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The combination of geostatistics and geochemical simulation for the site-specific management of soil salinity and sodicity

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A R T I C L E I N F O

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A B S T R A C T

The spatial variability of soil parameters such as salinity and sodicity is very effective in determining the suitable areal cropping pattern and appropriate management of agricultural lands. To conduct this study, a grid sampling at 100 m was carried out in an agricultural area of 30 ha located in Tajarak of Hamedan, western Iran. After physicochemical analyses of soil samples, soil properties which had significant correlations with the exchangeable sodium percentage (ESP) were identified using the statistical analysis. The ESP was significantly positively correlated with the clay content, pH, electrical conductivity (EC), cation exchange capacity (CEC), and sodium adsorption ratio (SAR), while it showed a significant negative correlation with the silt content. The spatial variability of ESP and its related parameters investigated by the geostatistical analysis showed that pH, EC, CEC, SAR, and ESP were strongly spatially dependent, while the clay and silt contents had a moderate spatial dependency. The distribution maps indicated that most soils in the study area did not have a sodicity problem, while ESP of soils in some parts was more than 15%. The long-term impact of the application of saline–sodic and non-saline–sodic irrigation waters on some chemical properties of a saline sodic soil under 20 years of the continuous cultivation of wheat and alternate cultivation of wheat and sugar beet was simulated using the geochemical PHREEQC program. The results showed that the chemical quality of the soil was significantly improved after 20 years of irrigation with non-saline–sodic water. On the other hand, the problem of the soil salinity was accelerated after 20 years of irrigation with saline–sodic water, while ESP remained unchanged. Due to the high water requirement of sugar beet, the effect of its cultivation was not significant in reducing soil sodicity despite the removal of Na^+ from the soil by this crop. Therefore, it is recommended that the cropping pattern should be changed by planting crops with low water requirements or rainfed crops if sodic irrigation water is applied.

1. Introduction

Salinity and sodicity are two of the most destructive processes in soils, particularly in arid and semi-arid areas. The investigation of changes in the soil salinity and sodicity, especially in large areas, is expensive and time-consuming. Hence, it is necessary to use techniques that can easily monitor a wide range of areas and examine the changes in the soil salinity and sodicity.

One of the key characteristics of soils is the spatial and temporal variability. There are several factors involved in the process of the soil formation that vary over the time and influence soil properties. On the other hand, the management of agricultural lands is impossible based on a set of discrete sampled points as these data must be converted to a continuous format of information. Therefore, it is necessary to apply the mathematical and statistical data analyzing methods able simultaneously to use the quantitative and numerical information of variables and information related to their geographical location.

The soil variability in the field is usually described by classical statistical methods and is assumed to be random (Cemek et al., 2007). The soil variability results from effects and interactions of different processes in the soil profile (Parkin, 1993). Webster (1985) indicated that soil properties are usually spatially dependent. Samples close to each other have more similar properties than those further away from each other. The spatial variability of surface soil properties (Brejda et al., 2000), amount of soil nutrients (Newman et al., 1997), soil chemical conditions (Lee et al., 2001), nitrate leaching (Ersahin, 1999), distribution of pesticides in the soil (Rao and Wagenet, 1985), and release of potassium (K^+) from some calcareous soils (Jalali, 2007a) has been analyzed using geostatistical methods. Information on the spatial variability of soil properties is necessary to implement a site-specific soil management, e.g., a variable rate of the application of fertilizers (Wei et al., 2009).

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The geostatistical technique is used to demonstrate the spatial dependency of soil properties, both isotropically and anisotropically (Burgess and Webster, 1980). Furthermore, the proper geostatistical analysis provides valuable information about the spatial distribution of soil properties in agricultural lands (Liu and Yang, 2008). Geostatistics can provide a description and modeling of spatial patterns, prediction at unsampled locations, and assessment of uncertainty of these predictions by using a set of statistical tools. Studies related to the spatial variability of soil properties have been performed since the 1970s. Geostatistics, based on the regional variables, has been proven to be one of the most effective methods to analyze the spatial distribution and variation of soil properties (Liu and Yang, 2008). A wide range of sampling points with different distances has been used in different studies, e.g., 33 sampling points in a representative of 929 ha (Shifteh Some'e et al., 2011), 40 sampling points from an agricultural field of 30 ha (Jalali, 2007a), 60 sampling points in a representative of 8.187 ha (Cemek et al., 2007), and 80 and 84 sampling points from areas of 11.2 and 6 ha, respectively (Lopez-Granados et al., 2002).

Sustainable agriculture is a potentially useful tool in meeting the future needs of a growing world population for food. The production of agricultural crops is difficult in saline and sodic soils. The proper efficiency in the agricultural production requires the use of cultivation principles based on the field variability and the subsequent estimation and mapping of soil properties. The irrigation water quality plays an important role in the agricultural production and has a significant effect on physical and chemical properties of the soil. Due to the lack of good-quality water specially in arid and semi-arid areas, the risk of soil salinization caused by the accumulation of salts resulting from the irrigation with low-quality waters increases (Jalali, 2007b). Because of increasing use of these waters for the irrigation, it is necessary to evaluate their potentially negative effects on the soil salinity and sodicity and to implement an appropriate strategy to reduce these problems.

Groundwater is the main source for irrigation of agricultural fields in Tajarak area located in Hamedan, western Iran. A geochemical evaluation by Jalali (2007b) indicated that water samples from wells located in the area were divided into two groups: (1) relatively low mineralized waters of calcium-bicarbonate ($Ca\text{-}HCO_3$) and sodium bicarbonate ($Na\text{-}HCO_3$) types with total dissolved solids (TDS) less than 1000 mg L^{-1}, and (2) high mineralized waters of sodium-sulfate ($Na\text{-}SO_4$) and sodium-chloride (Na-Cl) types. According to the adjusted sodium adsorption ratio (SAR), the concentration of Na^+ was low in 90% of water samples in group 1, so they could be used for irrigation without the risk of soil sodicity. However, the severity of the Na^+ problem in 40% and 37% of water samples in group 2 was medium and high, respectively. Therefore, it is necessary to implement a good management to reduce the sodification of agricultural soils in this region resulting from the low quality of irrigations waters.

Given the above, the objectives of this study were: (1) the evaluation of spatial dependency and preparation of distribution maps of the exchangeable sodium percentage (ESP) and related parameters in a selected part of Tajarak area, and (2) the simulation of long-term effects of saline–sodic and non-saline–sodic irrigation waters on some chemical properties of a saline–sodic soil under continuous cultivations of wheat and alternate cultivations of wheat and sugar beet using PHREEQC as a geochemical computer program (Parkhurst and Appelo, 1999).

2. Materials and methods

2.1. Description of the study area

The study area was a part of the agricultural lands with an area of 30 ha located in Tajarak of Hamedan, western Iran. The climate of the area is semi-arid, the average annual precipitation is 317.7 mm, the average annual temperature is 11.4 °C, and average monthly temperatures varies between −2.6 and 24.2 °C according to the data reported by the synoptic weather station of Hamedan airport by the end of 2010.

A systematic sampling method was performed using grids of 100 m × 100 m in an area of 1000 m × 300 m (approximately 30 ha). The number of soil sampling points on each *x*-axis (latitude) and *y*-axis (longitude) was 4 and 10, respectively, so, 40 soil samples were taken from vertices of regular square grids. The sampling depth was 0–30 cm. Latitude and longitude of each sampling point was recorded by a hand-held global positioning system (GPS) device. The study area was located between 34.94862° and 34.95679° N latitude equivalent to 321,000 m and 321,300 m in UTM coordinate and 49.03975° to 49.04284° E longitude equivalent to 3,869,100–3,870,000 m in UTM coordinate. The location of the sampling points is shown in Fig. 1.

The study area is under conventional tillage and cultivation of wheat and potato. The salinity and sodicity of soils as a result of application of low-quality irrigation water and inappropriate irrigation methods are two of major limiting factors in reducing the soil quality and crop production.

2.2. Analysis of soil samples

The soil samples were air-dried and passed through a 2-mm sieve after transportation to the laboratory. The particle size distribution was determined using the hydrometer method (Gee and Bauder, 1986). Soil chemical properties such as pH, electrical conductivity (EC), and concentration of soluble cations and anions were measured in the 1:5 soil to water extract and the exchangeable cations were extracted with 1.0 M ammonium acetate (NH_4OAc) solution (pH 7.0). The cation exchange capacity (CEC), SAR, and ESP were calculated based on measured data (Rowell, 1994).

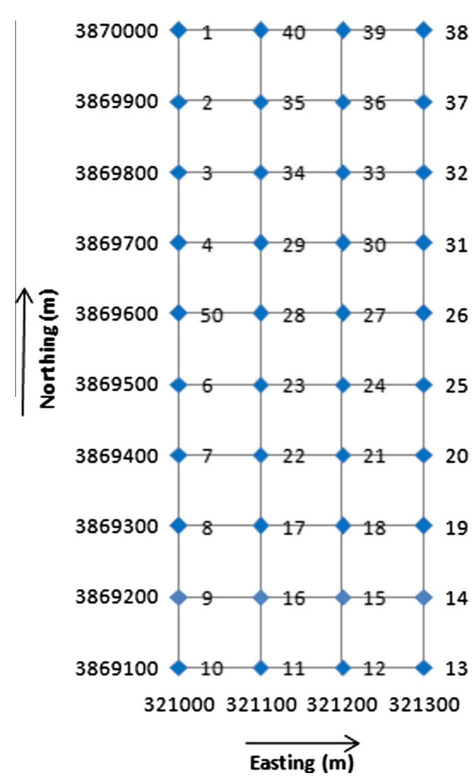

Fig. 1. The location of soil sampling with soil sample numbers.