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ANALYSIS AND INTERPRETATION OF PONDED INFILTRATION IN THE COMPARISON OF TILLAGE SYSTEMS IN THE SEMI-ARID TROPICS

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1. INTRODUCTION

Only a small proportion of northern Australia is suitable for dryland cropping. In these areas, red earth soils predominate, and of these, those of heavy texture are generally considered to have the most productive potential. Studies at Katherine on the Tippera clay loam provide much of our understanding of the behaviour of this group of soils. The aspect of their behaviour that is probably best known is the formation of surface seals of low water permeability, particularly following disturbance (Mott et al., 1979). Under pastures, however, water entry into these soils can be very high (McCown, unpublished data)

This paper reports early results of a study designed to compare long term effects of different land use and tillage systems on the water balance, and particularly on infiltration capacity. Land which has been under fertilized legume-grass pasture is being cropped using conventional cultivation and no-tillage technology. Trends in soil behaviour in the respective tillage systems are being compared with that of a continuous pasture.

2. MATERIALS AND METHODS

The experiment consists of two replications of four treatments; one pasture and three grain sorghum. The latter includes (1) cultivation with residues incorporated, (2) no-till with residues retained, and (3) no-till with residues removed. The pasture is 18 years old, dominantly grass, and produces 6-9 t/ha dry matter per wet season. Grazing ceased 3 years prior to the experiment.

Measurements, in addition to crop growth and yield, include weekly soil water profiles through the growing season and ponded infiltration in the dry season. We discuss only the ponded infiltration data in this paper. In each plot five rings were installed between wheel tracks. Rings 30 cm diameter and 20 cm high were driven 10 cm into moist soil during the late wet season. A 1 cm drainage hole at ground level, which prevented prolonged ponding following rain, was sealed for infiltration measurements. During the infiltration "run", a head of 30 mm water was maintained using a float valve (Ross et al. 1984), and water fall in a reservoir was recorded at 0.1 min intervals for five minutes. Virtually the entire head of water is applied instantaneously by pulling a plastic sheet from the ring on which the water is ponded. Correction is made for displacement of water due to the presence of the plastic sheet.

3. RESULTS AND DISCUSSION

A striking feature of the data was the large amount of water that entered the profiles in the first few seconds following ponding. It was common for as much as 20mm to enter the profile in the first 30 seconds (Fig. 1a). Modifications were made to the techniques to ensure that this early rapid entry was accurately measured. The I(t) plots (Fig. 1a) appear to conform to one dimensional flow, and the I(t^0.5) plots were consistently linear as displayed in Fig. 1b. It would seem that the data is consistent with early time one dimensional behaviour in which I=St^0.5+At as follows from the Philip (1957) analysis . If the method of data analysis used by Talsma (1969) is employed, the slope of the I(t^0.5) plot for short time could be interpreted as sorptivity (S) . Yet quite clearly this would be incorrect because in Fig. 1c we see that the data does not conform in any way to the Philip infiltration equation for early time. This plot of I/(t^0.5) against (t^0.5) as suggested by Smiles and Knight (1976) should yield a linear relation with intercept S and slope A if the Philip (1957) analysis is being obeyed. Clearly this is not the case in Fig. 1c. Further, if a simple least squares fit of I=St^0.5+At is used to generate S and A as suggested by Bristow and Savage (in press), these yield very large values of S and negative values of A. In this case the A parameter, which should reflect the soils transmission properites, has no physical meaning .

Both the above tests demonstrate that entry of water under ponded infiltration conditions in these soils does not conform to the one dimensional analytical theory of Philip (1957). Therefore, if one is to use these ponded infiltration studies to provide estimates of soil hydraulic properties an alternative analysis is needed.

It is the rapid initial entry of water that is characteristic of many surface soils which have been maintained under pasture or forest vegetation, as well as certain cropping situations (e.g. immediately following pasture or under a no-till system). Macroporosity, preferred pathways, and large channels which connect to the surface are features of these situations. The development of these desirable features are usually the goals of good soil surface management. It follows then that these features and the level of their development in a soil as a consequence of management are the properties one should seek to characterise in terms of water entry. Methods and measures (Clothier and White, 1981) that neglect these features are not helpful in the assessment of a particular soil management on soil physical properties.

It is important to note that Talsma (1969) was aware that the surface macroporosity and large channels were not part of the soil fabric which could be characterised by the sorptivity term S. He was careful to remove the surface horizons before he applied ponded infiltration. It is probably fair to say that many of the measures of S reported using ponded infiltration where the soil has been essentially undisturbed are a mixture of the initially rapid entry of water in macropores, cracks, preferrential pathways and large channels, and the sorption of water into the soil fabric which is dominated by capillarity. When the initial rapid entry is small, the Philip type analysis of Talsma (1969) will adequately describe the data and yield physically sensible but inexact estimates of S, A and Ks. As the rapid initial entry becomes larger the Philip equation fails as A becomes negative. In such circumstances the S and A terms have lost their physical interpretation and meaning. They are no longer soil hydraulic properties but simply fitted parameters (Bristow and Savage, In Press).

Collis-George (1977) recognised these difficulties and suggested that the initial rapid water entry be accounted for in a separate term, here referred to as B. For early time I=B+St^0.5 describes the data in Fig. 1b very well and for all of the 90 infiltration measurements conducted. The B term yields estimates of the magnitude of the rapid entry of water into cracks, macropores, and large channels for the treatments studied. The estimated value of B varied in magnitude from 2 to 15 mm. The value of S ranged from 1 to 2.5 mm/s^.5 and although large is consistent with values reported elsewhere in the literature. Although this form of analysis is largely empirical it does provide a pragmatic means of measuring and comparing the macro-structural features that are hydrologically important to crop production in the semi-arid tropics and which are sensitive to tillage systems and crop rotations.

Over the initial two minute interval, some 15-30mm of water entered the profile under ponded conditions. Excavation after ponding with pigmented water indicated that much of this water moved in an irregular manner into the ring and sometimes beyond it. Analysis is made difficult by the fact that the system consists of water rapidly entering the macro-structure (some of which extends beyond the ring) and then entering the capillary fabric of the soil by sorptive processes. However, even in three dimensions, a t^0.5 behaviour is expected (White et al. 1987).

Comparisons of treatment effects on B and S are shown in Table 1. Both B and S were significantly higher under pasture than any cropping treatment, but there were no differences among the latter. Variability within plots was high (Fig. 2). When I for various periods of time were compared, it was only for the initial 1 minute period that statistically significant differences between cropping treatments were obtained. Since this was the first year of cropping following nearly 18 years of pasture, we expect that changes in soil properties due to a return to cropping will become increasingly evident in the next few years.

TABLE 1. Comparison of parameters (mean values) for I=B+St^.5

Treatment	Pasture	Cultivation	No-till Plus mulch	No-till Minus mulch
B (mm)	9.4	6.7	6.9	3.4
S (mm/s^.5)	2.3	2.0	1.5	1.2

4. CONCLUSIONS

In spite of the problems of interpretation and variability, there seems to be no better alternative to the use of ponded infiltrometers in the tropics where rainfall infiltration often takes place under ponded conditions. Reduced problems of analysis and interpretation achieved by measuring infiltration under tension is of little consolation if it ignores the soil feature (namely macroporosity) most responsive to management. The use of I=B+St^0.5 for short time infiltration, while empirical, does mimic water entry under these conditions and provides an analysis which offers some insight to causation.

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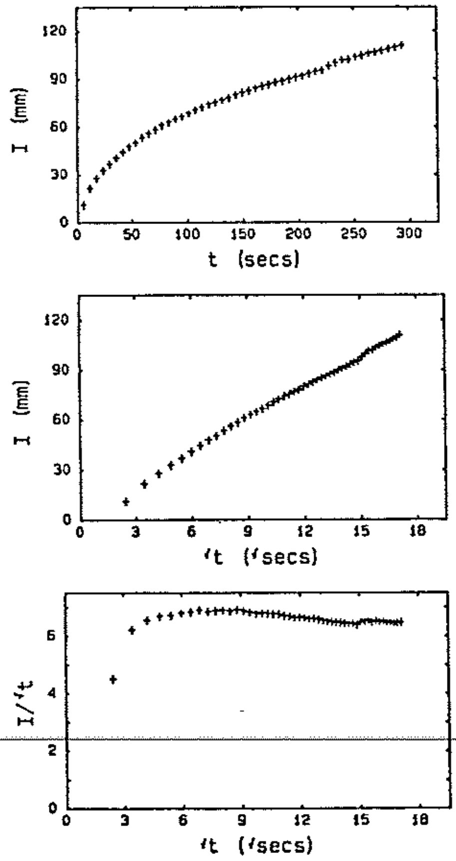

Fig. 1. Cumulative infiltration I (mm) as a function of time t (s):
a) I versus t
b) I versus t^.5
c) I/t^.5 versus t^.5

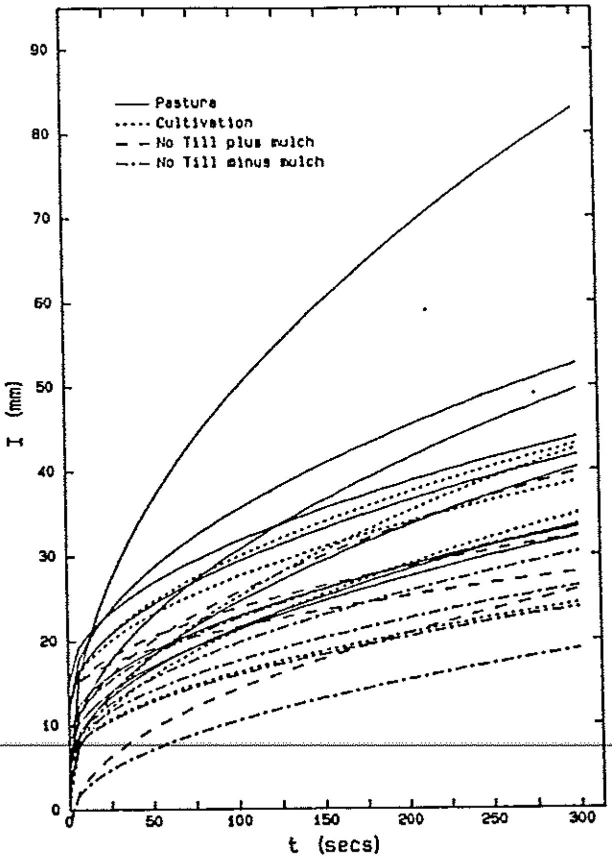

Fig. 2. Variability in cumulative infiltration.