Infiltration and sorptivity studies on some landform technologies for managing Vertisols

E. K. ASIEDU, Y. AHENKORAH, M. BONSU & J. W. OTENG
(E. K. A.: Soil Research Institute, Council for Scientific and Industrial Research, Kwadaso-Kumasi, Ghana; Y. A.: Department of Soil Science, University of Ghana, Legon, Ghana; M. B.: Department of Soil Science, School of Agriculture, University of Cape Coast, Cape Coast, Ghana; J. W. O.: University of Ghana Agricultural Research Station, Kpong, Ghana)

ABSTRACT

Infiltration and sorptivity were studied under four different Vertisol management technologies on the Accra Plains of Ghana. The technologies were the cambered bed, the Ethiopian bed, the ridge, and the flat bed. The initial values of both cumulative infiltration and infiltration rate were highest in the cambered bed. This was followed by the ridge, the Ethiopian bed, and the flat bed in that decreasing order. The terminal infiltration rates were quite similar for all the landforms and were about 0.05 m/s. Field-measured sorptivity followed the order: cambered bed > ridge > Ethiopian bed > flat bed. The results of the study on sorptivity were used to predict the relative time-to-incipient ponding of the various landform technologies. It was deduced that the cambered bed would take the longest time, and the flat bed the shortest time to get ponded. The time-to-incipient ponding of the ridge and Ethiopian bed were intermediate. The study showed that the cambered bed would be the best technology for agricultural productivity on the Vertisol in the wet season, while the flat bed is the least desirable, with the ridge and the Ethiopian bed being intermediates.

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RÉSUMÉ

ASIEDU, E. K., AHENKORAH, Y., BONSU, M. & OTENG, J. W.: *Etudes sur l'infiltration et l'absorptivité de quelques technologies de forme de terrain pour l'exploitation de vertisols.* L' infiltration et l'absorptivité étaient étudiées sous quatre différentes technologies d' exploitation de vertisols sur les plaines d' Accra du Ghana. Les technologies étaient (1) la couche cambrée (2) la couche éthiopienne (3) la crête et (4) le plateau. Les valeurs initiales de l'infiltration cummulative et de la vitesse d' infiltration à la fois étaient trouvées d' être les plus élevées dans les couches cambrées. Ceci était suivi par la crête, la couche éthiopienne et le plateau dans cet ordre décroissant. Les vitesses finales d' infiltration étaient tout à fait semblables pour tout les formes de terrain et étaient approximativement 0.05 m/s. L' absorptivité évaluée sur le terrain suivait l'ordre: la couche cambrée > la crête > la couche éthiopienne > le plateau. Les résultats de l'étude sur l'absorptivité se sont servi à prédire le temps relatif de blocage naissant de différentes technologies de forme de terrain. Il était déduit que la couche cambrée prendra le plus long temps et le plateau prendra le plus court temps d' être bloqué. Le temps de blocage naissant de la crête et de la couche éthiopienne étaient intermédiaires. L' étude montrait que la couche cambrée pourrait être la meilleure technologie pour la productivité agricole sur le vertisol pendant la saison humide, alors que le plateau est le moins désirable avec la crête et la couche éthiopienne étant les intermédiaires.

Introduction

One of the greatest challenges to agricultural scientists now and in the years ahead is the management of Vertisols for the full realization of the rich potentials of these soils.

Infiltration, which is defined as the entry of water into the soil (Hillel, 1980), plays a central role in Vertisol productivity. The peculiar nature of Vertisols, with their high clay content, restricted moisture range for tillage, and drainage constraints make the productivity of such soils highly dependent on the absorption, acceptance, and retention of water. This brings into focus the important role of infiltration and sorptivity in the management of Vertisols.

According to Folorunso & Ohu (1989), infiltration of water into Vertisols is at present not well understood, and defies application of familiar infiltration equations developed for non-swelling soils. However, it could be observed that when cracks have not yet developed, the infiltration process could be explained by using the basic infiltration equations.

The infiltration process, as observed by Yule (1987), may combine one-dimensional flow through the surface and preferential flow down the cracks. Infiltration is rapid in Vertisols when cracks are open, but infiltration rate becomes very slow when the cracks have closed and the soil is wet. According to Verma (1988), many infiltration trials under shallow ponding have shown infiltrability to vary and generally to decrease with time. This agrees with the report of Hillel (1980) that the cumulative infiltration, being the time integral of the infiltration rate, has a culvilinear time dependence, with a gradually decreasing slope.

Sorptivity, on the other hand, is a measure of the ability of the soil to absorb water without reference to gravitational effects (Philip, 1957a). Sorptivity depends on initial water content (Philip, 1957b; Chong & Green, 1979). According to Bonsu (1993), sorptivity is important in infiltration studies, since it governs the early stages of infiltration. Sorptivity can also be used to predict time-to-incipient ponding for constant and variable rainfall by using the equations of Mein & Larson (1971) and Parlange & Smith (1976), respectively. Prediction of time-to-incipient ponding is very important in Vertisol management, since the knowledge of it enhances the effective planning of field operations on these soils.

Vertisols are easily prone to water stagnation, especially during the wet season. Water ponding on the soil often causes crop stunting and low yields. In the attempt to increase the productivity of Vertisols, many management technologies have been assessed and used. Very often, surface drainage has been the criterion for assessing such technologies while the role of infiltration has been ignored. There is, however, the need to develop technologies that will encourage the absorption and retention of more water in the soil and minimize water wastage through ponding, runoff and evaporational losses, since water that infiltrates the soil is what becomes available for use by plants.

Van De Weg (1987) reported that little work has been done to assess the infiltration rate and permeability of Vertisols. Since infiltration and sorptivity have great implications for water and soil conservation as well as for the agricultural productivity of Vertisols, there is the need for their proper assessment in any management technology designed for the effective use of these soils. A knowledge of the relative time-to-incipient ponding of various management technologies is also essential in identifying technologies that are likely to cause less water stagnation and runoff on these soils.

In this work, infiltration and sorptivity studies on four landform technologies, *viz*, flat bed, ridge, Ethiopian bed, and cambered bed, were carried out with the following aims:

(1) To assess the infiltration and sorptivity behaviours of the various landform technologies for managing Vertisols of the Accra Plains of Ghana.

(2) To predict the relative time-to-incipient ponding in the various landform technologies for managing the Accra Plains Vertisols by using field-measured sorptivity.

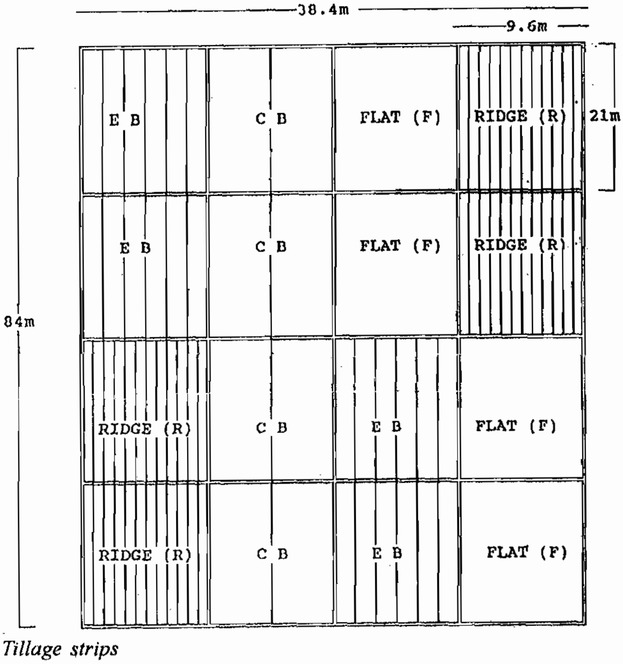
Materials and methods

Experimental site

The experiment was carried out at the University of Ghana Agricultural Research Station at Kpong in the Eastern Region of Ghana on the Akuse series (Adu, 1985) which is classified as Eutric Vertisol (FAO) and Typic calciustert (USDA). The parent material is garnetiferous hornblende gneiss (Brammer, 1955). The land has a general slope of less than 1.0 per cent. This, coupled with the high clay content, provides poor drainage and subjects the land to flooding in the wet season.

Field design and land preparation

Randomized complete block design was used, with the four landform treatments replicated four times. Fig. 1 shows the field design. The treatments, each of which covered an area of 9.6 m × 7.5 m, were flat bed, Ethiopian bed, ridge, and cambered bed.



Treatment	Code Tillage	Landform width (m)	No. of landforms per plot of 9.6 m width and 21 m length
1	F = Flat bed	9.6	1
2	CB = Cambered bed	4.8	2
3	EB = Ethiopian bed	1.6	6
4	R = Ridge	0.8	12

Fig. 1. Field plan for Vertisol landform tillage experiment at ARS, Kpong.

The field was slashed with a rotary slasher mounted on a tractor, ploughed, and harrowed soon after the major rains. The landforms were then prepared as follows:

Flat bed system. A polydisc plough with a one-way disc harrow of nine to12 discs was mounted on a 4-WD, 56-KW (75-hp) tractor and used to prepare the flat beds.

Ridge-and-furrow system. A concave lister mouldboard ridger was mounted on the tractor and used to prepare the ridges. Twelve ridges, spaced 0.8 m apart, were prepared for each of the plots. Each ridge had a width of 0.8 m at the base with a gradient of 75 per cent at the sides.

Cambered bed-and-furrow system. A polydisc plough with a one-way disc harrow mounted on a 4-WD, 56-KW (75-hp) tractor was used to prepare the cambered beds. Two cambered beds, each measuring 7.4 m long, 4.8 m in width, 0.35-0.40 m in height at the crest and with a gradient of 17-20 per cent at the sides, were prepared.

Ethiopian bed-and-furrow system. A tractor tool carrier with 560-mm scalloped disc was mounted on a 4 - WD, 56-KW (75-hp) tractor and used to prepare the Ethiopian beds. The beds measured 1.6 m wide and 7.5 m long with a gradient of 37 - 45 per cent at the sides.

All the landforms had furrows with a width of 0.8 m, a depth of 0.3 m, and a lengthwise slope of less than 1.0 per cent.

Data collection

Infiltration rate. This was determined by the single-ring infiltrometer method (Hillel, 1980). Infiltration was measured on all the landforms until a steady state infiltration rate was approached for each landform. There were four determinations on each landform, and the mean values were used in determining the cumulative infiltration and infiltration rates.

Sorptivity. The first 3-min cumulative infiltration was used to calculate sorptivity for the various landforms. The theoretical basis for using cumulative infiltration to calculate sorptivity is as follows:

Consider water ponded on a soil and infiltrates to a depth of x m in t s, after a cumulative infiltration of I, it can be shown that:

$$I = (\theta_f - \theta_i)x \qquad (1)$$

where θ_f = final water content after infiltration
θ_i = initial water content before infiltration

Using the Boltzmann similarity variable, $\lambda(\theta) = x\, t^{-1/2}$, the Equation (1) can be re-written by substituting for x as:

$$I = (\theta_f - \theta_i)\lambda(\theta)\, t^{1/2} \qquad (2)$$

By defining sorptivity, S, as:

$$S(\theta) = (\theta_f - \theta_i)\lambda(\theta) \qquad (3)$$

Then Equation (2) becomes (Philip, 1957):

$$I = S(\theta)\, t^{1/2}$$

For most soils, I versus $t^{1/2}$ curves give straight lines for small times ($t \leq 3$ min) (Bonsu, personal communication) and the slope of the I versus $t^{1/2}$ curve gives the sorptivity.

Results and discussion

Infiltration on the various landforms

Fig. 2 and 3 show the cumulative infiltration and infiltration rate as a function of time of the various landforms, respectively. Fig. 2 clearly shows that the cumulative infiltration at 2500 s after ponding water on the surface of the soil was highest in the cambered bed. This was followed by the ridge, the Ethiopian bed, and the flat bed in that decreasing order. For example, after 2500 s of infiltration, about 0.049 m of water entered the cambered bed, 0.0031 m of water entered the ridge, 0.0027 m of water entered the Ethiopian bed, and only 0.0015 m of water entered the flat bed.

The cambered bed had the highest infiltration rate, but the infiltration rates of the Ethiopian bed and the ridge were not very different, while the flat bed had the lowest infiltration rate. Similar infiltration behaviours in Vertisols have been reported by Hillel (1980) and Verma (1988). These findings have important implications on the hydrology of the landforms. Runoff is expected to be delayed on the cambered bed due to its high water infiltrability, while it is probably quick on the flat bed.

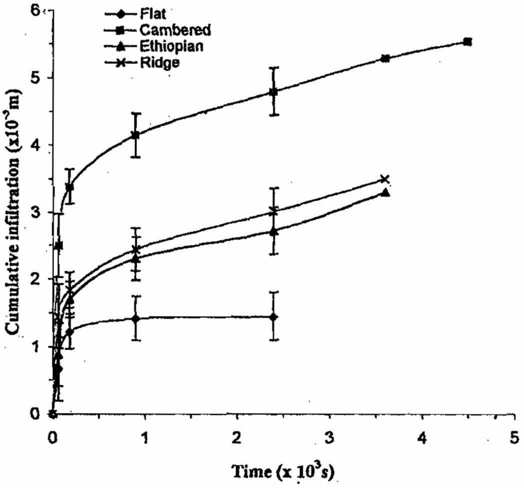


Fig. 2. Cumulative infiltration curves for various landforms. (Error bars represent LSD ($P < 0.05$) values at respective times).

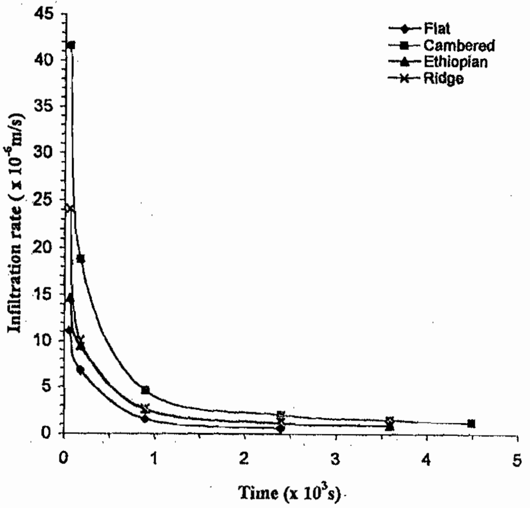


Fig. 3. Infiltration rates in different Vertisol landforms.

The terminal infiltration rates were quite similar for all the landforms and was about 0.05 m/s. This was expected, due to the swelling and blocking of the soil pores, but the time to reach these terminal infiltration rates was shortest (2400 s) with the flat bed. The Ethiopian bed and the ridge took almost the same time (3600 s), while the cambered bed took the longest time (4500 s) to approach the terminal infiltration rate. This also has some significance on drainability of the various landforms. The cambered bed with the higher infiltration rate is expected to be the best-drained technology, while the flat bed is expected to be the least-drained technology.

Sorptivity

Sorptivity is a measure of the soil's ability to absorb water without gravitational effect. Fig. 4 shows sorptivity values for the various landforms. Sorptivity was highest in the cambered bed. This was followed by the ridge and the Ethiopian bed in that order, with the flat bed giving the lowest sorptivity value.

Since the cambered bed was the best-drained technology, it may have more macro-pores than the others. The cambered bed may, therefore, have the greatest ability to absorb and conduct initial water during infiltration. The reverse is true for the flat bed which recorded the lowest sorptivity value. The ridge and the Ethiopian beds were intermediate in their behaviour. If sorptivity is used as an index for evaluating the soil water status of the various Vertisol landforms, the cambered bed may be the most preferable technology, followed by the ridge, the Ethiopian bed, and the flat bed in that decreasing order. This is because, among other things, the lower the sorptivity, the more the likelihood of ponding and runoff problems on the land. Thus, the flat beds probably have the most severe problem of surface ponding and runoff. Such problems, on the other hand, would be expected to be minimum on the cambered bed.

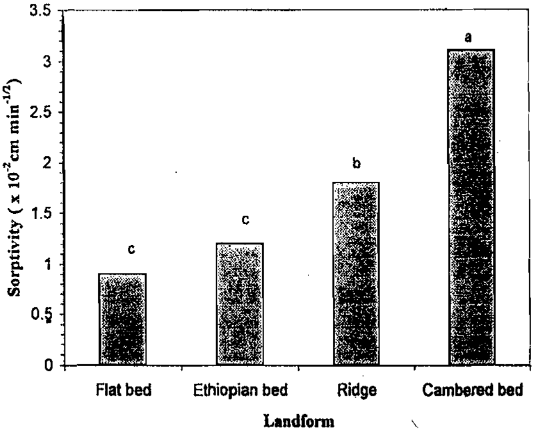


Fig. 4. Sorptivity in different Vertisol landforms.
Bars with identical letters are not significantly different at 0.01 level.

Time-to-incipient ponding

Mein & Larson (1971) and Parlange & Smith (1976) used sorptivity to predict time-to-incipient ponding. According to Chong & Moore (1982), sorptivity is related to time-to-incipient ponding, t_p, as follows:

$$t_p = S^2/2R^2 \quad (4)$$

where S is sorptivity and R is rainfall. It can be inferred from Equation (4) that the cambered bed will take a longer time to pond than either the ridge, the Ethiopian bed, or the flat seed bed. Since ponding has detrimental consequences on agricultural productivity (except for rice production), the high sorptivity of the cambered bed makes it the best option among the various management technologies for effective agricultural productivity of the Vertisol.

Conclusion

The study showed that the cumulative infiltration and the infiltration rate were highest in the cambered bed and lowest in the flat bed. The cumulative infiltration and the infiltration rates of the ridge and the Ethiopian beds lie between those of the cambered bed and the flat bed.

These findings have important implications on drainability of the various management technologies. Water stagnation is expected to be delayed on the cambered bed due to its high water infiltrability while for the same reason it is probably quick on the flat bed.

The terminal infiltration rates were quite similar for all the landforms. However, the time to reach these terminal infiltration rates was shortest with the flat bed and longest with the cambered bed. Sorptivity was highest in the cambered bed. This was followed by the ridge, the Ethiopian bed, and the flat bed in that decreasing order. Low sorptivity may induce high runoff whenever rainfall intensity exceeds the infiltration rate.

Using the sorptivity values and the relationship by Chong & Moore (1982), this study predicted the cambered bed to have the longest time-to-incipient ponding followed by the ridge, the Ethiopian bed, and the flat bed in that decreasing order. Since ponding is undesirable on Vertisols for the production of most crops (with the exception of rice), the cambered bed can be rated as the most desirable technology while the flat bed becomes the least desirable, in the wet season, with the ridge and the Ethiopian bed being intermediates for the Vertisol of the Accra Plains of Ghana.

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