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Impact of *Albizia procera* benth. based agroforestry system on soil quality in Bundelkhand region of Central India

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ABSTRACT

Agroforestry plays an important role in influencing soil quality indicators but their quantitative assessment in *A. procera* based agroforestry system were not existing in Bundelkhand region of Central India. Hence, study was undertaken at Central Agroforestry Research Institute, Jhansi to develop an additive unified Soil Quality Index (SQI) based on functional scores of soil quality indicators comprising of soil physical, chemical and biological properties, and determine how indicators respond to different management practices. Study was conducted in a well established 10 years old *Albizia procera* Benth. based agroforestry experiment consisting of five treatments viz. control (Pure crop), Pure tree (without inter cropping), zero pruning+ inter cropping, 50% pruning+ inter cropping and 70% pruning + inter cropping. Findings revealed that maximum value of SQI was observed for practice of zero pruning (0.54) closely followed by 50% pruning (0.53) and 70% pruning (0.52). Pure crop had the minimum SQI (0.37). Agroforestry plots *viz*. pure tree, zero pruning, 50% pruning and 70% pruning had improved soil health to the tune of 19.7, 31.3, 31.0 and 30.0 per cent, respectively, over pure crop. It has been observed that biological activities and water holding capacity of soil appears to be the most limiting indicators.

Key words: Indicator, Soil health, Soil quality index, Tree pruning, Semi-arid region

INTRODUCTION

Assessment of soil quality or health in agroforestry acquires more relevance due to expansion of area under agroforests in tropics and sub tropics, and their enhanced contribution toward sustainability of agricultural production. In India, as per one estimate, about 25.72 million ha area has been covered under various types of agroforestry plantations. The task force on Greening India (Anonymous, 2001) has identified a potential of 10 million ha in irrigated lands and 18 million ha in rainfed areas that could be developed through agroforestry on a watershed basis. The main driving force and objective of covering such large area under agroforests is to keep the soil resource productive on sustainable basis.

Soil degradation has become a major global issue in recent years. It has been estimated that the degraded area increased from 10% of the world's arable land in early 1970s (Biswas and Biswas, 1974) to 40% in early 1990 (Oldeman, 1994). In India, nearly 188 Mha land area suffers from one or other kind of land degradation. Various forms of soil / land degradation reduce soil's capacity to perform. Reduction in the functional capacity of soil results in decline of productivity. The declining trends in food grain productivity threaten agricultural sustainability. The concept of agricultural sustainability expressed during last two decades of twentieth century is being magnified in twenty first century because of limited arable land resources, rapid increase in population, conversion of agricultural land to other uses and persistence of hunger and malnutrition in several regions of the world (Lal, 1998). Therefore, the question of agricultural sustainability became extremely relevant and led to considerable interest in productivity trends of long-term experiments (Lal and Stewart, 1995). It is also emphasized that maintaining the quality of natural resource base would ensure sustainability of agricultural production.

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Assessment of soil quality depends on indicators that relate to various soil functions. Depending on approaches *viz*. descriptive or qualitative and quantitative soil quality assessment, the indicators can be observational features of soil or plants growing on it, and measure of physical, chemical and biological soil attributes. The quantitative approach offers greater precision but requires more resources for doing assessment. Before selecting soil quality indicators for assessment programme, the basic fact regarding soil to be given due consideration is that soil quality embraces two general elements *viz*. i) inherent properties of soil or inherent capacity and ii) dynamic nature of soil. The inherent capacity of soil is the result of factors of soil formation- climate, topography, vegetation, parent material and time. Attributes of inherent soil quality such as mineralogy and particle size distribution are almost static and show little change over time. The dynamic nature of soil encompasses those soil attributes that can change over relatively short time in response to human management. These soil attributes are referred as indicators of soil health. Hence, assessment of soil quality refers to assessment of dynamic soil attributes (Doran and Parkin, 1994). The selected indicators of soil quality should have greatest sensitivity to changes in soil function (Andrews *et al*., 2004). It is emphasized that soil quality indicators should correlate well with ecosystem processes; integrate soil processes, accessible to many users and sensitive to management and climate (Daran and Parkin, 1996; Sharma *et al*., 2010). Further, the group of indicators selected to measure soil functions must be sufficiently diverse to represent the chemical, biological and physical properties and processes of complex system.

The overriding objective of agroforestry land use, since its inception with establishment of World Agroforestry Centre in 1977, has been to develop integrated land management systems involving trees, crops and/ or animals, which would contribute substantially to decrease deforestation, increase food production, enhance biodiversity and protect environment (Nair, 1993). It is argued that presence of woody perennials in agroforestry system affects several bio-physical and bio-chemical processes that determine the health of soil substrate. The most obvious effects of trees on soil include amelioration of erosion primarily through surface litter cover and under story vegetation (Gupta and Arora, 2015); maintenance or increase of organic matter and diversity through continuous degeneration of roots and decomposition of litter (Solanki and Arora, 2015); nitrogen fixation; enhancement of physical properties such as soil structure, porosity and moisture retention due to extensive root system and the canopy cover; and absorb and recycle nutrients in the soil that would otherwise be lost through leaching (Sanchez, 1987). Although soil conservation for restoring quality and health of degraded soil has been advocated as primary goal of agroforestry (Young, 1989), the empirical estimates of accrued benefits are lacking due to temporal and spatial complexity of agroforestry systems and soil resource dynamics.

Use of soil quality index (SQI) value based on summarized soil properties to assess soil quality of agricultural and forest ecosystems is well established, however, the systematic information on use of a unified value of SQI to assess impact of various agroforestry systems on soil quality is lacking. Thus, development and application of a soil quality index for evaluation of changes in soil quality caused due to agroforestry practices is needed. Further it is hypothesized that various agroforestry systems being advocated are productive, remunerative and environment friendly; and to prove this hypothesis, it is essential to assess impact of various agroforestry management practices on soil quality. Therefore, the present study was conducted to assess changes in soil quality indicators and soil quality index due to pruning management practices in *Albizia procera* based agroforestry system in semi arid region of Bundelkhand, Central India.

MATERIALS AND METHODS

Site description: The study was carried out at the farm of ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi during 2010. The soil of the experimental farm is inter-mixed black and red soil, which represent *parawa* group of soil of Bundelkhand region covered under the order of Alfisol. The CAFRI farm is situated at 25º 27′ North latitude and 78° 35′ East longitude, 271 meters above mean sea level in the semi-arid tract of central plateau of India. Annual rainfall ranges from 700-1150 mm with a mean value of 958 mm of which, about 80% is received during southwest monsoon. The potential evapo-transpiration is quite high in the range of 1400-1700 mm with moisture index value of - 40 to -50. The pattern of the rainfall is highly erratic and more than 90 per cent of the total rainfall occurs within 10 weeks between July to mid September accompanied by intermittent long dry spells. The entire rainfall is

received in less than 50 rainy days. Winter showers are rare and uncertain. The frequent drought occurs in entire regions. Usually, monsoon commences by the last week of June but sometimes delayed to the first week of July. The active monsoon often withdraws up to the mid of September or the end of August. Mean annual temperature of the Jhansi is generally high with high degree of variation between maximum (39.8^{0}C in June) and minimum (5.8^{0}C in January) temperatures. Sometimes maximum temperature in the summer months of May and June touches 48^{0}C, which is the peak of summer season.

Experimental design and management: The present study was conducted in a well established 10 years old *A. procera* based agroforestry trial consisting of five treatments viz. control (Pure crop), Pure tree (without inter cropping), zero pruning + inter cropping, 50% pruning + inter cropping and 70% pruning + inter cropping during 2010. The trial was laid out in completely randomized block design (CRBD) with three replications. Trees planted at 8x4 m spacing were intercropped with wheat in winter season. The pruned biomass from 50% and 70% pruning treatment was added in soil as green manure in the month of October, at least one month before sowing of wheat as intercrop. Levels of pruning were based on a percentage of green crown length and pruning was done by cutting lower branches from stem or parent branch. Branches were taken out for using as fuel and green twigs/foliage was incorporated in the soil as green manure. Green biomass in the tune of 1.99 t/ha and 2.27 t/ha was added in 50% and 70% pruning treatments, respectively. Wheat *(Triticum aestivum* L. emend.) variety HD 2189 was grown as an inter crop. Standard package of practices of wheat cultivation were followed.

Soil sampling and analyses for soil health indicators: Rrepresentative soil samples were drawn (0-30cm depth) from all treatment plots before sowing of wheat. The soil samples were air dried and sieved to pass through a 2 mm-sieve. For the determination of bulk density, soil cores were collected. Soil samples collected were separately analyzed for physical, chemical and biological properties as listed below. Bulk density (BD) was determined from the soil cores using the procedure given by Veihmeyer and Hendrickson (1948), and porosity was derived from BD using the following formula: porosity (P) = [1- (BD/ PD)]*100, where PD is the particle density determined using a Keen Raczkowald (KR) box (Baruah and Barthakur, 1999). KR box is a circular brass box having an internal diameter of 5 cm and a height of 1.6 cm with perforated bottom having numerous holes of 0.75 mm diameter spaced at 4 mm apart. Maximum water holding capacity (WHC) was determined by equilibrating the soil with water through capillary action in a KR box (Baruah and Barthakur, 1999). Soil pH and EC were determined at 1:2.5 soil–water ratio using a glass electrode and conductivity bridge, respectively. Cation exchange capacity (CEC) was measured by the sodium saturation method (Jackson, 1973). Soil organic carbon (SOC) was determined by dichromate oxidation (Walkley and Black, 1934) and available N by the alkaline potassium permanganate distillation method (Subbiah and Asija, 1956). Available phosphorus (P) in soil was determined by extracting samples with 0.5 M $NaHCO_3$, and determining P colorimetrically using molybdate (Olsen *et al.*, 1954). Available potassium was determined using 1N ammonium acetate extraction followed by emission spectrometry (Jackson, 1973). Microbial biomass carbon was measured by the fumigation extraction method (Jenkinson and Ladd, 1981). Soil dehydrogenase was determined using the method of Klein *et al.* (1971).

Soil quality index (SQI) calculation

Analysis of variance (ANOVA) was performed to determine the effects of pruning treatments in Agroforestry systems on soil quality parameters. For calculating soil quality index (SQI) 12 soil quality indicators *viz*., bulk density, water holding capacity (WHC), porosity, pH, EC, SOC, CEC, available N, P and K; microbial biomass and dehydrogenase activity were as used as parameters. The minimum and maximum threshold values for each indicator are based on the range of values measured from agroforestry systems and on critical values in the literature. After setting thresholds, the soil parameter values recorded under *Albizia procera* based agroforestry system were transformed in to unit less scores (between 0 and 1) and three types of scoring functions *viz*. "More is better", "Less is better" and "Optimum" were generated following Karlen and Stott (1994). Such scoring curves were also used by Masto *et al*. (2007).

Linear scoring function:

LSF (Y) = (x-s)/ (t-s)……(1)

Y = 1-[(x-s)/ (t-s)]…… (2)

Where, Y is the linear score, x is the soil parameter value, s and t are the lower and upper

threshold values. Equation 1 is used for "More is better" scoring function, Equation 2 for "Less is better" and combination of both for "Optimum" scoring function (Fig. 1). If the calculated score is > 1.0, it was considered as 1.0. The individual scores were added up to obtain unified soil quality Index (SQI) as below:

$$SQI = {}_{i=1}\Sigma^{n} Si/n$$

Where, S denotes linear scores of observed soil quality indicator, n is the number of total indicator included in the index.

RESULTS AND DISCUSSION

Effect of pruning management on soil quality indicators

The data relating to mean values of all physical, chemical and biological parameters of soil under different pruning management regimes of *A. procera* based agroforestry system have been presented in Table 1. As revealed from data, pruning of trees significantly affected all studied soil health indicators except water holding capacity, EC and available K. Maximum bulk density was observed in pure tree plot while minimum in 50 % pruning. In comparison to pure crop plot bulk density was reduced in all agroforestry plots *viz*. zero, 50 % and 70 % pruning plots. Maximum porosity was found in 50 % pruning plot while minimum in pure crop. In general, there was increase in porosity in agroforestry plots subjected to pruning management in comparison to pure crop and pure tree plot. As compared to pure crop, soil pH was reduced in agroforestry plots. Maximum soil organic carbon was found in zero pruning plot while minimum in pure crop. There was significant increased in SOC in all agroforestry plots as compared to pure crop. Maximum CEC was found in 70 % pruning plots while minimum in pure crop plot. Pruning management in agroforesty plot significantly increased the CEC. In comparison to pure crop plot, available N increased in agroforestry plot with maximum in 50 % pruning. However, maximum value of available P was observed in zero pruning plot with minimum in pure crop. Maximum microbial biomass was observed in 70% pruning while minimum in pure crop plot. It increased in agroforestry plot with increasing levels of pruning from zero to 70%. Maximum dehydrogenase activity was found in pure tree plot and minimum in pure crop. In general, all agroforestry plots had more dehydrogenase activity than that in pure crop.

The practice of agroforestry for 10 years and tree pruning management brought a significant improvement in physical, chemical and biological parameters of soil, which may be due to increase in SOC, recycling of nutrients through leaf litter and favorable conditions for bio-chemical processes (Sanchez, 1987; Nair, 1993). Increase in SOC in agroforestry plots over pure crop might be due to comparatively resistant organic carbon added through tree pruning/ leaf letter and more root biomass yielded by trees (Ram Newaj *et al*., 2007; Prasad *et al*., 2015). Maximum available P in zero pruning plot may be due to the fact that increase in microbial biomass with dehydrogenase activity in agroforestry plots appears to have triggered biochemical process and transformation of nutrients in soil (Prasad *et al*., 2016).

Table 1. Impact of tree pruning on soil health indicator (0-30cm) values of *A. procera* based Agroforestry system system

Parameters	Treatments						
	Pure crop	Pure tree	Zero Pruning	50% pruning	70% pruning	Mean	LSD (P<0.05)
Bulk density (g/cm^3)	1.44	1.47	1.42	1.41	1.43	1.45	0.03
Water holding capacity (%)	13.83	13.63	15.03	15.42	16.30	14.84	3.14
Porosity (%)	29.63	32.70	34.06	35.28	34.92	33.32	3.08
pH	6.99	6.38	6.20	6.44	6.30	6.47	0.21
EC (dS/m)	0.34	0.20	0.19	0.15	0.18	0.21	Ns
SOC (%)	0.52	0.67	0.76	0.72	0.67	0.67	0.10
CEC (Cmol p+/kg)	11.63	13.13	13.23	15.00	15.17	13.63	2.39
Available N (kg/ha)	150.33	164.50	203.00	205.42	181.50	180.95	50.08
Available P (kg/ha)	11.32	14.34	20.01	19.03	18.37	16.61	3.49
Available K (kg/ha)	113.17	139.37	145.33	137.50	140.67	135.21	Ns
Microbial biomass (ug/g)	127.47	146.40	169.00	197.60	200.67	168.23	43.44
Dehydrogenase activity (ug TPF/g/day)	37.05	76.73	60.13	72.36	60.23	61.30	37.05

Soil Quality Index

Soil quality indicator values were normalized on 0 to 1 scale using linear scoring function and equation 1 and 2. After deciding the shape of anticipated response ('More is better'; 'Less is better' or 'Optimum') the minimum and maximum threshold values were assigned for each indicator (Table 2). From functional score SQI was calculated for all plots. As revealed from Table 2, the calculated SQI was maximum in 50 % pruning plots and minimum in pure crop plot. All agroforestry plots yielded more SQI indicating improvement in soil health. Over the base line reference SQI, the improvement in SQI ranged from 21.47 % in pure crop to 46.08% in zero pruning plot with mean value of 39.06%. The improvement over pure crop brought by agroforestry plots ranged from 19.65% in pure tree to 31.34% in zero pruning plot (Table 3). In comparison lower base line reference SQI, the quality index was found in order: Pure crop< Pure tree< 70% pruning< 50% pruning< zero pruning. The order of SQI over pure crop was in order: zero pruning> 50% pruning> 70% pruning> pure tree.

Use of SQI value based on summarized soil properties to assess soil quality of agricultural and forest ecosystems is well established. Use of index value based summarized soil properties have been used and suggested to assess soil quality of agricultural systems (Doran and Parkin, 1996; Kang *et al*., 2005). While evaluating sustainability of rice-wheat cropping system on a Vertisol in India, Mohanty *et al*. (2005) developed a soil quality index (SQI) based on bulk density (BD), penetration resistance (PR), water stable aggregates (WSA) and soil organic matter (OM) and concluded that SQI values of 0.84–0.92, 0.88–0.93 and 0.86–0.92 were optimum for rice, wheat and the combined system of rice + wheat, respectively. Sharma and Arora (2010) developed relative soil quality and production efficiency indices for maize-wheat in agro-climatic conditions of Himalayan ecosystem involving soil and climatic variables. Similar to agricultural systems, SQI has also been used to assess forest soil health. To assess trends in forest soil health under forest inventory analysis (FIA), a single value SQI integrating 19 physical and chemical properties of soil has been developed by Amacher *et al*. (2007) to monitor changes in soil

Table 2. Soil health indicator (0-30cm) values and their functional scores in soil of *A. procera* based agroforestry system

Indicator	Threshold		Reference/ value	Function	Score	Treatments				
	lower	Upper	Baseline		Reference	Pure crop	Pure tree	Zero pruning	50% pruning	70% pruning
Bulk density (g/cm^3)	1.3	2.1	1.66	Less is better	0.55	0.83	0.79	0.85	0.76	0.83
Water holding capacity (%)	10	25	12	more is better	0.13	0.26	0.24	0.34	0.36	0.42
Porosity (%)	20	80	31	optimum	0.18	0.19	0.21	0.23	0.26	0.25
pH	5.5	8.5	6.5	optimum	0.33	0.50	0.71	0.77	0.69	0.73
EC (dS/m)	0.2	4	0.5	Less is better	0.92	0.96	1.00	1.00	1.00	1.00
SOC (%)	0.2	1	0.4	more is better	0.25	0.40	0.59	0.70	0.65	0.59
CEC (Cmol P+/kg)	5	25	10	more is better	0.25	0.33	0.41	0.41	0.50	0.51
Available N (kg/ha)	80	250	140	more is better	0.35	0.41	0.50	0.72	0.74	0.60
Available P (kg/ha)	8	25	10	more is better	0.12	0.20	0.37	0.71	0.65	0.61
Available K (kg/ha)	100	300	140	more is better	0.20	0.07	0.20	0.23	0.19	0.20
Microbial biomass (ug/g)	50	400	75	more is better	0.07	0.22	0.28	0.34	0.42	0.43
Dehydrogenase activity (ug TPF/g/day)	25	275	50	more is better	0.10	0.05	0.21	0.14	0.19	0.14
SQI					0.29	0.37	0.46	0.54	0.52	0.53

properties of forest soil with time. They assigned an index value to each soil property and all individual index values were summed up to obtain a SQI. The SQI values were developed for six FIA plots of the United States. The average SQI values varied from 43% to 67% for different FIA plots. The lower values of SQI observed in present study indicate that soil used for agroforestry experiment was degraded and agroforestry practices brought improvement ranging from 19.65 to 31.34% over pure crop plot which, proves the hypothesis that practicing agroforestry with proper tree management restores degraded land and improves soil quality (Table 3).

CONCLUSION

The results of the study, apart from its scientific value, will have practical implications in bridging the gap in using SQI value based on summarized soil properties to assess soil quality of various agroforestry systems. Further, our findings proved the hypothesis that agroforestry is vital for restoration and revitalization of poor and marginal land resource. The low value of base line (reference) SQI (0.29) indicate that the soil health of Bundelkand region is poor and practice of agroforestry holds the potential to improve soil quality ranging from 19.7 to 31.3% after 10 years. The better effect of tree pruning on SQI confirms that the pruning of tree components in any agroforestry system is crucial for sustainability of land resource and productivity.

Table 3. Effects of tree pruning on soil quality index of *A. procera* based agroforestry system

Treatments	Soil Quality Index	% Over baseline	% over pure crop
Baseline (Reference)	0.29	-	-
Pure crop	0.37	21.47	-
Pure tree	0.46	36.90	19.65
Zero Pruning	0.54	46.08	31.34
50% Pruning	0.53	45.78	30.96
70% Pruning	0.52	45.06	30.04
Mean		39.06	28.00

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