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Research Findings

Field visit to SSNM plot. Photo by Ch. Srinivasa Rao.

Impacts of Participatory Site Specific Potassium Management in Several Crops in Rainfed Regions of Andhra Pradesh, India

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Introduction

In rainfed regions of India, declining soil fertility and nutrient imbalances are major issues affecting agricultural productivity. Organic matter levels have declined sharply in intensively cropped regions, leading to stagnant yields of major food crops. In addition to universal deficiency of nitrogen (N), deficiencies of potassium (P), sulphur (S) and micronutrients are emerging as constraints for sustaining and/or enhancing productivity under intensive crop production systems (Srinivasarao *et al.,* 2006, 2008, 2009a, 2010, 2011a). It is estimated that 29.4 m hectares (ha) of soils in India are experiencing a decline in fertility with a net negative balance of 8-10 million mt of nutrients per annum (Srinivasarao, 2011b). Poor nutrient use efficiency is another cause for concern. So far, soil fertility issues have been addressed mainly in irrigated agriculture, but recent studies have indicated that drylands are not only thirsty but also hungry (Srinivasarao *et al.,* 2011c; Srinivasarao and Vittal, 2007). Most of the soils in the rainfed regions are low in organic carbon and available N, and crops growing on these soils show multi-nutrient deficiencies, including secondary and micronutrient deficiencies.

Fertilizers contribute about 50 percent of the increased yields, as a component of improved technology. The dramatic increases in the yields of crops like wheat and rice have occurred because of the use of high yielding varieties and application of higher rates of fertilizer. However, for many dryland crops, despite the introduction of high yielding cultivars, yield potential has not been achieved because of low nutrient use. About 80 percent of the fertilizer applied in India is consumed in irrigated areas while only 20 percent is used in the rainfed areas that constitute 65 percent of the cropped area. Hence, low nutrient use in rainfed agriculture is one of the major causes of low yields (Srinivasarao

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Fig. 1. Andhra Pradesh district map with the target districts marked in grey. In total, 84 villages in the target districts were identified for demonstrations.

et al., 2011c; 2009b). Efforts should therefore be made to redefine fertilizer doses so that they are synchronized with crop nutrient demand and soil water availability, particularly in the drylands.

The target area for this study comprised of eight tribal-dominated districts of Andhra Pradesh covered by the Component 3 sub-project "Sustainable rural livelihoods through enhanced farming systems productivity and efficient support systems in rainfed areas" under the World Bank-supported National Agricultural Innovative Project (NAIP) which, since September 2007, is being implemented by a consortium led by the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (Fig. 1). The aim of the project is to improve the livelihoods of the rural poor by improving the overall systems productivity by following good agricultural practices, improved natural resource management and addressing the issues of profitability and sustainability through efficient institutional and support systems. The project sites were selected based on the criteria of dominance of rainfed farming, tribal dominant, low household income and poor infrastructure. A general description of the study sites is given in Table 1.

Participatory soil sampling and chemical analysis

Following several meetings and discussions with farmers in these villages, farmers were sensitized to the need for soil testing. Soil samples from 1,860 farmers' fields covering 84 villages of the eight districts were collected during 2007-2011 with farmer participation in soil sampling. After conducting farmers' meetings in each village and depending upon soil type, crop, slope and agricultural management, about 30 percent of farmers' fields were selected for sampling using stratified random sampling methodology (SRSM). Those farmers whose fields were selected were given group demonstrations of soil sampling procedure. Collected soil samples were labeled with cluster, village and farmer's names. In most of the clusters, the village sarpanch or village head was involved in participatory soil sampling. Collected soil samples were analyzed for soil chemical properties (pH, EC and organic carbon) as well as nutrient analysis (N, P and K), in the Soil Chemistry Laboratory at CRIDA as per standard methods (Jackson, 1973). Available K status was determined in 1N ammonium acetate extract determined using flame photometry (Hanway and Heidel, 1952) and soil K status less than 50 mg K kg^{-1} soil was considered deficient (Srinivasarao *et al.,* 2007; Subbarao and Srinivasarao, 1996; Srinivasarao, 2011b).

Table 1. Details of study sites/villages selected in the target districts.

District	Villages	No of villages	No. of households	Area (ha)	Characteristics of the cluster	Soil type	Crops
Adilabad	Seethagondi, Garkampet, Arkapally, Old Somwarpet, Pedamalkapur, Chinamalkapur, Kotwalguda, New Somwarpet	8+2*	575	1,296	High tribal population (70%) and close to forests, very low productivity and technology adoption	Black	Cotton Pigeonpea Chickpea Vegetables
Nalgonda	New Banjara Hills, Jamal Kunta Thanda, Seetamma Thanda, Yellapa Kunta Thanda, Chinagore Kunta Thanda, Pedagore Kunta Thanda, Peda Seetharam Thanda, China Seetharam Thanda, Lalsingh Thanda	9+9	621	500	Highly drought prone area, off season employment and high migration rates, small hamlets/thandas with more than 80% tribal population	Red	Groundnut Pigeonpea Green gram Sorghum Vegetables Horticulture crops
Khammam	Bheemavaram, Koremvarigumpu, Kurvapally Kothuru, Mamillavai, Ramavaram, Thummalacheruvu Venkatapuram	7+4	650	1,000	High tribal population assigned and forest lands, poor communication and market facilities, and high indebtedness	Red and black	Cotton Sorghum Maize
Mahabubnagar	Zamistapur, Telugugudem, Kodur Thanda	3+4	734	756	Highly drought prone area, more landless families, degraded lands, high livestock population, fodder scarcity, high migration and limited livelihood opportunities	Red and black	Castor Sorghum Groundnut
Anantapur	Pampanoor, Pampanoor Thanda, Yennamkothapally	4+4	576	1,430	Most drought prone area, extensive monocropping of groundnut, repeated crop failures and water shortages, limited livelihood opportunities	Red (gravelly)	Groundnut
Kadapa	B.Yerragudi, Kapu Palli, BA. Nagireddy Palli, Madhiga Palli, Moodindla Palli, Puttakarla Palli, Puttakarla Palli Colony, Konampeta	8+5	216	1,060	Drought prone area with predominance of small and marginal farmers with maximum erodable lands. Lacks proper credit and agricultural market facilities	Red and black	Groundnut Sunflower Vegetables
Warangal	Jaffer Gudem, Kusumbai Thanda and Satynarayana Puram, Jal Thanda, Ramanna Gudem, Vepalagadda Thanda, Cherla Thanda, Lokya Thanda	7+3	689	2,070	Village with high tribal population, degraded soils with good potential for water harvesting and drought proofing measures	Red and black	Cotton Rice Pigeonpea
Ranga Reddy	Ibrahimpur, Dhadi Thanda, Roopsing Thanda, Malkaypet Thanda	4+3	409	346	Village with high migration rates and lack of irrigation facility, more forest land, high use of chemical inputs and indebtedness	Red sandy	Maize Pigeonpea Vegetables

*Extended villages


K deficiency symptoms in groundnut (left) and cluster bean (right) in SSNM plots at farmers' fields. Photos by Ch. Srinivasa Rao.

Table 2. Cluster-wise fertility status in 1,860 farmers' fields in the tribal districts of Andhra Pradesh (AP), 2007-2011.

Name of the District*		pH	EC	OC	Av. N	Av. P	Av. K
			dS m^{-1}	*g kg^{-1}*		---mg kg^{-1}---	
Adilabad (139)	Range	6.2-8.8	0.08-2.66	2.7-13.3	55-159	2.7-48	20-245
	Mean	8.1	0.29	6.2	94	6.9	91
Nalgonda (420)	Range	5.3-8.8	0.07-1.60	1.4-11.3	61-133	0.1-22.4	9-154
	Mean	7.4	0.29	4.6	86	4.0	39
Khammam (161)	Range	4.8-8.6	0.03-0.82	3.2-15.0	70-153	0.1-25.8	14-382
	Mean	6.7	0.18	7.0	91	3.8	80
Mahabubnagar (121)	Range	6.0-10.2	0.01-2.37	1.3-11.3	48-120	0.1-19.6	11-563
	Mean	7.80	0.22	4.4	80	3.9	47
Anantapur (340)	Range	5.5-8.8	0.02-3.20	1.2-14.5	57-105	0.3-18.9	17-664
	Mean	7.4	0.18	4.5	78	3.75	52
Kadapa (320)	Range	6.0-8.8	0.02-1.30	1.2-13.1	28-174	0.2-6.0	7-215
	Mean	7.3	0.12	2.6	55	1.2	27
Warangal (336)	Range	6.1-9.4	0.04-1.68	0.8-8.4	34-190	0.2-23.8	9-125
	Mean	7.8	0.27	4.1	85	7.1	49
Rangareddy (125)	Range	4.7-8.2	0.02-1.16	1.5-15.6	39-151	0.2-26.7	11-180
	Mean	6.7	0.12	5.0	96	4.0	41

*In brackets, number of farmers' fields tested.

Potassium deficiencies in farmers' fields (1,860) in eight target districts

Potassium deficiency was observed in the soils of 84 villages and crops grown in farmers' fields. Deficiency was observed in groundnut, cluster bean, cotton, banana, upland rice, sunflower, maize and other crops on various soils including red soils, sandy light textured soils, degraded lands and shallow black soils in the districts of Anantapur, Nalgonda, Kadapa, Khammam, Warangal and Rangareddy (Srinivasarao *et al.*, 1997, 1998, 1999, 2000, 2001a, 2001b, 2001c, 2006, 2007, 2010, 2011b). From 1,860 farmers' fields as many as 65 percent of the soils were in the low and medium category (Table 2). In most of the districts, some of the farmers' fields were extremely low in available K status. In Adilabad districts, the K status varied from 20 to 245 mg kg^{-1} with the mean value of 91 mg kg^{-1}, corresponding to a medium K value (Srinivasarao *et al.*, 2000). In Nalgonda, from 420 farmers' fields, K status varied from 9-154 mg kg^{-1} with a mean of 39 mg kg^{-1}, a low K value. These soils are extremely low in K so that high value crops like tomato, vegetables, sweet orange, and mulberry, along with field crops like groundnut, cotton, maize, green gram, and black gram, respond to K application (Fig. 2 to 6). Soils of Khammam district are medium in K status ranging from 14-382 mg kg^{-1}. However, most of the cotton growing red soils are low in available K and significant cotton response was found with Specific Site Nutrient Management (SSNM) including K. In Mahabubnagar district, K status varied from 11-563 mg kg^{-1} with a mean of 47 mg kg^{-1} (low). Therefore, the deficient fields with cotton, castor, maize etc. require K application. In Anantapur district, the mean K status is low (52 mg kg^{-1}) although it varied from 17-664 mg kg^{-1} across 340 farmers' fields tested. In addition, other than small pockets of black soil patches, most of the groundnut growing red soils are K deficient and regular application of K is required. The soils in this district are unable to support banana cultivation, without external K application (Srinivasarao *et al.*, 2000, 2010). In Kadapa district, among the 320 farmers' fields tested, K status ranged from 7-215 mg kg^{-1} with the mean value of 27 mg kg^{-1} showing extremely low levels of soil K. In Warangal district, among 336 farmers' fields tested, K status varied from 9-125 mg kg^{-1} with a mean value of 49 mg kg^{-1} (low). In Rangareddy district, of the 125 farmers' fields tested, the mean K status was low (41 mg kg^{-1}) and in the range of 11-180 mg kg^{-1}.

K deficiency symptoms in rice at one of the SSNM plots. Photo by Ch. Srinivasa Rao.

Table 3. Farmer field specific fertilizer recommendations developed for oilseed/pulse crop (viz. groundnut, green gram, tomato and okra) based on soil test value for Dupahad cluster of Nalgonda district, AP (Similar SSNM data sheets developed for all other farmers fields across the eight districts).

Farmer No.	Village	Crop	Fertilizer requirement (kg ha^{-1})				
			Urea	DAP	MOP	Gypsum	$ZnSO_4$
1	Jalmakunta Thanda	Green gram	50	-	90	-	-
2	Jalmakunta Thanda	Groundnut	-	125	90	-	50
3	New Banjara Hills	Groundnut	50	-	65	150	50
4	Jalmakunta Thanda	Green gram	50	-	-	-	25
5	Jalmakunta Thanda	Green gram	-	125	90	150	50
6	Seetamma Thanda	Groundnut	50	-	90	-	50
7	Jalmakunta Thanda	Green gram	50	-	-	-	50
8	New Banjara Hills	Groundnut	-	125	65	150	50
9	Peddagarakunta Thanda	Green gram	50	-	90	150	50
10	Jalmakunta Thanda	Green gram	-	125	-	-	50
11	Jalmakunta Thanda	Green gram	-	125	90	-	50
12	Jalmakunta Thanda	Green gram	50	-	65	-	50
13	Jalmakunta Thanda	Green gram	-	125	90	150	50
14	Jalmakunta Thanda	Green gram	-	125	65	150	50
15	Jalmakunta Thanda	Groundnut	-	125	65	150	50
16	Jalmakunta Thanda	Groundnut	-	125	65	-	25
17	Jalmakunta Thanda	Green gram	50	-	65	-	50
18	Jalmakunta Thanda	Tomato	50	-	90	-	50
19	Jalmakunta Thanda	Okra	-	125	90	-	50
20	Peddagarakunta Thanda	Tomato	50	-	65	-	25

On-farm SSNM trials

During 2007-11, a total of 265 on-farm trials were conducted in different districts with different test crops: Adilabad (kharif cotton and rabi chickpea), Khammam (cotton), Warangal (cotton and pigeon-pea), Anantapur and Kadapa (groundnut, sunflower and vegetables), Mahbubnagar (cotton, castor and rabi groundnut), Rangareddy (maize and pigeonpea) and Nalgonda (groundnut, black gram, green gram and vegetable crops, such as tomato and okra). The objective of these tests was to demonstrate the comparative evaluation of SSNM, including micro and secondary nutrients and farmer's practice. Crops were grown on selected farmers' fields with known fertility status and SSNM-based nutrient application (Table 3).

In some of the fields across the districts (Warangal, Adilabad, Nalgonda, Khammam and Rangareddy), a build-up of phosphorous (P) in the soils was determined. In these farmers' fields, the application of P was reduced to half of the recommended P levels for various crops. Prior to this project, no farmer had applied any K fertilizer to the crops, even in cases where soils were deficient in available K. Some of the farmers did not even know about MOP fertilizer. Based on our project interventions, K fertilizer was included in SSNM package where soils testing of K was low and also for K exhaustive crops including cotton, maize, groundnut, vegetables and other horticultural crops. A model SSNM sheet is presented in Table 3 for some of the on-farm trials made in Nalgonda district on groundnut, green gram, tomato and okra. Similarly sulphur, zinc and boron were applied depending on soil test data. SSNM packages for individual farmers' fields were developed based on the crop grown and soil test data. Available N was invariably low in all the villages and recommended N was used for all crops with the exception of legumes where N was omitted as for groundnut and green gram (Table 3).

SSNM impacts on crop productivity in farmers' fields

The impacts of SSNM, based on participatory soil sampling, soil analysis at CRIDA laboratory, soil health cards, and SSNM recommendations to individual farmers depending upon crop and soil test data, were highly significant in all the tested crops in the eight districts. Response patterns of various crops in each district are discussed below:

Adilabad: In Adilabad district, the benefits of balanced nutrition through SSNM were much higher than at other sites. This could be due to a continuous cotton-based system with a mean yield of 2.37 mt ha^{-1} of seed cotton (SSNM) compared to a mean yield of 1.66 mt ha^{-1} under farmers' practice (FP), (a 43.1 percent yield increase). Low levels of fertilizer application to cotton, chickpea or cotton-pigeonpea intercropping systems over the years resulted in mining of soil nutrients. In these villages (70 percent tribal population), cotton has been grown for the last 10-15 years without much nutrient input. This is one of the reasons for higher cotton response to balanced nutrition. Among the rabi crops, chickpea (variety JG-11) showed significant response to SSNM in Seethagondi cluster of Adilabad district. Mean seed yield increased from 0.89 to 1.21 mt ha^{-1} due to balanced nutrition, a 35.1 percent yield increase. Being a pulse crop, S requirement was met from added S in the form of gypsum, besides application of other S-containing fertilizers. However, the variation in the crop response to balanced nutrition varied widely among farmers' fields. The improvement in chickpea yield with balanced nutrition varied from 15 to 58 percent over farmer's practice. These findings indicate that with improved varieties of chickpea (JG-11), a well nourished crop can yield up to 1.5 mt ha^{-1} on the deep black soils of Adilabad district.

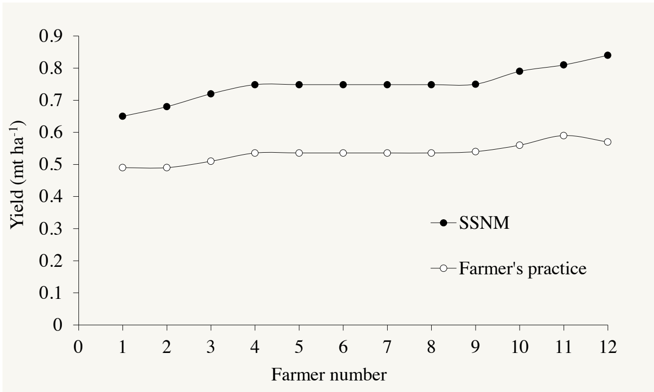

Fig. 4. Effects of balanced fertilization on green gram yield in farmers' fields of Dupahad cluster, Nalgonda district, AP, 2009-2010. (CD=0.07; p=0.05).

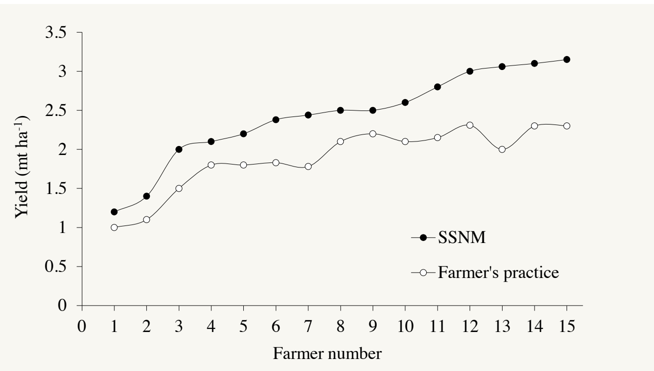

Fig. 2. Effects of balanced fertilization on Bt-cotton yield in farmers' fields of T. Cheruvu cluster, Khammam district, AP, Kharif 2009-2010. (BN=SSNM; FP=Farmer's practice only NP) (CD=0.23; p=0.05).

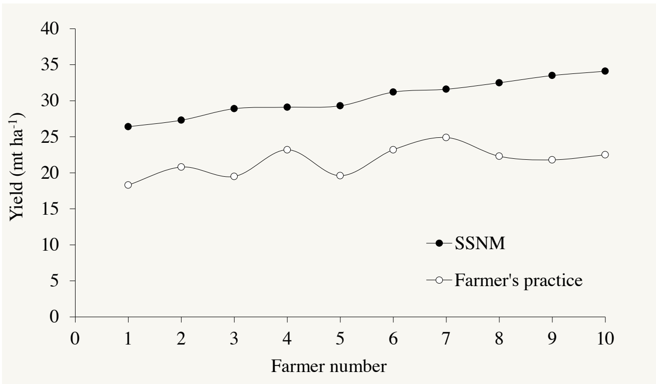

Fig. 5. Effects of balanced fertilization on tomato yield in farmers' fields of Dupahad cluster, Nalgonda district, AP, 2009-2010. (CD=0.9; p=0.05).

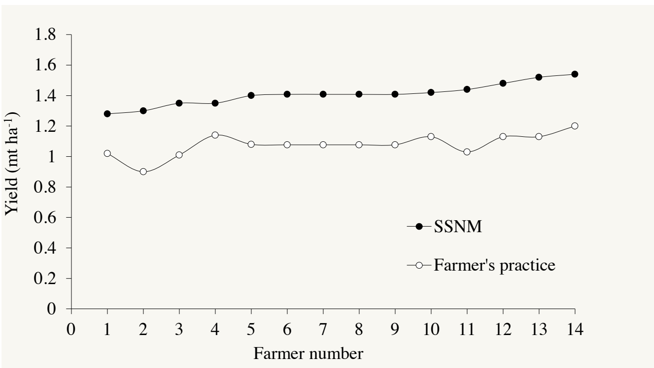

Fig. 3. Effects of balanced fertilization on groundnut yield in farmers' fields of Dupahad cluster, Nalgonda district, AP, 2009-2010. (CD=0.08; p=0.05).

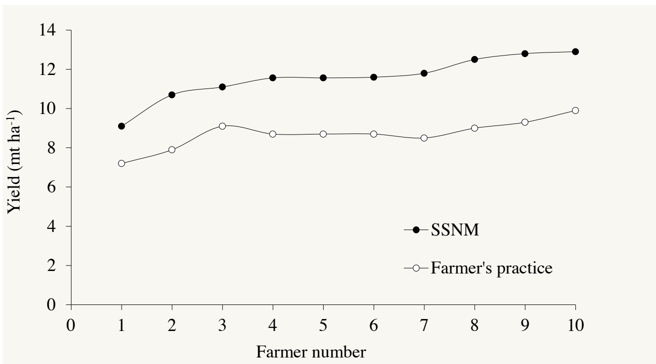

Fig. 6. Effects of balanced fertilization on okra yield in farmers' fields of Dupahad cluster, Nalgonda district, AP, 2009-2010. (CD=0.4; p=0.05).

Farmers' meeting to discuss and evaluate SSNM with research team in Anantapur.

Farmers' meeting to discuss and evaluate SSNM with research team in Adilabad.

Meeting with cotton farmers at SSNM for cotton.
Photos by Ch. Srinivasa Rao.

Khammam: Soils in Tummalacheruvu cluster in Khammam district are fine textured red soils with multi-nutrient deficiencies. Cotton yields (seed cotton) ranged from 0.9 to 2.5 mt ha^{-1} under FP with an average yield of 1.9 mt ha^{-1} whereas with SSNM, yield levels improved in the range of 1.3 to 3.2 mt ha^{-1} with an average yield of 2.4 mt ha^{-1}, a 13.6-53.0 percent increase in yield. The interesting point obtained from cotton yields from farmers' fields is that yield gaps between FP to SSNM have widened at higher productivity levels as compared to lower yield levels among 15 farmers' fields tested (Fig. 2).

Nalgonda: In the Dupahad cluster of this district, SSNM of groundnut and green gram brought about a mean yield increase from 1.08 to 1.41 mt ha^{-1} and from 0.54 mt ha^{-1} to 0.75 mt ha^{-1}, respectively, i.e. 31.1 and 39.6 percent yield increases. Green gram and groundnut yield responses also varied from 33 percent to 47 percent and 18 percent to 44 percent respectively. Among vegetable crops, tomato and okra, mean yield increased from 21.6 mt ha^{-1} to 30.4 mt ha^{-1} and 8.7 mt ha^{-1} to 11.6 mt ha^{-1}, i.e. 41 percent and 33 percent increases in yield respectively in this district (Fig. 3-6). In all the crops (oilseed, food legume and vegetables), groundnut, green gram, tomato and okra, the gaps in yields between FP and SSNM were much wider at high productivity levels, as in the case of cotton yields in Khammam district.

Warangal: In the Jaffergudem cluster, balanced nutrition improved cotton yields significantly in many farmers' fields. In some of the farmers' fields, cotton yields reached 1.6 mt ha^{-1} with balanced nutrition, with increased yields from five to 30 per cent over FP.

Kadapa: Groundnut yield increased from 0.65 mt ha^{-1} to 0.82 mt ha^{-1} due to balanced nutrition, registering a yield increase up to 15 to 18 percent.

Anantapur: As in Kadapa, groundnut yields were increased by balanced nutrition from 0.67 to 0.88 mt ha^{-1}. The response of groundnut to balanced nutrition ranged from 20 to 50 percent but generally it was around 25 percent (Srinivasarao *et al.*, 2010).

Mahabubnagar: Castor, cotton and rabi groundnut responded significantly to micronutrient application. The highest response among the crops was cotton (26 percent), followed by castor (19 percent) and groundnut (18 percent).

Rangareddy: Maize and pigeonpea responded to micro and secondary nutrient application on the light-textured sandy loam soils of Parigi cluster.

Based on several on-farm trails, SSNM improved productivity of various rainfed crops. The minimum mean increase in SSNM over FP was 19 percent in castor and the maximum mean increase was observed in tomato (41 percent) (Fig. 7), with other crops including cotton, chickpea, groundnut, green gram, maize and okra between these figures. Such large impacts of SSNM productivity of rainfed crops in eight districts was due to degraded soils with multi-nutrient deficiency, and where farmers seldom apply nutrients other than N and P. Potassium inclusion in the SSNM package as shown in Table 3 enhanced yield improvement as well as quality of vegetables like tomato and okra.

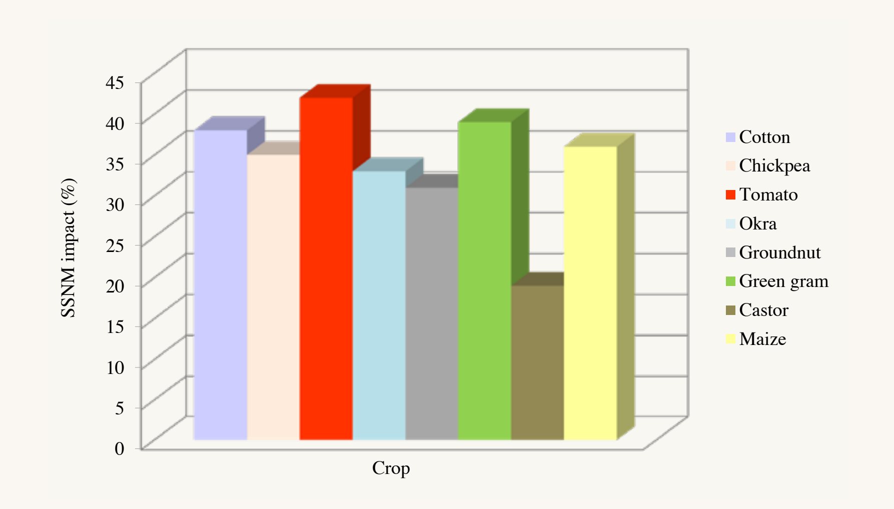

Fig. 7. Overall impacts of SSNM in different rainfed crops over farmer's practice.

Impact of SSNM on farm income

The economic viability of balanced nutrition over FP was calculated in relation to prevailing prices of input and output costs. The additional cost (Table 4) incurred in balanced nutrition as compared to FP was mainly due to the cost of the limiting nutrients and additional N and P. Net income and return per Rupee investment improved substantially through balanced nutrition.

Livelihood impacts of SSNM

Increasing crop productivity by application of improved technologies was one of the strategies for enhancing the livelihood security of the rural poor in the project. Thus, a systematic effort was made to assess the native nutrient status of soil and supplement it by application of appropriate nutrients at the required quantity. Enhancing crop productivity and household income has been adopted by the project as a short-term measure towards improving rural livelihoods. It was observed in many cases in the project area that the additional income generated due to higher productivity and profitability was mostly reinvested into farming as additional capital. Increased vegetable productivity enhanced cash flow in the family at short intervals. The families that participated in SSNM trials were shown to be higher consumers of vegetables at the household level leading to better nutritional security as well (Table 5).

Many farmers who realized higher profits due to better nutrient management used their additional income for improving housing, buying animals, educating children, meeting social obligation, etc. Pelli Venkanna of Jaffergudem says "From the additional profit I got from my cotton SSNM field, I spent Rs. 22000/- to plaster my house with cement," while Korra Harishehandra of the same cluster bought a sheep unit spending Rs. 13500/-. A relatively well to do farmer, Buke Balu invested his profit to fund his son's education (B.Tech).

In Adilabad, D. Ratan of Seethagondi cluster took up SSNM in chickpea and realized a 30 percent higher income compared to other farmers. He used this money to purchase Bt cotton seeds from a reputable company. He said, "Unlike previous years, I did not have to compromise with seed quality. Since I had extra money (Rs. 12000/-), I could go for the best in the market."

Though the anecdotes give a summary of the livelihood impacts of the SSNM interventions, they do not provide a total picture of all the farmers who adopted SSNM. However, the livelihood impacts which can be diverse and varied can only be captured through anecdotal evidence and qualitative data.

In Dupahad cluster of Nalgonda, the impact of SSNM was observed mainly in vegetables (tomatoes, okra), leafy vegetables (like palak) and flower crops (such as marigold). Though these did not translate into large gains, as in the case of cotton, the additional income nevertheless contributed to the purchase of household articles, better clothing and additional investment in purchasing better quality inputs for agriculture.

Acknowledgement

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Table 4. Economic benefits due to SSNM and balanced nutrition followed in different crops in target clusters of tribal dominated districts of Andhra Pradesh.

District/Cluster	Crop	No. of trials	Cost of cultivation		Net return		Return per Rupee investment	
			BN	FP	BN	FP	BN	FP
			---------------------------*Rs./ha*---------------------------					
Adilabad (Seethagondi)	Cotton	14	23,967	21,287	30,783-55,533 (47,174)[1]	19,213-38,113 (28,540)	2.28-3.32 (2.97)	1.90-2.79 (2.34)
	Chickpea	14	11,736	9,536	5,564-14,214 (9,123)	2,228-8,110 (5,898)	1.47-2.21 (1.78)	1.23-1.85 (1.62)
Khammam (Tummalacheruvu)	Cotton	15	23,967	21,287	15,033-70,533 (49,210)	5,713-53,713 (35,828)	1.63-3.94 (3.05)	1.27-3.52 (2.68)
Nalgonda (Dupahad)	Groundnut	14	18,500	16,300	8,380-13,840 (11,068)	2,600-8,900 (6,317)	1.45-1.75 (1.60)	1.16-1.55 (1.39)
	Green gram	12	12,173	9,973	4,207-8,995 (6,691)	2,375-4,895 (3,527)	1.35-1.74 (1.55)	1.24-1.49 (1.35)
	Tomato	10	58,074	55,874	47,526-78,326 (63,486)	12,926-43,726 (30,526)	1.82-2.35 (2.09)	1.23-1.78 (1.55)
Warangal (Jaffergudem)	Bhendi	10	39,030	36,830	15,570-38,370 (30,345)	4,570-24,370 (15,370)	1.40-1.98 (1.78)	1.12-1.66 (1.42)
	Cotton	13	23,967	21,287	9,033-22,533 (16,733)	10,213-17,713 (13,613)	1.38-1.94 (1.70)	1.48-1.83 (1.64)
Kadapa (B. Yerragudi)	Groundnut	13	9,500	7,300	2,050-11,500 (6,299)	575-7,138 (3,533)	1.22-2.21 (1.66)	1.08-1.98(1.48)
Anantapur (Pampanur)	Groundnut	9	9,500	7,300	5,200-7,300 (6,345)	3,200-6,875 (5,205)	1.55-1.77 (1.67)	1.44-1.94 (1.51)

BN = SSNM, or Balanced Nutrition
FP = Farmer's practice
[1]Values in parentheses indicate mean values

Table 5. Impact of SSNM implementation on weekly consumption of vegetables in households (g day^{-1}) in three tribal districts.

District	SSNM participant farmer	Check farmer (without SSNM)
Adilabad	350	200
Nalgonda	480	210
Khammam	450	350

Average household size of five members

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References

Hanway, J.J., and H. Heidel. 1952. Soil Analysis Methods as used in Iowa State College Soil Testing Laboratory, Iowa Agric. 27:1-13.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Srinivasarao, Ch. 2011a. Nutrient Management Strategies in Rainfed Agriculture: Constraints and Opportunities. Indian J. Fert. 7(4):12-28.

Srinivasarao, Ch., S.P. Wani, B. Venkateswarlu, K.L. Sahrawat, Sreenath Dixit, Sumanta Kundu, K. Gayatri Devi, and C. Rajesh. 2010. Productivity Enhancement and Improved Livelihoods through Participatory Soil Fertility Management in Tribal Districts of Andhra Pradesh. Indian Journal of Dryland Agricultural Research and Development 25(2):23-32.

Srinivasarao, Ch., A. Subba Rao, and T.R. Rupa. 2001. Need for Inclusion of Non-exchangeable Potassium in Soil Test Based Potassium Fertilizer Recommendations. Fertilizer News 46(5):31-40.

Srinivasarao, Ch., A. Subba Rao, Anand Swarup, S.K. Bansal, and V. Rajagopal. 2000. Monitoring the Changes in Conventional Estimates and Electroultrafiltration (EUF) Fractions of Potassium under Twenty Years of Rice-Rice Cropping on Inceptisol. Nutrient Cycling in Agroecosystems 56:277-282.

Srinivasarao, Ch., K.P.R. Vittal, G.R. Chary, P.N. Gajbhiye, and B. Venkateswarlu. 2006. Characterization of Available Major Nutrients in Dominant Soils of Rainfed Crop Production Systems of India. Indian Journal of Dryland Agricultural Research and Development 21:5105-113.

Srinivasarao, Ch. 2011b. Nutrient Ratio and Crop Response in Relation to Non-Exchangeable K in Different Agroecological Regions of India. Indian J. Fert. 7(7):32-45.

Srinivasarao, Ch., A. Swarup, A. Subba Rao, and V. Rajagopal. 1999. Kinetics of Non-Exchangeable Potassium Release from a Tropaquept as Influenced by Long-Term Cropping, Fertilization and Manuring. Australian Journal of Soil Research 37:317-328.

Srinivasarao, Ch., and K.P.R. Vittal. 2007. Emerging Nutrient Deficiencies in Different Soil Types under Rainfed Production Systems of India. Indian J. Fert. 3:37-46.

Srinivasarao, Ch., S.P. Datta, A. Subba Rao, S.P. Singh, and P.N. Takkar. 1997. Kinetics of Non-Exchangeable Potassium Release by Organic Acids from Mineralogically Different Soil. Journal of Indian Society of Soil Science 45:728-734.

Srinivasarao, Ch., D.K. Pal, and P.N. Takkar. 1998. Mathematical Models to Study the Kinetics of Potassium Release from Swell-Shrink Soils of Central India in Relation to their Mineralogy. Journal of Plant Nutrition and Soil Science 161:67-72.

Srinivasarao, Ch., T.R. Rupa, A. Subba Rao, G. Ramesh, and S,K. Bansal. 2006. Release Kinetics of Non-Exchangeable Potassium by Different Extractants from Soils of Varying Mineralogy and Depth. Communication in Soil Science and Plant Analysis 37:473-491.

Srinivasarao, Ch., T.R. Rupa, A. Subbarao, and S.K. Bansal. 2001. Subsoil Potassium Availability in 22 Benchmark Soil Series of India. Communication in Soil Science and Plant Analysis 32:863-876.

Srinivasarao, Ch., A. Subba Rao, and T.R. Rupa. 2000. Plant Mobilization of Soil Reserve Potassium from Fifteen Smectitic Soils in Relation to Soil Test Potassium and Mineralogy. Soil Science 165:578-586.

Srinivasarao, Ch., B. Venkateswarlu, R. Lal, A.K. Singh, K.P.R. Vittal, Sumanta Kundu, S.R. Singh, and S.P. Singh. 2012. Long-Term Effects of Soil Fertility Management on Carbon Sequestration in a Rice-Lentil Cropping System of the Indo-Gangetic Plains. Soil Science Society of America Journal 76(1):168-178.

Srinivasarao, Ch., B. Venkateswarlu, Sreenath Dixit, Sumanta Kundu, and K. Gayatri Devi. 2011c. Livelihood Impacts of Soil Health Improvement in Backward and Tribal Districts of Andhra Pradesh. Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India. 119 p.

Srinivasarao, Ch., B. Venkateswarlu, R. Lal, A.K. Singh, Sumanta Kundu, K.P.R. Vittal, J.J. Patel, and M.M. Patel. 2011d. Long-Term Manuring and Fertilizer Effects on Depletion of Soil Organic Carbon Stocks under Pearl Millet-Cluster Cean-Castor Rotation in Western India. Land Degradation and Development. DOI: 10.1002/ldr.1158.

Srinivasarao, Ch., K.P.R. Vittal, K.N. Tiwari, P.N. Gajbhiye, and S. Kundu. 2007. Categorization of Soils Based on Potassium Reserves and Production Systems: Implications in K Management. Australian Journal of Soil Research 45:438-447.

Srinivasarao, Ch., K.P.R. Vittal, B. Venkateswarlu, S.P. Wani, K.L. Sahrawat, S. Marimuthu, and S. Kundu. 2009a. Carbon Stocks in Different Soils Under Diverse Rainfed Production Systems in Tropical India. Communications in Soil Science and Plant Analysis 40(15):2338-2356.

Srinivasarao, Ch., S.P. Wani, K.L. Sahrawat, and B.K. Rajasekhara Rao. 2009b. Nutrient Management Strategies in Participatory Watersheds in Semi Arid Tropical India. Indian J. Fert. 5(12):13-128.

Srinivasarao, Ch., K.P.R. Vittal, S. Kundu, P.N. Gajbhiye, and M. Vijayasankarbabu. 2010. Twenty Years of Continuous Cropping, Fertilization and Organic Manure Application Effects on Forms of Potassium and Kinetics of Non-Exchangeable K Release in the Profile of an Alfisol Under Arid Conditions. Communications in Soil Science and Plant Analysis 41:(6)783-796.

Subbarao, A., Ch. Srinivasarao, and S. Srivastava. 2010. Potassium Status and Crop Response to Potassium on the Soils of Agroecological Regions of India. IPI Research Topic No. 20 (2nd revised ed.), International Potash Institute, Switzerland. 185 p.

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