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Effect of tree canopy management in agroforestry system on soil quality in central India

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Abstract
The present study dealt with the effect of canopy management of *Albizia procera* (planted at 8 m × 4 m spacing) in a 10-years old agroforestry system on soil quality indicators. Study comprised of five treatments *viz*., control (pure crop *i.e*. wheat), pure tree (without intercropping), zero pruning + intercropping, 50% pruning + intercropping and 75% pruning + intercropping. Soil samples were taken from all treatment plots and analyzed for 15 physical, chemical and biological properties. The quality of the soil was assessed by using two approaches *viz*., linear score function (LSF) and principal component analysis (PCA). Based on nature of land-use and management goal, minimum data set was identified. Soil properties which play important role in soil quality and soil functions in hot semi-arid region of northern plains were identified. The indicator values were converted into unit-less scores (0 to 1), based on critical values; and these scores were integrated into a single soil quality index (SQI) with the help of PCA. Tree pruning significantly affected most of the soil quality indicators. Maximum SQI was observed from 50% pruning plot (0.489) and minimum from pure crop (0.356). The improvement in SQI over experimental control ranged from 17.42 to 37.36%. The PCA revealed that soil organic carbon, microbial biomass carbon, porosity, water holding capacity and bulk density of soil were important contributing indicators in soil quality. The SQIs based on LSF and PCA were found highly correlated with biomass yield and had sensitivity of 1.38 and 2.00, respectively.

Keywords: *Albizia procera*, Soil health, Soil quality index, Tree farming, Tree pruning

Introduction
Soil is an important natural resource that provides food, fuel, fodder, timber etc. to us. Unfortunately, in modern times, it has been exploited mercilessly that resulted in enhanced rate of land degradation (Mythili and Goedecke, 2016). As per an estimate, India has 329 million ha land area, out of which 178 million ha (54%) is degraded wasteland (Dave *et al*., 2011). The total cultivable land in the country is about 144 million ha of which 56% (80.6 million ha) is degraded due to faulty agricultural practices. The intensive mining of nutrients from the soil has limited the output from agriculture. This has compelled scientific interventions for alternative land-use system. The practice of agroecosystem simplification has resulted in enhanced interest in agroforestry that can rehabilitate the degraded lands (de Carvalho *et al*., 2010).

Agroforestry, comprising of trees, crops and pastures plays an important role in improving soil fertility and its quality by several ways (Prasad *et al*., 2016). Out of the benefits associated with agroforestry in terms of soil quality, nutrient cycling is the most predominant process (Newaj *et al*., 2007). In a soil-plant system, plants take up nutrients from the soil and use them for metabolic activities. In-turn, these nutrients are returned back to the soil either naturally as litter fall (in unmanaged system), as pruned materials (in agroforestry system) or through root senescence. The microbes present in the soil decompose these plant parts and release nutrients into the soil. Apart from this, agroforestry also contributes in built up of organic matter in the soil (Prasad *et al*., 2015). According to de Carvalho *et al*. (2010), agroforestry have potential to control both water and wind erosion, which ultimately reduces the loss of soil organic matter.

Soil quality is considered a key element of any land-use system. Assessment of soil quality refers to measurement of relative changes in soil characteristics over time (Cardoso *et al*., 2013). The assessment depends on indicators that relate to various soil functions

(Gelaw *et al*., 2015). According to Andrews *et al.* (2004), the selected indicators of the soil quality should have greatest sensitivity to changes in soil function and climate. The indicators should correlate well with ecosystem and soil processes (Doran and Parkin, 1996). Further, the group of indicators selected to measure soil functions must be sufficiently diverse to represent the physical, chemical and biological properties, and processes of complex system (Brejda *et al*., 2000).

For assessment of the soil quality, various indices have been proposed for agricultural soils (Notaro *et al*., 2014). The indexing involves three main aspects: selection of appropriate indicators for a minimum data set (MDS); transformation of the indicators to scores; and combining the scores into an index (Masto *et al*., 2015). Though there are several studies on the assessment of soil quality index (SQI) of agricultural and forest ecosystems (Ghaemi *et al*., 2014), but the systematic information on use of a unified value of SQI to assess impact of agroforestry systems on soil quality is meager (Parra-González and Rodriguez-Valenzuela, 2017). In agroforestry system, total number of trees on a given unit of land and their canopy management may influence the productivity of the system (Newaj *et al*., 2003; Prasad *et al*., 2011; Palsaniya *et al*., 2012). Hence, a study was conducted to assess the changes in soil quality indicators and thus, SQI due to canopy management of *Albizia procera* (Roxb.) Benth. (a leguminous multipurpose tree) in a 10-years old agroforestry system in semi-arid region of Bundelkhand uplands, central India.

Materials and Methods

***Site description*:** The study was conducted at ICAR-Central Agroforestry Research Institute, Jhansi (24° 11' N and 78° 17' E), India during 2011-16. Mean annual rainfall of the region is 960 mm, with an average of 52 rainy days per year. The pattern of the rainfall is highly erratic and intermittent dry spells are very common. Evapo-transpiration rate is quite high (1400-1700 mm).Mean maximum temperature ranges from 23.5 °C (January) to 47.4 °C (June) and mean minimum temperature from 4.1 °C (December) to 27.2 °C (June). The maximum recorded temperature on a particular day often touches 47-48 °C in the summer. The main soil type at the experimental farm of the institute is inter-mixed black and red soil, covered under the order of Alfisol. The topography of the region is undulating.

***Experimental design and management*:** The present study was conducted in a well-established 10-years old *Albizia procera* based agroforestry system, comprising of five treatments *viz*., control (pure crop), pure tree (without intercropping), zero pruning + intercropping, 50% pruning + intercropping and 75% pruning + intercropping, and each treatment was replicated three times in completely randomized block design. In pure crop and agroforestry plots, *Triticum aestivum* L. (var. HD 2189) was grown as sole and understory crop, respectively; and in pure tree plot, no intercropping was done. Recommended package of practices for *T. aestivum* cultivation were followed. Trees of *A. procera* were planted at 8 m × 4 m spacing. In agroforestry plot, three pruning treatments (0, 50 and 75% pruning) were employed. Level of pruning was based on percentage of green crown length. Pruning was done at least one month prior to sowing of *T. aestivum i.e.* in the month of October. The pruned biomass (1.99 t/ha and 2.27 t/ha in 50 and 75% pruning treatments, respectively) was added in the soil as green manure.

***Soil sampling and analysis for soil health indicators*:** Representative soil samples were drawn (0-30 cm depth) from all the treatment plots before sowing of the wheat. The soil samples were air-dried, sieved (2 mm sieve) and analyzed for physical, chemical and biological properties. The bulk density (BD; g/cm^3) was determined using the procedure given by Veihmeyer and Hendrickson (1948) and porosity (POR: %) was derived from BD using the formula: POR = [1 - (BD/PD)] × 100, where PD is the particle density determined by using Keen Raczkowald (KR) box (Baruah and Barthakur, 1999). 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 electrical conductivity (EC; dS/m) were determined at 1:2.5 soil–water ratio by using pH tester (Waterproof pH Tester 30; Eutech Instruments; Thermo Scientific) and EC tester (Waterproof EC Tester 11+; Eutech Instruments; Thermo Scientific). Cation exchange capacity (CEC; meq/100 g) was measured by the sodium saturation method (Jackson, 1973). Soil organic carbon (SOC; %) was determined by dichromate oxidation (Walkley and Black, 1934), available nitrogen (N; kg/ha) by the alkaline potassium permanganate distillation method (Subbiah and Asija, 1956), available phosphorus (P; kg/ha) by extracting samples with 0.5 M $NaHCO_3$ and determining P colorimetrically using molybdate (Olsen *et al*., 1954), and available potassium (K; kg/ha) by 1 N NH_4OAc (pH 7) as an extractant (Jackson, 1973). Microbial biomass carbon (MBC; ug/g) was measured by fumigation extraction method (Jenkinson and Ladd, 1981), soil dehydrogenase activity (DHA; ug TPF/g/day) using the method of Klein *et al.* (1971) and potentially mineralizable nitrogen (PMN; kg/ha/week) using the method of Chhonkar *et al.* (2007).

Development of soil quality index: Soil quality was assessed by using two approaches, function-based (Masto *et al*., 2007) and statistical tool like principal component analysis (PCA)-based assessment (Andrews and Carroll, 2001; Sharma *et al*., 2005). For assessing the soil quality, minimum data set (MDS) comprising of soil properties *viz*., rooting depth, WHC, SOC, CEC, MBC, DHA, PMN, POR, infiltration rate (IR), pH, EC, BD and available, N, P and K was identified. The indicators that were selected as part of MDS relate to various soil functions, sensitive to changes in soil function and climate, and correlate well with ecosystem and soil processes (Doran and Parkin, 1996; Andrews *et al*., 2004; Gelaw *et al*., 2015). Besides, selected group of indicators were sufficiently diverse to represent the physical, chemical and biological properties (Brejda *et al*., 2000). Due consideration was also given to nature of land-use and management goal for identifying the MDS. In the present study, sustainable biomass productivity was considered to explain the function of the soil. Indicator weights were derived by using PCA. Then, indicator values were converted into unit-less scores (0 to 1), based on critical values. Thereafter, indicator scores were integrated into a single SQI with the help of PCA. SQI thus derived was calibrated by comparing the SQI values with the end point variables like biomass yield (Andrews *et al*., 2002). After calibration, a radar plot of the scores was drawn to identify limiting soil parameters.

Indicator transformation (scoring): In the present study, critical values were obtained by analyzing soil from different agroforestry systems, including natural agricultural system at our institute. The minimum and maximum threshold values for each indicator were fixed on the basis of range of values measured from agroforestry systems and critical values in the literature (Prasad *et al*., 2017; 2019) (Table 1). After setting the thresholds, reference values were established as baseline. Soil parameter values recorded from agroforestry systems were transformed in to unit-less scores (between 0 and 1) and three types of linear scoring functions (LSF) *viz*., “More is better”, “Less is better” and “Optimum” were generated following Karlen and Stott (1994). The LSF are given below:

$$LSF\ (Y) = (x\text{-}s)/\ (t\text{-}s)\ldots\ldots\ldots\ (1)$$

$$Y = 1\text{-}[(x\text{-}s)/\ (t\text{-}s)]\ldots\ldots\ldots\ldots\ (2)$$

Where, Y is the linear score; x is soil parameter value; s and t are lower and upper threshold values. Equation 1 was used for “More is better”, Equation 2 for “Less is better” and combination of both for “Optimum” scoring function. If the calculated score is > 1.0, it was considered as 1.0.

Table 1. Threshold values of selected soil quality indicators and scoring functions

Soil indicator	Threshold		Reference/value	Function
	Lower	Upper	Baseline	
Rooting depth (cm)	50	250	100	More is better
WHC (%)	10.00	25	12	More is better
SOC (%)	0.2	1	0.4	More is better
CEC (Cmol p+/kg)	5.00	25	12	More is better
Available N (kg/ha)	80	250	150	More is better
Available P (kg/ha)	8	25	12	More is better
Available K (kg/ha)	100	300	180	More is better
MBC (ug/g)	50	400	150	More is better
DHA (ug TPF/g/day)	25	275	100	More is better
PMN (kg/ha/week)	25	200	75	More is better
POR (%)	20	60	31	Optimum
IR (cm/hr)	1	4	2	Optimum
pH (1:2.5 soil: water ratio)	5.5	8.5	7	Optimum
EC (dS/m)	0.2	4	0.5	Less is better
BD (g/cm^3)	1.3	1.8	1.6	Less is better

WHC: Water holding capacity; SOC: Soil organic carbon; CEC: Cation exchange capacity; MBC: Microbial biomass carbon; DHA: Soil dehydrogenase activity; PMN: Potentially mineralizable nitrogen; POR: Porosity; IR: Infiltration rate; EC: Electrical conductivity; BD: Bulk density

Computation of soil quality index

***Unscreened transformation*:** Individual scores of each indicator were aggregated to obtain unified SQI as below:

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

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

***Principal component analysis (PCA)*:** Standardized PCA of all data (untransformed) was performed. Principal components (PCs) with eigen value e"1, explained at least 5% of the variation of the data (Wander and Bollero, 1999; Sharma *et al*., 2005). Under a particular PC, variables with high factor loading only were retained for soil quality indexing. High factor loading was defined as having absolute value within 10% of the highest factor loading (Wander and Bollero, 1999; Andrews *et al*., 2002; Sharma *et al*., 2005). When more than one variable was retained under a single PC, correlation matrix was employed to determine if the variables could be considered redundant and, therefore, eliminated from the SQI (Andrews *et al*., 2002). If the highly loaded factors were not correlated, then each was considered important, and thus retained in the SQI. Among well-correlated variables, the variable with the highest factor loading was chosen for the SQI. Each PC explained a certain amount of variation (%) in the total data set; this percentage provided the weight for variables chosen under a given PC. The final equation for PCA based SQI was as below: $SQI = {}_{i=1}\Sigma^{n}\ Wi \times Si$

Where, W was the PCA weighing factor; and S was the indicator's score. The equation finally normalized to get a maximum SQI of one.

***Evaluation of soil quality index*:** The indexing procedure was evaluated by correlation coefficient between SQI values and biomass productivity. Biomass productivity data ranged from 10.47 to 85.70 t/ha in different treatments (Dar and Newaj, 2007). The sensitivity was calculated as below:

$$\text{Sensitivity (Si)} = SQI_{(max)} / SQI_{(min)}$$

Where, $SQI_{(max)}$ and $SQI_{(min)}$ were the maximum and minimum SQIs observed for each treatments, respectively.

***Statistical analysis*:** Analysis of variance (ANOVA) was performed to determine the effects of pruning treatments in agroforestry systems on soil quality parameters. Soil quality indicators were tested for their level of significance at P=0.05. For statistical analysis of data (PCA, scoring functions) Microsoft Excel and XLSTAT (free download version) were used. All the graphs were prepared using Microsoft Excel.

Results and Discussion

***Effect of pruning management on soil quality indicators*:** Pruning of trees significantly affected all studied soil quality indicators, except WHC, EC, PMN and available K (Table 2). Rooting depth and IR were uniform for all treatments. Significantly higher BD was observed in pure tree plot. Its lower values were recorded in agroforestry plots when compared with pure crop plot. Maximum POR was found in 50% pruning which was comparable with other agroforestry plots, while it was recorded minimum in pure crop plot. Significantly higher soil pH was recorded in pure crop plot than agroforestry plots. Maximum SOC was found in zero pruning, which was significantly higher than other agroforestry treatments. Maximum CEC was found in 75% pruning plot, which was at par with other treatments. Its minimum value was recorded in pure crop plot. In comparison to pure crop plot, maximum available N was recorded in 50% pruning, which was at par with other agroforestry treatments and significantly higher than pure crop. Maximum value of available P was observed in zero pruning and its minimum value was recorded in pure crop plot. Maximum MBC was observed in 75% pruning, followed by 50% and zero pruning. Its least value was recorded in pure crop. Maximum DHA was found in pure tree plot which was at par with other agroforestry treatments. Its minimum value was recorded in pure crop.

Thus the results showed that practice of agroforestry for 10 years and tree pruning management significantly improved physical, chemical and biological indicators when compared with pure crop cultivation. This could be due to the increase in SOC, recycling of nutrients through leaf litter and favorable conditions for bio-chemical processes. According to Prasad *et al*. (2015) and Newaj *et al*. (2007), increase in SOC in agroforestry plots over pure crop plot might be due to comparatively slow decomposable organic carbon added through tree pruning/leaf litter and more root biomass yielded by trees. As per the results, agroforestry practice significantly increased MBC and DHA which signifies that trees help in harboring microbes by providing favorable conditions. The increase in available N, P and K in agroforestry plots over pure crop plot can be attributed to enhanced MBC and DHA which might have triggered biochemical processes and transformation of nutrients in soil (Prasad *et al*., 2016). Enhanced values of soil quality indicator in agroforestry plots could be due to *A. procera*, which is a leguminous tree species. According to Zeng *et al*. (2010), legumes can produce high quality residues and thus have the potential to promote nutrient cycling. Further, results showed that values of available P decreased with the increase in pruning intensity in agroforestry plots. This could be due to more competition between trees and intercrops which resulted in less availability of P (Shukla *et al*., 2009; Prasad *et al*., 2011). Addition of pruned material in soil appeared to have reduced BD and thus increased POR and WHC. Reduction in BD and improvement in POR and WHC were also reported in improved natural and traditional agroforestry systems based on Cacao in Peruvian Amazon (Arevalo-Gardini *et al*., 2015).

Development of soil quality index

***Unscreened transformation based soil quality index*:** Results revealed that SQI, calculated on the basis of functional scores, was maximum in 50% pruning plot while minimum in pure crop plot (Table 3). All agroforestry plots showed more SQI indicating improvement in soil health. Over the base line reference SQI, the improvement in SQI ranged from 0.3 (pure crop) to 37.7% (50% pruning plot). The improvement over experimental control (pure crop) brought by agroforestry plots ranged from 17.7 (pure tree) to 37.7% (50% pruning plot). In comparison to regional threshold SQI, the quality index was found in order: pure crop< pure tree< 75% pruning< zero pruning< 50% pruning. The order of SQI over experimental control (pure crop) was in order: 50% pruning>zero pruning>75% pruning> pure tree. Higher SQI value in 50% pruning plot, followed by 75% pruning signifies that imposing pruning beyond 50% height of the tree canopy is not a useful practice for agroforestry systems.

***Principal component analysis based soil quality index*:** The PCA was performed for all the data of soil variables. The first three PCs had eigen value $\geq$1.0 (Table 4). Under PC-1, the highly weighted variables were POR, available P, SOC, available N, available K and MBC. Under PC-2 and PC-3, WHC and BD, respectively were highly weighted variables. These highly weighted variables were retained for the calculation of SQI. Among these variables, SOC, MBC, POR, WHC and BD were chosen for final PCA. Weights for selected variables were determined by the per cent variation in the data set explained by the first three PCs. Within a particular PC, the weights were distributed among the correlated variables as per factor loadings, and for non correlated variable, full weights were assigned. The final normalized PCA based soil quality equation was:

$$SQI = 0.424 \times S(SOC) + 0.212 \times S(MBC) + 0.212 \times S(POR) + 0.083 \times S(WHC) + 0.069 \times S(BD)$$

Where, S was the score of the variable and the coefficients were from the weighting factors obtained from the results of PCA.

Table 2. Impact of tree pruning on soil quality indicator (0-30 cm) values of *Albizia procera* based agroforestry system

Soil quality indicator	Soil quality indicator value					$LSD_{0.05}$
	Pure crop	Pure tree	Zero pruning	50% pruning	75% pruning	
Rooting depth	150.00	150.00	150.00	150.00	150.00	NS
WHC	13.833	13.633	15.033	15.420	16.300	NS
SOC	0.523	0.673	0.757	0.720	0.673	0.110
CEC	11.633	13.133	13.233	15.000	15.167	2.400
Available N	150.333	164.500	203.000	205.417	181.500	50.080
Available P	11.320	14.337	20.008	19.031	18.367	3.490
Available K	113.167	139.367	145.333	137.500	140.667	NS
MBC	127.467	146.400	169.000	197.600	200.667	43.440
DHA	37.055	76.730	60.131	72.357	60.232	37.000
PMN	30.583	31.011	28.450	29.171	33.161	NS
POR	29.630	32.703	34.057	35.277	34.920	3.080
IR	1.80	1.80	1.80	1.80	1.80	NS
pH	6.997	6.380	6.203	6.440	6.303	0.210
EC	0.335	0.197	0.192	0.153	0.184	NS
BD	1.438	1.470	1.419	1.414	1.436	0.027

WHC: Water holding capacity (%); SOC: Soil organic carbon (%); CEC: Cation exchange capacity (meq/100 g); MBC: Microbial biomass carbon (µg/g); DHA: Soil dehydrogenase activity (µg TPF/g/day); PMN: Potentially mineralizable nitrogen (kg/ha/week); POR: Porosity (%); IR: Infiltration rate (cm/h); EC: Electrical conductivity (dS/m); BD: Bulk density (g/cm^3)

Table 3. Indicator's scores and soil quality index of *Albizia procera* based agroforestry system

Soil quality indicator	Baseline functional score	Soil health indicator's scores				
		Pure crop	Pure tree	Zero pruning	50% pruning	75% pruning
Rooting depth	0.250	0.500	0.500	0.500	0.500	0.500
WHC	0.133	0.256	0.242	0.336	0.361	0.420
SOC	0.250	0.404	0.592	0.696	0.650	0.592
CEC	0.350	0.332	0.407	0.412	0.500	0.508
Available N	0.412	0.414	0.497	0.724	0.738	0.597
Available P	0.235	0.195	0.373	0.706	0.649	0.610
Available K	0.400	0.066	0.197	0.227	0.188	0.203
MBC	0.286	0.221	0.275	0.340	0.422	0.430
DHA	0.300	0.048	0.207	0.141	0.189	0.141
PMN	0.286	0.032	0.034	0.020	0.024	0.047
POR	0.275	0.317	0.318	0.351	0.382	0.373
IR	0.333	0.364	0.267	0.267	0.267	0.267
pH	0.500	0.501	0.707	0.766	0.687	0.732
EC	0.921	0.964	1.000	1.000	1.000	1.000
BD	0.400	0.724	0.661	0.762	0.773	0.732
SQI	0.355	0.356	0.418	0.483	0.489	0.477
		(0.3%)[#]	(17.7%)	(36.1%)	(37.7%)	(34.4%)

WHC: Water holding capacity (%); SOC: Soil organic carbon (%); CEC: Cation exchange capacity (meq/100 g); MBC: Microbial biomass carbon (μg/g); DHA: Soil dehydrogenase activity (μg TPF/g/day); PMN: Potentially mineralizable nitrogen (kg/ha/week); POR: Porosity (%); IR: Infiltration rate (cm/h); EC: Electrical conductivity (dS/m); BD: Bulk density (g/cm^3); SQI: Soil quality index
Values in parenthesis are per cent increase over baseline functional score

Table 4. Principal component analysis of soil quality indicators of *Albizia procera* based agroforestry system

Principal components	PC-1	PC-2	PC-3	PC-4
Eigen value	**9.579**[#]	**1.879**	**1.553**	0.989
Variability (%)	68.424	13.421	11.092	7.063
Cumulative (%)	68.424	81.845	92.937	100.000
Eigen vectors				
BD	0.191	-0.178	**0.907**	-0.331
WHC	0.704	**0.636**	-0.241	-0.204
POR	**0.983**[$]	0.160	0.067	-0.065
pH	-0.915	0.109	0.127	-0.368
EC	-0.970	0.052	-0.228	-0.062
SOC	**0.945**	-0.301	-0.115	0.055
CEC	0.850	0.453	0.245	-0.109
Available N	0.889	-0.155	-0.212	-0.376
Available P	0.948	0.019	-0.285	-0.144
Available K	0.926	-0.151	-0.069	0.340
MBC	**0.866**	0.447	0.041	-0.219
DHA	0.742	-0.296	0.549	0.246

BD: Bulk density (g/cm^3); WHC: Water holding capacity (%); POR: Porosity (%); EC: Electrical conductivity (dS/m); SOC: Soil organic carbon (%); CEC: Cation exchange capacity (meq/100 g); MBC: Microbial biomass carbon (μg/g); DHA: Soil dehydrogenase activity (μg TPF/g/day); [#]Bold eigen values correspond to principal components (PCs) examined for the index. Bold factor loadings were considered highly weighted; [$]Bold underline factors correspond to indicators included in the index

PCA- SQI = 0.684SOC + 0.684(MBC+POR) + 0.134WHC + 0.111BD

Normalized SQI = (0.684SOC + 0.684(MBC+POR) + 0.134WHC + 0.111BD)/1.613

= 0.424SOC + (0.424(MBC + POR) + 0.083WHC + 0.069BD)

The correlation matrix of soil health indicators showed SOC was highly correlated with available K (r >0.947), available P (r >0.915) and available N (r >0.890). The MBC was correlated (r ≥0.940) with POR (Table 5). POR had the highest loading, followed by SOC and both were not correlated well. It may not be desirable to depend on POR alone for assessing SQI and hence all three POR, SOC and MBC, each representing physical, chemical and biological property of the soil, respectively were included in the SQI. The weights among the treatments were decided as per factor loadings. Further, the data on PCA based SQI of *A. procera* based agroforestry system showed that 50% pruning plot scored maximum SQI, closely followed by zero pruning (Table 6). The pure crop plot obtained lowest value of PCA-based SQI. In both indexing procedures (LSF-SQI and PCA-SQI), the values of SQI were recorded highest in 50% pruning plot and minimum in pure crop plot. Addition of pruned biomass in pruning plots and litter fall in other agroforestry plots have improved status of SOC, available nutrients, MBC,

Table 5. Correlation matrix (Pearson (n)) of soil health indicators

Variables	WHC	SOC	CEC	Avail-able N	Avail-able P	Avail-able K	MBC	DHA	PMN	POR	pH	EC	BD	Biomass yield
WHC	1													
SOC	0.490	1												
CEC	0.850	0.633	1											
Available N	0.655	**0.890#**	0.675	1										
Available P	0.777	**0.915**	0.760	**0.954**	1									
Available K	0.504	**0.947**	0.665	0.733	0.845	1								
MBC	**0.929**	0.668	**0.973**	0.774	0.849	0.658	1							
DHA	0.151	0.741	0.604	0.496	0.505	0.777	0.479	1						
PMN	0.248	-0.379	0.248	-0.499	-0.266	-0.097	0.134	-0.082	1					
POR	0.791	0.869	**0.932**	0.859	**0.924**	0.859	**0.940**	0.702	-0.028	1				
pH	-0.530	**-0.932**	-0.657	-0.718	-0.848	**-0.997**	-0.658	-0.732	0.062	-0.849	1			
EC	-0.583	**-0.910**	-0.850	-0.799	-0.845	**-0.911**	-0.813	-0.875	0.093	**-0.956**	**0.887**	1		
BD	-0.129	0.112	0.340	0.130	-0.032	0.029	0.197	0.611	-0.116	0.242	0.042	-0.381	1	
Biomass yield	0.426	**0.990**	0.552	0.833	0.878	**0.960**	0.586	0.718	-0.367	0.812	**-0.951**	-0.867	0.018	1

WHC: Water holding capacity; SOC: Soil organic carbon; CEC: Cation exchange capacity; MBC: Microbial biomass carbon; DHA: Soil dehydrogenase activity; PMN: Potentially mineralizable nitrogen; POR: Porosity; EC: Electrical conductivity; BD: Bulk density; #Bold figures represent significant level (P<0.05)

DHA and overall quality of the soil. The lower values of SQI observed in present study indicated that soil used for agroforestry experiment was degraded and agroforestry practices brought improvement ranging from 17.4 to 37.4% over pure crop plot, which proved the hypothesis that practicing agroforestry with proper tree management restores degraded land and improves soil quality.

***Evaluation of soil quality index*:** Both the indexing methods (LSF-SQI and PCA-SQI) for *A. procera* based agroforestry system were evaluated by SQI's relation with the biomass productivity. The sensitivity was also calculated. The values of LSF-SQI ranged from 0.356 to 0.489 and PCA–SQI from 0.357 to 0.529. The SQIs based on LSF-SQI and PCA-SQI were highly correlated with biomass yield (Fig 1). The PCA-SQI had more value of correlation coefficient (R^2 = 0.873) than LSF-SQI (R^2 = 0.836). Similarly the sensitivity of PCA-SQI was more (2.00) than that of LSF-SQI (1.38). The lower sensitivity of LSF-SQI than PCA-SQI was also reported earlier by Masto *et al.* (2008).

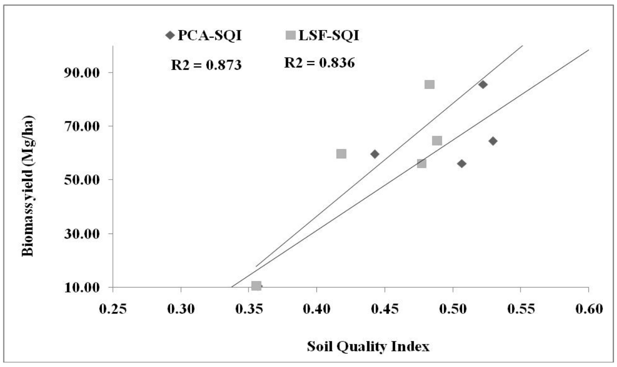

Fig 1. Relationship between biomass production and soil quality index

***Limiting parameter*:** For identifying the limiting soil parameters, a radar plot of linear scores of soil quality indicators was used to calculate SQI (Fig 2). The lines approaching towards web periphery indicated better soil quality with reference to particular indicator (axis) and lines toward the origin showed low soil quality. Comparison of indicator scores with reference helped in identifying the limiting soil parameter for agroforestry system in the region. Out of 15 indicators used for calculating SQI, PMN, MBC, DHA, WHC, available K and water movement into the soil were most critical indicators for management induced changes (Fig 2). Management strategies of agroforestry system can be drawn in relation to these limiting indicators to sustain long term biomass productivity.

Table 6. Principal component analysis (PCA) based soil quality index (SQI) of *Albizia procera* based agroforestry system

Indicators	PCA based indicators score					PCA based indicators weight					PCA-SQI
	SOC*	MBC	POR	WHC	BD	SOC	MBC	POR	WHC	BD	
Reference	0.250	0.286	0.275	0.133	0.400	0.106	0.061	0.058	0.011	0.028	0.264
Pure crop	0.404	0.221	0.317	0.256	0.724	0.171	0.047	0.067	0.021	0.050	0.357
Pure tree	0.592	0.275	0.318	0.242	0.661	0.251	0.058	0.067	0.020	0.046	0.442
Zero pruning	0.696	0.340	0.351	0.336	0.762	0.295	0.072	0.075	0.028	0.053	0.522
50% pruning	0.650	0.422	0.382	0.361	0.773	0.276	0.089	0.081	0.030	0.053	0.529
75% pruning	0.592	0.430	0.373	0.420	0.732	0.251	0.091	0.079	0.035	0.051	0.507

*SOC: Soil organic carbon; MBC: Microbial biomass carbon; POR: Porosity; WHC: Water holding capacity; BD: Bulk density

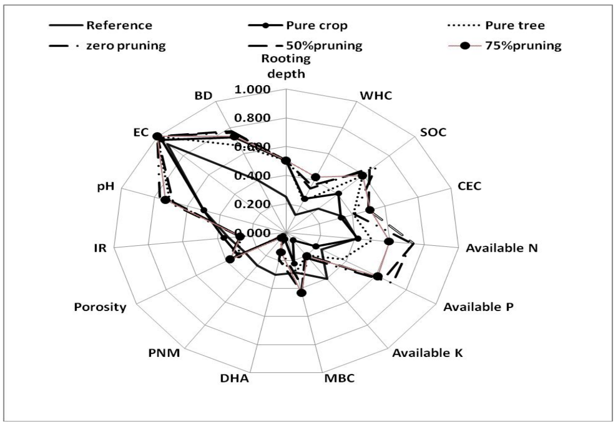

Fig 2. Radar plot of soil quality index (SQI) and linear scores of soil quality indicators in *Albizia procera* based agroforestry system

Conclusion

This study proved the hypothesis that agroforestry is vital for restoration and revitalization of poor and marginal land resource. Out of 15 indicators used to assess soil quality, most of them responded to management of tree canopy; however, PMN, MBC, DHA, WHC, available K and water movement into the soil were found most critical indicators for management induced changes. Practice of agroforestry holds potential to improve soil quality ranging from 14.8 to 27.2% after 10 years. Results of this study, apart from its scientific value, will have practical implications in bridging the gap in using SQI value based on summarized functional scores of soil indicators in assessing soil quality of various agroforestry systems.

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