Indian J. Fert., Vol. 5 (12), pp. 113-116, 119-122, 125-128 (12 pages)

Nutrient Management Strategies in Participatory Watersheds in Semi Arid Tropical India

Watershed based nutrient management options in different states (Andhra Pradesh, Madhya Pradesh, Karnataka, Rajasthan, Gujarat, Haryana and Tamil Nadu) were evaluated on farmer's fields based on initial soil characterization. Besides N and P, several other secondary and micronutrients such as S, Zn and B were found deficient in farmers' fields in watersheds. The extent of N deficiency in tested farmers' fields was 100%, P (upto 90%), Zn, B and S (upto 100%). Several rainfed crops responded significantly to balanced application of nutrients to the extent of more than 100%. The cost benefit ratio in production of crops was higher when S, B and Zn were supplied. Various integrated nutrient management options such as NP+micronutrients alongwith organic manures such as Gliricidia, vermicompost, tank silt, growing legumes in the systems or Rhizobium inoculation, FYM or application of groundnut shells, etc showed the yield advantages. Integrated nutrient management (INM) along with soil and water conservation measures doubled the yields of several crops.

CH SRINIVASA RAO
Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, 500 059, Andhra Pradesh

S.P. WANI,
K.L. SAHRAWAT
and
B. RAJASEKHARAO
Global Theme Agro-Ecosystems, ICRISAT, Patancheru 502 324, Andhra Pradesh

Semi-arid tropics (SAT) regions spread over 11.6 million sq km in the developing world are densely populated and poverty stricken largely as a result of dependence of the economy and livelihoods on subsistence agriculture. These regions did not benefit greatly from the green revolution for cereal production. Obviously there is a need for "Grey to Green Revolution" in the SAT to feed and provide proper nourishment to the ever-increasing population of the developing world. The soils of SAT are generally marginal and highly degraded and combating land degradation and increasing productivity is a major challenge (7). ICRISAT's mandate is to enhance the livelihoods of the poor in the SAT farming systems through integrated genetic and natural resource management strategies (24).

Since, water shortage is a key constraint to sustainable increased productivity beside soil fertility constraints, ICRISAT in partnership with national agricultural research systems (NARS) developed an innovative consortium model for sustainable development of watersheds. Watershed management is used as an entry point for improving livelihoods through sustainable use of natural resources and diversifying the systems (23). Apart from water shortage, low soil fertility is another major constraint to crop production and productivity in the SAT. The soils are not only thirsty but also hungry: and the hidden hunger often goes unnoticed. Better availability and utilization of water alongwith integrated nutrient management is the key to sustainable dryland agriculture.

CAUSES OF EMERGING NUTRIENT DEFICIENCIES IN DRYLANDS

Major cause for multinutrient deficiencies in dryland soils is poor in soil organic matter. This is because of high temperature, which causes rapid decomposition of organic residues in the SAT regions. Studies conducted at 21 locations of rainfed regions of India showed that most of soils are low in organic carbon (**Figure 1**) (15).

Further, the application of farmyard manure (FYM) was a common practice both in irrigated and dryland agriculture as a source of nutrients before the widespread use of NPK fertilisers. The FYM and other organic manures supply small quantities of micro and secondary nutrients. In recent years, the availability of FYM and organic manures and the quantity applied have declined drastically, resulting in micronutrient deficiencies. The problem of secondary and micronutrients is severe in drylands, as farmers preferentially apply whatever available small quantity of organic manure to irrigated rice, vegetables and cash crops like cotton and horticultural crops. Low value crops like sorghum, millets receive small quantities of FYM once in 3 to 4 years in some cases. Dryland farmers apply small quantities of N, P and K fertilisers to complement nutrients from other sources. Improper crop management in drylands due to inadequate supply of nutrients and other inputs, results in poor growth of crops, which in turn results in poor canopy development and soil erosion due to downpour during the rainy season. Thus, the nutrient-rich top soil is eroded resulting in various nutrient deficiencies.

EXTENT OF NUTRIENT DEFICIENCIES IN SAT INDIA

Most of the watersheds studied are about 500 ha (microwatershed) in area and number of farmers cultivating the arable land varied across the watersheds. To have an efficient, cost-effective, and representative sampling strategy, a stratified random sampling was developed for each watershed. Processed soil samples were used for analysis and sufficiency and deficiency of particular nutrient was done based on the following critical limits **(Table 1)**.

The nutrient status of soils from farmers' fields in the the benchmark watersheds of six states (Andhra Pradesh, Madhya Pradesh, Rajasthan, Gujarat, Haryana and Tamil Nadu) are presented in **Table 2** and **4**. Using the critical limit in the soil **(Table 1)**, it was observed that most of the soils were deficient in major nutrients like N, P and organic carbon. Results based on analysis of soils in Mahabubnagar, Nalgonda and Karnool districts of Andhra Pradesh revealed that nitrogen was deficient in 100% samples in all the three districts. While P deficiency varied from 37 to 40% fields and K deficiency varied from 3 to 8%. Similarly, N deficiency in Vertisols of Lalatora watershed in Madhya Pradesh showed that 100% fields were N deficient, 90% fields were P deficient, while none of fields were K deficient **(Table 3)**.

Soil analysis in Vidisha, Dewas and Guna (M.P) and Bundi (Rajasthan) watersheds showed that organic carbon was low in 0 to 39% in fields, available P

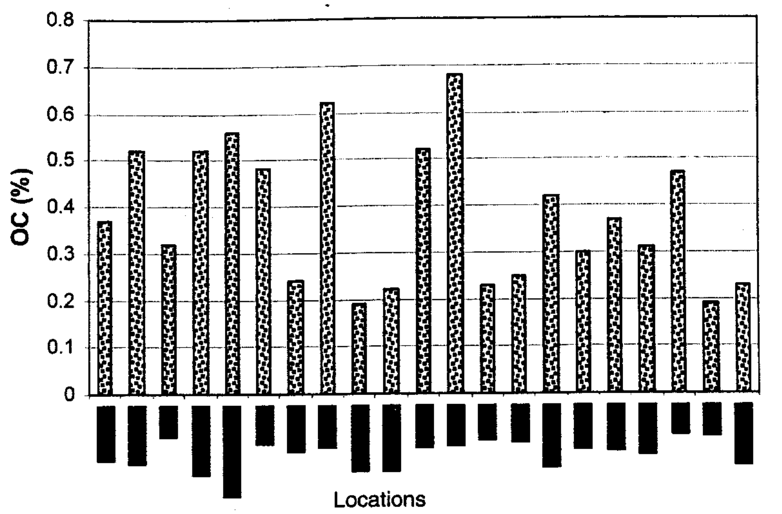

Figure 1. Organic carbon status of various soil types under diverse rainfed production system of India

Source: (15)

Table 1. Critical limits (CL) in the soil and plant tissue (fully developed youngest leaf) for micronutrient deficiencies in field crops.

Element	Soil		Plant tissue
	Extractant	CL (mg g^{-1})	CL (mg g^{-1})
S	$CaCl_2$	10	0.1-0.2%
Zn	DTPA[1]	0.75	10-20
B	Hot water	0.5	5-30

[1] DTPA = Diethylene triamine pentaacetic acid.
Source: 1, 5

Table 2. Results of soil analysis across three districts in Andhra Pradesh, India, 2002-03[1].

District	No. of farmers	pH	EC (d S m^{-1})	C[2]	Total N (ppm)	Available nutrients (mg/kg)	
						P	K
Mahabubnagar	262	7.1 5.4-9.1	0.12 0.03-0.56	0.3 0.1-0.8 59	342 123-783 100	8.6 0.7-61.0 37	104 25-416 7
Nalgonda	176	7.7 5.7-9.2	0.15 0.02-0.58	0.4 0.1-1.0 80	410 144-947 100	7.6 0.7-35.2 39	130 34-784 3
Kurnool	223	7.8 5.9-9.7	0.2 0.03-1.84	0.3 0.1-0.8 91	295 26-966 100	7.9 0.4-31.5 40	127 33-335 8
Critical limits			<0.8 (normal)				
Low				<0.5	500-1200	<5	<50
Medium				0.5-0.7 5	1200-250 0	5-10	50125
High				>0.75	>2500	>10	>125

[1] Values for each district in a column represent mean, range, and percentage of deficient fields.
[2] Data are percentage values.
Source: (6)

Table 3. Nutrient status of surface soils (0-15 cm) of farmers fields in Lalatora watershed, Madhya Pradesh (mean of 31 farmer's fields).

Parameter	Minimum	Maximum	Mean ± SD	Percent deficient fields
PH	7.61	8.31	8.14±0.14	-
EC	0.16	0.33	0.24±0.04	-
Organic carbon (%)	0.46	0.92	0.64±0.12	10
Total N (mg kg^{-1})	490	922	684±120	100
Available P (mg kg^{-1})	0.50	14.1	2.71±2.57	90
Available K (mg kg^{-1})	97	285	212±37	0

Source: (26)

in 53 – 96%, available K in 0-18%. Most of dryland cropping systems remove about 100 to 150 kg N ha^{-1} $year^{-1}$, with proper soil and water conservation practices' and this uptake is further increased due to higher yields. While addition of N vary between 0 to 40 kg ha^{-1}; there is net depletion of soil reserves. Even for dryland legume crops, general recommendation for N is 20 kg ha^{-1} as a starter dose for crops like chickpea, groundnut, lentil, soybean, etc., assuming remaining N requirements can be fulfilled by nitrogen fixation in these crops. Though these crops are able to fix nitrogen upto 200 kg ha^{-1} (25), BNF

Table 4. Extractable (available) zinc (Zn), boron (B) and sulfur (S) status of soil in farmers' fields in different locations in six states of India.

Locations	No. of farmers	Extractable Zn(μg g^{-1})			Extractable B(μg g^{-1})			Extractable S (μg g^{-1})		
	fields	Min		Max	Min		Max	Min		Max
Andhra Pradesh										
Nalgonda	176	0.08		2.20	0.02		0.8	1.4		50.5
(% deficient fields)			94			99			89	
Mahabubnagar	262	0.12		1.38	0.02		0.74	1.1		30.8
(% deficient fields)			83			98			89	
Kurnool	223	0.10		1.18	0.04		1.48	1.3		24.7
(% deficient fields)			81			92			88	
Madhya Pradesh										
Vidisha	12	0.16		0.96	0.65		1.2	3.2		5.35
(% deficient fields)			92			0			100	
Dewas	24	0.12		0.56	0.2		0.8	3.9		9.5
(% deficient fields)			100			96			100	
Guna	18	0.24		1.74	0.6		2.2	2.6		14.2
(% deficient fields)			78			0			89	
Rajasthan										
Bundi	36	0.20		1.8	0.1		0.98	3.2		50.9
(% deficient fields)			67			72			72	
Gujarat										
Bharuch Kutch	82	<0.2		2.45	0.06		0.49	1.1		150.4
(% deficient fields)			85			100			40	
Haryana										
Gurgoan	30	<0.2		0.87	0.09		0.85	<0.3		90.8
(% deficient fields)			89			93			60	
Tamilnadu										
Tiruneeveli	12	<0.2		<0.2	0.08		0.26	<0.3		3.4
(% deficient fields)			100			100			100	

Source: (6)

is often affected adversely by variable soil moisture, temperatures, organic matter content, salinity and sodicity (14). Absence of suitable rhizobia, deficiency and toxicity of a nutrient, water logging, acidity and sodicity, predators and pests are other factors which influence the potentiality of *Rhizobium* strain. Thus most of the dryland cropping systems including pulse-based systems, soil nitrogen balance is negative.

But the most revealing results are about micronutrional and S. In the watershed of Nalgonda district of Andhra Pradesh, 99% of the farmers' fields were deficient in available B, 94% of farmers fields were deficient in available Zn and 89% of farmers' fields were deficient in available S. In Mahabubnagar district, soil samples from 98% of farmers' fields were deficient in available B, 83% in available Zn and 89% in available S. Similarly, in the Kurnool district, soil samples from 92% of fields were deficient in available B, 81% in available Zn and 88% in available S.

In M.P., Zn deficiency was found upto 100%, B deficiency upto 96 % and S deficiency upto 100 %. In Bundi (Rajasthan), soil samples from 67% of farmer's fields were deficient in available Zn, 72% in available S. The extent of these nutrient deficiencies in other states were similar.

A study of soil samples from 10 farmers fields in Chintalavaripally (Chittor district), Gadimadidam gadda-1 (Sreekakulam) and Nettalamma gedda (Visakhapatnam) watersheds in Andhra Pradesh revealed extensive deficiencies of organic carbon, available P, B, S and Zn (**Table 5**). In Karnataka, Zn deficiency in farmers' fields varied from 34 to 93%, B deficiency from 54 to 96% and S deficiency from 81 to 93% (**Table 6**).

Results of soil analysis demonstrated a widespread deficiency of B, Zn, S along with N and P in farmers fields in the watersheds in six states of India. The deficiency is especially severe in the states of Andhra Pradesh, Madhya Pradesh, Karnataka, Tamil Nadu, Haryana and Gujarat. Thus, there is a need to use these results for developing site-specific nutrient management strategies for increasing productivity and sustainability of rainfed systems.

Table 5. Nutrient deficiencies in different watersheds of Andhra Pradesh

Deficient nutrient	Chintalavaripalli – 1 watershed (Chittor dt)	Gadimadidem gedda – 1 watershed (Sreekakulam)	Nittalamma gedda watershed (Visakapatnam)
pH	6.1-8.5(Normal)	7.0-8.6(Normal)	6.8-8.6(Normal)
Organic C (%)	0.22-0.95(7/10)*	0.35-0.71(4/9)	0.11-0.93(7/10)
Olsen P (mg kg^{-1} soil)	1.6-10.8(9/10)	3.0-23.2(6/9)	0.4-12.6(9/10)
Exch. K (mg kg^{-1} soil)	50-108(1/10)	111-1166(0/9)	29-144(1/10)
Boron (mg kg^{-1} soil)	0.10-0.36(10/10)	.26-1.36((7/9)	0.12-0.62(9/10)
Sulphur (mg kg^{-1} soil)	1.8-20.8(9/10)	1.0-4.8(9/9)	0.7-3.6(10/10)
Zinc (mg kg^{-1} soil)	0.40-0.86(9/10)	0.5-0.9(8/9)	0.2-1.2(7/10)
EC (DS m^{-1})	0.06-0.37(Normal)	0.14-0.25(Normal)	0.11-0.16(Normal)

* Number of deficient samples

Table 6. Extractable (available) Zn, B and S status of soil in farmers' fields in different watersheds of Karnataka

State/Location	No of farmers' fields	Zn (µg g^{-1})			B (µg g^{-1})			S (µg g^{-1})		
		Min		Max	Min		Max	Min		Max
Karnataka										
Dharwad (% deficient fields)	135	0.28	(34)	4.72	0.12	(54)	2.44	1.80	(83)	118.2
Haveri (% deficient fields)	217	0.20	(79)	2.32	0.08	(63)	1.58	1.80	(81)	60.70
Kolar (% deficient fields)	408	0.06	(64)	5.50	0.04	(90)	1.44	0.50	(87)	155.8
Tumkur (% deficient fields)	269	0.14	(88)	2.34	0.06	(96)	0.98	1.10	(93)	59.6
Chitradurga (% deficient fields)	231	0.08	(93)	3.40	0.04	(75)	4.08	1.20	(82)	601.4

* Percent deficient

NUTRIENT REMOVAL BY INTENSIVE CROPPING SYSTEMS

Some highly intensive production systems can remove up to 500 kg of N + P_2O_5 + K_2O ha^{-1} year^{-1} (**Table 7**). On the whole, the ratio of N: P_2O_5 : K_2O removal in these systems is 100: 34: 119.

Table 7. Nutrient removal by some intensively cropping systems.					
Cropping system	Yield (t ha^{-1})	Nutrient uptake kg ha^{-1} year^{-1}			
		N	P_2O_5	K_2O	Total
Maize-wheat	7.7	220	87	247	554
Pigeonpea-wheat	4.8	219	71	339	629
Soybean-wheat	7.7	260	85	204	549
Pigeonpea + sorghum**	0.8+1.1	185	19	299	503
Pigeonpea + pearl millet**	0.7+1.3	203	14	336	553
Pigeonpea + urdbean**	0.9+0.2	154	26	132	312

** Intercropping system
Source: Sekhon (18)

Under dryland agriculture, especially in the SAT regions, the situation differs from that of under irrigated, intensified systems. Most of the soils are marginal and frequent drought of various intensities result in low yields. Farmers have observed responses to small quantities of N, P, and K fertilisers and most of the farmers do apply some amount of fertilisers for crops like groundnut, maize, castor and sorghum. Thus, these crops mine the limited stocks of micro and secondary nutrients from the marginal soils, resulting in decline of these nutrients in the soil. With irrigations, however the extent of soil micronutrient depletion is much higher (**Table 8**) than under dryland conditions (**Table 9**). Even through the quantities of nutrients removed are small when compared to irrigated crops because of low yields, deficiencies do occur due to relatively small reserves in these marginal soils.

NUTRIENT DEPLETION AND BUILDUP

Based on 31 farmers' fields in Lalatora watershed (MP), mean N addition by

Table 8. Amount of micronutrients removed by major intensified production systems in India.							
Cropping system	Total grain yield (t ha^{-1})	Nutrient removed (g ha^{-1})					
		Zn	Fe	Mn	Cu	B	Mo
Rice-rice	8.0	320	1224	2200	144	120	16
Rice-wheat	8.0	384	3108	2980	168	252	16
Maize-wheat	8.0	744	7296	1560	616	-	-
Soybean-wheat	6.5	416	3362	488	710	-	-
Pigeonpea-wheat	6.0	287	4356	493	148	-	-

Source: (16)

Table 9. Mean yield and uptake of nutrients by crops grown in APRLP watersheds, Andhra Pradesh under rainfed conditions.											
Crop	Stover (t/ha)		Grain (t/ha)		Total Nutrients Removed (g/ha)						
					Control			Treated			
	Control	Treated	Control	Treated	S	B	Zn	S	B	Zn
Mungbean	0.73	1.00	0.77	1.11	2325	20	46	4009	30	68
Maize	3.46	4.29	2.73	4.56	4536	16	112	7014	19	192
Groundnut	1.99	2.49	0.70	0.94	4355	40	50	6418	52	81
Pigeonpea	1.31	2.10	0.54	0.87	1619	22	27	2649	36	45
Castor	0.82	1.19	0.59	0.89	2216	18	40	3650	26	62

Source: (6)

soybean-chickpea and soybean-wheat system was 27 and 71 kg ha^{-1} in 2000-2001 and 14 and 17 kg ha^{-1} in 2001-2002. Similarly, P addition to soybean-chickpea and soybean-wheat system was 31 and 39 kg ha^{-1} in 2000-2001 and 27 and 33 kg ha^{-1} in 2001-2002. Potassium was not applied.

Among nutrients, there was depletion of N and K, and build up of P in both the cropping systems **(Table 10)**. Among nutrients, depletion of K in soil was more drastic than N. Nitrogen depletion was higher in 2001-2002 than in 2000-2001. Overall, depletion of soil N was lower when N fertiliser was applied, while depletion was more in absence of N input. Net depletion of N was reported in absence of fertiliser N in a Vertisol under sorghum-chickpea system (17). Phosphorus buildup was observed in all the crops during the two seasons. It could be due to higher P input and low levels of P use efficiency and thereby larger build up of added P in the soil. Potassium mining from soil was more in second year due to higher crop yields. As there was no K input, total crop K requirements were fully met from soil K reserves. In absence of added K, crops depend on nonexchangeable K reserves in soils for their K requirements. Srinivasarao et al (10) reported that long term cropping in absence of external K input, depleted nonexchangeable K reserves in soil substantially and there were considerable reductions in the release rates from soil reserve K fraction in medium black soils. During the two years 133 kg ha^{-1} and 130 kg ha^{-1}, of N, respectively was taken up from the soil by soybean-chickpea system. More depletion of N with only legume i.e. soybean-chickpea system is largely due to low levels of fertiliser N application, low BNF in farmers fields due to inappropriate soil, water and nutrient management options and lack of return of residues to the soils. Similarly, P was buildup by 30 kg ha^{-1} and 39 kg ha^{-1} respectively in soybean-chickpea and soybean-wheat system. In case of K, depletion was 212 kg ha^{-1} and 200 kg ha^{-1} in soybean-chickpea and soybean-wheat systems, respectively. Tiwari *et al.* (19) resported that under long-term soybean-wheat system on a Vertisol at Jabalpur, build up of N and P was observed with recommended NPK, while there was net K depletion. In farmer's fields under sorghum and groundnut-based dryland cropping systems in semi arid tropical India, Rego *et al.* (4) reported net negative balances of N and K, whereas there was a buildup of P. Rego *et al.* (6) also stated that these rainfed soils had been under cultivation without much external input of nutrients for longer period, resulting in mining and depletion of scanty stocks of nutrients. They further stated that farmers avoid external input because of the risk of crop failure due to irratic rainfall in these regions.

Crop Response in Different Watersheds to Balanced Nutrition

Benefits of crop responses in different watersheds in different states are presented below.

Andhra Pradesh

After discussion on nutrient status of their fields, 15 volunteer farmers' fields from each nucleus watershed were identified for conducting on-farm trials initially (2002). There were only two treatments, i.e. control (farmers' nutrient inputs) and application of secondary and micronutrients (30 kg S ha^{-1} + 0.5 kg B ha^{-1} + 10 kg Zn ha^{-1}) in addition to farmer's inputs **(Table 11)**. Farmer's variety of crops and crop management were uniformed in both the treatments. Nearly 150 trials in the districts of Mahabubnagar, Nalgonda and Kurnool using test crops like maize (22), groundnut (19), mungbean (9), pigeonpea (43) and castor (8) were conducted. Farmers not only harvested more grain yields, but also benefited economically by spending of only Rs 1750 ha^{-1} for these secondary and micronutrients over and above their other nutrient inputs. For example, in

Table 10. Depletion and build up of nutrients under two cropping systems on Vertisols in farmers fields.

Year/Nutrient	Soybean	Chickpea	Total system	Soybean	Wheat	Total system
2000-2001(6)*						
N	-32 to -47(-41)**	-30 to +22(-13)	-54***	-31 to –61(-43)	-16 to +31(+9)	-34
P	+1 to +22(+16)	-4 to +6(+3)	+19	+13 to +18(+16)	+4 to +14(+8)	+24
K	-35 to -53(-45)	-34 to –50(-43)	-88	-40 to –69(-52)	-22 to –50(-37)	-89
2001-2002(8)*						
N	-23 to -49(-38)	-24 to -47(-41)	-79	-13 to –52(-33)	-46 to –91(-61)	-96
P	-3 to +19(+13)	-6 to +1(-2)	+11	+15 to +21(+18)	-6 to +1(-2)	15
K	-41 to -73(-53)	-59 to –82(-70)	-124	-25 to –61(-48)	-43 to –90(-62)	-111

** No. of farmers fields; ** Mean; *** Mean of the system.*
Source: (26)

Table 11. Crops response to secondary and micronutrients in watersheds in Andhra Pradesh (2002-2003).

Watershed	Crop	Grain yield (t ha^{-1})		Yield increase over control (%)
		Control	Treated	
Mahabubnagar				
Sripuram	Maize	2.38	4.37	84
	Pigeonpea[1]	0.24	0.42	75
Malleboinpally	Maize	2.98	4.57	53
Mentepally	Maize	1.20	1.74	45
Nalgonda				
Tirumalapuram	Castor	0.43	0.64	49
	Pigeonpea[1]	0.41	0.46	12
Nemmikal	Mungbean	0.84	1.10	31
	Pigeonpea[1]	0.35	0.66	89
Kurnool				
Karivemula	Groundnut	1.44	1.96	36
	Pigeonpea[1]	0.13	0.33	154
Devanakonda	Groundnut	0.94	1.24	32
	Pigeonpea[1]	0.23	0.50	117
Nandavaram	Castor	0.86	1.29	50
	Pigeonpea[1]	1.63	2.64	62

1 Represents intercrop
Source: (6)

Table 12. Crop response to secondary and micronutrients at optimum NP in watersheds in Andhra Pradesh (2003-04).

District	Crop	No. of farmers	Control	Control + S+MN	Control + S+MN + NP
Mahabubnagar	Maize	14	3.34	4.58 (37)*	5.17 (55)
	Sorghum	6	0.90	1.46 (62)	1.97 (119)
	Castor	8	0.94	1.38 (48)	1.65 (77)
	Pigeonpea	3	0.86	1.48 (71)	1.88 (118)
Nalgonda	Maize	10	2.01	3.60 (80)	4.46 (122)
	Mungbean	6	0.91	1.39 (54)	1.54 (70)
	Castor	9	0.48	0.76 (59)	0.78 (64)
	Groundnut (pod)	7	0.62	0.98 (49)	1.14 (84)
	Pigeonpea	5	0.65	1.21 (88)	1.22 (90)
Kurnool	Groundnut (Pod)	23	0.90	1.32 (47)	1.39 (77)
	Pigeonpea	4	0.70	1.06 (50)	1.20 (70)

* The values given in parenthesis are % increase in yield over the control.
S=sulphur; MN= Zn and B; NP= Nitrogen and Phosphorus

Mahabubnagar, net economic gain for maize was Rs 8200 ha^{-1}, while that for pigeonpea was Rs 2900 ha^{-1} in maize/pigeonpea cropping system. In Nalgonda, net economic gain for castor was 1600 ha^{-1} while that for mungbean was Rs 2700 ha^{-1}. In Kurnool net economic gain for groundnut was Rs 6500 ha^{-1} while that for pigeonpea was Rs 3200 ha^{-1} in groundnut/pigeonpea cropping system.

During 2003-04, 50 watersheds were characterized for soil fertility constraints. In addition to farmers practices, and S+Zn+B other treatments such as only B, only Zn, only S and B + Zn + S with and without optimum N and P combined application of micronutrients at optimum N + P level gave the maximum response and the additive response to each deficient nutrients at that level was obtained (**Table 12**). At farmers input level, the full potential of S, Zn and B would not have been obtained because of inadequate supply of N and P. This was proved by an increased response of yield of various crops to application of S, Zn and B along with N and thus in maize 51% and 76%, in sorghum 41 and 61%, in groundnut 47 and 78%, in mungmean 41 and 61%, in pigeonpea 71% and 90% and in castor 54% and 70% responses were obtained by combined application of B, Zn and S at farmers nutrient input level and optimum N and P level.

Madhya Pradesh

At Semli and Shyampura Watersheds, Bagli, Dewas (M.P.)

Effect of balanced nutrient application in Bagli watershed in Dewas (M.P.) showed (**Table 13**) that inclusion of S+Zn+B (200 kg gypsum+5kg borax+25 kg $ZnSO_4$ ha^{-1}) along with farmer's practice of applying only N and P, Sorghum yields improved by 60% at Neemkheda village, while soybean yields improved by 75%-79% at Semli.

Madhusudangadh Watershed, Guna (M.P.)

In three micro watersheds in Guna

Table 13. Effect of balanced nutrient application on crop yields in Bagli watersheds, Dewas (M.P.)						
Parameter	Neemkheda		Semli		Semli	
	FP+S+Zn+B	FP	FP+S+Zn+B	FP	FP+S+Zn+B	FP
Crop	Sorghum	Sorghum	Soybean	Soybean	Soybean	Soybean
Variety	JJ1041	JJ1041	JS-9305	JS-9305	JS-335	JS-335
Yield (kg ha^{-1})	3360	2100	700	400	2000	1120
Yield increase						
Over control (%)	60	-	75	-	79	-

FP = Farmer's Practice
Source: (2006)

district (Kailashpur, Barado Kala and Banjari Barri) application of B and S together significantly improved grain and haulm yields **(Table 14)**. The increase in grain yield was 83% and in haulm yield was 74% over control. Some farmers in Guna watershed evaluated the residue benefits of B and S application on chickpea and following soybean, which had received B and S treatments the rainy season. Chickpea responded to residual S as well as to B. The highest response was observed to residual S, which was approximately 68% higher (chickpea grain yield) over control **(Table 15)**.

Genotypic Variation in Crop Response to Balanced Nutrition

In the Madhusudangadh watershed (Guna, M.P), effects of balanced nutrition was tested with four chickpea varieties during post rainy season of 2004, 2005 and soybean during rainy season. The treatments tested were T1=Farmer's practice (FP), T2=FP+Zn+S+B, T3=Zn+S+B+optimum NP and T4=Farmer's practice+optimum NP. The quantity of nutrients added were as follows: Zn as $ZnSO_4$@50 kg ha^{-1}, S as gypsum @ 200 kg ha^{-1}, boron as borax@5 kg ha^{-1}, N and P were applied at 30 and 60 kg ha^{-1} respectively. The four improved chickpea varieties grown were KAK 2, ICCV 2, ICCV 10 and ICCC 37. The highest grain (2.24 t ha^{-1}) and straw (1.83 t ha^{-1}) yields were recorded in T2 treatement with KAK 2 variety, whereas other three varieties produced the highest grain and straw yields in T3 treatment. Similarly, in soybean, Zn+S+B+optimum NP recorded highest grain and straw yield compared to other nutrient treatments. Wide variation in micronutrient nutrition (Zn, Fe, Mn and Cu) of twenty chickpea genotypes was reported in multi-nutrient deficiency Typic Ustochrepts (13, 18).

Table 14. Effect of B + S application on grain and haulm yield (t ha^{-1}) of soybean in Guna district (M.P.).								
Treatment	Kailashpura		Baroda Kala		Banjari Barri		Pooled yield	
	Grain	Haulm	Grain	Haulm	Grain	Haulm	Grain	Haulm
Control	0.66	0.92	0.84	1.05	0.71	0.96	0.74	0.98
B + S	1.08	1.63	1.35	1.58	1.59	1.88	1.34	1.70
SE±	0.09	0.09	0.07	0.11	0.10	0.10	0.09	0.09
CD at 5%	0.28	0.25	0.22	0.31	0.30	0.29	0.26	0.28

Table 15. Residual effect of B, S and B+S applied to soybean on grain and haulm yield of chickpea in Guna district (M.P.).				
Treatment	Yield (t ha^{-1})		Yield increase (%) over control	
	Grain	Haulm	Grain	Haulm
B (1 kg ha^{-1})	1.61	1.66	54	10
S (30 kg ha^{-1})	1.76	1.92	68	27
B + S	1.55	1.79	48	18
Control	1.05	1.51	-	-

Rajasthan

Bundi Watershed, Bundi

At Bundi watershed, balanced nutrition trials were conducted with maize and urdbean in rainy season and wheat and chickpea in post-rainy season **(Figure 2)**. The treatments were: T1= Farmer's practice, T2= Farmers practices+borax 5 kg ha^{-1} + Gypsum 200 kg ha^{-1} + $ZnSO_4$ 50 kg ha^{-1}, T3= Farmer's practice+ borax 5 kg ha^{-1} + gypsum 200kg ha^{-1} + $ZnSO_4$ 50 kg ha^{-1} + urea 100 kg ha^{-1} + DAP 100 kg ha^{-1} and T4= Farmer's practice+urea 100 kg ha^{-1}+DAP 100 kg ha^{-1}. For all the crops, T3 treatment showed consistently superior yields compared to other treatments. The percentage increase in crop yields in T3 over T1(Farmer's practice) was highest in urdbean (47%) followed by maize (45%), chickpea (43%)

and wheat (16%). The economic analysis showed that the highest B:C ratio was obtained in case of balanced nutrition treatment as compared to farmers practice. These results clearly show that balanced nutrition, based on the application of limiting nutrients is essential for improving productivity of various dryland crops.

Karnataka

Kolar, Tumkur, Chitradurga, Haveri and Dharwad districts

Crop response data on several rainfed crops were obtained during trials conducted in 2002-2006, in different Karnataka watersheds. Response of crops due to Zn, B and S application alongwith N, P over Farmers' Practice (FP) (only N and P) in fingermillet (*Eleusine coracana*), maize (*Zea mays*), sunflower (*Helianthus annuus*), soybean (*Glycine max*) and groundnut (*Arachis hypogaea*) showed that significant yield responses in all the crops due to balanced nutrition treatment, which includes Zn, B and S alongwith N and P (**Table 16**). The Zn, B, S + FP treatment yielded 44% more stover, 56% grain yield and 48% total biomass over farmers' practice in case of finger millet. In maize Zn, B, S + FP treatment yielded 28% and 52% higher stover and grain yield than FP. Sunflower yielded 72% more stover and 156% were grain with Zn, B, S + FP treatment than FP (N+P). Significant stover (71%) yields and grain (70%) in soybean was obtained with Zn, B, S + FP treatment. In case of groundnut, significant yield response was obtained in stover (45%), grain (55%) and total biomass (47%).

INTEGRATED NUTRIENT MANAGEMENT

Organic matter is the storehouse of many plant nutrients and it strongly influences the biological activity and productive capacity of soils. Over the years, efforts have been made to improve organic matter status in continuously cropped soils by fertilization, manuring

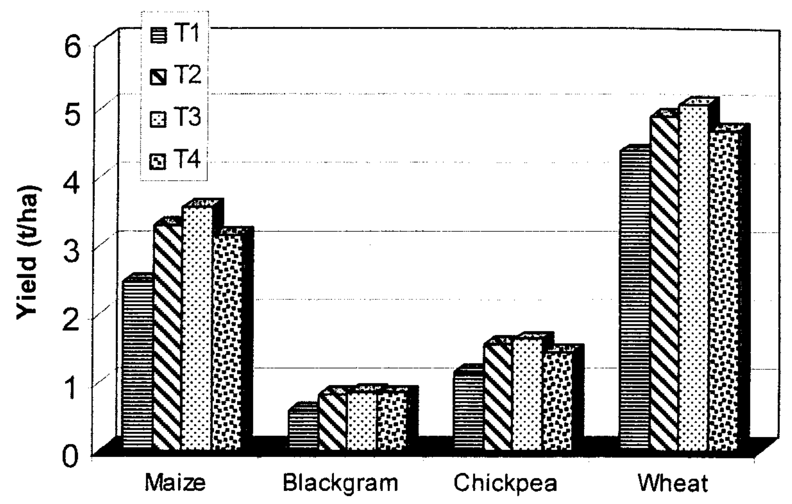

Figure 2 Effect of different nutrient management options on crop yields at Bundi Watershed

Table 16. Response of different crops to Zn, B, and S in Karnataka watersheds (2005-06)

Crop/Treatment	Yield		
	Stover	Grain	Total biomass
Fingermillet (16)*			
FP	4630	2142	6772
FP+ZnBS	6654 (44)**	3354 (56)	10008 (48)
CD (0.05)	694	252	826
Maize (9)			
FP	4619	4000	8619
FP+ZnBS	5919 (28)	6091 (52)	12010 (39)
CD (0.05)	962	395	910
Sunflower (11)			
FP	2531	901	3432
FP+ZnBS	4368 (72)	2309 (156)	6678 (94)
CD (0.05)	555	307	730
Soybean (6)			
FP	1254	2029	3282
FP+ZnBS	2151 (71)	3469 (70)	5620 (71)
CD (0.05)	350	664	1001
Groundnut (8)			
FP	2803	774	3576
FP+ZnBS	4079 (45)	1200 (55)	5279 (47)
CD (0.05)	625	330	733

FP= Farmers' practice (only N+P)
* = No of trials; ** percent increase over FP.

and residue management practices. However, maintaining and increasing organic carbon is a major challenge in dryland soils due to high prevailing temperatures. Studying 21 locations across rainfed regions of the country covering eight production systems revealed that most soils are low in organic carbon, available N, low to high in available P, K and S. Many soils are deficient in available Mg, Zn and B (11). Therefore, crop and soil management practices have to be tailored to ensure long term crop/ cropping systems that add organic matter to the soil. Application of plant nutrients and organic amendments, inclusion/cultivation of legumes favour improvement of soil fertility and sustainability. This is directly related to maintaining the quantity of soil organic matter, which is a critical component of soil productivity. However, resource poor farmers in dryland regions, apply meager quantity of nutrients and thus crops suffer from multi nutrient deficiencies (12). The best option seems to be integration of farm generated organic manure with fertilisers in order to improve soil organic matter, improving productivity and sustainability of dryland agriculture. Crop rotation, residue management and fertilisation can help to maintain the level of soil organic matter. The availability of organic crop residues is major problem in India due to their competing uses but some products like Gliricidia, vermicomposting, tank silt application, cover crops (20), and locally available organic resources like groundnut shells (for example at Anantapur) are available for soil application as they do not have major other alternate uses. Though fertilisation have demonstrable effect on yields, poor farmers in rainfed regions also rely on FYM and other organic manures because of cost factor. Therefore, application of fertilisers of inorganic and organic manures is the best option for maintaining long term sustainability of soil productivity.

INM with Farm Yard Manure

Farm yard manure is an important form of organic matter. However, its competing uses as fire wood will not allow its use for recycling. Many reports indicated the beneficial role of FYM in increasing crop yields as well as soil health. A combination of 50-50-25 NPK along with 10 tonnes (t) FYM ha^{-1} gave highest fingermillet yield on Alfisols of Bangalore (21) (**Table 17**).

Effect of different INM treatments for 20 years on soil available N is shown in Figure 3. Wide gap in available N status was observed between control and other treatments at all depths (**Figure 3**). However, in top soil layers, the differences were larger. Available N varied from 37.5 kg ha^{-1} to 78.5 kg ha^{-1} in control profile, from 60.0 to 143.0 kg ha^{-1} in 100% NPK and from 60.1 to 144.5 kg ha^{-1} in 50% NPK + 4t groundnut shells ha^{-1}. Other two treatments i.e. 50% NPK+ 4t FYM ha^{-1} and 100% organic (5t FYM ha^{-1}) had values in between. Despite continuous addition of nutrients both organic and fertiliser source for 20 years, all the profiles were found to be still N deficient (<280 kg N ha^{-1}). Continuous cropping of groundnut with lower doses of NPK and limited amount of organic manures like FYM or groundnut shells had improved available N in soil substantially but this level is still below deficiency limit (9)

Table 17. Effect of FYM and fertilisers on yields of fingermillet at Bangalore

N-P-K (kg/ha)	Control	FYM (10t/ha)	Green manure	Mean
0-0-0	19.0	26.4	24.3	23.2
25-25-25	26.2	33.6	30.6	30.1
50-50-25	31.5	37.1	30.6	33.1
0-25-25	22.9	28.4	28.2	26.5
Mean	24.9	31.4	28.4	-

Source: 21

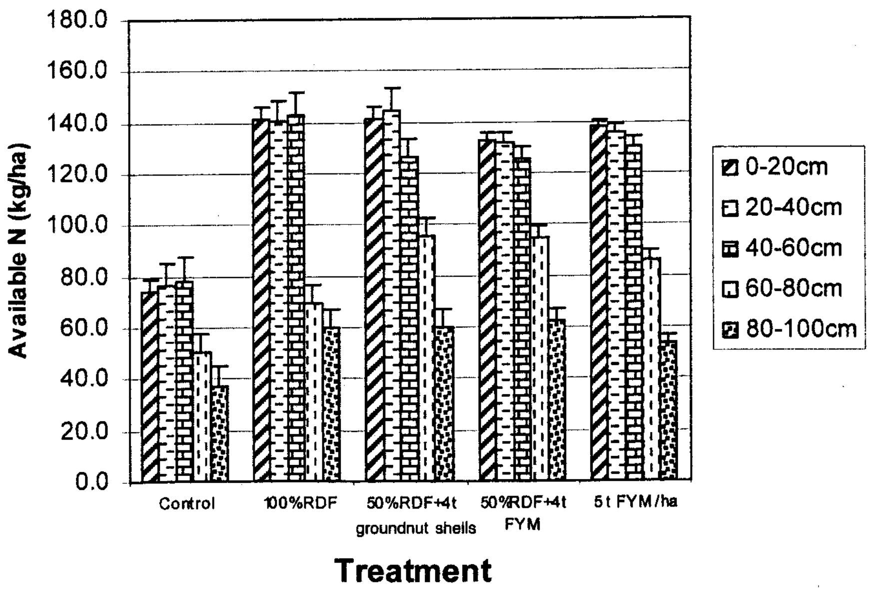

Fig 3. Effect of 20 years of groundnut cropping on soil available N

Inclusion of Legumes in the Cropping Systems

It was stated that by improving physical, chemical and biological properties of soils, food legume cultivation could arrest the declining trend in productivity of cereal-cereal systems. Wani et al (23) reported that with improved management system consisting of legume showed higher productivity besides maintaining better soil health than traditional system. However, N fixed by these legume crops varied widely from 3 -300 kg ha^{-1} depending upon soil conditions (25)

Gliricidia Leaf Manure

Gliricidia leaves contain 2.4% N, 0.1% P and 1.8% K besides several other nutrients. *Gliricidia* plants grown on 700 m long bunds can provide about 30 kg N/ha/year. In a year, three cuttings can be made which act as potential green leaf manure.

Vermicomposting

Earthworms consume various organic wastes and reduce the volume by 40-60%. The worm castings contain higher percentage (nearly twofold) of both macro and micro nutrients than the other composts (**Table 18**). Vermicompost plays a major role in improving growth and yield of different field crops, vegetables, flower and fruit crops. Application of vermicompost gave higher germination (93%) of mungbean compared to control (84%).

Table 18. Nutrient composition of vermicompost

Nutrient content	Vermicompost (%)
Organic carbon	9.8-13.4
N	0.51-1.61
P	0.19-1.02
K	0.15-0.73
Ca	1.18-7.61
Mg	0.093-0.568
Zn	0.0042-0.110
Source: (2)	

Tank Silt Application

Tank silt posses' high water retention capacity and acts as good source of nutrients. Analysis conducted in several tanks in Medak district of Andhra Pradesh showed the potential of tank silt in supplying organic carbon and several nutrients. Tank silt is particularly beneficial in light textured soils (**Table 19**).

Table 19. Amount of Sediment, Organic Carbon, N and P contents in different tanks in Medak District of Andhra Pradesh

Total number of Tanks	= 21
Amount of sediment	= 48777 tonnes
Amount of Carbon	= 521 tonnes
Amount of Nitrogen	= 34.1 tonnes
Amount of Phosphorus	= 14.9 tonnes
N Fertiliser Equivalent	= Rs 378240
P Fertiliser Equivalent	= Rs 285174
B:C Ratio of Desilting of Tanks: 1.23	
Source: (3)	

CONCLUSIONS

- Soils of rainfed regions of India are poor in organic matter and are multinutrient deficient.
- Application of N and P alongwith S and micronutrients gave best results for crop yields which were significantly higher than the farmers' practices.
- With one or two life saving irrigation of harvested water, benefits were much higher.
- Integrated nutrient management options not only improve crop productivity but also improve soil health.
- Various potential organic manure such as *Glyricidia,* vermicomposting, tank silt, legume cropping or Rhizobium culture and cover crops besides several other locally available organic sources can successfully be used as INM components.

FUTURE CHALLENGES

- Extending the delineation of micronutrient deficiencies in other watersheds.
- Optimum micronutrient doses for rainfed crops.
- Frequency of micronutrient application as a basal dose.
- Interaction effects of life saving irrigations and nutrient supply.
- Recycling of farm and other wastes

REFERENCES

1. Katyal, J.C. and Rattan, RK. *Fert. News* 48(4): 9-20 (2003).
2. Nagavallemma, K.P., Wani, S.P., Lacroix, S., Padmaja, K.V., Vineela, C., Baburao, M. and Sahrawat, K.L. Vermicomposting: Recycling wastes into valuable organic fertiliser. Global Theme on Agroecosystems Report No.8, ICRISAT, Patancheru. 20pp (2004).
3. Padmaja, K.V., Wani, S.P., Agarwal, L. and Sahrawat, K.L. Economic assessment of desilted sediment in terms of plant nutrients equivalent: A case study in the Medak district of Andhra Pradesh. Global Theme 3, Report No:4, ICRISAT, Patancheru, 24 pp (2003).
4. Rego, T.J., Seeling, B., Nageswara Rao, V., Pardhasaradhi, G., Kumar Rao, J.V.D.K., Myers, R.J.K. and Johansen C. *Plant Soil* 233:1-11 (2001).

5. Rego, T.J., Sahrawat, K.L., Wani, S.P., Pardhasaradhi, G., *J. Plant Nutr.* 30. In press. (2007)

6. Rego, T.J., Wani, S.P., Sahrawat, K.L., and Pardhasaradhi, G. Macro benefits from boron, zinc and sulphur application in Indian SAT. Global Theme on Agroecosystems Report No:16, ICRISAT, Patancheru, Andhra Pradesh p 20 (2005).

7. Singh, H.P., Sharma, K.D., Subba Reddy, G. and Sharma, K.L. Dryland Agriculture in India In: Challenges and Strategies for Dryland Agriculture. Crop Science of America and American Society of Agronomy, Madison, USA. Publication No: 32, 67-92 (2004)

8. Singh, M.V. Sulphur management for oilseed and pulse crops. Bulletin No.3, Indian Institute of Soil Science, Bhopal. (1999)

9. Srinivasarao, Ch. Annual report CRIDA-PPIC collaboration project, Central Research Institute for Dryland Agricutlure, Hyderabad (2005).

10. Srinivasarao, Ch., Anand Swarup, Subba Rao, A., and Venugopal, V. *Australian J Soil Res.* 37:317-328 (1999).

11. Srinivasarao, Ch., and Vittal, K.P.R. *Fert. News* 3(5): 37-44 &70 (2007).

12. Srinivasarao, Ch., Ganeshamurthy, A.N. and Ali, M. Nutritional constraints in pulse production. Bulletin, Indian Institute of Pulses Research, Kanpur, 1-34 (2003).

13. Srinivasarao, Ch., Ganeshamurthy, A.N., Ali, M and Venkateswarlu, B. *J. Plant Nutri.* 29(4):747-764 (2006).

14. Srinivasarao, Ch., Prasad, J.V.N.S., Vittal, K.P.R., Venkateshwarlu, B. and Sharma, K. *Fert. News* 48 (12):105-112 (2003).

15. Srinivasarao, Ch., Vittal, K.P.R., Chary, G.R., Gajbhiye, P.N. and Venkateswarlu, B. *Indian J. Dryland Agri. Dev.* 21:105-113 (2006).

16. Takkar, P.N. *J. Indian Soc. Soil Sci.* 44:563-581 (1996).

17. Talanur, S.I., and Badanur, V.P., *J. Indian Soc. Soil Sci.* 51:41-44 (2003).

18. Tandon, H.L.S and Sekhon, G.S. Potassium Research and Agricultural Production in India. FDCO, New Delhi (1987).

19. Tiwari, A., Dwivedi, A.K., and Dikshit, P.R., *J. Indian Soc. Soil Sci.* 50: 472-47. (2002).

20. Venkateswarlu, B., Srinivasarao, Ch., Ramesh. G., Venkateswarlu, S., Katyal, J.C., *Soil Use Manage* 23,100-107 (2006).

21. Vittal, K.P.R., Sankar, G.R.M., Singh, H.P. and Samra, J.S. Sustainability of Practices of Dryland Agriculture: Methodology and Assessment. All India Coordinated Research Project on Dryland Agriculture. Central Research Institute for Dryland Agriculture, Hyderabad, India pp 100 (2002).

22. Wani, S.P., Srinivasarao, Ch., Rego,T.J., Pardhasaradhi, G, Rangu Rao, Somnath Roy and Chourasia, A.K. *Indian J. Dryland Agri. Dev.* (In Press) (2006).

23. Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H. and Singh, P. *Soil Use Manage* 19, 217-222 (2003).

24. Wani, S.P., Pathak, P., Rego, T.J., A training manual on integrated management of watersheds. International Crops Research Institute for Semi Arid Tropics, Global Theme on Agroecosystems, Patancheru, Andhra Pradesh, India. (2002).

25. Wani, S.P., Rupela, O.P. and Lee, K.K. *Plant Soil* 174, 29-49 (1995).

26. Wani, S.P., Srinivasarao, Ch., Rego, T.J., Pardhasaradhi, G and Somnath Roy. *Indian J. Dryland Agri. Dev.* (In Press) (2007).