Soil Security for Sustainable Agriculture

Editors

S.V. Sarode **V. K. Kharche**

J. P. Deshmukh **Y. R. Sable**

DR. PANJABRAO DESHMUKH KRISHI VIDYAPEETH, AKOLA - 444 104 (MAHARASHTRA)

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Editors
S.V. Sarode
Director of Research
V. K. Kharche
Professor
J. P. Deshmukh
Dy. Director of Research
Y. R. Sable
Assistant Professor

DR. PANJABRAO DESHMUKH KRISHI VIDYAPEETH,
AKOLA - 444 104 (MAHARASHTRA)

Soil Health Awareness : Soil Science at Doorsteps of the Farmers

Suhas P Wani, Girish Chander and KL Sahrawat
International Crop Research Institute for the Semi Arid Tropics (ICRISAT),
Patancheru-502324, Andhra Pradesh, India

Issues in rainfed agriculture & importance of soil health

Rainfed semi arid tropics (SAT) are hot spots of poverty and malnutrition, and population explosion is further aggravating the problem. Out of 852 million hungry and malnutritioned poor worldwide, 221 million are in India. Attaining food and nutritional security for these regions is a big challenge particularly in view of climate change which is expected to hit hard again these areas. Poor soil health in addition to water scarcity, largely due to mining of soil nutrients and inappropriate nutrient management options adopted by the farmers, is a major constraint leading to sub optimal crop yields (1-1.5 t ha^{-1}) and lower economic returns inspite of existing potential (2.5-7.0 t ha^{-1}). Poor soil health is also responsible to low water use efficiency due to limiting nutrients and exhausted C. Now, there exists a vicious poverty-food security-land degradation nexus in which a farmer is trapped. The natural resources primarily soils in the target regions are the lifeline of the millions of rural poor and key to improvement in their livelihoods. If current agricultural practices are continued, it may severely affect soil health and rainfed SAT regions may face a serious food crisis in near future. Productivity and contributions to world's food basket from rainfed agriculture could be substantially improved through appropriate soil health management (Wani et. al. 2003a and b), but lack of awareness among farmers and other stakeholders is the main reason for current gloomy situation. Therefore, ICRISAT led team initiated to diagnose poor health of SAT soils through farmer involvement in soil sampling, shared soil issues through a range of media including new science tools and conducted farmer participatory on-farm R&D trials to evaluate and demonstrate the best practices. The objective of this communication is to show as to how farmer participatory soil analysis can be used to diagnose and monitor soil health issues, increase soil health awareness, adopt soil test based nutrient recommendations to substantially increase the productivity of crops and incomes in the semi-arid regions of India.

MATERIAL AND METHODS

ICRISAT led team intervened in soil health assessment of farmers' fields in target SAT regions of India in Andhra Pradesh, Karnataka, Madhya Pradesh and eastern Rajasthan by adopting farmer participatory stratified soil sampling method which has been standardized earlier to sample watersheds (Sahrawat *et al.* 2008).

The processed samples were analyzed for pH, organic carbon (OC), available-sulphur (S), boron (B), zinc (Zn), phosphorus (P) and potassium (K) in Charles Renard Analytical Laboratory, ICRISAT. Soil reaction (pH) was measured with the help of glass electrode using soil to water ratio of 1:2. Organic carbon was determined using the Walkley-Black method (Nelson and Sommers, 1996), available P using the sodium bicarbonate (NaHCO3) method (Olsen and Sommers, 1982), exchangeable K using the ammonium acetate method (Helmke and Sparks, 1996) and available S using 0.15% calcium chloride ($CaCl_2$) as an extractant (Tabatabai, 1996). Available Zn was extracted by diethylene triamine pentaacetic acid (DTPA) reagent (Lindsay and Norvell, 1978) and available B by hot water (Keren, 1996).

Farmer participatory soil sampling technique constituted a tool as an entry point activity to build rapport with and ensure farmer awareness right from beginning and participation for success of the initiative. The analysis results were shared with farmers through farmer meetings for creating soil health awareness. Wall writings, soil health cards, pamphlets, various media and pocket guides having soil health maps and recommendations were another means to create awareness among SAT farmers. Stakeholders including government departments, non-governmental organizations, farmers organizations and women's self help groups were brought together to improve farmers crop, water and soil skills. Soil test results were interpolated to develop interactive web based GIS maps and advisory on soil health issues. Some of the lead farmers in the villages across target SAT regions in India were motivated to conduct R&D trials to evaluate crop response to soil test based fertilizer practices addressing emerging soil health issues.

Follow-up on-farm trials were conducted on major crops of Rajasthan, Karnataka, Andhra Pradesh and Madhya Pradesh during 2007 rainy to 2009-10 post rainy seasons. There were two treatments—farmer's input and balanced nutrient application (N and P along with S, B and Zn). For applying nutrients as per SBZn + NP treatment, S, B and Zn were added as 200 kg gypsum (30 kg S ha^{-1}), 5 kg borax (0.5 kg B ha^{-1}) and 50 kg zinc sulfate (10 kg Zn ha^{-1}) ha^{-1}; N was applied at 50-60 kg N for cereals and 20-30 kg N ha^{-1} for legumes and P was added at 30-50 kg P_2O_5 ha^{-1}. Potassium was also applied in on-farm trials in Karnataka @ 10-15 kg K_2O ha^{-1}. The treatments were imposed on 2000 m^2 plots, side by side and uniform crop management practices were ensured in all the treatments. Each farmer field in cluster target villages in a district was treated as replication for statistical analysis of the data.

Farmer participatory R&D trials were also conducted to evaluate the use of Jatropha deoiled cakes as an organic source in partial substitution of plant nutrients for irrigated rice in Andhra Pradesh during rainy season 2007. The treatments under study were-(i) Control, (ii) Farmers practice (FP), (iii) Basal N through cake in FP, (iv) Recommended chemical fertilizers (RCF) and (v) Basal N through cake in RCF. The recommended N and P_2O_5 were applied to paddy @ 125 and 40 kg ha^{-1}, respectively. The trials were replicated on 10 farmers fields.

At maturity, the crop yields were recorded from 3 spots measuring 3X3 m^2, the average of which was converted into yield kg ha^{-1}. The benefit cost ratios of adopting the technology were worked out by dividing additional returns with additional costs over and above the farmers practice. The total amount of water used in crop production through rainfall was used to work out the water use efficiency as kg of food grain produced per mm of water per ha (kg mm^{-1} ha^{-1}). The data recorded was subjected to statistical analysis using the Genstat 13th edition.

RESULTS AND DISCUSSION

Soil health analysis and awareness

The soil health analysis revealed widespread deficiencies of secondary and micro nutrients namely sulfur (S), boron (B) and zinc (Zn) in majority of the farmers fields in addition to those of nitrogen (N) and phosphorus (P), while potassium (K) deficiency in general was not a problem (Table 1). Across the districts in target states, 71-84, 56-85 and 46-69% farmers' fields were deficient in available S, B and Zn, respectively which are apparently acting as limiting factors in under utilization of existing green water resources and low crop productivity. Present scenario so demands attention to include S, B and Zn in fertilization practice to arrest further degradation to land and improve soil health. Interestingly, majority of the farmers fields in different states except MP were not deficient in available-P. And only 1-21% of the fields sampled across target states were deficient in available-K. Here is the opportunity to reduce the amounts and cut costs in phosphatic and potassic fertilizers and to include emerged deficient secondary and micro nutrients to get economic productivity improvement and simultaneously address the issues of correcting nutrient imbalances and soil health improvement. In addition, majority (70-76%) of the farmers' fields in Karnataka and Andhra Pradesh were low in organic carbon (OC), in contrast to fields in eastern Rajasthan and Madhya Pradesh where only 22-38% fields were low in OC. Low soil-C contents are reasons and outcome as well of low crop productivity resulting low C-sequestration in rainfed degraded soils.

Table 1. Soil test results of farmers fields in different states of India

State	No. of Districts.	No. of Farmers	% deficiency					
			OC	Av-P	Av-K	Av-S	Av-B	Av-Zn
Karnataka	10	17712	70	46	21	84	67	55
Andhra Pradesh	11	3650	76	38	12	79	85	69
Rajasthan	9	421	38	45	15	71	56	46
Madhya Pradesh	12	341	22	74	1	74	79	66

The soil health issues and follow up strategy was shared with stakeholders thru traditional methods and new science tools. The soil analysis results were interpolated using GIS to develop an interactive web based maps and advisory to show soil health issues to stakeholders in a click of mouse.

Productivity response by rainfed crops in different states of India

A soil health corrective approach of applying soil test based balanced nutrition increased crop yields as compared to the farmer's input treatment during 2008 rainy and 2008-09 post-rainy seasons in the districts of Andhra Pradesh (see results in Tables 2 and 3). During rainy season, groundnut yield increased by 26% in Anandpur and 46% in Kadapa with a favourable B:C ratio of 1.46 and 2.12, respectively. Similarly, cotton yields increased by 25% in Khammam and 17% in Warangal with B:C ratio of 6.11 and 2.50, respectively. Several rainfed crops in earlier soil test based nutrient management options similarly responded beneficially to balanced application of nutrients (Rego *et al.* 2005; Rao *et. al.* 2009) simply with the inclusion of S, B and Zn which were holding back the crop yield potential.

Table 2. Effect of balanced nutrition on yield of crops in Andhra Pradesh during rainy season 2008

District	Crop	No. of Trials	Farmers Practice (kg ha^{-1})	Balanced Nutrition (kg ha^{-1})	CD (5%)	B:C ratio
Anantpur	Groundnut	9	597	756	44	1.46
Kadapa	Groundnut	13	506	737	109	2.12
Khammam	Cotton	13	1919	2408	465	6.11
Warangal	Cotton	13	1161	1361	103	2.50

Table 3. Effect of balanced nutrition on yield of crops in Andhra Pradesh during post-rainy season 2008-09

District	Crop	No. of Trials	Farmers Practice (kg ha^{-1})	Balanced Nutrition (kg ha^{-1})	CD (5%)	B:C ratio
Adilabad	Chikpea	14	607	1196	151	4.32
Anantpur	Groundnut	4	484	745	259	2.39
Kadapa	Sun flower	8	1586	2018	793	3.60

During post rainy season 2008-09 and 2009-10 in Rajasthan, balanced nutrition in contrast to farmers practice brought improvements in yields of chickpea (11-15%) and wheat (10-15%) crops (Table 4). The B:C ratio of adopting balanced nutrition varied from 1.37 to 1.57 in chickpea and 1.46 to 1.85 in wheat.

In line with findings in AP and Rajasthan, in MP also the inclusion of gypsum and agribor over and above the farmers practice recorded 10% increase each in chickpea grain and straw yields with a favourable B:C ratio of 3.11 (Table 5).

Table 4. Effect of balanced nutrition on yield (kg ha^{-1}) of crops in Rajasthan during post-rainy season 2008-09 & 2009-10.

Crop	No. of Trials		2008-09				2009-10			
	2008-09	2009-10	FP	BN	CD (5%)	B:C ratio	FP	BN	CD (5%)	B:C ratio
Tonk district										
Chickpea	7	7	1385	1599	79	1.57	1647	1836	263	1.39
Wheat	10	8	3771	4326	298	1.85	4248	4756	911	1.69
Sawai Madhopur district										
Chickpea	7	7	1329	1516	72	1.37	1465	1670	336	1.50
Wheat	10	9	4178	4693	374	1.72	4361	4799	642	1.46

FP=Farmers practice; BN=Balanced Nutrition

Table 5. Effects of balanced nutrient management on chickpea (JG 226) grain and straw yield in Jhabua, Madhya Pradesh during post-rainy season 2009-10

Crop	No. of	Grain yield (kg/ha)		B:C ratio*	Straw yield (kg/ha)	
	Trials	FP	BN		FP	IP
Chickpea	31	978	1077	3.11	896	981
CV (%)	4.74	5.43				
P-value		<0.0001			<0.0001	

**B:C ratio worked on additional gypsum @ 200 kg ha^{-1} & agribor @ 2.5 kg ha^{-1}*

During rainy season 2008, the rainfed crops in Karnataka also recorded a productivity improvement ranging from 43 to 54% in response to inclusion of deficient SBZn over the control.

The results presented clearly showed that soil testing can be used to diagnose the multi-nutrient deficiencies prevalent in the rainfed production systems and that balanced nutrient application based on the soil test results has the potential to enhance agricultural productivity in the rainfed areas of India.

Emergence of "Bhoochetana" – Boosting Rainfed Agriculture

Taking leads from the successes in substantially enhancing crop productivity through soil test based nutrient management in microwatersheds of the selected districts, the government of Karnataka has embarked on a path breaking project "Bhoochetana" to improve productivity in dryland agriculture across Karnataka. The support at policy level to encourage soil test based balanced nutrition by including deficient S, B and Zn along with N and P increased groundnut yield over farmers practices by 32- 43% in 6 targeted districts (Figure 6). Similarly, balanced nutrition in contrast to farmers' practice increased yield by 35-66% in ragi, 39-44% in maize and 39% in soybean in different districts of Karnataka (Figure 7). The emerging results of the mission mode project clearly points to bringing in policy supported "Bhoochetana" in all rainfed states to aware stakeholders and encourage adoption of science led approach to address soil health related issues to boost sustainable productivity improvement.

Water use efficiency enhanced through balanced nutrition

A real impact of the poor soil health in terms of limiting secondary and micronutrients appears in crops inability to make use of scarce water resources in food production. In studies conducted in Andhra Pradesh and Karnataka, a soil test based balanced nutrition was found to increase plants ability to make best of scarce water resources and increase rain water use efficiency (Figure 4 & 5). Balanced nutrition is thus way to increase proportion of water balance as productive transpiration, which is one of the most important rainwater management strategies to improve water productivity (Rockstrom *et. al.* 2010)

Alternate organic and biological sources of plant nutrients for soil health and productivity

Search and effective utilization of organic sources in replacing part of the nutrients from chemical fertilizers to cut short the cost of cultivation and as a strategy to adopt integrated nutrient management from soil health point of view is need of the hour.

Our on farm studies revealed deoiled *Jatropha* cake, a byproduct left after oil extraction from *Jatropha* seeds, excellent organic manure in replacing chemical fertilizers on basis of meeting 50% N requirement as basal application (Table 6). Rather replacement of basal N (i.e. 50% total N requirement) in chemical fertilizers with *Jatropha* cake increased paddy grain yield by 14% under farmers practice and by 9% under recommended fertilizer practice. The increased grain yield with inclusion of deoiled cake is apparantly due to addition of organic-C, secondary and micro nutrients (Wani *et. al.* 2006) resulting improvement in soil health. In addition, slow and sustained release of N from the deoiled cake might have reduced the loss of N through leaching and denitrification. The results clearly suggested *Jatropha, which is* a good candidate plant to grow on degraded lands to produces biodiesel and generate incomes from otherwise waste lands, also generates by-product cake which is rich in nutrients and C to arrest degrading soil health and produce more economic food.

Table 6. Effect of *Jatropha* deoiled cake on grain and straw yield in lowland rice during rainy season 2007

T. No.	Treatment Details	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
T1	Absolute control	3.54	4.45
T2	Farmers practice (FP)	4.66	6.18
T3	100% basal N thru cake in FP	5.29	6.03
T4	Rec. chem. fertilizers (RCF)	5.57	5.77
T5	100% basal N thru cake in RCF	6.05	5.45
	CD (5%)	0.86	NS

Similarly, vermicomposting is one of the best methods to convert available quantities of farm and other organic wastes generated in India (700 million t $year^{-1}$) into highly valuable nutrient rich compost with added growth promoting hormones (Nagavallemma *et. al.* 2005).

Short supply of organic manures and competitive uses of farm residues, necessitates to adopt on-farm biomass generation and recycling. *Gliricidia*, a fast growing leguminous tree is most suited in this context to grow on farm bunds for generating green leaf manure rich in N and simultaneously conserving soil through reduced soil erosion. *Gliricidia* loppings applied as chopped material adds nutrients and organic matter and increases productivity of soils (Piara Singh *et. al.* 2007).

Soil microflora in general is a real indicator of soil health and inoculation with efficient strains particularly of N-fixing and P-solubilizing microorganisms can play an important role in increasing nutrient availability and crop yields (Hameeda et. al. 2008; Gan et. al. 2010). The cost effectiveness of biofertilizers in comparison to soil health and yield benefits, are real incentive to adopt it in INM.

CONCLUSION

In view of findings of present study it may be concluded very precisely and accurately that widespread secondary and micronutrient deficiencies have led to a deteriorated soil health which is reason to low fertilizer response and crop yields in rainfed areas of India. The degrading soil health trend can be reversed through a (Soil) science led approach of adoption of soil test based application of deficient secondary and micronutrients to harness existing productivity potential on a sustainable basis. Soil health awareness of stakeholders from farmers to policy makers through a mix of tools is required urgently to address the issues of future food security and livelihood improvements of farmers in SAT regions.

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