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Prediction effect of farmyard manure, multiple passes and moisture content on clay soil compaction using adaptive neuro-fuzzy inference system

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ABSTRACT

Soil compaction by machine traffic is a complex process with many interacting factors. The strength of adaptive neuro-fuzzy inference system (ANFIS) is the ability to handle linguistic concepts and find non-linear relationships between inputs and outputs parameters. In this research, the effect of farmyard manure, the number of tire passes, soil moisture contents and three average depths on clay soil compaction is predicted using ANFIS and Regression. For the prediction of soil compaction, an agricultural tractor tire was used and the experiments were carried out in the controlled condition of soil bin facility utilizing a well-equipped single-wheel tester. To measure soil compaction, cylindrical cores in groups of three were inserted into the three different depths. Various member function ANFIS were tested to discover the supervised ANFIS-based models for the soil compaction. On the basis of statistical performance criteria of MAPE and R^2, Gaussian curve built-in membership function (gaussmf) was found as a proper model. In addition, the ANFIS model with 'Gaussian mf' is recommended considering the higher prediction performance values of MAPE = 0.2957%. The regression analyses of ANFI and Multiple Linear Regression (MLR) revealed a high correlation with farmyard manure, the number of tire passes, soil moisture, and depth. Also, it showed a higher performance compared to the regression model for predicting soil compaction. Thus, it can be concluded that ANFIS-based methodology is a soft computing approach that provides excellent nonlinear systems such as soil compaction.

1. Introduction

Soil compaction is one of the challenges facing modern agriculture as it reduces worldwide agricultural production. Agricultural machinery traffic plays an important role in soil compaction (Hamzaa and Andersonb, 2005). Soil compactability depends on soil properties such as soil texture, soil moisture content, organic matter content, and soil aggregation (Ekwue and Stone, 1995; Kay et al., 1997; Canbolat et al., 2002; Imhoff et al., 2004). On the other hand, tire-soil interaction influence on the soil compaction depends on tractor implement factors, particularly the tractor weight, stress at the soil-tire interface and number of the tractor passes (Patel and Mani, 2011). Managing soil compaction can be achieved through appropriate techniques such as the application of organic matter and controlled traffic (Hamzaa and Andersonb, 2005). In order to decrease soil compaction machine traffic on the field should be decreased; besides, the amount of the soil organic matter content of soil should be increased using farmyard manure, compost, green manure, etc. (Cochrane and Aylmore, 1994; Thomas et al., 1996; Aksakal et al., 2016). While plant residues are a common source of organic matter in the soil, animal manure is also used extensively by farmers to reduce soil compaction and improve soil fertility. Organic matter enhances soil resistance to deformation and increases its elasticity (rebound effects) Söane, 1990. The elasticity of manure prevents or reduces the transmission of the stresses toward the subsoil depths (Söane, 1990), then decreasing the soil stress results in a drop in soil volumetric strain thus acting as a buffer to decrease the impact of farm machinery on soil compaction.

Soil bulk density, soil sinkage, and penetration resistance were frequently used as an indicator of soil compaction (Mosaddeghi et al., 2000). Results showed that bulk density increased by 8.6% in comparison to the untrafficked condition. Soil strain transducers were used beneath a wheel drive tractor equipped with single and dual rear tires and beneath a steel track tractor in a silty clay loam

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soil (Kinney et al., 1992). The results of their research showed that soil bulk density and soil penetration resistance tend to increase as soil strain increases. Shahgholi and Abuali (2015) applied standard cylindrical cores to measure the effect of soil moisture, the tractor velocity, and depth on soil compaction under the rear tire of an MF285 tractor. Their results showed that there was no significant difference between two methods in terms of measuring soil bulk density. Mosaddeghi et al. (2000) reported that application of manure at the rates of 0, 50, and 100 Mg/ha to the soil counteracted soil compaction and decreased its compactibility. Their results demonstrate that manure application is an appropriate solution for managing soil compaction by reducing soil bulk density and soil sinkage at high soil moisture contents.

Soil compaction by agricultural machinery traffic is a complex process with many interacting factors. While such regression equations are capable of making a reasonable prediction within the range of conditions investigated, the equations lack the ability to learn and improve due to the large data size. Cannon and Whitfield (2002) found artificial neural networks (ANN) to be superior to linear regression procedures. Widely recognized as a universal approximator, the ability of ANNs has been demonstrated when applied to complex systems that may be poorly described or understood using mathematical equations; problems that deal with noise or involve pattern recognition, diagnosis and generation; and situations where input is incomplete or ambiguous by nature (Tokar and Markus, 2000). In recent years, new fields of soft computing techniques such as artificial neural networks (ANN), fuzzy inference systems (FES), evolutionary computation and their hybrids have been successfully employed for developing predictive models to estimate the required parameters (Yilmaz and Kaynar, 2011). In this regard, ANN has been reported as a promising tool for many complex modeling problems.

Adaptive neuro-fuzzy inference system (ANFIS) is a hybrid intelligent system that merges the technique of the learning power of the artificial neural network with the knowledge representation of fuzzy logic (Jang, 1993). Therefore, a combination of fuzzy system and neural networks handles limitations of both methods and offers an excellent datamining opportunity to solve the critical and complex problem in Geosciences (Tahmasebi and Hezarkhani, 2010; Singh et al., 2005; Grima et al., 2000). The major advantage of the ANFIS model is its computational efficiency and adaptability. Generating predetermined input–output subsets requires the construction of a set of fuzzy 'IF THEN' rules with the suitable membership function (MFs). The ANFIS can serve as the foundation for such a construction. The input–output data are converted membership functions. In accordance to the collection of input-output data, the ANFIS takes the initial FIS and adjusts it through a back propagation algorithm (Mohammadi et al., 2016). ANFIS is capable to learn and generalize the training data (Mohammadi et al., 2016). The strength of ANFIS is the ability to handle linguistic concepts and find nonlinear relationships between inputs and outputs (Krueger et al., 2011).

Çarman (2008) stated that prediction of soil compaction characteristics is necessary for agricultural engineering applications and applied fuzzy logic approach for prediction of the clay loam soil compaction at different vertical loads, forward velocities, and inflation pressures. This researcher compared the accuracy of results from neural network models with the results obtained from the regression model and reported that mean relative errors in regression models was greater than fuzzy expert system (FES) model. However, ANN has some drawbacks such as the case that the input data are less precise and in such condition it is hard to deal with ANN implementation. Therefore, a fuzzy system such as ANFIS may be a beneficial alternative which has been reported previously (El-Shafie et al., 2007). ANFIS has been successfully employed for mapping input–output relationship based on available data tuples (Gallo et al., 1999). Taghavifar and Mardani (2014) applied ANFIS for prediction of vertical stress transmission. Results showed that ANFIS was opted to assess the prediction of vertical stress transmission in the soil profile.

The objective of this study is to build an adaptive neuro-fuzzy inference system (ANFIS) for the prediction of the clay soil compaction as a dependent variable at different sheep manure rates, soil moisture content, the number of tire passes, and depth as input variables. Also, the output results of ANFIS and regression models were compared with measured values.

2. Materials and methods

The soil bin facility consisting of a single wheel-tester, carriage, control panel, and soil processing equipment was developed at the Biosystem Engineering Department of Urmia University in Iran (Mardani et al., 2010). At two sides of soil bin, a rail road was used to facilitate the movement of the carriage and attached single wheel-tester. An electromotor was used to pull a carriage on the side of rail road through chain system and an inverter is used to control the electromotor rotation speed Fig. 1. The system also includes a single-wheel tester of 220/65R21, which is an agricultural tractor tire. Tire inflation pressure was maintained at a constant value of 110 kPa under a vertical load of 4 kN, which was a recommended pressure corresponding to the load. It was operated at a forward velocity of 0.8 m s^{-1} during all tests. Physical properties of the clay soil tested in the present work are shown in Table 1. The critical moisture content of the soil was determined by conducting the standard Proctor test (Davis, 2008) as 18.6% (dry basis).

The experiments were conducted to investigate the effect of sheep manure, tire passes, soil moisture content, and depth on soil compaction. A summary of the experimental dependent and independent variables is presented in Table 2. Manure with a dry bulk density of 300 kg m^{-3} was provided by research farm of the University of the Urmia. Physical and chemical properties of the manure tested in the present work are presented in (Table 3). Manure was incorporate in the soil at rates of 0 (control without amendment), 45, 60 and 90 Mg ha^{-1} that are typical rates used

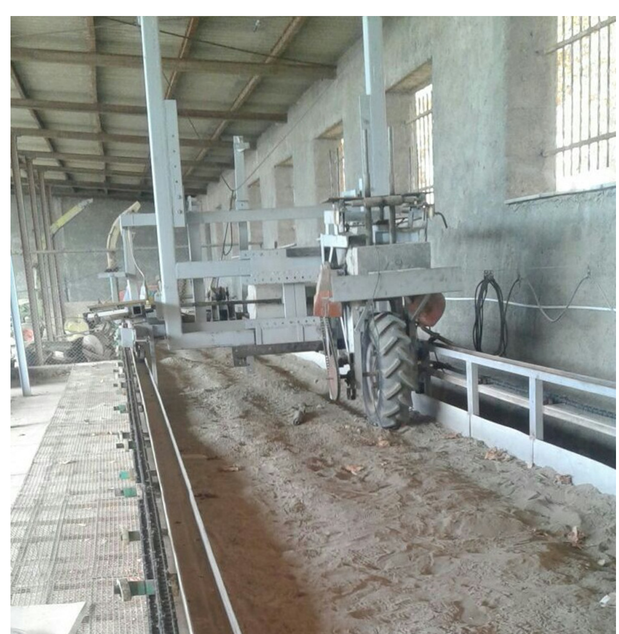

Fig. 1. The general testing of soil bin facility and single-wheel tester for conducting experiments.