A PORTABLE TILLAGE PROFILER FOR MEASURING SUBSOILING DISRUPTION

R. L. Raper, T. E. Grift, M. Z. Tekeste

ABSTRACT. *A portable tillage profiler (PTP) was constructed using a laser distance sensor, a linear actuator, a portable PC, and a lightweight aluminum frame that can quickly and accurately measure aboveground and belowground soil disruption caused by tillage. A laboratory experiment was conducted that determined that soil color did not detrimentally affect the PTP, with expected vertical errors of 2.3 mm and horizontal errors of 0.6 mm being found. However, when pure white and black objects were examined, the errors increased to 4.2 mm vertically and 11 mm horizontally. This maximum error was established when attempting to measure the height and width of a wedge, which had a sharpened edge pointing vertically upward. The PTP was used in the National Soil Dynamics Laboratory soil bins to measure both aboveground and belowground soil disruption caused by two subsoiler shanks. The PTP gave results that enabled differences between the aboveground disruptions caused by each subsoiler to be statistically established.*

Keywords. *Profile, Soil disruption, Subsoiling, Tillage.*

A significant amount of research has been conducted to determine relative differences in draft between various shanks used for subsoiling (Nichols and Reaves, 1958; Gill and Vanden Berg, 1966; Collins and Lalor, 1973; Upadhyaya et al., 1984; Garner et al., 1984; Owen, 1989). Most of these studies examined shanks that were mainly constructed to disrupt the entire soil profile and differed in their approach angle and shank design. Producers were mostly interested in the number of shanks that could be pulled with their tractors and had little regard for how much surface disruption was caused by subsoilers because secondary tillage would be used to even the soil surface prior to planting.

However, agriculture in the U.S. has changed substantially (Towery, 2000), and producers are now interested in much more than tillage energy. Many producers are now adopting conservation tillage systems that incorporate fewer passes of secondary tillage. Primary tillage as done with an in-row subsoiler may be followed directly with a planter. Residue should only be minimally disturbed so as to provide the soil adequate protection from water erosion. Many advertisements for subsoilers now contain not only draft force information, but also include the amount of residue remaining on the soil surface after tillage has been conducted.

Determining the amount of soil disruption or soil movement caused by tillage implements could be just as important as determining the draft energy. Pin-style profile meters have been the most common method of determining soil movement by tillage implements (Hirschi et al., 1987). These consist of a series of equally spaced pins that are lowered onto the soil surface until contact is made. However, manual recording of this information is time-consuming unless a photographic system is used to digitize this information (Wagner and Yu, 1991).

Several other methods have been developed that relied on a moving probe that contacted the soil surface and sensed the presence of soil (Henry et al., 1980; Harrison, 1990; Schafer and Lovely, 1967; Mitchell and Jones, Jr., 1973; Currence and Lovely, 1971). These devices were based on a single probe that was moved horizontally across the soil bed. To start, the probe was moved vertically downward until it contacted the soil surface. The probe maintained minimal contact with the soil and was moved horizontally until it sensed a substantial horizontal force. The probe was then lifted until the lateral force decreased and it continued its horizontal path along the soil surface. These methods, although an improvement over the pin-style profile meters, were mechanically complicated, could take a significant amount of time for measurements, and could disturb the soil profile.

To alleviate the problems previously mentioned, several non-contact methods have been developed based either on ultrasonic (Robichaud and Molnau, 1990) or optical sensors (Romkens et al., 1988; Huang and Bradford, 1990; Flanagan et al., 1995). The ultrasonic measurement systems have rather large horizontal errors (up to 30 mm), which could mask differences in subsoiler shanks.

According to previous research, optical sensors should have accuracy adequate for measurement of tillage profiles (Romkens et al., 1988; Huang and Bradford, 1990; Flanagan

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et al., 1995). However, previous research only examined relatively small differences in elevation, and the systems were not evaluated based on their ability to measure both the soil surface and the bottom of a subsoiled zone in one pass.

Measuring the distance to the soil surface with a laser requires the projection of a laser beam onto the soil, detection of the beam, and then calculation of distance through triangulation. Improvements in laser and instrumentation technology now enable researchers to use a single unit, which contains both the laser and the beam detection unit. It was expected that the close proximity between the laser and the detection unit would enable the bottom of the soil trench to be viewed by both devices at the same time.

Furthermore, the laser measurement system should be portable and be capable of being used in field experiments.

The objectives of this study are therefore:

- To develop a laser measurement system for recording soil surface elevations.
- To evaluate this system in a laboratory setting using various standard shapes.
- To determine if this device could be used to detect differences in soil disruption, both aboveground and belowground, caused by subsoiler shanks.

Methods and Materials

The portable tillage profiler (PTP) was constructed and assembled at the USDA-ARS National Soil Dynamics Laboratory (NSDL) and consists of four components: (1) a laser distance sensor, (2) a linear positioning actuator, (3) a portable PC, and (4) a lightweight aluminum frame.

The laser distance sensor used in this study was a Nova Ranger NR-40 (Nova Ranger, Inc., San Diego, Cal.), which uses a class IIIa laser with an output of less than 5 mW operating at a wavelength of 670 nm. This laser distance sensor has a distance range of 0.3 to 0.9 m (12 to 36 in.), over which it has a maximum reported error of 0.17%. The laser distance sensor requires 12 VDC. Data acquisition is provided by a portable PC, which is connected by an RS-232 cable. A computer program created in BASIC was used to acquire the data. Output is updated as fast as every 5 msec (200 Hz).

An NSK Positioning Actuator (NSK Ltd., Tokyo, Japan) was used to move the laser device across the soil surface. This unit requires 24 VDC and has a maximum distance range of 1 m. The unit has programmable feed rates of 5 to 400 mm/sec. For all of our tests, a standard rate of 50 mm/sec was used.

An aluminum frame was constructed at our laboratory that was both lightweight and portable. Figure 1 shows the frame with the positioning actuator and laser distance sensor attached. Overall length of the unit is 1.25 m (49 in.), height is 0.71 m (28 in.), and width is 0.61 m (24 in.). Total weight of the unit is 23 kg (50 lb). The laser distance sensor was mounted so that it would be positioned 0.425 m (16.8 in.) from the soil surface. This positioning allows the sensor to reliably measure displaced soil above the soil surface up to 0.13 m (5 in.) and below the soil surface down to 0.48 m (19 in.). Two fixed tabs are attached to the lower horizontal members of the frame so that the beginning and end of the data stream can be easily established.

During initial testing, the unit was expected to respond better to lighter colors, so an experiment was conducted to

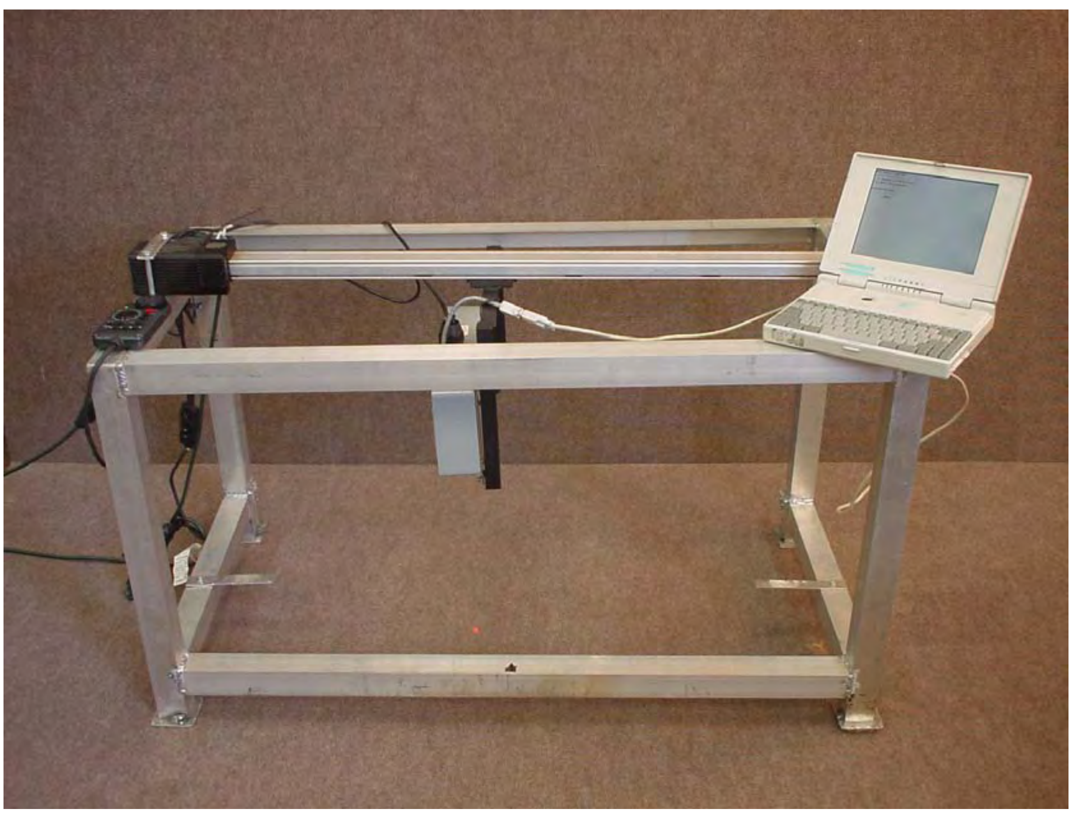

Figure 1. Portable tillage profiler consisting of laser distance measurement system, horizontal positioning actuator, portable PC, and lightweight aluminum frame.

determine if the PTP was sensitive to soil color and to determine its vertical and horizontal accuracy. Several objects, a square block (5.14 cm high × 5.04 cm wide), a cylinder (15.3 cm diameter), and a wedge (3.66 cm high × 7.11 cm wide), were painted four different colors. Munsell soil color charts were used to select colors for two soils. These soils are a Norfolk sandy loam soil (fine loamy, kaolinitic, thermic Kandiudults) and a Decatur clay loam soil (fine, kaolinitic, thermic Rhodic Paleudults) located in the indoor bins of the NSDL. According to Munsell notation (Soil Survey Division Staff, 1993), these soils have wet colors of grayish brown (10YR 5/2) for the Norfolk soil and dark reddish brown (5YR 3/2) for the Decatur soil. Two other colors were selected: white (1 8/1) and black (10YR 2/1). These two colors were chosen to provide upper and lower color extremes. According to these four descriptions, paint was purchased and used to paint the standard objects.

Each object was analyzed with an experiment as a randomized complete block design with 20 replications. To obtain a true height and width, the objects were manually measured prior to the test with a dial caliper. Each object was measured due to slight differences arising from manufacturing processes and a potential variation in paint thickness. Each object was then laid on a straight board below the PTP, and the PTP was operated at a constant speed of 50 mm/s. The laser distance sensor gave a direct reading of height, while the measurement of width was more complicated. First, the total distance traversed by the PTP was determined, and this value was divided by the number of acquired data points for each test run. This procedure allowed an average value of distance per reading to be obtained. This value was found to be relatively constant for each test performed. The laser distance sensor's output was then analyzed and the distance determined between the first and last measurement where the object was sensed. A calculation of percent error was obtained for each run, and these values were tested for statistical significance. Fisher's protected least significant difference (LSD) was used for mean comparison. A probability level of 0.05 was assumed to test the null hypothesis that no differences existed between the different colors.

The PTP was also used in an indoor soil bin experiment using the Norfolk sandy loam soil to determine differences in aboveground and belowground soil disturbance caused by two shanks operating in a soil wetted to several different moisture contents (Raper and Sharma, 2002). The shanks used for the experiment were manufactured by Deere & Co. (Ankeny, Iowa). The straight shank is 1.25 in. (31.8 mm) thick with a 5 in. (127 mm) LASERRIP Ripper Point and is currently used on the John Deere 955 Row Crop Ripper. The minimum-tillage shank is 0.75 in. (19 mm) thick with a 7 in. (178 mm) Min-till point and is used on the John Deere 2100 Minimum Till Ripper.

The aboveground soil disruption was measured in several locations along the path of the subsoiler shank immediately after tillage had been conducted. The loosened soil was then removed, the PTP repositioned, and measurements of the trenched zone acquired. Five measurements were taken in each location with the machine being repositioned across the subsoiled trench each time.

Results and Discussion

An example of the output received from the PTP is given in figure 2 for each of the three standard objects. Note the high values measured near the beginning and ending of each run. These points are purposely included to determine when the laser leaves the tabs on the edge of the PTP and begins measuring the distance to the ground.

Results from the experiment using the cube showed that the PTP obtained very accurate measurements for this object. Measurements of height were all within 4% (2 mm), with the white color having an error of 2.2% and the other colors having errors of -3.4%, -3.5%, and -3.7% for the black color, Norfolk soil color, and Decatur soil color, respectively (fig. 3). Measurements of width for this object also showed little error, with the minimum value attributed to the Norfolk soil color (0.4% error) and the maximum error found for the black color (-3.3% error).

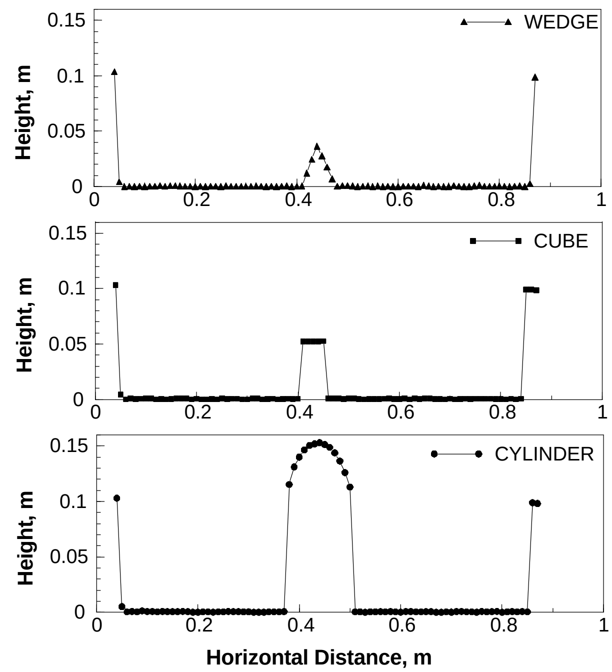

Figure 2. Example profiles of the standard objects painted dark reddish brown to simulate color of Decatur clay loam soil.

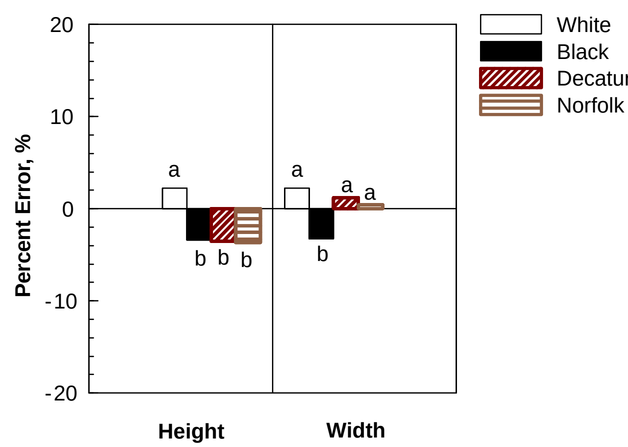

Figure 3. Percent error for measurements of height and width of the cube. $LSD_{0.05}$ (height) was 1.32%, and $LSD_{0.05}$ (width) was 2.46%.

Measurements of percent error for the height of the cylinder were also minimal (fig. 4), even though this object was three times larger than the cube. For the cylinder, the minimum value of error was found for the black color (0.3% error; 0.4 mm error) and the maximum value of error was found for the white color (-1.6% error; 2.4 mm error). However, width measurements of the cylinder were not as close for the black color. This color showed an error of -14.7% (22 mm error), while all other colors had errors much closer to zero (fig. 4).

The wedge proved to be the most challenging object to measure in both height and width (fig. 5). For the height measurement, the black color again gave the largest error of -11.4% (4.2 mm error) with the white color having the minimum value (-2.9% error; 1.1 mm error). Measurements of width proved to be difficult for the white and black colors, with rather large measurements of error of 14.9% (11 mm error) and 8.2% (5.8 mm error), respectively. Minimal values of error were both obtained for the Decatur soil color (0.5% error) and the Norfolk soil color (0.2% error).

From these experiments, it seems clear that the PTP is very capable of measuring accurate heights and widths of objects colored similar to the tested soils. The maximum percent errors of height found for these colors were for the wedge and were -6.1% for the Decatur soil color and -6.3% for the Norfolk soil color. These errors for soil-colored objects indicate that our height measurements should be within 2.3 mm of the actual measurement. All percent errors of width for soil colored objects were extremely small, with the maximum being obtained for the cube (Decatur, 1.2%). This measurement indicates that for soil-colored objects, our width measurements should be within 0.6 mm of the actual measurement.

However, pure black or white objects offered some limitations, with larger errors typically being found for these objects. The maximum height error was found for the black color for the wedge (11.4%), while the maximum width error was found for the white color for the wedge (14.9%). If these pure colors are encountered in soil, then larger errors should be expected.

The previous results showing the validity of the PTP for use in soils enabled us to pursue other research using the PTP to measure aboveground and belowground soil disruption. Figure 6 shows a profile constructed for each of the two tillage shanks used in this experiment. The straight shank has a slightly wider belowground profile with a more rounded bottom of the trench. The minimum-tillage shank is narrower and leaves a more pointed trench. However, there was no statistical difference in the amount of belowground disruption caused by these subsoilers, with the straight shank having an average cross-sectional area of 796 cm^2 and the minimum-tillage shank having an average cross-sectional area of 760 cm^2. The aboveground disruption of each subsoiler is similar, but the minimum-tillage shank does not disrupt the soil to the same height as the straight subsoiler, nor does it have the quantity of soil disrupted above the soil surface. A statistical difference ($P \leq 0.006$) was found between the two shanks, with the straight shank having an aboveground disruption cross-sectional area of 361 cm^2 and the minimum-tillage shank having an aboveground disruption cross-sectional area of 314 cm^2.

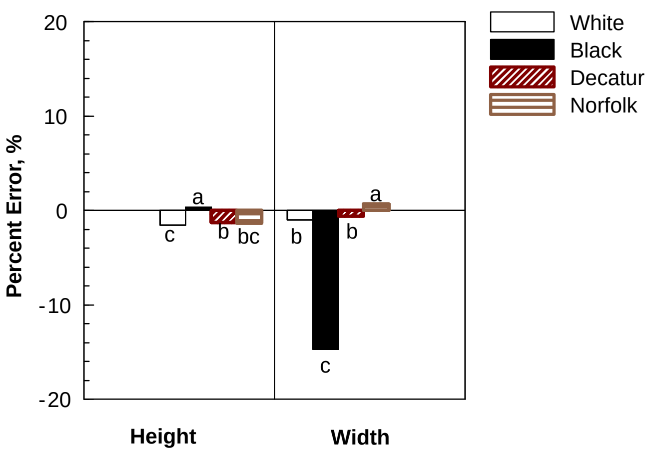

Figure 4. Percent error for measurements of height and width of the cylinder. $LSD_{0.05}$ (height) was 0.24%, and $LSD_{0.05}$ (width) was 1.30%.

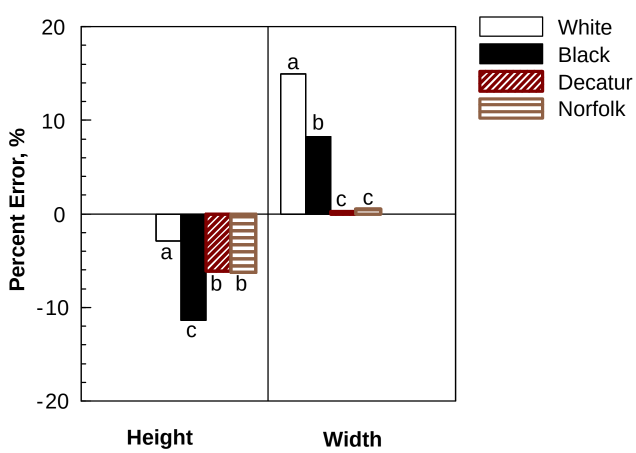

Figure 5. Percent error for measurements of height and width of the wedge. $LSD_{0.05}$ (height) was 1.63%, and $LSD_{0.05}$ (width) was 5.52%.

Conclusions

- A portable tillage profiler was constructed using four components (a laser distance sensor, a linear actuator, a portable PC, and an aluminum frame) that quickly and accurately measured aboveground and belowground soil disruption.
- A laboratory experiment demonstrated that the PTP was accurate when used with two soil colors commonly found in the southeastern U.S. When using the PTP to measure

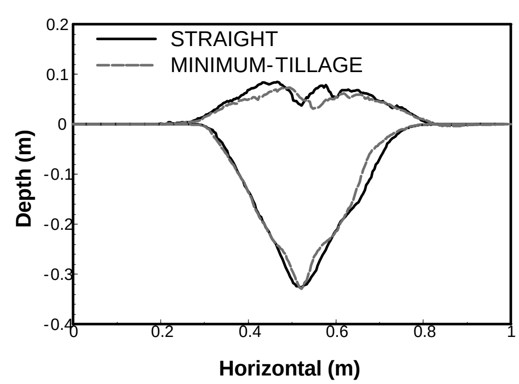

Figure 6. Average shank comparison profiles measured with the PTP showing differences between a straight shank and a minimum-tillage shank for both aboveground and belowground soil disruption.

height and width of objects colored to match these soils, maximum errors should not be greater than 2.3 mm vertically and 0.6 mm horizontally. However, when using the PTP to measure objects painted black and white, the accuracy was not as good, with maximum errors being 4.2 mm vertically and 11 mm horizontally.

- The PTP was used in the NSDL soil bins to detect differences in both aboveground and belowground soil disruption achieved between subsoiler shanks operating at several moisture contents. The results showed that the belowground disruptions were not different between the shanks, but that the minimum-tillage shank disrupted the soil surface to a lesser degree than the straight shank.

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