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Sustainable soil quality management for enhancing crop productivity in tribal areas of central India: A case study

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Abstract
The objectives of current investigation are to assess soil quality and sustainable management of soils for enhancing crop productivity in the tribal districts (Jhabua, Alirajpur and Dhar) of central India. Field trials were conducted in ten farmers' fields for two years. Soybean-wheat system was adopted in six farmers' fields and maize-wheat system in four farmers' fields. Treatments were integrated plant nutrient supply (IPNS); soil test based nutrient management (STNM); recommended doses of fertilizers (RDF) and farmers' practices (FP). Initial and post experiment soil samples were collected and analyzed. Soil quality changes were also studied. IPNS and STNM practices improved crop yield, farm income and soil quality compared to RDF and FP. Low organic carbon and deficiency of N, S and P are the major soil constraints in the region. Therefore, IPNS and STNM could be practiced to enhance crop productivity, farm income and to maintain soil health in the region.

Keywords: Crop yield, soil management, soil quality index, soil properties, tribal area

Introduction
Soil, together with water and air, constitute the most important natural resource. It is essential to use these resources wisely for sustainable development and feeding the growing world population [2]. Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world [5]. In the past decades, a significant decline in soil quality has occurred worldwide due to adverse side effects of different human activities and contamination by inorganic and organic chemicals used in agriculture and industry [25]. Intensification of agriculture is widely recognized as one of the most significant alterations to the global environment by humans. Concerns have developed, however, over the long-term sustainability and environmental consequences of intensifying agricultural production. In Asia, adverse effects on soil quality arise from soil erosion, loss of organic matter, localized nutrient depletion or excessive fertilization, soil pollution [12]. There is a need for greater as well as more reliable agricultural yield to feed the growing population. It can only be achieved when quality of soil is good enough to produce sufficient food. Interest in soil quality is increasing throughout the world as humankind recognizes the fragility of earth's soil, water, and air resources and the need to protect them for sustained agricultural production.
A better long-range, landscape-scale planning and land-use can be possible by addressing the integrated concept of soil quality. Accurate and consistent assessment of soil quality requires a systematic method for measuring and interpreting soil properties that adequately serve as soil quality indicators [9]. It is very well known that an individual soil property may not be an adequate measure of soil quality. Integrated soil quality indicators based on a combination of soil properties could better reflect the status of soil quality than individual parameters [3, 7]. Soil quality defined as the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation [4, 6, 15]. Soil quality assessment is a tool focus on dynamic soil properties and processes which are useful for assessing the

sustainability of soil management practices. Further assessment of soil quality is necessary to evaluate the degradation status and changing trends following different land use and smallholder management interventions [17].

Sustainable agriculture should involve the successful management of agricultural resources to satisfy changing human needs while maintaining or enhancing the natural resource base, and avoiding environmental degradation. Sustainable agriculture encompasses, but is not limited to, farming systems which are biological, ecologically clean, low-input, organic, and alternative agriculture. These systems emphasize the sustainability of the soil resource that is, along with the other essential resources of water, air, and light, sustaining our food production [11]. Thus, a major concern for sustainable societies should be the impact of soil management practices on the physical, chemical, and biological processes of soils that influence the sustainability of agriculture. The scientific basis of that integration, and the economic and social costs of all such practices that enhance soil quality, must be better understood and incorporated into the development of practices that can be widely implemented. Important questions concerning the definition and remediation of soil quality still need to be addressed. Developing the knowledge to define a healthy or high quality soil and what are the acceptable ranges of soil quality resulting from agricultural practices will require intensive research. Impact of specific farming practices and farming systems on soil properties and soil quality under various climatic conditions needs major attention. Additionally, the possibilities for crop yield improvement in low soil quality areas following soil quality remediation practices need to be investigated. Keeping all the above in mind, the investigation on assessment and sustainable management of soil quality for enhancing crop productivity in tribal areas of Madhya Pradesh has been undertaken to improve soil quality and maintain sustainable crop production for longer period by introducing improved management practices to enhance livelihood status of the tribal farmers.

Materials and Methods
Study area
Tribal dominated economically most backward districts of Madhya Pradesh state in the central India namely Alirajpur, Jhabua and Dhar districts were selected for the study. This region lies in the western part of Madhya Pradesh and comes under Central Plateau and Hills Agro-Climatic Region [1, 16] and Madhya Bharat plateau, western Malwa Plateau, eastern Gujarat plain Vindhya Satpura range and Narmada valley Agro-Ecological Region [8]. It is surrounded by Panchmahal and Baroda districts of Gujarat, Banswara district of Rajasthan, and Indore, Badwani, West Nimar, Ujjain and Ratlam districts of Madhya Pradesh. These districts are a tribal dominated about more than 80% of the total population in case of Alirajpur and Jhabua and more than 60% of total population in Dhar district. Almost half of the population lives below the poverty line. The Bhil and Bhilala are the major tribal peoples inhabit in these districts. This region comprises highly drought-prone and degraded waste lands. Major problems associated in the region are failure of rainfall and low water availability, severe land degradation and soil erosion, undulating topography, shallow soil, low soil water retention capacity, fluoride contamination in ground water, poor crop productivity, single crop per year and mono-cropping, low soil fertility, landless labours or marginal land holdings, agricultural indebtedness, migration, etc. Most of

the rural population in these areas are depends on agriculture for their livelihood. The major crops grown in these districts are maize (both in *kharif* and *rabi* season), soybean, cotton, and black gram in *kharif;* wheat and gram in *rabi*. Some of the minor crops are urd, groundnut, peas, sorghum, pigeon pea, chillies, garlic, potato, onion, tomato, and paddy. The soils are grouped under Entisols and more than 80% of the soils are shallow to medium deep soils [31].

Field experiment
Field trials were carried out in ten farmers' fields at five selected villages of Jhabua (Chotaguda and Bhaglawat), Alirajpur (Rodudah and Bawdi Kurd) and Dhar (Dilawra) districts to compare the different management interventions for enhancing of crop productivity and income of the farmers as well as soil quality. For that initial and final soil samples were collected from ten experimental fields and were analyzed. Soil quality was also assessed.

Experimental details
There were four treatment modules used and were farmers practices (FP), recommended doses of fertilizers (RDF), integrated plant nutrient supply (IPNS) (75% RDF + FYM, 2 t ha^{-1}), and soil test based nutrient management (STNM). The plot size was kept as 10 m length and 10 m width (100 m^2) for each treatment. Crops raised were soybean variety JS 9560 (in 6 farmers' field) and maize hybrid PEHM 2 (in 4 farmers' field) in *kharif* (rainy) season and wheat variety GW 322 (in all the farmers' fields) in *rabi* (winter) season. These experiments were carried out in two consecutive years from 2014-15 and 2015-16.

Description of the treatment
Generally farmers in these districts use only DAP at the time of sowing and small amount of urea for top dressing to maize and wheat. The average fertilizer consumption of these areas was only 26 kg ha^{-1}. Considering the above fact, in the FP about 50% RDs of N and P were applied. In RDF treatment recommended dose of fertilizers were applied through di-ammonium phosphate (DAP), urea and muriate of potash (MOP). The recommended doses of fertilizers were 20 kg N, 60 kg P$_2$O$_5$ and 40 kg K$_2$O ha^{-1} for soybean and 120 kg N, 60 kg P$_2$O$_5$ and 40 kg K$_2$O per ha^{-1} for wheat and maize. In case of IPNS 75% of RDFs through inorganic fertilizers mentioned above and 2 t FYM ha^{-1} to each crop before 15 days of sowing were applied. Whereas in STNM treatments, based on the soil test values of each field fertilizers were applied, if soil test value fell in medium category, then 100% RDF was practiced and if it were low, 25% extra nutrients was supplied over RDF and if it were high, 25% lesser nutrients were supplied than RDF. In STNM treatment, single super phosphate (SSP) was used as P source instead of DAP because all the soils were deficient in available S, hence, to meet the S requirement of crops as well as to avoid more expenses. In RDF, IPNS and STNM, all the fertilizers were applied as basal dose for soybean, whereas in maize and wheat all P and K, and 50% of N were applied as basal dose and the remaining N was applied in two equal splits as top dressing at 30 and 60 DAS. During *kharif* crops were grown in rain-fed conditions and for wheat total 3-4 irrigations were given. Pre-emergence herbicides were used to control the weeds and one hand weeding was done after 45 days. At maturity crops were harvested and seed/grain yield was recorded. At the end of the experiment soil samples were collected in each field and soil quality status was determined.

Soil sampling and analysis

Representative surface soil samples (0-15 cm depth) in the experimental fields before and after the experiment in all the treatment plots were collected. In each plot, soil samples collected from 6 places, mixed thoroughly and compartmenting and quartering method reduced to half kg to get representative sample. Collected soils were air dried, processed, passed through 2 mm sieve and stored. Soil organic carbon [32], pH [14], mineralizable N [29], Olsen P [22],

available K [10], available S [34], DTPA extractable Zn, Fe, Mn and Cu [19] were analysed following the standard procedures.

Soil quality assessment

Expert opinion method was adopted for soil quality assessment. Each of the indicators was divided into four classes namely, Class – I, Class – II, Class - III and Class - IV with an assigned score of 4, 3, 2 and 1, respectively and weights (Table 1).

Table 1: Soil quality indicators and their weights and classes for the evaluation of soil quality

Soil quality indicators	Weight	Class I	Class II	Class III	Class IV
Organic carbon (OC, %)	25	>1	1-0.75	0.75-0.5	<0.5
Soil pH	10	6.5- 7.5	6.5- 6/7.5-8	6- 5.5/8-8.5	<5.5/>8.5
Mineralizable N (kg ha^{-1})	15	>560	560-420	420-280	<280
Olsen P (kg ha^{-1})	10	>25	15-25	15-10	<10
Available K (kg ha^{-1})	10	>280	280-200	200-120	<120
Available S (mg kg^{-1})	10	>25	25-15	15-10	<10
DTPA- Zn (mg kg^{-1})	5	>2.0	2.0-1.0	1.0-0.5	<0.5
DTPA- Fe (mg kg^{-1})	5	>10.0	10-5.5	5.5-2.5	<2.5
DTPA-Mn (mg kg^{-1})	5	>10.0	10.0-4.0	4.0-2.0	<2.0
DTPA-Cu (mg kg^{-1})	5	>2.0	2.0-0.5	0.5-0.2	<0.2
Score	-	4	3	2	1

The soil quality index (SQI) was calculated by the following equation given by Wang and Gong [33].

$$SQI = \sum (W_i \times I_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. (1)$$

Where, Wi was the weight of the indicator and Ii was the marks/score of the indicator class. Thus, summing up of all the 15 indicators provided the SQI value for a particular soil of the farmer's field. In order to judge the SQI value of any site against the theoretical maximum value of SQI (i.e. 400), the concept of relative soil quality index (RSQI) was used. The RSQI was calculated as below:

$$RSQI = \frac{SQI_{sample}}{SQI_{max}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq. (2)$$

Where, SQI$_{sample}$ was the SQI calculated for particular sample using Eq. (1) and SQI$_{max}$ was the maximum SQI value.

Economics

The economic (net gain in Rs.) was calculated from the average yield obtained and fertilizers/manures consumed. The cost of fertilizers were kept as urea Rs. 6/kg, SSP Rs. 6.5/kg, DAP Rs. 22/kg, MOP Rs. 17/kg and FYM Rs. 500 t^{-1}. Further the prices of soybean Rs. 30 kg^{-1}; wheat Rs. 18 kg^{-1}; and maize Rs. 15 kg^{-1}. As all the management practices were common except fertilizers and manures in all the treatments, excess cost incurred and excess income generated in each

treatment when compared to farmers practice was calculated from these data. The difference in these two values was considered as net gain.

Results

Effect on crop yield

The average grain/seed yield of soybean, maize and wheat obtained under various treatments during *kharif* and *rabi* of 2014-15 and 2015-16 were presented in Table 2. It was observed that average soybean yield in FP, RDF, IPNS and STNM across the farmers' fields ranged from 11.76-14.61, 12.48-15.33, 12.39-15.43 and 12.85-15.58 kg plot^{-1}, respectively. Similarly the corresponding values were 15.23-21.26, 16.32-23.12, 16.46-23.26 and 17.09-23.99 kg plot^{-1} for maize; 21.75-26.95, 23.5-28.9, 23.25-29.00 and 24.55-30.10 kg plot^{-1} for wheat, respectively. Across the farmers field two years mean yield under FP, RDF, IPNS and STNM were 13.30, 14.10, 14.28 and 14.52 kg plot^{-1} for soybean; 18.10, 19.48, 19.51 and 20.17 kg plot^{-1}for maize; and 24.15, 25.74, 25.88 and 27.09 kg plot^{-1}for wheat, respectively (Table 2). The percent increase in crop yields under RDF, IPNS and STNM over farmers practices were 5.97%, 7.20% and 9.170% for soybean; 7.60%, 7.74% and 11.4% for maize; and 6.6%, 7.20% and 12.2% for wheat respectively (Fig 1). The response was more in maize followed by wheat and soybean to nutrient applications.

Table 2: Mean soybean, maize and wheat yields of two years (2014-15 and 2015-16)

Village	FP (kg plot^{-1})		RDF (kg plot^{-1})		IPNS (kg plot^{-1})		STNM (kg plot^{-1})	
	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat	Soybean	Wheat
Chotaguda	14.1	26.1	14.9	28.4	15.2	28.4	15.6	29.8
Dilawra	13.3	22.2	14.2	24.0	14.6	24.2	14.8	25.8
Bawdi Kurd	11.8	21.9	12.5	23.1	12.6	23.3	12.9	24.6
Bhaglawat	12.7	21.8	13.7	23.4	13.7	23.4	14.0	24.6
Dilawra	14.6	26.2	15.3	27.6	15.4	28.0	15.6	29.1
Rodudah	13.3	21.9	14.0	23.1	14.1	23.3	14.4	24.4
Mean	13.3	-	14.1	-	14.3	-	14.5	-
	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat
Chotaguda	21.3	27.0	23.1	28.6	23.3	29.0	24.0	30.0
Bhaglawat	16.7	24.1	18.2	25.2	18.0	25.5	18.6	26.3

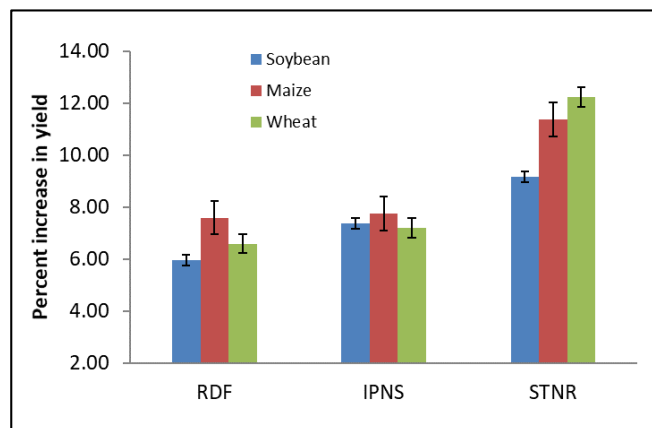|								
Bawdi Kurd	15.2	23.7	16.3	25.4	16.5	25.3	17.1	26.5
Rodudah	19.2	26.9	20.3	28.9	20.3	28.6	21.0	30.1
Mean	18.1	24.2	19.5	25.7	19.5	25.9	20.2	27.1

Fig 1: Percent mean yield increase under different management practices over farmers' practices

Influence on soil properties

After two years of experiment, there was significant improvement in SOC (from 0.61-0.68%), mineralizable-N (from 242-261 kg ha^{-1}) Olsen P (from 9.71-13.6 kg ha^{-1}) and available S (7.09-8.2 mg kg^{-1}) to STNM and IPNS practices. Practice of RDF maintained these soil properties, whereas FP caused the significant reduction in available K and slight reduction in OC, N, and S. As soils were already sufficient in all the micronutrients, there were no significant changes observed (Table 3).

Table 3: Change in soil properties under different management practices

Soil Properties	Initial	FP	RDF	IPNS	STNM
pH	6.96	7.12	7.17	6.90	7.29
Organic carbon (OC, %)	0.61	0.58	0.62	0.68	0.66
Mineralizable N (kg ha^{-1})	242	232	245	257	261
Olsen P (kg ha^{-1})	9.71	10.6	12.2	12.9	13.6
Available K (kg ha^{-1})	434	411	434	439	446
Available S (mg kg^{-1})	7.09	6.89	7.68	7.96	8.42
DTPA- Zn (mg kg^{-1})	1.54	1.49	1.53	1.75	1.48
DTPA- Fe (mg kg^{-1})	30.5	29.8	29.2	32.2	28.3
DTPA-Mn (mg kg^{-1})	33.6	31.2	31.0	30.8	30.7
DTPA-Cu (mg kg^{-1})	6.56	6.37	6.23	6.19	6.49

Values are mean of the ten farmers' field data

Soil quality improvement

The mean RSQI value had improved from 61.8% to 66.5% in IPNS, 65.9% in STNM, 62.8% in RDF. Whereas in farmers practice the soil quality was deteriorated (RSQI=63.7%) (Table 4). It was clear that IPNS, STNM and RDF improved the soil quality status of farmers' field, whereas in FP, soil quality was deteriorated when compared to initial soil quality status. Poor soil organic carbon and nutrient deficiencies particularly N, S, and P are the major indicators that constraint soil quality in this region.

Table 4: Changes in soil quality status under various management interventions

Farmer	Village	RSQI (%)				
		Initial	Final (after two years)			
			FP	RDF	IPNS	STNM
F$_1$	Chotaguda	53.8	53.8	53.8	62.5	62.5
F$_2$	Dilawra	58.8	52.5	58.8	62.5	61.3
F$_3$	Bawdi Kurd	67.5	61.3	67.5	70.0	72.5
F$_4$	Bhaglawat	67.5	66.3	70.0	70.0	70.0
F$_5$	Dilawra	76.3	63.8	76.3	76.3	76.3
F$_6$	Rodudah	51.3	51.3	51.3	57.5	51.3
F$_7$	Chotaguda	58.8	61.3	61.3	67.5	67.5
F$_8$	Bhaglawat	67.5	60.0	70.0	70.0	70.0
F$_9$	Bawdi Kurd	55.0	55.0	55.0	53.8	55.0
F$_{10}$	Rodudah	61.3	57.5	63.8	75.0	72.5
Mean		61.8	58.3	62.8	66.5	65.9

Economics

Expenses incurred, income generated, and net gain obtained in various management interventions was depicted in Table 5. It was found that the excess cost incurred (Rs. ha^{-1}) in RDF, IPNS and STNM were 1533, 1719 and 2347 for soybean; 1922, 1936 and 2632 for maize and wheat, respectively over FP. The excess income generated (Rs. ha^{-1}) in the corresponding treatments over FP were 2383, 2943 and 3655 for soybean, 2072, 2113 and 3096 for maize and 2871, 3121 and 5301 for wheat, respectively. Therefore farmers could get higher excess net gain (Rs. ha^{-1}) of 1308, 464 and 2669 by growing soybean, maize and wheat, respectively by adopting STNM. Similarly the excess net gains were (Rs. ha^{-1}) 1224, 177 and 1185 for IPNS and 850, 150, and 949 for RDF practices in these crops (Table 5).

Table 5: Excess cost incurred, excess income generated and net gain due to management interventions

Practices	Cost of fertilizers and manures (Rs.ha^{-1})			Income (Rs.ha^{-1})			Excess Cost incurred over FP (Rs.ha^{-1})			Excess income over FP (Rs.ha^{-1})			Net gain (Rs.ha^{-1})		
	S	M	W	S	M	W	S	M	W	S	M	W	S	M	W
FP	1723	2024	2024	39893	27150	43461	-	-	-	-	-	-	-	-	-
RDF	3256	3946	3946	42275	29222	46332	1533	1922	1922	2383	2072	2871	850	150	949
IPNS	3442	3960	3960	42835	29263	46582	1719	1936	1936	2943	2113	3121	1224	177	1185
STNM	4070	4656	4656	43548	30246	48762	2347	2632	2632	3655	3096	5301	1308	464	2669

S-Soybean; M-Maize; W-Wheat

Discussion

Fertility status of the soils is low particularly in case of OC, N, S and P. Soil quality of the region is also found to be very poor. The poor soil fertility and soil quality of the study area are due to low soil organic carbon, excessive nutrient mining, soil erosion, etc. The low soil organic carbon in these soils are because of higher temperatures and poor management practices such as inadequate and imbalanced supply of manures and fertilizers, poor soil and water conservation practices, mono-cropping for a longer period. Similar results are reported by many workers that high temperature in summer might have led to loss of soil organic matter and depletion of soil organic carbon because of imbalance nutrient management [18]. Further nutrient mining is found to be higher in imbalanced fertilizer treatments than balanced fertilizers applied treatments [23, 24, 27]. The field experiments across ten

farmers' fields in the region disclose that improved management practices like STNM and IPNS have improved the crop yield, farmers' income and soil quality. All management interventions have showed better crop yield compared to FP. The STNM treatment has edged over other practices. This is followed by IPNS and RDF. This is due to adequate need based balance supply of nutrients in STNM and reduction of nutrient loss, enhanced and prolonged nutrient availability along with organic matter induced microbial activity in IPNS. Similarly, IPNS and balanced fertilization practices are found to be sustained the different agricultural production systems [20, 21, 28, 30]. Integrated nutrient management, balanced nutrient use with high nutrient use efficiency, choice of cropping system, green manuring, etc are technological options for improving soil C buildup in India [18]. Further soil quality improved due to management practices are in the order of IPNS>STNM>RDF. The higher soil quality enhancement in improved management practices are results of high organic C and available nutrients particularly S and P due to addition of organic matter and balanced fertilization. Whereas in FP soil quality has degraded because of depletion of organic carbon and excess nutrient mining due to inadequate supply on manures and fertilizers. The soil properties like OC, P and S has improved in IPNS treatments as a result of addition of FYM and balanced fertilizers. Similarly in STNM also these parameters increased owing to adequate application of deficient nutrients. Further soil quality also has enhanced in these practices. Though the changes are not much in long run it will be beneficial. Moreover the soils in the study area have shallow depth and are prone to erosion because of undulating topography and poor management practices. Major soil texture found in these districts are sandy loam which is reported to be poor in water holding capacity and are conducive to loss of applied fertilizers by leaching process than other textural classes such as loam, clay loam, sandy clay loam, clay, etc [13, 26]. Therefore soil and water conservation practices along with the nutrient management intervention will be of more advantageous in sustaining crop production in the region.

Table S1: Soybean and Maize yield during *kharif* 2014-15

Farmer	Village	Variety	FP (kg/plot)	RDF (kg/plot)	IPNS (kg/plot)	STNM (kg/plot)
Soybean						
F_1	Chotaguda	JS 9560	13.5	14.0	14.3	14.5
F_2	Dilawra	JS 9560	12.9	13.5	13.8	14.0
F_3	Bawdi Kurd	JS 9560	11.9	12.5	12.6	12.8
F_4	Bhaglawat	JS 9560	13.1	13.9	14.0	14.1
F_5	Dilawra	JS 9560	14.1	14.6	14.9	15.1
F_6	Rodudah	JS 9560	12.4	12.1	13.0	13.2
Maize						
F_7	Chotaguda	PEHM 2	20.1	21.9	22.1	22.7
F_8	Bhaglawat	PEHM 2	16.3	17.4	17.2	17.9
F_9	Bawdi Kurd	PEHM 2	15.0	15.8	16.0	16.7
F_{10}	Rodudah	PEHM 2	18.4	19.3	19.3	19.7

Table S2: Wheat yield during *rabi* 2014-15

Farmer	Village	Variety	FP (kg/plot)	RDF (kg/ plot)	IPNS (kg/plot)	STNM (kg/plot)
F_1	Chotaguda	GW 322	24.7	26.9	27.1	28.4
F_2	Dilawra	GW 322	21.3	23.4	23.7	24.5
F_3	Bawdi Kurd	GW 322	20.9	21.8	22.0	23.1
F_1	Bhaglawat	GW 322	21.1	22.8	23.0	23.9
F_5	Dilawra	GW 322	26.0	27.4	27.8	28.9
F_6	Rodudah	GW 322	21.6	22.7	22.9	24.2
F_7	Chotaguda	GW 322	27.2	28.6	29.1	30.3
F_8	Bhaglawat	GW 322	24.5	25.3	25.9	26.4
F_9	Bawdi Kurd	GW 322	22.8	23.9	24.3	25.3
F_{10}	Rodudah	GW 322	25.3	27.3	27.2	28.1

Table S3: Soybean/Maize yield during *kharif* 2015-16

Name	Village	Variety	FP (kg/plot)	RDF (kg/plot)	IPNS (kg/plot)	STNM (kg/plot)
Soybean						
F_1	Chotaguda	JS 9560	14.7	15.8	16.1	16.6
F_2	Dilawra	JS 9560	13.2	15.0	15.4	15.6
F_3	Bawdi Kurd	JS 9560	11.6	12.4	12.6	12.9
F_4	Bhaglawat	JS 9560	12.3	13.5	13.5	13.8
F_5	Dilawra	JS 9560	15.1	16.0	16.0	16.1
F_6	Rodudah	JS 9560	14.2	15.2	15.3	15.6
Maize						
F_7	Chotaguda	PEHM 2	22.4	24.4	24.4	25.3
F_8	Bhaglawat	PEHM 2	17.1	19.0	18.9	19.2
F_9	Bawdi Kurd	PEHM 2	15.5	16.8	16.9	17.5
F_{10}	Rodudah	PEHM 2	20.1	21.3	21.3	22.3

Table S4: Wheat yield during *rabi* 2015-16

Name	Village	Variety	FP (kg/plot)	RDF (kg/ plot)	IPNS (kg/plot)	STNM (kg/plot)
F_1	Chotaguda	GW 322	27.5	29.8	29.7	31.1
F_2	Dilawra	GW 322	23.0	24.5	24.7	27.1
F_3	Bawdi Kurd	GW 322	22.9	24.3	24.5	26.1
F_1	Bhaglawat	GW 322	22.4	23.9	23.8	25.2
F_5	Dilawra	GW 322	26.4	27.8	28.1	29.2
F_6	Rodudah	GW 322	22.1	23.5	23.6	24.6
F_7	Chotaguda	GW 322	26.7	28.5	28.9	29.6
F_8	Bhaglawat	GW 322	23.6	25.1	25.0	26.1
F_9	Bawdi Kurd	GW 322	24.5	26.8	26.3	27.6
F_{10}	Rodudah	GW 322	28.4	30.5	30.0	32.1

Table S5: Changes in Soil pH, OC and mineralizable N

Farmers	pH					OC (%)					Available N (kg ha^{-1})				
	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM
F_1	6.6	6.8	6.9	6.7	7.1	0.33	0.35	0.46	0.54	0.52	165	178	189	198	207
F_2	7.1	7.1	6.9	7.0	7.2	0.52	0.48	0.54	0.61	0.57	208	197	204	215	235
F_3	7.5	7.3	7.1	6.9	7.1	0.78	0.75	0.78	0.80	0.80	227	221	223	225	233
F_1	6.3	6.7	7.1	6.8	7.2	0.85	0.77	0.80	0.85	0.84	289	254	278	293	289
F_5	6.6	7.1	7.3	6.9	7.1	0.82	0.70	0.75	0.81	0.80	305	286	303	310	322
F_6	7.8	8.1	8.0	7.5	8.2	0.42	0.44	0.46	0.52	0.51	231	234	245	261	263
F_7	6.3	6.5	6.8	6.3	7.1	0.61	0.59	0.61	0.65	0.64	272	251	270	283	291
F_8	6.3	6.6	6.8	6.5	6.9	0.79	0.70	0.74	0.79	0.78	294	267	281	293	295
F_9	7.3	7.1	7.3	6.9	7.4	0.22	0.29	0.33	0.42	0.39	147	159	167	188	179
F_{10}	7.8	7.9	7.5	7.5	7.6	0.74	0.72	0.72	0.79	0.76	282	277	286	301	294

Table S6: Changes in Available P, K and S

Farmers	P					K					S				
	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM
F_1	12.1	12.9	14.5	16.1	15.6	222	209	235	230	247	4.75	4.93	5.95	6.23	7.01
F_2	7.61	9.12	10.2	10.8	11.2	350	319	345	351	354	8.65	8.02	9.31	9.45	9.91
F_3	11.6	13.4	14.6	15.2	16.1	263	250	272	276	280	4.29	4.36	4.92	5.01	5.50
F_1	4.18	6.31	9.40	9.63	9.81	364	347	369	365	372	4.53	5.01	6.03	6.19	6.22
F_5	10.7	9.74	11.4	12.5	14.4	468	451	460	471	471	10.4	9.45	10.2	10.9	11.4
F_6	12.1	12.4	13.9	13.9	14.7	378	354	391	389	397	9.43	9.01	10.1	10.4	10.9
F_7	6.58	8.43	8.95	10.1	10.9	830	762	805	821	839	8.21	8.19	8.95	9.25	9.55
F_8	12.1	12.1	13.6	14.1	14.5	245	236	246	254	255	5.50	5.01	5.50	5.78	6.31
F_9	11.6	12.9	13.4	14.0	14.6	441	425	449	453	458	5.38	5.20	5.61	5.69	6.30
F_{10}	8.53	8.32	10.2	12.4	13.9	780	753	772	781	785	9.75	9.71	10.2	10.7	11.1

Table S7: Changes in DTPA-extractable micronutrients

Farmers	Zn					Cu					Fe					Mn				
	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM	Initial	FP	RDF	IPNS	STNM
F_1	1.52	1.40	1.61	1.63	1.57	7.81	6.45	6.73	7.12	6.80	40.3	39.9	39.0	45.1	38.5	43.5	37.1	41.8	42.9	41.0
F_2	0.91	0.83	0.90	1.03	0.87	6.05	6.19	6.09	5.95	6.11	20.3	19.7	18.4	22.1	18.7	23.5	25.1	22.8	21.0	22.3
F_3	2.42	2.33	2.40	2.69	2.23	4.77	4.68	5.11	4.57	5.04	28.3	28.9	30.1	33.0	27.9	22.6	18.3	16.4	19.9	17.8
F_1	1.13	1.17	1.14	1.34	1.10	11.2	10.1	9.44	10.9	9.89	42.7	43.1	42.1	44.3	42.3	51.2	45.9	44.1	40.9	43.8
F_5	2.05	1.93	2.11	2.43	2.01	9.87	9.49	10.1	9.23	10.7	45.2	42.0	41.0	43.1	39.1	38.4	37.0	36.7	34.4	35.2
F_6	0.82	0.84	0.80	1.11	0.72	0.82	0.97	0.85	1.12	0.87	12.3	12.0	12.2	13.8	12.5	18.4	19.1	17.5	18.2	17.1
F_7	2.72	2.64	2.68	2.98	2.62	8.76	8.59	8.54	7.92	8.74	31.7	33.5	29.2	32.6	29.9	48.5	44.9	45.7	42.7	44.0
F_8	1.64	1.63	1.60	1.65	1.58	10.4	11.2	9.93	9.67	10.9	50.7	47.1	48.0	49.2	44.1	46.3	41.2	42.0	44.5	43.6
F_9	0.61	0.59	0.57	0.97	0.57	2.11	2.17	2.04	1.99	2.08	21.1	19.8	20.2	25.7	18.9	15.0	14.3	15.2	14.7	14.1
F_{10}	1.56	1.54	1.50	1.69	1.49	3.83	3.88	3.45	3.40	3.72	12.8	12.0	11.8	13.4	11.3	28.9	29.4	28.0	28.5	27.6

Conclusions

From the study it is apparent that the soils in the region are deficient in many numbers of available nutrients and have poor soil quality status. Further they are prone to soil erosion due to shallow soil depth, undulating topography and poor management practices. Introduction of improved management interventions like IPNS and STNM have enhanced crop yield, farmers' income and quality of soil. Therefore it is recommended that adoption of improved management practices such as IPNS and STNM in the region could sustain the production system. Moreover impact of long term adoption of soil and water conservation along with these management practices on soil quality and crop productivity in these regions will give more understanding of the subject which is beyond the scope of the current investigation.

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