

Long-term effects of land use on soil aggregate stability

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Abstract. In the study presented here, the long-term effects of two land uses of forest and tea garden on soil aggregate stability as an indicator of soil quality were investigated at three landscapes in Lahijan, North Iran. In each landscape, soil samples were collected from two slope positions and two depths of adjacent forest and tea garden, and were analyzed for their physical and chemical properties including aggregate size distributions by dry and wet sieving. Soil properties and aggregate stability indices were compared for the two land uses by the algorithms of nested design. The results showed that organic matter content, hydraulic conductivity, field capacity moisture content, mean weight diameter, and geometric mean diameter of the soil aggregates were significantly lower for the tea garden than for the forest, while bulk density and fractal dimension of aggregates were higher. Traffic and cultural operations, combined with increased organic matter decomposition in the tea garden, disintegrated the large aggregates into smaller aggregates (0.25-0.5 mm), resulting in a lower proportion of large aggregates in these soils. All measured soil properties were statistically the same for two depths of 0-15 and 15-30 cm, except for organic matter, field capacity and permanent wilting point. There were also no differences between two slope positions regarding the soil properties.

Key words: land use, aggregate stability, soil erosion, slope position, humid climate

INTRODUCTION

Fertile soil and good quality water are vital for human survival and must be used properly and conserved against different types of degradation. Soil degradation is a world problem involving various forms of water and wind erosion, salinization, acidification, water logging, decline in soil fertility, pollution, and compaction. Some of the soil degradation forms, like erosion, are irreversible in a short time. Water erosion rate is affected by lithological and soil proper-

ties, climate, topography, and land use (Kirkby *et al.*, 2000). The importance of land use is greater than that of other factors, because of the direct human involvement.

The area of forests and pastures in Asia decreased by about 313 mln ha during the period from 1970 to 1980, and that was the greatest reduction in the world (Chuluun and Ojima, 2002). In the past (1942), the area of forests in Iran was 19.5 mln ha. Last estimates indicated that the forest area has decreased to 12 mln ha. About 1.9 mln ha of these forests extend throughout the south coast of the Caspian Sea, in the northern part of the country. Some of the main causes of soil erosion and degradation in Iran are overgrazing, land use changes, and land mismanagement.

Soil structure has a key role in the functioning of soil, its capacity to support plant and animal life, water availability, soil erodibility and response of soil to changes in the environment. Soil structure holds a vital, but often neglected role in sustainable food production and achievements toward a well developed society. Different management practices can affect the soils aggregate stability as an index of soil structure status and soil quality (Czyż and Dexter, 2009; Josa *et al.*, 2010). Differences in soil aggregate stability may largely influence soil susceptibility to degradation (Lipiec *et al.*, 2006, Shein *et al.*, 2010).

The aim of this study was to assess the long-term effects of land use (forest and tea garden) on some soil properties, including soil structure and its stability in a humid region of Iran.

MATERIALS AND METHODS

The study area is located to the southeast of the city of Lahijan (37° 09' to 37° 11' N, 50° 02' to 50° 03' E; 160 m a.s.l.), Guilan province, North Iran. The prevailing climate of the region is humid temperate, with annual precipitation

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of 1 320 mm, mean annual temperature of 16.5°C. Soil moisture and temperature regimes are Udic and Thermic, respectively. Dominant soils in the study area are Typic Hapludalf, Ultic Hapludalf and Typic Udurtent. Dominant vegetation covers in the forest are *Alnus subcordata*, *Parrotia persica*, *Discopyros lotus*, *Quercus macranthera*, *Carpinus*, and evergreen plants.

Based on the land use map of the region and field surveying, three landscapes were selected for sampling, in which tea gardens were adjacent to the forest. The landscapes were the same in slope steepness, shape, and aspect at both land uses. The duration of tea cultivation was between 40 and 50 years. Soil samples (about 4 kg) from depths of 0-15 and 15-30 cm were randomly collected from summit and shoulder positions of each landscape in both land uses. These samples were air dried and divided into two parts. One portion was ground and sieved through a 2 mm screen for physical and chemical analysis. Another portion was sieved through a 9.5 mm sieve for soil aggregates stability test. Core samples of depths 0-5 and 15-20 cm were taken from the same location by a steel core sampler of a 100 cm³ volume (5 cm in diameter and 5 cm in height), with two replications, for bulk density and saturated hydraulic conductivity measurements. Soil samples were collected during November of 2007.

Particle size distribution and soil organic carbon were determined by the Bouyoucos hydrometer method (Dane and Topp, 2002) and the modified Walkley-Black wet oxidation procedure (Sparks, 1996), respectively. Dry bulk density was determined by the core method, saturated hydraulic conductivity was measured by the falling-head method. The water content of soil samples at field capacity and permanent wilting point were determined using the pressure plate apparatus at 0.033 and 1.5 MPa (Dane and Topp, 2002).

Aggregate stability in the layers of 0-15 and 15-30 cm was evaluated by dry and wet sieving method in three replications. In wet sieving, the set of sieves had openings of 4, 2, 1, 0.5, 0.25, 0.1 and 0.05 mm in diameters, and the sieving took place in water at 35 oscillations per minute (along 1.3 cm amplitude) for 6 min duration. Weighted percent of water-stable aggregates in different diameter classes and mean weight diameter (MWD), geometric mean diameter (GMD), and fractal dimension of soil aggregates were determined using the wet and dry sieving data.

Fractal geometry is a useful tool in quantifying scale-dependent soil properties such as aggregate mass, particle mass, soil particle surface, surface roughness, hydraulic conductivity, *etc.* (Salako, 2006). The fractal dimension, D , was calculated as:

$$N > x = K(x)^{-D}, \quad (1)$$

where: $N > x$, is the accumulated number of aggregates higher than x , and K is a constant, relative to the number of fragments in one volume unit. The value of D is obtained

from the slope of the regression of $\log N > x$ vs. $\log x$, assuming that the aggregates have a cubic shape and constant density (Perfect and Kay, 1991). The value of D depends on the aggregate fragmentation, therefore, a higher absolute value of D is considered indicative of a higher fragmentation.

The number of aggregates left on i th sieve of a nest of sieves can be computed from aggregate mass data as follows (Tyler and Wheatcraft, 1992):

$$N_i = M(x_i) / x_i^3, \quad (2)$$

where: N_i and $M(x_i)$ are the number and mass of aggregates left on i th sieve of a nest of sieves, respectively, x_i is the size of aggregates in mm. Inserting Eq. (2) into Eq. (1) and assuming scale-invariant density and shape of aggregates, the following equation is derived for the estimation of D from mass-size distribution:

$$\sum_{x=1}^x [M(x) / x^3] = Kx^{-D}. \quad (3)$$

Analysis of variance was performed using Statistical Analysis System (SAS Institute, 2001) to determine the significance of land use effect on soil properties based on a nested factorial design. Duncan's test was used to separate means of measured values. A value of $P < 0.05$ was selected to represent statistical significance.

RESULTS AND DISCUSSION

The results (Tables 1 and 2) showed that land use had a significant effect ($P < 0.05$) on soil organic matter, wet mean weight diameter, geometric mean diameter and fractal dimension of aggregates, bulk density, field capacity and weight percent of stable aggregates in the diameter class of 0.25-0.5 mm. Furthermore, land use had a significant effect ($P < 0.01$) on weight percent of stable aggregates in the diameter class > 4 mm and soil hydraulic conductivity. Among all soil properties only organic matter, field capacity and permanent wilting point were significantly ($P < 0.05$) different between the two depths. Bulk density was affected significantly ($P < 0.05$) by the interaction of land use and depth as well.

Soil organic matter was significantly higher in the forest soils than in the tea garden soils (Table 3). Changing of the land use caused 24% reduction in soil organic matter in the 0-30 cm soil horizon. Similar findings were reported by Solomon *et al.* (2002) who observed that the conversion of natural forests to tea gardens resulted in a 51% reduction in SOC for a soil depth of 0-10 cm over 35 years in sub-humid Ethiopian highlands. Conversion of natural forest to hoop pine plantations in Subtropical Australia decreased SOC by 19.8% (Chen *et al.*, 2004). Land use change involving forest conversion has the potential to affect levels of soil C through soil loss and accelerated oxidation of organic C associated with site disturbance, and changes in the amount and nature

Table 1. Variance analysis (mean squares) of dry and wet mean weight diameter (MWD_d, MWD_w) and dry and wet geometric mean diameter (GMD_d, GMD_w), fractal dimension of aggregates (*D*), soil organic matter (SOM), bulk density (BD), soil hydraulic conductivity (K_s), field capacity (FC) and permanent wilting point (PWP)

Sources of variation	d _f	MWD _d	MWD _w	GMD _d	GMD _w	<i>D</i>	SOM	BD	K _s	FC	PWP
		(mm)					(g kg ⁻¹)	(Mg m ⁻³)	(cm h ⁻¹)	(%)	(%)
Site	2	2.01**	0.78 ^{ns}	0.18**	0.04 ^{ns}	0.007 ^{ns}	5.93 ^{ns}	0.01 ^{ns}	247.9 ^{ns}	478.6**	145.8 ^{ns}
Land use	1	0.08 ^{ns}	1.86*	0.00 ^{ns}	0.12*	0.020*	1236.03*	0.04*	1220.0**	43.0*	10.6 ^{ns}
Slope position	1	0.20 ^{ns}	0.02 ^{ns}	0.02 ^{ns}	0.001 ^{ns}	0.000 ^{ns}	197.76 ^{ns}	0.05 ^{ns}	0.6 ^{ns}	3.8 ^{ns}	6.3 ^{ns}
Depth	1	0.02 ^{ns}	0.03 ^{ns}	0.01 ^{ns}	0.02 ^{ns}	0.000 ^{ns}	4748.34*	0.01 ^{ns}	20.4 ^{ns}	39.0*	43.1*
Site×Slope position	1	0.78*	0.40 ^{ns}	0.00*	0.04 ^{ns}	0.002 ^{ns}	31.64 ^{ns}	0.04 ^{ns}	116.0*	15.4 ^{ns}	15.4 ^{ns}
Land use×Slope position	1	0.37 ^{ns}	0.04 ^{ns}	0.06 ^{ns}	0.04 ^{ns}	0.000 ^{ns}	0.00 ^{ns}	0.00 ^{ns}	11.9 ^{ns}	12.6 ^{ns}	49.5 ^{ns}
Land use×Depth	1	0.01 ^{ns}	0.05 ^{ns}	0.00 ^{ns}	0.000 ^{ns}	0.000 ^{ns}	239.30 ^{ns}	0.04*	16.1 ^{ns}	6.9 ^{ns}	12.6 ^{ns}
Error of land use (Site)	2	0.02 ^{ns}	0.21 ^{ns}	0.00 ^{ns}	0.02 ^{ns}	0.001 ^{ns}	559.68 ^{ns}	0.02*	321.2*	139.6*	9.1 ^{ns}
Total error	12	0.19	0.22	0.01	0.01	0.002	180.62	0.01	55.4	7.2	5.5

P*<0.05, *P*<0.01, ns – not significant.

Table 2. Variance analysis (mean squares) of weight percent of stable aggregates in the diameter classes

Sources of variation	d _f	>4	4-2	2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	<0.05
		(mm)							
Site	2	279.32 ^{ns}	54.74 ^{ns}	36.37 ^{ns}	3.61 ^{ns}	1.55 ^{ns}	7.17 ^{ns}	0.20 ^{ns}	9.46 ^{ns}
Land use	1	584.06**	11.51 ^{ns}	3.72 ^{ns}	52.44 ^{ns}	41.05*	6.52 ^{ns}	0.07 ^{ns}	7.60 ^{ns}
Slope position	1	17.27 ^{ns}	52.6 ^{ns}	2.98 ^{ns}	1.04 ^{ns}	3.53 ^{ns}	0.47 ^{ns}	1.24 ^{ns}	4.17 ^{ns}
Depth	1	8.74 ^{ns}	66.14*	31.05 ^{ns}	0.01 ^{ns}	8.52 ^{ns}	7.72 ^{ns}	0.87 ^{ns}	14.73 ^{ns}
Site×Slope position	1	88.26 ^{ns}	14.28 ^{ns}	3.10*	4.59 ^{ns}	7.88*	6.68 ^{ns}	1.38 ^{ns}	9.62 ^{ns}
Land use×Slope position	1	38.11 ^{ns}	1.15 ^{ns}	1.41 ^{ns}	21.38 ^{ns}	0.01 ^{ns}	0.56 ^{ns}	0.01 ^{ns}	4.74 ^{ns}
Land use×Depth	1	18.70 ^{ns}	2.71 ^{ns}	0.10 ^{ns}	32.74 ^{ns}	0.23 ^{ns}	0.00 ^{ns}	0.01 ^{ns}	0.49 ^{ns}
Error of land use (Site)	2	66.36 ^{ns}	15.76 ^{ns}	2.43 ^{ns}	0.28 ^{ns}	22.82 ^{ns}	17.44*	1.42 ^{ns}	17.05 ^{ns}
Total error	12	56.83	12.42	7.00	15.72	7.72	3.03	0.49	5.51

Explanations as in Table 1.

Table 3. Effects of land-use types on soil organic matter (SOM), dry and wet mean weight diameter (MWD_d, MWD_w), dry and wet geometric mean diameter (GMD_d, GMD_w) and fractal dimension (*D*) of soil aggregate at 0-30 cm soil depth

Land use	SOM	MWD _d	MWD _w	GMD _d	GMD _w	<i>D</i>
	(g kg ⁻¹)	(mm)				
Forest	59.7a	3.5a	3.11a	1.41a	1.26a	3.20b
Tea garden	45.4b	3.4a	2.57b	1.40a	1.12b	3.25a

Means within a column that share the same letters are not significantly different at *P* < 0.05.

of plant residues returned to the soil. In the forest there is a considerable equilibrium between soil organic matter decomposition and plant residues, but in the tea garden this equilibrium is disturbed by picking off the tea leaves causing a new equilibrium. In addition, excess stems are thrown away while lopping, therefore replacement rate of SOM reduces. Acceleration of soil organic matter oxidation due to microclimate change (higher radiation and evaporation and lower moisture) and agricultural operation in tea garden, which results in degradation of aggregates and more availability of SOM for microorganisms, are other eventual reasons for reduction of SOM.

Dry MWD and GMD of soil aggregates did not differ between the forest and tea garden (Table 3). Soil aggregate stability was high enough in both land uses, which could be affected by the force applied in dry sieving. The wet MWD and GMD of aggregates, however, were significantly greater in the forest soils than in the tea garden soils at 0-30 cm depth.

Fractal dimension of aggregates differed significantly between the forest and tea garden soils in the 0-30 cm horizon (Table 3). According to the fractal fragmentation model, the fractal dimension in soil is expected to be <3 , since the inequality $D \geq 3$ would require that the probability of grain fragmentation be ≥ 1 , which is not valid. Perfect and Kay (1991), however, indicated that the value of D determined from aggregate-size distribution is a measure of soil fragmentation and showed that it can be as high as 3.5.

Lower MWD and GMD and higher fractal dimension of aggregates in the tea garden soil show lower aggregate stability. There is a strong and mutual relationship between soil organic matter and aggregation. Organic matter fortifies aggregation and aggregates protect organic matter from microbial decomposition. Conversion of forest to cultivation caused 61% reduction in MWD for the 0-10 cm layer

and 52% for the 10-20 cm layer (Celik, 2005). Study of land use effects on some structural properties of an Ultisol in south-eastern Nigeria by Igwe (2001) showed that forest land had the highest structural stability, followed by grassland and oil palm, and arable land had the lowest structural stability. Mbagwu and Piccolo (2004) also reported a reduction in structural stability of soil aggregates when the forested soils were converted to cultivated soils.

Considering the significance of differences between wet aggregate stability of the forest and tea garden soils, the distribution of the aggregate size classes was analyzed to study aggregate stability among the different size classes (Fig. 1). The tea garden soils had a significantly higher weight percentage of aggregates in the smaller diameter class of 0.5-0.25 mm than the forest soils. In the >4 mm class, however, the forest soils showed greater weight percentage of aggregates than the tea garden soils. Similar findings were reported by Celik (2005). Small aggregate sizes (<1.2 mm) can be a useful indicator of soil degradation, traffic and cultural operation in tea garden soils having disintegrated the large aggregates into smaller aggregates, resulting in the higher proportion of small aggregates (0.5-0.25 mm) in these soils (Fig. 1). Due to the labile nature of macroaggregate binding agents, the effect of soil management on macroaggregates and the OM retained within them is greater than that on microaggregates having stable and more humified organic binding agents.

Soils under tea garden had higher bulk density than the soils under forest at the 0-20 cm depth (Table 4). Higher bulk density can be attributed to compaction and degradation of soil structure (Igwe, 2001). Bulk density did not differ between the forest and tea garden soils at the 15-20 cm depth, but significantly differed in the 0-5 cm soil layer (Fig. 2). This indicates that soil surface is more affected by land use

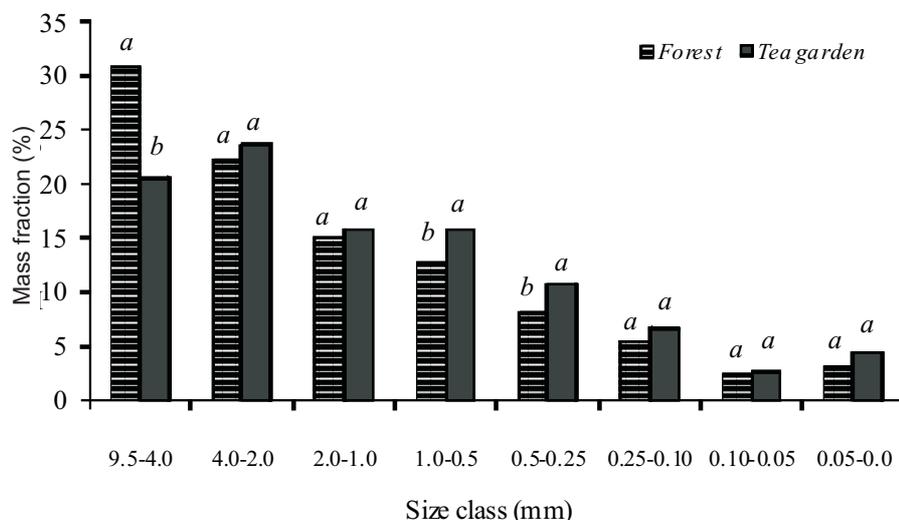


Fig. 1. Effects of two land-use types on soil aggregates (depth of 0-30 cm). The mass percents that share the same letters are not significantly different at $P < 0.05$.

Table 4. Effects of land-use types on soil bulk density (BD), soil hydraulic conductivity (K_s) and field capacity (FC) at 0-20 cm depth

Land use	BD (Mg m^{-3})	K_s (cm h^{-1})	FC (%)
Forest	1.18b	18.78a	40.07a
Tea garden	1.25a	4.52b	38.02b

Explanations as in Table 3.

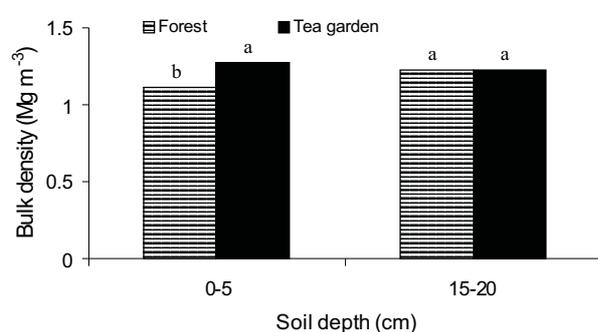


Fig. 2. Effects of two land-use types on bulk density (depth of 0-5 and 15-20 cm).

change. Such an increase in bulk density can be due to a reduction in SOM, more intensive traffic, and/or more impact of rain drops on soil surface in the tea garden than in the forest. Zolfaghari and Hajabbasi (2008) reported that conversion of forest to agricultural land resulted in a significant increase of bulk density from 1.19 to 1.3 Mg cm^{-3} .

Soil hydraulic conductivity was significantly greater in the forest land than in the tea garden (Table 4). Changing of land use caused 74% reduction in hydraulic conductivity at the 0-20 cm soil depth. It is well recognized that soil hydraulic conductivity is a highly dynamic soil property (Lin *et al.*, 2005), and is affected by the soil structure. Aggregate breakdown in the tea garden may cause a reduction in hydraulic conductivity by reducing large pores and continuity of the pores. Also, land use change resulted in a reduction of soil cracks and fissures by decreasing the number of soil organisms like earth worms.

Soils under forest had greater field capacity moisture than the adjacent soils under tea garden at the 0-20 cm soil depth (Table 4). Field capacity is affected by soil texture and structure. Considering that soil texture was not significantly different between the two land uses, the difference in field capacity had to be related to the structural stability status. Soil moisture at permanent wilting point was statistically the same for the two land uses, because it is not related to soil structure and is highly affected by soil texture.

CONCLUSIONS

1. Soils in forest had higher organic matter than those of tea garden at 0-30 cm depth.

2. Mean weight diameter, geometric mean diameter of aggregates and weight percent of aggregates in > 4 mm class were significantly greater in forest soils, but weight percent of aggregates in the smaller diameter class of 0.5-0.25 mm and fractal dimension of aggregates were greater in tea garden soils at 0-30 cm depth.

3. Bulk density did not differ between the forest and tea garden soils at the 15-20 cm depth, but differed at the 0-5 cm soil depth.

4. Hydraulic conductivity decreased in tea garden up to 74% which can cause more runoff and it may lead to flooding.

5. Field capacity was lower in tea garden than in forest soils, but permanent wilting point did not show any significant difference.

6. Degeneration of soil properties interrelated with structure stability is demonstrative of structure degradation and generally it can be concluded that conversion of forest to garden, by degradation of soil structure, can accelerate erosion and cause loss of soil and water.

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