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Improved crop productivity and rural livelihoods through balanced nutrition in the rainfed semi-arid tropics

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

Diagnostic soil analysis in targeted clusters of eight districts in Andhra Pradesh revealed critical deficiencies of sulphur (61 to 98%), boron (23 to 98%) and zinc (45 to 85%) in addition to that of soil carbon (25 to 97%), and phosphorus (14 to 84%) which are apparently holding back the productivity potential. The soil test based application of sulphur, boron and zinc together increased productivity by 8 to 102% in cotton, groundnut, castor, sorghum, greengram, cowpea, chickpea and maize. Economic assessment reveal that per rupee invested as additional cost (₹ 1,400/- to ₹ 2,150/-) gave ₹ 1.6 to 28.5 in return. Residual benefits of balanced nutrition were observed during 4 succeeding seasons. Soil health improved in balanced nutrition plots, inspite of higher yields and nutrient removal. The results showed that balanced nutrition is the way forward to increase crop productivity through resilience building of production systems and improve farm based livelihoods in the SAT regions.

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Improved Crop Productivity and Rural Livelihoods through Balanced Nutrition in the Rainfed Semi-Arid Tropics

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Contents

Introduction

Worldwide, rain-fed agriculture is practiced in 80% of the agricultural area and generates 62% of the world's staple food (FAOSTAT 2005). These regions are home to the world's poor and malnourished people, and almost all population growth (95%) is taking place in these developing regions (Wani et al. 2012a). In India, area under rain-fed agriculture is 89 million ha (2/3rd of total), and contributes to 44% national food production (Wani et al. 2012b). In context of irrigated regions in India having reached productivity plateau, rain-fed regions offer hope to increase food production to required 290 million t by 2025 to meet the food requirement (Amarasinghe et al. 2007; Wani et al. 2008). But, rain-fed semi arid tropics (SAT) areas in India are the hot spot of land degradation, low crop yields and poverty. Out of 852 million poor and malnourished people in the world, 221 million are in India. Similar situation more or less exists in Andhra Pradesh state in India. In Andhra Pradesh, agriculture contributes to about 20% of the GDP (Gross domestic product), but provides employment and livelihood to more than 60% of rural population. Thus any growth in agriculture directly translates into poverty reduction in rural areas. Growth in agricultural productivity also accounts for a large share of economic growth. Agriculture-led development is feasible in these rain-fed regions only by applying scientific knowledge to increase crop productivity and incomes.

Large yield gaps between current and potential yields

An analysis of major rain-fed crops in semi-arid regions in Andhra Pradesh reveal large yield gaps between farmers' current yields and the achievable potential yields. The farmers' current yields are 2–4 times lower than achievable yields (Figure 1). The historic trends show a growing yield gap between farmers' practices and farming systems with improved management (Wani et al. 2003a). Data from long-term experiment at International Crops Research Institute for the Semi-

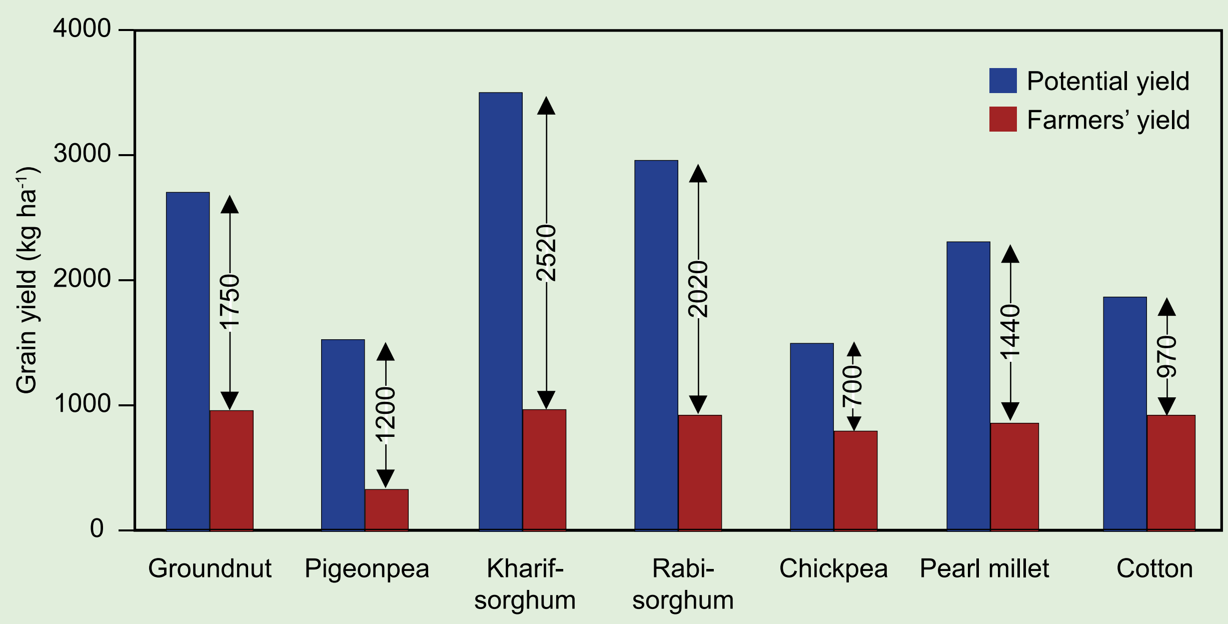

Figure 1. Yield gap for different crops in Andhra Pradesh (Source: Singh et al. 2009).

Arid Tropics (ICRISAT) heritage watershed site has demonstrated that integrated watershed management interventions which focus on balanced nutrient management along with crop, land and water management practices can sustainably increase rain-fed crop yield by five folds as compared to that under traditional farmer's practices (Wani et al. 2003a, 2011, 2012a).

Nutrient mining and land degradation – threat to sustainability

The soils in SAT regions are not only thirsty but also hungry. The SAT soils are generally marginal compared to those in the irrigated or assured rainfall regions. Poor soils with low nutrient reserves are brought under cultivation due to population pressure and that too without much external input of nutrients for a long time, resulting in mining and depletion of scanty stocks of nutrients. Farmers avoid external balanced nutrient inputs because of the risk of crop failure due to erratic rainfall in these regions unlike in the irrigated or assured rainfall regions where risks of crop failure are minimal. Further, the rate of organic matter degradation in the SAT is relatively higher than in the temperate region due to prevailing high temperatures and drying and wetting cycles. These soils are prone to severe wind and water erosion, which take away nutrient rich fine top fertile soil layer. Thus, soil erosion along with mining of nutrients by continuous cropping, without adequate additions of nutrients, have impoverished the soils over the years. Wide-spread deficiency of macro, micro and secondary nutrients have been reported in rain-fed areas (Wani et al. 2003b; Rego et al. 2005; Sahrawat et al. 2010; Girish Chander et al. 2012) which must be overcome to enhance productivity in a sustainable manner to meet the current and future food needs of the growing population.

The father of Green Revolution, Dr Norman Borlaug while accepting the Nobel Peace Prize in 1970 aptly said: "If the dwarf wheat varieties developed (by him) was the vehicle, the fertilizers were the fuel which produced high yields and triggered the Green Revolution in many developing countries including India." This synergy between improved genetic resources and adequate nutrient supply sustained the increased productivity of rice and wheat for nearly three decades. In recent years the high productivity in irrigated agriculture is stagnating or declining in spite of supplying increasing nitrogen (N), phosphorus (P) and potassium (K) fertilizers. One of the major factors for this situation has been identified as inadequate supply of micronutrients. And it is important that such mistake is not repeated in the rain-fed semi-arid tropics.

In dryland tropics, farmers have noticed responses to N, P and K fertilizers and most of the farmers do apply these fertilizers to their crops like groundnut, maize, castor and sorghum. Thus, crops in SAT mine the limited stocks of micronutrients and secondary elements from the marginal soils, resulting in their decline in these soils. Table 1 gives the amounts of micro and secondary nutrients removed by various crops under rain-fed dryland conditions. Even though 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. In recent years, the availability of farm yard manure (FYM) and organic manures and the quantity applied have declined drastically resulting in micronutrient deficiencies. The problem of secondary nutrients and micronutrients is severe in drylands, as farmers preferentially apply whatever available small quantities of organic manure to irrigated rice, vegetables and cash crops. Low-value crops like sorghum, millet, etc receive small quantities of FYM, once in 3 to 4 years in some cases. 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 more soil erosion due to downpour in the rainy season. Thus the nutrient-rich topsoil is eroded resulting in various nutrient deficiencies.

Table 1. Mean yield and uptake of nutrients by crops grown in the Andhra Pradesh Rural Livelihood Program (APRLP) watersheds, Andhra Pradesh, India in 2002

					Nutrients removed (g ha^{-1})					
	Grain yield (kg ha^{-1})		Stover yield (kg ha^{-1})		Control			Treated		
Crop	Control	Treated	Control	Treated	S	B	Zn	S	B	Zn
Mungbean	770	1110	730	1000	2325	20	46	4009	30	68
Maize	2730	4560	3460	4290	4536	16	112	7014	19	192
Groundnut	700	940	1990	2490	4355	40	50	6418	52	81
Pigeonpea	540	870	1310	2100	1619	22	27	2649	36	45
Castor	590	890	820	1190	2216	18	40	3550	26	62

Source: Rego et al., 2005

Study sites

The targeted cluster of villages (Figure 2; Table 2) in eight mandals in Adilabad, Anantapur, Kadapa, Khammam, Mahabubnagar, Nalgonda, Rangareddy and Warangal districts were selected by the ICRISAT-led consortia in view of the subsistence farming prevalent and very low productivity. The number of households range from 216 in B.Yerragudi cluster of Kadapa district to 739 in Jamistapur cluster of Mahabubnagar district, while the cultivable area varies from 346 ha in Ibrahimpur cluster of Rangareddy district to 2070 ha in Jaffergudem cluster of Warangal district. The major crops grown in the area are cotton, pigeonpea, groundnut, castor, maize, chickpea, sorghum, rice and sunflower. The soils of the region are predominantly red (Alfisols) and black (Vertisols and associated Vertic soils). In general, the selected project sites are inhabited by the indigeneous people who are very poor and highly indebted. They have limited livelihood opportunities and therefore migration also happens to some extent. Among major constraints to a higher productivity include land degradation and occurrence of droughts. The irrigation facility is scarce and productivity is very low. Therefore, the overall goal of the intervention was to lead to sustainable intensification and reduce poverty in the target dryland upstream areas.

Consortium and convergence approach

To bring in impact in productivity and livelihood improvement in rural areas, a holistic farming systems approach is needed to tackle multiple issues at the farm level. ICRISAT in its integrated watershed management programs over the years has evolved a consortium (of technical institutions) and convergence (of interventions/developmental schemes) approach in different sectors like livestock, markets, policies, institutions, finances, monitoring and evaluation in addition to agricultural production related. The consortium and convergence mechanism has been refined over the years to change the lives of smallholders in the semi-arid tropics in India (Wani et al. 2012c).

In order to change the livelihoods of farmers in cluster villages in eight rain-fed districts of Andhra Pradesh an Indian Council of Agricultural Research (ICAR) supported National Agricultural Innovation Project (NAIP) namely “Sustainable rural livelihoods through enhanced farming system productivity and efficient support systems in rain-fed areas”, was implemented during 2007-08 to

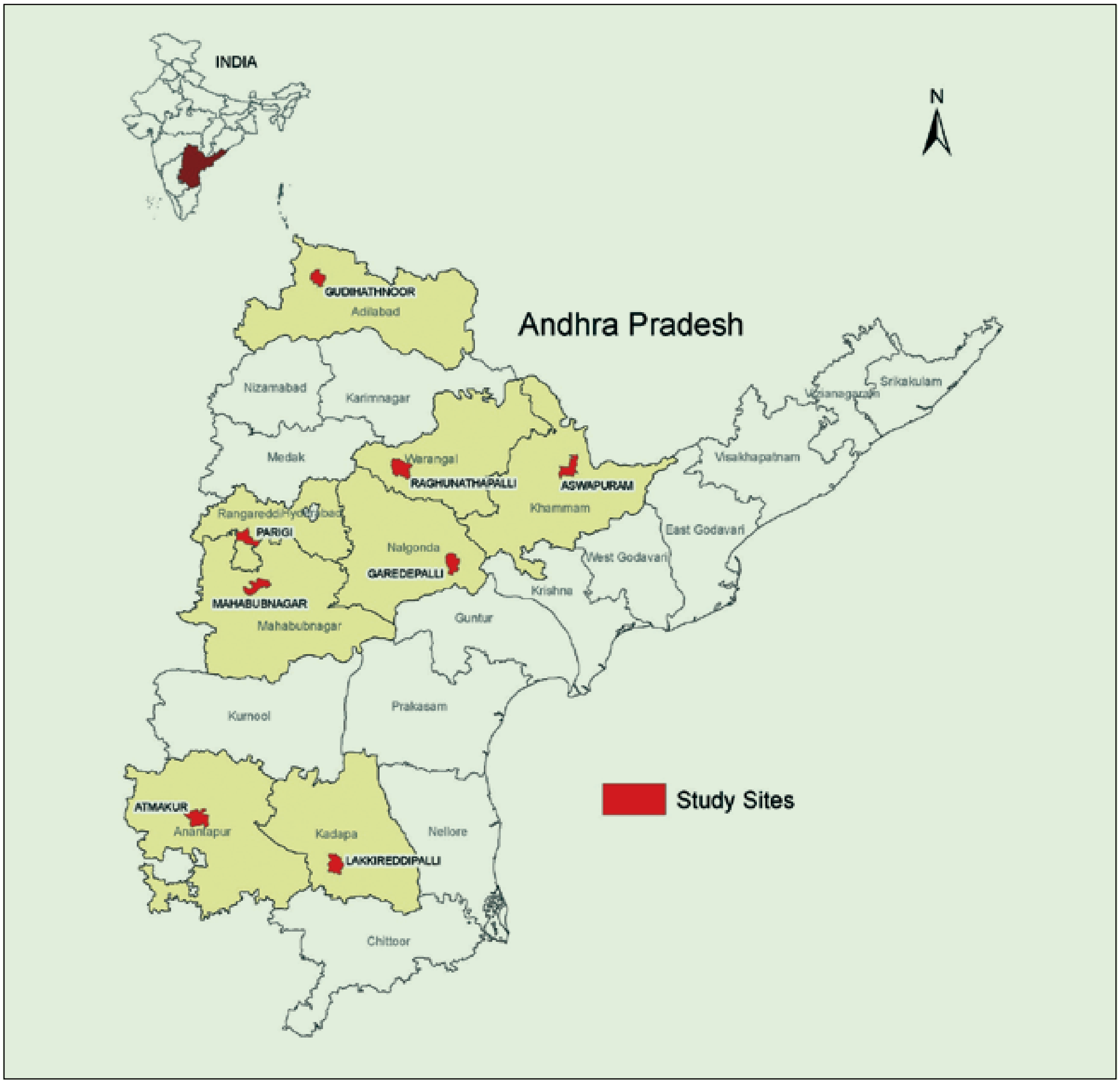

Figure 2. Study sites in eight districts in Andhra Pradesh, India.

2011-12. Central Research Institute for Dryland Agriculture (CRIDA)-led consortium consisting of research institutions like ICRISAT Patancheru and Acharya NG Ranga Agricultural University (ANGRAU) Hyderabad; non-governmental organizations (NGO's) in eight districts; and I-Kisan, the information and communication technology (ICT) and market linkage partner, implemented it.

As part of the broad livelihood improvement initiative under NAIP-project in Andhra Pradesh, ICRISAT was responsible to manage the issues of increasing crop productivity and ensuring sustainability under the sub-project namely "Increasing crop productivity through soil-test based sustainable nutrient management in eight target rain-fed districts". A consortium and participatory approach formed the core of the strategy to take science at the doorsteps of farmers. In order to undertake on-farm research for impact an ICRISAT-led consortia of technical institutionas was constituted and other consortia partners were Krishi Vignan Kendra (KVK), ANGRAU Hyderabad,

Table 2. Details of study sites in the target districts in Andhra Pradesh

District (Mandal)	Villages (Name for cluster of villages in bold)	No. of Households	Cultivable area (ha)	Soil type
Adilabad (Gudihatnoor)	Seethagondi, Arkaplli, Kotwalguda, Newsomavarpet, Old Somvarpet, China Malkapur, Garakampet, Peddamalkapur,	575	1296	Black
Anantapur (Atmakur)	Pampanur, P.thanda, Y.Kothapalli	576	1430	Red (gravelly)
Kadapa (Lakkireddipalli)	B. Yerragudi, Kapupalli, B A Nagireddipalli, Madiga palli, Moodindlapalli, Putakarlapalli, PP colony, Konampet	216	1060	Red and black
Khammam (Aswapuram)	Tummalachervu, Bheemavarm, Koremvarigumpu, K. Kothuru, Mamillavai, Ramavaram, Venkatapuram	650	1000	Red and black
Mahabubnagar (Mahabubnagar)	Jamistapur, Telugugudem, Kodur Thanda	734	756	Red and black
Nalgonda (Garedepalli)	New Banjarahils, Jamalkunta Thanda, Seetamathanda, Lalsingh Thanda, Chinagorekunta, Pedagorekunta, Yellappakunta Thanda, Pedasetaram Thanda, Chinnaseetarm Thanda (Dupahad cluster)	621	500	Red and black
Rangareddy (Parigi)	Ibrahimpur, Dadithanda, Roopsingh Thanda, Malkaipet Thanda	409	346	Red (sandy)
Warangal (Raghunathapalli)	Jaffergudem, Jal Thanda, Kusumbaithanda & Satyanarayanapuram, Ramannagudem, Vapalgadda Thanda, Cherla Thanda, Lokya Thanda	689	2070	Red and black

in Adilabad district; Watershed Support Services and Activities Network (WASSAN), Rangareddy; Modern Architects for Rural India (MARI), Warangal; BAIF Institute of Rural Development (BIRD BAIF), Anantapur & Mahabubnagar; Sri Aurobindo Institute for Rural Development (SAIRD), Nalgonda; Center for World Solidarity (CWS), Khammam; and Aakruthi Agricultural Associates (AAKRUTI), Kadapa. Farmer participatory action research approach was adopted to bring in the farmers at center stage and take ownership. Soil testing constituted as an entry point activity for building the trust and strengthening the partnership by ensuring tangible economic benefits for the farmers through science-led productivity enhancement initiative. A need-based on-farm research/ demonstration with major crops constituted the core strategy for capacity building of farmers in addition to the trainings and exposure visits.

Soil health assessment

Participatory and stratified soil sampling

Soil testing plays an important role in the diagnosis of nutrient deficiencies and determining the nutrient requirements of crops for judicious use of external inputs of fertilizers and amendments. Soil sampling is an important component of soil fertility evaluation and nutrient management research. Soil sampling constituted an important entry point activity for the consortia to make rapport with the farming community (Figure 3). Soil samples were collected by the farmers themselves with required handholding support from the experts.

As soil analysis involves huge cost, human and other resources, we had a challenge to restrict sampling to selected farmers, but without compromising on precision. To solve this problem, ICRISAT has developed and evaluated a stratified soil sampling method (Sahrawat et al. 2008). In this method, if a target region is sampled in a way to represent different strata based on topography, soil color, soil texture, crop management, socio-economics etc., the 20-25% samples give the same results as 100%, and thus brings in the scales of economy. This plan takes into consideration the variation in different subpopulations in an effort to increase the overall precision of the estimates over the entire population (representing a field, plot or watershed).

Figure 3. Participatory Soil Sampling in Warangal district cluster.

For sampling study sites, we divided cluster villages in three parts – upper, mid and lower parts of the topo-sequence. Soil fertility might be dependent mainly on the farmer's inputs, which in turn depends on the resourcefulness of the farmer, i.e. large, medium or small landholder. Therefore, at each topo-sequence location, socio-economic condition using farm size as a proxy was super imposed. Twenty percent farms were sampled to represent proportionately different farm-holding sizes and within each farm class to represent variations like soil color, texture, cropping system etc.

At ultimate sampling unit in a farmer's field, we collected 8 to 10 cores of surface (0–0.15 m) soil samples and mixed together to make a composite sample. For economic and precision reasons, soil samples taken were made into composites on the basis of a plot, field or at a part of the watershed under sampling. In this case, it is assumed that a reasonable and valid estimate of the mean of characteristic of the population can be made from the single analysis of the composite sample. For this assumption to be true it must be ensured that all soil samples that form a composite are drawn from the population and each sample contributes the same amount to the composite (Petersen and Calvin 1996). The precision with which mean is estimated can be increased by increasing the number of samples that form a composite.

Methods of soil and plant analysis

Soil samples were processed before analysis in the laboratory for various characteristics. The samples were air-dried in the shade and sieved through a 2-mm sieve for general analysis. However, for organic carbon (OC) soil samples were ground to pass through a 0.25 mm sieve. Soil analysis was done to determine the pools of available nutrients in the soil with a view to make judicious use of external inputs of nutrients for achieving a given yield. The principle underlying soil chemical analysis is that the amount or concentration of a nutrient present in the representative soil sample is proportional to the amount that would be made available to the plant during the growing season. This assumption may or may not hold as the growth or yield of a crop is determined by several prevailing agroclimatic conditions during the growing season, especially soil moisture, solar radiation and temperature. However, with these limitations soil testing has proved useful in making a more rational use of fertilizers. A number of standard texts are available that describe the various methods used for determining the pools of available major (N, P and K), secondary [calcium (Ca), magnesium (Mg) and sulphur (S)] and micronutrients [iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B) and molybdenum (Mo)] (Jackson 1958; Sparks 1996). For undertaking analysis of soil samples collected from farmers' fields in Andhra Pradesh, we employed the following standard methods (Table 3).

Table 3. Different methods used for chemical analysis of soil samples collected from farmers' fields in Andhra Pradesh, India.

Soil property	Description
pH	Soil to water ratio of 1:2, using glass electrode
EC	Same as above, using E.C. meter
Organic carbon (OC)	Wet dichromate oxidation (Nelson & Sommers 1996)
Available phosphorus (P)	Olsen P (0.5 M $NaHCO_3$, pH 8.5) (Olsen and Sommers 1982)
Available potassium (K)	1 N ammonium acetate (Helmke and Sparks 1996)
Available sulphur (S)	$CaCl_2$/ MCP extraction (Tabatabai 1996)
Available zinc (Zn)	DTPA extractable Zn (Lindsay and Norvell 1978)
Available boron (B)	Hot water extractable B (Keren 1996)

The critical limits adopted for delineating deficient samples from sufficient in a parameter or nutrient are - 0.50% for OC, 5 mg kg^{-1} soil for P, 50 mg kg^{-1} for K, 10 mg kg^{-1} for S, 0.58 mg kg^{-1} for B and 0.75 mg kg^{-1} for Zn.

Total N, P and K in plant materials were determined by digesting them with sulfuric acid-selenium mixture, while N and P in the digests were analyzed using auto-analyzer and K using atomic absorption spectrophotometer (Sahrawat et al. 2002a). Zinc in the plant materials was determined by digesting them with triacid and Zn in the digests was determined using atomic absorption spectrophotometer (Sahrawat et al. 2002b). Total S and B in plant samples were determined by Inductively Coupled Plasma Emission Spectrophotometer (ICP-AES) in the digests prepared by digesting the samples with nitric acid (Mills and Jones 1996).

Extent of nutrient deficiencies in study sites

The results of the analysis of soil samples in the village clusters of eight districts are presented in Table 4 to indicate per cent farms with low levels of nutrients along with mean values and range of the nutrients found in the targeted clusters. Results showed besides deficiencies of N (in terms of organic carbon) and P, the widespread deficiencies of S, B and Zn in all the districts. Majority (>50%) of the farmers' fields in all the districts (55 to 97% fields), except in Adilabad and Khammam, had low levels of soil C which indicated general poor soil health. Low levels of C specifically indicated N deficiencies. Phosphorus deficiencies were prominent in Adilabad (60% fields), Kadapa (84% fields) and Khammam (60% fields) districts, while the other districts (Anantapur, Mahabubnagar, Nalgonda, Rangareddy, Warangal) had rather majority fields with sufficient levels of P, thereby indicating scope to reduce use and cost of phosphatic fertilizers. Potassium as such was not a problem in any of the district except in Kadapa where majority (54%) fields had low levels of K. In addition to macronutrient deficiencies, the analysis results showed widespread deficiencies of secondary and micronutrients mainly S, B and Zn. All the districts were found with majority of the fields having low levels of S (61 to 98% fields). Boron deficiency was found in majority fields (83 to 98% fields) in all the districts except Nalgonda and Warangal districts. Similarly Zn was deficient in majority fields (51 to 85% fields) in all the districts except Khammam and Mahabubnagar. Keeping in mind the essentiality of nutrients, apparently the S, B and Zn deficiencies along with that of N and P are holding back the realization of productivity potential.

Development of fertilizer recommendations

Based on the results of analysis done on sampled soils, we developed soil test-based fertilizer recommendations at the level of cluster of villages (or mandal), as against the state level blanket recommendations which are generally followed in India. As % nutrient deficiency is indicative of nutrient mining, we recommended to apply full dose of a nutrient if deficiency was observed in >50% fields and half dose of nutrient if deficiency was observed in <50% fields. The state fertilizer recommendations for N, P and K (Table 5) were modified based on this principle to address varying soil fertility needs at cluster of villages level. Similarly, for newly emerged deficiencies of S, B and Zn, the general per ha recommendations of 30 kg S (through gypsum), 5 kg zinc and 0.5 kg boron were adjusted on the principle of deficiency to meet soil fertility needs.

Table 4. Soil fertility status of farmers' fields in targeted clusters in 8 districts of Andhra Pradesh

District (Cluster)	No. of farmers	Parameter	pH	EC (dS m^{-1})	OC (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available S (mg kg^{-1})	Available B (mg kg^{-1})	Available Zn (mg kg^{-1})
Adilabad	63	Range	6.4-8.9	0.06-2.86	0.27-1.33	0.2-48.8	46-549	2.0-142	0.10-0.84	0.10-2.90
(Seetagondi)		Mean	8.2	0.27	0.62	6.9	205	12.2	0.37	0.66
		% deficiency			27	60	2	76	87	71
Anantapur	82	Range	5.5-8.8	0.02-3.20	0.12-1.45	0.6-42.4	38-1488	3.5-117	0.06-1.40	0.26-5.00
(Pampanur)		Mean	7.4	0.18	0.45	8.4	116	10	0.32	0.88
		% deficiency			66	32	9	85	88	61
Kadapa	83	Range	6.0-8.8	0.02-1.30	0.12-1.31	0.2-13.4	17-482	1.8-223	0.10-3.65	0.24-5.20
(B. Yerragudi)		Mean	7.3	0.12	0.26	2.5	61	6.6	0.4	0.61
		% deficiency			97	84	54	98	88	85
Khammam	102	Range	3.8-8.8	0.03-0.86	0.32-1.50	0.2-57.8	31-856	3.6-71.9	0.12-1.22	0.28-6.80
(Tummalacheruvu)		Mean	6.8	0.15	0.7	8.5	180	10.6	0.39	1.09
		% deficiency			25	60	2	67	87	45
Mahabubnagar	133	Range	6.0-10.2	0.01-2.37	0.13-1.13	0.2-44.4	25-1263	3.4-287	0.04-1.24	0.30-4.68
(Zamistapur)		Mean	7.8	0.22	0.44	8.7	105	11.6	0.36	0.96
		% deficiency			62	43	18	73	83	48
Nalgonda	142	Range	5.5-9.0	0.03-1.60	0.14-1.13	0.6-50.4	21-346	2.1-140	0.10-3.00	0.22-6.58
(Dupahad)		Mean	7.6	0.29	0.46	8.6	89	17	0.85	1.02
		% deficiency			68	38	14	61	36	51
Rangareddy	121	Range	4.7-8.2	0.02-1.16	0.15-1.56	0.2-60.0	24-405	1.1-81.6	0.06-1.24	0.15-4.00
(Ibrahimpur)		Mean	6.7	0.12	0.5	8.9	92	3.7	0.26	0.64
		% deficiency			55	39	17	98	98	76
Warangal	100	Range	6.1-9.4	0.04-1.68	0.08-0.84	0.2-53.4	21-280	1.8-48.9	0.25-3.55	0.26-3.88
(Jaffergudem)		Mean	7.8	0.27	0.41	16	118	9.4	0.94	0.96
		% deficiency			81	14	5	77	23	50

Table 5. General nutrient recommendations for different crops in Andhra Pradesh, India (State agricultural university; and ICRISAT)

	Nutrient recommendations (kg ha^{-1})					
Crop	N	P_2O_5	K_2O	S	B	Zn
Cotton	120	60	60	30	0.5	10
Groundnut	20	40	50	30	0.5	10
Castor	75	40	30	30	0.5	10
Sorghum	80	40	30	30	0.5	10
Greengram	20	50	0	30	0.5	10
Cow pea	20	50	0	30	0.5	10
Chickpea	10	25	20	30	0.5	10
Maize	100	50	40	30	0.5	10

On-farm farmer participatory trials on balanced nutrition

Based on the soil test results, on-farm participatory trials were planned and conducted in all the clusters to evaluate and demonstrate the effects of balanced nutrition in different rainy (June to September) and post-rainy (October to January) season crops (Table 6).

Table 6. Detail of farmer participatory evaluation trials on soil test based balanced nutrition during 2008-09 to 2011-12

		2008-09		2009-10		2010-11		2011-12	
District	Crop	Rainy season	Post-rainy season	Rainy season	Post-rainy season	Rainy season	Post-rainy season	Rainy season	Total
Adilabad	Cotton			13				6	19
	Sorghum					4			4
	Chickpea		14		8		5		27
Anantapur	Groundnut	9	4	3	9	5	5	5	40
Kadapa	Groundnut	13		11	6		6	3	39
	Sunflower		8		7				15
	Tomato				1				1
Khammam	Cotton	13				5		4	22
	Greengram						5		5
Mahabubnagar	Castor	2				1		5	8
	Groundnut		4				4		8
Nalgonda	Groundnut		3	5	4	5	8	8	33
	Tomato				6				6
Rangareddy	Cowpea							4	4
	Groundnut				5				5
Warangal	Cotton	13		15		4		6	38
	Maize				15		5		20
	Tomato		4						4
	Okra		2						2
	Brinjal		1						1
Total		50	40	47	61	24	38	41	301

There were two treatments:

1. farmers' practice (FP, application of N, P and K)

2. balanced nutrition (BN, applications of N, P, K plus S, B and Zn)

All the nutrients except N were added as basal. Nitrogen was added in three equal splits at sowing, one month after sowing and two months after sowing. The fertilizer sources for nutrients were urea for N, DAP (diammonium phosphate) for P and N, gypsum for S, zinc sulphate for Zn and agribor for B. The treatments were imposed on 2000 m^2 plots, side by side and uniform crop management practices were ensured in both the treatments. At maturity, the crop yields were recorded from three sub-plots measuring 3 m $\times$ 3 m, the average of which was converted into final yield. The results presented are the averages of the trials conducted in a district. The test of significance was conducted at 5% probability level during statistical analysis of the data using the Genstat 13th edition (Ireland 2010). Each farmer's field was considered a replication. Thus, in all trials conducted in farmers' fields, the farmer's practice treatment was compared with balanced nutrition treatment (combined application of N, P, K with S, B and Zn). Details of participatory trials conducted during 2008-09 to 2011-12 are given in Table 6.

The rainfall received in the target districts during rainy (June through September) and post-rainy (October through January) seasons during 2008-09 to 2011-12 is given in Table 7. The total amount of water received through rainfall (mm) during crop growth at respective trial locations was also used to work out the rainwater use efficiency (RWUE) of crop production as kg of food grain produced per ha through per mm of rainwater received (kg mm^{-1} ha^{-1}).

Table 7. Rainfall received during crop seasons in Andhra Pradesh during 2008-09 to 2011-12

	Rainy (Jun-Sept) season				Post-rainy (Oct to Jan) season		
District	2008	2009	2010	2011	2008-09	2009-10	2010-11
Adilabad	838	594	1227	855	27	88	170
Anantapur	488	365	432	286	175	160	241
Kadapa	259	369	505	392	282	167	328
Khammam	1288	538	1378	793	97	145	233
Mahabubnagar	421	456	646	393	46	258	79
Nalgonda	604	343	729	464	58	133	210
Rangareddy	628	608	926	430	49	124	136
Warangal	1060	504	1123	795	49	136	161

Trials during rainy seasons

Across the districts, the balanced nutrition improved crop productivity of a range of rainy season crops like cotton, groundnut, castor, sorghum and cowpea (Table 8; Figure 4-5).

During four years (2008 to 2011), on-farm cotton productivity under farmers' practices in Adilabad, Khammam and Warangal districts varied between 1060 kg ha^{-1} and 2470 kg ha^{-1}. The on-farm trials during 2008 to 2011 showed beneficial responses to balanced nutrition. The application of balanced nutrition increased cotton productivity (lint+seed) by 14% to 62% over the farmers' practice.

Table 8. Effects of balanced nutrition on crop yield during rainy seasons 2008 to 2011

		2008				2009				2010				2011			
District	Crop	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% Inc	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% inc	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% inc	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% inc
Adilabad	Cotton	-	-	-	-	1060	1350	94	27	-	-	-		1610	1840	314	14
	Sorghum	-	-	-	-	-	-	-	-	2270	2770	1457	22	-	-	-	-
Anantapur	Groundnut	600	760	44	27	380	500	129	32	330	570	361	73	500	740	655	48
Kadapa	Groundnut	510	740	109	45	620	1250	234	102	-	-	-	-	510	670	694	31
Khammam	Cotton	1920	2410	465	26	-	-	-	-	1670	2070	213	24	1440	1740	388	21
Mahabubnagar	Castor	650	850	130	31	-	-	-	-	730	790	-	8	690	830	381	20
Nalgonda	Groundnut	-	-	-	-	1320	1780	471	35	1400	1750	334	25	670	920	119	37
Rangareddy	Cowpea	-	-	-	-	-	-	-	-	-	-	-	-	1220	1420	180	16
Warangal	Cotton	1160	1360	103	17	2470	4010	568	62	1730	2430	132	40	2190	2670	268	22

Table 9. Effects of balanced nutrition on crop yield during post-rainy seasons 2008-09 to 2010-11

		2008-09				2009-10				2010-11			
District	Crop	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% inc	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% inc	FP (kg ha^{-1})	BN (kg ha^{-1})	LSD (5%)	% inc
Adilabad	Chickpea	610	1200	151	97	2130	2950	921	38	1760	2460	696	40
Anantapur	Groundnut	480	750	259	56	1820	2220	929	22	1800	2970	839	65
Kadapa	Sunflower	1590	2020	793	27	360	580	506	61	-	-	-	-
	Groundnut	-	-	-	-	1030	1800	731	75	1330	1860	374	40
Khammam	Green gram	-	-	-	-	-	-	-	-	200	300	88	50
Mahabubnagar	Groundnut	1940	2590	989	34	-	-	-	-	750	880	168	17
Nalgonda	Groundnut	1610	1790	67	11	1470	2270	810	54	860	1600	482	86
Rangareddy	Groundnut	-	-	-	-	1800	2160	317	20	-	-	-	-
Warangal	Maize	-	-	-	-	5810	6550	455	13	5540	7320	377	32

Figure 4. Farmers practice (Left) and balanced nutrition (Right) in cotton in Khammam district during rainy season 2010.

Figure 5. Farmers practice (Left) vs. balanced nutrition (Right) in cotton in Warangal district during rainy season 2011.

The farmers' practice of groundnut cultivation in Anantapur, Kadapa and Nalgonda districts recorded groundnut yield in the range of 330 kg ha^{-1} to 1400 kg ha^{-1}. The application of balanced nutrition increased yield by 25 to 102% over the farmers' management.

Similarly, the application of balanced nutrition increased crop productivity in castor (8 to 31%) in Mahabubnagar, sorghum (22%) in Adilabad and cowpea (16%) in Rangareddy districts.

Trials during post-rainy seasons

Like rainy season crops, the benefits of balanced nutrition in improved productivity were also found in post-rainy season crops like groundnut, chickpea, sunflower, greengram and maize (Table 9; Figure 6-8).

Figure 6. Farmers practice (Left) vs. balanced nutrition (Right) in chickpea in Adilabad district during post-rainy season 2010-11.

Figure 7. Farmers practice (Left) vs. balanced nutrition (Right) in groundnut in Nalgonda district during post-rainy season 2010-11.

Figure 8. Farmers practice (Left) vs. balanced nutrition (Right) in maize in Warangal district during post-rainy season 2010-11.

Participatory trials were conducted with post-rainy season groundnut in Anantapur, Kadapa, Mahabubnagar, Nalgonda and Rangareddy districts during three constructive years (2008-09 to 2010-11). Across the districts, the farmers' management practice recorded yields in the range of 480 kg ha^{-1} to 1940 kg ha^{-1}, thereby showing higher groundnut yields during post-rainy season in comparison to rainy season. The results showed 11 to 86% increase in productivity with the application of balanced nutrition (880 kg ha^{-1} to 2970 kg ha^{-1}) as compared with the farmers' practice.

The benefits of balanced nutrition in productivity improvement over the farmers practice were also recorded in chickpea (38 to 97%) in Adilabad, sunflower (27 to 61%) in Kadapa, greengram (50%) in Khammam and maize (13 to 32%) in Warangal.

Economics of crop production

Rainy season crops

An economic analysis in case of cotton in Adilabad, Khammam and Warangal districts showed per ha gross return in the range of ₹ 39750/- to ₹ 92625/- for farmers practice; while the balanced nutrition increased it in the range of ₹ 50625/- to ₹ 150375/- (Table 10). The adoption of soil test-based application of S, B and Zn under balanced nutrition brought in per ha additional cost of ₹ 1400/- to ₹ 2150/- with additional returns of ₹ 7500/- to ₹ 57750/-. The benefit to cost ratio varied between 3.7 to 28.5, thus showing soil test based balanced nutrition an acceptable technology at the farm level.

In groundnut crop, the gross returns ranged from ₹ 9240/- to ₹ 39200/- under the farmers practice which increased to from ₹ 14000/- to ₹ 49840/- under the balanced nutrient management. The additional cost incurred on balanced nutrition was from ₹ 2025/- to ₹ 2150/-, while the additional returns varied between ₹ 3360/- and ₹ 17640/-. A favorable benefit to cost ratio (1.6 to 8.2) showed economic viability of the technology for scaling up at the farm level.

Similarly, the gross returns were lower under the farmers management for castor (₹ 25350/- to ₹ 28470/-) in Mahabubnagar, sorghum (₹ 34050/-) in Adilabad, and cowpea (₹ 24400/-) in Rangareddy which enhanced under the balanced nutrient management to ₹ 30810/- to ₹ 33150/- for castor, ₹ 41550 for sorghum and ₹ 28400/- for cowpea. The additional cost of technology was mere ₹ 1400/- for castor, while ₹ 2150/- each for sorghum and cowpea. The benefit to cost ratio of balanced nutrient management was very favorable for castor (1.7 to 5.6) in Mahabubnagar district, sorghum (3.5) in Adilabad and cowpea (1.9) in Rangareddy for adoption at farm level.

Post-rainy season crops

The cultivation of groundnut crop in the targeted districts under the farmers' management practice brought in a gross return in the range of ₹ 13440/- to ₹ 54320/- (Table 11). The benefits of balanced nutrition were evident in enhanced gross returns at ₹ 21000/- to ₹ 83160/-. In different districts, the additional cost of soil test based balanced nutrition varied between ₹ 1400/- and ₹ 2150/-. The additional returns were higher at ₹ 3640/- to ₹ 32760/-. Per rupee invested on balanced nutrition returned ₹ 2.5 to ₹ 15.2, thereby proving it a profitable proposition.

Table 10. Gross returns under different management and benefit to cost (B:C) ratios of balanced plant nutrient management in rainy season crops

		Gross returns (2008)		Gross returns (2009)		Gross returns (2010)		Gross returns (2011)	
District	Crop	FP (₹)	BN (₹)	FP (₹)	BN (₹)	FP (₹)	BN (₹)	FP (₹)	BN (₹)
Adilabad	Cotton	-	-	39750	50625 (5.1)	-	-	60375	69000 (4.0)
	Sorghum	-	-	-	-	34050	41550 (3.5)	-	-
Anantapur	Groundnut	16800	21280 (2.1)	10640	14000 (1.6)	9240	15960 (3.1)	14000	20720 (3.1)
Kadapa	Groundnut	14280	20720 (3.0)	17360	35000 (8.2)			14280	18760 (2.1)
Khammam	Cotton	72000	90375 (13.1)	-	-	62625	77625 (10.7)	54000	65250 (8.0)
Mahabubnagar	Castor	25350	33150 (5.6)			28470	30810 (1.7)	26910	32370 (3.9)
Nalgonda	Groundnut	-	-	36960	49840 (6.4)	39200	49000 (4.8)	18760	25760 (3.5)
Rangareddy	Cowpea	-	-	-	-	-	-	24400	28400 (1.9)
Warangal	Cotton	43500	51000 (3.7)	92625	150375 (28.5)	64875	91125 (13.0)	82125	100125 (8.9)

Figures in the parentheses indicate benefit to cost ratios of balanced nutrition over the farmers' practice (benefit in straw biomass increase is not taken into account as is generally not traded, but has economic value as fodder/fuel, and is thus another added advantage);

Additional cost was worked out in BN treatment for gypsum @ ₹ 2/- per kg, zinc sulphate @ ₹ 30/- per kg and borax @ ₹ 50/- per kg;
Additional returns were worked out at per kg farm gate price of ₹ 37.5 for cotton, ₹ 15/- for sorghum, ₹ 28/- for groundnut, ₹ 39/- for castor and ₹ 20/- for cowpea.

Table 11. Gross returns under different management and benefit to cost (B:C) ratios of balanced plant nutrient management in post-rainy season crops

		Gross returns (2008-09)		Gross returns (2009-10)		Gross returns (2010-11)	
District	Crop	FP (₹)	BN (₹)	FP (₹)	BN (₹)	FP (₹)	BN (₹)
Adilabad	Chickpea	13420	26400 (6.0)	46860	64900 (8.4)	38720	54120 (7.2)
Anantapur	Groundnut	13440	21000 (3.5)	50960	62160 (5.2)	50400	83160 (15.2)
Kadapa	Sunflower	39750	50500 (5.0)	9000	14500 (2.6)	-	-
	Groundnut	-	-	28840	50400 (10.0)	37240	52080 (6.9)
Khammam	Green gram	-	-	-	-	10000	15000 (3.6)
Mahabubnagar	Groundnut	54320	72520 (13.0)	-	-	21000	24640 (2.6)
Nalgonda	Groundnut	45080	50120 (2.5)	41160	63560 (11.1)	24080	44800 (10.2)
Rangareddy	Groundnut	-	-	50400	60480 (4.7)	-	-
Warangal	Maize	-	-	58100	65500 (3.7)	55400	73200 (8.8)

Figures in the parentheses indicate benefit to cost ratios of balanced nutrition over the farmers practice (benefit in straw biomass increase is not taken into account as is generally not traded, but has economic value as fodder/fuel, and is thus another added advantage);
Additional cost was worked out in BN treatment for gypsum @ ₹ 2/- per kg, zinc sulphate @ ₹ 30/- per kg and borax @ ₹ 50/- per kg;
Additional returns were worked out at per kg farm gate price of ₹ 22/- for chickpea, ₹ 28/- for groundnut, ₹ 25/- for sunflower, ₹ 50/- for greengram and ₹ 10/- for maize.

Similarly, farmers' input treatment recorded gross returns in the range of ₹ 13420/- to ₹ 46860/- for chickpea in Adilabad, ₹ 9000/- to ₹ 39750/- for sunflower in Kadapa, ₹ 10000/- for greengram in Khammam and ₹ 55400/- to ₹ 58100/- for maize in Warangal. However, the adoption of balanced nutrition recorded higher gross returns at ₹ 26400/- to ₹ 64900/- for chickpea, ₹ 14500/- to ₹ 50500/- for sunflower, ₹ 15000/- for greengram and ₹ 65500/- to ₹ 73200/- for maize. The additional cost of technology was ₹ 2150/- for both chickpea in Adilabad and sunflower in Kadapa, while ₹ 1400/- for greengram in Khammam and ₹ 2025 for maize in Warangal. The additional returns under balanced nutrition varied from ₹ 12980/- to ₹ 18040/- for chickpea, ₹ 5500/- to ₹ 10750/- for sunflower, ₹ 5000/- for greengram and ₹ 7400/- to 17800/- for maize. The benefit to cost ratios of the technology in all the crops were very favorable to promote it at the farm level – 6.0 to 8.4 in chickpea, 2.6 to 5.0 in sunflower, 3.6 in greengram and 3.7 to 8.8 in maize.

Diversification to vegetables

The issue in dryland tropics in Andhra Pradesh is not only of low crop productivity, but also of low value crops. In the IMOD (Inclusive Market Oriented Development Strategy) model for livelihood improvement in the dryland tropics, crop diversification with high-value crops is promoted with the rural poor to generate more incomes. In Warangal district, farmers diversified to different vegetable crops and harvested 4,710 kg ha^{-1} tomato, 5,600 kg ha^{-1} okra and 3,790 kg ha^{-1} brinjal with cultivation by their own management (Figure 9). In the plots where balanced nutrition was followed, they got higher productivity to the tune of 21% in tomato, 17% in okra and 14% in brinjal. In balanced nutrition, farmers incurred an additional cost of ₹ 2025/- on the application of deficient S, B and Zn, while received far higher additional returns to the tune of ₹ 4,950/- in tomato, ₹ 11,650/- in okra and ₹ 6,240/- in brinjal.

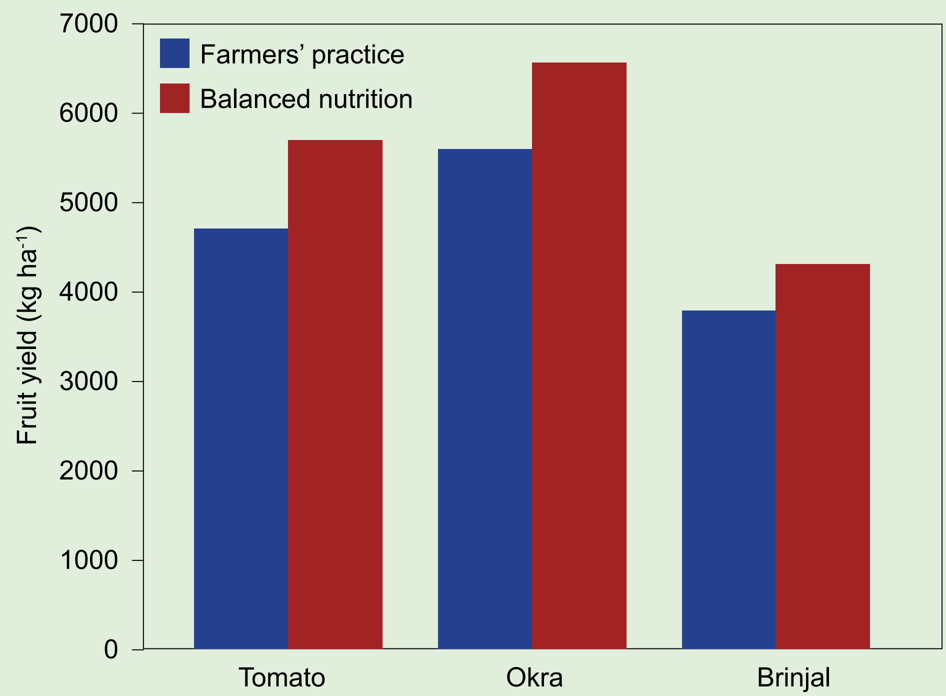

Figure 9. Effects of balanced nutrition on vegetable yield in Warangal district during post-rainy season 2008-09

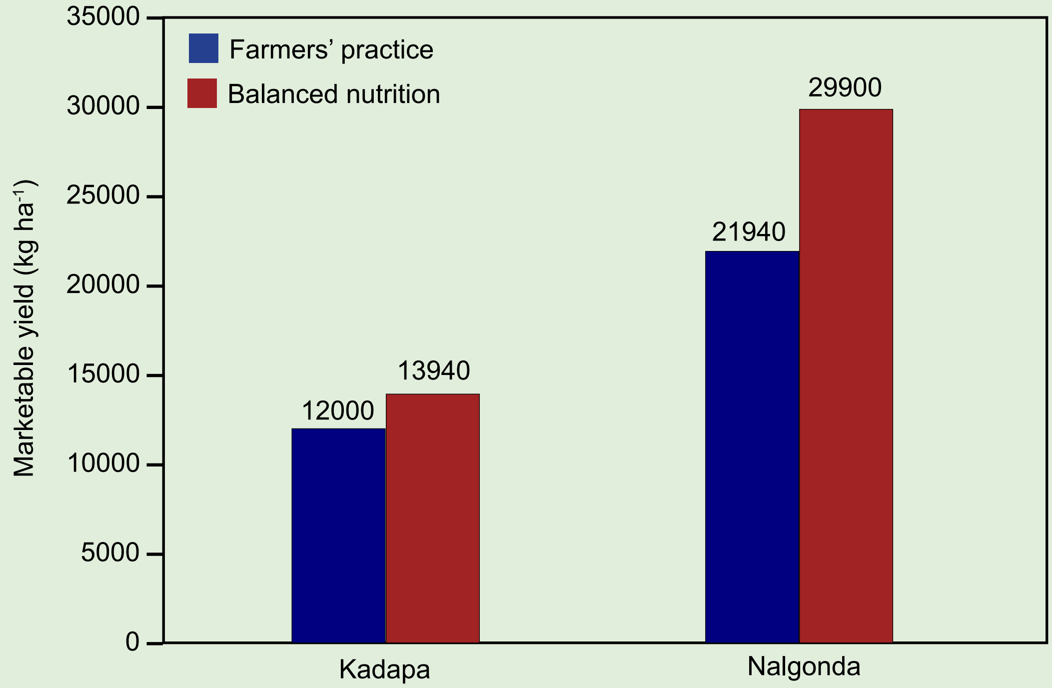

Figure 10. Effects of balanced nutrition on tomato marketable yield in Kadapa and Nalgonda districts during post-rainy season 2009-10.

In Kadapa and Nalgonda district, farmers diversified to tomato crop and harvested 12,000 kg ha^{-1} in Kadapa, while 21,940 kg ha^{-1} in Nalgonda by following their own management (Figure 10). In the plots where balanced nutrition was applied, they got 16% higher productivity in Kadapa and 36% in Nalgonda. In improved management plots, farmers incurred an additional cost of ₹ 2,150/- in Kadapa and ₹ 2,050/- in Nalgonda on the application of deficient S, B and Zn. The additional returns however were far higher than additional cost of balanced nutrition, at ₹ 9,700/- in Kadapa and ₹ 39,800/- in Nalgonda.

Rainwater use efficiency

Water is a scarce resource and chief determinant of poverty and hunger in rural areas in Andhra Pradesh. So improving rainwater use efficiency (RWUE) is important for achieving food security and better livelihoods. Rainwater use efficiency indicates how best the precious rainfall is used for crop production. The RWUE in simple terms is calculated as grain yield (kg) produced per unit (mm) of rainfall per ha and expressed as kg mm^{-1} ha^{-1}.

In general the RWUE of food grain production is low under the current farmers' practice of cultivation which varied between 1.09 to 4.89 kg mm^{-1} ha^{-1} for cotton, 0.77 to 3.84 kg mm^{-1} ha^{-1} for groundnut, 1.13 to 1.76 kg mm^{-1} ha^{-1} for castor, 1.85 kg mm^{-1} ha^{-1} for sorghum and 2.84 kg mm^{-1} ha^{-1} for cowpea (Table 12). The plants were not able to make the best of available water resources because of constraints to growth in terms of low soil fertility due to deficiencies of secondary and micronutrients. Under balanced nutrition, the RWUE increased to 1.28 to 7.96 kg mm^{-1} ha^{-1} in cotton, 1.31 to 5.19 kg mm^{-1} ha^{-1} in groundnut, 1.22 to 2.11 kg mm^{-1} ha^{-1} in castor, 2.26 kg mm^{-1} ha^{-1} in sorghum and 3.30 kg mm^{-1} ha^{-1} in cowpea. In monetary terms, 1 mm of rainfall

Table 12. Effects of balanced nutrition on rainwater use efficiency (RWUE) in terms of food grain production and economic returns during rainy seasons 2008 to 2011

		RWUE in food grain production (kg mm^{-1} ha^{-1})								RWUE in economic terms (Rs mm^{-1} ha^{-1})							
		2008		2009		2010		2011		2008		2009		2010		2011	
District	Crop	FP	BN	FP	BN	FP	BN	FP	BN	FP	BN	FP	BN	FP	BN	FP	BN
Adilabad	Cotton	-	-	1.78	2.27	-	-	1.88	2.15	-	-	67	85	-	-	71	81
	Sorghum	-	-	-	-	1.85	2.26	-	-	-	-	-	-	28	34	-	-
Anantapur	Groundnut	1.23	1.56	1.04	1.38	0.77	1.31	1.75	2.58	34	44	29	39	22	37	49	72
Kadapa	Groundnut	1.97	2.86	1.68	3.38	-	-	1.30	1.71	55	80	47	95	-	-	36	48
Khammam	Cotton	1.49	1.87	-	-	1.21	1.50	1.82	2.19	56	70	-	-	45	56	68	82
Mahabubnagar	Castor	1.54	2.02	-	-	1.13	1.22	1.76	2.11	60	79	-	-	44	48	69	82
Nalgonda	Groundnut	-	-	3.84	5.19	1.93	2.40	1.44	1.98	-	-	108	145	54	67	40	55
Rangareddy	Cowpea	-	-	-	-	-	-	2.84	3.30	-	-	-	-	-	-	57	66
Warangal	Cotton	1.09	1.28	4.89	7.96	1.54	2.17	2.75	3.36	41	48	183	299	58	81	103	126

Table 13. Residual effects of S, B and Zn applied in 2009-10 season on crop yield during rainy 2010 and post-rainy 2010-11 seasons

			Pod/Grain Yield (kg ha^{-1})			
District	Crop	No. of trials	FP	BN	LSD (5%)	% inc
2010 rainy season						
Anantapur	Groundnut	2	380	640	95	68
Nalgonda	Groundnut	2	1850	2810	1849	52
Warangal	Cotton	4	1830	2360	80	29
2010-11 post-rainy season						
Rangareddy	Groundnut	3	1770	2642	2278	49

under farmers' practice yielded gross returns between Rs 41 to 183 with cotton, Rs 22 to 108 with groundnut, Rs 44-69 with castor, Rs 28 with sorghum and Rs 57 with cowpea. While under balanced nutrient management practice, 1 mm rainfall enhanced gross returns varying from Rs 48 to 299 in cotton, Rs 37 to 145 in groundnut, Rs 48 to 82 in castor, Rs 34 in sorghum and Rs 66 in cowpea. The results showed that soil fertility management with a purpose to increase proportion of water balance as productive transpiration, is one of the most important rainwater management strategies to improve yields and water productivity (Rockstrom et al. 2010).

Nutrient uptake by crops

Nutrient uptake study with sorghum in Adilabad showed higher nutrient removal under the balanced nutrition as compared with the farmers' practice. The farmers' practice removed 114 kg N ha^{-1}, 23 kg P ha^{-1}, 104 kg K ha^{-1}, 8 kg S ha^{-1}, 35 g B ha^{-1} and 284 g Zn ha^{-1} (Figure 11). The balanced nutrition increased uptake by 41% in N, 37% in P, 62% in K, 43% in S, 66% in B and 26% in Zn. This increase in nutrient uptake resulted due to increased growth and yield. Development of extensive roots apparently absorbed nutrients very effectively from far off places. Applied S, B and Zn in balanced nutrition apparently increased their availability in soil and uptake by the plants. Moreover, the nutrients like B enhances P availability in soil (Saha and Haldar 1998) probably due to borate-phosphate exchange mechanism resulting more uptake by plants. Extensive studies have also supported the idea that B in plants is credited with maintaining membrane integrity (Cakmak et al. 1995) and hence enhanced ability of membranes to transport vital nutrients.

Similarly, the uptake study with groundnut crop in Nalgonda showed nutrient removals to the tune of 138 kg N ha^{-1}, 13 kg P ha^{-1}, 86 kg K ha^{-1}, 10 kg S ha^{-1}, 230 kg B ha^{-1} and 188 kg Zn ha^{-1} (Figure 12). The balanced nutrition increased the nutrient removal by 48% in N, 37% in P, 47% in K, 50% in S, 39% in B and 77% in Zn.

Residual effect of secondary and micronutrients

Micronutrients are no doubt essential for plant production, but are required in small amounts and so may not be required to be added every season due to residual effects. Therefore, the residual effects of S, B and Zn added during the previous seasons were evaluated for crop production.

The residual benefits of previous seasons (post-rainy 2009-10) applied micro and secondary nutrients were evaluated during 2010 rainy season in Anantapur, Nalgonda and Warangal districts, and during 2010-11 post-rainy season in Rangareddy district. Residual benefits were evident in increased yields as compared with the farmers' practice (Table 13; Figure 13). The yields were higher in plots with residual effects by 68% in groundnut in Anantapur, 52% in groundnut in Nalgonda and 29% in cotton in Warangal. In Rangareddy, the residual effects were seen even after 1 year of application. The groundnut crop pod yield was 49% higher as compared with the farmers practice (Table 13).

During 2011 rainy season, residual effects after one, two and four seasons were studied with cotton crop in Adilabad and Warangal district. The cotton yields in farmers' fields in Adilabad and Warangal where S, B and Zn were applied during rainy season 2009, rainy season 2010 and

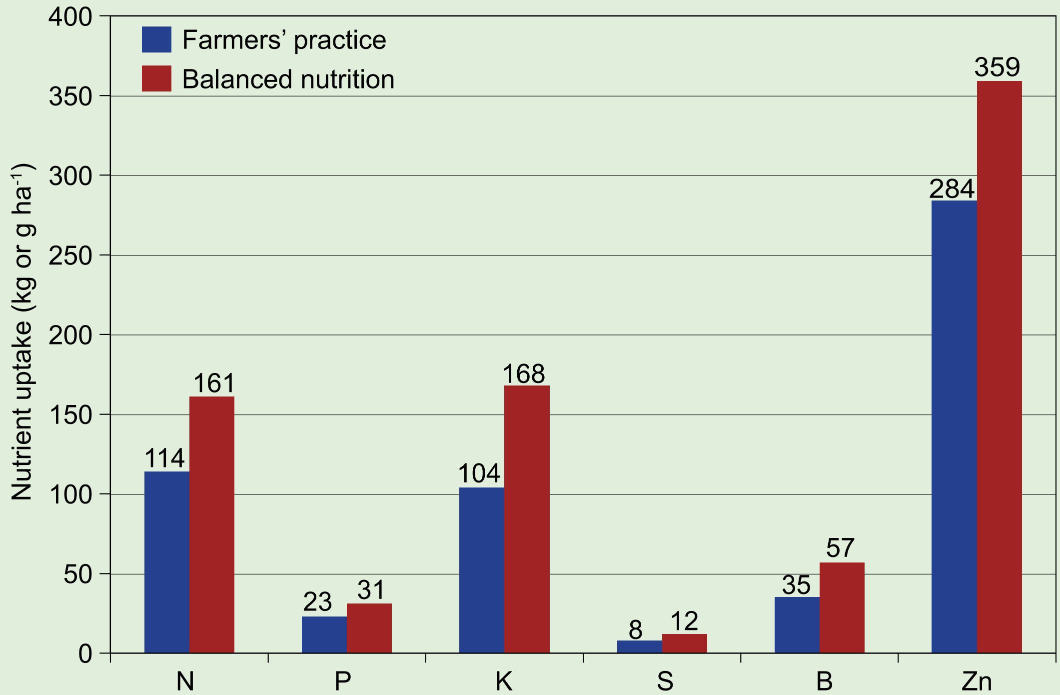

Figure 11. Effects of balanced nutrition on nutrient uptake (per ha) in sorghum in Adilabad during rainy season, 2010 (In kg ha^{-1} for N, P, K, S and in g ha^{-1} for micronutrients B and Zn)

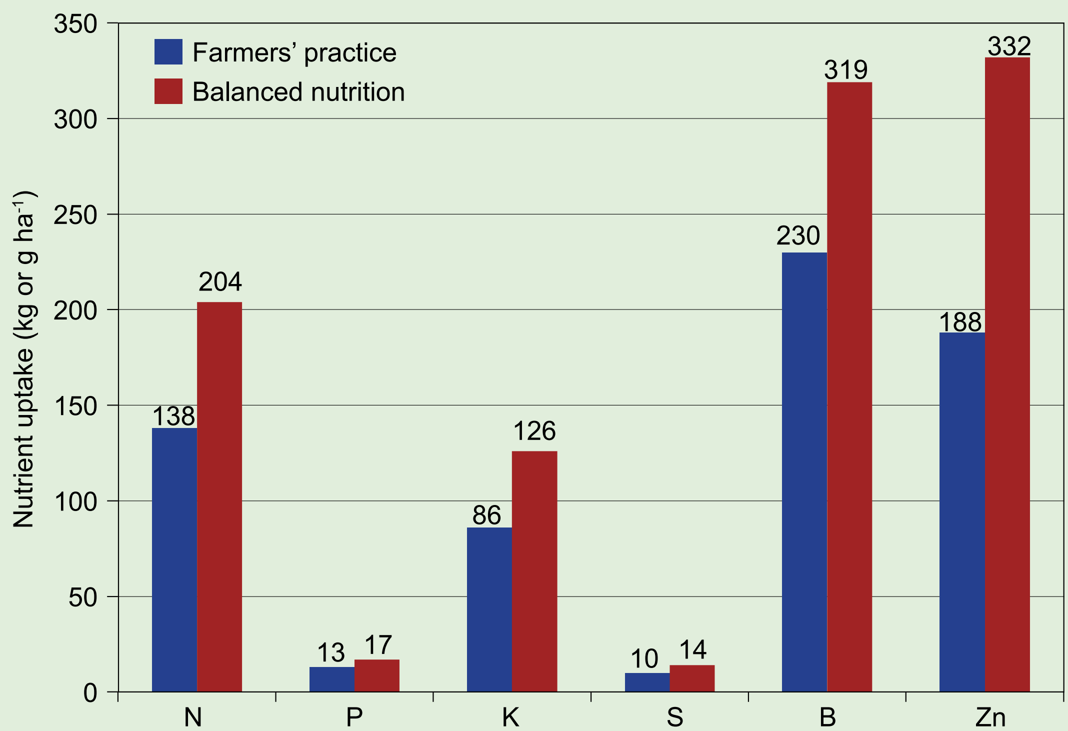

Figure 12. Effects of balanced nutrition on nutrient uptake (per ha) in groundnut in Nalgonda during rainy season, 2010 (In kg ha^{-1} for N, P, K, S and in g ha^{-1} for micronutrients B and Zn)

Figure 13. Farmers practice (Left) vs. residual effects of balanced nutrition (Right) in cotton in Warangal district during rainy season 2010

post-rainy season 2010-11were observed higher than the farmers practice plots. In 2 districts, the residual benefits varied between 5 and 24% (Table 14). The soil test based balanced nutrition, thus not only benefits farmers during the season of application, but rather increases the resilience of production systems for benefits in future.

Table 14. Residual effects of S, B and Zn application on crop yield during rainy season 2011

District	Crop	No of trials	Season of SBZn application	Pod/Grain/seed cotton yield (kg ha^{-1})			
				FP	BN	LSD (5%)	% inc
Adilabad	Cotton	3	Post-rainy 2010-11	1690	1780	286	5
Adilabad	Cotton	3	Rainy 2010	1530	1660	500	8
Adilabad	Cotton	2	Rainy 2009	1410	1530	141	9
Warangal	Cotton	3	Post-rainy 2010-11	2040	2470	125	21
Warangal	Cotton	3	Rainy 2010	2040	2520	130	24
Warangal	Cotton	3	Rainy 2009	2040	2360	185	16

Soil health under balanced nutrition

The soil test-based fertilizer application ensures adequate and proportionate supply of nutrients, and thereby making best of all resources to give the highest yields with maximum nutrient uptake. The studies were conducted to evaluate the soil health status after 2010 (Figure 14a) and 2010-11 (Figure 14b) crop (groundnut) harvest in Nalgonda district. The results showed higher available contents of macro and micronutrients like P, S, B and Zn in the balanced nutrition plots than those of farmers' practice, which apparently explains residual benefits in the succeeding seasons.

In Rangareddy district, even the plots where residual effects of S, B and Zn were studied in groundnut during 2010 rainy (Figure 15a) and 2010-11 post-rainy (Figure 15b) seasons, showed in general at par or higher levels of S, B and Zn in the post-harvest soil analysis. A soil test based application of balanced nutrition, thus after yielding good crops for two seasons, maintained soil fertility level, however, some declining trends seen particularly in case of S and B showed need for regular recommended application along with N and P.

The results of soil health analysis confirmed that the soil test-based fertilizer application technology can not only intensify agriculture, but is sustainable in the long run through building the resilience of production systems.

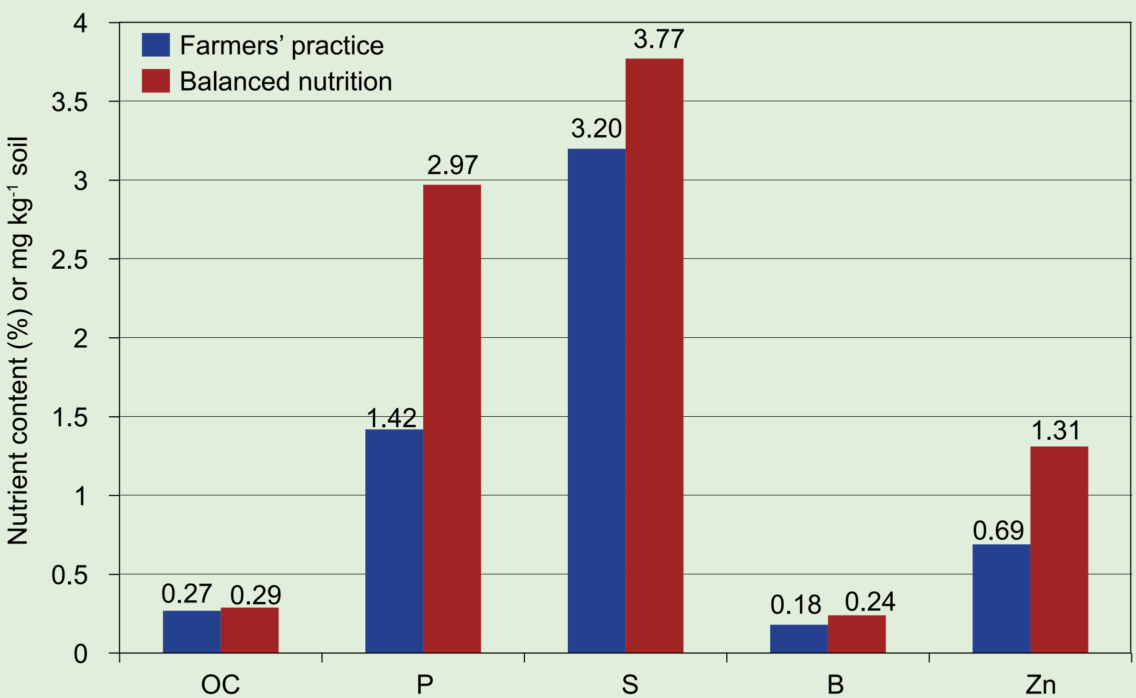

Figure 14a. Soil health status after 2010 rainy season trials on balanced nutrition in groundnut in Nalgonda.

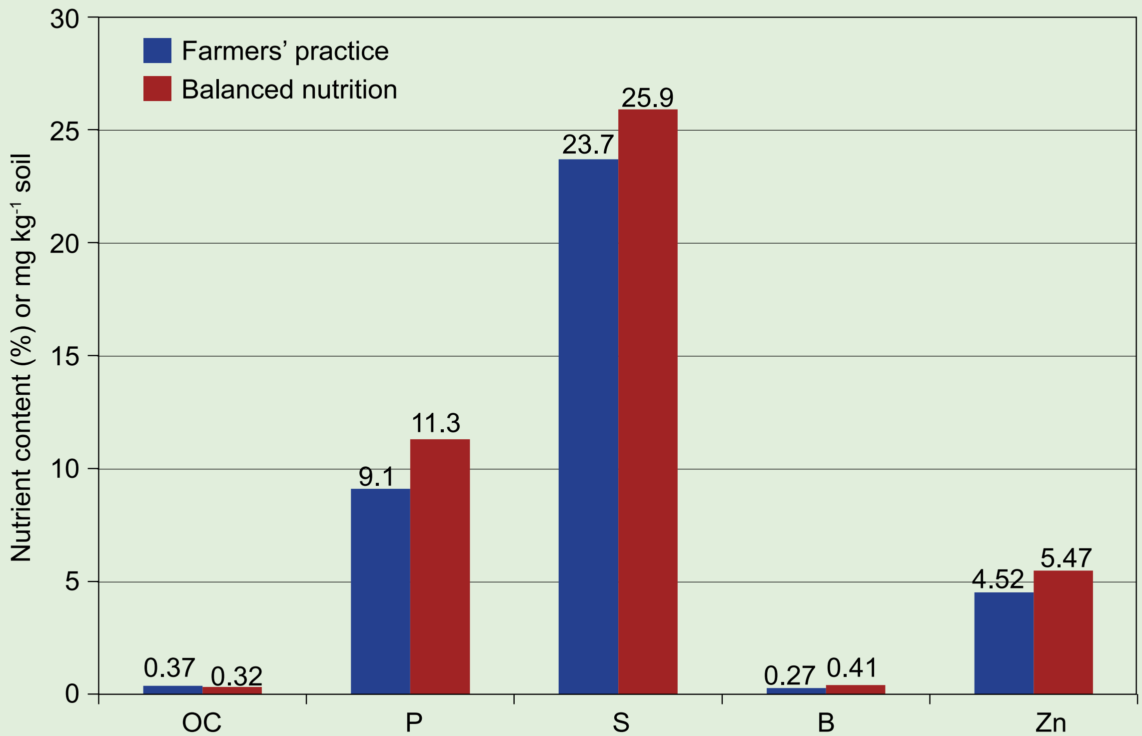

Figure 14b. Soil health status after 2010-11 post-rainy season trials on balanced nutrition in groundnut in Nalgonda.

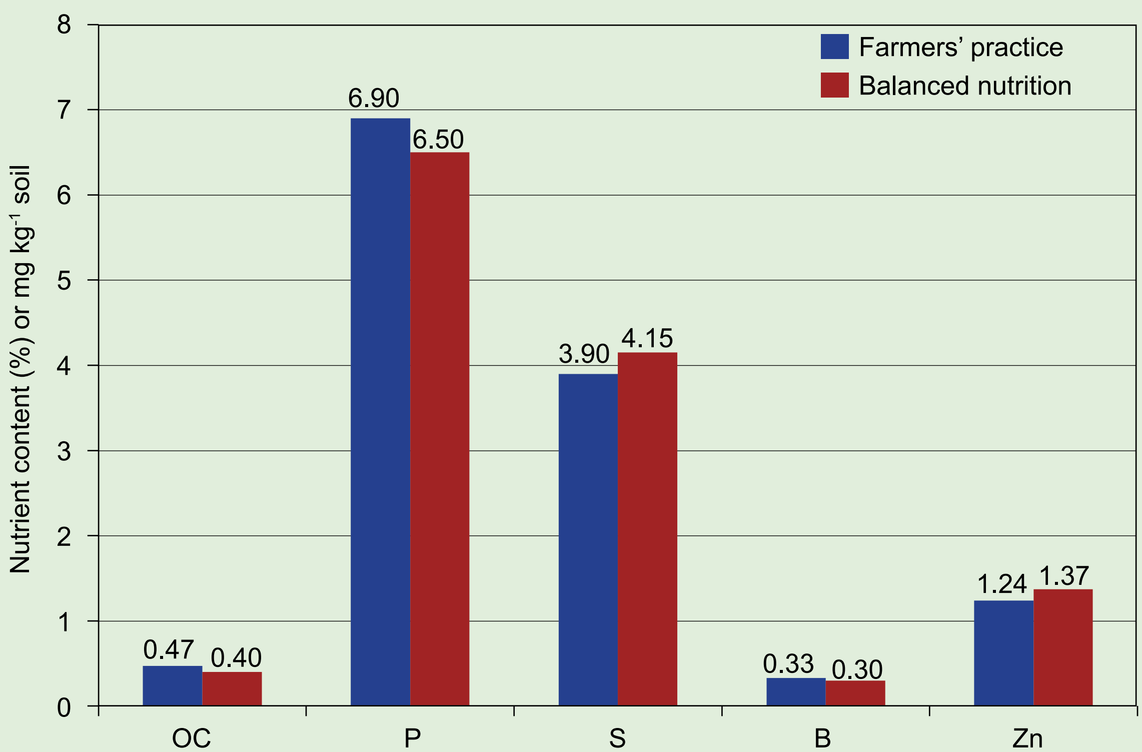

Figure 15a. Soil health status after residual effects of balanced nutrition in groundnut in Rangareddy, 2010 rainy season.

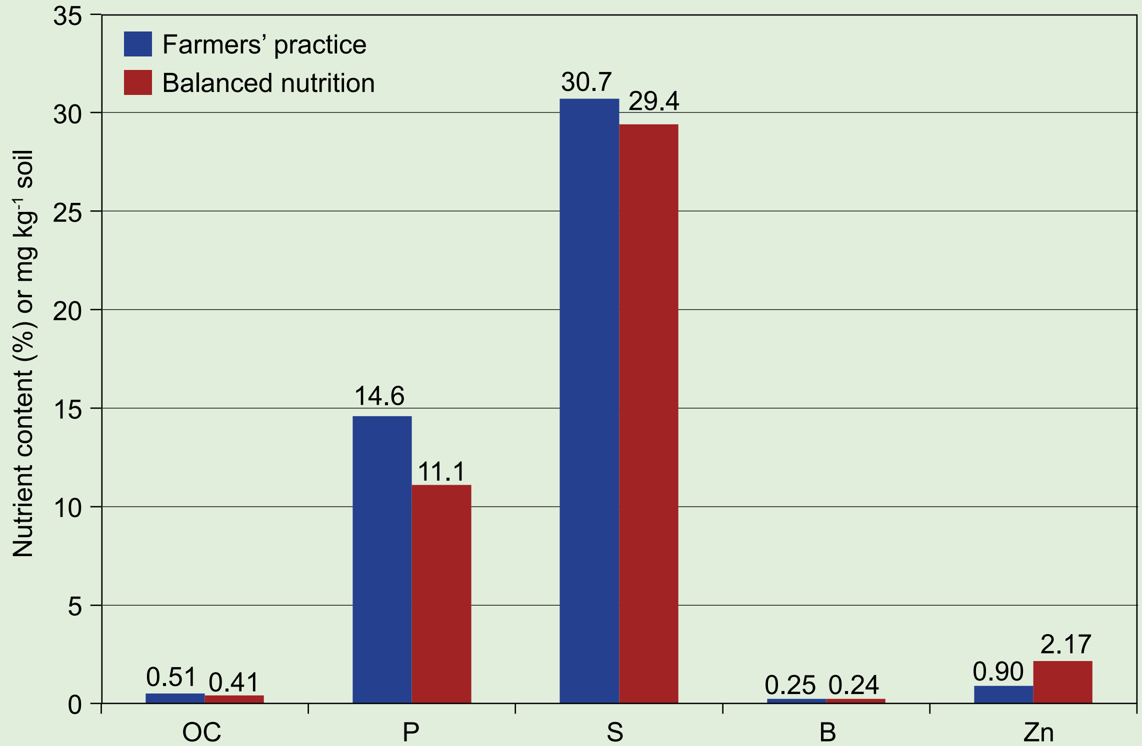

Figure 15b. Soil health status after residual effects of balanced nutrition in groundnut in Rangareddy, 2010-11 post-rainy season.

Integration of on-farm produced vermicompost in nutrient management strategies

Understanding the efficacy of vermicomposting in recycling the farm wastes into valuable manure for restoring soil productivity by balanced nutrition and reducing cost on chemical fertilizers, it was promoted among farmers (Figure 16, 17, 18) through technical support to farmers at their doorsteps for successful vermicomposting. Trainings and exposure visits were conducted for strengthening their capacity and earthworm cultures were provided to start preparing vermicompost for use in their fields.

Farmers prepared vermicompost from their on-farm organic wastes and cattle dung. Rock phosphate being a cheap source of P was added @ 3% of composting biomass to improve P content in vermicompost as a result of solubilization action of humic acids and phosphate solubilizing bacteria (Hameeda et al. 2006) during vermicomposting process. *Eudrilus Eugenie* and *Eisenia foetida* species of earthworms were used for vermicomposting. The mature vermicompost contained on dry weight basis on an average 1.0% N, 0.8% P, 0.7% K, 0.26% S, 110 mg B kg^{-1}, 60 mg Zn kg^{-1} and 14% organic C.

In addition to balanced nutrition trials (BN trials), other trials were conducted on farmers' fields similar to those based on soil test- based balanced nutrient management trials, but with an additional treatment, and the treatment consisted of 50% of recommended fertilizers plus vermicompost (integrated nutrient management or INM trials). The quantity of the vermicompost added was adjusted to meet the 50% P requirement of the legume crop or 50% N requirement of non-legume crop.

Figure 16. Vermicomposting in Anantapur district, Andhra Pradesh.

Figure 17. Vermicomposting in Nalgonda district, Andhra Pradesh.

Figure 18. Vermicomposting in Khammam (L) and Kadapa (R) districts, Andhra Pradesh.

The results showed that the use of vermicompost through INM strategy not only produced crop yields at par or higher than that through balanced nutrition solely through chemical fertilizers (Table 15; Figure 19), but also reduced cost of chemical fertilizers upto 50% in addition to effective disposal of farm wastes.

Table 15. Effects of integrated nutrient management on crop yield during rainy season 2011

District	Crop	No of trials	Pod yield (kg ha^{-1})			
			FP	BN	VC	LSD (5%)
Anantapur	Groundnut	3	680	1130	1030	1216
Nalgonda	Groundnut	2	620	1020	1340	519

Figure 19. Groundnut crop in Anantapur, Andhra Pradesh, rainy season 2011 – Left: Farmers' practice; Center: Balanced nutrition; Right: INM (50% BN + VC).

Future Research and Development Needs

1. There is need to understand and quantify other benefits of balanced nutrition in terms of produce quality, ecosystem service through C sequestration etc.

2. Most of the agricultural decisions particularly nutrient management are site specific as well as farmer specific. A proper decision support system is needed to identify the nutrient deficiencies and to apply appropriate quantities of these nutrients through different available sources as per requirement of crops and farmers' ability to spend money for purchasing inputs. Targeted yield approach is a possible system. So, a decision support system with different available options is required for productivity and livelihood improvement in the semi-arid tropics.

3. Keeping in mind the widespread deficiencies of S, B and Zn, there is no proper formulation available in the market, and that creates difficulty in handling, storage and application of many newly deficient nutrients along with primary macro nutrients. In addition the gypsum, a cheap source of S is very bulky to handle. So, there is need to bring in market new low volume formulations that contain the required proportions of S, B and Zn, and do not compromise on the effectiveness and low price of earlier formulations.

4. Timely availability of required fertilizer inputs is also a major problem which farmers face in Indian semi-arid tropics.

5. The smallholders in the semi-arid tropics have low purchasing power and find it difficult to link with markets. Therefore, some incentives or credit availability can ensure the adoption of such best bet options at the farm level.

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