Interaction of above-and below-ground bioresources for improvement of chemical and biological health of soil

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Abstract

Impacts of different land use systems on faunal density, nutrient dynamics and biochemical properties of soil were studied in different agrisilviculture systems of Jodhpur district of Rajasthan (India). The selected uses were tree (*Zizyphus mauritiana, Prosopis cineraria, Acacia nilotica*) and crop (*Pennisetum glaucum, Vigna radiata, Sesamum indicum*) combinations. Soil is aridisol, coarse loamy, mixed hyperthermic type. Populations of Acari, Myriapoda, Coleoptera, Collembola, other arthropods and total soil fauna exhibited significant changes with respect to different land use practices and tree species. In most of the cases, the populations of different groups of soil fauna were higher under the canopy of tree alone than in different cropping systems with tree. However, this was not true for *V. radiata* cultivated land which showed higher faunal population than that of tree field alone. Different groups of soil fauna demonstrated a significant positive correlation among themselves. The Coleoptera exhibited greatest association with all agrisilviculture fields. However, *Z. mauritiana* system indicated highest facilitative effects on all groups of soil fauna. Soil temperature and pH decreased but soil moisture, organic carbon, available nitrogen, phosphate-phosphorus, soil respiration and dehydrogenase activity increased considerably under the canopy of tree than that of open field. However, these chemical constituents did not differ between tree and crop field which may be due to an increased biotic activity in cultivated land. Soil temperature and pH of *V. radiata* field were lower than that of *P. glaucum* and *S. indicum* cultivated land. In contrast, the gradation of soil moisture, organic carbon and organic matter, nitrate- and ammonical-nitrogen, phosphate-phosphorus, soil respiration and dehydrogenase activity was *V. radiata*> *P. glaucum*> *S. indicum*. Thus increase in soil temperature and pH might be mainly responsible for decrease in chemical and biochemical constituents of cultivated land in desert. Negative correlation of soil temperature with different soil characteristics except pH shows that the increase in soil temperature is not conducive for soil health in desert. The negative correlation of soil pH with other chemical and biological properties of soil may be due to reduction in soil pH as a result of litter decomposition and humic acid formation. A positive and significant correlation among organic carbon, nitrate- and ammonical-nitrogen, available phosphorus, soil respiration and dehydrogenase activity clearly reflects increase in soil nutrients with the increase in microbial and other biotic activity. *Z. mauritiana* field harbouring *V. radiata* crop was best for agrisilviculture practices in arid region. The increase in soil nutrients and microbial activity is associated with the increase in soil faunal population. This suggests that litter addition and decomposition in arid agrisilviculture system induce activities of microbial and faunal resources for improving chemical and biological health of soil.

Additional keywords: agrisilviculture; fauna; nutrients; respiration; dehydrogenase activity.

Resumo

TRIPATHI, G.; SHARMA, B. M. Interação entre recursos biológicos acima e abaixo da superfície para melhoria da sanidade química e biológica do solo. **Científica**, Jaboticabal, v.34, n.1, p.75 - 91, 2006.

Impactos de diferentes modos de uso da terra na densidade de fauna, na dinâmica de nutrientes e nas propriedades bioquímicas do solo foram estudados em sistemas agrossilviculturais em Jodhpur, distrito de Rajasthan, Índia. Os usos selecionados foram combinações de árvores (*Zizyphus mauritiana, Prosopis cineraria, Acacia nilotica*) e culturas (*Pennisetum glaucum, Vigna radiata, Sesamum indicum*). O solo é um aridissol, tipo hipotérmico misto. Populações de Acari, Myriapoda, Coleoptera, Collembola, outros artrópodos e a fauna total do solo apresentaram modificações significativas em relação a diferentes práticas de uso da terra e às espécies de árvores. Na maioria dos casos, as populações dos diferentes grupos de fauna do solo foram maiores sob a copa somente de árvores do que em diferentes sistemas de cultivo com árvores. Entretanto, isso não ocorreu com o solo cultivado com *V. radiata*, que apresentou maior população de fauna do que a área somente com árvores. Diferentes grupos de fauna do solo mostraram correlação positiva significativa entre eles. Os Coleoptera exibiram a associação mais alta com todas as áreas de agrossilvicultura. Entretanto, o sistema com *Z. mauritiana* indicou efeitos benéficos maiores para todos os grupos de fauna do solo. A temperatura e o pH do solo diminuíram, mas a umidade do solo, o carbono orgânico, o nitrogênio disponível, o fósforo em forma de fosfato, a respiração do solo e a atividade de desidrogenase aumentaram consideravelmente sob a copa de árvores, em comparação com áreas abertas. No entanto, esses constituintes químicos não diferiram entre árvores e culturas, o que pode decorrer de aumento da atividade biológica em solo cultivado. A temperatura e o pH do solo na área de *V. radiata* foram mais baixos do que nas áreas com *P. glaucum* e *S. indicum*. Por outro lado, o gradiente de umidade do solo, o carbono orgânico e a matéria orgânica, o nitrogênio nítrico e amoniacal, o fósforo em forma de fosfato, a respiração do solo e a atividade de desidrogenase seguiram a ordem *V. radiata*> *P. glaucum*> *S. indicum*. Portanto, o aumento da temperatura e do pH do solo poderia ser, principalmente, responsável pelo decréscimo dos valores dos constituintes químicos e bioquímicos de solos cultivados no deserto. A correlação negativa da temperatura do solo com diferentes características do solo, exceto pH, mostra que o aumento da temperatura do solo não leva à melhoria do solo no deserto. A correlação negativa do pH do solo com outras propriedades químicas e biológicas pode ser devida à diminuição do pH causada pela decomposição dos restos orgânicos e pela formação de ácido húmico. A correlação positiva significativa entre carbono orgânico, nitrogênio nítrico e amoniacal, fósforo disponível, respiração do solo e atividade de desidrogenase reflete claramente aumento nos nutrientes do solo com o aumento da atividade microbiana e outras atividades bióticas. A consorciação de *Z. mauritiana* com *V. radiata* foi a melhor para práticas agrossilviculturais em região árida. O aumento de nutrientes no solo e da atividade microbiana está associado com o aumento na população da fauna do solo. Isso sugere que a adição e a decomposição de restos orgânicos em sistemas agrossilviculturais em região árida induzem a atividade dos recursos microbianos e faunísticos para melhorar a qualidade química e biológica do solo.

Palavras-chave adicionais: agrossilvicultura; sistemas agroflorestais; fauna; nutrientes; respiração; atividade de desidrogenase.

Introduction

The greatest concentration of life occurs in soil. There is hardly any group of living things that is not represented in soil systems. The significant effects of soil fauna on the nutrient dynamics of the soil ecosystem have been documented (BUTCHER & SNIDER, 1971; MOORE et al., 1988; VERHOEFF & BRUSSAARD, 1990). The soil inhabiting animals play a vital role in humus formation and maintaining a control over plant-damaging species (SINGH & PILLAI, 1973). REDDY (1995) described association of soil organisms with litter decomposition in the tropics. The composition and seasonal abundance of soil inhabiting arthropods and their relationship with the temperature and moisture content of soil have been studied (SANYAL, 1996; SHWETA & GUPTA, 1997). JAIN et al. (1998) studied the seasonal composition of the acarine fauna in the leaf litter and top soil of a *Dalbergia sissoo* plantation. Knowledge of desert-inhabiting arthropods is largely confined to the larger forms (CLOUDSLEY-THOMPSON, 1964; KRIVOLUCKIJ, 1966 and 1968). WOOD (1972) described the distribution and abundance of Collembola and other microarthropods in arid and semi-arid soils in Southern Australia. The composition of the soil arthropods of Indian desert even in terms of their major groups is unknown.

Soil faunal density may be linked to litter quality and nutrient cycling rates. Depending on the densities of the soil arthropod populations, the effects of their activities range from minor to major. Macroarthropods directly improve soil structure and function (ABBOTT, 1989) and microarthropods affect soil structure indirectly and nutrient cycling directly (POWERS et al., 1998). Many studies have demonstrated the importance of the soil fauna as a regulator in nutrient cycling (ANDERSON et al., 1985; PERSSON, 1989; SETALA, 1990). KNOEPP et al. (2000) studied the biological indices of soil quality and compared with four common groups of soil biological indicators including soil microarthropods. In the tropics, soil fauna act as potential indicators of sustainability of rural activities (ERWIN, 1997). Sustainability of different farming activities may be viewed as the opportunity to match biodiversity and abundance of soil invertebrates and to assess human impact on agroecosystems (PAOLETTI & BRESSAN, 1996; PAOLETTI et al., 1996). NETRUZHILIN et al. (1999) assessed agricultural impact using ants as bioindicators in the Amazonian Savanna-forest ecotone. The plant cover provides food for many species of litter-dwellers. Cover crops build up a large root biomass, which alongwith the litter dropped from the above ground parts, provide food for arthropods. Specific crop types with differential nitrogen content may influence the dominance of different species of Collembola (MITRA, 1993; REDDY et al., 1994).

As the interest in sustainable farming systems continues to increase the role of soil biological interactions in processes such as the release of nutrients and the maintenance of soil structure become increasingly important to farmers. More imaginative thought and further research are required to identify a diverse range of biologically oriented measures that can be used for soil monitoring. In the present context of agro environmental deterioration and loss of soil fertility, there is an urgent need to maintain the biological health and productive capacity of agroecosystem. Desert soil is nutrient deficient and the soil biological process is of crucial importance to this region. Therefore, an attempt was made to study the biodynamic of soil fauna in relation to agrisilvicultural practices in Indian Thar desert. This will help in improving functional aspects of soil by nurturing selected soil fauna in arid environment.

Materials and methods

Study area and climate

Studies were done in agriculture land of an area of about 10 km^2 in Bilara Tehsil of Jodhpur district of Rajasthan. This area is situated between 26º 45´ North latitude and 72º 03´ East longitude in northwestern dry region of India. The climate of the study area is dry tropical type characterized by extremes of temperature, fitful and uncertain rainfall, high potential evapotranspiration and strong winds. The study was performed in rainy season which extends from mid July to September. Maximum temperature is recorded in May which suddenly drops down to about 35 °C at the onset phase of monsoon. The mean annual rainfall varies from 100 to 450 mm with 40 to 50% coefficient of variation and average number of rainy days of 15 to 21. The southwest monsoon, which begins in the last week of June, lasts till middle of September. Average wind speed is 14 to 18 km/h. The winds are strongest (60-70 km/h) during the months of June and July. The wind direction is west to south westerly in rainy period. Potential evapotranspiration was exceedingly higher than the precipitation resulting in perceptual water deficit throughout the year.

Land use systems and faunal extraction

The selected agroforestry tree systems were *Zizyphus mauritiana, Prosopis cineraria* and *Acacia nilotica*. The cropping systems with these trees were *Pennisetum glaucum, Vigna radiata* or *Sesamum indicum*. The faunal sampling was also done from an adjacent open (uncovered) field in order to see the impact of tree only on soil fauna. The frequency of irrigation was equal in all fields and no fertilizers or pesticides were used in the cropping systems. The samplings were done before irrigation. Studies were done in rainy season (August to September) of the years 2001 and 2002. Samplings were done using quadrat method by marking randomly 25 sites each of 25x25 cm area in a field of one hectare. Average data of five subunits (25x25 cm) were taken for converting the faunal population per square metre. The value recorded for one square metre was considered as observation for one replication. Five such replications were taken for the observations of one hectare area. The soil physical and chemical properties from each sampling site were analyzed as described in later part of this section. The soil samples were brought to the laboratory in polybags and labeled for date of sampling, habitat, place name, vegetation etc. These samples were processed for extraction of soil fauna by using Tullgren funnel with a 60 watt bulb. Fauna were allowed to move down into the funnel for 24 hours and they were collected in vials containing 70% alcohol. The vials were numbered for record of soil faunal collection site. The different groups of soil arthropods were sorted out by naked eye and under stereoscopic microscope, then placed in a flask containing 70% alcohol solution for later identification.

Physicochemical analysis

A soil thermometer was used to measure the soil temperature at 10 cm depth (WORLD METEOROLOGICAL ORGANIZATION, 1983) on each studied sites at the time of sampling. Soil moisture content was determined gravimetrically by oven drying at 105 °C until the weight stabilized, according to PAGE et al. (1982). Soil pH was determined in 1:2 soil water ratio with the help of a pH meter (RHOADES, 1982). Organic carbon was determined by the partial oxidation method (WALKLEY & BLACK, 1934). The organic matter was calculated by multiplying organic carbon content with Walkley-Black value (i.e., 1.724). The principles adopted for estimation of nitrate-nitrogen (NO_3-N) and ammonical-nitrogen (NH_4-N), and extractable phosphorus were mainly based on the methods described by ANDERSON & INGRAM (1993). An autoanalyzer (Tecator Model Enviroflow-5012) was used to determine these soil nutrients.

Biochemical analysis

Soil respiration was measured using 0.1M KOH solution that absorbs CO_2. This solution was exposed to CO_2 evolving from soil. It was then titrated with standardized 0.1M HCl after addition of saturated $BaCl_2$ solution. Absorbed CO_2 was calculated by taking 1 mL of 0.1M HCl equivalent to 2.2 mg CO_2. This was measured according to the method of ANDERSON (1982). Soil dehydrogenase activity was analyzed as described by SINGH et al. (1999). One gram of air-dried soil was kept in an air-tight screw capped test tube. 0.2mL of 3% TTC (triphenyl tetrazolium chloride) solution was added in each of the tubes to saturate the soil. Then 0.5 mL of 1% glucose solution was added in each tube. The bottom of the tube was gently tabbed to drive out all trapped oxygen and the water seal formed above the soil. The tube was incubated at 28 ± 0.5 °C for 24 hours. After incubation, 10 mL of methanol was added and shaken vigorously. Then it was allowed to stand for 6 hours. The clear pink colored supernatant was decanted and its absorbance was measured at a wave length of 480 nm in a spectrophotometer.

Statistical analysis

The statistical treatments are used viz., one-way and two-way analysis of variance (ANOVA) followed by a post-hoc test (i.e., LSD and DMRT tests). Pearson correlation coefficients were also calculated to correlate the changes in different observations. These statistical analyses were done with the help of a computer using a package. The interactions of tree species (S) and land use system (i.e., tree plus crop) (L) were also computed. The level of significance was set at 0.05.

Results and discussion

Impact of land use systems on soil fauna

Figure 1 shows the effects of land use systems on different groups of soil fauna. The Acari population varied significantly ($P<0.001$) due to changes in land use system except between *P. glaucum* and *S. indicum* ($P=0.065$). The variation due to tree species approached to a significant level (P=0.055). However, its population differed significantly (P<0.05) except between *Z. mauritiana* and *A. nilotica* soil system. But the population variation was statistically insignificant (P>0.05) between *Z. mauritiana* and *P. cineraria* and those between *P. cineraria* and *A. nilotica* (P>0.05). The interaction between tree species and land use system was not significant (P>0.05). Population of Acari was higher in *Z. mauritiana* field as compared to *P. cineraria* and *A. nilotica* system. Population of Myriapoda varied significantly (P<0.05) due to changes in tree species except between *Z. mauritiana* and *P. cineraria* field. The population also varied significantly (P<0.001 to 0.05) with respect to land use systems. But there was no significant (P>0.05) difference between *P. glaucum* and *S. indicum* agrocropping fields. The interaction of tree species and land use systems was insignificant (P>0.05). The myriapod population was higher in *Z. mauritiana* than *P. cineraria* and *A. nilotica* field. Population of Coleoptera changed significantly (P<0.001) as a function of changes in tree species. Significant population differences were also observed among different tree systems after LSD analysis. Similarly, it changed significantly (P<0.001) in various land use systems. The interaction between tree species and land use systems was not significant (P>0.05). Coleoptera population was higher in *Z. mauritiana* as compared to *P. cineraria* and *A. nilotica*. Population of Collembola changed significantly (P<0.001) with respect to changes in tree species except between *Z. mauritiana* and *P. cineraria* field. The faunal population changes due to different land use systems were significant (P<0.001 to 0.05) except between open field and *S. indicum* crop (P>0.05). The interaction between tree species and land use systems was not significant (P>0.05). The Collembola population was highest in *Z. mauritiana* and lowest in *A. nilotica* field. Population of other soil arthropods varied significantly (P<0.001) due to variation in tree species except between *Z. mauritiana* and *P. cineraria* (P<0.05) (Figure 2). The population changes due to different land use systems were significant (P<0.001) except between open field and *S. indicum* crop. The interaction between tree species and land use systems was not significant (P>0.05). The population was higher in *Z. mauritiana* as compared to *P. cineraria* and *A. nilotica* field. Population of total soil faunal groups changed significantly (P<0.001) due to variation in tree species. This also varied significantly (P<0.001) with respect to variation in different land use systems. The interaction between tree species and different land use systems was insignificant (P>0.05). The population of total faunal groups was highest in *Z. mauritiana* and lowest in *A. nilotica* field.

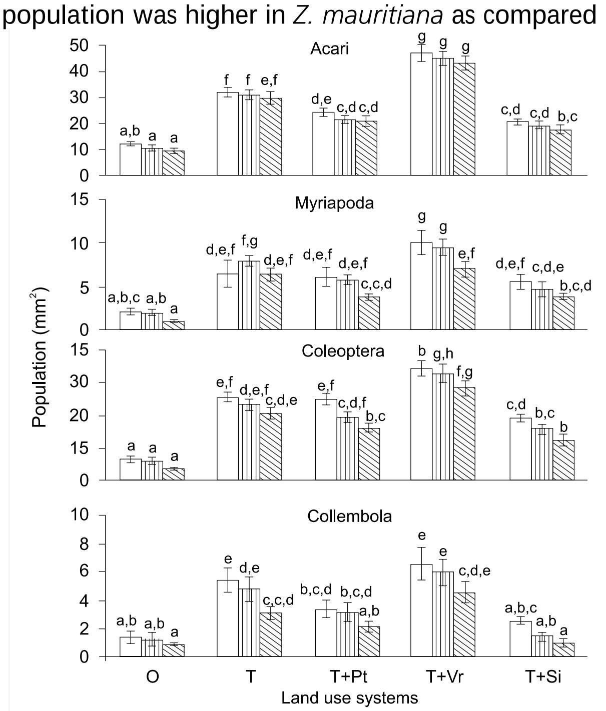

Figure 1 - Effect of land use system and tree species on populations of among groups (Acari, Myriapoda, Coleoptera and Collemb ola) of soil fauna. O: Open field; T: Tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata* and Si: *Sesamum indicum*. Tree species: □ *Zizyphus mauritiana*; ▥ *Prosopis cineraria* and ▧ *Acacia nilotica*. Bars with different letters are significantly different.

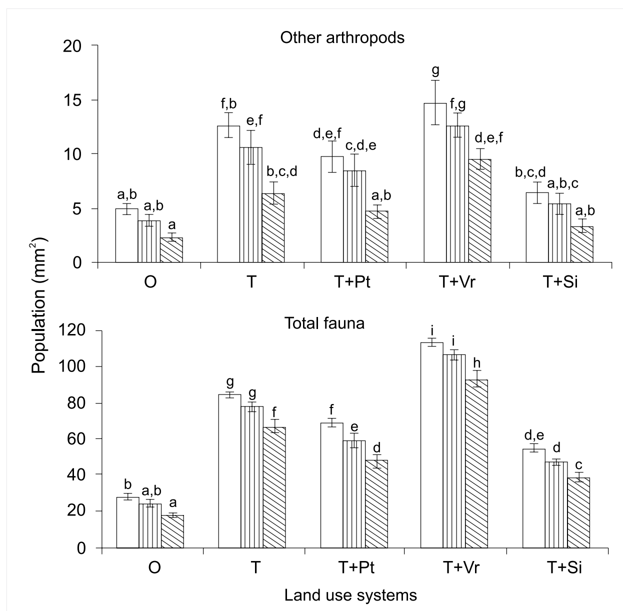

Figure 2 - Effect of land use system and tree species on populations of other arthropods and total fauna. O: Open field; T: Tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata* and Si: *Sesamum indicum*. Tree species: □ *Zizyphus mauritiana*; ▥ *Prosopis cineraria* and ▧ *Acacia nilotica*. Bars with different letters are significantly different.

Effect of tree on faunal population

The relative tree effect (RTE) for the population of different groups of soil arthropods exhibited negative value (Figure 3). RTE value was most negative in *Z. mauritiana* for all groups of soil arthropods. However, minimum negative value of RTE was observed in *A. nilotica*. The order of highest negative value to lowest negative value of RTE for different tree based system was *Z. mauritiana*> *P. cineraria*> *A. nilotica.* In term of greatest to lowest RTE values for all tree systems the soil arthropod groups can be graded as *Coleoptera*> *Myriapoda*>*Acari*> *Collembola*> other soil arthropods. It means Coleoptera have greatest association with different tree based agrisilviculture systems. The observations also indicated the highest facilitative effect of *Z. mauritiana* system in desert.

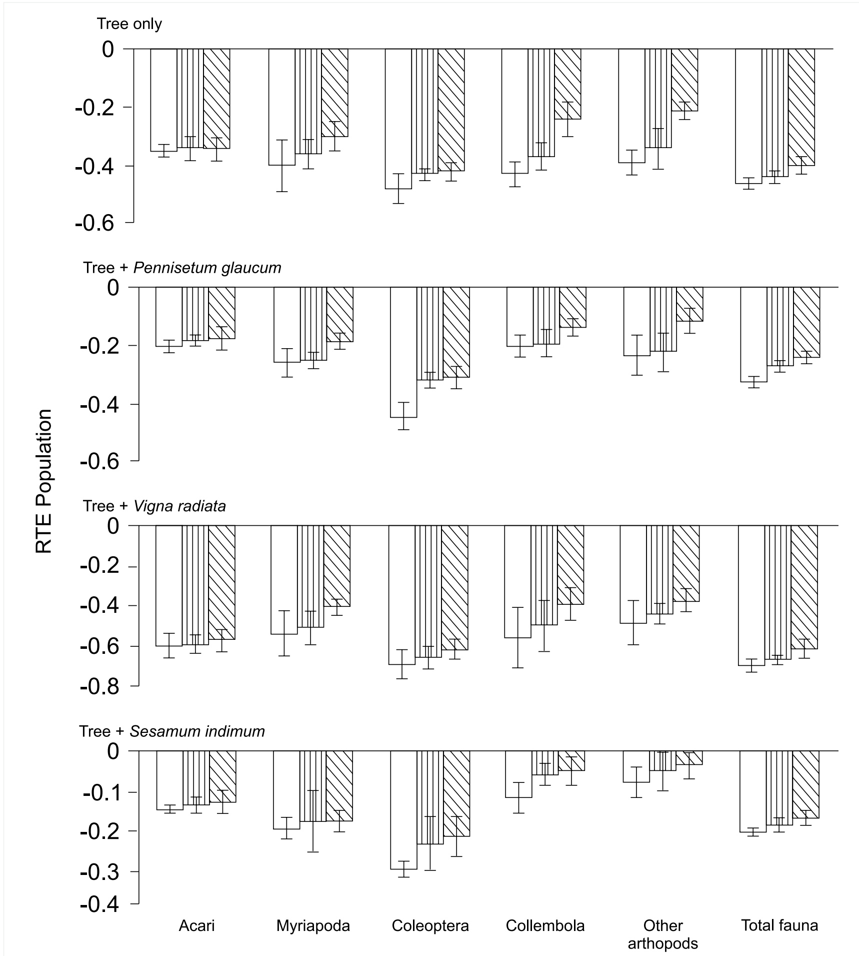

Figure 3 - Relative tree effect (RTE) of different soil arthropods population invarious agrisilviculture systems. Tree species: □ *Zizyphus mauritiana*; ▥ *Prosopis cineraria* and ▧ *Acacia nilotica*. Bars with different letters are significantly different.

Relation between land use practices and soil characteristics

Soil temperature varied (26.8-41.8 °C) significantly (P<0.001 to 0.05) with respect to changes in tree species and land use systems except between tree alone and tree plus *S. indicum* (P>0.05) crop (Table 1 and Figure 4). The soil temperature was highest in *A. nilotica* (41.8 °C) and lowest in *Z. mauritiana* field (26.8 °C). There was 4 to 16% reduction in soil temperature under the tree canopy than that of uncovered land. The temperature reduction had its maximum under *P. cineraria* system, which may be due to tree and soil interaction. But the crops cultivated in the rainy season with trees exhibited 7 to 31% reduction in soil temperature. The highest reduction was observed with *P. glaucum* cultivation in *P. cineraria* based system. Soil moisture varied (1.88-7.85%) significantly (P<0.001) due to variation in tree species and land use systems (Table 1 and Figure 4). The interaction between tree species and land use systems was significant (P<0.001). The soil moisture was highest in *Z. mauritiana* field as compared to *P. cineraria* and *A. nilotica*. There was 1.6 to 3.9 fold increase in soil moisture under the canopy of tree alone than that of uncovered area. Cropping system produced 1.1 to 4.2 fold increase in soil moisture as compared to uncovered land. Thus there was almost no difference in the effect of tree and land use system on soil moisture in the rainy period. The increase in moisture content was maximum (4.2 fold) in *P. cineraria* based *V. radiata* cultivation and minimum (2 fold) in *S. indicum* with *Z. mauritiana*. This shows that combination of *P. cineraria* and *V. radiata* is helping more in moisture conservation than other agrisilviculture system. Soil pH varied significantly (P<0.001) due to variation in tree species. LSD also presented significant differences in pH due to tree species. Soil pH also changed significantly (P<0.001) with respect to changes in different land use systems (Table 1 and Figure 4). The interaction between tree species and land use systems was significant (P<0.05). The soil pH was highest in *A. nilotica* and lowest in *Z. mauritiana*. The soil pH decreased by 2 to 6% under the canopy of tree as compared to adjacent open field in rainy period. Land use systems produced 1 to 8% reduction in soil pH than the pH of uncovered area. Thus the cultivated land showed a decreasing in soil pH which may be due to decomposition of organic matter and humus formation.

Table 1 – Effect of tree species and land use system on soil temperature, moisture and pH during rainy season. Values are mean ±SEM of five replications.

Land use system (L)	Tree species (S)			ANOVA results		
	Z. mauritiana	*P. cineraria*	*A. nilotica*		F value	P value
		Soil temperature				
O	38.8	39.2	41.3	S	12.803	<0.001
	± 0.74	± 0.68	± 1.55	L	13.614	<0.001
T	33.0	37.8	34.6	S x L	0.982	>0.05
	± 0.97	± 0.93	± 0.77			
T+ Pt	31.0	27.5	36.1			
	± 0.97	± 0.80	± 0.86			
T+ Vr	26.8	31.0	33.3			
	± 0.57	± 0.97	± 0.70			
T + Si	30.8	34.7	38.5			
	± 0.91	± 0.74	± 0.84			
		Soil moisture				
O	2.19	1.62	1.88	S	228.936	<0.001
	± 0.15	± 0.22	± 0.09	L	89.129	<0.001
T	7.36	6.26	2.91	S x L	4.994	<0.001
	± 0.45	± 0.34	± 0.14			
T+ Pt	6.28	5.37	2.31			
	± 0.37	± 0.39	± 0.28			
T+ Vr	7.85	6.75	3.28			
	± 0.44	± 0.26	± 0.16			
T + Si	6.22	3.86	2.02			
	± 0.34	± 0.23	± 0.21			
		Soil pH				
O	8.3	8.3	8.4	S	18.05	<0.001
	± 0.09	± 0.09	± 0.07	L	26.31	<0.001
T	7.8	7.9	8.2	S x L	2.11	<0.05
	± 0.04	± 0.06	± 0.04			
T+ Pt	8.0	8.1	8.2			
	± 0.03	± 0.06	± 0.06			
T+ Vr	7.6	7.6	8.0			
	± 0.07	± 0.06	± 0.04			
T + Si	8.1	8.2	8.3			
	± 0.04	± 0.05	± 0.07			

O: open field; T: tree only; Pt: *Pennisetum glaucum;* Vr: *Vigna radiata*; Si: *Sesamum indicum.*

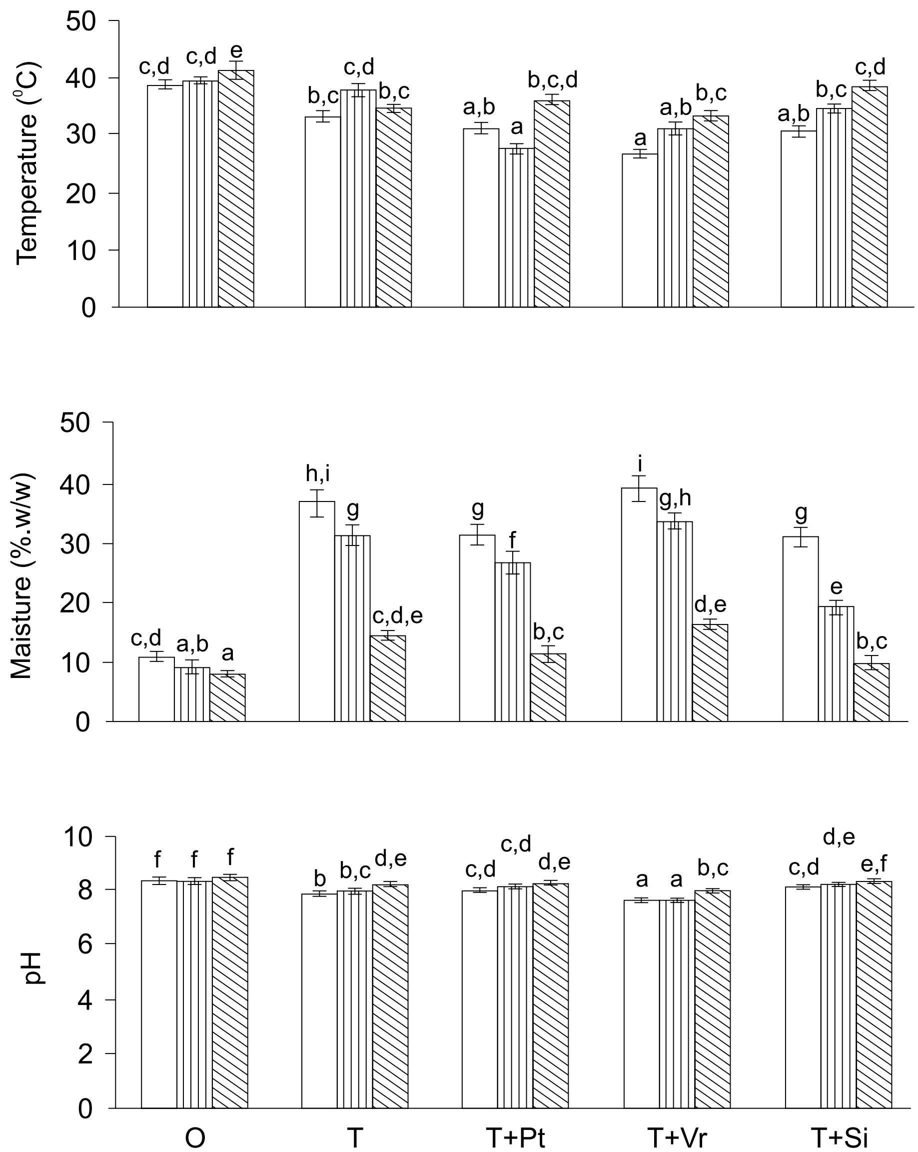

Figure 4 - Effect of land use system and tree species on temperature, moisture and pH of soil. O: Open field; T: Tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata* and Si: *Sesamum indicum*. Tree species: □ *Zizyphus mauritiana*; ▥ *Prosopis cineraria* and ▧ *Acacia nilotica*. Bars with different letters are significantly different.

Organic carbon changed (0.155-0.610%) significantly (P<0.001) due to changes in tree species and land use systems (Table 2 and Figure 5). The interaction between tree species and land use system was significant (P<0.05). The organic carbon was higher in *Z. mauritiana* as compared to *P. cineraria* and *A. nilotica* field. Organic carbon increased (2.7 to 3.1 fold) under the canopy of tree as compared to adjacent open field. Different cropping systems produced 1.9 to 3.6 fold increase in organic carbon than that of open field. It means tree alone and crop cultivation along with tree exert almost similar degree of effects on soil organic carbon content. The increase in soil organic carbon may be due to addition of leaf litter under plantation. The increase in organic carbon was maximum (3.6 fold) in *A. nilotica* having *V. radiata* crop which may be due to more litter addition from *V. radiata* into field.

Nitrate-nitrogen changed (2.10 – 14.21 mg kg^{-1}) significantly (P<0.001) due to changes in tree species and land use systems (Table 2 and Figure 5). Changes in nitrate-nitrogen were also significant after LSD analysis. The interaction between tree species and land use systems was significant (P<0.001). The nitrate-nitrogen of soil was highest in *Z. mauritiana* and lowest in *A. nilotica* field. It increased 2.9 to 4.0 fold under the canopy of tree alone than open field in rainy season. Different land use agricultural practices caused 1.8 to 4.8 fold increase in nitrate-nitrogen of soil as compared

Table 2 – Effect of tree species and land use system on organic carbon, nitrate-nitrogen, ammonical-nitrogen and phosphate-phosphorus during rainy season. Values are mean ±SEM of five replications with standard error in parentheses.

Land use system (L)	Tree species (S)			ANOVA results		
	Z. mauritiana	*P. cineraria*	*A. nilotica*		F value	P value
			Organic carbon			
O	0.198	0.182	0.155	S	48.12	<0.001
	± 0.029	± 0.022	± 0.028	L	105.15	<0.001
T	0.603	0.569	0.421	S x L	2.87	<0.05
	± 0.030	± 0.028	± 0.026			
T+ Pt	0.582	0.541	0.333			
	± 0.027	± 0.034	± 0.020			
T+ Vr	0.610	0.603	0.564			
	± 0.026	± 0.028	± 0.024			
T + Si	0.556	0.452	0.294			
	± 0.021	± 0.025	± 0.022			
			Nitrate-nitrogen			
O	3.00	2.61	2.10	S	271.83	<0.001
	± 0.25	± 0.24	± 0.05	L	425.61	<0.001
T	11.99	9.37	6.03	S x L	3.97	<0.001
	± 0.31	± 0.44	± 0.11			
T+ Pt	9.01	6.07	3.95			
	± 0.57	± 0.47	± 0.19			
T+ Vr	14.21	12.17	9.57			
	± 0.38	± 0.31	± 0.29			
T + Si	6.42	5.08	1.73			
	± 0.27	± 0.29	± 0.11			
			Ammonical-nitrogen			
O	8.79	7.67	6.50	S	29.70	<0.001
	± 0.76	± 0.46	± 0.28	L	159.42	<0.001
T	40.61	33.75	26.84	S x L	3.88	<0.001
	± 2.45	± 2.32	± 1.32			
T+ Pt	34.97	36.94	31.09			
	± 1.32	± 2.09	± 1.12			
T+ Vr	45.45	39.56	34.85			
	± 3.41	± 1.51	± 0.57			
T + Si	32.07	28.97	23.86			
	± 1.73	± 1.52	± 1.38			
			Phosphate-phosphorus			
O	7.12	6.77	6.50	S	42.60	<0.001
	± 0.75	± 0.72	± 0.45	L	78.90	<0.001
T	30.92	25.63	21.71	S x L	1.56	>0.05
	± 1.52	± 1.42	± 1.68			
T+ Pt	27.82	21.55	18.92			
	± 1.80	± 2.07	± 1.49			
T+ Vr	33.25	28.23	24.31			
	± 3.23	± 1.53	± 1.59			
T + Si	29.34	18.23	14.02			
	± 1.44	± 1.71	± 1.30			

O: open field; T: tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata*; Si: *Sesamum indicum*.

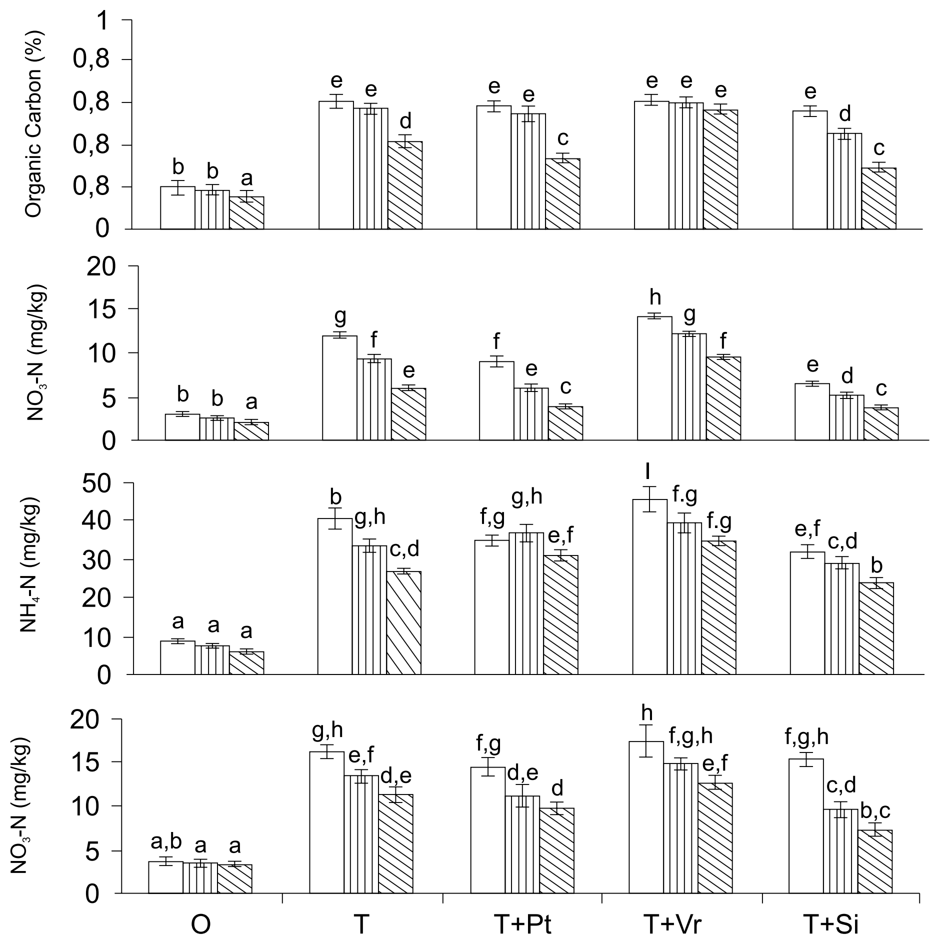

Figure 5 - Effect of land use system and tree species on chemical properties of soil. O: Open field; T: Tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata* and Si: *Sesamum indicum.* Tree species: □ *Zizyphus mauritiana*; ▥ *Prosopis cineraria* and ▧ *Acacia nilotica*. Bars with different letters are significantly different.

to adjacent open field. Higher soil nitrate-nitrogen in cropping system may be due to decomposition and mineralization of crop litter and nitrogen fixation by specific crop. It is also clear that cultivation of crops in *A. nilotica* based agroforestry system had higher nitrate-nitrogen in soil as compared to other tree-crop geometry. Thus *A. nilotica* crop-interaction is helpful in improving soil fertility. Ammonical-nitrogen varied (6.50–45.45 mg kg^{-1}) significantly ($P<0.001$) with respect to tree species and land use systems except between *P. glaucum* and *V. radiata* ($P>0.05$) (Table 2 and Figure 5). The interaction between tree species and land use systems was also significant ($P<0.001$). The ammonical-nitrogen was higher in *Z. mauritiana* as compared to *P. cineraria* and *A. nilotica* field. There was 4.1 to 4.6 fold increase in ammonical-nitrogen under the canopy of tree as compared to uncovered land. The different tree-crop combinations increased ammonical-nitrogen by 3.7 to 5.4 fold than in adjacent open field. Impact of tree alone and cultivation of crop along with tree on soil ammonical-nitrogen content was more or less the same. The increase in ammonical-nitrogen content was maximum (5.4 fold) in *A. nilotica* having *V. radiata* based system and minimum in *Z. mauritiana* with *S. indicum*. This shows that the combination of *A. nilotica* and *V. radiata* is improving ammonical-nitrogen content of soil system. Soil phosphorus changed (6.50–33.25 mg kg^{-1}) significantly ($P<0.001$) due to changes in tree species and land use systems except between *P. glaucum* and *S. indicum* ($P>0.05$), whereas the interaction between tree species and land use systems was insignificant ($P>0.05$). The soil phosphorus was highest in *Z. mauritiana* and lowest in *A. nilotica* based pedoecosystem (Table 2 and Figure 5). There was 3.3 to 4.3 fold increase in soil phosphorus under the canopy of tree alone as compared to of open field. The changes in different land use systems increased 2.2 to 4.7 fold soil phosphorus as compared to adjacent uncovered area, indicating almost no difference between tree alone and land use systems. Higher phosphorus (33.25 mg kg^{-1}) content in soil of *V. radiata* cultivated *Z. mauritiana* field may be due to faster decomposition and mineralization of leaf litter to release phosphorus in soil and/or less utilization of phosphorus by *V. radiata* crop.

Soil respiration (248.00 – 1286.00 mg CO_2 m^{-2} h^{-1}) and soil dehydrogenase activity varied (7.88 - 40.47 pkat/g) significantly ($P<0.001$) due to changes in tree species and land use systems (Table 3 and Figure 6). The interaction between tree species and land use systems was significant ($P<0.001$) for soil respiration and insignificant ($P>0.05$) for dehydrogenase activity. These were highest in *Z. mauritiana* field and lowest in *A. nilotica* based pedoecosystem. The soil respiration increased 4.1 to 4.3 fold under the canopy of tree alone as compared to adjacent open field. Cropping system produced 2.7 to 4.8 fold increase in soil respiration than that of open field. It reflects almost similar degree of effects of tree and cultivation of crops alone with tree on soil respiration. Higher soil respiration in *Z. mauritiana* based system may be because of a higher biota activity especially microbial activity in soil. Cultivation of *V. radiata* promoted development of soil biota leading to a higher soil respiratory activity in its field. Like soil respiration, the soil dehydrogenase activity increased by 4.1 to 4.7 fold under the canopy of tree alone as compared to open field (Table 3 and Figure 6). Cropping land use systems caused 2.8 to 5.3 fold increase in dehydrogenase activity than that of uncovered land. *Z. mauritiana* based agroforestry system showed higher dehydrogenase activity than *P. cineraria* and *A. nilotica*. It again substantiates *Z. mauritiana* dependent higher growth of microbial population in soil. *V. radiata* was found as a better agricultural crop in increasing soil dehydrogenase activity.

Table 3 – Effect of tree species and land use system on soil respiration and soil dehydrogenase activity during rainy season. Values are mean ±SEM of five replications with standard error in parentheses.

Land use system (L)	Tree species (S)			ANOVA results		
	Z. mauritiana	*P. cineraria*	*A. nilotica*		F value	P value
			Soil respiration			
O	270.00	258.00	248.00	S	124.39	<0.001
	± 9.41	± 14.42	± 7.07	L	3031.80	<0.001
T	1203.40	1147.60	1021.00	S x L	9.93	<0.001
	± 10.03	± 19.47	± 8.52			
T+ Pt	953.00	932.00	904.00			
	± 11.90	± 13.99	± 9.24			
T+ Vr	1286.00	1232.00	1156.00			
	± 15.19	± 10.54	± 14.21			
T + Si	762.00	690.20	710.20			
	± 11.58	± 11.99	± 7.18			
			Soil dehydrogenase activity			
O	7.70	8.32	7.88	S	7.16	<0.002
	± 1.74	± 1.13	± 0.88	L	76.58	<0.001
T	36.53	34.76	32.09	S x L	0.15	>0.05
	± 2.75	± 2.52	± 3.36			
T+ Pt	32.45	30.89	27.82			
	± 2.34	± 2.92	± 1.80			
T+ Vr	40.47	37.90	35.16			
	± 3.01	± 2.57	± 3.12			
T + Si	29.35	28.24	21.73			
	± 1.44	± 1.53	± 1.36			

O: open field; T: tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata*; Si: *Sesamum indicum.*

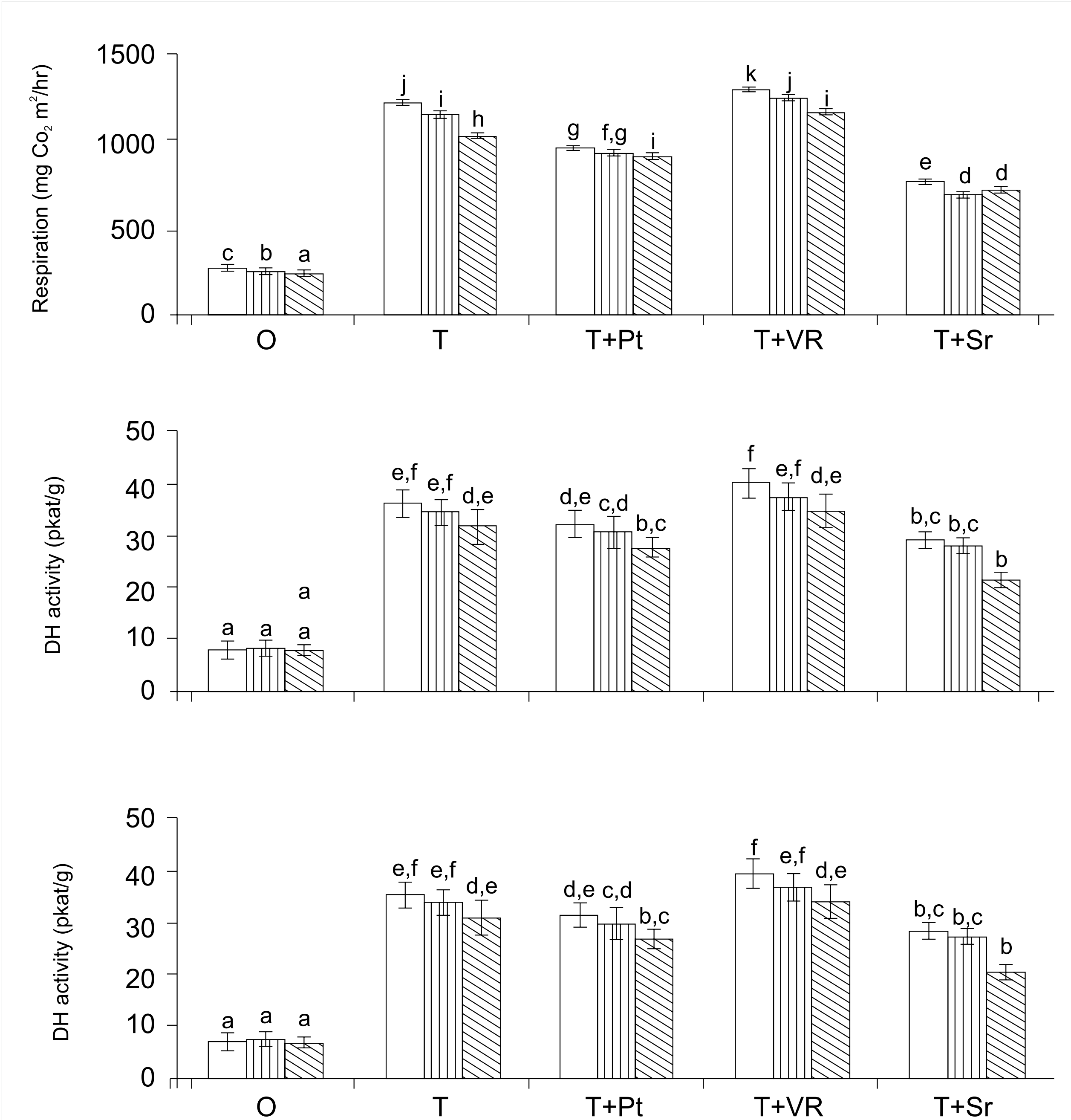

Figure 6 - Effect of land use system and tree species on biological properties . O: Open field; T: Tree only; Pt: *Pennisetum glaucum*; Vr: *Vigna radiata* and Si: *Sesamum indicum.* Tree species: □ *Zizyphus mauritiana*; ▥ *Prosopis cineraria* and ▧ *Acacia nilotica*. Bars with different letters are significantly different.

Correlation among soil fauna, physicochemical and biochemical properties

There was a significant ($P<0.001$) positive correlation between among groups of soil fauna (Acari, Myriapoda, Coleoptera, Collembola, other arthropods and total fauna) population in different land use systems (Table 4). The physicochemical and biochemical properties of soil (temperature, moisture, pH, organic carbon, nitrate-nitrogen, ammonical-nitrogen, phosphate-phosphorus, soil respiration and dehydrogenase activity) showed a significant positive correlation with different groups of soil fauna (Acari, Myriapoda, Coleoptera, Collembola, other arthropods and total fauna) (Table 5) and among themselves except soil temperature and pH (significant and negative) (Table 6) in various land use systems of arid zone of Jodhpur.

Table 4 – Correlation between different groups of soil fauna during rainy season.

Fauna	Myripapoda		Coleoptera		Collembola		Other arthropods		Total fauna	
	r	P	r	P	r	P	r	P	r	P
Acari	0.782	<0.001	0.816	<0.001	0.690	<0.001	0.715	<0.001	0.950	<0.001
Myriapoda	_	_	0.748	<0.001	0.581	<0.001	0.625	<0.001	0.827	<0.001
Coleoptera	_	_	_	_	0.742	<0.001	0.727	<0.001	0.936	<0.001
Collembola	_	_	_	_	_	_	0.716	<0.001	0.798	<0.001
Other arthropods	_	_			_	_	_	_	0.827	<0.001

Table 5 – Correlation between different groups of soil fauna and physicochemical properties of soil during rainy season.

Fauna	Acari		Myriapoda		Coleoptera		Collembola		Other arthropods		Total fauna	
	r	P	r	P	r	P	r	P	r	P	r	P
Temperature	-0.462	<0.001	-0.500	<0.001	-0.532	<0.001	-0.384	<0.001	-0.487	<0.001	-0.535	<0.001
Moisture	0.603	<0.001	0.660	<0.001	0.705	<0.001	0.699	<0.001	0.730	<0.001	0.734	<0.001
pH	-0.654	<0.001	-0.626	<0.001	-0.749	<0.001	-0.651	<0.001	-0.664	<0.001	-0.754	<0.001
Organic carbon	0.717	<0.001	0.705	<0.001	0.815	<0.001	0.644	<0.001	0.697	<0.001	0.814	<0.001
Organic matter	0.717	<0.001	0.705	<0.001	0.815	<0.001	0.644	<0.001	0.697	<0.001	0.814	<0.001
Nitrate-nitrogen	0.832	<0.001	0.766	<0.001	0.882	<0.001	0.790	<0.001	0.829	<0.001	0.925	<0.001
Ammonical-nitrogen	0.642	<0.001	0.688	<0.001	0.772	<0.001	0.590	<0.001	0.637	<0.001	0.753	<0.001
Phosphorus	0.69 8	<0.001	0.718	<0.001	0.797	<0.001	0.700	<0.001	0.748	<0.001	0.816	<0.001
Soil respiration	0.852	<0.001	0.780	<0.001	0.891	<0.001	0.713	<0.001	0.740	<0.001	0.919	<0.001
Soil de-hydrogenase	0.736	<0.001	0.708	<0.001	0.829	<0.001	0.615	<0.001	0.674	<0.001	0.822	<0.001

Soil faunal population dynamics

Impact of land use system and tree species on population density of different groups of soil fauna (Acari, Myriapoda, Coleoptera, Collembola, other arthropods) was statistically significant. There was 2.6 to 6.2 fold increase in these groups of soil fauna under the canopy of tree (*Z. mauritiana, P. cineraria, A. nilotica*) than in adjacent open field. The increase (6 fold) in Myriapoda and Coleoptera population was higher than that of other groups in *A. nilotica* based pedoecosystem. It means *A. nilotica* might be providing somewhat a better soil environment for the development of myriapods and coleopteran. In tree with *P. glaucum* cultivated field, population of soil faunal groups increased 2.0 to 4.8 fold as compared to open land, whereas in tree plus *S. indicum* field, this population increase was 1.1 to 5 fold. However, the population increase (3 to 8.4 fold) of different faunal groups in tree plus *V. radiata* system was much higher, showing crop-associated substantial population growth in soil fauna. The increase in faunal population in tree plus *V. radiata* cultivated land was even higher than that of population under the canopy of tree alone (Figure 1). Since *V. radiata* cultivated land remains fully covered with leaves thus retaining sufficient soil moisture with adequate litter fall, it provides a good soil environment providing faunal food and shelter. A similar pattern of change was also observed in different land use systems after considering a total of all faunal groups. The variations in soil fauna due to land use system and tree species were significant except in case

Table 6 – Correlation between physicochemical and biological properties of soil during rainy season.

Soil properties		Moisture	pH	Organic carbon	Nitrate-nitrogen	Ammonical -nitrogen	Phosphate-phosphorus	Soil respiration	Dehydrogenase activity
Temperature	r	-0.546	0.410	-0.561	-0.529	-0.542	-0.618	-0.546	-0.482
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Moisture	r	-	-0.753	0.828	0.843	0.753	0.823	0.711	0.699
	P	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
pH	r	-	-	-0.697	-0.807	-0.725	-0.670	-0.729	-0.666
	P	-	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Organic carbon	r	-	-	-	0.811	0.825	0.858	0.855	0.836
	P	-	-	-	<0.001	<0.001	<0.001	<0.001	<0.001
Nitrate-nitrogen	r	-	-	-	-	0.744	0.810	0.851	0.782
	P	-	-	-	-	<0.001	<0.001	<0.001	<0.001
Ammonical-nitrogen	r	-	-	-	-	-	0.813	0.882	0.897
	P	-	-	-	-	-	<0.001	<0.001	<0.001
Phosphorus	r	-	-	-	-	-	-	0.846	0.796
	P	-	-	-	-	-	-	<0.001	<0.001
Soil respiration	r	-	-	-	-	-	-	-	0.896
	P	-	-	-	-	-	-	-	<0.001

of Acari. The present study clearly suggests location and land use system-specific changes in below-ground faunal density. In arid region, *Z. mauritiana* is a better tree and *V. radiata* is the best rainy crop for promoting development of soil fauna.

An increase in population density of microfauna leads to an increase in soil humus contents thereby enhancing soil fertility (KUMAR et al., 1999). It is because soil microinvertebrates play a valuable role in the breakdown and decomposition of organic litter which makes pedoecosystems self sustainable. A soil system harboring sufficient biodiversity does not require any extra organic or chemical (fertilizers and pesticides) inputs. Soil arthropods are highly adaptive group which invades different types of pedoecosystems including barren land. The different degrees of colonization in different land use systems indicate impacts of agricultural practices on development of different faunal communities. Significantly more negative value of $RTE_{population}$ also indicated the beneficial effect of trees on the population of soil arthropods. The Coleoptera exhibited greatest association with all agrisilviculture fields. However, *Z. mauritiana* system indicated highest facilitative effects on all groups of soil fauna. Changes in values of $RTE_{population}$ with soil arthropod groups suggested that the populations of various major groups of soil arthropods are dependent upon the quality of food resources available in that agrisilviculture system (SEASTEDT et al., 1988). This reflects that the development of one group of faunal population facilitate the development of another group by creating a conducive soil environment. Since soil fauna occupy many important positions (detrivorous, omnivorous, herbivorous, predacious etc.) in the tropical levels in ecosystems (PARAMENTER et al., 1991; GANIHAR, 1998), the present observations will help in developing strategies to enrich soil biodiversity and improve sustainability of agroecosystem in arid environment. It may also help in selecting combinations of tree and crops for conservation of below-ground fauna and, in turn, soil conservation on a sustainable basis. The present study may also prove to be useful for faunal recolonization in desert region.

Agrisilviculture-induced soil improvement

The reduction in soil temperature (26.8 - 41.3 °C) under tree and agrisilviculture land as compared to open field (Figure 4) is mainly due to decrease in light fall on soil surface. The higher soil temperature (41.3 °C) of tree system in rainy season compared to tree plus cropping pedoecosystem may be assigned to many factors including seasonal differences in water utilization by agroforestry tree. *S. indicum* plants remain erect and have limited leaves for covering land which permits more light fall on ground thereby raising more soil temperature as compared to fields of other crops. Like temperature, soil moisture is higher under canopy of tree than in cultivated field (Figure 4). This may be due to more utilization of water by tree plus crop system. In the present study moisture varies (1.88-7.85%) mainly due to cropping system and not the tree, which indicates almost no competition for water between tree and crop. This is totally in agreement to the report of GUPTA et al. (1998) who showed that the most important agroforestry tree *P. cineraria* meets its water requirement reaching soil layers deeper than 75 cm and does not compete with the companion agricultural crops (*Vigna mungo, Vigna aconitifolia, Cyamopsis tetragonoloba, Pennisetum glaucum*) for water. The water use of pearlmillet has been reported as 290-310 mm, water use of mungbean and mothbean as 130-170 mm and of clusterbean as 140-195 mm (GUPTA & GUPTA, 1982 and 1983). GUPTA et al. (1998) also described the differences between the cropped and uncropped plots in terms of their soil water content which was much higher with pearlmillet than mungbean. Pearlmillet takes up more water, perhaps because of its vigorous vegetative growth and thus may offer more competition in agroforestry systems. This study also suggests suitability of pulse crop than any other crop in *Z. mauritiana, P. cineraria* or *A. nilotica* based agroforestry system of desert. SINGH & RATHOD (2002) did not find variation due to vegetation type in desert except in June and October, which reflects differences in water-utilization capacity of the plant species in these months. Slightly lower (7.6-8.3) soil pH in agroforestry field than the adjacent uncovered land may be because of leaf litter decomposition and humic acid formation at a higher temperature (Figure 4). The soil pH of *V. radiata* cropping system was more or less similar. So it may be an appropriate crop for development of biological activity in soil at a neutral pH. WALIA & MATHUR (1997) also reported that soil pH does not vary much during sampling period in annual and perennial crop field. NGUYEN et al. (1995) found slightly higher pH in cropped and pastoral soils under conventional and biodynamic (organic) agriculture. This report is comparable to the present findings.

Higher organic carbon under the canopy of tree than uncovered area (Figure 5) may be due to leaf litter fall and its decomposition in soil. No difference in organic carbon contents of soils of tree field and crop plus tree pedoecosystem is because of equal degree of biological activity and decomposition. More soil organic carbon in *A. nilotica* based system is due to lesser biotic activity and minimum litter degradation. Maximum organic carbon in soil of *V. radiata* field (0.610%) is because of more addition of leaf litter to the soil from this plant in rainy days. The organic carbon content in soil of Jodhpur district of Rajasthan (0.089 to 0.610%) is lower than Hissar and Sirsa districts of Haryana (0.01 to 1.3%) (SINGH & RAJ, 1994) and too less as compared to cropping forms in New Zealand (2.9 to 3.9%) (NGUYEN et al., 1995). The similar organic carbon content under tree alone and tree plus cropping systems is in agreement to the report of NGUYEN et al. (1995) who found no change in organic carbon between pastoral and cropping system. A greater level of soil nitrate-nitrogen and ammonical-nitrogen under the canopy of tree than that of open field is because of decomposition and release of nitrogen from leaf litter available under the canopy of tree (Figure 5). The maximum nitrogen content (14.21 mg kg^{-1}) in *Z. mauritiana* and minimum (2.10 mg kg^{-1}) in *A. nilotica* based cropping system may be due to crop tree interaction. The highest nitrate-nitrogen content in *V. radiata* field may be due to its nitrogen fixing property. The report of NGUYEN et al. (1995) regarding higher nitrogen content of pastoral soil than cropped one is in concurrence to the present findings. They have also described the higher nitrogen content at sites having nitrogen fixing species like peas. Higher soil nitrogen content in agroforestry system than uncovered land is further supported by the observations of SINGH & RATHOD (2002) who found a substantial increase in desertic soil under vegetation cover. Highest phosphorus content in *V. radiata* soil (33.25 mg kg^{-1}) appeared to be due to lesser utilization of phosphorus. Higher available phosphorus content of soil under the canopy of tree than cultivated land is similar to the higher phosphorus content in pastoral soil than cropped one (NGUYEN et al., 1995). They also found a lower level of available phosphorus in soils on the alternative than conventional farms. In contrast, SINGH & RATHOD (2002) did not find any significant difference in soil phosphate-phosphorus between planted (tree, shrub) land and control plots.

No difference in soil respiration and dehydrogenase activity between tree and cropped field might be because of similar microbial and biotic population (Figure 6). More or less similar moisture content and leaf litter in these fields promotes almost equal growth of soil biota. *V. radiata* was best crop for promoting development of soil biota in desert area. Cultivation of this crop will considerably help in improving sustainability and productivity of agroforestry system in desert. Since biotic component of soil includes plants, animals, fungi and bacteria and they are closely associated and combined to influence physical, chemical and biological properties of soil (PARK & COUSINS, 1995), the changes in soil respiration and dehydrogenase activity reflect the health of soil in natural and agroecosystem.

Relations among physicochemical and biological factors

Negative correlation of soil temperature with various physicochemical and biological properties of soil except with pH in the rainy season indicates that increase in soil temperature is not conducive for soil health. In contrast to temperature, the exactly opposite correlation of soil moisture with different soil properties in the present case is obvious because soil temperature remains inversely related to soil moisture. Whereas the negative correlation of soil pH with other chemical and biological characteristics of soil may be due to reduction in soil pH as a result of litter decomposition and humic acid formation. However, a positive and significant correlation among organic carbon, nitrate-nitrogen, ammonical-nitrogen, phosphate-phosphorus, soil respiration and dehydrogenase activity clearly reflects increase in soil nutrient with the increase in microbial and other biotic activities. These observations are in support to the reports of other workers who documented carbon mineralization as a convenient surrogate for nitrogen dynamics because carbon mineralization is believed to be coupled to nitrogen mineralization via C/N ratios of detrital resources and their consumers (SMITH, 1994; MARY et al., 1996; MYROLD, 1998). In fact, mineralized carbon is released as CO_2, while mineralized nitrogen may be immobilized by plants and microbes.

Negative correlation of soil temperature and pH with the population of Acari, Myriapoda, Coleoptera, Collembola, other arthropods and total soil fauna appeared to be due to a positive correlation of these faunal groups with moisture. Decrease in temperature increases soil moisture content which, in turn, promotes faunal population growth. It supports the observations of WALIA & MATHUR (1997) who found high acarine population from July to September due to favorable soil temperature and moisture. They also showed that soil pH and organic carbon do not influence mite population, which does not agree to the present findings. The increase in organic carbon and organic matter, nutrients (nitrate-nitrogen, ammonical-nitrogen, phosphate-phosphorus) and microbial activity is associated with the increase in soil faunal population. This suggests that litter fall and decomposition in agrisilviculture system induce microbial and faunal activity, as a result of which, the different nutrient contents are increased in soil system. Since the agroenvironment of desert region is harsh and farmers are poor, there is very less chance of organic inputs in soil. Therefore, the role of soil fauna becomes very important for a sustainable agrisilviculture system in desert environment.

The present study indicated that *Z. mauritiana* field harbouring *V. radiata* crop was best for agrisilviculture practices in arid region. The increase in soil nutrients and microbial activity is associated with the increase in soil faunal population. This suggests that litter addition and decomposition in arid agrisilviculture system induce microbial and faunal activities, as a result of which the different nutrient content increases in soil system and help in conservation of desert pedoecosystem on a sustainable basis and it provides baseline information to develop technical strategies for improvement in the productivity of desert agroenvironment. Consideration should be given on these aspects to enhance the interrelation between soil fauna and microorganisms are a fascinating field of study for soil zoologists and soil microbiologists.

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