



RESEARCH ARTICLE

Soil chemical properties, nutrient and microbial dynamics under mango-based agroforestry system

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Abstract

Improper management in old mango orchards renders them senile and less productive. Intercropping with suitable and synergistic crop improves the fertility and maintains soil health. Field experiment was conducted during 2022–2023 to find out the effect of intercropping with 4 crops: Ginger (*Zingiber officinale* Roscoe), turmeric (*Curcuma longa* L.), stevia (*Stevia rebaudiana* Bertoni) and kalmegh (*Andrographis paniculata* (Burm.f.) Wall. ex Nees) on the soil physico-chemical properties and microbial population in a 29 years old mango orchard located in the sub-tropics of Jammu Shivaliks, Jammu and Kashmir, India. The results of the study revealed that the intercropping was effective in bringing about slight improvement in all the physico-chemical properties such as soil moisture, bulk density, cation exchange capacity (CEC), pH, electrical conductivity (EC), available nitrogen, phosphorus and potassium clearly signifying that intercropping in old orchards will built the fertility level on long term basis. The microbial count showed a decreasing trend at the depths 0–15 cm and 15–30 cm, which might be due to no tillage prior to the experimentation, but it could be postulated that with continuous cropping, intercultural operations and consequent soil health improvement the microbial load would increase in the long run.

Keywords: mango-based intercropping; medicinal plants, microbial count; soil physicochemical properties

Introduction

Agriculture, with its allied sectors, is the largest source of livelihood in India. About 70 % of rural households still depend primarily on agriculture for their livelihood, with 82 % of farmers being small and marginal (1). The average land holding of Indian farmers has consistently declined by over 6 % between 2010–11 and 2015–16, with operational holding in the country dropping to 1.08 ha from 1.15 ha in 2010–11 (2). Indian agriculture is resource intensive, cereal centric and regionally biased which has raised serious sustainability issues. India needs to improve its management of agricultural practices on multiple fronts (1). There is a need to develop a management system integrating land, water and resources with suitable cropping and agronomic methods to sustain production in marginal and degraded drylands (3). The sub-montane region of the outer Himalayas fringing Shivalik hills in Jammu and Kashmir known as 'bhabar' or 'kandi' covers 3 districts, namely Jammu, Samba and Kathua in Jammu region. The landscape of kandi area comprises of undulating topography, steep and irregular slopes, erodible and poor water retentive soils and badly dissected terrain by numerous gullies. The prominent land uses include agriculture, horticulture, agroforestry and the forest. People usually practice rainfed agriculture, horticulture, agroforestry for their sustenance and are intrinsically dependent on nearby forests to meet their energy and fodder requirements (4). Agroforestry land use system in kandi areas primarily comprise of fruit-based systems. The dominant fruit trees in the area are *Mangifera indica* L.,

Litchi chinensis Sonn., *Emblica officinalis* Geartn. and *Grewia asiatica* L., *Zyziphus* spp. Among others, mango occupies 12739 ha of area producing 24150 metric tons of fruit (5). People have very old mango orchards (30–40 years) having trees 9–10 m apart with large canopy and are usually unmanaged. The decline in productivity has been noticed due to overcrowded, intermingled branches and low foliage, poor light penetration within the canopy. Only less than 30 % of the leaves are photosynthetically active and become a burden on the tree draining the carbohydrate resources rendering the orchard uneconomical (6). Thus becomes imperative on the part of the orchardist to augment his income by growing some suitable and synergistic crops (vegetables/medicinal plants) as intercrop in the vacant inter-row space to ensure quick and sustainable returns consistently and annually. Although voluminous research has been done on intercropping young mango orchards but information on intercropping potential in old mango orchards is scanty. It is reported that mango performs better in low-fertility soils but the productivity declines with age and poor management (7). Growing those crops which could sustain such adverse conditions and still perform better to yield good economic returns could be the valid option. In addition to the monetary gains, the cultivation of crops improves the health of the soil and the orchard. To ascertain the effect of different crops on soil health in such orchards, the present investigation was undertaken. Four crops, namely ginger, turmeric, kalmegh and stevia, were grown as intercrops under a mango orchard in the subtropics of the Jammu Shivaliks to study their

impact on the physico-chemical properties and microbial load.

Materials and Methods

Study area

The study was conducted at Experimental Farm of Advance Centre for Horticulture Research, Sher-e-Kashmir University of Agricultural Sciences and Technology, Udheywalla, Jammu, located at an altitude of 327 m above mean sea level, between 32°73' N latitude and 74°87' E longitude. The experimental site falls under sub-tropical zone of Jammu division of Jammu and Kashmir, hot dry summers, hot humid rainy and cold winter months. The average annual rainfall of the experimental location is about 1000–1200 mm, 75–80 % of which is received during July to September and during winter months. The maximum temperature rises up to 45 °C during May to June and minimum falls to 1 °C during December-January. The soil of the experimental plot was sandy clay loam in texture, neutral in reaction, low in organic carbon, available nitrogen and phosphorus but medium in potassium with electrical conductivity (EC) in the safe range.

Experimental methodology

The study consisted of 2 structural and functional components viz. mango (*M. indica*) fruit tree as woody perennial and 4 crops as intercrop. The trees in the selected orchard (29 years old) were spaced at 9 x 9 m. The average height of the trees varied from 4.5–6.2 m, average basal diameter of the trees ranged from 0.39–0.46 m, crown spread ranged from 7.12–10.05 m, crown projection area varied from 35.77–76.16 m and canopy volume ranged from 630.97–985.97 m³. Under the tree canopy 4 crops (Ginger (*Zingiber officinale* Roscoe)-G, Turmeric (*Curcuma longa* L.)-T, Stevia (*Stevia rebaudiana* Bertoni)-S and Kalmegh (*Andrographis paniculata* (Burm.f.) Wall. ex Nees)-A) were grown at 3 spacings (30 x 20 cm-S₁, 30 x 30 cm-S₂, 30 x 40 cm-S₃) in plot size of 3.6 x 4.2 m. The layout was done as per Factorial RBD. The crops were grown in 12 treatment combinations and 3 replications. The data was analysed using OPSTAT programme.

The physico-chemical properties of the soil under the canopy of mango were determined at the time of layout and at the end of the experiments. Five composite soil samples were taken at 3 depths viz. 0–30 cm, 30–60 cm and 60–90 cm for each replication within each treatment. The samples were air dried under shade and crushed using wooden mortar and pestle, sieved through 2 mm plastic sieve. Nitrogen was determined by alkaline potassium permanganate method (8), phosphorus was determined by Olsen's method of extraction (9), potassium was determined by Neutral N ammonium acetate method (10), bulk density was determined by Core tube method (11), moisture content in soil was estimated by gravimetric method, cation exchange chromatography (CEC) by Sodium acetate method (12), pH and EC by 1:2.5 soil: water suspension (13). Microbial load at 2 depths 0–15 cm and 15–30 cm was determined by standard serial dilution plate technique. The colony forming units were determined by the formula:

No. of microorganisms per gram of sample = No. of colonies × dilution factor

Baseline soil physico-chemical properties and microbial load are presented in Tables 1 and 2.

Table 1. Physico-chemical properties of mango orchard soil before start of experimentation

Parameters	Soil depth		
	0–30 cm	30–60cm	60–90cm
Bulk density (g cm ⁻³)	1.173	1.327	1.371
Soil moisture (%)	17.65	18.64	20.18
CEC (c.mol.P ⁺)	13.26	12.28	10.58
pH (1:2.5 :: soil: water)	6.35	6.42	6.47
EC (dS m ⁻¹)	0.11	0.10	0.09
Available nitrogen (kg ha ⁻¹)	200.07	186.42	178.27
Available phosphorus (kg ha ⁻¹)	13.40	12.04	10.90
Available potassium (kg ha ⁻¹)	120.40	115.00	110.38

Table 2. Soil microbial count before start of experimentation

Parameter	Soil depth	
	0–15 cm	15–30 cm
Soil microbial count (x 10 ⁴ cfu g ⁻¹ soil)	343	178

Results and Discussion

Effect of intercropping on physical properties of soil

The data recorded on physical properties of orchard soil at the end of the experiment are presented in Table 3. The study revealed that the intercrops resulted in improvement in bulk density of soil at all the depths. Maximum improvement (1.120, 1.320 and 1.362 g cm⁻³) was recorded under ginger crop in all the 3 depths 0–30 cm, 30–60 cm and 60–90 cm respectively which was followed by stevia, turmeric and kalmegh. The improvement in bulk density might be attributed to increased incorporation of the biomass of intercrops in the soil thereby increasing the organic-matter content and promoting better soil aggregation. Decrease in bulk density of soil while studying the effects of intercropping in mango orchards have also been reported (14). The improvement might also be due to intercultural operations carried out in the orchard which led to loosening of soil and increased aeration compared to no tillage prior to this experiment. Earlier works also reported that clean cultivation resulted in higher bulk density in mango orchards compared to conservation horticulture (15). However, bulk density increased with increasing depth possibly due to increased accumulation of leaf litter in surface layer and soil compaction in lower depths. Similar results have also been reported in mango orchards of old alluvium of Indo- Gangetic Plains (16). The data recorded for soil moisture clearly indicates that there was no significant effect of intercropping on soil moisture content in different depths. The moisture content varied from 17.63–18.66 % with initial value of 17.65 % at 0–30 cm depth when no intercrop was grown. The moisture content increased with increasing depths. The slight improvement might be due to the intercultural operations and addition of plant residues into the soil. The moisture content was minimum under mango + stevia. It might be due to poor survival of stevia which led to minimal leaf production, hence, minimal crop residue. The result is in confirmation previous results who had reported more variation in soil moisture content in fallow land than intercropping treatments and who have attributed higher soil moisture to incorporation of crop residues and farm yard manure thereby reducing evaporation losses from the soil (3, 17).

Table 3. Soil physical properties as affected by intercrops and different spacings under mango orchard

Treatment combination	Soil moisture (%)			Bulk density (g cm ⁻³)		
	0–30	30–60	60–90	0–30	30–60	60–90
Depths (cm)						
Crops						
Ginger (G)	18.66	19.64	21.98	1.120	1.320	1.362
Turmeric (T)	18.01	21.05	23.58	1.147	1.327	1.346
Stevia (S)	17.63	18.76	22.09	1.124	1.331	1.368
Kalmegh (K)	18.31	19.27	21.08	1.166	1.347	1.368
±SE(m)	0.56	0.59	0.29	0.04	0.01	0.01
CD_{0.05}	NS	0.74	0.88	NS	NS	NS
Spacing						
20 x 30 cm (S ₁)	18.56	19.48	21.89	1.138	1.338	1.348
30 x 30 cm (S ₂)	17.54	19.45	21.76	1.148	1.336	1.374
30 x 40 cm (S ₃)	18.37	18.61	22.15	1.208	1.344	1.361
±SE(m)	0.48	0.51	0.25	0.04	0.01	0.01
CD_{0.05}	NS	NS	NS	NS	NS	NS
Crops x spacing						
G S ₁	18.69	20.18	21.37	1.133	1.347	1.330
G S ₂	18.38	17.54	19.99	1.133	1.350	1.400
G S ₃	18.92	18.21	21.59	1.393	1.360	1.357
T S ₁	17.71	21.00	23.04	1.180	1.357	1.360
T S ₂	17.43	22.06	23.69	1.133	1.313	1.323
T S ₃	18.88	20.10	24.01	1.127	1.310	1.353
S S ₁	17.97	18.34	22.14	1.110	1.313	1.343
S S ₂	16.77	19.37	21.93	1.133	1.313	1.380
S S ₃	18.16	18.58	22.20	1.130	1.367	1.380
K S ₁	19.86	18.40	21.00	1.127	1.333	1.357
K S ₂	17.57	18.84	21.43	1.190	1.367	1.393
K S ₃	17.51	17.57	20.81	1.180	1.340	1.353
±SE(m)	0.97	1.02	0.52	0.07	0.02	0.02
CD_{0.05}	NS	NS	NS	NS	NS	NS
Initial value	17.65	18.64	20.18	1.173	1.327	1.371

NS- Non significant.

Table 4. Soil chemical properties as affected by intercrops and different spacings under mango

Treatment combination	Soil moisture (%)			Bulk density (g cm ⁻³)			
	Depths (cm) Crops	0–30	30–60	60–90	0–30	30–60	60–90
Ginger (G)		18.66	19.64	21.98	1.120	1.320	1.362
Turmeric (T)		18.01	21.05	23.58	1.147	1.327	1.346
Stevia (S)		17.63	18.76	22.09	1.124	1.331	1.368
Kalmegh (K)		18.31	19.27	21.08	1.166	1.347	1.368
±SE(m)		0.56	0.59	0.29	0.04	0.01	0.01
CD_{0.05}		NS	0.74	0.88	NS	NS	NS
Spacing							
20 x 30 cm (S ₁)		18.56	19.48	21.89	1.138	1.338	1.348
30 x 30 cm (S ₂)		17.54	19.45	21.76	1.148	1.336	1.374
30 x 40 cm (S ₃)		18.37	18.61	22.15	1.208	1.344	1.361
±SE(m)		0.48	0.51	0.25	0.04	0.01	0.01
CD_{0.05}		NS	NS	NS	NS	NS	NS
Crops x spacing							
G S ₁		18.69	20.18	21.37	1.133	1.347	1.330
G S ₂		18.38	17.54	19.99	1.133	1.350	1.400
G S ₃		18.92	18.21	21.59	1.393	1.360	1.357
T S ₁		17.71	21.00	23.04	1.180	1.357	1.360
T S ₂		17.43	22.06	23.69	1.133	1.313	1.323
T S ₃		18.88	20.10	24.01	1.127	1.310	1.353
S S ₁		17.97	18.34	22.14	1.110	1.313	1.343
S S ₂		16.77	19.37	21.93	1.133	1.313	1.380
S S ₃		18.16	18.58	22.20	1.130	1.367	1.380
K S ₁		19.86	18.40	21.00	1.127	1.333	1.357
K S ₂		17.57	18.84	21.43	1.190	1.367	1.393
K S ₃		17.51	17.57	20.81	1.180	1.340	1.353
±SE(m)		0.97	1.02	0.52	0.07	0.02	0.02
CD_{0.05}		NS	NS	NS	NS	NS	NS
Initial value		17.65	18.64	20.18	1.173	1.327	1.371

NS- Non significant.

Effect of intercropping on chemical properties of soil

Perusal of the data shows that no significant change was observed in pH and EC being static properties and short period of 2 years can scarcely bring any significant impact (Table 4). Maximum change in pH 6.75, 6.78 and 6.68 within 0–30 cm, 30–60 cm and 60–90 cm deep, respectively against 6.35, 6.42 and 6.47 under the mango initially (no intercrop) was observed under mango + kalmegh. Maximum EC was observed under mango + ginger in all the depths. Increase in pH of soil towards neutrality is a positive sign of improvement. It could be attributed to the addition of biomass of intercrops which improved the ion exchange capacity of the soil, hence increase in soil pH. Similar results have been reported while studying improvement in soil health in mango orchards (3). Both pH and EC increased upto 30–60 cm and decreased at 60–90 cm. It might be due to the high organic matter content in the surface soil which tightly bind with basic ions and reduce their activity in the soil solution thereby raise soil pH and reduce acidity. Increasing sand content with increasing depth might also be responsible for the decrease in pH and EC in deeper soil layers (60–90 cm). Previous works reported loss of base forming cations down the soil profiles enhances the activity of Al^{3+} and H^+ in the soil solutions, which reduces soil pH and thereby increases soil acidity (18).

The CEC of a soil represents the total amount of exchangeable cations that the soil can adsorb. Though the data for CEC showed no significant variation at the 3 depths, yet maximum improvement (13.88 c mol P^+) was recorded in mango + turmeric at 0–30 cm followed by ginger and stevia. At 30–60 cm, maximum CEC content (12.57 c mol P^+) was recorded for stevia followed by ginger and turmeric compared to the initial value under sole mango crop. The CEC value decreased with increasing depth. It might be due to the increase in pH of the soil due to intercropping (19). This

reduction could also be due to the decreasing organic matter content in the deeper layers of the soil. Decrease in CEC value with increase in soil depth in mango orchards has also been reported (20). The low values of CEC might also be due to the sandy texture (60% sand) of the soil of the experimental site.

A perusal of the results (Table 3 and 4) show that compared to available nitrogen, available phosphorus and available potassium in sole mango at the start of the experiment, there was slight improvement at all the depths at the end of the experiment, but it was not significant. Maximum improvement in available nitrogen (235.09 kg ha^{-1} and phosphorus (14.76 kg ha^{-1}) content was in mango + ginger at 0–30 cm, while maximum improvement in available potassium (144.57 kg ha^{-1}) was in mango + turmeric. The marginal increase after 2 years might have taken place due to decomposition of biomass of intercrops in addition to leaf litter of mango in the orchard soil. Similar results of improved soil characteristic have also been reported (21) in apple-based hortipasture system and in bael-based hortipasture system (22). Increase in available nitrogen, phosphorus and potassium might be due to application of recommended doses of NPK fertilisers to the intercrops (Table 5). It was also observed that the NPK content decreased with increasing depths which might be due to leaching losses and progressive reduction in organic matter with increasing depth (23, 24).

Effect of intercropping on microbial count

In the present study microbial load was calculated at 2 depths 0–15 cm and 15–30 cm after the completion of the experiment. It was found that the microbial population decreased at both the depths in all the 4 intercrops (Table 6). The decrease was more drastic (169–184 $\times 10^4$ cfu g^{-1} soil) in mango + kalmegh at 0–15 cm

Table 5. Available nutrients as affected by intercrops and different spacing under mango orchard

Treatment combination	Available N (kg ha^{-1})			Available P (kg ha^{-1})			Available K (kg ha^{-1})		
	0–30	30–60	60–90	0–30	30–60	60–90	0–30	30–60	60–90
Depths (cm) Crops									
Ginger (G)	235.09	186.21	161.55	14.76	11.29	10.77	127.27	132.64	121.48
Turmeric (T)	230.54	206.44	168.68	14.32	12.18	11.98	144.57	135.69	127.49
Stevia (S)	221.79	204.55	167.24	14.65	13.94	10.29	136.58	113.06	112.35
Kalmegh (K)	224.19	196.78	162.64	13.29	11.04	9.17	124.82	115.40	105.25
±SE(m)	3.92	3.87	2.12	0.93	0.48	0.42	5.66	2.51	4.37
CD_{0.05}	NS	11.43	NS	NS	NS	1.24	NS	7.41	12.92
Spacing									
20 x 30 cm (S ₁)	238.39	199.25	161.04	14.45	12.94	9.80	132.05	126.86	119.13
30 x 30 cm (S ₂)	217.77	192.06	160.15	14.88	12.01	11.56	133.34	122.63	109.22
30 x 40 cm (S ₃)	227.55	204.18	173.89	13.44	11.39	10.29	134.55	123.11	121.58
±SE(m)	3.39	3.35	1.83	0.80	0.42	0.36	4.90	2.17	3.79
CD_{0.05}	10.01	NS	5.41	NS	1.23	1.07	NS	NS	NS
Crops x spacing									
G S ₁	251.70	177.01	151.35	14.38	10.22	8.07	116.29	143.11	122.52
G S ₂	214.61	168.08	138.42	14.99	11.35	11.93	139.92	137.94	120.39
G S ₃	238.96	213.54	194.89	14.90	12.31	12.30	125.62	116.88	121.52
T S ₁	249.13	221.99	170.84	14.94	14.65	12.55	151.27	141.42	138.70
T S ₂	218.69	196.96	164.48	14.59	10.61	13.54	137.24	127.11	105.97
T S ₃	223.79	200.36	170.71	13.43	11.27	9.85	145.21	138.55	137.80
S S ₁	226.32	206.76	161.30	15.47	16.15	9.28	151.27	112.68	108.75
S S ₂	217.70	207.80	168.86	15.24	14.91	11.99	137.24	109.29	112.86
S S ₃	221.33	199.08	171.56	13.24	10.77	9.61	145.21	117.21	115.43
K S ₁	226.38	191.23	160.68	13.00	10.75	9.31	129.02	110.24	106.54
K S ₂	220.08	195.38	168.85	14.70	11.16	8.77	120.19	116.16	97.65
K S ₃	226.12	203.72	158.39	12.17	11.21	9.41	125.26	119.79	111.57
±SE(m)	6.78	6.71	3.67	1.60	0.84	0.73	9.80	4.35	7.58
CD_{0.05}	NS	19.80	10.82	NS	2.47	2.15	NS	12.84	NS
Initial value	200.07	186.42	178.27	13.40	12.04	10.90	120.40	115.00	110.38

NS- Non significant.

Table 6. Soil microbial count at varying depths affected by different crops under mango orchard

Treatment combinations		Microbial count (x 10 ⁴ cfu g ⁻¹ soil)	
		Mango orchard	
Crop	Spacings	0–15 cm	15–30 cm
<i>Zingiber officinalis</i>	S1 30 x 20 cm	280	149
	S2 30 x 30 cm	271	131
	S3 30 x 40 cm	266	144
<i>Curcuma longa</i>	S1 30 x 20 cm	315	174
	S2 30 x 30 cm	298	185
	S3 30 x 40 cm	281	151
<i>Stevia rebaudiana</i>	S1 30 x 20 cm	209	108
	S2 30 x 30 cm	206	105
	S3 30 x 40 cm	199	102
<i>Andrographis paniculata</i>	S1 30 x 20 cm	184	101
	S2 30 x 30 cm	175	98
	S3 30 x 40 cm	169	95
Initial status		343	178

depth as compared to initial value (343 x 10⁴ cfu g⁻¹soil). In mango + ginger, mango + turmeric, mango + stevia, microbial load at depth 0–15 cm ranged from 266–280 x 10⁴ cfu g⁻¹soil, 281–315 x 10⁴ cfu g⁻¹ soil and 199–209 x 10⁴ cfu g⁻¹soil respectively. The load of microbes decreased with increasing depth (15–30 cm). It could be ascribed to the fact that the floor of the orchard was not cultivated prior to this experiment and thus the microbial population was high, but, when it was brought under intercropping, various intercultural operations and application of fertilizer doses altered the surrounding physical environment of the soil especially in 0–30 cm depth which led to the decrease in microbial load. Earlier results reported that tilling of agricultural soil may magnify the degree of nutrient waste and runoff by altering nutrient cycles through changes to microbial communities (25), the diversity decreased as tillage practices intensified (26). The decrease might also be due to the increased crop diversity (intercrops), different plant species secrete diverse root exudates, which might have affected the soil microbial diversity (27, 28). Previous works reported that at the soil surface, microbial biomass carbon (MBC) was higher with no-tillage than standard tillage (29). They further opined that MBC per square meter was higher in the soil surface layer in no-tillage + continuous cropping than other treatments.

Conclusion

Intercropping system based on mango with 4 crops viz. ginger (*Z. officinale*), turmeric (*C. longa*), stevia (*S. rebaudiana*) and kalmegh (*A. paniculata*) did not cause significant changes in the soil physicochemical characteristics such as soil moisture, bulk density, CEC, pH, EC, available nitrogen, available phosphorus and available potassium in the 2 growing seasons. However, slight improvements were observed across these parameters, clearly signifying that intercropping in old orchards can contribute to building fertility over the long term. Furthermore, microbial population are also likely to improve in the long run with the continued cultivation of suitable intercrops in such orchards under the sub-tropical conditions of Jammu and Kashmir.

Authors' contributions

Conceptualisation was carried out by MG and LMG. The methodology was developed by MJ. Software development and formal analysis were performed by SS. Validation was conducted by MG and SK, while investigation was undertaken by LMG.

Resources were collected by KKS, and data curation was performed by MG. The original draft was prepared by MJ and review and editing were carried out by LMG and VM. Visualisation was completed by SKG. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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