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Introduction of modeling a tillage tool on soil (a Review)

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Abstract: Summary of the study that in spite of numerous numbers of researches in this area, tillage must still be a technique or art more than being a science. Another point is that efforts should focus on finding particular equations for particular soil, tool, and operating conditions. At the same time, efforts should be made to investigate the components of total draft and energy requirements for different tillage operations. This approach will lead to a reduction of energy requirement of a particular tool by optimizing soil, tool, and operating parameters based on the collected information. Literature showed that there is a lack of experimental data for the vertical narrow tillage tools particularly at high speed of operations. Since new cultivation methods such as no tillage and minimum tillage methods mostly use some kinds of vertical tools, it is very important to collect more force and energy data of these tools. This will facilitate any calculation-based design of tillage tools in the future.

Key words: Optimizing soil; Minimum tillage, Tillage

1. Introduction

During the years, Different modeling tools have been implemented to model soil failure during tillage operations. Experimental, empirical, analytical, and numerical modeling methods are different approaches to achieve this goal. Analytical methods have received much attention over last decades from many researchers. Because of the importance of this approach in calculating draft and energy requirements of particularly narrow tillage tools, a fairly extended discussion on analytical models is developed in this chapter. On the other hand, numerical approaches such as Finite Element Method (FEM), Discrete Element Method (DEM), and Artificial Neural Networks (ANN) have been implemented in tillage science as the result of appearance of powerful computers.

To date, there are only few reports on using DEM for tillage studies (Shikanai and Ueno 2002; Khat et al. 2005). This method is one of the numerical analyses in which solid body is treated as aggregate particles. The behavior of the solid body is estimated from the solution to the equation of motion with respect to each of the particles in the DEM. With this technique, it is possible to treat the phenomenon of soil destruction by agricultural machines. In DEM, dynamic behavior is described numerically using a time stepping algorithm. The time step is selected such that (1) velocities and acceleration can be assumed constant within the time step, and (2) the time step is indiscriminately small in manner that disturbances cannot propagate from one element further than its immediate neighbor during a single time step. The calculation cycle alternates between force displacement law at the contacts and Newton's second law of motion. The force displacement law is used to calculate the contact forces from relative displacements at contacts. Hryciw et al. (1997) used video tracking and digital image analysis method for experimental validation of DEM simulation for large discontinuous deformation in sandy soil during plowing.

This can be related to the difficulty of modeling soil failure by DEM during dynamic processes such as tillage operations.

There has also been an attempt to apply Computational Fluid Dynamics (CFD) for soil failure modeling. This method was applied to simulate the soil flow around a simple tool. Simulations used a vertical blade in a rectangular flow domain (Karmakar and Kushwaha 2005a). Soil was treated as a Bingham viscoplastic material in respect to its non-Newtonian rheology. Free-surface simulation of an open channel visco-plastic soil flow indicated soil deformation patterns and the effect of speed on the failure front propagation. Soil deformations, as the flow of a visco-plastic material with yield stress, were observed to possess "plastic flow" and "plug flow" patterns. For a tool speed of 6 m s-1, with a vertical tool of 20 mm thick and 50 mm wide, operating at 100 mm depth, the soil failure front was observed to be 160 mm at a depth of 10 mm below the top soil surface. The critical speed range was found to be 5 to 6.5 m s 33-1. Soil pressure on the tool surface increased with the tool operating speed. Pressure concentration was the highest at the tool tip; it decreased towards the soil surface and

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extended over greater area on the tool surface with increase in tool speed (Karmakar and Kushwaha 2005b). Draft was related as a square function of speed. Since this research is the only one found in literature, further investigation would be required to judge about the ability of the method in modeling soil-tool interaction.

Among the numerical approaches, FEM has received more attention and was implemented earlier than the other numerical methods. In addition, literature shows acceptable results obtained from FEM modeling research, however, the results emphasized on the limitations of this method. Therefore, in this paper, results of some research pertinent to FEM modeling are presented. These reports will focus on draft and energy affecting factors data resulted from this modeling method.

-Analytical Models
-Payne model
-O'Callaghan-Farrely model
-Hettiaratchi-Reece model
-Godwin-Spoor model
-Mckyes-Ali model
-Grisso et al. model
-Dynamic models
-Finite Element Method (FEM) Models
-Kushwaha and Shen model
-Rosa and Wulfsohn model
-Chi and Kushwaha model
-Mouazen and Nemenyi model
-Fielke model
-Plouffe et al. model

2. Results

In the result paper, most of the static and dynamic analytical models developed to predict applied forces on narrow and wide tillage tools were introduced, and some governing equations, assumptions, and their limitations were broadly discussed. Finally, different stress-strain relationships of agricultural soils to be applied in a FEM modeling were introduced and many research works using FEM to measure soil forces on tillage tools were discussed. Based on the above mentioned summary of literature, the following points can be concluded:

1. Developing a single equation that can predict draft or energy requirement of a particular tool at different soil and operating conditions is not realistic. The reason refers to the non-homogeneity of soil as a complex mixture of solids, air, and water which reacts differently under different ambient conditions and operational situations.

2. Previous models which have been implemented to predict applied forces of tillage tools used several assumptions that make their area of application limited.

3. To manifest dynamic effects of a tillage operation, tool should be run at high speeds. Achieving such speeds faces practical problems and needs special measuring devices which are not always available.

4. Interpreting results of corresponding tests such as high speed triaxial tests on soil makes some difficulties which affect the results. For example, it is difficult to justify having a homogeneous applied load within whole sample of soil at such high rate of loading. As well, it is hard to believe that remolded soil samples act similar to field soil under loading conditions

5. To date, force and energy requirements of different tillage tools have been measured or calculated in total. In literature, there is no reported information on the subdivisions of those total forces or energies in order to know the contribution of each individual factor in total energy requirement.

7. Different types of soil failure patterns such as shear, tension, compression, and plastic flow have been introduced and defined in the literature. However, the soil failure pattern developed by each tillage implement is not clear enough yet. In addition, if some implements develop more than one pattern of failure to the soil, it is required to know the conditions at which those patterns occur.

8. Using Limit Equilibrium Method (LEM) analysis needs in advance an assumption of a failure profile. Since this assumption has changed from one researcher to another one, the results have accordingly changed.

9. In an analytical approach, different layers of soil have been assumed to have uniformity in their mechanical properties, whereas it is not true, particularly, for soils under natural situations such as soils of agricultural fields.

10. Analytical models do not reflect the influence of tool speed on the shape of soil failure pattern although this influence is well known and accepted.

11. To date, only a few number of FEM modeling have been successfully used in prediction of draft requirement of a real tillage tool. At higher speeds of travel, the closeness of the simulated results to the experimental data reduces dramatically. On the other hand, those research accomplished at lower speeds have not been able to investigate dynamic properties of soil.

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