

Soil hydraulic conductivities of latosols under pasture, forest and teak in Rondonia, Brazil

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Abstract:

We investigated the changes of saturated hydraulic conductivity, K_{sat} , with depth of latosols developed on Precambrian basement rocks under primary rainforest, pasture and teak. In all cases, K_{sat} decreased with depth, with most of the decrease occurring between the surface and a depth of 30 cm. In conjunction with prevailing rainfall intensities and frequencies, this anisotropy supports a pronounced lateral component of hillslope flow paths, and also of overland flow under pasture. Our results are at variance with data from other latosols where K_{sat} tends to increase with depth, and hence suggest that considerable restraint is needed in generalization and extrapolation until results from a co-ordinated effort at hydrology-oriented data collection become available. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS soil hydraulic conductivity; latosols; pasture; forest; teak; Brazil; Amazonia; land cover change

INTRODUCTION

Recent research activities in the Amazon Basin, such as the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS, Gash *et al.*, 1996) and the Large-Scale Biosphere Atmosphere Experiment (LBA, 1996), which require soil information as input for atmospheric circulation and hydrological models, have brought into focus the inadequate soils database for that region. While the efforts of national institutions, e.g. Brazil's EMPRABA (Empresa Brasileira de Pesquisa Agropecuaria) and Peru's ONERN (Oficina Nacional de Evaluación de Recursos Naturales), have contributed substantially to our knowledge of major soil types and their broad geographical distribution, a serious co-ordinated field effort to link soil types, lithology and topography at a regional scale and to measure relevant soil physical parameters has yet to be initiated. This unsatisfactory situation has resulted in an over-reliance on case studies, notably from central Amazonia (Reserva Ducke near Manaus and its environs), which themselves set the stage for unfortunate generalizations and simplifications with regard to the hydrological functioning of rainforest soils. The scarcity of data has also fostered attempts to derive soil physical parameters from presumably available or more easily collected soils information by means of pedotransfer functions (e.g. Van den Berg *et al.*, 1997).

The focus of soil physical investigations on latosols (Brazilian system, see Oliveira *et al.*, 1992), classified as ferralsols and oxisols in the FAO system (Dudal, 1974) and the US soil taxonomy (Soil Survey Staff, 1975), respectively, which are derived from the Tertiary Barreiras formation in the central Amazon basin (Nortcliff

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and Thornes, 1989; Tomasella and Hodnett, 1996), has created the widely accepted belief in predominantly vertical flow paths due to uniformly high hydraulic conductivities to a depth of 1 m or more; the popular notion of overland flow-free tropical rainforests, if only undisturbed, is a consequence of this belief, as is the conviction that any deviation from this flow path pattern must be a result of disturbance. In fact, it is not known whether this pattern also holds for other types of latosols derived from the Barreiras formation, let alone for latosols developed on Precambrian basement rocks elsewhere in the Amazon Basin.

Elsenbeer and Lack (1996) pointed out that such a pattern certainly does not apply for certain podzólicos (acrisols and ultisols in the FAO system and US soil taxonomy, respectively) which are widespread in the western basin, and that high-level soil taxonomic units are poor predictors of soil hydraulic properties. These are not used as classification differentiators in the first place and may be determined by factors that are reflected at lower levels (subgroup, family) and independent of high-level classification (e.g. mineralogy).

Our objective was to determine soil hydraulic conductivities of soils developed on the Brazilian craton from Precambrian basement rocks under three types of vegetation cover to explore the range of hydraulic patterns, and hence hydrological behaviour, of Amazonian soils and their corresponding response to cover change.

RESEARCH AREA AND METHODS

The research sites are located at Rancho Grande (10°18'S, 62°52'W, 143 m a.m.s.l.) in the state of Rondonia, Brazil. Mean air temperature (MAT) is about 27°C, and mean annual precipitation (MAP) 2265 mm (H. Schmitz, personal communication), based on a 12-year record (1984–1995). The area is underlain by Precambrian gneiss, weathered to a landscape with long, smooth, convex slopes of low relief, with intervening steep ridges rising up to 500 m a.m.s.l. These residual topographic heights and a portion of the lowlands are covered by rainforest, and the remaining area by secondary forest ('capoeira'), pasture (*Brachiaria brizantha* and *B. decumbens*) and a small teak (*Teca grandis*) plantation. Latosols (Oliveira *et al.*, 1992), in places with a well-defined surficial layer of ironstone concretions to a depth of 1 m, prevail on the low relief portion of the landscape.

We measured saturated hydraulic conductivity, K_{sat} , at 25 m intervals along three interfluvium–stream channel transects under the bunch grass *B. brizantha* ($n = 5$), on bare soil between *B. brizantha* bunches ($n = 5$), *B. decumbens* ($n = 7$) and rainforest ($n = 11$), respectively, and in a grid pattern in the teak plantation ($n = 8$). We calculated surface K_{sat} from disk permeameter (Soil Measurement Systems, Tucson) measurements of K at supply potentials of -3 and -6 cm. This method relies on the solution of flow from a disk source (Wooding, 1968) and an exponential relationship between K and matric potential (Gardner, 1958). We measured K_{sat} over an integrated depth of 5–15 cm with a Guelph permeameter (Soilmoisture Equipment Corp., Santa Barbara), and 12–30, 32–50 and 72–90 cm with an amoozemeter (Ksat Inc., Raleigh). These are constant-head well permeameters designed by Reynolds *et al.* (1983) and Amoozegar (1989).

RESULTS AND DISCUSSION

K_{sat} in pastures

We first established whether the two different pasture species, *B. brizantha* and *B. decumbens*, had an influence on K_{sat} at any of the depths, and whether there was a difference in the *B. brizantha* pasture between the topographically low (<2 cm) bare spots (at the end of the dry season) and the bunches of grass itself (with the stems trimmed carefully at ground level). None of the medians for a given depth, shown in Table I, are significantly different ($\alpha = 0.05$) for the given sample sizes, although the infiltration rate appears to be twice as high on the bunches as on the bare spots.

For further analyses, we pooled these three data sets to obtain one pasture data set ($n = 17$). The apparent difference in the infiltration capacity between *B. brizantha* and bare soil might play an important role in the

Table 1. Median K_{sat} values for pasture

| | Surface | 15 cm | 30 cm | 50 cm | 90 cm |
|-----------------------------|---------|-------|-------|-------|-------|
| <i>B. brizantha</i> — bare | 13.0 | 13.5 | 6.3 | 0.85 | 0.7 |
| <i>B. brizantha</i> — bunch | 28.1 | 21.8 | 2.6 | 5.1 | 0.7 |
| <i>B. decumbens</i> | 11.9 | 8.55 | 5.1 | 3.9 | 9.3 |

generation of ponded water over a range of rainfall intensities at the initial stage of a rain event. Dunne *et al.* (1991), however, identified the role of root-filled, aggregated soil beneath a groundcover versus the bare, compact soil between grass bunches, and showed that their variation in infiltration with rainfall leads to a systematic increase in the apparent infiltration with rainfall intensity and vegetation density. As a result, the spatially averaged saturated hydraulic conductivity increases.

Trends in K_{sat} with depth

Figure 1 summarizes the K_{sat} –depth relationship under forest, pasture and teak. Except for teak, surface K_{sat} appears to be very low, and while this may be explained as a consequence of compaction in the pasture,

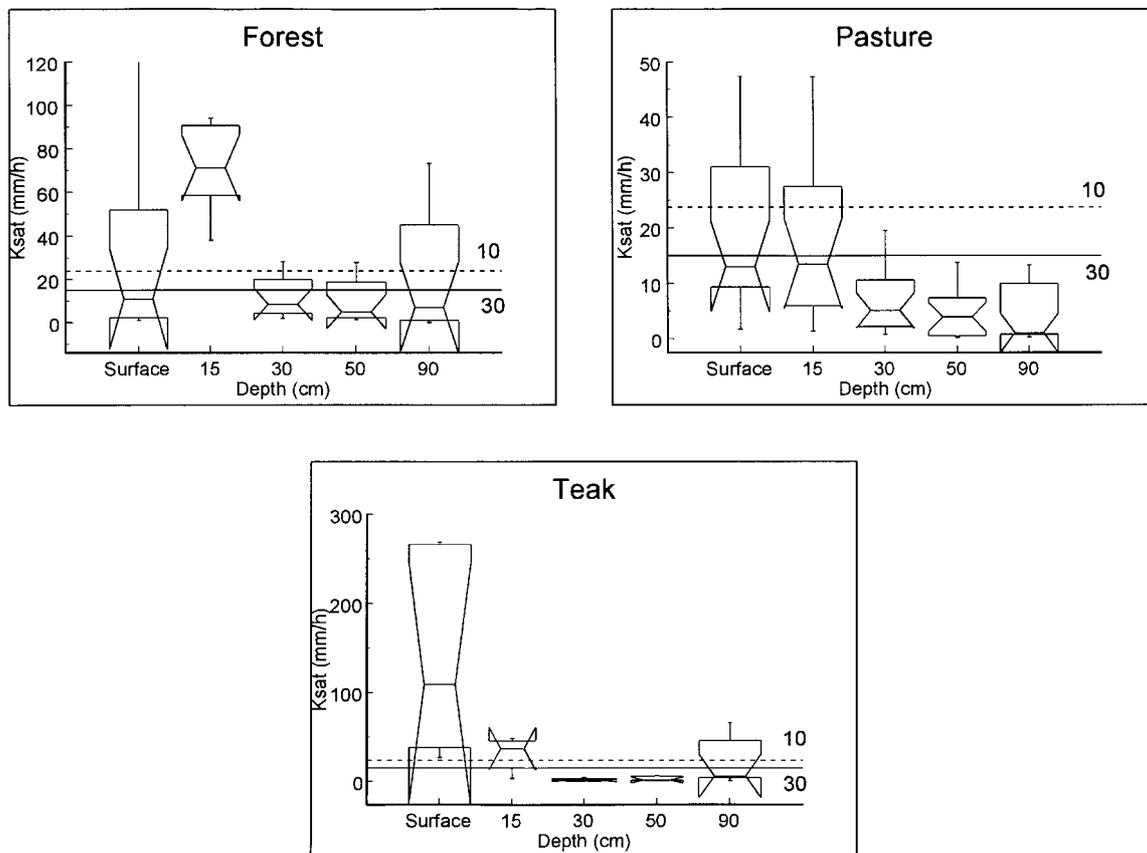


Figure 1. K_{sat} as a function of depth under forest, pasture and teak. The reference lines labelled '10' (dashed) and '30' (solid) indicate the one-hour rainfall intensities (24 and 15 mm/h, respectively) that have a recurrence interval of 10 and 30 times per year, respectively. To emphasize the trends in the location estimates (medians), we omitted outlying data points, defined as being further away from the quartiles than 1.5 times the interquartile range. There are one or two such points at any depth in the pasture, and two at the 15 cm depth in the forest

technical reasons must be invoked to account for the pattern in the forest. We suspect that the prolonged dry period of the southern hemisphere winter promoted some degree of hydrophobicity in the forest soil which may have reduced the area actively involved in infiltration, the overall effect being an underestimation of K_{sat} . The possibility of water repellency will be investigated during an upcoming field campaign. For the time being, we consider the forest surface K_{sat} data suspect: first, because of the much higher values at the 5–15 cm depth; secondly, after the observation of widespread ponding in the pasture, but not in the forest, in response to a high-intensity rainstorm; and, thirdly, because rainfall simulation data (E. Safran and T. Dunne, unpublished data) from Rondonia yielded infiltration capacities of 146 and 181 mm/h, i.e. an order of magnitude larger than our results. Sprinkling experiments on pastures, in contrast, yielded a range of 13–41 mm/h, which is in line with our results. Regardless of vegetation cover, K_{sat} decreases abruptly with depth under forest, teak, and more gradually under pasture (Figure 1). For the given sample sizes, these trends are not statistically significant in all cases. This is especially true for teak. In the forest, the only abrupt and significant change occurs between a depth of 15 and 30 cm, below which there is very little change. Under pasture, the decrease becomes significant between 15 and 90 cm.

Our results differ from previously published ones in two ways.

1. The decrease of K_{sat} at a shallow depth under forest (Figure 1) was not observed in latosols (ferralsols, oxisols) of the Barreiras formation in central Amazonia (Elsenbeer and Lack, 1996, p. 944; Wright *et al.*, 1996, p. 497), where there is either an increase or very little change. Rather, this pattern is similar, thought not in magnitude, to that of a podzólico (acrisol, ultisol) on Tertiary sediments in western Amazonia (Elsenbeer and Lack, 1996, p. 944). Owing to this decrease, the subsoil K_{sat} values reported here are two to three orders of magnitude lower than those reported for the central basin. They do not support the generalization of a uniformly high permeability of tropical rainforest soils, and, by implication, of predominantly vertical flow paths.
2. An increase of K_{sat} with depth under pasture (Tomasella and Hodnett, 1996, p. 107; Wright *et al.*, 1996, p. 497) is not necessarily to be expected for latosols (ferralsols, oxisols) (Figure 1). This suggests that the commonly assumed causal link between land cover change and soil physical properties — compaction and hence lower hydraulic conductivity of surface horizons — cannot be generalized. Compaction may well result in a lower surface K_{sat} compared with pre-land cover change conditions, but the overall anisotropy need not change.

This obvious pattern of an anisotropy — strong in comparison with previously studied latosols (ferralsol, oxisol), modest in comparison with a podzólico (acrisol, ultisol) — has implications for hydrological processes that are best examined by comparing this pattern with rainfall intensities and frequencies. The two reference lines in Figure 1 show the one-hour rainfall intensities (24 and 15 mm/h) with return intervals of 10 and 30 times per year, respectively. We infer from the position of these lines that:

- (1) ponding, and presumably Hortonian overland flow, occur quite frequently on the pasture;
- (2) a perched water table, and presumably saturation overland flow, are likely to be generated, independent of cover type, due to the anisotropic profile of K_{sat} which decreases to a depth of about 30 cm, on average;
- (3) there is a strong lateral subsurface component of hillslope flowpaths in this latosol landscape.

The occurrence of overland flow may not matter at every place from a water budget perspective because of a possibly limited magnitude and ‘effectiveness’ due to partial re-infiltration, as ponding water covers a greater area, encroaching on microtopographic upstanding root mounds with higher infiltration capacities. From a sediment and solute transport perspective, however, most of the annual hillslope-to-stream transfer is usually accomplished by a few major precipitation events which, at least under pasture, are prone to trigger overland flow that reaches stream channels.

CONCLUSIONS

The latosols (ferralsols, oxisols) on Precambrian basement rock examined in this study show a pronounced anisotropy of K_{sat} regardless of land cover. With respect to this hydrologically relevant feature, they differ strongly from latosols in the central Amazon basin, but resemble a podzólico (acrisol, ultisol) in the molasse foreland basin of western Amazonia. This anisotropy results in a pronounced lateral flow component, not typically assumed in other Amazonian regions, and potentially in a shallow perched water table. During a storm event, rainfall intensities commonly exceed infiltration capacities of pastures, which promotes a partitioning of water between on-surface and below-surface flow paths. It is our view, however, that most surface water re-infiltrates into local areas of higher infiltration capacity. The potential for a substantial overland flow contribution to stream flow is therefore limited.

In view of the scarcity of ground truth-based soil information in the Amazon basin, it is premature to even speculate as to whether soil hydraulic properties estimated at a particular site are representative of a particular landscape, let alone to extrapolate to a whole region. A co-ordinated soil–landscape-based approach to the field collection of soil hydraulic data relevant for climate and hydrological models has yet to be initiated.

In a wider context, we hope that our results contribute to dispelling the pervasive and persistent prejudice of a particular hydrological functioning of ‘tropical’ soils. Many latosols (acrisols, oxisols) certainly match the popular notion of a ‘tropical’ soil, and these soils certainly cover vast areas in the Amazon basin and elsewhere in the tropics. At this level of generalization, however, there is no one particular functional behaviour, such as hydrological, because these soils with their seemingly uniform ‘tropical’ appearance span such a wide range of functionally relevant properties that no particular ‘tropical’ hydrological functioning can be inferred, much as there is no particular equivalent ‘temperate’ functioning. As our database of soils in tropical areas and their functional properties improves, the still popular tropical vs. temperate dichotomy as a last resort in the face of inadequate process understanding ought to become obsolete.

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