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Development of pedotransfer functions for prediction of soil nitrogen and its spatial distribution in conservation of Damavand's rangelands

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Abstract

In Iran, soil nitrogen is very low in most areas of production like agriculture and rangeland. This fact indicates that minor changes in soil nitrogen could have a high impact on the soil properties and soil quality in arid and semi-arid conditions. Determination of nitrogen content in soil is of utmost importance because of its role in soil physical, chemical and biological properties. This research was aimed to estimate soil nitrogen using pedotransfer functions and independent variables of soil physical and chemical properties. For this purpose, 60 soil samples were taken systematically from depth of 0-30 cm, and soil organic carbon content, pH, lime, nitrogen, sand, silt and clay were determined. According to the obtained results, the average, minimum and maximum nitrogen content of the soil was 0.846, 0.706 and 1.608 $grkg^{-1}$, respectively. Nitrogen content showed the highest correlation coefficient with organic carbon (r= 0.930**, P< 0.01) and clay (r= 0.765**, P< 0.01).

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Introduction

Using simulation models of soil processes have increased rapidly in recent years. Collected data on soil properties are essentially required for management models or simulation of environmental processes. Soil properties can be highly variable and temporary, therefore, direct measurement of some of them is very time-consuming and expensive due to abundant sampling. Consequently, in recent years, indirect methods have been considered (Mohajer *et al.*,2010).

Pedotransfer functions are one of these methods used to estimate readily available properties from costly measured properties. For the first time, Bouma (1989) found regression relationships between readily available properties and costly measured properties and called them pedotransfer functions. Regression is considered as one of the methods of extracting pedotransfer functions. In this method, the relationship between a dependent variable and several independent variables are presented in a regression equation (McBrantey *et al.,* 2002).

The use of soil fertility indicators may be useful in improving the quality of soil maps. The measurement of nitrogen, as an index of soil fertility, is less considered in soil maps because of being time-consuming and costly (Mohajer *et al.,*2010). Nitrogen is an important and vital element which is used as a macro element for the growth of plant species. In addition to forming the structure of proteins, nitrogen forms a part of the chlorophyll. Nitrogen deficiency results in yellowing of leaves and growth stop (Malakouti and Homaee, 2006).

In modeling natural systems such as soil, imprecise observations and vague relations are generally identified. Therefore, the use of fitting functions, able to explain the ambiguous structure of the system and providing the patterns which are in accordance with reality, is essential (Mohammadi and Taheri,2006).
In rangelands and forests of Guilan, Shalmani (2010) evaluated the resistance of soil aggregates, in order to save time and money indirect methods were used. Among different methods, PTFs was compared with ANNs to estimate the stability of soil aggregates. The measured parameters included the percentage of sand, silt, clay, organic matter, lime, bulk density, distribution of particles, the mechanical strength of the soil, soil pH, and soil electrical conductivity. According to the results, ANNs, with six hidden layers, showed more precision and a higher degree of correlation compared to PTFs.

Bayat *et al.*, 2011, estimated soil hydraulic properties by PTFs with using soil particle size distribution, resistance of soil aggregates and their relative sizes in the provinces of Hamedan and Guilan. Mohajer *et al.*, 2009 estimated the cation exchange capacity, with correlation coefficient of 0.81, with using organic matter and clay percent as readily available properties and PTFs.

This research was aimed to investigate the soil nitrogen status in the study area and also to develop pedotransfer functions for prediction of soil nitrogen. In addition, created models were compared with other regression models.

Material and methods

Sampling

The study area is located in the North-East of Tehran, on the road of Tehran Firoozkooh. It lies between longitudes of 51° 59' 11'' and 52° 02' 37'', and latitudes of 35° 38' 01'' to and 35° 40' 33''. The altitude of the study area is 1800-2000 m above sea level (Fig. 1). The total area was 230 ha.

First, the maps, studies and research background of the study area were prepared by library activities and by referring to the relevant institutions. In this regard, all maps including, topography, soil, climate, geology, land use, were collected along with aerial photographs and satellite images of ETM+ 2002, IRS 2007, and MODIS 2010, the copied data were digitized.

Some of the maps or secondary data were determined from above maps including, DEM, slope, aspect, and landuse at a scale of 1:25000. Afterward, on the basis of this information, the land units map was determined for sampling and field studies. To determine the land units based upon map scale, it is necessary to calculate Minimum Decision Area. Minimum Decision Area was also determined.

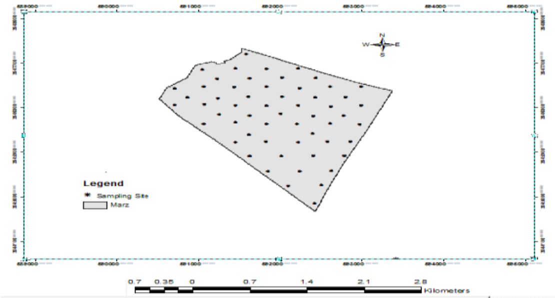

Fig. 1. Sampling points in the study area.

With regard to the scale of the integrated maps (hypsometry, slope and aspect) a minimum area of 10 hectares was designated for poly-gons. The formula for determining the Minimum Decision Area is as follows:

Equation (1):

$$MDA(hac) = 1.6cm^2 \times 10^{-8} (hac.cm^2)(Scalefacto\,r.mm^{-1})$$

Therefore, the boundaries with less than 10 hectares should be integrated. Sampling sites were located in the field using GPS in October 2011. At each sampling location, three separate points (approximately 10 m apart) was sampled at 0–30 cm soil depth. These three individual samples were combined to form a single bulk sample for each site. Samples were sealed in plastic bags and transported to the laboratory.

Laboratory analysis

Soil samples were air-dried and sieved in the laboratory to retain the <2 mm fraction. Soil pH was measured in a 1:1 suspension of soil and distilled water (McLean, 1982). Soil organic carbon was determined using the Walkey–Black method (Walkley and Black, 1934). Bulk density (BD) was measured using standard paraffin wax procedures. (USDA, 1995). Total Nitrogen (TN) was determined using the Kjeldahl method (USDA, 1995). Calcium carbonate equivalent (T.N.V), was measured using the Acidimetric method, which involved neutralization of the sample by a titrated acid. Back-titration using a base that used to determine CaCO3 content (USDA, 1995). Particle size distribution was determined using the hydrometer method (Gee and Bauder, 1979)

Statistical and geostatistic analysis

The main statistical parameters, including mean, standard deviation, variance, coefficients of variation, and maximum and minimum values, Skewness, kurtosis and histogram display the distribution of a quantitative variable. To decide whether or not the data follow the normal frequency distributio (Paz-Gonzalez *et al.*, 2000). To determine the spatial relationship of a random variable, namely interaction between sample semivariogram is used, It means that adjacent samples depend on each other up to a certain distance. This dependency between samples may be presented in a mathematical model as semivariogram. semivariogram is a vector quantity which shows the spatial relationship between the values of a measured variable in terms of squared difference between two values. A semivariogram estimates the desired characteristic in not measured points using theoretical mathematical models. The formula of a semivariogram is as follows:

Equation (2):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{n} (Z(x_i + h) - Z(x_i))^2$$

where z(xi) is the value of the variable Z at location of xi and N(h) is the number of pairs of sample points separated by h. For irregular sampling, it is rare for the distance between the sample pairs to be exactly equal to h; that is, h is often represented by a distance band. The experimental variogram is calculated for several lag distances. This is then generally fitted with a theoretical model, such as spherical, exponential, and Gaussian models.

To evaluate the performance of interpolation methods Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Mean Bias Error (MBE) were used.

Equation (3):

$$RMSE = \frac{1}{n} \sqrt{\sum_{i=1}^{n} \left(z^*(x_i) - z(x_i)\right)^2}$$

Equation (4):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|z^*(x_i) - z(x_i)\right|$$

Equation (5):

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(z^*(x_i) - z(x_i)\right)$$

Where z*(*xi*) is the value to be estimated at the location of *xi*, z (*xi*) the known value at the sampling site *xi* and n is the number of sites.

Damavand's protected rangelands were selected for investigation. Physiographic factors affecting soil nitrogen can be determined to predict the amount of soil nitrogen using regression models between independent variables with a high correlation. Also, with the use of modeling, the amount of nitrogen can be simulated in areas with similar conditions.

Results

Soil nitrogen status in the study area

The results of statistical analysis of organic carbon are presented in Table 1. The average amount of nitrogen in the study area was 0.846 g kg^{-1}. Considering the amount of skewness, Kurtosis and Normality Test (Kolmogorov-Smirnov) soil nitrogen showed a normal distribution. For this reason, Co-Kriging method using organic carbon, as an auxiliary variable, could be applied for spatial description of soil nitrogen.

Table 1 Significant correlation between the amount of soil organic carbon and nitrogen content (r=0.930**,P< 0.01) confirms that after organic carbon, nitrogen is the most abundant element in the organic matter.

However, the ratio of these two elements varies according to the type of organic matter. Positive and significant effect of the clay on soil nitrogen is also notable (P< 0.01, r= 0.756**). Pedotransfer functions were fitted by multiple linear regression and independent variables entered the model. Afterward, regression models were derived in both linear and nonlinear mode.

Pedotransfer functions for prediction of soil nitrogen

Independent variables were divided into two groups. The first group included organic carbon (univariate) and the second group included organic carbon, clay content, pH, lime, sand and bulk density (multivariate). The dependent variable was estimated using the point transfer functions, in the next step, stepwise method was applied to the input variables to determine the priority of variables.

Table 1. Descriptive analysis of soil organic carbon.

N(g kg-1)	Result
Mean	0.846
Median	0.828
Variance	0.012
Std.deviation	0.110
Minimum	0.706
Maximum	1.068
Range	0.362
Skewness	0.713
Kurtosis	0.416

The results of stepwise regression showed that organic carbon and clay were the most important variables determining changes in soil N, respectively. It is a positive correlation and increasing clay content and carbon increase the nitrogen content of the soil. Other independent variables have small coefficient which represents their minor and indirect role on the amount of soil nitrogen. The determined correlation coefficient indicates that there is a higher correlation between non linear regression and organic carbon compared to other models. This shows the importance of organic carbon in estimation of soil nitrogen, Linear and nonlinear regression models (univariate and multivariate) were determined (Table 2).

Table 2. Regression models for the estimation of the soil nitrogen.

Method	Estimating model	Correlation coefficient
Linear	N (g kg-1) = 0 .699+0.0853OC	0.920
	N (g kg-1) = 2.837+0.087 OC - 0.005Clay	0.92
nonlinear	N (g kg-1) = -5.582-1.696 OC +0.431 OC2	0.950
Non-linear Multivariable	N%=a-ln((OC/100) b) ×e + (OC ×Clay/100) 2 ×g +(Clay×d) 2 - Gravel×h+ pHc + 1/Exp(Silt) f + (log(Bd) f) × i) + Exp((Sand) m ×l) + (k× ln(Gravel))	r= 0.967

To assess the reliability of functions, the Mean Absolute Error (MAE) and Mean Bias Error were used (Table 3).

Table 3. Evaluation indexes and the significance level of regression models.

Model	MAE	MBE	Correlation coefficient
Linear	0.82	0.0	0.92
Linear Multivariable	0.80	0.0	0.92
Nonlinear	0.75	0.0	0.95
Non-linear Multivariable	0.60	0.0	0.967

Comparison of created models

The estimates of the regression model implemented in the region showed that models at all levels had no over-estimated or under-estimated soil N because MBE index was approximately zero and MAE represented the model accuracy. These values were lower in the non-linear multivariate regression compared to other models which represents the low error of estimation.

In order to develop an appropriate mode to estimate N, different models of spherical, exponential, linear and Gaussian were fitted on semivariogram of soil organic carbon. Among the mentioned models, exponential model was chosen as a suitable model for the entire region. Parameters obtained from the model are presented in Table 4.

Table 4. Methods used to estimate N.

Method	Nugget effect	Sill	Range	Neighborhood	Variable variance	Model
Ordinary Kriging	0.03223	0.06409	2400	13	____________	Exponential
Ordinary Co-kriging	0.02354	0.06997	1400	15	Main	Exponential
Ordinary Co-kriging	0.00502	0.08702	700	5	Auxiliary	Exponential
Ordinary Co-kriging	0.0068	0.0062	600	15	Main & Auxiliary	Exponential

Root-mean-square error was calculated to be 0.03202 in Kriging method. In Co-Kriging method, the main variable and auxiliary variable (organic carbon) had a root-mean-square error of 0.02647 and 0.024, respectively. The estimation maps of soil nitrogen were presented with the lowest error using Co-Kriging (Fig. 2).

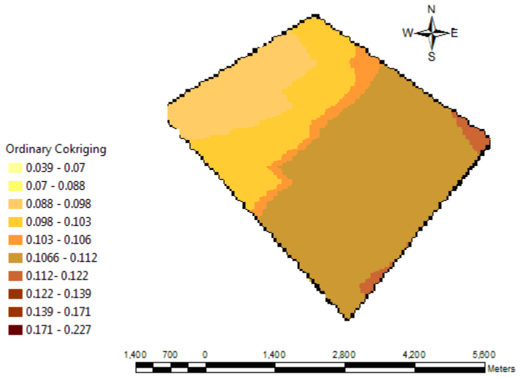

Fig. 2. Nitrogen zoning map by Kriging method in Damavand's protected rangelands.

According to the maps and mean comparisons of root-mean-square error, Co-Kriging showed the lowest error and N values measured in the region were compatible with the produced map in most parts.

Discussion

According to the results of the statistical analysis, a positive and significant correlation was found between nitrogen and organic carbon and then the highest correlation was found between N and clay. Positive and significant effects of clay on the amount of soil organic carbon and nitrogen were obvious. The reason may be due to the ability of clay in formation of clay and humus complexes and stabilization of organic matter in the soil for longer periods and increasing the biological activity of micro-organisms. On the other hand, enzymes were absorbed into the clay minerals and thereby would come to be inactive and hard to break (Mahmoudi and. Hakimian, 2006).

According to the results of a research performed by Kasel *et al.*,(2011), a significant relationship was found among nitrogen, organic carbon and clay content used to estimate soil organic carbon in different regions, It should be noted that the clay mineralogy will also impact the amount of N accumulation.

Accurate estimates of soil carbon and nitrogen storage are appropriate and effective strategies to control climate change and atmospheric conditions (Lufafa *et al.*, 2008, Zhao *et al.,* 2010) According to the results, multivariate non-linear regression had a higher correlation coefficient compared to univariate and multivariate linear regression because the factors that can influence the amount of nitrogen were applied to the formula. Wang *et al.*, 2010 found that managment, soil properties and physiographic characteristics have the greatest impact on organic carbon and nitrogen.

Parvizi 2010 identified the sources of variability in carbon with using physical variables and land use type. The estimation accuracy of multivariate regression methods in range and forest land use was determined with a higher coefficient. Nitrogen concentration is influenced by density and type of vegetation as the highest value is observed in areas with low grazing. In other words, the loss of vegetation, due to factors such as overgrazing, will result in aggravated soil erosion and loss of soil organic carbon storage.

Sequestrated carbon of plant biomass returns to the soil through litter and this part of the ecosystem plays an important role in the cycling of carbon and nitrogen in ecosystems. Consequently, the reduction of nitrogen and organic carbon in areas affected by livestock grazing is due to the litter fall as a result of vegetation loss (Azarnivand *et al.*, 2010).

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