Comparative assessment of water infiltration of soils under different tillage systems in eastern Botswana

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ABSTRACT

Water infiltration is an important component of water balance for improving crop production potential in dryland soil tillage systems in Botswana, particularly in the eastern region. Hardsetting soils common in arable lands of Botswana often require some kind of tillage such as mouldboard ploughing, chisel ploughing and ripping to improve water harvesting and crop growth conditions. The objective of this study was to compare ponded cumulative infiltration, steady state infiltration rate and sorptivity of soils cultivated using deep ripping, single and double mouldboard ploughing. This study was conducted on Chromic Luvisols (sandy loam), Haplic Luvisols (sandy clay loam), Ferric Luvisols (clay loam), and Ferric Arenosols (sand). Infiltration was measured using double ring infiltrometer method for 4 h. Although infiltration was smaller on traffic line of deep ripping system at all sites, it was only significantly (*P < 0.05) different on Ferric Luvisols and Ferric Arenosols. Compared with conventional ploughing, steady state infiltration was greater but not significantly (*P > 0.05) different under deep ripped. Cumulative and steady state infiltration were greater under sandy than heavy soils, smaller under double ploughing compared with single ploughed and deep ripped soils. Sorptivity was not significantly (*P > 0.05) different among tillage systems but was greater under sandy than heavy loam soils. Information on tillage and infiltration can improve implementation of water harvesting technologies and crop production in Botswana.

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1. Introduction

Patterns of rainfall common in semiarid regions in particular Botswana are high intensity storms leading to excess water in a short period of time. Impacts of heavy rainstorms include destruction of soil structure by raindrops that lead to crusted soil surface and increased runoff. For certain high intensity rainfalls, runoff can be as high as 50% and can decrease soil water infiltration (LWMP, 1992) and limit water available to crops. The presence of a thin compacted layer in the topsoil can reduce infiltration rate and enhance runoff and soil erosion (Wilcock, 1981; FAO, 1993). Thus, the ability of a soil to infiltrate rainwater and store it in the soil is of great importance in determining the amount of runoff and soil water storage for crop production (Hudson, 1987; Unger and Skidmore, 1994). Possible tillage options to reduce runoff and increase infiltration on croplands are roughened soil surface to increase surface water retention, surface residue management, and ripping or subsoiling. This change soil surface characteristics as well as chemical and physical properties in the soil profile.

Most arable soils in Botswana are characterized by petrofacies dense layers, low organic matter content, low nutrient content and low pH or are typically ferrirogenous tropical soils. Hardsetting soils are generally characterized as massive or structureless and shrink and set hard on drying, reducing macroporosity that conduct water during infiltration process (Wilcock, 1979; Mullins et al., 1990). Causes of hardsetting of hard-setting soils are acidity, low fertility and low organic matter content and inappropriate tillage operations. Textural properties of hardsetting soils range from loamy sand to sandy clay with low shrink–swell capacity and can pack to high bulk density values on drying. In consideration of relatively compacted surface soil layers with low infiltration capacity, low vegetation cover and high intensity rainfall patterns, runoff potential is high particularly in eastern Botswana.

Mouldboard ploughing (10–20 cm depth) is a conventional soil tillage practice in Botswana (LWMP, 1992; Persaud et al., 1992). Deep tillage (>20 cm soil depth) is often needed on poorly drained or hardsetting soils to improve water infiltration and seedbed conditions for plant growth (Baver, 1956; Wilcock, 1981). Further non-inversion tillage operation such as chisel ploughing or ripping can decrease soil strength while causing little damage to soil.
structure on fragile soils (Willgoose, 1979). Deep ripping is defined as a mechanical manipulation of soil to break up or pierce highly compacted and root restrictive, impermeable or slowly permeable soil layers (Baver, 1966). The effectiveness of deep ripping depends on soil texture, soil water content, compaction depth, compaction extent and ripper time spacing and type. Dry soil ripping shatters the soil and effectively loosens compacted soils although the costs increase with depth and soil dryness (Richards et al., 1995; Lacey et al., 2001). Generally, subsoiling clay accomplishes very little benefits because of the puddling action of the subsoiler (Willgoose, 1979; Bonneman et al., 1989).

In deep ripping systems of silty loam textured soils, infiltration can be increased and has been shown to be directly related to structural stability (Tisdall and Aden, 1985), bulk density (Patel and Singh, 1981) and pore structure (Antony, 1990). Thus, tillage alters soil pore size and geometry and consequently influences soil water transmission and storage on all loam soils (Brees et al., 1992; Lal et al., 1994). The effects of ripping are not permanent but long-term correction may be done using vertical mixing (Marshall and Holmes, 1979) or using gypseum and liming (Richards et al., 1995). Soil surface crusting inhibited seedling emergence (Sumner and Stewart, 1992) while compacted subsoil reduced root development, and low water-holding capacity limited crop establishment and crop yields (Willgoose, 1979; Hamblin, 1985). Although bulk density was greater under no tillage, ponded infiltration was equal or greater than tilled soils of silty loam texture (Ehlers, 1975; Sauer et al., 1990).

Hydraulic properties that determine water entry into the soil surface and movement in the soil profile are sorptivity, infiltration and hydraulic conductivity and may be used to evaluate tillage operations. Infiltration rate was successfully used to characterize tillage techniques on sandy dayeay loam soils (Topalolu, 1999). Infiltration rate may be defined as the volume of water flowing into the soil profile per unit surface area of the soil (Hill, 1980). Soil infiltration capacity is initially high and tends to constantly decrease until it asymptotically approaches a constant rate termed final or steady state infiltration rate. The steady state infiltration rate represents saturated hydraulic conductivity of the soil. When water delivery to the soil is less than infiltration capacity, the supply rate determines the infiltration rate. If water delivery exceeds infiltration capacity, surfaces conditions determine the infiltration rate and excess water is lost as runoff.

Sorptivity is water uptake by the soil in the absence of gravitational effects (Philip, 1957a). It is a theoretically and physically based hydrologic parameter that can be rapidly measured in the field (Smiley and Knight, 1976; Walker and Cheng, 1986). Sorptivity provides the water absorption rates and varies with soil water content. Soil sorptivity and infiltration can be a good indicator of how tillage affects soil structure.

The objective of this study was to compare the effect of single moldboard ploughing, double moldboard ploughing, deep ripping, and permanent traffic lines between riprines on infiltration capacity and sorptivity under different soil types.

2. Materials and Methods

2.1. Site description

Four sites with different soil types were selected at Sebele near Gaborone, Tswidi (Pelohtsehla) in Kanye area and Sese near Jwaneng during the 1988/1989 cropping season. The four soil types were classified as follows: (a) Chronic Luvic (FAO, 1998) or Haplustalf (Soil Survey Staff, 1998); (b) Ferric Luvic (FAO, 1998) or Haplustalf (Soil Survey Staff, 1998); (c) Hapludalf (FAO, 1998) or Haplustalf (Soil Survey Staff, 1998) and (d) Ferric Arenosols (FAO, 1998), or Quartzipsamments (Soil Survey Staff, 1998). In Sebele, the experiment was conducted at two sites on Chronic Luvic (Sebele 1) and Ferric Luvic (Sebele 2). The soils in Sebele and Haplic Luvic (Tswidi developed from granite parent material (DAR, 1981). Ferric Luvic (or sandy clay loam soils) have poor internal drainage while Chronic Luvics (sandy loam soils) are well drained (Joshua, 1990). Selected soil properties at the experimental sites are presented in Table 1. Soils at Sese were the Kalahari sands (Ferric Arenosols) that developed from aeolian deposits. They were very deep, sandy in texture, have single grain structure and well drained.

2.2. Tillage treatments and experimental design

This was the first season during which the tillage experiment was conducted. Tillage treatments were as follows: (1) single moldboard ploughing and planting (conventional); (2) double ploughing with early spring mouldboard ploughing with first rains followed by second mouldboard ploughing on the day of planting; and (3) deep ripping consisting of cultivated strips (riprines) that were permanently laid out 1.5 m apart and about 40 cm wide (DLRS, 1974, 1980; Persaud et al., 1992). The strips were ripped to 50–60 cm deep and crops were planted on these riprines. The area between the riprines was the traffic line and was never cultivated except for shallow scraping with a blade to control weeds. The traffic lines served as passage area for any field operation and were also meant to generate runoff and concentrate rain water onto crops planted on the riprines. At Sebele 2 double ploughing was not done.

The experiment was laid out as randomised complete block design with two replicates and tillage systems randomised within the blocks. The size of the plot was 40 m by 15 m. At each site, phosphorus was applied at 20 kg ha$^{-1}$ and grain sorghum (Sorghum bicolor Moench (L), var. segalane) was planted. Tillage, planting and harvest dates are given in Table 2. Infiltration measurements were conducted once on each replicate. In the deep ripplng treatment, infiltration tests were done on both riprines and traffic lines.

2.3. Infiltration tests

Field infiltration measurements were determined using double ring infiltrometers using procedure described by Joshua (1960) and Green et al. (1986). The infiltration rate was measured by

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Site</th>
<th>Sebele 1</th>
<th>Sebele 2</th>
<th>Tswidi</th>
<th>Sese</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (CaCl$_2$)</td>
<td></td>
<td>5.0</td>
<td>5.8</td>
<td>4.8</td>
<td>5.5</td>
</tr>
<tr>
<td>OC (%)</td>
<td></td>
<td>0.04</td>
<td>0.31</td>
<td>0.50</td>
<td>0.1</td>
</tr>
<tr>
<td>OC (g kg$^{-1}$)</td>
<td></td>
<td>32</td>
<td>6.5</td>
<td>4.5</td>
<td>2.8</td>
</tr>
<tr>
<td>P (ppm)</td>
<td></td>
<td>19</td>
<td>23</td>
<td>7.5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>BD (kg m$^{-3}$)</td>
<td></td>
<td>1.58</td>
<td>1.54</td>
<td>1.02</td>
<td>1.60</td>
</tr>
<tr>
<td>FWMC (mm m$^{-1}$)</td>
<td></td>
<td>35</td>
<td>30</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>Sand (%)</td>
<td></td>
<td>78.5</td>
<td>62.9</td>
<td>84.0</td>
<td>92.8</td>
</tr>
<tr>
<td>Sh (%)</td>
<td></td>
<td>74</td>
<td>10.1</td>
<td>7.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Clay (%)</td>
<td></td>
<td>13.1</td>
<td>28.4</td>
<td>8.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Textural class</td>
<td>Sandy-loam</td>
<td>Sandy clay-loam</td>
<td>Clay-loam</td>
<td>Sandy</td>
<td></td>
</tr>
<tr>
<td>Slope (%)</td>
<td></td>
<td>3.0</td>
<td>3.8</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
</tbody>
</table>

OC, organic carbon (Wallhey and Black, 1944); CEC, cation exchange capacity (Rhoades, 1982); P, Bray 2 available phosphorus (Bray and Kurtz, 1945); BD, bulk density (Blake and Hartge, 1986) and RWAC, plant available water capacity. * Particle size analysis (Smee and Bousley, 1986)
Table 2

<table>
<thead>
<tr>
<th>Operation</th>
<th>Site</th>
<th>Sebele 1 (SA)</th>
<th>Sebele 2 (SCJ)</th>
<th>Tswidi (CL)</th>
<th>Sese (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dates of operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting</td>
<td>01/12/1988</td>
<td>22/12/1988</td>
<td>05/12/1988</td>
<td>05/12/1988</td>
<td>05/12/1988</td>
</tr>
<tr>
<td>Harvest</td>
<td>19/04/1989</td>
<td>19/05/1989</td>
<td>31/05/1989</td>
<td>24/05/1989</td>
<td>24/05/1989</td>
</tr>
</tbody>
</table>

Planting Density (plants ha$^{-1}$)

| Single ploughing     | 50000         | NA            | 54000          | 41000       |           |
| Double ploughing     | 53000         | NA            | 57000          | 43000       |           |
| Deep sowing          | 34000         | NA            | 37000          | 24000       |           |

NA, data not available; SL, sandy loam; SCJ, sandy clay loam; CL, clay loam and S, sand.

observing the decreasing water level within the inner ring. Water in the outer ring was kept at approximately the same level as in the inner ring to prevent lateral flow to promote vertical water movement in the soil. Steady state infiltration rates were derived from plots of cumulative infiltration versus time. Cumulative infiltration was described using the following equation described by Hillel (1980):

$$I = a^n$$  \hspace{1cm} (1)

Where $I$ is cumulative infiltration (L), $t$ is time (T), and $a$ and $n$ are empirical constants that are specific to soil conditions and depend on soil texture, moisture contents, bulk density and other soil properties. Cumulative infiltration was calculated after 240 min. To determine $a$ and $n$ constants, logarithm on both sides of Eq. (1) taken to obtain:

$$\log(I) = \log(a) + n \log(t)$$  \hspace{1cm} (2)

Plotting $\log(I)$ versus $\log(t)$ enables obtaining values of $n$ (slope) and $\log(a)$ from the y-intercept. The value of $a$ was obtained from antilog($\log(a)$), i.e.

$$a = 10^{\log(a)}$$  \hspace{1cm} (3)

Integrating Eq. (1), yields instantaneous infiltration rate described by:

$$\frac{dI}{dt} = an^{n-1}$$  \hspace{1cm} (4)

Inserting values of $a$ and $n$ into Eq. (4), steady infiltration rate at 240 min of different tillage systems were calculated.

2.4. Soreptivity

For early stage (<30 min), infiltration calculated using equation described by Philip (1957a), i.e.:

$$I = S_o t^{1/2}$$  \hspace{1cm} (5)

where $I$ is cumulative infiltration (L), $S_o$ is sorptivity (LT$^{-1/2}$) and $t$ is time (T). Therefore, sorptivity value was calculated from the slope of a plot of cumulative infiltration, $I$ versus square root of the elapsed time, $t^{1/2}$ (Taisma, 1969).

Statistical analyses on all variables were conducted using analysis of variance (ANOVA) for randomized complete block design (SAS, 2007). The mean separation test used Fisher’s protected least significant difference (Steel and Torrie, 1980).

3. Results and discussions

3.1. Rainfall

Rainfall occurs between October and April (Bhalotra, 1987) and coincides with cropping season. Seasonal rainfall during the 1988/1989 cropping season at Sebele 1, Sebele 2, Tswidi and Sese was 585, 573, 593, and 480 mm, respectively (Fig. 1). Total rainfall was within the long-term average rainfall of 525 mm at Sebele and 400 mm in the Kanye and Jwaneng area (Bhalotra, 1987). At Sebele, Sese and Tswidi, rainfall events that were less than 15 mm were 55%, 30% and 30% of total rainfall, respectively. Rain-

![Fig. 1](image-url)
fall events that are less 15 mm are prone evaporation under semi-arid environment and may reduce effective rainfall. Rainfall events that were greater 40 mm constituted 16%, 9% and 22%, respectively. Rainfall during the experimental period was fairly well distributed and had potential to support a crop growth fairly well.

3.2. Soil properties

Arable farming in Botswana is generally conducted on semi-arid tropical soils. Selected arable soil properties at experimental sites in eastern Botswana are presented in Table 1. Inherent low fertility, low pH and crust prone soils result in low crop yields. Organic carbon content is typically less than 1% and together with low pH, makes the soil fragile and susceptible to degradation. Soils were moderately deep at Sebele and Tswidi and very deep at Sese (Table 1). The slope covered a narrow range (0–4%) and under such conditions, continuity of slope and soil surface conditions controls rainwater infiltration and runoff (L&WMP, 1992). More efficient use of rainwater and nutrient as well as conservation farming practices is essential for improving crop production in Botswana.

3.3. Sorghum grain yield

Grain sorghum (S. bicolor L. Moench; Sesa) var. was used as test crop in this study. The effect of tillage systems on sorghum..
grain yield is presented in Table 3. At Tswidwi, tillage did not significantly \( (P > 0.05) \) affect sorghum grain yield (Table 3). Tillage significantly \( (P < 0.05) \) affected grain yield of sorghum at both Sebele 1 and Sese. At Sebele 1, there were no significant \( (P > 0.05) \) differences between deep ripping and conventional ploughing and was significant \( (P < 0.05) \) under ploughing. Sorghum grain yield was not significantly \( (P > 0.05) \) different conventional and double ploughing at Sese (Table 3) but was significantly \( (P < 0.05) \) smaller deep ripping (Table 3). Compared with mouldboard ploughing, sorghum grain yield was smaller by 26%, 18% and 65% at Sebele 1, Tswidwi and Sese, respectively.

3.4. Cumulative infiltration

The influence of tillage on cumulative water infiltration on different soil types is presented in Fig. 1 and Table 3. At Sebele 1 (sandy loam), and Tswidwi (clay sandy loam) cumulative water infiltration was not significantly \( (P > 0.05) \) different among tillage systems, and between tillage treatments and traffic lines (Table 3). At Sebele 2 (sandy clay loam) and Sese (sandy) cumulative infiltration was also not significantly \( (P > 0.05) \) different among tillage systems but was significantly \( (P < 0.05) \) smaller under traffic lines compared with tillage systems. Infiltration was highly variable as indicated by CV that ranged from 11% to 43% (Table 3) and this probably explains lack of significant differences between tillage systems. The aim of traffic line was to generate runoff into rills where crops were planted. The greatest potential to generate run-off into rilled soils and increase available soil water for crops was on sandy clay loam (Sebele 2) and sand (Sese) (see Fig. 2).

Cumulative water infiltration was greatest under deep ripping, followed by conventional, double ploughing and was least under traffic lines at all sites (Fig. 1). Average cumulative infiltration after 4 h was 120, 102, 63 and 55 cm at Sese (Ferric Arenosols), Sebele 1 (Chromic Luvisols), Sebele 2 (Ferric Luvisols) and Tswidwi (Haplic Luvisols), respectively. Notably, Kalahari fine sandy (Sese) and sandy loam (Sebele 1) had the greatest average cumulative infiltration. Sandy soils have larger pores that highly influence infiltration, particularly under ponded infiltration where gravity forces dominate water flow. In contrast, soils with loamy texture at Sebele 2 and Tswidwi had lower infiltration. In fact Ferric Luvisols at Sebele 2 were classified as having poor soil drainage (DAFS, 1981) and had patchy water tables in some places within the experimental plot (see Table 4).

2.5. Infiltration rate

Infiltration rate is the amount at which water enters the soil at the surface (Hillel, 1980) and it determines potential for surface storage or ponding, soil water storage or runoff during rainfall or irrigation. Steady state (or final) infiltration rates under different tillage systems in different soils are presented in Table 5. At Tswidwi (texture), there were no significant \( (P > 0.05) \) differences among tillage systems, and between tillage systems and traffic lines. Also, lack of significant \( (P > 0.05) \) differences between deep ripping and conventional ploughing was observed at Sebele 2 but infiltration was significantly \( (P < 0.05) \) smaller on traffic lines. There were no significant \( (P > 0.05) \) differences between deep ripping and conventional ploughing and between double ploughing and traffic lines at Sebele 1. At Sese, infiltration rate was not significantly \( (P > 0.05) \) different between deep ripping and conventional ploughing, and between conventional and double ploughing but was significantly \( (P < 0.05) \) smaller under traffic lines compared with rolled soil.

Average steady state infiltration rates were 11, 14, 23 and 27 cm h\(^{-1}\) on Ferric Luvisols (Sebele 2), Haplic Luvisols (Tswidwi), Chromic Luvisols (Sebele 1) and Ferric Arenosols (Sese), respectively. Steady state infiltration rates from double ring method ranging from 3 to 15 cm h\(^{-1}\) are considered moderate to moderately high (Landon, 1984). Infiltration rates on heavier textured soils (Sebele 2 and Tswidwi) were smaller compared with light textured (Sebele 1 and Sese). Infiltration rate data can assist in designing water harvesting systems such as deep ripping by determining the size of area of traffic lines, the area from which rainwater is harvested. Except at Sese, infiltration rate on deep ripping and conventional ploughing was statistically the same.

2.6 Sorptivity

Sorptivity values under different tillage and soils are presented in Table 6. There were no significant \( (P > 0.05) \) differences between treatments at Sebele and Tswidwi. At Sese, there also no significant \( (P > 0.05) \) among tillage systems but sorptivity was significantly \( (P < 0.05) \) smaller on traffic lines. Average sorptivity values across tillage systems were 3.88, 4.52, 2.35 and 2.92 cm min\(^{-1}\) at Sese

### Table 4

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Sebele 1 (SL)</th>
<th>Sebele 2 (SCL)</th>
<th>Tswidwi (CL)</th>
<th>Sese (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep ripping</td>
<td>11.0 (1)</td>
<td>50.1 (1)</td>
<td>75.6 (1)</td>
<td>122.5 (1)</td>
</tr>
<tr>
<td>Double plowing</td>
<td>54.1 (2)</td>
<td>39.8 (2)</td>
<td>40.8 (2)</td>
<td>108.0 (2)</td>
</tr>
<tr>
<td>Conventional</td>
<td>32.5 (3)</td>
<td>59.1 (3)</td>
<td>74.0 (3)</td>
<td>118.5 (3)</td>
</tr>
<tr>
<td>Traffic line</td>
<td>45.4 (4)</td>
<td>73.3 (4)</td>
<td>32.1 (4)</td>
<td>7.0 (4)</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>17.7 (7)</td>
<td>34.5 (3)</td>
<td>85.5 (3)</td>
<td>32.5 (7)</td>
</tr>
<tr>
<td>CV (%)</td>
<td>11.4 (1)</td>
<td>30.7 (1)</td>
<td>42.0 (1)</td>
<td>11.1 (1)</td>
</tr>
<tr>
<td>F (1, 1)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>
| LSD, least significant difference; CV, coefficient of variation; SL, sandy loam; SCL, sandy clay loam; CL, clay loam; S, sand; the same letter within each column indicate no significant differences; NS, not significant; \( *, P < 0.05 \); **, \( P < 0.01 \).

### Table 5

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Sebele 1 (SL)</th>
<th>Sebele 2 (SCL)</th>
<th>Tswidwi (CL)</th>
<th>Sese (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep ripping</td>
<td>26.5a (1)</td>
<td>64.1a (1)</td>
<td>14.7a (1)</td>
<td>36.0a (1)</td>
</tr>
<tr>
<td>Double plowing</td>
<td>17.5b (2)</td>
<td>12.3b (2)</td>
<td>12.2b (2)</td>
<td>23.6b (2)</td>
</tr>
<tr>
<td>Conventional</td>
<td>25.6c (3)</td>
<td>12.8c (3)</td>
<td>14.7c (3)</td>
<td>27.0c (3)</td>
</tr>
<tr>
<td>Traffic line</td>
<td>19.5d (4)</td>
<td>10.5d (4)</td>
<td>0.7d (4)</td>
<td>0.7d (4)</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>5.5e (5)</td>
<td>6.2e (5)</td>
<td>14.5e (5)</td>
<td>6.1e (5)</td>
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<tr>
<td>CV (%)</td>
<td>0.04 (6)</td>
<td>0.04 (6)</td>
<td>0.04 (6)</td>
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</tr>
<tr>
<td>F (1, 1)</td>
<td>NS</td>
<td>NS</td>
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</tbody>
</table>
| LSD, least significant difference; CV, coefficient of variation; SL, sandy loam; SCL, sandy clay loam; CL, clay loam; S, sand; the same letter within each column indicate no significant differences; NS, not significant; \( *, P < 0.05 \); **, \( P < 0.01 \).

### Table 6

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Sebele 1 (SL)</th>
<th>Sebele 2 (SCL)</th>
<th>Tswidwi (CL)</th>
<th>Sese (S)</th>
</tr>
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<tbody>
<tr>
<td>Deep ripping</td>
<td>3.87 (1)</td>
<td>2.61 (1)</td>
<td>2.70 (1)</td>
<td>4.28 (1)</td>
</tr>
<tr>
<td>Double plowing</td>
<td>4.87 (2)</td>
<td>1.76 (3)</td>
<td>3.70 (3)</td>
<td>5.70 (3)</td>
</tr>
<tr>
<td>Conventional</td>
<td>4.83 (3)</td>
<td>2.43 (4)</td>
<td>3.30 (4)</td>
<td>3.70 (3)</td>
</tr>
<tr>
<td>Traffic line</td>
<td>3.03 (4)</td>
<td>0.14 (5)</td>
<td>0.14 (5)</td>
<td>1.02 (4)</td>
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<td>LSD (0.05)</td>
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<tr>
<td>CV (%)</td>
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<td>F (1, 1)</td>
<td>NS</td>
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</tbody>
</table>
| LSD, least significant difference; CV, coefficient of variation; SL, sandy loam; SCL, sandy clay loam; CL, clay loam; S, sand; the same letter within each column indicate no significant differences; NS, not significant; \( *, P < 0.05 \); **, \( P < 0.01 \).
4. Summary and conclusions

Cumulative ponded infiltration and steady state infiltration rate were similar under deep ripping and conventional ploughing but greater as compared with double ploughing. On traffic lines, infiltration was consistently smaller than on ploughed or 'ripped' soils. Except on sandy loam soil (Sebele 1), cumulative infiltration decreased by at least 73% on traffic lines compared with tillage systems. Soriptivity was highly variable and was not affected by tillage. High intensity rainfall and dense Luvisol increase the potential of water loss by runoff on arable lands of eastern Botswana.

Soils of arable lands in Botswana have low organic matter content and poor structural stability and the effects of cultivation disappear as the soil consolidates during the growing or rainy season. Using non-inversion tillage methods such as chisel and deep ripping can minimize destruction of soil structure and improve water infiltration over extended periods. Preserving or increasing crop residue on the soil surface or the use of lime and gypsum can reduce re-compaction of hardsetting soils and increase crop production in Botswana.

Fig. 3. Infiltration patterns on Chromic Luvisol (Sebele 1), Ferric Luvisol (Sebele 2), Haplic Luvisol (Tswidi) and Ferric Arenosols (Sese) under different tillage systems in southeastern Botswana.
Fig. 4. Cumulative infiltration versus square-time (between 0 and 45 min) on Chronic Luvisol (Sebele 1), Ferric Luvisol (Sebele 2), Haplic Luvisol (Tswidi) and Ferric Arenosol (Sese) under different tillage systems in southwestern Botswana.

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