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A portable device to measure soil erosion/deposition in quarter-drains

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Abstract

Assessment of soil loss/deposition from quarter-drains (drainage ditches perpendicular to furrows) at specific locations or determining sediment transport within ditch systems following a rainfall event is difficult and time consuming. Automatic samplers are stationary and usually located at the end of plots to assess total sediment loss from a whole area. However, to quantify changes to cross-sectional areas at specific points within a ditch system, a portable measuring tool is required. To precisely assess soil erosion along the length of a quarter-drain, a portable device was designed and tested under typical field conditions. One person can effectively operate the device and because of its low cost, it is ideal for cases where budget constraints exist. The tool can measure depths up to 500 mm and easily be modified for usage with large ditches. The device was successfully employed in the spring and summer of 2003 and 2004 where it was utilized after rainfall events to assess soil erosion/deposition from quarter-drains on sugarcane fields in southern Louisiana.

Keywords: Soil erosion, portable erosion meter, quarter-drain, surface drainage

Introduction

Automatic sampling systems have been used to quantify sediment loss from run-off and are usually located at the end of plots to assess total sediment loss from a whole plot area. However, to quantify changes at a specific cross section within a surface ditch system, a portable measuring device is needed that can be easily and quickly used following rainfall events. In many previous designs, soil surface height was measured from the displacement of steel pins that were lowered from a reference level onto the soil surface to be measured (Burwell *et al*., 1963). Mitchell & Jones (1973) used a rotational potentiometer to sense the height of the soil surface. Moore & Larson (1979) used a camera to record the pin locations at the soil surface. A linear variable differential transducer (LVDT)-based meter was developed by Podmore & Huggis (1981) to measure soil surface roughness. In another soil erosion study, a camera and slide film were utilized with a rillmeter, and then projected colour slides were used to read data against the end of each pin (Elliot *et al*., 1997). Wagner & Yu (1991) developed a digitization procedure of pin-based profile meter photographs using a digitizing scanner to scan photographs and a custom-written computer program. This procedure allows more accurate data to be obtained, but requires several steps to take the data and two people to move the meter to different measuring locations. A common problem with steel pins is their heavy weight, which increases the weight of the meter and the accidental falling of the pins on the soil surface resulting in errors in depth measurements. Other more complex electronic meters have been developed (Henry *et al*., 1980; Hirshi *et al*., 1987; Harrison, 1990). Non-contact meters have also been developed for measuring the roughness of a soil surface using sonar (Kolstad & Schuler, 1980), acoustic backscatter (Oelze *et al*., 2003) and lasers (Raper *et al*., 2003). Most electronic meters are heavy, expensive, require custom-made carriage frames, and require at least two people to operate the devices. In addition, electronics can malfunction under very humid weather and wet soil conditions.

In southern Louisiana, the assessment of soil loss under natural weather conditions from quarter-drains installed on alluvial clay soils is usually performed following a rainfall event when the soil surface is still soft, relative air humidity is extremely high and vegetation (i.e. sugarcane) is still wet. Because of these conditions, a non-electronic, lightweight

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portable device was needed to measure changes in quarter-drains' cross-sectional profiles over a 450-mm depth range following rainfall events.

Cost-effective methods are required to better assess the distribution of soil erosion and deposition at particular points in a quarter-drain system. The objective of this study was to develop a lightweight, inexpensive, hand-held device which was capable of being operated by one person to quickly measure soil loss from the entire cross-sectional profile at specific locations in surface ditch (quarter-drain) systems.

Development and design criteria

The concept of measuring soil erosion or deposition depth and the associated cross-sectional shape of a quarter-drain ditch is based on using a frame holding multiple equally spaced (every 38 mm) aluminium pins that could be easily positioned to make contact with the cross-sectional profile of the quarter-drain. The spacing between pins was determined by comparing the area of the actual semi-circular cross section of the freshly constructed quarter-drain with the area calculated from the width of the quarter-drain and linear distances between contact points (pins) at the quarter-drain's surface. The objective was to keep the difference between these areas less than 1% and to minimize the weight of the meter. By connecting all points of the upper end of these pins, the shape of the quarter-drain can be quantified (Figure 1). The pin housing consisted of two parallel aluminium bars (914 mm long) mounted together; aluminium pins were located between the aluminium bars. Compression springs were also inserted between the aluminium bars to provide continuous tension between the two bars. This portable meter can be easily modified by increasing the width of the pin housing and increasing the number of pins in order to make measurements in wider surface ditches.

Meter design

The design details of the portable soil erosion meter are shown in Figure 2. Nineteen (8-mm-diameter) 610-mm-long aluminium pins were inserted inside this aluminium frame. To provide pin guidance, sliding channel slots were created by drilling (8-mm-diameter holes) simultaneously through the two aluminium rectangular pieces which were clamped together with a 1.6-mm aluminium flat bar insert. This was necessary to obtain positive friction for all 19 pins after the unit was tightened. In addition, to compensate for some flexing of the aluminium housing caused by the two compression springs and locking bolts, each pin was individually secured by a silicone tip. The silicone was placed in a 6-mm-diameter plug hole drilled in the middle of each sliding channel slot in one half of the aluminium housing. Even if the two wings nuts were loose, the silicone provided sufficient friction for each pin, so that the pins could be easily adjusted vertically; this also prevented pins from falling which could disturb the soil surface of the quarter-drain to be profiled. The horizontal plug holes drilled concentrically in the aluminium housing and filled with silicon plugs against vertical aluminium pins gave improved pin control over other designs. Nineteen stainless steel millimetre scales were glued to the aluminium sheet in such a way that each pin was against the millimetre

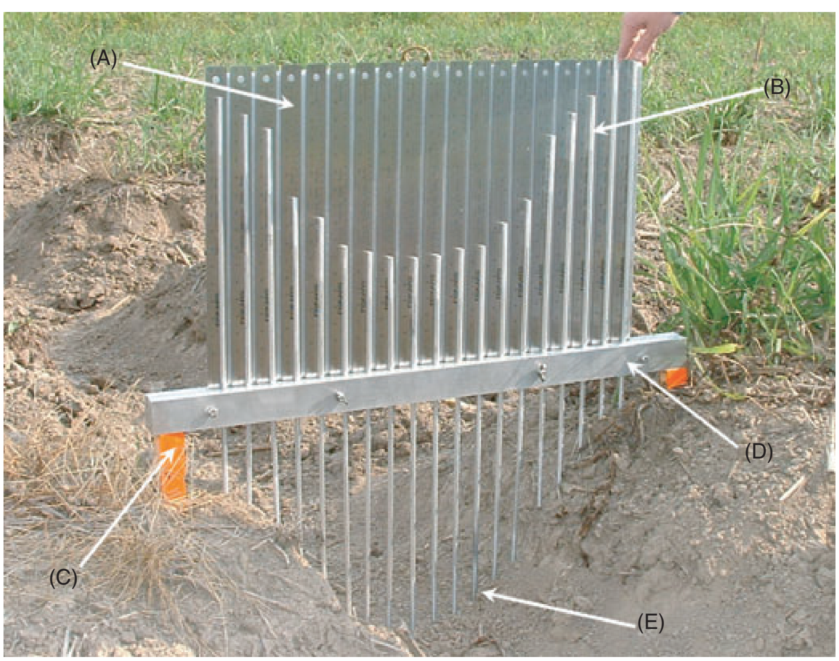

Figure 1 Portable meter placed in a quarter-drain to obtain a depth profile: (A) stainless steel millimetre scale glued on the aluminium sheet, (B) aluminium pin, (C) benchmark stake, (D) aluminium housing, (E) pins (total of 19) in contact with quarter-drain soil surface.

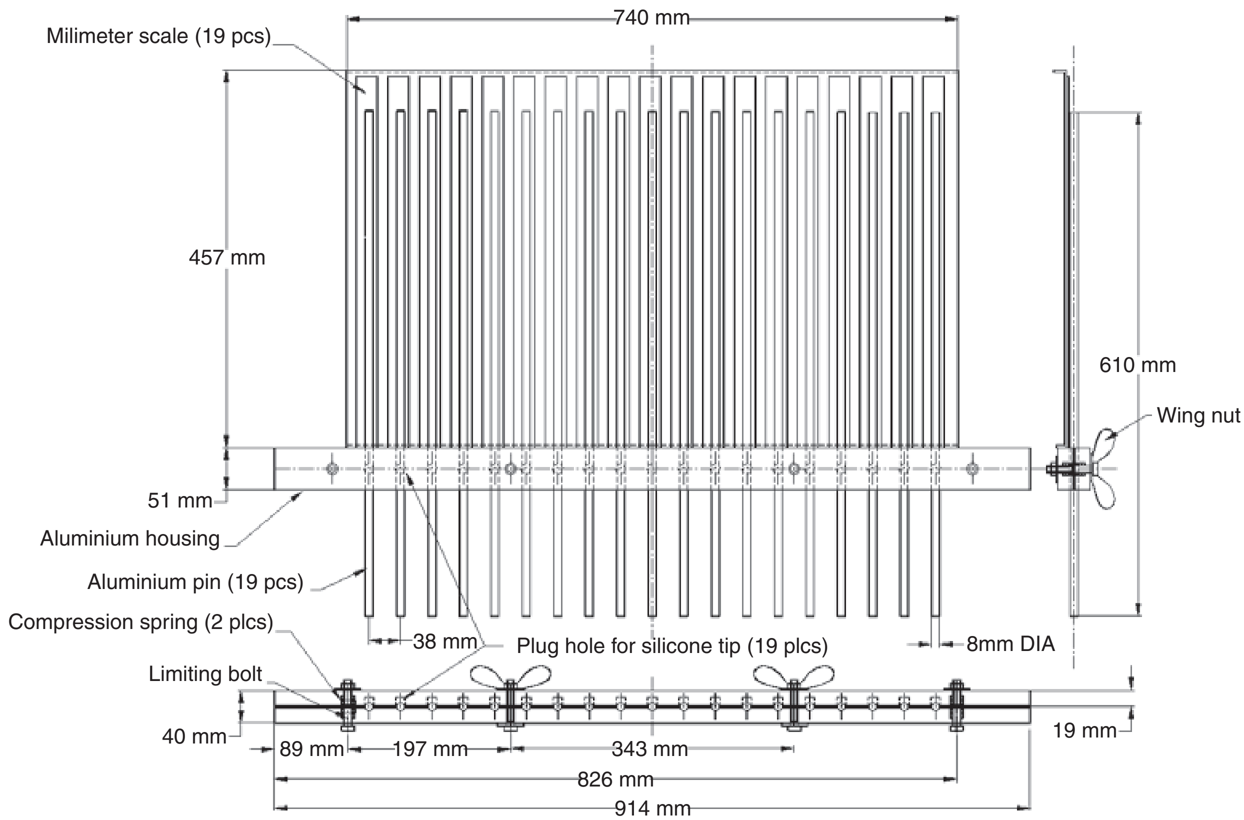

Figure 2 Design of portable soil erosion meter with the following dimensions: length, 914 mm; width, 40 mm; height, 800 mm; pin diameter, 8 mm; pin length 610 mm; pin reach, 500 mm.

scale. The aluminium sheet with scales was attached by screws to the top of one piece of the aluminium housing.

Site preparation

Two wooden stakes (one on each side of the quarter-drain; approx. 0.8 m apart) were inserted into the ground and levelled to provide a benchmark for consecutive measurements (Figure 3). For best results, a 1.2-m-long level was used to adjust for proper horizontal alignment of the measuring device. A hammer was used to drive the stakes into the ground.

Device positioning

In order to make repeated measurements at the same location over time, alignment marks were made on the wooden stakes and on the instrument's frame (Figure 4a); this allowed for exact repositioning of the device each time. Alternatively, to simplify positioning the device on benchmark stakes, a round metal rod could be used (instead of a wooden stake) on which the device could be precisely positioned using a plug hole drilled in the centre of the meter's frame (Figure 4b).

Operation

The measuring device must first be correctly positioned on the two wooden stakes with respect to the reference benchmark stakes and meter's frame (i.e. flush with the chosen vertical edge of the stake; Figure 4a). Next, the two outer wing nuts (5/16″ × 18NC) are released, so that the 19 aluminium pins can be positioned against the semi-circular cross-sectional profile of the quarter-drain. The silicone tips provide enough friction to prevent pins from falling into the soil surface; however, each pin must be manually positioned to ensure proper pin to ground contact. After all pins are in contact with the quarter-drain surface, the two wing nuts must be tightened to secure the aluminium pins prior to data collection.

Data collection

The measuring device is equipped with 19 individual millimetre scales glued to the aluminium sheet mounted to the frame behind the pins (Figures 1 and 2). The upper ends of the aluminium pins move against 19 stationary stainless steel rulers so that the upper ends of each pin can be used as a reading point. After reading the distances for each pin, data

Figure 3 Preparing and leveling benchmark stakes for erosion/deposition measurements in the field.

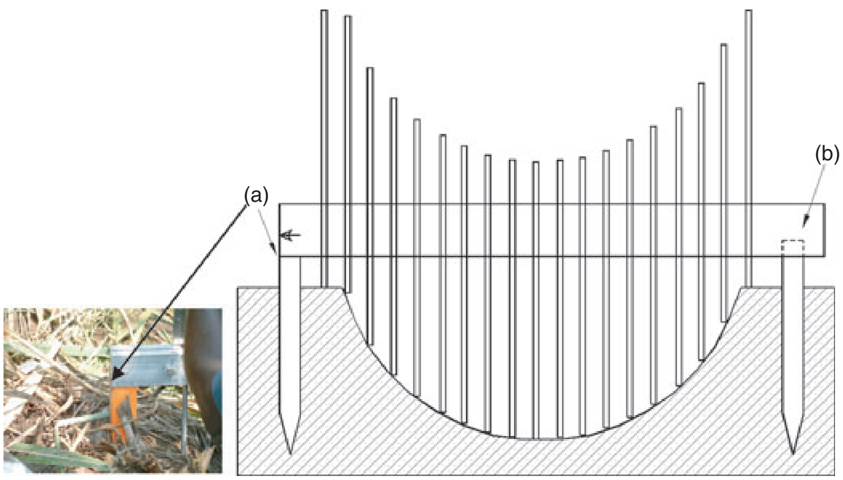

Figure 4 Placement of the device on benchmark stake or on a round metal stake. (a) Vertical edge of the stake matches the frame's end. (b) A plug hole in the meter's frame for easy positioning of the frame on a round metal stake.

were manually entered to a data-logger and then data downloaded to a computer spreadsheet program at a later time. This process was repeated at each location following rainfall events that occurred during the experiment (Figure 5).

Quarter-drain cross-sectional area calculation

Initial cross-sectional area calculation. As the spacing between centres of all pins is constant (distance *b*), the initial cross-sectional area is calculated as a sum of trapezoidal areas using the trapezoidal integration technique (Burden & Faires, 2000) (Figure 6) as follows:

$$A_1 = (H_1 + H_2)\frac{b}{2}, A_2 = (H_2 + H_3)\frac{b}{2}, \ldots, A_{18} = (H_{18} + H_{19})\frac{b}{2} \qquad (1)$$

where A_1 to A_{18} is the initial area 1 to 18; H_1 to H_{19} is the trapezoidal base (length of aluminium pin above the frame); *b* is the height of trapezoid (distance between centres of pins).

By adding sections of areas between each pin, the total initial area above the meter's frame at location (*l*) is calculated from the equation:

$$A_{\mathrm{t\_init}}(l) = A_1 + A_2 + A_3 + \cdots + A_{18} \qquad (2)$$

$$A_{\mathrm{t\_init}}(l) = \frac{b}{2}(H_1 + 2H_2 + 2H_3 + \cdots + 2H_{18} + H_{19}) \qquad (3)$$

Cumulative cross-sectional area calculation. After each rainfall event that produces run-off or has the intensity for causing erosion and sediment transport, the device must be used again in the same exact manner as in the initial measurement of the cross-sectional area. The cumulative cross-sectional area of soil erosion/deposition (Figure 6) was calculated from the following equation:

Figure 5 Data collection from quarter-drain cross section following a typical rainfall event.

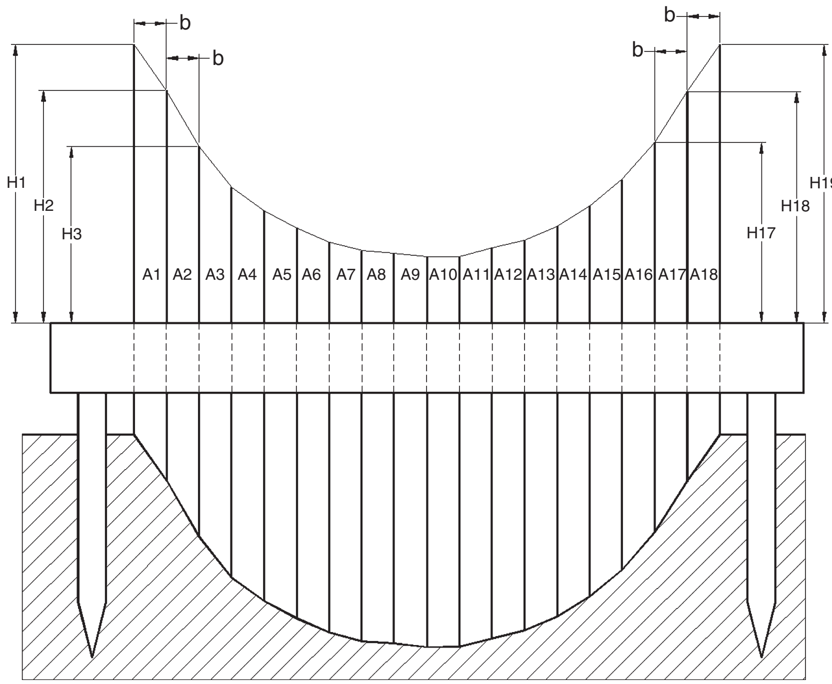

Figure 6 Calculation of the initial cross-sectional area above the upper edge of the device's frame.

$$A_{\mathrm{cum}}(i,l) = A_{\mathrm{t\_cons}}(i,l) - A_{\mathrm{t\_init}}(l) \quad (4)$$

where $A_{\mathrm{cum}}(i, l)$ is the cumulative eroded/deposited area at location (l); $A_{\mathrm{t\_cons}}(i, l)$ is the total consecutive area following rainfall (i) at location (l); $A_{\mathrm{t\_init}}(l)$ is the total initial area measured at the beginning of experiment at location (l), $i = 1$ to n; n is the number of rainfall events during the experiment.

Calculation of the net cross-sectional area caused by a single rainfall event. To determine the effect of rainfall on soil loss in quarter-drains produced by a single rainfall event, the net area can be calculated from the following equation:

$$A_{\mathrm{net}}(i,l) = A_{\mathrm{t\_cons}}(i,l) - A_{\mathrm{t\_cons}}(i-1,l) \quad (5)$$

where $A_{\mathrm{net}}(i, l)$ is the net eroded/deposited area at location (l) caused by a single rainfall event (i); $A_{\mathrm{t\_cons}}(i, l)$ is the total consecutive area following the last rainfall (i) at location (l); $A_{\mathrm{t\_cons}}(i - 1, l)$ is the total consecutive area following the previous rainfall ($i - 1$) at location (l).

To distinguish between soil erosion and sediment deposition in quarter-drains, two mathematical expressions were

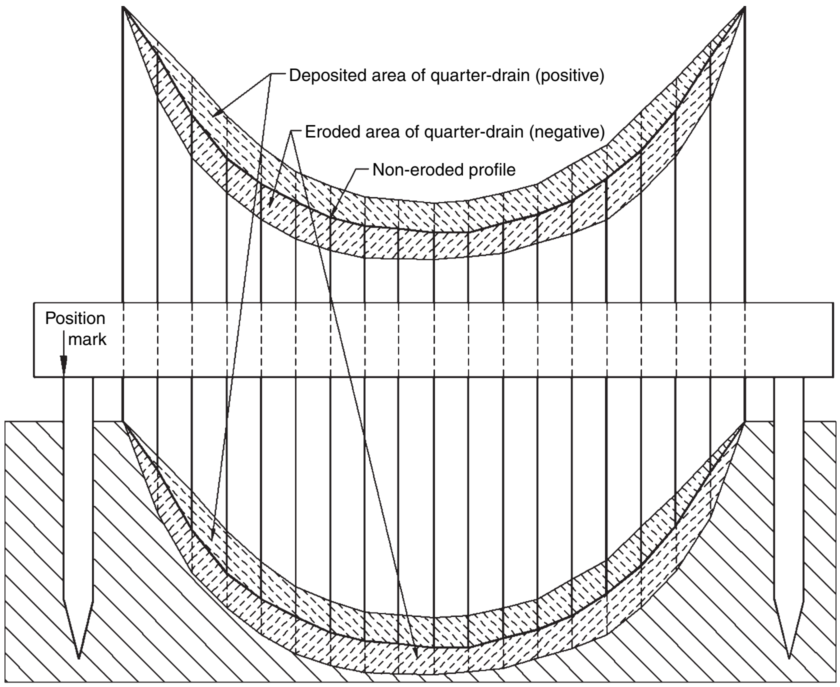

Figure 7 Calculation of the net eroded or deposited area for a quarter-drain.

used. The millimetre-scale stainless steel ruler is attached on the meter's frame in such a way that if the difference between present and previous area (net area) is negative, then soil erosion is indicated, and if the net area is positive, then soil deposition is indicated (Figure 7).

Calculation of the average cross-sectional area of erosion/deposition in a quarter-drain. To assess soil erosion/deposition from the entire length of quarter-drain the average area was calculated from the following equation:

$$A_{\mathrm{c\_avg}}(i) = \frac{\sum A_{\mathrm{cum}}(i,l)}{k} \tag{6}$$

$$A_{\mathrm{n\_avg}}(i) = \frac{\sum A_{\mathrm{net}}(i,l)}{k} \tag{7}$$

where $A_{\mathrm{c\_avg}}(i)$ is a cumulative average area following rainfall event (i); $A_{\mathrm{cum}}(i, l)$ is a cumulative area at location (l); $A_{\mathrm{n\_avg}}(i)$ is a net average area due to a single rainfall event (i); $A_{\mathrm{net}}(i, l)$ is a net area at location (l) due to a single rainfall event (i); where l = 1 to k; k is the number of locations.

Calculation of soil loss or sediment deposition volume into quarter-drain. From data entered into a spreadsheet, the volume can be easily computed using known formulas for area and volume. The volume is determined by multiplying the average cross-sectional area of the eroded/deposited soil (equation 6) by the length of the quarter-drain. The average mass of soil loss can be found using known soil bulk density multiplied by the volume of soil eroded or deposited. By increasing the number of measuring points, the accuracy of the calculated average volume can also be increased.

Field performance and results

The device's performance was based on field testing in the spring and summer of 2003. The experiment was designed to measure soil erosion from small surface ditches (quarter-drains) on sugarcane land. Four locations were chosen to assess soil loss from each quarter-drain. One quarter-drain was chosen to evaluate the performance of the portable profile meter. Changes in quarter-drain profile were measured at four locations evenly spaced at 1.79 m along the quarter-drains, after a rainfall event. The example below shows changes in cross sections of the quarter-drain at four locations due to the first rainfall that produced 17 mm of precipitation. Based on this rainfall event, there was evidence of erosion (negative depth) to the side walls of the quarter-drain and some soil deposition close to the centre of the quarter-drain (locations A, C and D) except for location B at which soil erosion occurred (Figure 8).

Changes in quarter-drain profile averaged over the entire length of the quarter-drain were also evaluated (cumulatively) following four consecutive rainfall events. Based on the chosen quarter-drain average, changes in cross-sectional profile were calculated. Following the first rainfall event (17 mm) erosion from side walls was visible with minor deposition near the centre of the quarter-drain (Figure 9a). After the second rainfall event (16 mm) the deposition increased at the bottom of the quarter-drain (near centre). However, the erosion from the side walls decreased,

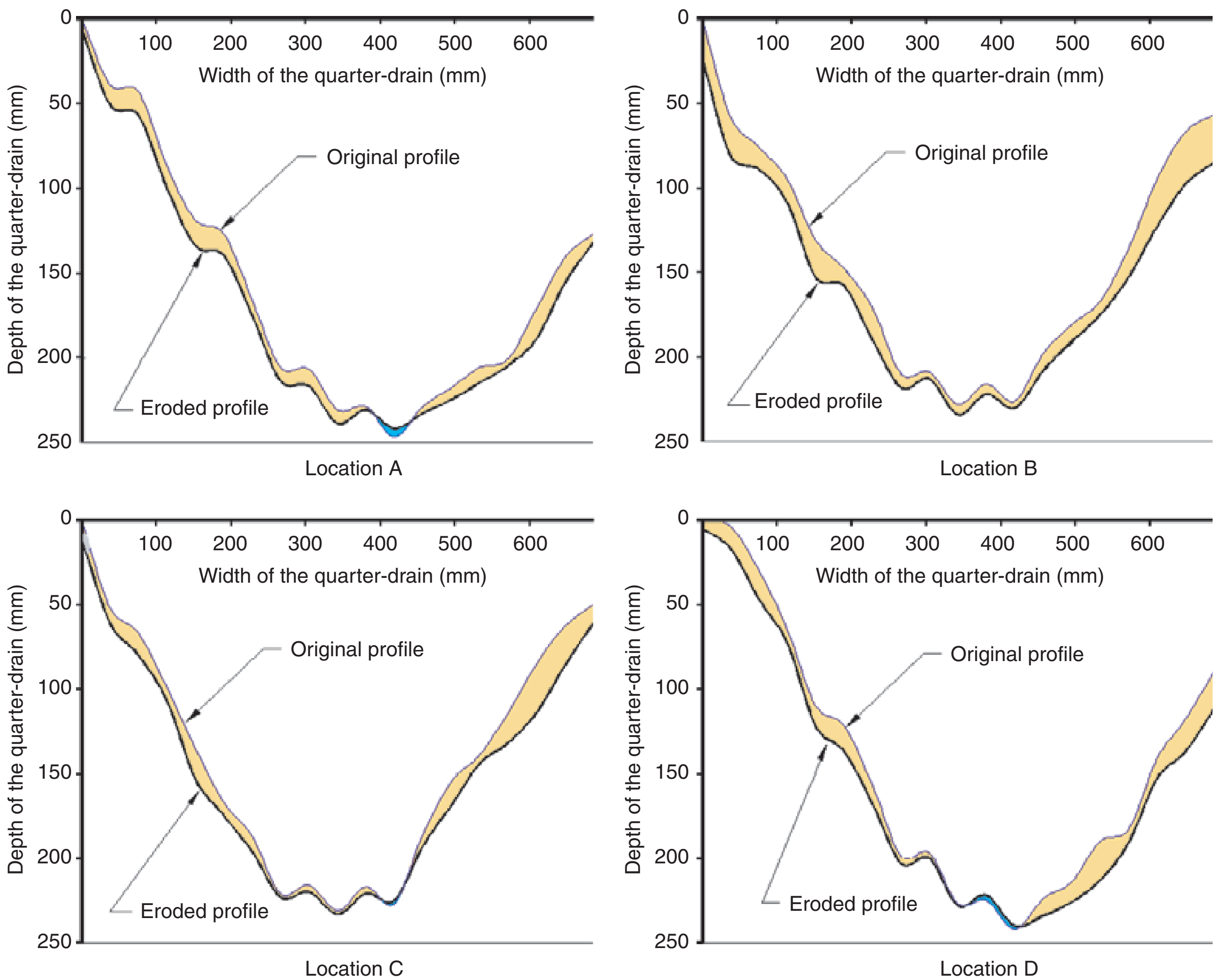

Figure 8 Soil erosion or deposition depth and areas measured across quarter-drain's cross section at various locations. Locations A–D spaced 1.79 m apart in the quarter-drain. Data are associated with a rainfall event which produced 17 mm of rain.

indicating sediment deposition from furrows (Figure 9b). After the third rainfall event (13 mm) the deposition at the bottom of the quarter-drain increased and erosion from side walls slightly decreased indicating further deposition from different areas of the ditch system (Figure 9c). After the fourth rainfall event (32 mm) deposition at the bottom of quarter-drain further increased and erosion from the side walls also increased indicating that the eroded sediment from the side walls was deposited near the middle of the quarter-drain (Figure 9d).

Conclusions

This inexpensive, portable and lightweight (9 kg) measuring device performed very well under typical weather and soil conditions. As the meter was built from non-corrosive materials such as aluminium (pins, base and frame) and stainless steel (bolts, nuts, washers and rulers with millimetre scale), no problems were reported in functioning of the tool during the two measuring seasons. The operator could read the device to 500 mm within 1-mm accuracy (the smallest graduation interval of the scale). Occasional cleaning was required to remove moist soil particles and moisture from pins. Because of its simplicity, the meter can be fabricated and assembled in 1 day with a cost not exceeding $200. This measuring system is ideal for cases where budget constraints exist. In particular, this system's low cost may make it an attractive tool for erosion assessment where budget constraints exclude the purchase of an expensive electronic meter. The meter was successfully operated by one person due to the locking feature of pins with respect to the meter's frame and utilizing horizontal plug holes in the frame filled with silicone tips to improve pin control. Locking wing nuts also allowed the user to read data after moving the meter from the benchmark location for more convenient readings from the millimetre rulers. This portable meter allowed for the study of changes in cross-sectional area due to soil erosion/deposition in small surface ditches (quarter-drains) at specific locations within a

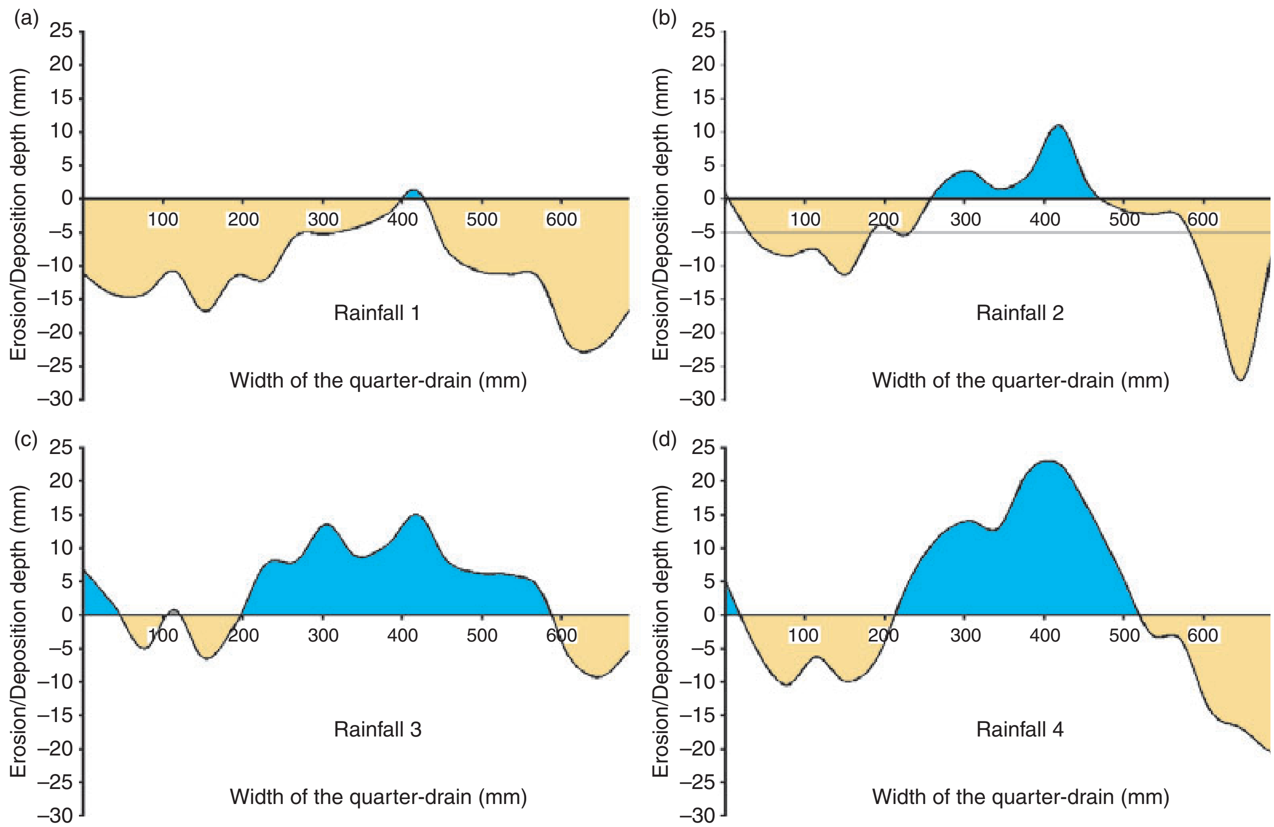

Figure 9 Average cumulative changes in cross-sectional area of the quarter-drain following rainfall events showing erosion (−) deposition (+): (a) after first rainfall event; (b) after second rainfall event; (c) after third rainfall event; (d) after fourth rainfall event.

ditch network. Monitoring these changes is important in terms of proper ditch management (sizing, cleaning), and improving effectiveness of residue management in minimizing run-off/sediment loss within the field.

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