	1998-2002	2003-2007
• No. of watersheds assessed	37	837	947
• No. of states involved	16	9	17
• No. of districts involved	34	121	169
• No. of stakeholders in the study	2480	33880	66680
(b) Salient Results			
• Soil and water conservation			
- Reduction in soil erosion (%)	27	22	40
- Reduction in runoff (%)	34	46	NA
• Enhancement of groundwater table (m)	1.58	1.20	1.70
• Improvement of wastelands (%)	13.6	20.0	13.0
• Increase in irrigated area (%)	16.8	28.0	9.3
• Enhancement of crop yields (%)			
- Cereals	73.5	49.0	18.0
- Pulses	37.5	28.0	33.0
- Oil seeds	55.4	28.	44.0
• Increase in cropping intensity (%)	15.8	24.0	9.0
• Enhancement of yield of milk (%)	62.0	45.0	25.6
• Increase in income generation (Rs/ household)	20268	NA	32472
• Debt reduction (%)	28.9	37.0	36.0
• BCR	1.57	1.4	2.6

increase in milk yields over the data in non-watersheds or pre-project period

- There was enhanced employment with reduced migration in the watershed areas
- All these led to enhanced income generation at the household level with attendant debt reduction
- Finally the BCR was well above the 1.33 set by the Planning Commission for a viable investment in the watersheds

Emerging Issues

Soils back on the agenda

World is losing soil 10 to 20 times faster than it is replenishing. In the past 4 decades 30% arable land of the planet became unproductive. Our system is clearly dysfunctional and is destroying the soil and we are putting enormous burden on future generations. As soil thins the crop yields decline exponentially. Among soil scientists, concern over the global fast depleting soil is universal (Montgomery, 2010; Harteminh, 2008). We like to place the following for consideration:

- Soil is a non-renewable resource
- Soil is the basis for more than 90% of the world food production
- Soil loss outpaces soil formation at least by ten-fold
- Annual soil loss by erosion works out to 3 tons per person
- About 30% of the global land area is degraded affecting 1.5 billion people
- Costs of inaction are much higher than the costs of action

- Aim at zero net land and soil degradation.

We are delighted to learn that FAO (Anonymous, 2011) called for Global Soil Partnership for food security and climate change mitigation and adaptation. They point at the need to build capacities and enlarge knowledge and technologies for sustainable management of soil resources at all levels to enhance food security in the era of climate change. Further they call for evolving means from national and international agencies for soil quality-soil health best practices, standards, guidelines and monitoring systems. Their vision is for healthy productive soils for food secure world.

More recently, Global Soil Week as a support to the global soil partnership was held (Anonymous, 2012). It is a contribution to Global Soil Partnership. It was emphasizing the role of soil as a finite and vital resource for sustainable development and human well being. Key objectives of the meet were:

- To foster the exchange of knowledge and experiences on sustainable soil management between scientists, decision makers and practitioners on an equal footing
- To set 'agenda for action' to improve the sustainable management of soil and its restoration for sustainable development
- To outline ways in which global soil week can contribute to implement the agenda

We also have been insisting over the last decade that fuller expression of the potential of improved crop genotypes (hybrids, GMOs) would not be possible unless the base (soil) is made productive by improving the soil organic matter so that the soils become functional.

Planetary boundaries

There was an interesting study of the Stockholm Resilience Centre (Rockstrom *et al*., 2009) on identifying and quantifying planetary boundaries that must not be transgressed, which could help preventing human activities from causing unacceptable environmental changes. The planetary boundaries set by the group are provided below alongwith the parameters, proposed boundaries and current status.

As seen below the loss in biodiversity, climate change and human interference in N-cycle have already crossed the planetary boundaries and causing unacceptable environmental changes.

Loss in biodiversity leads to increased vulnerability of terrestrial and aquatic ecosystems to influence climate and ocean acidity.

Modern agriculture is a major cause of environmental pollution, including large-scale nitrogen and phosphorus induced environmental damage. When we consider biological global cycle, ~ 80 Mt of atmospheric N is industrially fixed (fertilizer) and ~40 Mt is through agricultural fixation (Rhizobia and other N fixing organisms). Much less of it is actually utilized, leaving 50-70% to pollute the groundwater and ocean as NO_3-N and as nitrous oxide in the atmosphere. In fact the estimates of crop physiologist Abrol (2005) indicate 67% of the annual loss of N fertilizer worth upto Rs 72,000 crores is from urea. Insofar as P is concerned, mineral P-fossil (phosphate rock) is mixed for human use. About 63 Mt of P_2O_5 (26 Mt of P) is present annual fertilizer production, of which ~10.5 Mt are lost from crop lands through erosion and ~20 Mt is through human excreta. About 1.0 Mt of it is added naturally to the earth ecosystem through geological and weathering processes. These enter the water bodies leading to eutrophication, environmental damage and loss in public health. Thus P additions to the earth ecosystems is on the verge of becoming a threat, if boundary for P is taken as 11.0 Mt per year.

Organic agriculture possibly is one route that may partly mitigate the problem. Presently (Willer, 2011) 37.2 Mha are under organic agriculture in 160 countries, of which only 1.18 Mha is in our country, the maximum being in Australia (12.0 Mha). For the health of the nation, this route needs to be further pursued.

Way Forward

'Business As Usual' is not an option in future. We must look for alternate paths. Several of the technological leap froggings aiming at non-chemical agriculture are discussed above. There is nothing of a brahminical distaste of the chemical agriculture. Both food and environment should win. Increased production must be achieved with a decreased impact on the natural resources, more so at a time when the cost of energy continues to rise. This is the wake up call to all of us. Perhaps a lot of research is needed to kill prejudices. In any case, resilience in production systems has to be achieved, particularly in view of the climate change. This can be achieved by building up the impoverished soil organic matter (SOM). Enhanced SOM improves nutrient and water holding capacity of the soil. It acts as a glue and improves soil structure, reduces erosion as well as waterlogging improves macroporosity, enhances biodiversity (in soils), creates ideal tilth and prevents soil surface crusting. All these lead to increased yields, reduced input costs and increased nutrient-use efficiency. It also chelates metallic micronutrients for their slow release, reduces use of herbicides and pesticides; prevents pollution and improves crop quality. The SOM provides resilience in production systems even against climate change and can wean out crops from addiction to fertilizers.

In order to reduce cost and also to enable the farmer to come out of dependence to independence in production systems non-chemical sources of feeding the soil and the crops have been in use in traditional systems. They can be incentivized, adapted and improved with the advances in our knowledge.

That organic manure mean composts or FYM and animal manure is a MUST is not wholly true. Biomass, in any form (trees, dung and crop residues) should be in focus. All the needed nutrients for the present and future production can be met from such sources. For instance Partap (2006) and Chillat (2007), extensively using the data from Michigan State University (USA), found that greater use of N-fixing crops and trees globally could result in the production of 140 Mt of N, which would be more by 82 Mt than the presently produce chemical nitrogen (i.e. 58 Mt). Multipurpose Trees (MPTs) are a boon of not only providing fodder and fuel, but also supply much needed plant nutrients and biomass for pest management. In one estimate, the working group on animal husbandry for the XI Five Year Plan (FYP) indicated that as much as 800 Mt animal dung would be available annually, of which even if 1/3rd is used as manure, it would provide 7.5 Mt of nutrients (2.90 Mt N, 2.75 Mt P_2O_5, and 1.89 Mt of K_2O). Such simple technological innovations were upscaled through community managed development with SHGs as the platform by Vijayakumar (2007). Such sustainable, regenerative and eco-friendly systems (Johl, 2006) as an alternative to chemical agriculture needs all the support of the government through incentivization using Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) for works and by providing subsidies as done for chemicals (fertilizers and pesticides).

Non-conventional sources of plant nutrients have also been suggested by TIFAC (2001) and are presented in Table 22.

On a modest estimate, about 10 to 12.5 t ha^{-1} of farm-based fresh biomass can be generated with little or no effect on the main crops grown in the fields. Even that small loss, if any, will be amply compensated in the subsequent years through recycling processes. This is besides carbon sequestration.

Epilogue

Sustainable development in rainfed agriculture can be achieved by encouraging the smallholders and women to take up internalized

Table 22. Non-conventional sources of plant nutrients

Nutrient	Non-conventional sources
N	Rhizobia, Actinomycetes, Azolla, Azotobacter, Azospirillium, Blue Green Algae (~20111 tons produced upto March 2008)
	Agricultural waste, urban refuse, Animal waste, Municipal sewage, Sledge, Green manure (Potential 10-13 Mts NPK equivalent)
P	Reserves of Apatite and Phosphorite (170 Mts) and Low grade rock phosphate (124 Mts) - in Purulia, Mussourie, Udaipur
	Bone meal, steamed bone meal
	Phosphate solubilizing bacteria and VAM Fungi
K	Glauconite deposits (2000 Mts) in Madhya Pradesh, Rajasthan, Uttar Pradesh and Kerala
Soil conditioners	Basic slag, fly ash, lignite, press mud, molasses, gypsum, dolomite

production systems. There need be a paradigm shift from overexploitation of groundwater to efficient participatory management. Similarly the shift has to be from routine soil conservation to improved land husbandry. Ecological niches for crops and cropping systems help in proper crop planning. In this context, the traditional systems need to be considered as the first step.

Soil health has to be retrieved to exploit the roles of soil biota in the production systems. Synergy between crop-livestock-tree systems must be on the agenda. With these thrusts, the production costs would come down. The farmers, particularly the smallholders could free themselves from dependence on ever increasing costly external inputs to internalized independence in production systems. The present IWMP as well the MGNREGS could be the platforms to achieve these goals.

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