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Impacts of deforestation and reforestation on soil organic carbon storage and CO_2 emission

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Abstract

Soil organic carbon (SOC) storage and CO_2 flux into the atmosphere can be influenced by land use change, especially re/deforestation. The impacts of conversion of primary deciduous (PF) to secondary coniferous (SF) forest and deforestation of PF land to abandoned rangeland (AR) on various soil properties, SOC storage, and soil CO_2 emission were investigated on the selected sites (Neshat and Garakpass) in Kelardasht region, northern Iran. The highest SOC storages were determined in coniferous forest land uses (SF_1=255.00 and SF_2=237.90 Mg C ha^{-1}) followed by deciduous forest (PF_1=216.74 and PF_2=159.12 Mg C ha^{-1}) and abandoned rangeland (AR_1=185.31 and AR_2=151.60 Mg C ha^{-1}). Land use changes showed significant impacts on soil CO_2 efflux. The significant positive correlations, with exponential and linear relationships were observed between the monthly CO_2 emissions; the minimum air temperature and the cumulative precipitation in the last week ended to CO_2 measurement time. The highest recorded soil CO_2 efflux in a wide range of land uses were obtained in August to October due to more suitable temperature and rainfall distribution. Based on lower CO_2 emission in abandoned rangelands, lesser soil organic carbon is related to lower input to soil. The higher C: N ratios in litter and some of mineral horizons (SF_2) and lower CO_2 emissions by the higher lignin and polyphenol concentrations (SF_1) in coniferous forests compared to deciduous forests have probably caused increasing SOC storage.

Key words: Deforestation, reforestation, soil organic carbon storage, CO_2 emission

Introduction

More than 80% of the above ground terrestrial carbon and more than 70% of soil organic carbon are stored in forest ecosystems (Six *et al.,* 2002). There is an ongoing effort to accurately quantify the effects of various land uses on the global C storage and the rate of deforestation (Kaul *et al.,* 2009). Land use change is the most dynamic driving factor of terrestrial carbon stock changes, SOC storage, and also an important factor in future carbon sequestration that cannot be ignored (Ussiri *et al.,* 2006; Poeplau and Don, 2013). One of the most effective activities to improve soil C sequestration is choosing suitable forest tree species. Unfortunately, there is limited knowledge of it (Vesterdal *et al.,* 2008). The impacts of conversion of deciduous forests to coniferous ones and vice-versa, on SOC storage have not been fully investigated. In the study of Hiltbrunner *et al.* (2012), soils have been assessed under spruce afforestations (*Picea abies)*. Afforestation with coniferous trees increased the total amount of C stored. So, Higher SOC contents have been reported for coniferous forest species than those of deciduous ones by Berger *et al.,* (2002); Nobakht *et al*. (2010) and Ayoubi *et al*. (2011). On the contrary, some studies have cited considerably lower soil C storages for coniferous forests than beech trees (Martin *et al.,* 2010). Also, plant litter effect on carbon and nitrogen is different. Riaz *et al*. (2011) have investigated effects of plant litter on the regulation of nitrogen and organic carbon from soil profiles. Their results demonstrated that litter plays an important role in reducing nitrogen and carbon in winter months. Globally, the second important source of CO_2 release to the atmosphere after croplands is the conversion of forests to pastures and rangelands (Houghton and Goodale, 2004). Since the pasture/range land areas are not cultivated, it might be expected that conversion of natural forests to these land uses have a little influence on soil carbon storage (Houghton, 2010). Nevertheless, these types of land use conversions can result in notable changes, both increasing and decreasing SOC (Post and Kwon, 2000; Khormali *et al*., 2009). Soil CO_2 emission is one of the main components of ecosystem respiration (Janssen *et al.,* 2001), that is dependent on soil properties and climatic factors (Cantú *et al.,* 2010), as well as land uses (Luo and Zhou, 2006). Generally, the effects of land use changes on the components of CO_2 emission should be a priority for future researches (Wang and Fang, 2009). Drastic land use changes have occurred in the forest lands of northern Iran (FRWOI, 2008) (especially in Kelardasht region) in the last decades. Based on the hypothesis of affecting SOC storage and CO_2 emission by land use changes, the aims of this study were to investigate the impacts of re/deforestation on

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SOC storage, CO_2 emission and various soil physical and chemical properties in Kelardasht, north of Iran.

Materials and Methods

Study area

The study area comprised of natural deciduous forests, coniferous forests converted from natural deciduous forests, and deforested rangelands, located between 51°, 07′- 51°, 14′ E longitudes and 36°, 29′-36°, 34′ N latitudes, in the Kelardasht suburb, Mazandaran province, north of Iran (Figure1 a). Soil moisture and temperature regimes are typic xeric, and mesic, respectively (Banaei, 1998). Long-term (1965-2010) means of annual precipitation, potential evapotranspiration, and temperature are 566, 670 mm and 10.3°C, respectively (ROWR, 2006). The studied soils were developed on Permian carbonatic and Jurassic shale and sandstone rocks. Main vegetation cover is natural deciduous forest comprising beech trees '*Fagus orientalis'* with a dense canopy (Pourbabaei and Dado, 2003; Meamarian *et al.,* 2006). Nearly 65 ha of this deciduous forest were changed to Norway spruce '*Picea abies'* as a non-native species, in 1964 (Pourmajidian, 1991) which now have got big trees (mean diameter of 20 cm in the height ~1 m) but with more scattered canopy compared to deciduous forest (Pourbabaei and Dado, 2003; Meamarian *et al.,* 2006). Deforestation since 1984 has gradually caused the developing of rangelands instead of deciduous forest, dominated by meadow, shrubs, and grass species (Khodabakhsh, 1997). Furthermore, plant litter burning by farmers and land use change from rangeland to urban, have occurred (Figure 2).

Site selection

Land use changes were distinguished by comparison of the supervised classifications of 1984 and 2009 TM images. Two sites including Neshat and Garakpass, with different altitudes and aspects were selected (Figure 1. b; Table 1). The selected land use types in each site were located on similar slope gradient, aspect, altitude, geological, climatological and geomorphic properties. Land utilization types in the Neshat site were primary deciduous forest (PF_1), secondary coniferous forest (SF_1), and abandoned rangeland (AR_1) both converted from PF_1. The same requirements were considered for land use selection in Garakpass site, namely PF_2, SF_2 and AR_2 (Figure 1.b; Table 1). Primary deciduous forests were considered as the reference land use for comparison. Hence, a random experimental design with three treatments (land uses) and eight iterations (soil profiles) was used for statistical comparison (Figure 1. b).

Table 1: Site characteristics and soils classification

Site	Coordinates (m)	Land use	Slope (%)	Aspect	Altitude (m)	Soil classification
Neshat (1)	515110.17E, 4038148.97N	PF1	20-25	NW	1300 to 1400	Very fine, mixed, active, mesic, Aquic Palexeralfs
	515063.14E, 4038159.59N	SF1				Clayey-skeletal, mixed, active, mesic, Calcic Pachic aploxerolls
	514994.87E, 4038258.19N	AR1				Very fine, mixed, active, mesic, Typic Haploxerolls
Garakpass (2)	516032.54E, 4038998.52N	PF2	20-25	NE	1200 to 1300	Very fine, mixed, active, mesic, Typic Haprendolls
	515967.31E, 4039136.57N	SF2				Very fine, mixed, active, mesic, Pachic Haploxerolls
	516077.19E, 403913.88N	AR2				Very fine, mixed, active, mesic, Typic Haploxeralfs

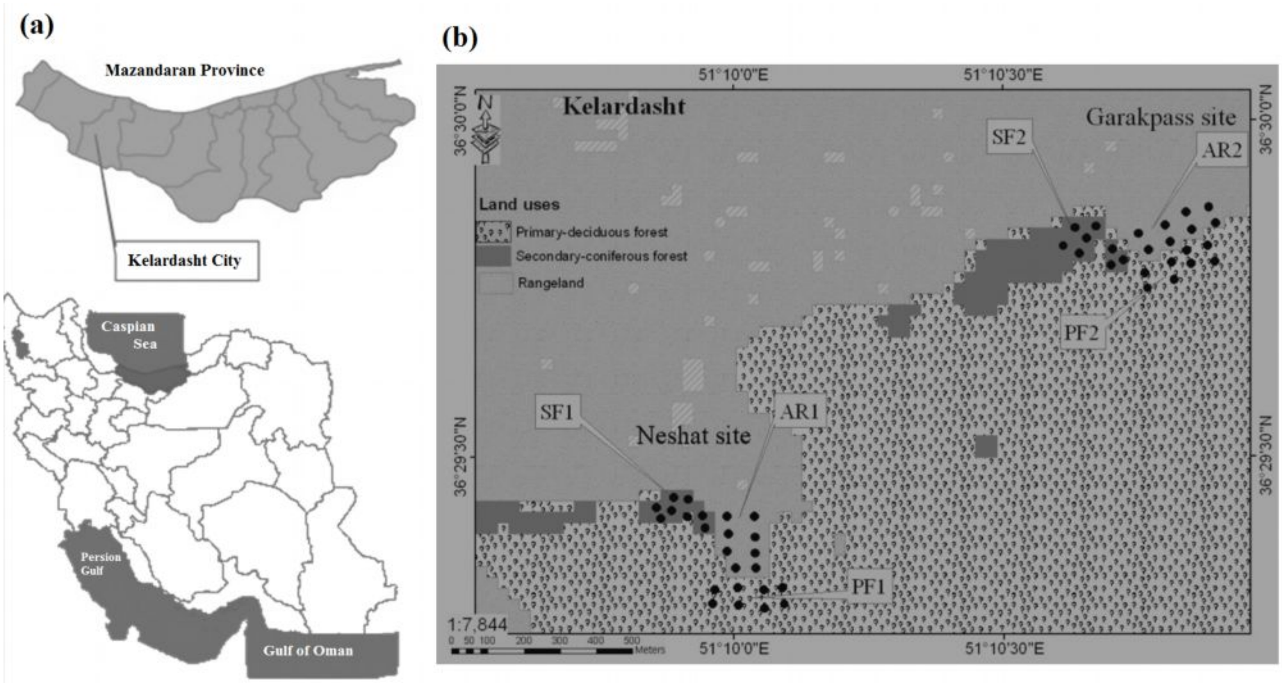

Figure 1: a) The studied area at Kelardasht, Mazandaran province, North of Iran; b) the selected (Neshat at the left), (Garakpass at the right) sites and locations of soil profiles

Soil Sampling and Analyses

According to the experimental design, in each land use type, eight soil profiles were excavated, described and sampled (Schoeneberger *et al.,* 2002). Soil samples were air-dried, ground to pass through 2-mm sieve and used for physico-chemical analyses. Soil was classified according to the Keys to Soil Taxonomy (Soil Survey Staff, 2010). Organic carbon (Walkley and Black), total nitrogen (Kjeldahl), electrical conductivity (EC meter), soil reaction (pH meter), bulk density (core method), calcium carbonate equivalent (volumetric method) and base saturation percentage (NH_4OAC pH: 8.2) were measured according to the standard methods (Burt, 2004).

The organic carbon storage for a given soil horizon with thickness *d* was calculated using Eq. 1:

$$\text{Mg SOC ha}^{-1}{}_{\text{(each horizon)}} = \%\ \text{SOC} \times \rho b \times d \times 10^{4} \qquad \textbf{Eq.1}$$

Where ρb is the bulk density (Mg m^{-3}) of the soil horizon and SOC concentration is expressed as weight based percentage (Ussiri *et al.,* 2006). In order to carry out statistical analysis, SOC storage of each horizon (Eq.1), was converted to Mg C/ha per cm, and divided by thickness *d* (cm). Total field CO_2 emission (i.e. root and microbial respiration) for each land use was determined by the closed static chamber (CSC) method (Luo and Zhou, 2006). An impermeable end closed plastic cylinder, 35 cm in diameter, 30 cm in height was placed on soil surface and sealed. CO_2 was trapped 6 times (May, June, August, October, and November in 2009 and February in 2010) in each land use, with three iteration, using 50 cm^3, 1N NaOH solution in containers 8 cm in diameter, as chemical absorbent for 24 h. Whereas mean soil respiration is more sensitive to an increase in minimum temperature than an increase in mean or maximum temperature (Luo and Zhou, 2006), the minimum air temperature and the cumulative precipitation were recorded for the last week (1 week) before CO_2 measurement, according to the nearest climatological station data (distance 1000 m; altitude 1150 m; ROWR, 2006). Then meteorological parameters were corrected on the base of the interpolation model for the studied sites (Table 2). The obtained results (mol C ha^{-1}. h) were converted to (kg C/ha per month). Total CO_2 emission was calculated using Eq. [2] and [3]:

$$CO_{2\ \text{in trap}}\ (\text{mol C}) = 0.5\times [(V_{NaOH} \times C_{NaOH}/1000) - (V_{HCl} \times C_{HCl}/1000)] \qquad \textbf{Eq.2}$$

$$\text{Soil } CO_2 \text{ emission (mol C/ha. h)} = (CO_{2\ \text{in trap (sample)}} - CO_{2\ \text{in trap (blank)}}) / [\text{time (h)} \times \text{area (ha)}] \qquad \textbf{Eq. 3}$$

Where V_{NaOH} and V_{HCl} are the volume (mL) of NaOH and HCl solutions, C_{NaOH} and C_{HCl} are their normality (N), respectively (Luo and Zhou, 2006; Hopkins, 2008).

Table 2: Variations of the minimum air temperature and cumulative precipitation in the last week ended to CO_2 measurement time, at the both sites (corrected from ROWR, 2006)

Month	Neshat site		Garakpass site	
	Temperature (ºC)	Cumulative Precipitation (mm)	Temperature (ºC)	Cumulative Precipitation (mm)
May	4.55	0	5.15	0
June	13.55	4.76	14.15	5.12
August	15.55	18.42	16.15	20.5
October	11.8	15.08	12.4	16
November	-1.7	7.42	-1.1	7.6
February	-5.7	5.32	-5.1	5.7

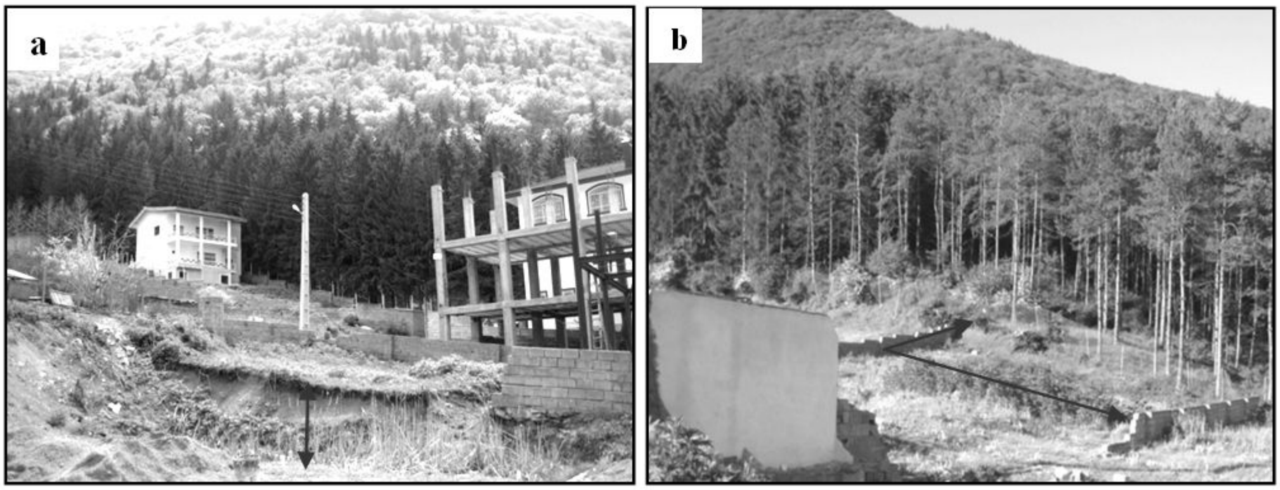

Figure 2: Soil degradation in the abandoned rangelands, arrows show the excavated areas, a) Neshat site, and b) Garakpass site

Statistical Analysis

The land-use change effects on soil properties and CO_2 emission were assessed performing variance analysis (ANOVA), and mean comparisons via least significant difference (LSD) test for all data by SPSS 16.0. A bivariate correlation and regression analysis were used to examine putative influences and relationships of temperature and precipitation on soil CO_2 emissions.

Results

Soil properties

Some of physico-chemical properties of selected sites are presented in Tables 3 and 4. At Neshat site, soil pH varied between 6.02 and 7.84, 7.75 and 8.09 and 7.86 and 8.09 in PF_1, SF_1 and AR_1 land uses, respectively. Soil electrical conductivities (EC_e) were less than 2.18 dS m^{-1} in all land uses (Table 3). The EC_e were less than 1.37 dS m^{-1}, in all Garakpass site land uses (Table 4). Correspondingly, in PF_2, SF_2, and AR_2 land uses of Garakpass site, pH_s varied from 7.41 to 8.22, 7.31 to 7.8 and 8.15 to 8.3, respectively. pH values showed significant increase by depth in PF_2 and SF_2 land uses ($p<0.05$), while, this trend did not emerge in the AR_2 land use (Table 4). Comparison between different land uses indicated that soil pH did not show a consistent trend in the studied land uses (Tables 3 and 4).

Bulk density increased by depth in all land uses (Tables 3 and 4). The highest and lowest bulk densities were observed in the rangelands, and O horizons of deciduous and coniferous land uses, respectively (Tables 3 and 4). Unlike C: N ratio, total nitrogen contents for different land uses did not show significant difference in soil and litter samples (Tables 3 and 4).

Soil organic carbon storage

Soil organic carbon contents (%) regularly decreased by depth at both sites (Table 5). Statistical comparison of SOC storage (Mg C ha^{-1} per cm) of soil horizons was not significant in PF_1 and SF_1 land uses, except for B_{t1} and B_{k1} horizons (Table 5; $p>0.05$); while significant differences

Table 3: Statistical analysis of the land-use changes effects on some of soil properties at Neshat site

horizon	Land uses	pH_s	EC_e* (dS m^{-1})	*BD (Mg m^{-3})	*CCE (%)	TN* (%)	C/N	*BSP (%)
Foliar litter	PF_1	-	-	-	-	1.07(0.05)b	45.69(1.95)a	-
	SF_1	-	-	-	-	1.15(0.06)b	38.94(2.18)b	-
	AR_1	-	-	-	-	1.51(0.01)a	26.89(0.1)c	-
O	PF_1	6.02 (0.07)b+	1.54 (1.02)	0.40(0.03)b	0.1(0.05)b	1.33 (0.14)	23.19 (1.68) a	-
	SF_1	7.75 (0.05)a	2.18 (0.3)	0.48(0.04)a	2.0 (0.1)a	1.20 (0.05)	21.13 (0.69) b	-
A	PF_1	7.84(0.03) b	1.45(0.95)	1.02(0.03)b	0.2(0.05)b	0.38(0.05)	15.6(2.72)a	54.33
	SF_1	8.02(0.01)a	2.01(0.24)	1.01(0.03)b	17.97(0.5)a	0.45(0.12)	14.8(4.40)a	86.10
	AR_1	7.99(0.04)a	1.31(0.29)	1.23(0.07)a	0.44(0.1)b	0.35(0.06)	10.07(1.81)b	84.53
AB	PF1	7.50(0.15)b	0.54(0.17)c	1.24(0.03)a	0.1(0.03)b	0.26(0.04)	12.73(1.66)a	66.76
	SF1	8.01(0.12)a	1.27(0.25)a	1.2(0.03)ab	24.0(1.0)a	0.29(0.13)	18.28(5.81)b	86.54
	AR1	8.09(0.04)a	0.91(0.06)b	1.29(0.08)ac	0.23(0.1)b	0.31(0.04)	8.89(1.86)c	79.76
$\mathbf{B_{t1}}$	PF_1	7.60(0.24)b	0.54(0.21)b	1.47(0.06)a	0.15(0.1)b	0.1■	10.71	85.92
$\mathbf{B_{k1}}$	SF_1	8.09(0.09)a	0.88(0.08)a	1.33(0.05)b	26.49(2.0)a	0.20	13.40	80.16
$\mathbf{B_{w1}}$	AR_1	8.05(0.06)a	0.90(0.21)a	1.30(0.02)b	0.2(0.15)b	0.10	23.40	89.69
$\mathbf{B_{t2}}$	PF_1	7.43(0.11)b	0.39(0.02)b	1.53(0.04)	0.1(0.05)b	0.06	17.32	88.84
$\mathbf{B_{k2}}$	SF_1	8.01(0.04)a	0.61(0.03)a	1.52(0.03)	28.42(1.0)a	0.09	11.60	79.37
$\mathbf{B_{w2}}$	AR_1	7.98(0.12)a	0.64(0.22)a	1.52(0.03)	0.14(0.04)b	0.07	13.18	90.23
$\mathbf{B_{t3}}$	PF_1	7.61(0.27)	0.41(0.04)	1.55(0.04)b	0.15(0.05)b	0.05	16.69	79.68
$\mathbf{B_{k3}}$	SF_1	7.94(0.02)	0.48(0.04)	1.53(0.01)b	0.76(0.2)a	0.05	16.23	76.63
$\mathbf{B_{w3}}$	AR_1	7.86(0.39)	0.49(0.11)	1.61(0.02)a	0.39(0.2)b	0.05	2.40	91.70

*EC_e; Electrical Conductivity of saturation extract; pHs: soil pH; BD: Bulk Density; CCE: Calcium Carbonate Equivalent; TN: Total Nitrogen; BSP: Base Saturation Percentage; +Standard deviations of the means in parentheses; compares means of the same property from similar horizons, similar lowercase letters are insignificant (*p> 0.05*), ■: data were not compared by LSD (no iteration). B_{t1}, B_{k1} mean clay and Carbonates illuviation (accumulation), respectively; B_{w1} means development of soil structure (Soil Survey Staff, 2010)

for SOC storage were obtained in all horizons of PF_1 and AR_1 land uses (Table 5; $p<0.05$). In the PF_2, SF_2 and AR_2 land uses, the SOC storage was significantly different in all horizons, except in AB and B_{k3} (Table 5; $p<0.05$). The highest total SOC storages in the upper 100 cm were belonged to the secondary coniferous forests (SF_1 and SF_2) with 255.00 and 237.9 Mg C ha^{-1}, respectively. The primary deciduous forests (PF_1 and PF_2) were the second (216.74 and 159.12 Mg C ha^{-1}), and abandoned rangelands (AR_1 and AR_2) were the last (185.31 and 151.60 Mg C ha^{-1}), respectively (Table 5). Changing from PF_1 to AR_1 has decreased the SOC storages about 31.43 Mg C ha^{-1} equal to 14.5% in the upper 100 cm of the soils (Table 5; $p<0.05$). Conversion from PF_2 to AR_2 has caused insignificant decrease of SOC storage about 7.52 Mg ha^{-1} (equal to 4.7%) (Table 5; $p>0.05$). In general, changes from PF_1 to SF_1 land use have caused an increase in SOC storage in the upper 100 cm by 38.26 Mg ha^{-1} equal to 17.6%. On the Garakpass site, conversion of deciduous to coniferous forest, significantly increased SOC storage in the upper 100 cm by 78.77 Mg ha^{-1}, equal to 49.5% (Table 5; $p<0.05$). The results also indicated that SOC storages on the Neshat site were significantly higher than the Garakpass site (Table 5; $p<0.05$).

Soil respiration rate

Table 6 shows the measured soil CO_2 emissions in different land uses. CO_2 emissions exhibited temporal variations in different land uses of Neshat site. The minimum soil CO_2 emission for PF_1 land use (46.21 kg C ha^{-1} $month^{-1}$) was observed in February. While in SF_1 and AR_1 land uses, the minimum records (33.54 and 18.72 kg C ha^{-1} $month^{-1}$, respectively) were obtained in May. The maximum values for CO_2 emissions were obtained in August, 424.67, 339.27 and 375.54 kg C ha^{-1} $month^{-1}$, in PF_1, SF_1 and AR_1 land uses, respectively ($p<0.05$, Table 6).

Besides in Garakpass site, soil CO_2 emissions showed significant temporal variations with minimum values of 49.72, 56.74 and 31.59 kg C ha^{-1} $month^{-1}$, in PF_2, SF_2 and AR_2 land uses in February, respectively. Also, the maximum values for PF_2 and AR_2 land uses (529.96, 510.07 kg C ha^{-1} $month^{-1}$) were observed in August, and 570.91 kg C ha^{-1} $month^{-1}$ for SF_2 land use in October (Table 6; $p<0.05$). As shown in Figure 3a, there is an exponential relationship between soil respiration and minimum air temperature in PF_1 land use (R^2 =0.83) with a positive significant correlation ($p<0.05$) r = 0.86 (Pearson correlation coefficients). Polynomial relationships with R^2 =

Table 4: Statistical analysis of the land-use changes effects on some of soil properties at Garakpass site

Horizon	Land uses	pH_s	EC_e* ($dS\ m^{-1}$)	*BD ($Mg\ m^{-3}$)	*CCE (%)	TN* (%)	C/N	*BSP (%)
Foliar litter	*PF_2	-	-	-	-	1.01(0.01)a	46.51(0.31)b	-
	SF_2	-	-	-	-	0.79(0.02)b	61.67(0.2)a	-
	AR_2	-	-	-	-	0.94(0.01)c	43.55(0.56)c	-
O	PF_2	7.45(0.06)b$^+$	1.37(0.25)a	0.46(0.05)a	0.1(0.05)	1.61(0.05)	16.06(1.95)b	-
	SF_2	7.65(0.1)a	1.12(0.12)b	0.39(0.05)b	0.2(0.14)	1.62(0.06)	18.32(3.19)a	-
A	PF_2	7.41(0.26)b	1.39(0.25)a	1.21(0.04)b	0.45(0.1)a	0.51(0.17)a	7.59(2.65)a	59.83
	SF_2	7.80(0.22)b	1.31(0.07)a	1.12(0.03)c	0.26(0.16)b	0.36(0.06)ab	13.48(2.70)b	78.81
	AR_2	8.29(0.12)a	0.83(0.02)b	1.35(0.05)a	0.1(0.02)b	0.28(0.04)b	8.67(0.55)a	84.51
AB	PF_2	7.84(0.09)b	0.72(0.27)	1.32(0.05)b	0.56(0.35)	0.20(0.05)	12.47(0.87)a	78.07
	SF_2	7.55(0.18)b	0.64(0.17)	1.3(0.02)b	0.22(0.1)	0.23(0.03)	11.88(0.89)a	95.91
	AR_2	8.3(0.18)a	0.75(0.2)	1.4(0.03)a	0.1(0.01)	0.20(0.03)	8.89(1.73)b	79.23
B_{k1}	PF_2	8.22(0.15)a	0.53(0.09)	1.55(0.01)a	23.57(2.1)a	0.07■	8.33	89.91
B_{w1}	SF_2	7.31(0.27)b	0.55(0.23)	1.44(0.04)bc	0.14(0.02)b	0.06	24.70	94.68
B_{w1}	AR_2	8.22(0.08)a	0.74(0.01)	1.44(0.02)c	0.1(0.03)b	0.17	8.95	81.98
B_{k2}	PF_2	8.2(0.02)a	0.42(0.07)	1.58(0.02)a	35.14(2.0)a	0.07	6.53	87.59
B_{w2}	SF_2	7.67(0.41)b	0.54(0.1)	1.5(0.04)b	0.27(0.15)b	0.05	13.54	96.36
B_{w2}	AR_2	8.15(0.06)a	0.54(0.26)	1.55(0.03)a	1.0(0.02)b	0.07	8.61	81.98
B_{k3}	PF_2	8.26(0.08)	0.34(0.02)	1.56(0.02)	63.40(3.31)b	0.04	8.41	95.23
B_{k1}	SF_2	7.97(0.07)	0.45(0.2)	1.55(0.02)	13.62(2.3)a	0.03	15.90	68.69
B_{t1}	AR_2	8.09(0.01)	0.43(0.1)	1.58(0.01)	1.0(0.02)b	0.1	3.45	88.00

* EC_e; Electrical Conductivity of saturation extract; pHs: soil pH; BD: Bulk density; CCE: Calcium Carbonate Equivalent; TN: Total Nitrogen; BSP: Base Saturation Percentage; +Standard deviations of the means in parentheses; compares means of the same property from similar horizons, similar lowercase letters are insignificant (*p> 0.05*); ■: data were not compared by LSD (no iteration), B_{t1}, B_{k1} mean clay and Carbonates illuviation (accumulation), respectively; B_{w1} means development of soil structure (Soil Survey Staff, 2010)

0.70, and 0.77, were obtained for SF_1, and AR_1 land uses, respectively, (Figure 3, b, & c) with r = 0.57, and 0.72 (p>0.05) that were not significantly correlated. On the other hand, there were linear relationships with R^2 = 0.79, 0.82, and 0.74 between soil CO_2 emission and the cumulative precipitation (last week), by a significant correlation (r = 0.89, 0.90 and 0.83 (p<0.05)), in PF_1, SF_1 and AR_1 land uses, respectively (Figure 3. d, e, & f). In Garakpass site, the best fitting relation between soil CO_2 emission versus minimum air temperature was exponential with R^2 =0.88, 0.89 and 0.89, for PF_2, SF_2, and AR_2 land uses, respectively (Figure 4. a, b, & c; p<0.05), with positive significant correlation and r = 0.92, 0.90, and 0.93 (p<0.01), accordingly. Similar to Neshat site, there was a linear relationship with R^2 =0.46, 0.63, and 0.44 between soil respiration and cumulative precipitation, but without a significant correlation (r = 0.68, 0.79 and 0.66 *(p>0.05*), in PF_2, AR_2 and SF_2 land uses, respectively (Figure 4. d, e, & f). The Garakpass site compared with Neshat site showed higher CO_2 emission in all land uses (Table 6; *p<0.05*).

Discussion

Influences of land use changes on soil properties

According to the literature, soil pH is expected to reduce by reforested coniferous species (Augusto and Ranger, 2001). However, our results did not obey such a trend in soil pH, especially in O horizons at SF_1 and SF_2 compared to PF_1 and PF_2 land uses (Tables 3 and 4). This can be attributed to the calcium carbonate equivalent (CCE) content and its hydrolysis effects (Tables 3 and 4) in accordance with Foth (1990). The organic acids released by coniferous species have been probably neutralized by carbonates before the soil pH decrease. Soil pH values in PF_1 land use were lower, compared to AR_1, which can be attributed to the soil aquic conditions [Soils currently undergo continuous or periodic saturation and reduction (Soil Survey Staff, 2010)] (Table 1) and higher CO_2 emission in PF_1 land use (Table 6). Furthermore, higher pH values in the AR_1 land use might be interpreted by hydrolyses of basic exchangeable cations and higher base saturation percentage (BSP) (Table 3) (Foth, 1990; Bohn *et al.,* 2001).

Comparison of means of soil pH in PF_2 and SF_2 land uses, was not significant except for some horizons (B_{k1} and B_{w1} and B_{k2} and B_{w2}), probably due to the higher amounts of carbonates in PF_2 land use (Table 4). However, it was significant for the upper A and AB horizons of PF_2 and AR_2 land uses probably because of higher SOC content and CO_2 emission on the upper horizons (A and AB horizons) of PF_2 (Tables 5 and 6) and also relatively high BSP in AR_2 land use (Table 4; Bohn *et al.,* 2001). Strong relationships

Table 5: Statistical analysis of the land-use changes effects on soil organic carbon at Neshat and Garakpass sites

Garakpass site				**Neshat Site**			
OC storage (Mg C ha^{-1} cm^{-1})	**OC* (%)**	**Land uses**	**Horizon**	**OC storage (Mg C ha^{-1} cm^{-1})**	**OC* (%)**	**Land uses**	**Horizon**
-	47.04(0.28)b	*PF_2	Foliar litter	-	48.87(0.03)a^{+}	PF_1	Foliar litter
-	48.90(0.15)a	SF_2		-	44.63(0.22)b	SF_1	
-	41.06(0.02)c	AR_2		-	40.73(0.41)c	AR_1	
11.97(0.47)b**b**•	26.43(3.76)b	PF_2	O	12.53(0.30)a**a**•	31.18 (3.14)a	PF_1	O
12.62(0.46)a**a**	32.41(4.51)a	SF_2		12.11(0.51)a**b**	25.47 (1.79)b	SF_1	
4.39(0.4)b**b**	3.65(0.47)b	PF_2	A	6.25(0.35)a**a**	6.12 (0.53) a	PF_1	A
5.21(0.27)a**b**	4.63(0.35)a	SF_2		6.41(0.27)a**a**	6.37 (0.44) a	SF_1	
2.98(0.5)c**b**	2.98(0.27)c	AR_2		4.19(0.74)b**a**	3.45 (0.84) b	AR_1	
3.23(0.48)a**b**	2.46(0.44)a	PF_2	AB	4.03(0.32)a**a**	3.25 (0.33) a	PF1	AB
3.47(0.16)a**b**	2.67(0.15)a	SF_2		4.48(0.33)a**a**	3.74 (0.37) a	SF1	
2.38(0.27)b**b**	1.7(0.22)b	AR_2		3.59(0.71)b**a**	2.80 (0.77) b	AR1	
0.87(0.12)b**b**	0.56(0.08)b	PF_2	B_{k1}	1.74(0.6)b**a**	1.19 (0.46) b	PF_1	B_{t1}
2.04(0.35)a**b**	1.43(0.28)a	SF_2	B_{w1}	3.12(0.51)a**a**	2.34 (0.47) a	SF_1	B_{k1}
2.02(0.23)a**b**	1.4(0.18)a	AR_2	B_{w1}	2.82(0.98)a**a**	2.11 (0.84) a	AR_1	B_{w1}
0.57(0.20)b**b**	0.36(0.13)b	PF_2	B_{k2}	1.09(0.40)a**a**	0.72 (0.28)	PF_1	B_t
1.45(0.39)a**a**	0.98(0.28)a	SF_2	B_{w2}	1.25(0.35)a**b**	0.83 (0.25)	SF_1	B_{k2}
0.88(0.31)b**b**	0.57(0.21)ab	AR_2	B_{w2}	1.25(0.3)a**a**	0.83 (0.21)	AR_1	B_{w2}
0.77(0.01)a**b**	0.41(0.11)ab	PF_2	B_{k3}	0.95(0.43)a**a**	0.62(0.3)a	PF_1	B_{t3}
0.87(0.16)a**b**	0.55(0.08)a	SF_2	B_{k1}	1.06(0.1)a**a**	0.61(0.15)a	SF_1	B_{k3}
0.56(0.01)b**a**	0.35(0.01)b	AR_2	B_{t1}	0.34(0.21)b**a**	0.21 (0.13) b	AR_1	B_{w3}
159.12(5.73)b**b**	-	PF_2	Total SOC storage Mg C ha^{-1}m^{-1}	216.74(5.70)a**a**	-	PF_1	Total SOC storage Mg C ha^{-1}m^{-1}
237.90(12.11)a**b**	-	SF_2		255.00(0.25)b**a**	-	SF_1	
151.60(4.92)b**b**	-	AR_2		185.31(3.70)c**a**	-	AR_1	

*OC: Organic Carbon; +Standard deviations of the means in parentheses; compares means of the same property from similar horizons, similar lowercase letters are insignificant ($P > 0.05$), • compare the effects of altitude on means of SOC storage of similar soil horizons with each other between sites 1 and 2, similar bolded lowercase letters are insignificant ($P > 0.05$); B_{t1}, B_{k1} mean clay and Carbonates illuviation (accumulation), respectively; B_{w1} means development soil structure (Soil Survey Staff, 2010)

Table 6: Soil CO_2 emissions at different land uses

Month	**Studied sites**					
	Neshat (1)			**Garakpass (2)**		
	PF_1	**SF_1**	**AR_1**	**PF_2**	**SF_2**	**AR_2**
	Soil Respiration Rate (kg C ha^{-1} month^{-1})					
May	81.9(2.34)Ea$^{\times}$	33.5 (12.01)Db	18.7 (2.34)Ec	84.2(4.68)Ea	101.8(19.89)Da	73.7(3.51)Ea
Jun.	224.6 (4.68)Cb	177.8 (33.74)Bc	271.4 (4.68)Ba	460.9(4.68)Ba	396.6(8.19)Cb	472.6(11.7)Ba
Aug.	424.7(15.21)Aa	339.3(20.0)Ab	375.5 (24.57)Ab	530.0(21.06)Aa	522.9(10.0)Ba	510.1(4.68)Aa
Oct.	374.4(23.4)Ba	197.7 (17.55)Bc	276.1 (11.7)Bb	339.3(23.4)Cb	570.9(23.4)Aa	358.0(7.02)Cb
Nov.	114.7(11.7)Db	177.8 (11.7)Ba	188.3 (5.85)Ca	121. 7(2.34)Da	116.4(0.58)Da	106.8 (10.88)Da
Feb.	46.2 (0.58)Fb	127.5 (15.21)Ca	108.8 (9.36)Da	49.7(1.75)Fa	56.7(7.6)Ea	31.6(2.34)Fb
(6 month)	1266.4 (28.66)a**b**	1053.7(35.63)c**b**	1238.9 (35.1)a**b**	1585.8(2.93)b**a**	1767.4(6.49)a**a**	1552.8(21.41)b**a**
kg C ha^{-1} year^{-1}	2532.8 (57.32)a**b**	2107.4(71.26)c**b**	2477.8(70.19)a**b**	3171.6(5.85)b**a**	3534.7(13.0)a**a**	3105.6(21.49)b**a**

× Standard deviations of the means in parentheses. Capital letters: Means comparison of columns data, lowercase letter: Means comparison of rows data, similar letters show no significant difference ($P > 0.05$). The Bolded-lowercase letters compares the effects of altitude on soil CO_2 emission ($P < 0.05$) between similar land uses of two sites

were observed between bulk densities and SOC contents of all land uses (Tables 3, 4 and 5). Similar results have been reported by Lantz *et al.* (2002), about reduction of bulk densities by increasing SOC contents.

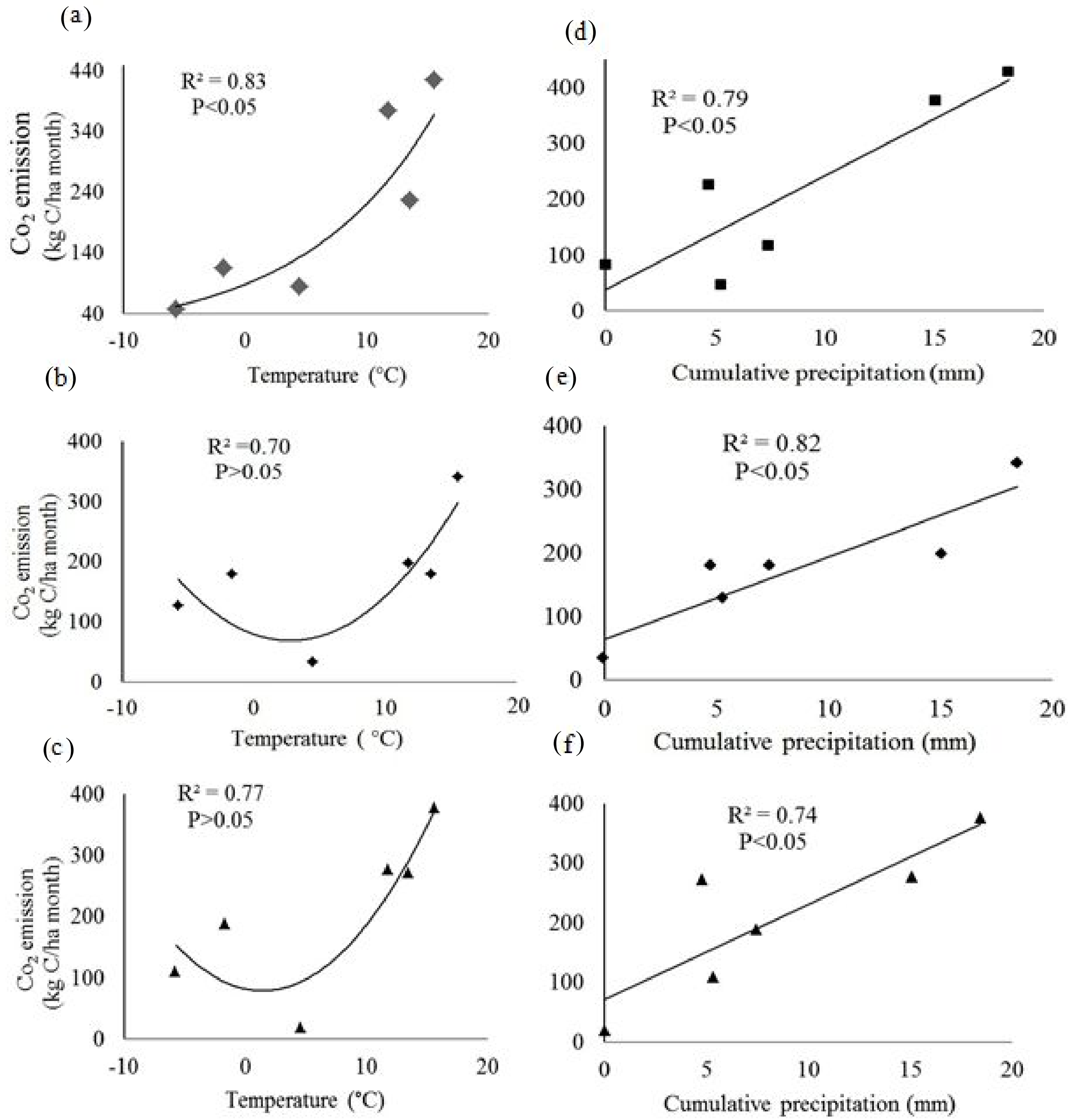

Figure 3: Relationships between soil CO_2 emission and minimum air temperature and cumulative precipitation (last week) at Neshat site; a & d: PF_1, b & e: SF_1, and c & f: AR_1; (CO_2 emission is expressed as kg C per hectare per Month)

Despite the insignificant difference observed between the plant litter N contents in deciduous and coniferous forests in Neshat sites (Table 3), a significant difference was found between deciduous and coniferous forests in Garakpass site (Table 4). Considering that soil N directly originates from the plant litter, it might be expected that soil N contents would not show significant difference. However, litter N contents of forests were significantly different from the rangeland (Tables 3 and 4; $p< 0.05$). The C:N ratio irregularly was decreased by increasing soil depth in all land uses of both sites (Table 3 and 4), probably due to illuviation of more humified SOM to lower horizons

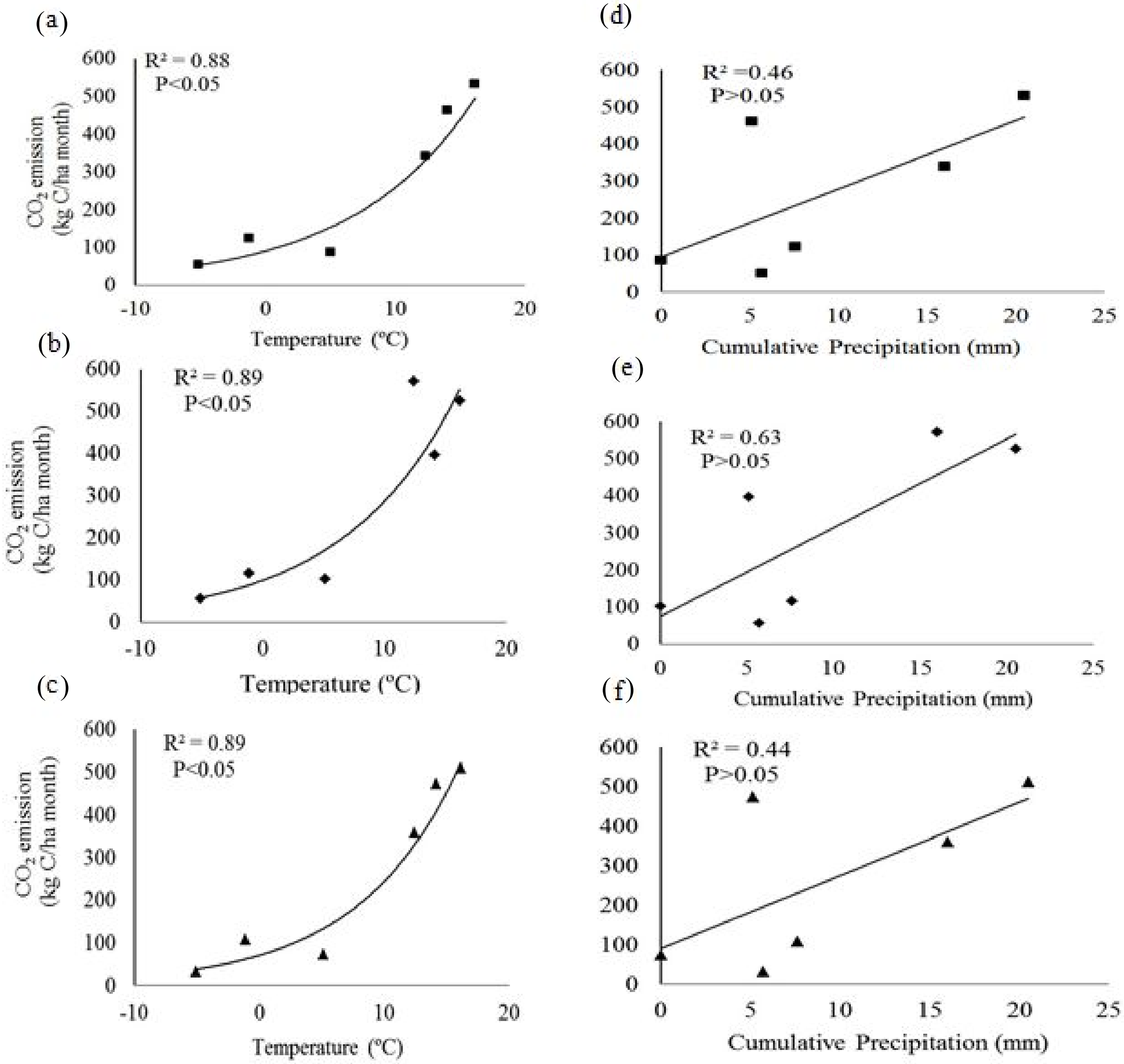

Figure 4: Relationships between soil CO2 emission and minimum air temperature and cumulative precipitation (last week) in Garakpass site; a & d: PF_2, b & e: SF_2, and c & f: AR_2; (CO_2 emission is expressed as kg C per hectare per Month)

(Johnson *et al.,* 1992). As shown in Tables 3 and 4, the C:N ratio were significantly different on upper horizons of all land uses. These probably have been caused by the influence of carbonates and litter composition type. In SF_1 - and PF_2 land uses, C:N ratio variations can be attributed to the variability of CCE, but in the SF_2 and PF_1 land uses, which carbonates are traced, it might be attributed to the litter composition only (Tables 3 and 4). $CaCO_3$ may stimulate the microbial activities, deprotonation of organic substances, and biodegradation processes. These can be attributed to the decrease of bonding between organic compounds and soil particles; and consequently decrease in C:N ratio (Table 3) (Bouajila and Gallali, 2008). Additionally, the slower decomposition of conifer litter compared with deciduous litters along with their higher C: N ratio (Table 4) has been reported (Ussiri *et al.,* 2006).

Dissimilar relationships between C: N ratio in the studied sites most probably has been resulted by differences in the soil attributes e.g. their organic matter quality, carbonate content and parent material (Van Breemen, and Buurman, 2002). Based on Table 3, lower base saturation percentage (BSP) and pH on the upper horizons of PF_1 land use resulted by the lack of carbonates have caused poorer soil nutritional condition compared to SF_1 land use. This causes extremely higher C: N ratio in PF_1 land use (Van Breemen and Buurman, 2002).

Effects of de/reforestation on SOC storage

Rangeland soils tend to have a higher SOC storage than deciduous forest on the middle horizons (Table 5; $p<0.05$), probably due to dense and prolific root systems (Lantz *et al.,* 2002). Increase of SOC storage in the lower horizons (B_3) under PF and SF compared to AR land uses probably was due to increase in SOC originated from deeper developed root biomass (Trumbore *et al.,* 1995). Whereas soil organic carbon reduces by either lessening carbon input or increasing carbon loss (Luo and Zhou, 2006). Although, lower CO_2 emission in rangelands (Table 6) demonstrates that it cannot be the reason of SOC reduction (Table 5) in this land use. However, lesser soil organic carbon is related to lower input to soil, that can be attributed to destroying of O horizon (Table 5), burning of biomass, removing of total soil mass for urban constructions (Figure 2), and also lower C:N ratio of litter (Tables 3 and 4). Significant decrease in SOC storage of Neshat site as a result of deforestation (Table 5) agrees with Powers (2004). However, minimum disturbance in rangelands has caused little reduction in SOC storage in Garakpass site (Table 5; Houghton, 2010). As shown in results, the highest SOC storages (255.0 and 237.9 Mg C ha^{-1}), were observed in coniferous SF_1 and SF_2 land uses (Table 5). These are the results of higher and continuous annual litter production in coniferous forests (Norway spruce) compared to deciduous forests (Pedersen and Bille-Hansen, 1999). At all, broadleaf components may decompose more rapidly (Comeau, 1996). Singh and Gupta (1977) were reported that litter decomposition rate of beech "*Fagus orientalis*' is 0.23 percent per day, however, it is between 0.03-0.082 for the spruce "*Picea abies*'. Considering higher C:N ratios in some of mineral horizons of SF_2, compared to PF_2 land uses (Table 4), increasing SOC storage can be attributed to the slower decay of spruce litter (Berger *et al.,* 2002; Arai and Tokuchi, 2010). In addition, the slower decomposition of SF_1 litter compared to PF_1 probably is related to the higher lignin and polyphenol concentrations or poorer quality substrate (O'Connell and Sankaran, 1997).

Finally, it can be stated that there were significant differences between the SOC storages of the studied sites (Table 5). It seems that the difference between physiographic conditions, slope aspect and altitude (Garten Jr and Hanson, 2006) in the studied sites, have played an important role in SOC storage. Neshat site with NW aspect and higher altitude has got higher SOC storage (Table 5) compared to Garakpass site (NE aspect and lower altitude) (Table 1). Various studies indicated that increasing soil C storages with elevation could be caused by (i) lower temperatures, (ii) higher soil water contents during most part of the year, (iii) radiation, (iv) greater organic matter inputs, (v) and less organic matter decomposition (Zimmermann *et al.,* 2009). On the contrary, lower altitudes with warmer temperatures enhance decomposition of SOM (Table 6) (Nieder and Benbi, 2008). The present investigation, in agreement with Martin *et al.* (2010), denotes that the soil organic carbon storage in the forest and rangelands is highly dependent on physical attributes such as climate, altitude, and vegetation type.

Seasonal soil CO_2 efflux at different land uses

Soil moisture and temperature regimes were xeric-mesic, which can play a great role in soil CO_2 emission (Jones *et al.,* 2003). The maximum and the minimum seasonal soil CO_2 efflux, in the most land uses were observed in summer and winter, respectively (Table 6). The highest soil CO_2 efflux also was recorded in August to October. Soil CO_2 emission changes from the growing to non-growing seasons in all land uses, showed that the spatial pattern of soil respiration may vary with time because of changes in controlling factors (Ohashi and Gyokusen, 2007). More suitable temperature and rainfall distribution in August to October (Table 2) enhance soil metabolic activity and plant growth (Luo and Zhou, 2006). Soil CO_2 efflux exhibited a sharp decrease (Table 6), starting the cold season on November and lasting to May, can likely be related to root and microbial respiration depression at low soil temperature (<10 °C; Table 2) (Iqbal *et al.,* 2008). The recorded CO_2 efflux for November (minimum temperature -1.7 and -1.1°C), was higher than May with (4.55 and 5.15 °C). This can be attributed to continued live plant respiration before completely destroying of vegetation cover in autumn and lower biological activity before establishing new vegetation cover in spring. On the Neshat site, soil CO_2 efflux in AR_1 remained significantly high in November to February (Table 6; *$p<0.05$*) which is typical characteristic of Mediterranean ecosystems, in which grass is biologically active during cool season (Wang and Amundson, 1999). As expected, the temporal trends in the CO_2 efflux rates (Table 6) were positively related to the minimum temperature fluctuation and the cumulative precipitation (Table 2). Significant relationships between temperature and CO_2 flux were obtained at PF_1, PF_2, SF_2, and AR_2 land uses (Figure 3 and 4). Our results corroborated with those of similar studies (Iqbal *et al.,* 2009). The best fitted relationship between CO_2 emission and temperature in PF_1, PF_2, SF_2, and AR_2 land use was positive exponential relation ($p<0.05$) (Figure 3.a and Figure 4.a, b, c; Schaufler *et al.,* 2010). However, a polynomial relation was obtained for SF_1 and AR_1 land uses, (Figure 3 b, c; $p>0.05$) instead of the typical exponential one. These differences probably can be related to soil and land attributes (e.g. microclimate), and soil properties (Tables 3, 4 and 5). The strong positive correlation between the cumulative precipitation and soil CO_2 emissions in all land uses, (p<0.05 fitted) with linear relationships (Figure 3 and 4. d, e, f). Linear increasing of soil CO_2 efflux with precipitation was in agreement with Luo and Zhou (2006). Microbial activities and CO_2 emission increase suddenly after rainfall (Luo and Zhou, 2006). In general, unlike low SOC storage, annual soil CO_2 efflux of Garakpass site was higher than that of the Neshat site (Table 6). This spatial variability of soil CO_2 emissions among the both sites was related to certain topographical and landscape positions (see previous section; Table 1) (Ohashi and Gyokusen, 2007).

Land use showed a significant impact on soil CO_2 flux (Table 6), which was in agreement with the findings of Iqbal *et al.* (2008). Despite the lower SOC storage in PF_1 compared with SF_1 land use (Table 5; $p<0.05$), its CO_2 efflux was 17% higher (Table 5; $p<0.05$). Despite lower SOC storage in PF_1 compared to SF_1 land use (Table 5), it has maintained higher respiration rate than SF_1 due to poorer quality of coniferous litter (Table 6). Unlike Raich and Tufekcigul (2000), on the second site the studied coniferous forest (SF_2) had about 11% higher respiration rates (Table 6; $p<0.05$), than the adjacent PF_2 land use. This can be attributed to the higher SOC storage in SF_2 land use (Table 5; Hutsch, 1998), and more forest floor vegetation resulted from low canopy density in coniferous forests which causes trapping of much more solar radiation (Pourbabaei and Dado, 2003; Meamarian *et al.,* 2006), this is in agreement to Cantú et al. (2008). Such findings indicate that vegetation type is an important determinant of soil CO_2 emission, and therefore the changes in vegetation have the potential to modify the responses of soils to environmental change (Raich and Tufekcioglu, 2000). Due to lower SOC content, the soil CO_2 efflux in AR_2 was a little (2 %) lower than PF_2 land use (Table 6; $p>0.05$),which is in agreement with the results of Luo and Zhou (2006) which showed that soil respiration is consistently greater in forests than rangelands.

In general, effects of soil properties, vegetation cover, also different quantity and quality of litter probably affect total soil CO_2 flux (Iqbal *et al.,* 2008). Although the measured total SOC storage followed by: SF_1 >SF_2 > PF_1 > AR_1> PF_2> AR_2 (Table 5), the total soil CO_2 emissions among different land use types showed different trends: SF_2 >PF_2 > AR_2 > PF_1> AR_1> SF_1 (Table 6). This means that the Neshat site has higher C storage capability compared to Garakpass site. Moreover, reforestation by *Picea abies* species has increased, while deforestation has diminished SOC storage.

Conclusion

Land use changes and their effects on soil properties, SOC storage, and CO_2 efflux have had many attractions for soil and environmental scientists in recent decades. Although, land use changes did not significantly affect soil pH, EC_e, and total N, bulk density and C: N ratios were significantly affected. SOC storage was significantly higher in the coniferous forests and the lowest SOC storage belonged to the abandoned rangelands. Generally, it can be concluded that deforestation has caused significant effects on SOC storage due to the decrease of organic carbon input in abandoned rangeland. Conversion of deciduous to coniferous forests has caused a significant increase in SOC storage, due to slower decay. The *Picea abies* species were more efficient in SOC storage compared with the other species. Seasonal changes in soil CO_2 flux were influenced by combination of environmental factors including soil properties, geomorphology (altitude and slope), canopy density, forest floor vegetation, and minimum air temperature and the cumulative precipitation during the final week before CO_2 measurement.

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