Use of factor analysis to evaluate soil quality relation to land use change in Azadshar district, north of Iran

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1. Abstract

This study was conducted to use factor analysis to evaluate soil quality in relation to deforestation and land use change in the loessial hillslopes of Azadshahr district in northern Iran. Thirty soil samples were collected from the 0-30 cm depth of three different adjacent land uses including natural forest, cultivated land and reforested land. Fourteen soil attributes including some physical, chemical and biological properties were determined using standard methods. The results of factor analysis by maximum likelihood method showed that factors 1 and 2 are more significant in explaining the system variance, and collectively accounted for 80.74% of the total variance. The magnitude of the loadings which explaining a great part of variance in each factor was used as for naming the factors. Factor 1 had positive loading from SOM, MWD, WSA and high negative loading from BD and namely as "aggregation". Factor 2 had high positive loadings from P_{ava}, and high negative loading of CCE namely as "soil fertility". The two factors explained more than 85% of variance in SOM, WSA, MWD, P_{ava}, and CCE. Based on the results of factor analysis and communality values, SOM, MWD, and CCE are the easily measurable and reasonable indicators for the soil quality assessment in the study region in relation to land use changes.

2. Introduction

Land degradation in the forms of soil erosion, declining fertility and destructive flooding are serious challenges induced by land use change over past decades in Golestan province, north of Iran. Despite the general recognition of the threat from land degradation on land productivity and ecosystem sustainability, few studies have been made to quantify the proper indicators for evaluating and monitoring soil quality.

The capacity of soil to function can be reflected by measured soil physical, chemical and biological properties, also known as soil quality indicators (Shukla *et al*., 2006). Soil properties that can be changed in a short time by land use dynamic are considered as soil quality indicators (Carter et al., 1997). For evaluation of soil quality, it is desirable to select indicators that are directly related to soil quality. If a set of attributes is selected to represent the soil functions and if appropriate measurements are made, the data may be used to elaborate the soil quality (Heil and Sposito, 1997). For soil quality assessment, a minimum data set (MDS) should be composed of soil attributes that account for majority of the variances. A large body of information is now available that shows clearly severe damage to the soil quality and increased soil erosion caused by agricultural practices in the forest areas (Sigstad *et al*, 2002; Evrendilek *et al*, 2004).

The parent materials in the hillslopes of Golestan province are composed of loess materials which are so susceptible to soil erosion and need to be properly managed. While there is diagnosis of rill, gully and even landslide soil erosion patterns on hillslopes induced by improper conservation practices in deforested land, degraded land has been reclaimed by reforestation with *Cupressus arizonica* by governmental organizations since 30 years ago in some particular sites.

Assessment of soil properties upon conversion of natural forests for agricultural purposes and reforestation is importance to detect early changes in soil quality. The objective of the present study was to identify soil quality indicators using factor analysis of measured soil properties, and compare the changes in the soil quality indicators in response to land use change in Azad shar district, northern Iran.

3. Materials and Methods

The study area is located between 36° 38 and 38° 10 northern latitudes, and 53° 59 and 56° 34 eastern longitudes located near Azadshar city ,east of Gorgan , Golestan province, northern Iran. The parent material is composed mainly of loess material highly sensitive to erosion and has hilly physiographic landform with 20-35% slope. The mean annual precipitation and the mean annual temperature are 535 mm. and 15.3° C, respectively. The soil moisture and temperature regimes are xeric and thermic, respectively according to Soil Taxonomy. Treatments studied include three adjacent land uses in Azadshar site including, natural hardwood forest, cultivated land and reforested land with *Cupressus arizonca*.

Surface soil samples from 0-30 cm depth were collected from thirty randomly selected points in each three adjacent land uses using a hand auger in May 2004. A total of 90 samples were air-dried and passed through 2 mm sieve, and selected soil attributes including soil microbial respiration rate(MR), EC, pH, soil organic matter(SOM), total nitrogen(TN),bulk density(BD), calcium carbonate equivalent(CCE), particle size distribution (clay, silt and sand), water stable aggregate(WSA), mean weight diameter of aggregates(MWD) available potassium(K_{ava}), available phosphorus(P_{ava}), were determined using standard methods. Descriptive statistics and factor analyses using maximum likelihood procedures were used to rank the 14 initial attributes and calculate communality values for each soil attribute by SPSS software.

4. Results and Discussion

The descriptive statistics of soil parameters suggested that they were all normally distributed (according to Kolmogorov-Smironov test). Coefficient of variation for all of variables was low, the lowest CV was related to pH and EC. This finding is also in accordance with Paz Gonzalez *et al*., (2000).Highly positive correlations are obtained for total nitrogen versus soil organic matter, and mean weight diameter versus water stable aggregates (r>0.85).

If field sampling and determinations are properly conducted, the variances of the measurements collectively indicate the land use effects. Attributes selected for soil quality assessment ideally must account for most, if not all, of the variances observed in the measurements taken. For the 14 soil attributes measured, there exists a maximum of 14 factors that may explain the total variance. The total variance of each factor was defined as eigenvalue. An eigenvalue plot enables one to identify the significant factors that collectively represent major proportions of the total variance.

Table 1 Rotated loadings, initial eigenvalue and communality values

Soil attribute	Fcator 1	Factor 2	Communality value
Sand	-0.73	-0.54	0.83
Silt	0.32	0.8	0.75
Clay	0.77	0.14	0.62
SOM	0.96	-0.01	0.92
TN	0.56	-0.01	0.67
BD	-0.84	-0.22	0.77
MWD	0.93	-0.02	0.87
MR	0.88	0.27	0.81
WSA	0.92	0.17	0.88
pH	-0.06	-0.56	0.66
CCE	-0.69	-0.96	0.99
EC	0.1	-0.57	0.34
Pava	0.18	0.95	0.93
Kava	0.19	0.76	0.78
Initial eigenvalue	6.4	2.3	_
Varaice explnied%	55.3	25.44	_
Cummulative variance	55.3	80.74	

The first and most important factor (Factor1) explained 55.3 % of the total variance. Second factor accounted for a further 25.44% of total variance. Factors 1 through 2 collectively accounted for 80.74% of the total variance.

A factor, as an array variable, holds contributions (in the forming of loadings or weights) from all of the 14 attributes. The weights (loadings) for the first two factors are illustrated in Table 1. The magnitude of the eigenvalues was used as a criterion for interpreting the relationship between soil attributes and factors. Soil attributes were assigned to a factor for which their eigenvalues was the highest. The magnitude of the loadings which explaining a great part of variance in each factor was used as for naming the factors. Factor 1 had positive loading from SOM, MWD, WSA, and high negative loading from BD and namely as "aggregation". Factor 2 had high positive loadings from P_{ava}, and high negative loading of CCE namely as "soil fertility".

The relative importance of each soil attribute, in terms of its contribution to all of the factors, is jugged by its communality value, a value that indicates the residual variance of the attribute in comparison to a critical convergence value of confidence (Joreskog, 1977). If the residual variance is less than the convergence value, the corresponding communality of the attribute is equal to 1. The two factors explained more than 85% of variance in SOM, WSA, MWD, P_{ava}, and CCE. A high proportion of communality estimate suggests that a high portion of variance was explained by the factor; therefore, it would get higher preference over a low communality estimate (Shukla *et al*., 2006). Meanwhile the Electrical conductivity was the least important attribute due to the lowest communality estimates (Table 1).

Mean scores for Factor 1 was higher for natural forest, than cultivated land, and this score had significant differences between three land uses (Table 2). Also Factor 2 had significant differences among three treatments. Land use effects on mean scores are consistent with the results from the analysis of variance of the most effective soil attributes which presented in table3.

Table 2 Effect of selected land uses on factor scores for the upper 30 cm depth

Land Use	Mean score(F1)	Mean score(F2)
	Aggregation	Soil Fertility
Natural Forest	1.27 a	-0.22 b
Cultivated land	-1.1 c	-0.68 c
Reforested land	-0.19 b	0.85 a

a, b,… letter indicate significant differences ($p<0.01$) among treatments based on Duncan's mean test

For soil quality assessment, a minimum data set should be composed of soil attributes that account for majority of the variances. This data set will have the smallest possible number of soil attributes for a practical assessment. Ideally, the selected attributes should be easily measured and the measurements are reproducible and standardized. Based on the results of factor analysis and communality values, in the present study the attributes which explained the most portion of total variance included SOM, WSA, MWD, P_{ava}, and CCE. These parameters are the reasonable indicators for the soil quality assessment in the study region in different land uses. The WSA was strongly correlated (0.90) with MWD and relatively high (0.85) correlated with SOM. Also CCE was high negatively correlated with P_{ava}. Since the measurement of WSA is more expensive and time consuming than measuring SOM and MWD, and determining of CCE is easier than P_{ava}, therefore it is reasonable that data set be reduced to MWD, SOM and CCE as the most effective attributes for assessing soil quality for land use change in the study area.

The conversion of forest into cropland is known to deteriorate soil physical properties and subsequently soils become more susceptible to erosion since macro-aggregates are disturbed (Celik, 2005). Loss of organic matter is expected to have soil aggregates easily broken down, and consequently the finer particles are transported by erosion.

The results of ANOVA indicated that there was significant ($p<0.01$) differences between three treatments according to selected data set. The lowest value of MWD, SOM, and highest CCE was shown in agricultural land and reverse results in natural forest. It seems that in the selected site, deforestation leaded to soil quality declining. Lower water leaching in cultivated land compared to natural forest, and appearance of substratum calcium carbonate in the surface because of intensive tillage and erosion, has increased significantly CCE, and decreased phosphorus availability. Higher pH values in cultivated land compared to natural forest confirmed the mentioned conclusion. The result of multiple comparison test (Duncan's method) verified that there were significant differences ($p<0.01$) between mean values of the mentioned attributes in natural forest, cultivated land and reforested land.

Table 3 Multiple Comparisons of mean values of selected soil attributes in the study system (Duncan method)

Land Use	SOM	MWD	CCE
Natural Forest	5.62 a	2.48 a	2.02 c
Cultivated land	1.33 c	0.73 c	15.32 a
Reforested land	3.02 b	1.11 b	9.8 b

a, b, c, … indicate significant differences ($p<0.01$) among treatments based on Duncan's mean test

Soil organic matter has already reported as the most powerful soil attributes for assessing soil quality in different region of world under varied land uses and managements (Shukla *et al*, 2006, Ajami *et al*, 2006). The results of ANOVA showed that there were significant differences among treatments. The mean comparisons using Duncan's approach indicated that there was significant ($p<0.01$) differences in soil organic matter between three understudy land uses, especially between natural forest (5.62%) and cultivated land (1.33%) (Table 3). Evrendilek *et al* (2004) showed that deforestation and subsequently cultivation decreased organic matter as well as 48.8%. Also various studies revealed that there were significant differences in SOM content between cultivated and mature woodland (Ajami *et al*, 2006).

Deforestation and cultivation have led to a decrease (76.33%) in the concentration of soil organic matter (Table 3). Disturbance of soil can alter temperature, moisture and aeration, and increase the decomposition rate of soil organic matter, which involves a loss of soil quality. Forested soil had higher SOM than cultivated ones because the soil was not tilled or exposed to erosion. The loss of soil organic matter combined with poorer aggregation probably accounted for the higher bulk density under cultivation compared to the natural forest (approximately 35.96 increase). These processes could get even worse by continuing the use of heavy farm machineries. Similar finding were reported by Celik (2005) that deforestation and subsequent tillage practices resulted in nearly a 7.87 % increase in bulk density for surface soil in southern highlands of Turkey. Reforestation of degraded land with *Cupresus* increased about 2 times compared to cultivated land and there were significant differences between reforested soils with cultivated ones (3). Results shown are consistent with those observed for surface soils after afforestation (Pauel *et al*. 2002; Ritcher *et al*., 1999). Increased SOM improves aggregation, water holding capacity, nutrient-retention capacity and biodiversity in soil. Because of the above effects of SOM, natural forest soils had more TN, AWHC and MR compared to cultivated soils (Table 3).

Evrendilek *et al*. (2004) also suggested that cultivation decreased total soil porosity, soil respiration rate and nutrient-retention capacity.

The mean weight diameter of soil aggregates was significantly ($p<0.001$) different among land uses (Table 3). Comparison test using Duncan's method showed that there was significant differences ($p<0.01$) between natural forest soils (2.48 mm) and cultivated soils (0.73 mm) (Table 3).

Aggregate stability depends on interaction between primary particles and organic constituents to form stable aggregates, which are influenced by various factors related to soil environmental conditions and management practices. Soil organic matter plays a key role in the formation and stabilization of soil aggregate. Loss of soil organic carbon with cultivation is connected to destruction of macro-aggregates. The result of correlations showed that there is a highly significant correlation between soil organic matter and mean weight diameter. Thus, the differences observed in the percentage of stable aggregates according to land use probably resulted from the differences in the quality and quantity of organic matter between different land uses. Caravaca *et al* (2004) indicated that aggregate stability of cultivated soils was significantly lower (mean 40%) than that of forested soils (mean 82%). Findings of Celik (2005) also indicated that cultivation has caused 61 and 52 % decreases in MWD, respectively for the 0-10 cm and 10-20 cm respectively. The higher aggregation in forested soils may have protected easily decomposable SOM from microbial degradation. This conclusion is accordance with suggestions of Celik (2005) and Evrendilek *et al*. (2004). The findings of Celik (2005) also showed significant differences between forest and cultivated soils for size distribution of aggregates. Reforestation in the study area has caused to an increase in larger aggregates portion and reduce the smaller ones significantly.

5. Conclusion

Based on the results of factor analysis and communality values, in the present study the attributes which explained the most portion of total variance included SOM, WSA, MWD, P_{ava}, and CCE. Overall results revealed that, three reasonable properties including MWD, SOM, and CCE could be proposed for soil quality assessment related to land use change. Mean comparison of minimum data set showed that there were significant ($p<0.01$) among three land uses. Overall results revealed that deforestation leaded to soil degradation and reforestation has been improved soil quality.

6. References

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