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Effect of Land Use Change on Selected Soil Physical and Chemical Properties in North Highlands of Iran

[1]Mostafa Emadi, [2]Mehdi Emadi, [1]Majid Baghernejad, [1]Hamed Fathi and [1]Mahboub Saffari
[1]Department of Soil Science, College of Agriculture, Shiraz University, Shiraz, Iran
[2]Department of Geology, Shiraz University, Shiraz, Iran

Abstract: The objective of this study was to quantify the effects of cultivation on selected soil properties in the northern highland of Iran. Three adjacent land-use types including cultivated lands (which have been converted from pastures and forests for 18 years), a native forest and pasture lands were studied. Soil samples were collected from four sites in each of the three different land use types in the depths of 0-10 and 10-20 cm. Results showed that conversion of native pasture and forest soils into cropland during the 18 year-period increased soil Bulk Density (BD) by 16%, plasticity index by 30% and soil erodibility by 51%. In addition, it decreased Soil Organic Matter (SOM) and Total Nitrogen (TN) by 50% each, tilth index by 40% and available water capacity by 40% for the 0-20 cm soil depth. There were significant differences in soil BD between depths in the pasture and cropland, but not in the forest. Depending upon the increases in soil BD and disruption of pores by cultivation, total porosity decreased accordingly. The Mean Weight Diameter (MWD) and Water-Stable Aggregates (WSA) were greater in the pasture and forest soils in comparison with the cultivated soils and did not change with the depth for each land use type. The distribution of Organic Carbon (OC), Total Nitrogen (TN) and available Phosphorus (P) within WSA showed preferential enrichment of these elements in the macroaggregate fraction (4.76-2.0 mm) for the uncultivated soils and microaggregate fraction (>0.25 mm) for the cultivated soils. These results suggest that the cultivation of native forests and pasture lands in the northern highlands of Iran-degraded soil properties left soil more susceptible to erosion. Since smaller aggregates are preferentially removed by erosion, there is a need to consider appropriate management practices for increasing soil sustainability and productivity.

Key words: Alborz mountains range, land-use change, tilth index, mean weight diameter, water-stable aggregate

INTRODUCTION

Rapid population growth in northern Iran requires additional farmlands for food production leading to clear cutting of forests and converting pastureland to the cropland. Between 1955 and 1999 in north Iran, pasture and forest area have decreased significantly, while arable crop land have increased. Clearing of forests for agricultural production and grazing is widespread, particularly in the highlands of the central Alborz Mountains of the southern Mazandaran province of Iran. The prevailing semi-arid climate and sloping topography in the region render ecosystems more vulnerable and less resilient to incompatible changes in land use. The destruction of the natural forest and pasture ecosystems and conversion to cropland can reduce soil productivity because of increased erosion, decline in fertility, changes in aeration and moisture content, salinization or change in soil flora or fauna (Bossuyt *et al*., 1999). Effects on vegetation and species distribution have been documented in different ecosystems following anthropogenic activities (Peterken, 1974; Six *et al*., 2000; Bruun *et al*., 2001; Foster *et al*., 2003). Land use-induced changes in nutrient availability may influence secondary succession and biomass production (Foster *et al*., 2003) and reduce Soil Organic Carbon (SOC) which plays a crucial role in sustaining soil quality, crop production and environmental quality (Doran and Parkin, 1994). Such changes directly affect soil physical, chemical and biological properties, such as soil water retention and availability, nutrient cycling, gas flux, plant root growth and soil conservation (Gregorich *et al*., 1994). Maintenance of SOC is especially important due to the effects of SOC on soil nutrient status and soil structural stability.

Conversion of native forests and pasturelands to cultivation is usually accompanied by a decline in SOC and nutrients and deterioration of soil structure

Corresponding Author: Mostafa Emadi, Department of Soil Science, College of Agriculture, Shiraz University, Shiraz, Iran
Fax: +987116289017

(Detwiler, 1986; Balesdent *et al*., 1998; Spaccini *et al*., 2001). The changes in SOC induced by cultivation depend on the particular agronomic practices adopted and on the properties of the virgin soil (Christensen, 1992). Reduction in SOC changes the distribution and stability of soil aggregates (Singh and Singh, 1996) making the soils more susceptible to erosion (Cambardella and Elliott, 1993; Six *et al*., 2000).

Identifying and monitoring such changes in soil quality is the essential first step in countering land degradation in the Northern highlands of Iran and in improving soil and land management in this region. The objective of this study was to quantify effects of changes in land-use type on soil physical and chemical properties in a selected region of the Alborz mountains range in the Northern highlands of Iran.

MATERIALS AND METHODS

Study area: The study area was located in the Kiyasar region, southeast Sari, Mazandaran province within the northern Rajaei watershed (36° 10′ to 36° 13′ N, 53° 30′ to 53° 35′ E) of the central Alborz mountain range, Iran. The study area is a plateau with elevation about 2100 meters, lying in east to west and covering approximately 3150 ha of which forest occupies 1500 ha, pastureland 800 ha and cropland 600 ha. Most part of the cropland acreage were converted from forest or pastureland 18 years previously. Some pasture and forest soils have been converted to rainfed wheat (*Triticum aestivum* L.) since 1988. The remainder of the area consists of roads, rivers and residential areas. The prevailing climate is Mediterranean with the long-term mean annual temperature and precipitation of 18°C and 520 mm. Soil moisture and temperature regimes were determined as xeric and thermic. Most of precipitation is received during the winter and spring (November-May). Soils are a mosaic of clay loams and silty clay derived from limestone. The dominant soils in the study area are Typic Haploxerolls (Soil Survey Staff, 1999). The area is hilly, with slopes between 15 to 30%. No salinity and drainage problems exist. The calcium carbonate equivalent and electrical conductivity of a saturated soil solution extract were 22% and 1.01 dS m^{-1}. Dominant tree species in the forests are *Acer persicum*, *A. pojark*, *Pinus nigra* and *P. brutia*. Plant cover of the pastureland ranges from 80 to 60% because of overgrazing. Dominant grass species include *Agropyrom intermedium* (Host), *P. beauv*, *Hurdeum bulbosum* L. and *Festuca ovina*.

Soil sampling: Soil samples were collected in September 2006 from four locations in each of the three land use types (forest, pasture and cropland). The three types were either adjacent to one another separated by no more than 1000 m. within the same physiographic unit and with similar slope and aspect. Soil samples were taken from 0-10 and 10-20 cm at each of the four locations in each land use type. Soil samples were brought back to the laboratory and air-dried for 1 week.

Laboratory studies

Physical properties: Bulk density at the air-dried moisture content was measured on clods (Plaster, 1985). Particle size distribution was determined using disturbed soil samples sieved through a 2 mm by the hydrometer method (Gee and Bauder, 1986). Soil erodibility (USLE-K factor) was estimated using the equation suggested by Wischmeier and Smith (1978). Plasticity index was measured using the Casagrande apparatus (Casagrande, 1948). Water retention capacity at -33 kPa (field capacity) and at -1500 kPa (permanent wilting point) were measured using a pressure membrane apparatus (Gardner, 1986). The tilth index was calculated using the equation and coefficients reported by Singh *et al*. (1992) without using the cone index parameter. Aggregate size distribution was expressed in terms of the uniformity coefficient, which is the ratio of D_{60} to D_{10}, where D_{60} and D_{10}, are the diameters corresponding to 60 and 10% finer on the ordinate of the soil particle size curve (Wary, 1986). The size distribution of soil aggregates was measured by wet sieving through a series of sieves (2.0, 1.0, 0.5, 0.25 mm) following the procedure of Cambardella and Elliott (1993). In this procedure, 50 g of the <4.76 mm aggregates were placed on the topmost of a nest of sieves of opening 2.0, 1.0, 0.5 and 0.25 mm. The sieves were immersed in the water for 10 min and then sieved by moving the sieve 3 cm vertically 50 times during a period of 2.0 min. The mass resultant aggregates on each sieve were dried at 105°C for 24 h and weighed. The percent water-stable aggregates (%WSA) on each of the following size ranges: 4.76-2.0, 2.0-1.0, 1.0-0.05, 0.5-0.25 and <0.25 mm were then determined. Thus,

$$\%WSA = ((M_{a+s} - M_s)/(M_t - M_s)) \times 100$$

Where:

M_{a+s} = Mass of the resistant aggregates plus sand (g)
M_s = Mass of the sand fraction alone (g)
M_t = Total mass of the sieved soil (g)

The model of Van Bavel (1950) as modified by Kemper and Rosenau (1986) used to determine the Mean Weight Diameter (MWD) of wet-stable aggregates. Thus,

$$MWD = \sum_{i=1}^{n} X_i W_i$$

Where:

X_i = Mean diameter of each size fraction (mm)

W_i = Proportion of the total mass in the corresponding size fraction after deducting the weight of stones (upon dispersion and passing through the same sieve) as indicated above

Chemical properties: Organic Carbon (OC) was determined by the Walkley and Black method (1934) as modified by Allison (1965). Total Nitrogen (TN) was determined with the Kjeldahl method (McGill and Figueiredo, 1993), Available Phosphorus (P) was measured by the Olsen method (Olsen *et al*., 1954).

Data analysis: One-way analysis of variance on the measurements was performed using SAS software (1999). Means were compared by Least Significant Difference (LSD) at $p<0.05$ level.

RESULTS AND DISCUSSION

Bulk density and total soil C and N: The Bulk Density (BD) values were significantly different for the land-use types (Table 1). Soils under cultivation had higher bulk density (almost 16%) than adjacent soils under forests and pastures for the two different depths. The highest bulk density values occurred at the 0-10 cm soil depth for the cultivated land. For the pasture and cropland, the BD values at the two sampling depths were significantly different. Such differences might be ascribed to the compaction of topsoil due to overgrazing of the pasture and use of machinery (Lal, 1986) or intensive agricultural practices for croplands. Vanden Bygaat *et al.* (1999) observed a reduction of total pore volume and in total number of pores in the top 0 to 0.25 m of soils after 11 years of no-till. However, they stated that increase in root penetration and biological activity in no-till fields might facilitate aeration and water entry due to formation of biopores and decrease the bulk density in the long term. Li *et al.* (2004) found that tillage affected soil BD differently at different slope positions. In their study, BD increased from 1.14 to 1.28 mg m^{-3} in the upper slope and decreased from 1.1 to 1.03 mg m^{-3} in the middle slope.

The results (Table 1) tended to confirm that conversion of the natural forest and pasture into cultivation resulted in significant reduction of stocks of SOC and TN for the two sampling depths. SOM over the 0-20 cm depth of the cultivated soils was lower than corresponding values for the forest and pasture soils by 49.5 and 47.9%, respectively. Similarly, after 18 years of cultivation, TN decreased by 51 and 47.7%, respectively compared to the forest and pasture soils. Comparable losses of SOC and TN due to cultivation of forest or pasture have been reported (Brown and Lugo, 1990; Spaccini *et al*., 2001; Wu and Tiessen, 2002).

C/N ratio was also significant narrowed from 11.0 in the pasture soils to 8.4 in the cultivated soils (Table 1). The substantial losses of organic C and TN were expected since 18 years of tillage would tend to break-up soil aggregates and increase aeration. In addition, removal of large amounts of aboveground biomass at harvest and the common practice of burning crop residues during land preparation would favor decomposition of SOM. Su *et al.* (2004) found that even short-term cultivation had a significant influence on soil C, N and soil biological of properties, with lower basal soil respiration and enzyme activities than the native grasslands soils.

Aggregate size distribution and stability: Results presented in Table 2 show that in uncultivated (forest and pasture) soils, the aggregates >0.25 mm decreased significantly with cultivation. In the forest and pasture soils, the 4.76 to 0.25 mm size aggregates were predominant comprising 83 and 90%, respectively (Table 2). Compared to forest soils, cultivation decreased the WSA proportion of 4.76 to 2.0 mm size aggregates in depth 0-20 cm by 3.6 times; while the decrease was 85% for 2.0 to 1.0 mm size aggregates. Comparison of cropland and pasture soils followed the pattern observed with forest soils; showing 4.3 times decease for 4.76 to 2.00 mm fraction and 89% decease for 2.0-1.0 mm fraction.

However, in the cropland soil, a significantly large proportion of the aggregates were <0.50 mm in size. Smaller size aggregates of <1.2 mm was found to be a useful indicator of soil degradation (Whalen and Chang, 2002). The results (Table 2) indicated that tillage in the cropland had caused breakdown of the large aggregates into smaller aggregates, resulting in higher proportion of small aggregates (<0.50 mm) in this soils (Table 2).

Table 1: Effect of three land-use types on soil Bulk Density (BD), Soil Organic Matter (SOM), soil Total Nitrogen (TN) and C/N ratio

	Forest			Pasture			Cropland		
	0-10	10-20	0-20	0-10	10-20	0-20	0-10	10-20	0-20
Parameters	(cm)								
BD (mg m^{-3})	1.24^{c}	1.26^{c}	1.25^{c}	1.28^{c}	1.13^{d}	1.21^{d}	1.48^{a}	1.39^{b}	1.50^{ab}
SOM (g kg^{-1})	41.50^{b}	38.53^{c}	40.20^{bc}	44.70^{a}	41.20^{b}	42.30^{b}	22.80^{d}	20.70^{e}	21.70^{e}
TN (g kg^{-1})	3.90^{b}	3.69^{c}	3.79^{c}	3.74^{a}	4.08^{b}	3.91^{b}	2.70^{d}	2.26^{e}	2.48^{e}
C/N	10.64^{ab}	10.44^{ab}	10.54^{ab}	11.01^{b}	10.57^{a}	10.79^{b}	8.41^{c}	9.06^{bc}	8.74^{c}

Values with different letter(s) in rows of each depth indicate significant differences at $p<0.05$

Aggregate formation and stability depends strongly on the microbial gums produced by the breakdown of organic matter and acting as cementing agents. The smaller aggregates in the cropland soils are therefore consistent with the lower SOM content (Table 1).

Loss of the larger aggregate sizes in cropland could also be due to tillage rapidly destroying live and decaying plant roots, fungal hyphae, earthworms and termites. These factors tend to favor the formation of larger-sized aggregates (Tisdale and Oades, 1982). These results confirm earlier observations that the size distribution of aggregates is affected by the change in land use and management (Beare *et al*., 1994; Puget *et al*., 1995; Spaccini *et al*., 2001; Ashagrie *et al*., 2007). The loss of large-sized water stable aggregates under cultivation was also associated with a significant reduction in stability as measured by the MWD (Table 2). The stability of intact WSA, showed higher values in uncultivated soils than in cultivated soils. The aggregate stability of cropland soils was 40 and 45% lower compared to the forest and pasture soils, respectively. There were no significant differences in MWD between the forest and pasture soils for each depth.

Carbon, nitrogen and available phosphorus distribution in WSA: Results in Table 3 for the OC and TN (in g kg^{-1}) distribution within the WSA for the three land use types showed that OC and TN were preferentially occluded in the 4.76 to 2.00 mm size aggregates for the native forest and pasture soils and in the <0.25 mm size aggregates for the cultivated soils. In the soils under forest and pasture, neither OC or TN content was significantly different among the 5 aggregate size classes. In contrast, the OC and N content tended to increase with reduction in aggregate size most likely due to mechanical disruption of the larger aggregates under tillage as reported by Dormaar (1983) and Christensen (1992). The available phosphorus distribution within the WSA for the forest and pasture soils followed the trend observed with OC and TN. In croplands available phosphorus increased significantly ($p<0.05$) as the aggregate size decreased (Table 3). The higher level of available Phosphorus (P) found in the smaller sized aggregates contradicts the observation of Adesodun *et al*. (2005) and Mbagwu and Piccolo (1990). Mbagwu and Piccolo (1990) reported that OC, N and P levels were higher in the larger sized aggregates in North Central Italian soils.

Table 2: Aggregate size distribution (WSA%) and stability (MWD) of soils of the three adjacent land use type for depth 0-20 cm

Land use type	Aggregate sizes (mm)^{A} 4.76-2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25	MWD (mm)^{B}
Forest	28.2^{a}	20.7^{a}	14.8^{b}	19.2^{a}	17.1^{b}	3.61^{A}
Pasture	23.4^{a}	23.9^{a}	22.2^{a}	20.4^{ab}	10.1^{b}	3.92^{A}
Cropland	5.2^{d}	12.5^{c}	10.2^{c}	33.9^{b}	38.2^{a}	2.13^{C}

^{A}: Values (aggregate sizes) with different letter(s) in rows indicate significant differences ($p<0.05$), ^{B}: Values (MWD) with different letter(s) in column indicate significant differences ($p<0.05$)

Tilth index and soil erodibility: Tilth Index (TI) is a quantitative estimate for soil tilth proposed by Singh *et al.* (1992). In this study, the tilth index was calculated based on measurements of bulk density, organic matter content, aggregate uniformity coefficient and plasticity index. Singh *et al.* (1992) included the cone index but this parameter could not be reliably obtained in this study because the soils had a high clay content (>30%) and were unsaturated during the season. The TI was significantly lower in the cultivated soil compared with the forest and pasture soils (Table 4). There were no significant differences in TI between the two sampling depths and between the two native soils (Table 4). Tilth index decreased approximately 40% after conversion of native forest and pasture to cropland. The USLE-K factor, an indicator of soil erodibility, was significantly higher in the cultivated than the corresponding values for the forest and pasture soils by 60 and 43%, respectively (Table 4). There was no significant difference in the K factor between the forest and pasture for both depths. These results could be partly attributed to the removal of permanent vegetation, loss of soil organic matter and decrease in WSA and MWD following the conversion of native forest and pasture into cultivated land. Mays (1996), Eynard *et al.* (2004) and Celik (2005) reported similar findings.

Table 3: Organic C, total N and available phosphorus (P) (g kg^{-1}) of soil aggregate size classes in the 0-20 cm soil depth in three land use types

Aggregate size (mm)	Forest C	Forest TN	Forest P	Pasture C	Pasture TN	Pasture P	Cropland C	Cropland TN	Cropland P
4.76-2.00	47.2^{a}	4.6^{a}	43.1^{a}	51.1^{a}	5.20^{a}	47.10^{a}	20.0^{bc}	2.46^{d}	18.26^{c}
2.0-1.0	42.1^{a}	3.81^{a}	30.2^{a}	36.3^{a}	3.47^{a}	32.30^{a}	21.0^{c}	2.50^{cd}	15.18^{c}
1.0-0.50	40.9^{a}	3.63^{a}	22.8^{a}	39.4^{a}	3.40^{a}	20.82^{a}	19.0^{bc}	2.29^{bc}	15.20^{c}
0.50-0.25	36.2^{a}	3.60^{a}	22.8^{a}	37.1^{a}	3.85^{a}	19.12^{a}	28.4^{b}	3.23^{bc}	29.21^{b}
<0.25	28.6^{a}	2.88^{a}	21.4^{a}	33.3^{a}	3.33^{a}	16.10^{a}	38.0^{a}	4.06^{a}	32.30^{a}

In a column, means followed by the same lower case letter (a-d) are not significant different ($p<0.05$)

Table 4: Comparison of Tilth Index (TI) and soil erodibility (USLE-K) of forest, pasture and cropland soils for depths of 0-10, 10-20 and 0-20 cm

Land use type	TI 0-10 cm	TI 10-20 cm	TI 0-20 cm	USLE-K 0-10 cm	USLE-K 10-20 cm	USLE-K 0-20 cm
Forest	0.864^{a}	0.8680^{a}	0.866^{a}	0.114^{b}	0.117^{b}	0.115^{b}
Pasture	0.844^{a}	0.8420^{a}	0.843^{a}	0.157^{b}	0.167^{b}	0.162^{b}
Cropland	0.619^{b}	0.5242^{b}	0.596^{b}	0.281^{a}	0.292^{a}	0.286^{a}

Means followed by the same lower case letter (a, b) are not significantly different (p<0.05)

Table 5: Effect of three adjacent land-use types on Available Water Capacities (AWC), Plasticity Index (PI) and Total Porosity (TP) for depths of 0-10 and 10-20 cm

Parameters	Forest 0-10 cm	Forest 10-20 cm	Forest 0-20 cm	Pasture 0-10 cm	Pasture 10-20 cm	Pasture 0-20 cm	Cropland 0-10 cm	Cropland 10-20 cm	Cropland 0-20 cm
AWC (%)	12.44^{ab}	11.12^{ab}	11.75^{ab}	14.82^{a}	14.93^{a}	14.38^{a}	9.01^{b}	9.27^{b}	9.18^{b}
PI (%)	23.50^{b}	19.30^{bc}	21.20^{bc}	19.00^{bc}	19.50^{bc}	19.25^{bc}	29.75^{a}	30.25^{a}	30.0^{a}
TP (%)	53.90^{b}	53.30^{b}	53.60^{b}	60.60^{a}	53.10^{b}	56.85^{ab}	50.37^{c}	48.30^{c}	49.3^{c}

Means followed by the same lower case letter are not significantly different at p<0.05

Available water capacity, plasticity index and total porosity: The cropland soils had a significantly lower (p<0.05) AWC than the adjacent forest and pastureland soils in both depths (Table 5). The higher AWC for pasture soils compared to forest soils was not significant at p<0.05. On average, AWC in the 0-20 cm layer of cropland soil was 28 and 56% less than the pasture and forest soils, respectively. Hajabbasi *et al*. (1997) and Evrendileka *et al*. (2004) reported similar findings. In contrast, the PI, in the cropland soils was significantly greater than in the forest and pasture soils. Generally, cultivation caused a 35 and 24% increase in PI for the 0-20 cm layer of the cropland soil relative to the forest and pasture soils, respectively. This could be attributed to the higher organic matter content in the forest and pasture soils (Table 1). This favorable effect of SOM is most likely due to the moisture-holding capacity of the SOM and its beneficial influence on soil structure and soil porosity. The TP under forest and pasture soils were 0.53 and 0.56, respectively, compared with 0.49 for the cultivated soils. Tillage tends to decrease TP, mostly at the expense of large pores and pore continuity (Rasiah *et al*., 2004). Reduction in porosity, pore continuity and pore closure at the surface could impede infiltration and percolation and hence favor an increase in surface runoff and erosion.

CONCLUSION

This study indicated that cultivation reduced the SOM, TN, C/N ratio, AWC, TP, TI and aggregate stability. On the contrary, the BD, soil erodibility and PI increased following land use changes. Because of its effect on many other soil chemical and physical properties, decreased soil organic matter (as high as 49% within 18 years after conversion to cropland) can serve as a good indicator of the vulnerability of the high altitude ecosystem observed in this study. Conversion to cropland also resulted in a predominance of small-sized (<1 mm) Water-Stable Aggregates (WSA) compared with the forest and pasture soils with percentages skewed towards the large sized aggregates (>1 mm). This change in size distribution after conversion to cropland was most likely associated with the loss of SOM that binds the smaller into larger aggregates. The higher OC, N and available P content the small sized WSA for the cropland soils emphasized the need for sustainable soil management practices that would minimize nutrient loss and maintain good structure when forest or pasture lands are converted to cropland. In summary, the findings of this study indicates that, given the semi-arid climate and hilly topography of the highland ecosystems of northern Iran, clearance of forest and pasture lands for agricultural production may lead to loss of soil productivity and land degradation. It is clear that there is a need for greater attention to developing sustainable land use practices in management of these ecosystems.

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