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Predicting soil fragmentation during tillage operation using fuzzy logic approach

Yousef Abbaspour-Gilandeh *, Reza Sedghi

Department of Agricultural Machinery, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, Iran

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Abstract

One of the main characteristics of the soil structure, which affects the plant growth and its yield, is its aggregates size. Correct tillage operations leads to prevention from soil degradation and help to maintain and improve its physical, chemical, and biological characteristics. In this paper, a model based on fuzzy logic approach was used to describe the soil fragmentation for seedbed preparation in the composition of primary and secondary tillage implements of subsoiler, moldboard plow and disk harrow as conventional tillage composition in the region. Field experiments were carried out at educational and research farms of faculty of agriculture, University of Mohaghegh Ardabili. In this paper, an intelligent model, based on Mamdani approach fuzzy modeling principles, was developed to predict soil fragmentation during tillage operation. The model inputs included soil moisture content, tractor forward speed and soil sampling depth. The fuzzy model consisted of 50 rules, in which three parameters of root mean square error (RMSE), relative error (ε), and coefficient of determination (R^2) were used to evaluate the fuzzy model. These parameters were calculated 0.167%, 3.95%, and 0.988%, respectively. According to the results of this research, the fuzzy model can be introduced as one of the methods for predicting soil fragmentation during the tillage operation with high accuracy.

Keywords: Tillage; Soil fragmentation; Mamdani approach; Fuzzy model

1. Introduction

Soil is one of the renewable natural resources, which is renewed in very long time intervals rarely. Soil conservation depends on how it is used. One of the main characteristics of the soil structure, which affects the plant growth and its yield, is its aggregates size. Predicting soil fragmentation during tillage operation could be used to predict water movement in the soil, infiltration rate and drainage.

There are several ways for showing the status of aggregates, which included median weight diameter (MWD). In addition to soil intrinsic factors such as soil texture that affects the soil aggregate stability, the other various factors also have effects on the degree of soil fragmentation during tillage operations including: soil moisture content, forward speed, different methods of tillage, soil organic matter content, soil density, and mechanical properties of soil (Al Tahan et al., 1992).

Proper tillage operations, using appropriate tillage tools and accurate operation, leads to prevention from soil degradation and help to maintain and improve its characteristics (Aluko and Koolen, 2000). The preparation of seedbeds is principally done by a soil fragmentation process. Tillage implements fragment the soil into small aggregates. Tillage which plays a significant role in agricultural crop production changes soil structure, aiming to improve the tilth (Mosaddeghi et al., 2009).

Abbaspour-Gilandeh et al. (2009) investigated the effects of different tillage operations on soil crumbling.

* Corresponding author. Tel.: +98 914 451 6255; fax: +98 45 33510135.
E-mail address: abbaspour@uma.ac.ir (Y. Abbaspour-Gilandeh).

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Results showed that the tillage treatments had a significant effect on soil crumbling. Also, soil crumbling varied with soil depth and the optimum particle sizes were developed at the 5–20 cm soil depth. There was a non-linear correlation between soil crumbling percentage and tillage depth.

According to the fact that soil moisture content is the main limiting factor for tillage operations, acceptable moisture content range for tillage should be determined. For tillage operation, the soil moisture content imagines two extremes: upper tillage limit (θ_{UTL}) and lower tillage limit (θ_{LTL}). Several equations have been reported for the range of optimum soil moisture content for tillage operations using water field capacity data and soil plastic limit (θ_{PL}). Dexter and Bird (2011) stated that the optimum soil moisture content for tillage introduced $0.9\theta_{PL}$. Apart from that, they expressed that field capacity (FC) plays a more important role. They concluded that the moisture content of a soil with a good workability could be fallen in $\theta_{FC} < \theta_{PL}$ limit. Mosaddeghi et al. (2009) evaluated a model for soil crumbling for 10 agricultural soils (from sandy loam to clay textures). The results showed that the optimum moisture content values obtained by the model for different soils were in the range of $0.79–0.91\theta_{PL}$. Loghavi and Moradi (1996) investigated the effect of soil moisture on the final condition of soil after plowing by moldboard plow in a clay loam soil and reported better and more uniform fragmentation of soil range in the soil moisture range of 16–18%. Ojenigi and Dexter (1979) found the greatest creation of small aggregates and lowest proportion of large voids when a sandy loam soil was tilled at $0.84–0.90\theta_{PL}$.

The general conclusion from many experiments has been that a good seedbed for cereals should have approximately 50% of the aggregates by weight in the range of 0.5–6.0 mm (Berntsen and Berre, 1993).

Soft computing technology is an interdisciplinary research field in computational sciences. At present, various techniques of soft computing, such as statistics, machine learning, neural network, and fuzzy data analysis, are being used for exploratory data analysis.

Zadeh (1965) proposed a fuzzy set theory in which the set boundaries were not precisely defined; but, boundaries were in fact gradational. Such a set was characterized by the continuum of grades of membership (characteristic) function which assigned a grade of membership ranging between zero and one to each object. The central concept of fuzzy set theory is a membership function, which numerically represents the degree to which an element belongs to a set. In fuzzy set theory, an element can be a member of a particular set and, at the same time, a member of a different set to a certain degree. In fuzzy rule-based systems, knowledge is represented by if–then rules. Fuzzy rules consist of two parts: an antecedent part, which states conditions on the input variable (s), and a consequent part, which describes the corresponding values of the output variable (s) Allahverdi, 2002; Çarman and Şeflek, 2004.

The use of fuzzy set theory allows the user to include unavoidable imprecision in the data. Fuzzy inference is the actual process of mapping from a given set of input variables to an output based on a set of fuzzy rules. The essence of modeling is to identify fuzzy rules. Four fundamental units are necessary for the successful application of any fuzzy modeling approach, which are the fuzzification unit, knowledge base (which is composed of the database and the rule base), inference engine, and defuzzification unit (Allahverdi, 2002; Zadeh, 1965).

Fuzzy inference systems are widely used in different areas, including agricultural applications. Çarman (2008) developed a model based on Mamdani approach fuzzy modeling principles to predict changes in soil compaction due to wheel traffic. Mean relative error of the measured and predicted values was 3.35% for penetration resistance, 7.76% for lasting pressure, and 2.98% for bulk density. Also, Marakoglu and Carman (2010) developed a model based on Mamdani approach fuzzy modeling principles for fuzzy knowledge-based model to predict soil loosening and draft efficiency in tillage. Mean relative error of the measured and predicted values was 2.41% for soil loosening and 2.68% for draft efficiency.

The aim of this study was to develop a fuzzy knowledge-based model based on the Mamdani approach for predicting the soil fragmentation for seedbed preparation in the composition of primary and secondary tillage implements of subsoiler, moldboard plow and disk harrow as conventional tillage composition in the region.

2. Materials and methods

2.1. Devices used in project implementation and field experiments

A 2WD, 75 HP instrumented tractor (Massey Ferguson MF-285) was used for tillage operation and collecting data of forward speed during the tillage operation. The instrumented tractor was equipped with the fifth wheel velocity measurement sensor and data collecting system. A notebook, which was connected to the DT800 data logger, was used to collect the measured data. Also, a curved arm tine subsoiler, three bottom moldboard plow, and disk harrow were used for seedbed preparation. The field experiment was carried out at Educational and Research Farm of Faculty of Agriculture, University of Mohaghegh Ardabili.

The field area of 250 m^2 (10 × 25 m) was chosen for tillage operation. This area was divided into 5 plots with dimension of 10 × 5 m. Then, the soil samples of each plot were selected in order to determine the soil texture.

In order to determine the amount of soil moisture, these samples were taken from each plot at depths of 0–10, 10–20, and 20–30 cm while the field experiment was done. Table 1 provides soil characteristics of the experiment farm. Soil texture was determined using hydrometer method based on USDA soil texture triangle.

Atterberg limits including liquid limit (θ_{LL}), plastic limit (θ_{PL}) and shrinkage limit (θ_{SL}) were determined,