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Soil quality under *Grewia optiva* based agroforestry systems in western sub-Himalaya

R. Kaushal[1*], Archana Verma[2], H. Mehta[1], D. Mandal[1], J.M.S. Tomar[1], C. Jana[1], Rajkumar[3], J. Jayparkash[1] and O.P. Chaturvedi[4]

[1]ICAR-Indian Institute of Soil and Water Conservation, Dehradun-248195, India
[2]ICAR-Central Arid Zone Research Institute, Jodhpur-342003, India
[3]ICAR-Indian Institute of Soil and Water Conservation, Research Center Vasad-388306, India
[4]ICAR-Central Agroforestry Research Institute, Jhansi-284003, India
*Corresponding author e-mail: kaushalrajesh1@rediffmail.com
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Abstract

Soil quality assessment was done in Grewia (*Grewia optiva*) based agroforestry system in Himalayan foothills. Soil samples were collected from six different treatments *viz.*, (i) Sole Grewia (ii) Grewia + Finger millet (*Eleusine coracana*), iii) Grewia + Barn yard millet (*Echinochloa crus-galli*), iv) Finger millet alone, v) Barn yard millet alone and vi) fallow and evaluated for different soil properties and soil quality. There were significant differences in soil properties and quality under different treatments after four year of plantation. Saturated hydraulic conductivity was higher in sole Grewia (1.45 cm h^{-1}) plots followed by that under agroforestry plots (0.80-0.95 cm hr^{-1}). Soil bulk density was least in sole Grewia plot (1.40 mg m^{-3}) and was highest (1.50 mg m^{-3}) in fallow plots. Water stable aggregates were 16-18 % higher in agroforestry plots. In sole Grewia plots increase of 42% was observed for water stable aggregates as compared to fallow plot. Organic carbon increased by 13-46% in different treatments as compared to fallow plot. N, P and K were also higher under sole Grewia and agroforestry plots. The soil quality index (Q) varied from 0.32 in fallow to 0.50 in sole Grewia thereby indicating the superiority of forest land use system in terms of maintaining greater soil quality than other land-use systems. Results further reveals that as compared to sole Grewia plots, there was 33% reduction in soil quality in fallow plots and 16.8-22.8% in agriculture plots. Soil quality in agroforestry plots was comparatively better than sole crops and fallow with only 6.9% reduction in soil quality as compared to sole Grewia.

Keywords: Grewia, Hydraulic conductivity, Organic carbon, Soil quality, Water stable aggregates

Introduction

Soil quality has been defined as the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994). It is assessed by measuring key soil attributes or indicators (Larson and Pierce, 1994). Soil quality indicators are categorized by physical, chemical, and biological indicators which help in monitoring changes in soil quality by assessing changes in these indicators (Doran and Parkin, 1994). Methods for measuring individual indicators and minimum data sets and for calculating indices from groups of indicators are being developed for the purposes of monitoring soil quality over time and evaluating the sustainability of agricultural and land management (Karlen and Stott, 1994). Arshad and Coen (1992) suggested soil depth to a root restricting layer, available water holding capacity, bulk density or penetration resistance, hydraulic conductivity, aggregate stability, soil organic matter content, nutrient availability, pH, and electrical conductivity, as soil quality indicators because those measurements are generally responsive to management practices. Larson and Pierce (1994) suggested a minimum data set for assessing soil quality; however, they substituted particle size distribution for aggregate stability.

Agroforestry is a collective term for land use practices that optimize the environmental as well as economic benefits. Trees in agroforestry systems use nutrients and water from lower soil depths that shallow plant roots cannot access. Agroforestry practices have been shown to check soil erosion and runoff, maintain soil organic matter, improve soil physical properties, minimize nutrient loss, promote efficient nutrient cycling, sequester carbon and provide numerous ecosystem services (Soni *et al.*, 2008; Singh and Gill, 2014). Benefits of agroforestry practices have been reported in literature but quantitative data to compute it as an index of soil quality, are scanty.

Grewia *(Grewia optiva* Drummond) locally called as 'Beul' or 'Bhimal', is one of important agroforestry tree species available with majority of farmers in the lower and mid-hills of western Himalaya (Verma *et al.,* 2002). It is an important tree, which provides leaf fodder during the winters when no other green fodder is available. The green leaves constitute about 70% of the total green weight of branches. Leaf fodder yield from mature trees is reported to be 12-30 kg tree^{-1}. Leaves are fairly rich in protein and other nutrients and do not contain tannins. Crude protein is highest in young leaves and in winter leaves but decreases during the rainy season. (Orwa *et al.,* 2009; Verma *et al*., 2014). The high calorific value (4920 k cal kg^{-1}) of the tree wood makes it a very good fuel wood and alternate source of energy. It also provides fiber, edible fruits and has medicinal value. Besides producing valuable product, the tree also provides varieties of ecological functions and associated services (Verma *et al*., 2014). In spite of large area under Grewia in western Himalaya*,* studies related to soil quality evaluation are meager. Therefore, we hypothesized that adoption of Grewia based agroforestry system improves soil properties. This study aimed to compare the differences in soil properties and quality under Grewia based agroforestry systems with sole tree and agriculture in Doon valley of western Himalaya.

Materials and Methods

Study site: The study was conducted at ICAR-Indian Institute of Soil and Water Conservation Research Farm, Selakui Dehradun in the sub-humid, subtropical climate of western sub- Himalaya. The farm is located at 30^0 21' N latitude, 70^0 52' E longitude and at an altitude of 517 m above mean sea level (m.s.l). The climate of the study area is sub tropical with an average annual rainfall of 1625.3mm. About 81% of the total rainfall is received in 80 rainy days during the monsoon season between mid June to mid September. As much as 90 mm hr^{-1} of precipitation may fall, and caused erosivity (R = 428) based on EI30. Considerable erosion may be caused by exceptionally high intensity storms in June when the canopy cover is negligible (Dobhal *et al.,* 2013).

Experimental design**:** Six different treatments *viz*., (i) Grewia (ii) Grewia + Finger millet (*Eleusine coracana*), iii) Grewia + barn yard millet (*Echinochloa crus-galli*), iv) Finger millet alone (FM), v) barn yard millet alone (BM) and vi) fallow were evaluated for different soil properties after 4 year of establishment. Grewia trees were established in runoff plots (4% slope) of 45 x 15 m in the year 2009 at spacing of 5.0 x 4.5 m. Each plot had 30 trees. Intercrops *viz*., finger millet and barnyard millet was grown each year in summer (*kharif*) season followed by wheat in winter (*rabi*) season*.* Sole FM, BM, Grewia without intercropping and fallow plots were also maintained throughout the study. Recommended package and practices were given to the field crops.

Soil analysis**:** Bulk and core soil samples were collected from different treatment plots from 0-15 cm layer. Samples were taken from the centre of the plot. About 500 g composite soil sample was obtained after combining three cores at each point. Air dried soil samples were gently ground and passed through a 2 mm sieve and stored for analysis. Bulk density was measured by the core method (Blake and Hartge, 1986). The aggregate-size distribution was determined by the wet-sieving method as described by Yoder (1936). Saturated hydraulic conductivity (Ks) was measured by the constant head method. Soil organic carbon (SOC) was determined by the wet combustion method (Walkley and Black, 1934). Total nitrogen (TN) concentration was determined by the Kjeldahl method. Available P and K were determined calorimetrically by the Olsen method and flame photometry, respectively.

Statistical analysis: Measured data were analyzed by analysis of variance (ANOVA) using statistical package (SAS 9.3) to examine the effect of different treatments on overall soil performance. Statistical significance of each attribute was assessed using Tukey's HSD (Honest significant difference) at $P < 0.05$.

Indicators selection criteria and soil quality evaluation**:** The most relevant indicators representing various functions were selected. Seven soil quality indicators *viz*., saturated hydraulic conductivity (Ks), water stable aggregates (WSA), bulk density (BD), soil organic carbon (SOC), total N, extractable P, available K were included for the study. These factors were adopted to reflect the various aspects of soil quality in relation to plant growth. After selecting the appropriate indicators, the measured values of indicators were transformed into a unit less score of 0-1. The score for each indicator (0-1) was calculated after establishing baseline values and threshold limits (upper and lower) from different scoring curves and published data (Karlen and Stott, 1994). Appropriate scoring methods were used to transform indicators into dimensionless scores (Table 1).

Weights were assigned to the indicators depending on their relative importance and sensitivity. In case of Ks, an

Table 1. Categorical ranking of soil characteristics

Soil attributes	Weight		Categorical ranking				
			1	2	3	4	5
Saturated hydraulic conductivity (cm h^{-1})	0.35	Range	0.5-1.0	1.0-2.0	2.0-3.5	3.5-5.0	>5.0
		Score	0.2	0.3	0.5	0.8	1
Water stable aggregates	0.25	Range	<0.10	0.10-0.29	0.30-0.49	0.50-0.69	>0.70
		Score	1	0.8	0.5	0.3	0.2
Bulk density (mg m^{-3})	0.10	Range	<1.40	1.40-1.47	1.48-1.55	1.56-1.63	>1.63
		Score	1	0.8	0.5	0.3	0.2
Soil Organic carbon (%)	0.15	Range	<0.50	0.50-0.75	0.75-1.00	1.00-1.50	>1.50
		Score	0.2	0.3	0.5	0.8	1
Total N (%)	0.05	Range	<0.01	0.01-0.03	0.03-0.06	0.06-0.1	>0.1
		Score	0.2	0.3	0.5	0.8	1
Extractable P (kg ha^{-1})	0.05	Range	<2.5	2.5-5.0	5.0-10.0	10.0-25.0	>25.0
		Score	0.2	0.3	0.5	0.8	1
Available K (kg ha^{-1})	0.05	Range	<60	60-100	100-140	140-280	>280
		Score	0.2	0.3	0.5	0.8	1

Table 2. Soil attributes under different treatments

Soil attributes		Treatment					
		Grewia	Grewia + FM	FM	Grewia + BM	BM	Fallow
Saturated hydraulic	Range	1.4-1.45	0.88-0.95	0.55-0.58	0.8-0.83	0.66-0.71	0.35-0.39
conductivity (cm h^{-1})	Average	1.43[a]	0.92[b]	0.56[e]	0.82[c]	0.68[d]	0.37[f]
	SD	0.025	0.038	0.015	0.017	0.026	0.021
Water soluble	Average	54.34	44.28	37.71	40.31	31.19	38.16
aggregates >0.25 mm	Range	1.4-1.41	1.4-1.44	1.42-1.45	1.42-1.44	1.43-1.47	1.47-1.53
	Average	1.40[c]	1.42[bc]	1.44[bc]	1.43[bc]	1.45[ab]	1.50[a]
Bulk density (mg m^{-3})	Range	0.91-0.99	0.89-0.95	0.67-0.8	0.89-1.0	0.76-0.84	0.64-0.67
	Average	0.95a	0.92a	0.74b	0.95a	0.80b	0.65e
Soil organic carbon (%)	SD	0.039	0.028	0.065	0.058	0.042	0.017
Total N (%)	Range	0.085-0.09	0.07-0.077	0.059-0.067	0.082-0.92	0.074-0.078	0.087-0.092
	Average	0.087[a]	0.074[b]	0.064[c]	0.087[a]	0.076[b]	0.089[a]
	SD	0.003	0.0038	0.0038	0.005	0.002	0.003
Extractable P (kg ha^{-1})	Range	17.36-25.26	22.89-26.09	19.93-24.78	21.4-22.47	22.24-22.78	17.96-21.32
	Average	21.58[ab]	24.67[a]	22.45[a]	21.94[a]	22.60[a]	19.83[b]
	SD	3.97	1.63	2.43	0.54	0.31	1.71
Available K (kg ha^{-1})	Range	189.4-205.2	143.8-164.0	142.2-150.9	262.2-272.9	198.6-213.7	87.6-107.8
	Average	195.8[b]	153.7[e]	146.2[c]	266.1[a]	205.8[b]	98.8[d]
	SD	8.4	10.1	4.4	5.9	7.6	10.3

Mean followed by same letter are not significantly different; SD: Standard deviation

indicator of water transmission properties *'more is better'* concept was used since resistance to erosion would be better with a higher value of infiltration rate. The Ks was assigned the maximum weightage (0.35). For example, in case of hydraulic conductivity the ideal value was set at 5 cm h^{-1} following the critical level concept developed by Lal (1996), while crossover point (marginal) was set between 1 and 2 cm h^{-1}. WSA, indicative of the resistance to physical degradation, was assigned the second highest weightage of 0.25. A lower asymptotic or *'less is better'* function was used in case of BD because of its inhibitory effect on root growth and soil porosity. BD was assigned a weight of 0.10. The SOC and Ks are ascending logistic *i.e. more-is-better* function based on their role in water entry, water partition, structural stability and soil fertility The SOC concentration was assigned weight of 0.15. Concentration of N, P and K representing nutrient status of soil was given weightage of 0.15 (0.05 each).

According to the concept of Karlen and Stott (1994), seven indicators were combined into a soil quality index (Q) which was calculated separately by multiplying weight of

Table 3. Mean value of attributes and converted scores used for computation of soil functions

Soil attributes		**Treatment**					
		Grewia	**Grewia + FM**	**FM**	**Grewia + BM**	**BM**	**Fallow**
Saturated Hydraulic conductivity (cm h^{-1})	value	1.43	0.92	0.56	0.82	0.68	0.37
	score	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
Water Soluble Aggregate >0.25 mm	value	54.34	44.28	37.71	40.31	31.19	38.16
	score	(0.5)	(0.5)	(0.3)	(0.5)	(0.3)	(0.3)
Bulk density (mg m^{-3})	value	1.40	1.42	1.44	1.43	1.45	1.50
	score	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.5)
Soil Organic carbon (%)	value	0.95	0.92	0.74	0.95	0.80	0.65
	score	(0.5)	(0.5)	(0.3)	(0.5)	(0.5)	(0.3)
Total N (%)	value	0.087	0.074	0.064	0.087	0.076	0.089
	score	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Extractable P (kg ha^{-1})	value	21.58	24.67	22.45	21.94	22.60	19.83
	score	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Available K (kg ha^{-1})	value	195.8	153.7	146.2	266.1	205.8	98.8
	score	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)	(0.3)
Aggregated Score	q	0.50	0.47	0.39	0.47	0.42	0.32
	% change		-6.93	-22.7	-6.93	-16.8	-33.66
Soil group		II	II	II	II	II	I

indicators and points allotted to each class as described in equation below, in which potential indicators were assigned weights as per their relative importance;

$Q = q_{wc}\ w_{wc}+q_{wt}w_{wt}+q_{wsa}w_{wsa}+q_{rbd}w_{rbd}+q_{spg}w_{spg}$

Where, Q is the soil state or soil condition, $\boldsymbol{q_{wc}}$ is the rating for Ks, q_{wt} is the rating for BD, q_{wsa} is the rating for WSA, q_{rbd} is the rating for SOC and q_{spg} is the rating for fertility status (N, P, K) of soils and w is the weight factor for each function. Summing the values of the weighted parameters, a quantitative value (Q) indicating the state of soil is obtained. This model was used for assigning performance of soil.

Soil grouping was done on the basis of aggregated score (Q) obtained from the above model. Three soil groups I (Q < 0.33), II (Q 0.33- 0.66) and III (Q > 0.66) based on the aggregated score (Q) were formed. Soils under group III perform all functions at optimal levels than those under groups I or II.

Results and Discussion

Soil properties: The Ks (cm hr^{-1}) was higher in sole Grewia (1.43) plots followed by that under agroforestry plots (0.80-0.95; Table 2). The Ks decreased in sole crop plots (0.56-0.68) and was the least (0.37) in fallow plots. Higher Ks values under trees are attributed to the fine root production by the trees which result in a greater proportion of larger pores that enhance Ks, preferential flow, and macropore flow (van Noordwijk and Brouwer, 1991; Cadisch *et al.*, 2004). The WSA was higher under trees either as sole plot or intercropped plots. Macroaggregates (diameter >0.25 mm) are considered as a secondary soil structure associated with pores, microbial habitat, and physical protection of organic matter and decrease erosion risks in response to rainfall (Carter, 2004; Paudel *et al.*, 2011). Higher WSA in agroforestry and sole tree plots is attributed to the high SOC and fine roots which act as binding agents between particles (Islam and Weil, 2000). The BD was least in sole Grewia plot (1.40) and it increased in intercropped plots (Table 2). Agroforestry plots showed lower BD (1.42-1.43) compared to sole crop plots (1.44-1.45) and fallow plot (1.50). The lower values in sole tree plot are due to the absence of ploughing activities in the plot. Lower values in agroforestry plots as compared to sole agriculture plots are attributed to improvement in soil properties caused by fine roots production, turnover, bio-pores, organic matter, fauna, and other related biological processes (Seobi *et al.*, 2005; Udawatta *et al.*, 2008). Increase in bulk density and compaction under continuous cultivation was also reported by Lal (1985) and Mandal *et al.* (2010). The SOC ranged from 0.64 to 1.0 % indicating that SOC content varied greatly in different treatments (Table 2). The highest average value of SOC (0.95%) was recorded in sole Grewia plots followed by Grewia based intercropped plots. In sole agriculture plots of FM and BM, the SOC content varied from 0.67-0.84%. In fallow plot least SOC (0.65%) was observed. Land use change has a great influence on many soil quality attributes mostly through its effect on

SOC. Structural stability of soils is affected by land use, which in turn is positively associated with total organic content (Caravaca *et al.* 2004). The enhanced SOC under trees may be attributed to fine root production and turnover which lead to organic enrichment of soil layer (Verma *et al.*, 2014). Raizada *et al.* (2013) reported that seasonal mean fine root biomass in Grewia was 432 and 265 g m^{-2} at 1m and 2m distance from tree base. The higher values of SOC in sole tree plots may also be attributed to rapid recovery of the natural vegetation, less erosion and slower oxidation of the new organic material (Seybold *et al.*, 1999; Panwar *et al.,* 2013). Total nitrogen (TN) content was higher in sole Grewia which however, was at par with Grewia + BM plot. The FM either as sole or in combination with Grewia showed lower values for TN. Yield in general is higher in FM as compared to BM which should be the possible reason for lower nitrogen values in FM plots. Average values of extractable P were at par in agroforestry and sole crop plots because of application of phosphatic fertilizers to the agriculture crops. Fallow plot showed least values of extractable P (19.83 kg ha^{-1}). Available K was more in plots having BM either as sole or intercropped plot. Fallow plot showed least available K content.

Soil quality: Mean values of original soil properties were converted into standard scores (Table 3) using the appropriate scoring functions. Among the various treatments, sole Grewia, had the highest score (0.8), whereas fallow plot had the lowest score (0.5) for BD. Converted score of Ks ranged between 0.20 and 0.30. The converted value of SOC was highest in sole Grewia (0.8), and lowest (0.3) in fallow and sole FM plots. The WSA scored maximum value (0.5) in plots having Grewia as one of the components. The converted values of TN and extractable P were same (0.8) for all the plots. For available K, the least score (0.3) was observed in fallow plot (Table 3). Using the proposed scoring technique overall soil performance was compared for all the treatment plots. Mean data on various properties were used to measure soil quality index for different land uses. Overall, the soil quality was better in sole Grewia plot. The aggregated score ranged between 0.32-0.50 (Table 3). Fallow plot had the lowest soil quality. Overall soil performance was compared for different treatments which revealed that the percentage change of various soil attributes with respect to sole Grewia plot was greater in agroforestry plots (6.93%) which were followed by BM plot (16.83%). The present results are in the line with the findings of Mandal *et al.* (2010).

Conclusion

Increasing anthropogenic pressure is leading to widespread resource degradation in the fragile western Himalaya. A more holistic approach is therefore required for sustainable production and protecting the natural base from further degradation. We suggest that soil quality analyses can provide an objective basis for evaluating the sustainability of an array of systems. Soil quality indicator results in this site led us to conclude that Grewia-based agroforestry systems in western Himalaya have potential to improve soil quality which can lead to sustainable production and optimum utilization of resources.

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