Width Prediction of a Side Circular Crescent Failed by a Tillage Tool in a Sandy Clay Loam Soil

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ABSTRACT

Some of the mathematical force models employing limit equilibrium analysis are based on the soil-volume tilled to predict the draft requirements of a tillage tool. At the same time, such models require a preliminary assumption of the soil failure pattern ahead of the tool. It is imperative therefore to accurately determine the dimensions of the idealized soil-failure model to ensure accurate prediction of the soil-volume tilled and thus the tillage-tool draft requirements.

Among the commonly idealized models, is the model that divides the soil failure ahead of a simple tillage tool into a center wedge and a side circular crescent on each side of the tool. However, the available model for determining the maximum width of the side circular crescent was found to over predict its size. This was mainly due to being insensitive to soil water content. A study was therefore carried out to develop a model expressing the maximum width of the failed side circular crescent in terms of soil water content. Tests were conducted under field conditions in a sandy clay loam soil using conventional subsoilers in a tandem configuration at an operating depth of 600 mm.

The results showed that the proposed model adequately predicted the maximum width of the failed side circular crescent resulting in satisfactory prediction of the tilled soil volume. This would lead to limit equilibrium analysis based models to sufficiently predict draft requirements of tillage tools. It was concluded therefore, that models which are a function of soil water content predict better the size of the failed soil wedge than those that are a function of geometric parameters of the tillage tool.

Key worlds: Side circular crescent, failed soil-wedge, model, maximum width, tillage tool

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1. INTRODUCTION

Energy efficiency for tillage tools is greatly influenced by their draft requirements. This has forced a number of researchers (Fielke, 1996; McKyes and Maswaure, 1997; Manian *et al.,* 2000; Gratton *et al.,* 2003; Mamman and Oni, 2005; Manuwa and Ademosun, 2007) to investigate draft requirements for these tools. Mathematical methods and models based on either analytical or numerical approaches have been developed to predict the draft (McKyes and Ali, 1977; Stafford, 1979 & 1984; Oni *et al.,* 1992; Shirin *et al.,* 1993; Zeng and Yao, 1990 & 1997; Chi and Kushwaha, 1990 & 1998; Shrestha *et al.,* 2001; McLaughlin and Campbell, 2004). The use of limit equilibrium analysis as an analytical approach to study the soil-tillage tool interaction requires a preliminary assumption of the soil failure pattern (Kushwaha *et al.,* 1993). Many researchers therefore, idealized soil-failure profile models to evaluate the performance of simple tillage tools in terms of soil forces and cross-section areas tilled. These models were derived from Terzaghi's (1943) passive earth pressure theory. Hettiarratchi and Reece (1974) used them to develop a technique for determining the draft requirements of a tillage tool. This technique was simplified when McKyes and Ali (1977) modified the soil failure ahead of a tillage tool into a center wedge (ABDEDOP in Figure 1), a side circular crescent (BCDP) on each side of the tool, and a plane failure surface (OPDE) at the bottom of the failed soil wedge that made it easy to solve limit equilibrium equations.

In an effort to determine the volume of the side circular-crescent, Swick and Perumpral (1988) developed equation 1, expressing its maximum width (s) as a function of the rupture radius (R) in centimetres and tool rake angle (α) in degrees.

$$s = 0.46(R) + 0.904(\alpha) - 6.03 \ldots\ldots \text{(1).}$$

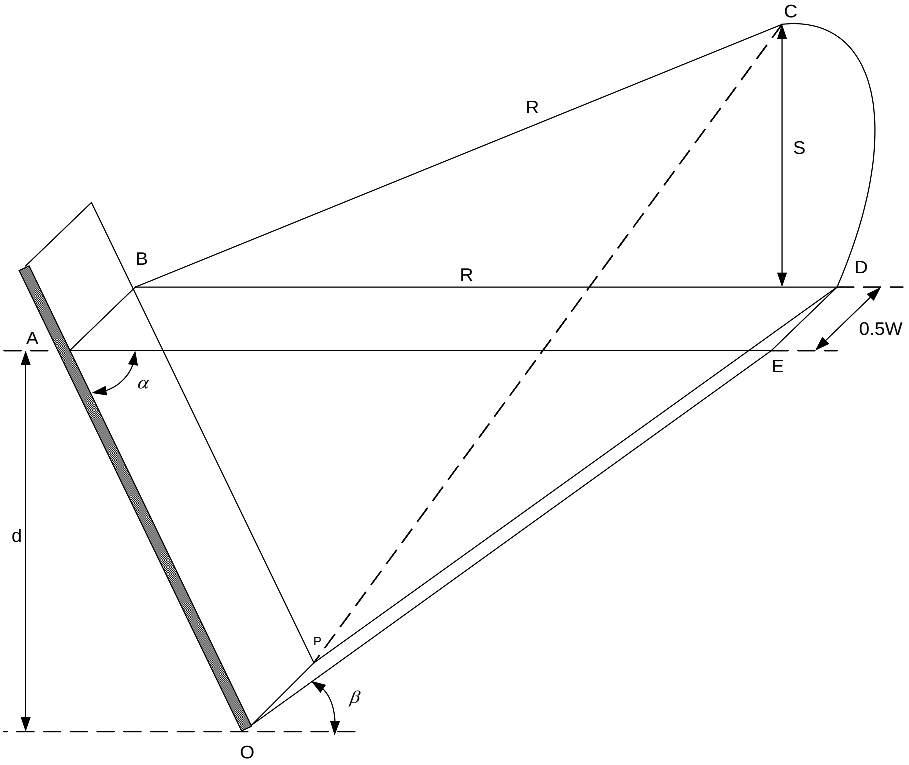


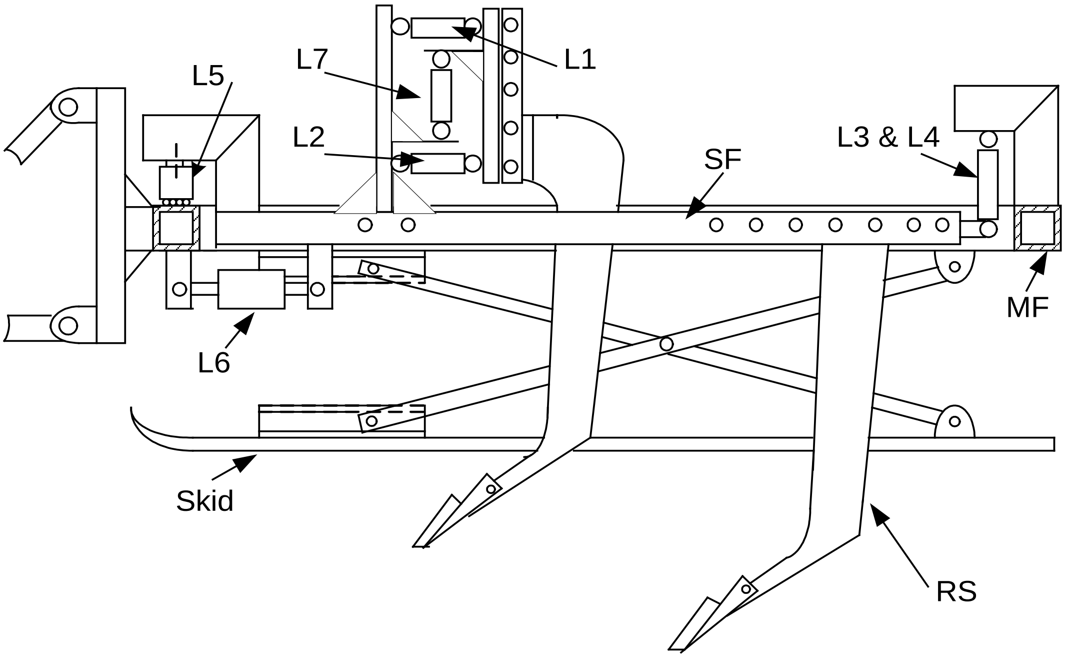
Figure 1. Mid-section of an idealized soil failure pattern ahead of a simple tillage tool

In some maize growing regions of South Africa, farmers are increasingly use two subsolers in a tandem configuration to burst open hard soil layers up to a depth of 600 mm. They use them in this configuration, probably to avoid the problems of tilling below the critical depth of a single subsoiler (Kasisira, 2004). Operating in this mode necessitated a study to develop mathematical force models predicting draft requirements of both the front and rear subsoiler at the above operating depth.

During this study under field conditions, equation 1 over predicted the maximum width of the failed side circular crescents thus the soil volume tilled resulting in the proposed mathematical force models over predicting the exerted draft. Furthermore, it was observed that the sizes of the failed soil-profiles were greatly affected by the soil water content to which equation 1 was insensitive. Based on this observation, tests were conducted to develop a model expressing the maximum width of the failed side circular crescent in terms of soil water content at an operating depth of 600 mm.

2. PROCEDURE

Tests were conducted under field conditions in a sandy clay loam soil with varying soil water content at the experimental farm of the University of Pretoria. Two subsoilers in a tandem configuration were mounted onto an instrumented tillage dynamometer (Fig. 2). The tillage dynamometer was equipped with load cells (L_1- L_7) that measured soil forces and exerted draft reported by du Plessis and Kasisira (2003). It was also equipped with skids that slide over the ground, thus maintaining a uniform operating depth. The geometry of the subsoilers employed in this study is presented in Figure 3.



MF = Main frame, SF = Sub-frame, L_1....L_7 = Load cells, RS = Rear subsoiler

Figure 2. An instrumented tillage dynamometer

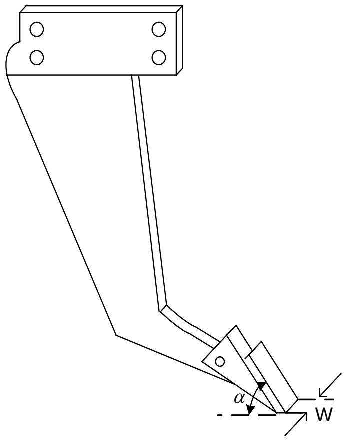


Figure 3. The geometry of the subsoiler

At the beginning of each run, the rear subsoiler (RS) was engaged into the ground to the required operating depth of 600 mm and the tillage dynamometer was properly levelled in both lateral and horizontal planes by the hydraulic system of the tractor. The tractor was then driven towards an already prepared area at the end of the test ground. An area was cleared of surface curve at the end of the treatment area for measuring the projected cross-section area of the three-dimensional failed soil profiles. On reaching the cleared area, the tractor was stopped and the subsoilers disengaged from the ground. A manual method, employing the pin-profile meter was used to measure the failed profiles as described by Kasisira and du Plessis (2003). A Matlab based computer program was coded to use the recorded measurements to calculate the actual maximum width of the side circular crescent, the maximum cross-section area and thus the volume of the failed profile.

The experimental field was divided into treatment areas with sufficient size to ensure that the disturbed soil resulting from a previous run would not affect the current test. Twenty three tests were conducted at the same gear transmission ratio and a constant speed of 2 km per hour.

3. RESULTS AND DISCUSSION

As shown in Figure 4, the measured values of the maximum width (s) at different soil water content were best fitted with an exponential regression curve. Thus expressing it as a function of soil water content:

$$s = 114.6e^{-0.1413x} \quad \text{...} 2.$$

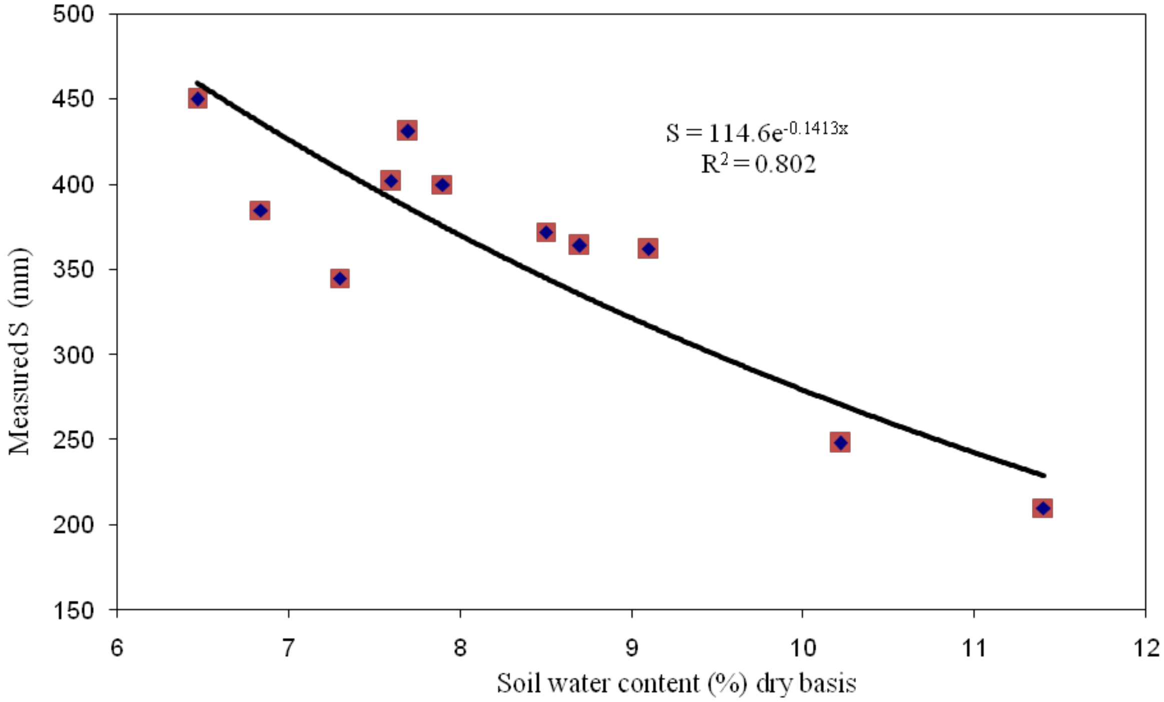


Figure 4. Measured “s” versus soil water content at an operating depth of 600 mm

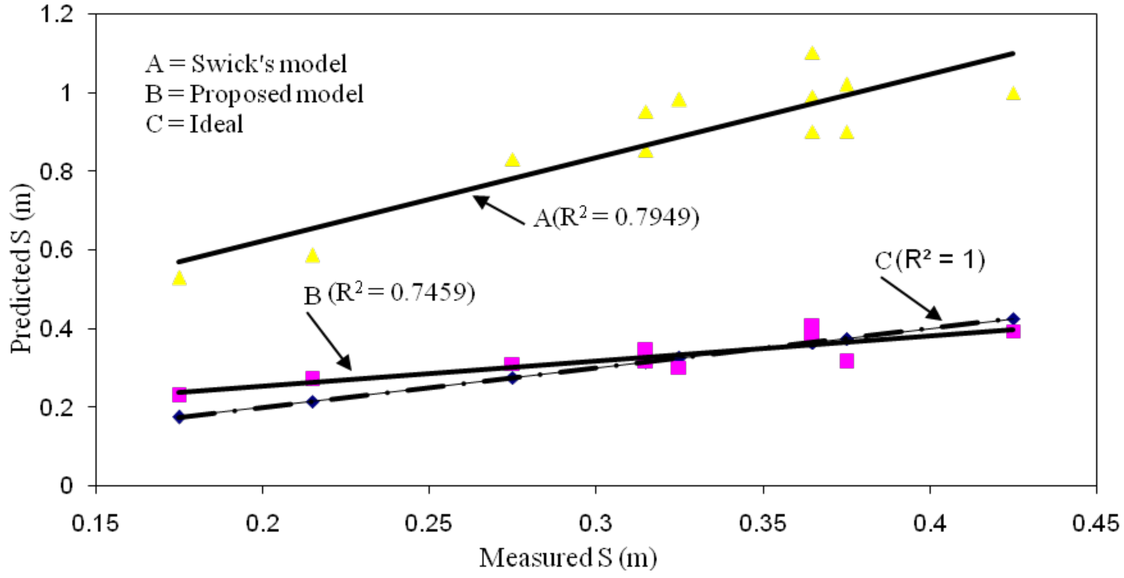


Figure 5. Comparing measured “s” with “s” predicted by the proposed and Swick’s models

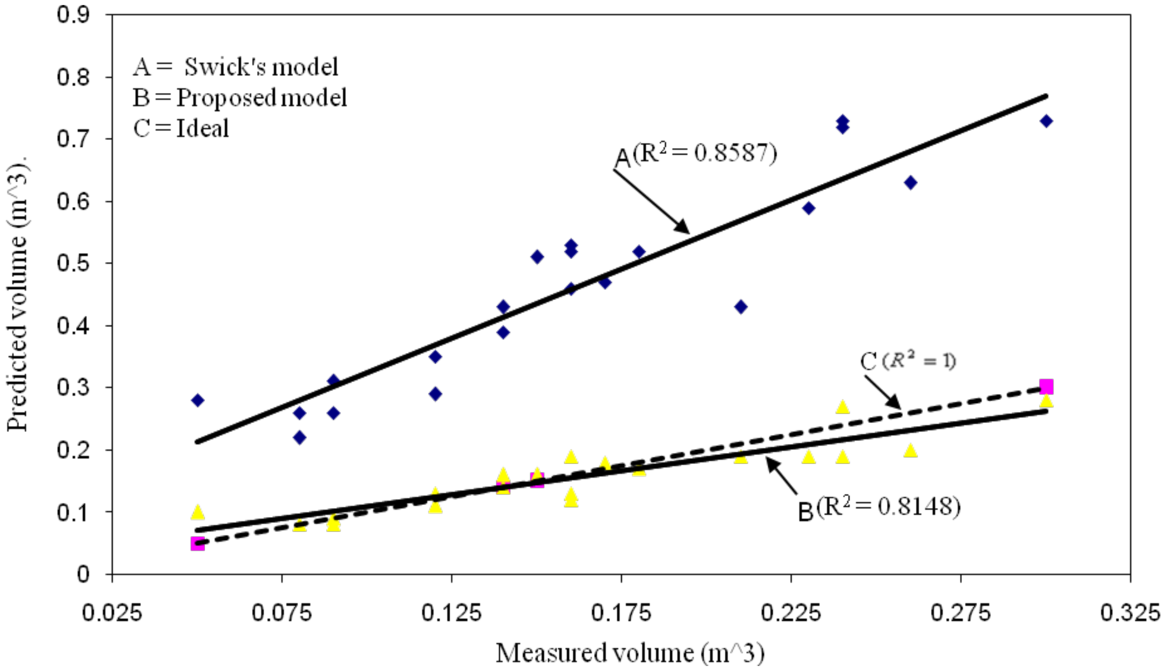


Figure 6. Comparison of measured and predicted volume of the failed soil-profiles

The recorded maximum width of the side circular crescents was compared with those predicted by Swick-Perumpral model (equation 1) and the proposed model (equation 2). Their relationship as presented in Figure 5 shows that the regression line A determined by equation 1 greatly over predicted the actual width as defined by the ideal regression line C. However, it was satisfactory predicted by the regression line B of the proposed model.

As expected, the use of equation 1 resulted in over prediction of the tilled soil volume (Figure. 6). This would lead a mathematical force model to over predict the draft force requirements of a tillage tool. From the same figure, the proposed model adequately predicted the soil volume tilled.

4. CONCLUSION

From the above results, it was concluded that models which are a function of soil water content predict better the size of a failed soil wedge than those that are a function of geometric parameters of the tillage tool. The use of the proposed equation in a mathematical force model is therefore, likely to result in better prediction of the soil-force components acting on the tool than models based on the geometric dimensions of a tillage tool.

5. RECOMMENDATION

The proposed model is valid for sandy clay loam soils at an operating depth of 600 mm. It is therefore recommended to develop similar models for different soils and different operating depths.

6. NOTATION

d = tilling depth
R = rupture radius
s = maximum width of the side circular crescent
x = soil water content (dry basis)
w = tillage-tool width
α = rake angle
β = angle between the rapture plane and the horizontal soil surface

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