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ORIGINAL RESEARCH

Influence the status of soil chemical and biological properties by intercropping

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Abstract
Background Intercropping systems significantly influence chemical and biological properties of the soil. Our objective was to evaluate the effects of intercropping systems on soil organic carbon (SOC), total Kjeldahl nitrogen (TKN), available N, P and K, soil microbial biomass carbon (MB_C) and microbial biomass nitrogen (MB_N) under geranium (*Pelargonium graveolens* L.)-based intercropping systems.
Results Geranium-based intercropping (with cereals, pulses, fodder, and vegetables) resulted in increase of SOC and TKN by 7.8–69.2 % and 10.7–92.8 %, respectively, over geranium alone. Similarly, microbial respiration was higher under geranium intercropped with oat (36.3 %) followed by wheat (30.5 %) and barley (12.5 %) as compared to that under geranium alone. Soil MB_C accounted for 3.3–4.7 % of SOC content and soil MB_N accounted for 3.1–3.5 % of TKN under different intercropping conditions. A higher CO_2 evolution rate and a wider soil MB_C/MB_N ratio were recorded with cereals and fodders.
Conclusions It is concluded that the build-up of the organic matter and enhancement of soil MB_C in the intercropping study should promote long-term stability of soil health.

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Keywords Geranium · Intercrops · Soil microbial biomass C · Soil microbial biomass N · Sustainability · SOC · TKN

Background

Geranium (*Pelargonium graveolens* L.) is an aromatic crop, the shoot biomass of which, on steam distillation, yields an essential oil which is widely used in fragrance and flavour industries. It is a vegetatively propagated (through rooted cutting) crop and is initially slow growing. The wide uncovered interspaces between the rows of geranium harbour a large number of weeds in the initial stage of crop growth resulting in suboptimal utilization of natural resources and inputs leading to yield losses and increased cost of cultivation (Rajeswara Rao et al. 1993). Crop diversification, following intercropping and agroforestry, has been reported to be a potential alternative for enhancing per capita (unit area and time) productivity in the context of shrinking land holding and increasing human and livestock population (Swaminathan 2001). Crop diversification increases resource use, reduces production cost, and improves or maintains soil quality in intensive agriculture systems (Andersen et al. 2004). Geranium cultivation provides income only once a year and the cultivation of some winter crops is sacrificed due to a long duration of this crop. In this context, inclusion of short duration, high value, and midseason income generating intercrops could be highly remunerative. Earlier studies on geranium-based intercropping indicated that the systems, besides being remunerative, maintain the soil quality (Verma et al. 2009).

Different plant growth habits allow crops to use resources at different times in the growing season (Fukai and Trenbath 1993). Main and intercrops having similar root systems, canopy and growth habits may compete for natural resources, fertilizers and irrigation input. Plants with different growth habits, root systems, canopy and growth period may help in optimum and rational use of resources. For example, legumes, as an intercrop component, complement the N requirement of the non-legume component (Patra et al. 1986). The beneficial interaction could be the result of increased resource utilization through root-induced changes in the rhizosphere (Ae et al. 1990; Horst and Waschkies 1987).

Soil quality, defined as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health, improves with suitable intercropping as compared to pure stand (Doran and Parkin 1994). To evaluate soil quality, key biological and chemical indicators need to be evaluated for their sensitivity to changes in the management or disturbances. Soil microbial biomass is a sensitive indicator of soil quality and is influenced by many ecological factors such as plant community composition, soil organic matter levels, moisture, and temperature (Jenkinson and Ladd 1981; Patra et al. 1992, 1995; Li and Chen 2004). It gives an indication of any change in the quality of soil much before the bulk soil organic matter (Patra et al. 1991). The microbial metabolic quotient (qCO_2) has been used as a bioindicator of environmental stress on microbial communities (Anderson and Domsch 1993; Chand et al. 2004).

Geranium is a nearly a 9 months' crop; it provides enough time for crop residue turnover, thus maintaining soil quality in terms of nutrients, soil respiration, microbial biomass, and microbial activity in the soil. Studies on geranium-based intercropping with special reference to soil fertility, organic matter turnover, etc., are very scanty. Keeping the above in view, a field experiment was conducted to study the changes in soil organic matter, nutrient bioavailability, and microbial biomass C and N under different geranium intercropping systems.

Methods

Experimental site and treatments

A field experiment was conducted in the *rabi* (winter) season (cooler winter–warmer summer period, October to June) at the Central Institute of Medicinal and Aromatic Plants (CIMAP), Research Centre, Purara, Bageshwar, Uttarakhand, India, located at 30° 44′N–80° 24′E (1,250 m above mean sea level). The experimental area was characterized as a temperate region (western Himalayan) having hot summers and cold winters with mean annual maximum and minimum air temperatures of 34 and 1.0 °C, respectively. The monsoon in this region usually breaks in June and continues up to September. The soil of the experimental site is hilly sandy loam with the following initial properties: pH 6.6, soil organic carbon 4.0 g kg^{-1} soil, total Kjeldahl nitrogen (TKN) 0.30 g kg^{-1} soil, available N 220 kg ha^{-1}, NH_4-F extractable P 18.52 kg ha^{-1}, and NH_4 OAC-extractable K 140 kg ha^{-1}. Before planting geranium, soil samples were drawn from a 0 to 15 cm soil layer by a core sampler at different places in the experimental fields. The samples so collected were thoroughly mixed and bulked, and a representative sample was drawn for initial biological and chemical analysis. Rooted plantlets (40 days old) of geranium were planted in October as sole crop and other main component of intercropping, where the companion crops

Table 1 Crop culture summary for rose-scented geranium with different intercrops

Treatment cropping	Planting month	Harvesting month(s)	Seed rate/plantlets (ha)	Crop geometry geranium/intercrops
Geranium sole	October	March/June (240 days)	37,037 nos.	1
Geranium + wheat	November	April (185 days)	80 kg	1:2
Geranium + barley	November	March (150 days)	70 kg	1:2
Geranium + oat	November	January/February (125 days)	100 kg	1:2
Geranium + berseem[a]	October	January/February (125 days)	30 kg	1:2
Geranium + lentil[a]	November	March (150 days)	50 kg	1:2
Geranium + mustard	November	March (140 days)	1.5 kg	1:1
Geranium + cabbage	November	February (110 days)	55,555 nos.	1:1
Geranium + cauliflower	October	February (110 days)	37,037 nos.	1:1
Geranium + pea[a]	October	March (125 days)	100 kg	1:1
Geranium + radish	October	January (55 days)	7.5 kg	1:1

[a] Rhizobium culture treated seed; Fertilizer application N:P:K = 100:60:60 in sole geranium and intercrops, 1/3 N, Full P and K at planting; 1/3 N at last week of December; and 1/3 N after intercrops harvest

were wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), berseem (*Trifolium alexandrium* L.), lentil (*Lens esculenta* Monench.), mustard (*Brassica juncia* L.), radish (*Raphanus sativus* L.), vegetable pea (*Pisum sativum* L.), cabbage (*Brassica oleracea* L. var.capitata) and cauliflower (*Brassica oleracea* L. var.botrytis). Altogether there were 11 treatment combinations consisting of geranium alone and intercropping. Treatments were laid in a randomized block design (RBD), with three replications. As mentioned earlier, 40-day-old plantlets of geranium were planted in rows of 60 cm apart keeping a plant-to-plant distance of 45 cm. For intercropping, the intercrop components were planted in the space between two rows. Planting/sowing of crops, crop geometry, fertilizer application, harvesting, etc., are given in Table 1.

Soil sampling and analysis

Composite surface (0–15 cm) soil samples (i.e., five random core samples from each plot were thoroughly mixed together) were collected from each plot (i.e., replicate) at harvesting stage, on 26 June 2008. The composite samples were placed in plastic bags and brought to the laboratory, where field moist soils were sieved (<2 mm), homogenized and stored at 5 °C in an airtight container in the presence of soda lime. Soil organic carbon (SOC) in soil was determined by the Walkley and Black (1934) method, TKN by the micro-Kjeldahl methods (Page et al. 1982), available N (Subbiah and Asija 1956), NH_4-N extracted with 2 M KCl (Page et al. 1982), available P using NH_4-F method (Bray and Kurtz 1945) and available K using NH_4OAC method as described by Page et al. (1982). Soil microbial C (MB_C) and N (MB_N) were determined using chloroform fumigation-incubation method. Fifty grams soil sample was fumigated with chloroform, defumigated and then incubated with 1 g fresh unfumigated soil. This was incubated for 10 days in the presence of NaOH in a vial suspended inside the flask to trap the evolved CO_2. Fifty grams of the same soil sample was taken in another beaker without chloroform fumigation and incubated similarly in the presence of NaOH to trap the evolved CO_2. Microbial biomass C (C_{mic}) was determined by using the equation: Biomass $C = (F_C - UF_C)/K_C$, where $F_C = CO_2$ evolved from fumigated soil, $UF_C = CO_2$ evolved from unfumigated soil, $K_C = 0.45$ (Jenkinson and Ladd 1981). The amount of soil microbial biomass N (N_{mic}) was calculated by using following equation: $N_{mic} = (F_N - UF_N)/K_N$, where $F_N = NH_4$-N mineralized during 10 days from fumigated soil, $UF_N = NH_4$-N mineralized during 10 days from unfumigated soil, $K_N = 0.54$ (Jenkinson 1988). All parameters were expressed on dry weight basis soil.

Statistical analysis

A one-way analysis of variance (ANOVA) was performed to determine the effects of intercrops' treatments on the estimated parameters. Least significant difference (LSD at $p = 0.05$) was used to determine whether means differ significantly. Correlation coefficient was calculated to assess the inter-relationship between the different parameters measured (Snedecor and Cochran 1967).

Results and discussion

Soil organic carbon (SOC) and total Kjeldahl nitrogen (TKN)

Data on soil organic C (SOC) indicate that it significantly increased due to intercropping (Table 2). SOC increased by 8.2 % in geranium-cropped soil over the initial (4.0 g kg^{-1} soil) value. Similarly, the extent of increase in SOC over initial value was 24.0, 17.4, 28.2, 57.5, 83.2, 19.0, 66.5, 25.7, 32.5 and 36.5 %, when geranium was intercropped with wheat, barley, oat, berseem, lentil, mustard, vegetable pea, radish, cabbage and cauliflower, respectively. In general, the extent of increase in SOC was higher when berseem and cabbage were grown as intercrops. The status of TKN in the post-harvest soil was marginally different from SOC. Total N marginally decreased in geranium-planted soil as compared to the initial value. However, except in case of barley, the remaining intercropping systems exhibited a significant increase in TKN when compared to the initial value. The decline in TKN under sole geranium might be due to supplementary availability of N

Table 2 Soil organic C (SOC), total Kjeldahl N (TKN), and C/N ratio in geranium post-harvest soil as affected by different treatments

Treatments	SOC (g kg^{-1} soil)	TKN (g kg^{-1} soil)	C/N ratio
Initial	4.00	0.30	13.30
Geranium sole	4.33	0.28	15.30
Geranium + wheat	4.96	0.36	13.56
Geranium + barley	4.70	0.31	14.87
Geranium + oat	5.13	0.33	15.54
Geranium + berseem	7.33	0.54	13.58
Geranium + lentil	6.30	0.48	12.94
Geranium + mustard	4.76	0.47	10.14
Geranium + cabbage	6.66	0.51	13.07
Geranium + cauliflower	5.03	0.48	10.48
Geranium + pea	5.30	0.49	10.81
Geranium + radish	5.46	0.47	11.63
LSD ($p = 0.05$)	0.28	0.02	1.04

from additional dose of fertilizer applied to the intercrop and biomass mediated N from the intercrop vis-a-vis root turnover. A positive correlation (0.63) was found between SOC and TKN (Table 5). This indicates that, with more SOC and TKN, the availability of nitrogen increased which might be due to the mineralization processes by the microorganisms having C as the energy source at their disposal. Although any permanent change in soil organic matter is a very slow process, the carbon pool is easily affected by cultivation, fertilization, other management practices, stress (both biotic and abiotic) and climatic conditions (Suman et al. 2006; Zaman and Chang 2004). It indicates that berseem and pulses as intercrops exhibited a higher build-up of SOC and TKN. The C/N ratio of the soil varied significantly across intercrops, the lowest being recorded in mustard as intercrop and highest in oat as intercrop (Table 2). Apparently, no correlation was found among SOC, TKN, soil MB_C, MB_N and available N in this study as has been observed by other researchers (Zak Donald et al. 1990).

Microbial changes

Data presented in Table 3 indicate that the intercrops had a significant influence on soil respiration as compared to the soil grown with geranium alone. Higher soil respiration was under oat (36.3 %), followed by wheat (30.5 %), berseem (20.9 %) and lowest under lentil and vegetables. Suman et al. (2006) and Raiesi (2004) reported an increase in soil respiration by 6–35 % due to residue incorporation and decomposition. Similar observations have also been made by Patra et al. (1995). Vegetables and mustard intercrops, however, did not have any significant affect on respiration rate as observed under other intercrops. Soil microbial biomass C and N indicate the status of nutrient turnover and nutrient bioavailability. Soil microbial biomass carbon (MB_C) was highest under berseem (23.3 %) intercropping, followed by vegetable pea (20.4 %), lentil (17.8 %) and lowest under vegetables (Table 3). Similarly biomass nitrogen (MB_N) was significantly higher in the intercropped plots being highest under berseem (92.5 %), followed by vegetable pea (77.5 %) and lentil (65.5 %). Soil microbial C/N ratio was narrow under the aforesaid intercropping systems. The wider MB_C/MB_N ratio in crops other than berseem and pulses is due to the low MB_N, which might be due to less TKN and available nutrient in these treatments (Suman et al. 2006). The C/N ratio of the microbial biomass is also an indicator of the relative proportion of fungi to bacteria (Wheatley et al. 1990; Fauci and Dick 1994). The soil MB_C accounted for 3.3–4.7 % of the SOC content under different intercropping systems (Table 4). Chand et al. (2004) reported that the proportion of SOC or MB_C ranged between 25 and 51 mg MB_C g^{-1} SOC in soils amended with mint (*Mentha arvensis*) distillation waste materials. Similar trends have also been reported by other workers (Suman et al. 2006; Sparling 1992). The proportion of SOC to MB_C varied due to several managements, inputs and soil conditions. For example, Patra et al. (1995) reported a higher proportion of MB_C in light texture soil cropped with aromatic grasses than other crops especially in the hot and humid period of the

Table 3 Soil biological properties including soil respiration, soil microbial biomass (MB_C) and biomass nitrogen (MB_N) in geranium post-harvest soil as affected by different treatments

Treatments	Respiration rate (mg CO_2-C evolved kg^{-1} soil d^{-1})	Soil MB_C (mg kg^{-1} soil)	Soil MB_N (mg kg^{-1} soil)
Geranium sole	17.44	197.73	10.03
Geranium + wheat	22.77	215.03	12.77
Geranium + barley	19.63	205.47	11.38
Geranium + oat	23.78	226.36	10.50
Geranium + berseem	21.09	243.99	19.20
Geranium + lentil	18.08	233.09	16.51
Geranium + mustard	16.68	228.66	14.64
Geranium + cabbage	16.10	238.23	17.70
Geranium + cauliflower	15.01	220.94	15.72
Geranium + pea	16.24	224.67	15.57
Geranium + radish	17.23	226.67	15.24
LSD ($p = 0.05$)	2.04	5.27	1.19

MB_C Soil microbial biomass carbon, *MB_N* Soil microbial biomass nitrogen

Table 4 Variation in soil biological properties and metabolic quotient (qCO_2) in geranium post-harvest soil as affected by different treatments

Treatments	qCO_2	Soil MB_C/MB_N	CO_2–C/soil MB_N
Geranium sole	88.27	19.71	1.73
Geranium + wheat	105.90	16.83	1.77
Geranium + barley	95.65	18.16	1.73
Geranium + oat	105.22	21.60	2.26
Geranium + berseem	86.55	12.70	1.09
Geranium + lentil	77.17	14.11	1.09
Geranium + mustard	73.03	15.64	1.14
Geranium + cabbage	67.73	13.45	0.92
Geranium + cauliflower	67.96	14.10	0.95
Geranium + pea	72.42	14.42	1.03
Geranium + radish	76.11	14.87	1.12
LSD ($p = 0.05$)	9.21	1.59	0.21

MB_C Soil microbial biomass carbon, *MB_N* Soil microbial biomass nitrogen, Soil organic carbon, *TKN* Total Kjeldahl nitrogen

Table 5 Correlation among soil chemicals and biological properties of geranium intercropped with cereals, fodders, pulses and vegetables

Chemical and biological properties	SOC	TKN	C/N	CO_2–C evolved	Soil MB_C	Soil MB_N	MB_C/MB_N	q CO_2	CO_2/MB_N
SOC	1.00								
TKN	0.63[b]	1.00							
C/N	−0.34[a]	−0.002	1.00						
CO_2–C evolved	−0.52[b]	−0.35[b]	0.80[b]	1.00					
Soil MB_C	0.62[b]	0.49[b]	−0.60[b]	−0.94[b]	1.00				
Soil MB_N	−0.16	−0.08	−0.64[b]	−0.71[b]	0.58[b]	1.00			
MB_C/MB_N	0.50[b]	0.11	−0.23	0.08	−0.15	−0.33	1.00		
qCO_2	−0.48[b]	−0.21	0.61[b]	0.61[b]	−0.58[b]	−0.35[a]	−0.21	1.00	
CO_2/MB_N	−0.54[b]	−0.42[a]	0.32	0.53[b]	−0.61[b]	−0.25	−0.10	0.34	1.00

[a] qCO2 metabolic quotient = μg CO2−C evolved 10 d^{-1} g^{-1} soil/μg soil MBC g^{-1} soil 10d × 1,000 (Meyer et al. 1996)

cropping year. It has also been observed that addition of organic residue had a greater effect on MB_C than cropping history and inorganic NPK addition (Fauci and Dick 1994). This might create a calibrated soil quality indicator that only predicts whether soil is accumulating or losing soil C. Soil MB_C/SOC had a very strong positive correlation with, SOC, TKN, MB_C and MB_C/SOC (Tables 4, 5). Such results have also been reported by other workers on different soil and climatic conditions (Suman et al. 2006). Moreover, the substrate type has a marked impact on MB_C and MB_N, as evidenced by the effects of different crop residues and plant litter on a range of above- and below-ground properties and processes (Chand et al. 2004). Crop residues of soybean [*Glycin max*. (L.) Merr.] and other pulses supported more microbial growth although they have less residue input to soils then cereals and other crops (Balota et al. 2003).

The metabolic quotient (qCO_2) also called as biomass-specific respiration is defined as respiratory CO_2 released per unit microbial biomass per unit time. The results reveal that the cropping system significantly influenced the qCO_2 (Table 4). The data indicate that apparently the cereal/fodder-crop-based intercropping system resulted in a high qCO_2 which may presumably be due to a high C input at the disposal of microorganism and that higher microbial activity is maintained at high C expense (Chand et al. 2004). Odum (1985) postulated that, under stress, qCO_2 increases due to diversion of energy from growth, maintenance, and reproduction, which was further extrapolated to the soil microbial community by Anderson and Domsch (1993). Therefore, qCO_2 was calculated in soil under each intercrop and it was found that a higher qCO_2 with wheat, oat and barely intercrops gives an indication of either variable microbial communities or stressed conditions due to variable quality and quantity of the crop residues as compared with other intercrops. Strong positive correlation of qCO_2 with C/N and soil respiration rate and negative correlation with SOC MB_C, MB_N were observed (Table 5); the variable qCO_2 in this study is due to different substrate inputs. Mader et al. (2002) observed that qCO_2 is lower under conservative management than under conventional management where a different type of organic substrate is added to the soil.

Table 6 Status of available N, P and K in geranium post-harvest soil as affected by different treatments

Treatments	Available N (kg ha^{-1} soil)	Available P (kg ha^{-1} soil)	Available K (kg ha^{-1} soil)
Initial	220	18.52	140
Geranium sole	226	19.59	156
Geranium + wheat	239	21.81	170
Geranium + barley	236	22.78	161
Geranium + oat	231	20.09	156
Geranium + berseem	245	22.23	158
Geranium + lentil	242	25.43	167
Geranium + mustard	250	22.58	163
Geranium + cabbage	249	22.89	175
Geranium + cauliflower	238	25.24	149
Geranium + pea	245	23.88	149
Geranium + radish	238	24.08	153
LSD (p = 0.05)	9.36	2.14	8.16

Inorganic nutrients

Availability of N significantly increased (2.2–15.0 %) due to different intercrops as compared with sole geranium, being highest with mustard, followed by vegetable pea, cabbage and berseem (Table 6). The availability of P also increased due to intercrops except for oat (fodder crop). Cong and Mercky (2005), while reviewing the postulated mechanisms for improved availability of P due to green manuring and plant residue incorporation, have shown that an improved availability of P can be due to the release of P from the decomposition of crop residues, reduced P sorption due to blocking of P sorption sites by organic compounds leading to P release from Al to P complexes, or decreased soil pH leading to an increased P concentration in the soil solution. In general, a significant change in the availability of P was observed as a result of intercropping. Available K did not follow any specific trend due to intercropping. However, the available P was marginally low under radish and cabbage as intercrops. Similar observations have been made by Suman et al. (2006).

Conclusions

The capacity of a soil to function within ecosystem boundaries is to sustain biological productivity, maintain environmental quality, and promote plant and soil health by several factors. The cropping system and crops can play an important role in soil chemical and biological properties. In the present study, soil organic matter and microbial biomass C were higher in intercropping systems. Higher organic C inputs through decomposition of plant residues helped in increasing microbial activities. In this study, we evaluated soil quality indicators in different geranium-based intercropping systems. Our overall interpretation of these diverse sets of data is that the quality of soils varies with different geranium-based intercropping conditions. The incorporation of berseem and pulses as intercrops (biological N fixer) led to improved soil chemical and biological properties in a temperate region.

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