**Soil Tilth: An Approach for Soil Health Management**

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**ABSTRACT**

Soil is one of the most important natural resources to produce food for all living creature. The production capacity of soil depends upon the health of the soil. It has been damaged by erosion and intensive agricultural practices. To sustain a productive and profitable agriculture, soil management must be improved. Tilth has been used to describe the physical state of the soil. It denotes the ease with which tillage, seedbed preparation, seedling emergence, and root growth can be accomplished. Tilth, in fact, is a composite of physical properties such as texture, structure, strength, organic matter, and consistency. The management practises to achieve desired soil conditions is difficult because the processes affecting tilth are poorly understood by the farmers. Tillage is one of the main activities that leads to the long-term deterioration of tilth because it accelerates the rate of organic matter oxidation. Tillage typically enhances tilth over the short term because it improves soil-air-water relations for plants. Plant growth incorporates the influences of crop, soil, and microclimate, making it a useful predictor of soil tilth. The evaluation of soil tilth levels in agriculture is a difficult task, requiring a lot of time and knowledge. This chapter aims to give an insight about the available soil tilth assessment techniques.

**Keywords –** soil tilth, clod mean weight diameter, mechanical transducer, digital sieving

1. **INTRODUCTION**

Soil is one of the most valuable natural resources and it is being damaged by agricultural practises and erosion **(Knuti et al., 1979).** One of the most significant agricultural activities is tillage, which is the physical disturbance of soil with implements and tools to create an adequate seedbed that produces good tilth for improved germination and better crop growth. Tilth is a qualitative term that indicates the physical status of the soil, showing how easily tillage operations can be carried out, seedlings may emerge and roots can grow **(SSSA, 1979; Plaster, 1985).** In reality, tilth is a composite of various physical characteristics, such as texture, structure, strength, organic matter content, and consistency. It is a dynamic property, making it susceptible to both natural change and artificial manipulation, like cultivation and tillage **(Brady, 1984).** Implementing strategies to maintain or improve the physical, chemical, and biological characteristics of the soil can increase soil functions. The health of the soil is greatly influenced by its tilth **(Singh et al., 1992).** Plant growth incorporates the influences of the crop, soil, and microclimate, making it a useful predictor of soil tilth **(Karlen et al., 1990).** Because some plant species can penetrate into compacted soil layers while others promote aggregate and macropore stability, plant selection can have an impact on soil tilth **(Elkins, 1985).**

Better crop management decisions regarding tillage, crop rotation, fertiliser management, and yield targets can be made by identifying which soil tilth conditions are best for different crops and by knowing how tillage alters soil tilth. The biological, chemical, and physical characteristics of the soil all play a role in determining how healthy the soil is. Bulk density, infiltration, soil structure, porosity, and compaction are among the biological properties that depend on soil tilth. Tillage is one of the main activities that leads to tilth deterioration over the long run because it accelerates the rate of organic matter oxidation. Tillage often enhances tilth over the short term because it improves soil-air-water relations for plants. Because of the dynamic interplay between the physical, chemical, and biological processes causing or maintaining tilth, time has an impact on soil tilth **(Karlen et al., 1990).** If management techniques like conservation tillage are employed for long enough to generate new equilibriums within the soil matrix, they frequently result in a new soil tilth state **(Bauer and Black, 1981; Bauder et al., 1981; Voorhees, 1983; Voorhees and Lindstrom, 1984).**

In order to maximise production and profitability, it is critical to measure soil tilth. However, assessment of soil tilth in a farm level is a difficult task that require a lot of effort and knowledge. Soil tilth assessment is necessary because a good soil tilth avoids erosion, floods, stream siltation, and improve the soil-air-water relationship for plants, strong soil tilth resists compaction, rapidly absorbs water and stores it for later plant use. Poor tilth soils, on the other hand, are readily compacted, restrict water absorption, cause runoff and erosion, diminish crop yields, and inhibit plants from utilising nutrients and soil moisture **(Erbach, 1989).** An expert can determine the tilth of a soil by sight and touch. In current practice, tilth levels are frequently determined by applying subjective logic or judgement. Once the condition of the soil tilth is known, certain actions may be performed to preserve or enhance the tilth. With the use of this knowledge, farmers are able to predict how long-term farming techniques will affect soil resources and, in turn, identify the best management strategies that will encourage the ongoing management of soil and water resources.

In these circumstances, using an expert system to solve the soil tilth assessment problem is suitable. Computer programmes or expert systems may be created to simulate the information and thought processes that real experts would apply to a problem in their area of competence. The development of a knowledge-based decision support system, image processing technique and mechanical transducer-based technique can help to address site-specific soil tilth problems and be very beneficial to both farmers and extension professionals. The objective of this chapter is to explain the techniques available for soil tilth assessment and soil health management. There are very few methods available for soil tilth assessment involving different principles. Only three methods which are important from subject point of view have been discussed in this chapter.

1. **TILTH INDEX: AN APPROACH FOR QUANTIFYING SOIL TILTH**

As tilth is a qualitative term to describe the physical status of the soil, assessing the tilth Scientists, engineers, and farmers would all be benefited from a quantitative understanding of soil tilth. **Singh et al. (1992)** developed a tilth index to measure the soil tilth. A qualitative term used to describe the physical status of the soil is tilth. Scientists, engineers, and farmers would all benefit from a quantitative understanding of soil tilth. Tilth was measured using a tilth index. The tilth index, which ranges from 0 (for soil conditions unsuitable by plants) to 1 (highly useful for cultivation), was calculated using five soil physical parameters, including bulk density, cone index, uniformity coefficient, organic matter content, and plasticity index. The parameters were chosen in part because they could be quickly measured outside. Near Ames, Iowa; and Waseca, Minnesota, field trials were carried out to ascertain how the soil's tilth and crop output responded to various tillage systems, including the mouldboard plough, chisel plough, till plant, spring disc, and slot plant ridge. Both webster (a silty clay loam soil) and clarion (a loam soil) were used for the studies. For the previous ten years at Ames and the preceding four years at Waseca, the fields had been managed with the same tillage and rotation practises. This was the very first approach to quantify soil tilth.

The following polynomial relationship was developed to represent the tilth coefficient related to soil characteristics (bulk density, cone index, uniformity coefficient, organic matter content and plasticity index):

(1)

Where:

CFx is Tilth coefficients for the soil properties (X)

A0, A1,... An are the constants

The tilth index was determined using the tilth coefficients using the following equation:

(2)

Where:

TI = tilth index

CF = tilth coefficients for each of soil properties

The tilth coefficients and tilth index both were normalized to lie in between 0 and 1.

1. **Bulk density**

Bulk density is defined as the dry soil mass per unit volume. A perfect soil has a volume ratio of roughly 50% solid particles and 50% pore space **(Hillel, 1982; Plaster, 1985).** Such a mineral soil has a bulk density of roughly 1.3 Mg/m3. For the sake of all computations, the particle density of soil was taken to be 2.65 Mg/m3, assuming that there are no pore spaces and only solid particles. Any soil with a bulk density of less than or equal to 1.3 Mg/m3 was considered to nonlimiting based on the review of literature **(Kar et al., 1976).** Bulk density of 2.1 Mg/m3 was taken to be suitable decision for maximum value of bulk density based on experience as there was no specific literature for the highest value of the bulk density that would be regarded useless by plants. Equation (4) used a regression analysis of those selected points. The produced curve was forced to pass through the end points in equations (3) and (5) in order to determine the number of significant digits. The bulk density of the fields used to evaluate this relationship was less than 1.7 Mg/m3. However, equations (3) to (5) represented the hypothesised relationship between the bulk density (BD) and the tilth coefficient (CF(BD)).

, for BD ≤ 1.3 Mg/m3 (3)

(4) [for 1.3 ≤ BD ≤ 2.1 Mg/m3]

(5) [for BD ≥ 2.1 Mg/m3]

1. **Cone index**

It is crucial to persuade the researchers that using the cone index to measure mechanical resistance to roots is a reliable technique **(Cassel, 1982).** Cone index is a gauge of soil tensile strength and a predictor of plant development and crop yield due to how easily roots may penetrate the soil **(Taylor and Gardner, 1963; Taylor and Burnett, 1964; Taylor and Bruce, 1968).** It was crucial that supporting bulk density and water content data be gathered because cone index depends so significantly on these variables **(Cassel, 1982).** Any soil with a cone index less than or equal to 1 MPa was considered nonlimiting, and one with a cone index greater than or equal to 10 MPa was considered unusable by plants. This classification was made in the absence of any specific literature for the cone index corresponding to nonlimiting and plant-unusable soil, and it was based on experience and general trends found in the literature. Based on the average of cone indices measured at soil depths of 50, 100, and 150 mm, these values are to be determined. However, equations (6) to (8) described the hypothesised relationship between the tilth coefficient [CF(CI)] and the cone index (CI).

(6) [for CI ≤ 1.0 MPa]

(7) [for 1.0 ≤ CI ≤ 10.0 MPa]

(8) [for CI ≥ 10 MPa]

1. **Organic matter**

The potential productivity, tilth, and fertility of agricultural soils are significantly associated with their organic matter content **(Smith and Elliott, 1990).** Although the majority of semiarid dryland soils contain only a small quantity of soil organic matter; usually less than 1% and its impact on the soil's attributes is significant. Soil productivity is reduced by a decreasing soil organic matter levels in soil. According to **Brady (1984),** organic matter, which is primarily found in the top few inches of soil, both provides nutrients for plants and helps the soil develop in ways that are good for plant growth. When 45% of the soil volume is made up of mineral matter and 5% is organic matter, the soil conditions are non-limiting for plant growth **(Hillel, 1982; Plaster, 1985).** According to **Bowen (1981),** the majority of mineral soil constituents have specific densities between 2.65 and 2.7 Mg/m3, whereas residual humus materials, if any, have densities of about 1.4 Mg/m3. Therefore, a nonlimiting soil will contain about 5.38% of its weight in organic matter. Any mineral soil with an organic matter content higher than or equal to 5% by weight was considered nonlimiting based on the research assessment. The smallest amount of organic matter that might be regarded as useless by plants was not specifically documented in any literature that was available. Based on prior experience, it was determined that an organic matter level of less than or equal to 1% with the lowest tilth coefficient of 0.70 was the greatest option for reducing the impact of low organic matter. To generate equation (10), a regression analysis was used. The produced curve passed through equations (9) and (11) end points caused the number of significant digits to increase. Equations (9) to (11) depicted the suggested relationship between the organic matter (OM) and the tilth coefficient (CF(OM)).

(9) [for OM ≥ 5%]

(10) [for 1% ≤ OM ≤ 5%]

(11) [for OM ≤ 1%]

1. **Uniformity coefficient**

Depending on how the grain size distribution curve is shaped representing a soil is either well-graded or poorly-graded. The diameter of the largest grains in the assemblage and the grading pattern, or whether the soil is formed of distinct groups of particles each of uniform size or whether it consists of a more or less continuous array of sizes, are two pieces of information that may be obtained from this curve. Poorly graded soils display a step-like distribution curve. Well-graded soils have a smooth distribution curve that is flattened and devoid of obvious discontinuities.The homogeneity coefficient, which is the ratio of D60 to D10 and represents the diameter at which 60% of 33 the soil mass is finer, can be used to indicate this aspect of grain size distribution. D10 is the comparable diameter at which 10% is finer **(Wray, 1986).** In this investigation, a well-graded soil with a homogeneity coefficient more than or equal to 5 was chosen. According to the aforementioned discussion, soils with uniformity coefficients of 5 or more were regarded nonlimiting, whilst soils with uniformity coefficients of 2 or lower were considered unsuitable by plants. A value of 0.75 was considered to be the optimum option based on experience. A uniformity coefficient less than or equal to 2 tends to mitigate the effect of low uniformity coefficient because there was no particular literature for the lowest tilth coefficient. For obtaining equation (13), a regression analysis was used. The curve passed through equations (12) and (14) end points forced the number of significant digits to increase. However, equations (12) to (14) indicated the hypothesised relationship between the uniformity coefficient (UC) and the tilth coefficient (CF(UC)).

(12) [for UC ≥ 5]

(13) [for 2 ≤ UC ≤ 5]

(14) [for UC ≤ 2]

1. **Plasticity index**

The difference in moisture content between the soil's liquid and plastic limits is known as the plasticity index. It is a measurement of the soil's cohesive quality. High plasticity index materials typically soften and become slick in damp conditions. According to **Towner (1986),** the particle size distribution of soils varies. The characteristics of soils that impact soil-water relations are rarely uniform. Variations result from naturally existing variances in texture and structure as well as those caused by tillage, compaction, cropping, and other management activities **(Chaudhary and Sandhu, 1983).** Clay soils are difficult to manipulate because they are sticky when wet and hard when dry. Medium plastic soils were defined as having an average plasticity index of 15%, and very high plastic soils were defined as having an index of plasticity more than or equal to 40%. A value of 0.80 was deemed to be the optimum option, based on experience, for a plasticity index more than or equal to 40% to restrict the effect of a high plasticity index because there was no specific literature for the lowest tilth coefficient. Equation (16) was obtained by a regression analysis. However, the relation proposed between the tilth coefficient [CF(PI)] and the plasticity index (PI) was represented by equations (15) to (17).

(15) [for PI ≤ 15%]

(16) [for 15% ≤ PI ≤ 40%]

(17) [for PI ≥ 40%]

1. **Decision support system for soil tilth assessment**

A decision support system for soil tilth assessment was developed by **Singh et al. (1992).** The system could generate a numerical tilth index that ranges from 0 for soil conditions unusable by plants to 1 for nonlimiting soil using the values of five soil physical parameters: bulk density, cone index, organic matter, uniformity coefficient, and plasticity index. Additionally, it makes an estimation of crop yield, reports the soil's tilth status at a specific moment, and provides potential solutions for preserving and/or enhancing tilth and crop output. The technology gives the farmer the capacity to assess the effects of a future farm plan's overall strategy on the condition of the soil and to pinpoint potential fixes for site-specific soil tilth issues. The ideal tilth for crop development and higher yield was regarded to be tilth index value in between 0.8 and 1, and tilth index values below 0.5 was not acceptable for plant growth.

1. **Modified tilth index for rice-wheat system**

**Tripathi et al. (2005)** calculated tilth index to optimise tillage in the rice-wheat cropping system from tillage-induced soil physical characteristics and crop yield. The experiment was carried out in a shallow water table that fluctuated between 0.02 and 0.96 m below the surface and was coupled with a silty clay loam. The tillage methods used for rice were: direct sowing without puddling (DSWP), reduced puddling (ReP), conventional puddling (CP), and four runs of a rotary puddler (PR). Over the plots of rice tillage treatments, wheat tillage treatments included zero tillage (ZT) and conventional tillage (CT). In the rice and wheat seasons, measurements were conducted of the different parameters such as bulk density, saturated hydraulic conductivity, infiltration rate, plasticity index, porosity, and organic carbon (only during the rice season). Wheat yield was highest in the DSWP plots under ZT condition and was statistically equivalent to that in the ReP plots, but rice yield was highest in the PR plots and statistically equal to that in the ReP plots.

Two methods were used to calculate the tilth index (TI): a proposed regression model and the model proposed by **Singh et al.** The physical characteristics of the soil that have a substantial impact on crop output are used in the suggested regression model. Rice yield dropped with increasing TI from 0.67 to 0.81, but wheat yield increased linearly with increasing TI from 0.75 to 0.89, according to the **Singh et al.** model. The following expressions for the tilth index were created for the rice and wheat cropping systems:

for rice (18)

for wheat (19)

Where:

=normalised bulk density

= normalized saturated hydraulic conductivity

= normalized infiltration rate

= normalized porosity

1. **MECHANICAL TRANSDUCER FOR REAL-TIME SOIL TILTH SENSING**

In the context of precision agriculture, the development of real-time and continuous sensing systems for soil attributes offers an invaluable tool for obtaining affordable and timely information on the soil's current condition and future management. By analysing the dynamic strain behaviour of commercially available spring tines, **Bogrekci & Godwin (2007)** developed a straightforward transducer for soil tilth measurement. Utilizing straightforward strain gauge circuits, the response from coarse, moderate, and fine tilths was examined in order to identify the dynamic properties of the tines. Utilizing digital signal processing techniques, the obtained signals were examined. Correlations between the results of the signal analysis and those of conventional sieving were found. The findings demonstrated that one useful factor for determining clod size was signal amplitude. The mean weight diameter of the tilth grading curve could be calculated within 76.3 mm of the value obtained from mechanical screening.

Three types of spring tines (S, Vibroflex, and double coil) were chosen to measure the clod sizes. The tines were affordable and easily accessible. Table 1 represents the geometry and natural frequencies of the tines. The frequency and amplitude responses of the tines were examined in order to ascertain the dynamic response of tine transducers. A spectrum analyzer (Hewlett Packard 3582A, Agilent Inc., Palo Alto, CA, USA) was used to measure the three spring tine transducers' inherent frequencies. The tine tip was subjected to an impulse force in the horizontal plane, and the spectrum analyser provided the data.

**Table 1: Tine geometry, natural frequency and sensitivity**

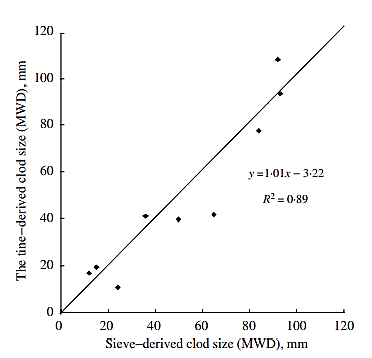
|  |  |  |  |
| --- | --- | --- | --- |
| **Type of tine** | **S** | **Vibroflex** | **Double coil** |
| Width (mm) | 30 | 35-155 | 25 |
| Height (mm) | 55 | 72 | 68 |
| Thickness (mm) | 20 | 30 | 25 |
| Stiffness (N/mm) | 2.5 | 6.1 | 6.6 |
| Rake angle (º) | 45 | 45 | 45 |
| Natural frequency (Hz) | 9 | 13 | 18 |
| Sensitivity (mv/N) | 0.79 | 0.15 | 0.44 |

S type spring tine was chosen for the further experiment due to its lowest natural frequency and highest sensitivity. The type and instalment of a sensor were determined in order to instrument the spring tine with a suitable measurement method. The most affordable and dependable option was a strain gauge system. Utilizing finite element analysis (FEA), the location of the highest potential strain on the tine body was determined in order to strategically place the strain gauges for optimal utilisation. The highest shear stress was determined when the horizontal force was applied. A system with full bridge gauge was established. Two dummy gauges were placed in an instrumentation box, and two gauges were fixed on the tine at the same ambient temperature.

Tillage operations with a mouldboard plough, a mouldboard plough followed by a chisel tine, and a mouldboard plough followed by a power harrow were used to create three different soil tilths. Clay loam and sandy loam were the two types of soil chosen. The relative sizes of the three tilths for sandy loam and clay loam soils respectively represented their mean weight diameters.

According to the results of the linear regression analysis of the standard deviation vs clod size, it was clear that the standard deviation was an effective statistical tool to determine the soil tilths in terms of clod size variability. The S tine transducer was used to get the standard deviation findings (force) for the three soil tilths. The sensing speed was 1.39 m/s, and each application lasted for 10 seconds. The mean standard deviations and sieve-derived aggregate sizes (MWD) were 105, 36, and 21 N. and, 82, 58, and 22 mm respectively for the tilth created by a mouldboard plough, a mouldboard plough plus tine, and a mouldboard plough plus power harrow. The tine transducer was able to detect and discriminate the three different soil tilths with great clarity.

Figure 1 illustrates the assessment of the tine transducer prediction for the identification of the clod size distribution. There was a correlation between the sieve clod size results and the clod size prediction results from the tine transducer. The R2 value of the relation between two clod sizes was 0.89, which showed the good corelation between these two methods. The findings of the error study showed an RMSE of 6.3 mm for both the sieve-derived and tine-predicted clod diameters. The evaluation results indicated that the S tine transducer can accurately predict clod size distribution in MWD with a maximum RMSE of 6.3 mm.



**Figure 1: The relationship between the tine and the sieve derived clod sizes (Source: Bogrekci & Godwin, 2007)**

1. **Image-processing technique for soil tilth sensing**

It takes a lot of time and effort to collect, handle and sieve soil samples to determine the distribution of clod sizes. Therefore, computer vision technique was used by **Bogrekci & Godwin (2007)** to determine the distribution of clod/aggregate size in the field using a non-contact measurement technique. For sandy loam soils, three different soil tilths: coarse, intermediate, and fine were digitally captured. The geometric and quality distortions in the photographs were corrected using geo-correction models, digital filters, and image-enhancement techniques. In order to assess the distribution of clod sizes, three digital image processing methods namely contrast detection, edge detection, and aggregate finding and classification (AFC) analysis were examined. Results of standard sieving were correlated with those of image processing.

The overall methodology to determine image processing soil tilth status is summarised below:

(1) A sandy loam soil was created with three different soil tilths.

(2) Digital image acquisition methods were used to capture the images.

(3) Geo-correction techniques were used to fix geometric distortions in the photos.

(4) In order to improve the quality of the photographs, image-enhancement techniques were utilised.

(5) An image's visually derived mean weight diameter (MWD) was estimated, and the results were compared to those obtained using a traditional sieve technique.

1. **Image acquisition**

Both in the field and in a lab, the photographs were taken using sources of structure and ambient light. The frame was 500mm by 500mm without the grid, and 1000mm by 1000mm with the grid. Images were captured using a camcorder (Canon MV1, Canon Inc., Tokyo, Japan) with a progressive scan CDD image sensor and a lens that was able to zoom in and out by 14 times at a focal length of 5.2 to 72.8 mm. In this investigation, clods were initially collected, transported, and sieved before photographs were captured. The camera was perpendicular to the ground while taking images, mounted on a tripod at a height of 1.1m.

1. **Geometric correction and image enhancement**

Image geometric rectification/correction is crucial when determining the clod size. Any geometrical inaccuracy in the photographs has a high likelihood of portraying and interpreting the real data incorrectly. Image-processing software (Erdas Imagine 8.3.1, Leica Geosystems Inc., St. Gallen, Switzerland) was used to create models to fix the geometric distortions because some of the photos of soil tilths had geometry and projection issues. The characteristics of the camera's optics also contribute to geometric distortion. For each image, a frame with known dimensions was chosen, and forty geometric correction points were chosen.

The process image enhancement improving an image and making it easier to understand for a specific use. By making the best use of the colours present on the display or output device, contrast enhancement helps the visual features stand out more sharply. A soil tilth image is shown in Fig. 12 both before and after contrast enhancement. For each image, linear contrast stretching was done. The results showed the original pictures. Due to the nature of the process, some information was lost during linear contrast stretching. For instance, some lower grey values were zero, while others had maximum grey values. Making an image simpler to understand for a particular purpose is a part of the improvement process. Contrast enhancement makes the most of the colours that are available on the display or output device to make the visual characteristics stand out more strongly. Stretching of the linear contrast was done for each image. The outcomes displayed the original images. Due to the nature of the procedure, linear contrast stretching resulted in some information loss. As an illustration, while some grey values had minimum values, others had maximum values.

1. **Feature extraction**

A boundary between two disparate portions of an image is referred to as an edge. There are typically two phases in edge extraction procedures. (1) By looking for gradient discontinuities, pixels in the image where edges are likely to appear are located. Edge points, edge pixels, or edgels are common names for the points that define an image's edges. (2) By connecting the edge locations, lines and curves are used to describe the edges. Edge identification was accomplished using a Sobel filter (GLOBAL LAB Image, Data Translation Inc., USA).

Alternately, a line-scanning method was employed for edge and contrast detection, and an area scanning method was used for the aggregate finding and classification (AFC) analysis. A virtual sieve was made specifically for these two techniques. The authors created a virtual sieve, which is a hypothetical computer sieve where the number and size of the sieves can be adjusted for a specific application to provide the grading curve and the MWD of the clods. The virtual sieve programme calculates the volume and mass of clods using the diameter of clod size from each image processing programme created by **Bogrekci (2001)**. The user chooses the quantity and dimensions of each virtual sieve, and the clods are fed through them. The clods' MWD is determined by the results of the virtual sieves, and the mass that passes through each sieve is utilised to calculate the percentage of clods that pass each sieve to produce the grading curve. To create frames with 1000 by 1000 pixels, the photographs were resized. The picture particles were discovered once the colour level was reduced to 16 grey (4 bits). A determination was made in the aggregate finding and classification procedure regarding whether or not a surrounding pixel was a component of the same particle, aggregate, or clod as the selected pixel.

Standard mechanical sieving of clod/aggregate size distribution is a static measurement, but visual sensing of clod/aggregate size distribution can be either a static or a dynamic measurement. The general correlations between the MWD of aggregates as estimated by computer vision and mechanical sieving. In general, the clod/aggregate sizes for the three soil tilths are over-predicted by image-processing techniques. The fitted straight line (R2 = 0.96) had a slope 21% higher than unity, yet it went through the y-axis at zero, according to regression analysis. The root-mean-square errors (RMSEs) for the contrast, edge, and AFC detection approaches for forecasting the clod size were 14, 21, and 37 mm, respectively. Since contrast detection technique had the lowest RMS error, it was advised for determining the distribution of clod sizes.

Comparisons were made between the outcomes of mechanical sieving and those of three different digital image-processing techniques, namely contrast recognition, edge detection, and AFC analysis. The horizontal axis compares the soil tilths used to determine the clod size distribution, while the vertical axis displays the MWD of clods and aggregates. The clod size distribution produced by the three image-processing methods was typically coarser than that of mechanical sieving. The breakage of clods during the sampling, transporting, air drying, and sieving processes as well as the huge clods on the surface disguising the smaller ones below where the reasons why optical approaches calculated the size of clods coarser than that of mechanical sieving. Although the standard deviation of clod sizes was lower than that of mechanical sieving, the results of the AFC analysis for the ploughed tilth were comparable to those of mechanical sieving. Contrarily, for the ploughed plus power-harrowed tilth, the discrepancies between the MWDs of the AFC analysis and mechanical analysis were substantially different from one another (P>0.05), whereas those for the other two tilths were within the range of the least-significant difference (LSD). Additionally, the results demonstrated that for all tilths, the edge and contrast recognition algorithms yield findings that are not statistically different from mechanically sieved data at the 95% confidence level. Even though its estimations were higher than those of mechanical sieving, edge detection technique produced good results for the ploughed plus tined and ploughed plus power-harrowed tilths.

1. **CONCLUSION**

The following conclusions can be drawn from the above discussion:

1. Knowing the status of soil tilth allows soil to be managed appropriately, if necessary, for better crop yield.

2. Based on a number of factors, including bulk density, cone index, uniformity coefficient, organic matter content, and plasticity index, tilth index, coupled with DSS, gives a quantitative measurement of soil tilth ranging from 0 to 1.

3. When the three computer vision methods are compared to mechanical sieving, it appears that the contrast enhancement method is better at determining the clod size precisely than the other methods.

4. For determining the CMWD, the image processing-based technique (R2=0.96) performed better than the mechanical transducer-based technique (R2=0.89).

**REFERENCES**

1. L.L. Knuti, D.L. Williams and J.C. Hide, “Profitable soil management,” Prentice-Hall, Inc., New Jersey,1979.
2. E.J. Plaster, “Soil science and management,” Del mar Publishers Inc., Albany, New York, 1985.
3. K.K. Singh, T.S. Colvin, D.C. Erbach and A.Q. Mughal, “Tilth Index: An Approach to Quantifying Soil Tilt,” Transactions of the ASAE, vol. 35(6), pp.1777–1785,1992.
4. N.C. Brady, “The nature and properties of soils,” 9th ed. MacMillan Publishing Co., New York, 1984.
5. SSSA, “Glossary of soil science terms,” Soil Sci. Soc. Am., Madison, WI, 1979.
6. C.B. Elkins, “Plant roots as tillage tools,” In Proc. Int. Conf. on Soil Dynamics, Auburn Univ., Auburn, AL. vol. 3, pp.519-523, 1985.
7. D.L. Karlen, E. C. Berry, T. S. Colvin and R. S. Kanwar, “Twelve-year tillage and crop rotation effects on yields and soil chemical properties of three hapludolls,” Communications in Soil Sci. and Plant Analysis, 1991.
8. Voorhees, W. B. 1983. Relative effectiveness of tillage and natural forces in alleviating wheel induced soil compaction. Soil Sci. Soc. Am. J. 47:129-133.
9. Voorhees, W. B., and M. J. Lindstrom. 1984. Long term effects of tillage method on soil tilth independent of wheel traffic compaction. Soil Sci. Soc. Am. J. 48:152-156.
10. Bauder, J. W., G. W. Randall, and J. B. Swan. 1981. Effect of four continuous tillage systems on mechanical impedance of a clay loam soil. Soil Sci. Soc. Am. J. 45:802-806.
11. Bauer, A., and A. L. Black. 1981. Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. Soil Sci. Soc. Am. J. 45:1166-1170.
12. Erbach, D. C. 1989. Soil tilth: How to maintain and improve it for soil erosion control and productivity. Vlllth Annual Inland Empire Conserv. Farming Conf., Pullman, Washington.
13. Kar, S., S. B. Varade, T. K. Subramanyam, and B, P. Ghildyal. 1976. Soil physical conditions affecting rice root growth: Bulk density and submerged soil temperature regime effects. Agron. J. 68:23-26.
14. Plaster, E. J. 1985. Soil science and management. Del mar Publishers Inc., Albany, New York.
15. Hillel, D. 1982. Introduction to soil physics. Academic Press, Inc., Orlando, FL.
16. Taylor, H. M., and H. R. Gardner. 1963. Penetration of cotton seedling tap roots as influenced by bulk density, moisture content, and strength of soil. Soil Sci. 96:153-156.
17. Taylor, H. M., and E. Burnett. 1964. Influence of soil strength on the root growth habits of plants. Soil Sci. 98:174-180.
18. Taylor, H. M, and R. R. Bruce. 1968. Effects of soil strength on root growth and crop yield in the Southern United states. Trans. 9th Int. Congress Soil Sci. 1:803-811.
19. Cassel, D. K. 1982. Tillage effects on soil bulk density and mechanical impedance. ASA Spec. Publ. No. 44. ASA, CSSA, and SSSA, Madison, WI.
20. Smith, J. L., and Elliott, L. F. (1990). Tillage and residue management effects on soil organic matter dynamics in semiarid regions. In R. P. Singh, J. F. Parr, and B. A. Steward (eds.). *Advances in Soil Sci.,* Spring-Verlag New York Inc., 13:69- 85.
21. Bowen, H. D. (1981). Alleviating mechanical impedance, p. 21-57. In G. F. Arkin and H. M. Taylor (eds.). Modifying the root environment to reduce crop stress. *Am, Soc. Agri. Engrs*., St. Joseph, MI.
22. Wray, W. K. (1986). Measuring engineering properties of soil. Prentice Hall, Inc., Englewood Cliffs, NJ.
23. Chaudhary, T. N., and. Sandhu, K. S. (1983). Soil physical environment and root growth. In K. V. paliwal (ed.). *Advances in Soil Sci.* 1:1-43.
24. Towner, G. D. (1986). The influence of particle size distribution on soil physical properties. *J. Agric. Sci.,* Camb. 106:527-535.
25. Tripathi, R.P., Sharma, P. and Singh, S. (2005). Tilth index: an approach to optimize tillage in rice–wheat system. *Soil and Tillage Research,* 80:125-137.
26. Bogrekci, I., Godwin, R.J. (2007). Development of an image processing technique for soil tilth sensing, *Biosystems Engineering*, 97, 323-331.
27. Bogrekci, I., Godwin, R.J. (2007). Development of a mechanical transducer for real-time soil tilth sensing, *Biosystems Engineering*, 98, 127-137.
28. **Bogrekci I**(2001). Soil tilth sensing. Unpublished PhD Thesis, Cranfield University, Silsoe, UK