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Application of machine vision for classification of soil aggregate size

Fatemeh Rahimi Ajdadi[a], Yousef Abbaspour Gilandeh[a,*], Kaveh Mollazade[b], Reza PR Hasanzadeh[c]

[a] Department of Biosystems Engineering, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, 56199-11367 Ardabil, Iran
[b] Department of Biosystems Engineering, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran
[c] Department of Electrical Engineering, Faculty of Engineering, University of Guilan, 41996-13769 Rasht, Iran

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ABSTRACT

Tillage operations demand more than half of the total energy consumed in mechanized agriculture. Simultaneous measurement of tillage quality during the operation, would present the possibility of real time adjustments of the tillage tool parameters. The development of such a method would result in a desirable plough with the least possible running cost. On that basis, the purpose of this study was to develop an algorithm that supplies the potential of real-time measurement of tillage quality using image processing. Photography was performed at three camera heights and covering nine different sizes of soil aggregates. Textural information from tilled soil images was extracted by four methods, including first order statistics of image histogram, gray level co-occurrence matrix; gray level run length matrix and local binary pattern. A data mining procedure by CfsSubsetEval was used for feature selection. Networks with topology of 19-19-1, 14-22-1, and 17-20-1 neurons represented the best classification performance for photography heights of 60, 80, and 100 cm, respectively. The best overall accuracy of the ANN classifier was obtained from images taken at the height of 60 cm (72.04%). Results indicated that the present approach for estimating mean weight diameter up to about 35 mm had the best performance with an accuracy of over 80%. The technique suggested in this study is feasible for implementation in variable rate secondary tillage machines.

1. Introduction

Soil is the main source of production in agriculture. It provides a medium for plant establishment, seed germination, root growth and development. The physical and structural properties of soil have a direct effect on rooting and seed germination. Fundamentally, granular soil structure is the most desirable because it allows for good water infiltration, maintains water properly, increases air capacity, facilitates soil conditioning and reduces resistance to rooting.

The purpose of tillage operation is to enhance the soil's tilth. Tilth is the physical condition of soil in relation to its aggregate size. Proper sizes of aggregates cause a good air to moisture ratio and consequently, produce a better yield. The most desirable tillage condition is one whereby the size of aggregate around a seedbed is changed according to seed requirements. The creation of smaller aggregates causes energy losses due to unneeded tillage as well as extra tillage, in turn, increases the potential for soil compaction. On the other hand, in case of larger aggregates, re-tillage operation will be required. As a result, if the operator is informed about the sizes of aggregates during tillage, he can achieve desirable tillage quality by adjusting parameters such as tractor forward speed and tillage depth. Knowing that the tillage operation expends more than half of the energy consumption of agricultural productions, this serves to keep production costs low.

This serves to keep production costs low. Braunack and Dexter (1989a,b) illustrated the importance and efficacy of different aggregate sizes in a seedbed on plant emergence and growth. Assessing the quality of a tillage operation is accomplished by a degree of soil pulverization and is defined in terms of aggregate size (Spoor et al., 1976). Researchers generally use MWD[1] of aggregates as the most important criterion for defining the degree of soil pulverization. Currently, sieving soil through a set of standard multiple sieves is the method used to measure the MWD index. In this method, sieves are arranged on top of each other and they gradually decrease in size from top to bottom. Obviously, extensive sampling is required for application of this method on

* Corresponding author.
E-mail address: abbaspour@uma.ac.ir (Y.A. Gilandeh).

[1] mean weight diameter

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large-scale tillage quality and tilth. Furthermore, some factors such as aggregate failure during sampling and transportation to the laboratory, air drying and sieving can produce results that deviate from actual readings. Static measurement is another disadvantage of this method that hampers 'on the go' applications of. Indeed, precision agricultural approaches and spatial variability are not considered. However, using a dynamic approach can lead to the use of simultaneous measurements for 'on the go' mechanisms to improve soil pulverization. In addition, it selects optimal sowing conditions in terms of the best size distribution of soil aggregates.

Several research groups attempted to develop new methods that were not limited by the process of sieve analysis. For instance, Olsen (1992) used a horizontal mini-penetrometer with a diameter of 5 mm with sensitivity to force only at its probe tip. The result indicated that direct sensing of individual aggregate size was impossible by this method. However, it was capable to derive a parameter from the penetration force signal to determine overall coarseness of an aggregate bed. Some researchers have suggested image analysis as an alternative to the laborious sieving method to evaluate seedbed roughness. Application of image analysis has increased rapidly in recent years due to advances in technology such as digital cameras, higher resolution, faster processors, digital image capturing and improved storage capacity (Atkinson, 2008).

Following this progress, there have been many applications of image processing in other fields of agricultural research, but the technique has had little application in clod analysis, mainly because of the difficulty of accurate determination because of very low-level color variation substrate between soil and substrate. Additionally, the nature of soil and overlapping of the aggregates makes it difficult to discriminate aggregates and to determine diameter. Research on image processing falls into two major groups: one group in which imaging was done in a laboratory, and individual aggregates were spread on a white background (Campbell, 1979; Sandri et al., 1998). In the other group of research studies, imaging was done in the field without eliminating overlap between aggregates. (Stafford and Ambler, 1988, 1990; Bogrekci and Godwin, 2007). The latter method highlights the potential for application of machine vision for variable rate tillage machines.

Bogrekci and Godwin (2007) applied morphological methods of image analysis to estimate distribution of clod size. The report concluded that the technique of contrast enhancement had greater precision compared with other techniques. Also, the value of MWD obtained by their method was 21% larger than standard sieving method. One disadvantage of approaches based on morphological features is that computations lead to an MWD value that is higher than the actual one due to omission of small aggregates.

Itoh et al. (2008) developed an algorithm to measure aggregate size using rock fragments as experimental material; The relationship between aggregate size and textural features was expressed by multiple regression equations. It should be noted that measuring the size of a rock fragment does not incur problems such as crunching and overlapping.

In recent years, several field studies on clod detection by DEM[2] images have been conducted (Vannier et al., 2009; Taconet et al., 2010,2013; Chimi-Chiadjeu et al., 2012, 2014). These images are taken by stereo photogrammetry systems and the value of every pixel represents the elevation or altitude (z coordinate) (Chimi-Chiadjeu et al., 2014). In stereo photogrammetry technique, to develope 3D simulation of clods, two photographic images of the same spot are taken by combining two cameras looking vertically on the soil (Taconet and Ciarletti, 2007). The elevation of each pixel is calculated by the information about image resolution, photography height and control points. The main drawback of the DEM method is that it cannot be used in real time applications such as variable rate tillage machines.

According to the literature, most of the research on determining soil clod size using image processing has been done in the three decades from 1970 to 2000. Subsequently, there has been no adequate research published on assessing tillage quality that has the potential for real time application. In addition, a review of the literature shows that in most previous studies, morphological features have only been used for determinations of clod size distribution. However, only recognizable clods were involved in MWD calculations and smaller or overlapped aggregates were overlooked. Overlapping between adjacent aggregates caused lower values for MWD than the actual value.

In the present study, statistical textural features extracted from soil images were correlated with soil aggregate size. This method was advantageous in that all components of soil were involved in aggregate size determination. Hence, one objective of this study was to develop an approach that enables assessment of soil tillage quality by image processing based on textural features extracted from soil images coupled with an artificial neural networks (ANNs) classifier. Another objective was to find the optimum distance of the camera from the ground for image analysis.

2. Materials and methods

2.1. Site soil preparation

Field experiments were done in the educational field of the Technical and Vocational Training Centre, Guilan Province, Rasht City. The site has a temperate climate and annual rainfall of 1359 mm. Soil texture in the test field is silty clay. The results of soil textural analysis are shown in Table 1. The purpose of preparing the test site was to achieve nine different aggregate size distributions of up to about 100 mm (MWD < 100 mm). This range of aggregate size distribution is common for agricultural applications including primary and secondary tillage. To meet this objective, firstly the whole area was prepared using a mould board plough to the depth of 35 cm. It was then divided into nine plots. Plots were tilled with a rotivator in order to obtain nine different aggregates size classes. Nine different aggregate sizes were supplied with three different types of parameters related to tillage operation; these were forward speed, cover position and frequency of tillage operation. Four forward speeds were obtained by changing four forward gears from 1 to 4 in heavy gears. Motor revolution was set at 1500 rpm. Cover positioning consisted of two levels of cover positioning (including down and top). Frequency of tillage for all classes of tilled soil was once except for class 1, in which tillage operation was performed twice by the rotavator.

[2] Digital Elevation Model

Table 1
Soil properties of the test site.

Soil textural fraction	Mass percent
sand	12
silt	60
clay	28