ເຄື່ອງວັດແທກການຊຶມນໍ້າ ສຳລັບດິນຄ້ອຍຊັນ

ຊັງປີແອ ວັນເດີແອ, ໂອລີວີເອ ຣີໂບນຊີ, ໂອລີດ ແສງຕາເຮືອງຮຸ່ງ

ບົດຄັດຫຍໍ້

ການເຊາະເຈື່ອນຂອງດິນ ແມ່ນປັດໄຈສຳຄັນທີ່ເກີດຂຶ້ນ ໃນເຂດພື້ນທີ່ດິນກະສິກຳ ທີ່ມີຄວາມຄ້ອຍຊັນ ຢູ່ທາງພາກເໜືອ ຂອງ ສ.ປ.ປ ລາວ. ການວາງແຜນນຳໃຊ້ທີ່ດິນ ທີ່ມີປະສິດທິຜົນສູງ ຕ້ອງເຂົ້າໃຈຢ່າງເລິກເຊິ່ງກ່ຽວກັບຂະບວນການ ດ້ານຊີວະ - ດິນ - ນໍ້າ ດ້ວຍການນຳໃຊ້ຮູບແບບຈຳລອງ. ຮູບແບບຈຳລອງທີ່ນຳມາໃຊ້ ຈະຕ້ອງສາມາດຄຳນວນໄດ້ຢ່າງນ້ອຍ ໂຕແປປ່ວນຂອງລະບົບການເຄື່ອນຍ້າຍຂອງນໍ້າໃນດິນ ວິທີການດັ່ງກ່າວ ເປັນວຽກທີ່ຫຍຸ້ງຍາກ ແລະ ໃຊ້ເວລາດົນ ໃນການວັດແທກ. ເຄື່ອງວັດແທກນໍ້າຊຶມແບບໃຊ້ຈານ ແມ່ນໃຊ້ວັດແທກຄຸນສົມບັດຂອງນໍ້າໃນດິນ, ການນໍາໃຊ້ເຄື່ອງດັ່ງກ່າວ ແມ່ນຍັງຈຳກັດ ສຳລັບແຕ່ລະປະເພດດິນ. ເຄື່ອງວັດແທກການຊຶມນໍ້າທີ່ໄດ້ກ່າວໃນບົດນີ້ ແມ່ນໃຊ້ສຳລັບວັດແທກລະບົບນໍ້າໃນດິນຄ້ອຍຊັນ. ພວກເຮົາໄດ້ທຳການທົດລອງ ຢູ່ 14 ຈຸດ ໃນເຂດອ່າງໂຕ່ງຫ້ວຍປ່ານໍ່, ບ້ານຫຼັກສິບ, ແຂວງຫຼວງພະບາງ ໃນເຂດທີ່ມີໄມ້ສັກ ຄວາມຄ້ອຍຊັນ 35% ແລະ 67.5%. ຄ່າຄວາມໄວການຊຶມນໍ້າໃນດິນ ແມ່ນຢູ່ລະຫວ່າງ 4 ແລະ 22 ມມ/ຊົ່ວໂມງ.

A new tension infiltrometer to measure the soil hydrodynamic properties on steep slopes

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Abstract

In Northern Laos, there is increasing concern over soil erosion, an important factor of which is linked with land cultivation on steep slopes. Effective remediation or land use policies require in depth knowledge of the hydro-pedo-biological processes involved in these erosion mechanisms, which can only be achieved through the use of models. However, all models must be parameterized with correct estimates of their driving variables. Among those variables, at least one is always devoted to quantifying the soil hydrodynamic behaviour, generally the soil hydraulic conductivity, which is unfortunately complex and time-consuming to measure. Tension disc infiltrometers are often used to characterise this soil attribute but their use is limited to quasi-horizontal areas. A new approach is presented in this paper which aims to measure the soil hydrodynamic properties on steep slopes. The principle of tension disc infiltrometers – measured parameters are related to a known slightly negative pressure head value - was modified in order to combine the advantages of large and small discs. With large discs, a well-conditioned hydraulic conductivity is determined whereas a quasi-homogeneous pressure head condition on a slope is applied with small discs. Thus, the new device was used successfully to estimate hydraulic conductivity in a well-defined slightly unsaturated condition. Fourteen tests were carried out in the Houay Pano catchment in Northern Laos on 35% and 67.5% sloping teak tree stands. Steady state infiltration fluxes, closely related to hydraulic conductivity, ranged between 4 and 22 mm/h indicating a soil a soil predisposed to a high risk of runoff. These preliminary results also indicate that more permeable soils are found on the steeper places in the old teak stands but on the lower slopes in the young teak stands where measurements were made.

Key words: *Disc infiltrometer; Slope gradient; Soil hydrodynamic properties; Teak plantations; Lao P.D.R*

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Introduction

Over the last twenty years, tension disc infiltrometers have become increasingly popular tools for measuring soil hydrodynamic properties close to saturation (Thony et al. 1991; Warrick, 1992; Hussen and Warrick, 1993; Logsdon and Jaynes, 1993 ; Cook and Broeren, 1994). Similar to their well-known predecessor, the Muntz device (Angulo-Jaramillo et al., 2000), the principle consists in applying a constant pressure of water over a small surface of soil and measuring the amount of infiltrating water, the soil having initially a much lower water pressure head (h) than that applied at the surface. With Muntz devices, the pressure head boundary condition (h_0) is positive, i.e. a thin layer of water is maintained above the soil inside a ring which is inserted into the soil to prevent water runoff around the test area. The soil is thus completely saturated. After years of use, soil physicists realised that a major drawback of inserting the ring into the soil is that, in the case of a fragile soil surface, soil crust, roots, stones, etc., measurements will be inaccurate due to damage caused to the soil structure and the creation of artificial macropores. A further negative aspect of the technique is that, by saturating the soil, soil cracks become hydraulically active, increasing hydraulic conductivity (K) by several orders of magnitude (Boolting et al., 1991, Schaap and van Genuchten, 2006) compared to soil without cracks, and thus the actual properties of the soil matrix are masked during the experiment.

Tension disc infiltrometers appeared to solve the two problems cited above. They impose a slightly negative pressure head at the soil surface, i.e. the applied water pressure is lower than the surrounding atmospheric pressure. Thus, well-defined soil parameters at the h_0 pressure head boundary value can be calculated, namely the hydraulic conductivity $K(h_0)$ and the capillary sorptivity $S(h_0)$, (Philip, 1957 ; Elrick and Robin, 1981). However, this is valid only when the boundary condition is uniform, which limits the use of disc infiltrometers to approximately horizontal surfaces. When the aim is to characterise the first centimeters under the soil surface, which is frequently the case, it can not be dug out to create a flat horizontal area because this removes the soil layer which is of interest. The purpose of this paper is to present a modified infiltrometer design that aims at maintaining a quasi-uniform pressure head boundary condition on sloping soil and measuring the surface properties without damaging it at all. Some preliminary results obtained in the Houay Pano catchment (Valentin et al., 2008) in November 2007 are reported.

Theory

Tension disc infiltrometers (Perroux and White, 1988) are made of a disc positioned on the soil surface and a water reservoir closed at the upper end. The air is forced into a resistant path, either a Mariotte vase or a hypodermic needle, which maintains a slightly negative pressure head at the base of the disc what prevents water from flowing freely out of the device. Consequently, the unsaturated porous media (i.e. the soil) on which the disc is placed will pull water out of the reservoir by exerting a capillary force due to the pressure head difference. If the soil is initially at equal or superior pressure head than that applied (which corresponds to a very wet state), no flow will occur.

Because only porous media will make water flow out of the disc, no physical boundary of any kind is required and the disc is simply placed onto the soil. An intimate hydraulic contact is needed between the disc and the soil, which is usually impossible if the soil is not flat and/or covered with vegetation. Thus, all aerial vegetation must be cut off, leaving roots in place to keep the soil structure intact. To smooth out the irregular soil surface, a layer of fine sand is placed and flattened to receive the disc. The effects of this sand layer were extensively discussed by Vandervaere et al. (2000a) who showed that particular attention must only be paid to it at the beginning of the assessment because after approximately one minute of infiltration, the sand no longer influences the observed flow.

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beginning of the assessment because after approximately one minute of infiltration, the sand no longer influences the observed flow.

At short time intervals, water flows into the soil mainly driven by capillarity due to the difference between the initial soil moisture content (θ_i) and that of the boundary condition (θ_0). This effect is represented by the capillary sorptivity S [LT-1/2] which depends on both θ_i and θ_0. As time advances and water progresses into the soil, the capillary force decreases, as does the observed flow, until gravity becomes dominant. After a theoretically infinite time, all the surrounding soil will reach the θ_0 moisture value and the vertical component of the flow equals the hydraulic conductivity K (θ_0). However, because of the laterally moving water at the edge of the circular source (Turner and Parlange,1974),the total flow q_∞ still depends on S(θ_i., θ_0). Wooding (1968) and White and Sully (1987) showed that the steady value of the axisymmetric flow can be expressed by the so-called Wooding's equation:

$$q_\infty = K + \frac{2.2\,S^2}{\pi r\,(\theta_0 - \theta_i)} \qquad (1)$$

where r is the disc radius. After measuring q_∞ and estimating θ_0 and θ_i by soil sampling, determination of K requires the estimation of S which can be achieved by analysing the infiltration curve at short time intervals (Smettem et al., 1994; Vandervaere et al., 2000a). Note that, in the case of an infinite disc radius, Eq. (1) would simply reduce to its vertical component:

$$q_\infty = K \qquad (2)$$

As the sand must not impede the flow, a highly conductive type of sand is chosen with generally a 100-200 µm homogeneous granulometry. The hydraulic head H is defined as:

$$H = h + z \qquad (3)$$

where z is vertical elevation, is quasi-uniform within the whole sand layer since the hydraulic conductivity of the soil is always much lower than that of the sand. Thus, in the case of a horizontal soil surface and a thin sand layer, the pressure head h_0 is also uniform within the whole sand layer and the calculated soil parameters will correspond to their well-defined h_0 values, K(h_0) and S(h_0). The applied pressure head h_0 is freely chosen by the experimenter, usually between -200 mm and -10 mm. A value of -10 mm corresponds to a saturated soil matrix with empty large cracks and macropores (>3 mm). This is the most frequently used value because cracks and large macropores, when present, do not follow a Darcian behaviour and requires specific treatment within flow models. At a -200 mm pressure head, only pores smaller than 0.15 mm are filled with water. Finally, by experimenting with several pressure head values on a given soil, an interesting exploration of the soil structure with respect to flow properties can be achieved.

However, because of the non-flat nature of the soil surface, in reality the applied pressure head cannot be absolutely homogeneous over the sampled area. In the case of a microrelief with a 3 cm difference in elevation between high and low points (Figure 1), the pressure head of the soil will vary within a 3 cm range because the hydraulic head H, not the pressure head h, is homogeneous within the contact layer. A 3 cm variation range is the usual pressure head step between measurements made at different pressure values (Ankeny et al., 1991; Reynolds and Elrick, 1991) and it is thus considered an acceptable uncertainty on h_0. For example, if h0 is set at -5 cm, the applied pressure head at the soil surface will vary between -8 and -5 cm with a 3 cm microrelief (Figure 1). In such a case, it is very important to keep the infiltrometer pressure setting always less than -3 cm otherwise the low points would be at a positive pressure head and water would runoff freely at the soil surface. This illustrates the need for careful observation of the experimental area before choosing the infiltrometer pressure setting, to ensure that the entire sampled plot remains unsaturated. In the example above, a pressure head great than -3.5 cm of water should not be set.

The infiltrometer disc size is generally between 5 and 25 cm diameter. Large discs are more difficult to maintain in good contact with soil surface and require large quantities of water on permeable soils. Small discs are more portable but because a smaller area is sampled it may not be representative of the larger area under study unless many replications are performed. Another important limitation of using a small disc is that more water will flow by capillarity at the edge of the disc compared with water flowing vertically and the second term at right-hand side of Eq. (1) may become dominant over the first one to the point that K cannot be properly estimated. A small disc infiltrometer then becomes a "sorptivitymeter". It is generally considered that a 15 to 20 cm diameter is an appropriate compromise (Smettem and Clothier, 1989; Elrick et al., 1990; White et al., 1992).

On lands with up to 67.5% slope such as those found in the Houay Pano watershed (Valentin et al., 2008), the use of a 15 cm disc infiltrometer is unsuitable because the pressure head difference between the upper end and lower end points of the sampled area would reach 8.5 cm, which exceeds the desired 3 cm range limit corresponding to a reasonable accuracy. Table 1 summarizes the characteristics of the different devices available for use on a 67.5% sloping soil. The new device proposed here combines the advantages of the classic small and large disc infiltrometers.

Technical specifications

A 15 cm diameter test zone is divided into 7 mini compartments to each of which a separate mini disc infiltrometer with a hypodermic needle air entry is applied. Several needle diameters are available to choose from allowing the boundary conditions to be set between -100 and -5 mm. The 7 mini compartments are separated from each other with a tube guide made out of PVC which was specially designed for this purpose (Figure 2). Very soft split rubber tubing is stuck on the lower side of the tube guide to improve the contact with the irregular soil surface. Each mini parcel has a maximum extension of 45 mm in the direction of the slope to keep the pressure head variations less than 3 cm within the corresponding soil area. In the direction perpendicular to the slope, the mini compartments have the maximum possible extension (Figure 2) so that the area covered by the sum of the 7 mini compartments is very close to a full 15 cm diameter disc.

As described above, with classic horizontal disc infiltrometers, the contact between the disc and the soil is ensured with fine sand. On sloping land, it is very difficult to keep a sand layer parallel to the soil surface without moistening the sand. Moreover, because of the irregular soil surface, sand would move from one mini compartment to another because the rubber tubing cannot keep the compartments totally separated from each other. This would create hydraulic contact above the soil surface between the 7 corresponding zones which must be avoided (otherwise, the experimental conditions would resemble those of the classic 15 cm disc simply posed on a slope). For this purpose hydrophilic cotton is used as the contact material instead of sand (Figure 3). Cotton wool has enough rigidity to remain within one mini compartment without invading the neighbouring one. By gently moistening the lower side with a common water spray hose, it is soft enough to mould into the irregular soil surface encountered inside a mini compartment. The very high hydraulic conductivity of cotton wool ensures excellent water transfer from the device to the soil (Figure 4). Finally, note that another important advantage of cotton wool compared with fine sand is that it does not fall into soil cracks, thus preventing them from becoming artificially active under unsaturated conditions.

The seven individual infiltrometers are maintained perpendicular to the surface using a tripod suitable for slopes (Figure 5). The water levels in the seven reservoirs are monitored with pressure sensors installed at their upper ends. The sensors used have a limited range (0.5 psi) so that sufficient accuracy is guaranteed even in the case of a 45° angle between the reservoir and the vertical plane, which would correspond to a 100% slope. To prevent any error due to sensor electronic shift with time and/or temperature variations, at least two manual readings are taken, during all experiments, on each of the seven reservoirs, to calibrate the seven relations between sensors signals (mV) and water levels. Measurements are recorded every second with a CR1000 Campbell datalogger. Once the seven water levels are calculated, the cumulative infiltration curve for the 15 cm diameter area can be establish by adding the seven values, which can then be analysed using the same methods developed for classic infiltrometer data. Figures 6 and 7 show the infiltration area before and after the PVC tube guide was removed and the cotton remaining untouched. It can be seen from Figure 7 that the contact surface covered with cotton is very close to the full 15 cm diameter disc. The area not covered with cotton wool is visually estimated at less than 10% of the total area. Regardless, it is only at the beginning of the test that this has an effect on the infiltration curve. After a few minutes, the seven soil zones become hydraulically connected, each of them, however, remains at its own hydraulic head value because of the resistance to the flow in the soil.

The test duration is not known, a priori, since it will depend on the desired outcome. If the aim is to measure the steady rate of infiltration, the test will continue until an apparent steady flow is reached, which requires a real time survey of the water levels. If only the first one or two centimeters of soil is being sampled, the test can be shorter than 20 minutes and it is likely then that only a transient regime of infiltration will be available for analysis (Vandervaere et al., 2000b).

Results and discussion

Figure 8 gives an example of a water level recording. Two flow patterns, a fast flow at the beginning of the test (water infiltrating the cotton followed by capillary-driven flow into the soil) followed by a slower gravity-driven near constant flow, can be clearly seen. Short-time variations in the signal correspond to bubbles going through the hypodermic needle. Each time a bubble is released in the reservoir, the pressure suddenly increases. To facilitate the analysis of the transient flow regime, the signal was smoothed by only keeping the lower points (Fig. 8). This was done manually at present but should be achieved with a specially designed computing program in the near future.

At present, only the steady regime will be discussed as the sorptivity estimations are still under analysis. Nevertheless, the hydraulic conductivity can be evaluated as 60 to 80% of the steady flow values, based on field observations of the edge front progression at the periphery of the test areas. Tests were conducted on two teak stands, old teak (OT) and young teak (YT) and two slopes, 35% and 67.5%. Results presented in Table 2 and Figure 9 show markedly different characteristics for each stand.

The most permeable area of the four units was the 35% slope YT soil. In the OT stand, the less permeable soils were found on the 35% slopes whereas in the YT stand these were found on the 67.5% slopes. The OT results concur with previous findings by Janeau et al. (2003) in Northern Thailand regarding runoff decrease with slope. However our finding in the YT plantation do not, suggesting a complex relationship between land use and soil properties. It is likely that the young teak trees have not yet had a marked influence on the soil of this area suggesting that the values found in the YT stand may reflect the previous land use, which was as fallow.

In the above analysis, it was assumed that the infiltration bulbs inside the sloping soil are behaving similarly as in horizontal soil. Indeed, in the sloping geometry the lack of soil material downslope is partially compensated by the upslope soil surplus which probably makes the two bulbs quite equivalent, at least in volume. However, this clearly needs further investigating and quantifying in the future through numerical modelling work.

Conclusion and perspectives

After important modifications to the classic tension disc infiltrometer design, a new device was proposed which was used successfully to provide infiltration measurements with unbiased comparisons between sites with very different slopes. Steady infiltration values ranging from 4 to 22 mm/h were obtained on 35% and 67.5% sloping teak stands showing that the relation between slope angle and infiltration capacity is probably complex and strongly depends on soil use history prior to the tests. These preliminary results, however, were obtained with a limited number of observations.

Although still under processing at present, the analysis of the first stages of infiltration should provide sorptivity estimations that can be used to calculate the hydraulic conductivity from steady state flux values by differentiating vertical and lateral flow components. Finally, forthcoming work will aim to improve quantification of the effects of the sloping geometry on the infiltration bulb, to confirm if it can reasonably be treated as an axisymmetric situation and thus be described with the equations developed in this context.

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Table 1 – *Some characteristics of two pre-existing and the new infiltrometer operating on a 67.5% sloping soil.*

	Classic disc 5 cm diameter	Classic disc 15 cm diameter	New disc 15 cm diameter
Suitable for K estimation	no	yes	yes
Suitable for S estimation	yes	yes	yes
Pressure head homogeneity	acceptable (28 mm)	not acceptable (84 mm)	acceptable (28 mm)

Table 2 – *Steady infiltration flow in mm/h on two Houay Pano stands, Old Teak (OT) and Young Teak (YT). Mean (bold), unbiased standard deviation (std dev) and number of measurements (n) in brackets.*

		OT	YT
35% slope:	**mean**:	**4.1**	**14.8**
	std dev:	1.0	6.2
	(n):	(4)	(3)
67.5% slope:	**mean**:	**12.2**	**4.4**
	std dev:	5.3	0.8
	(n):	(4)	(3)

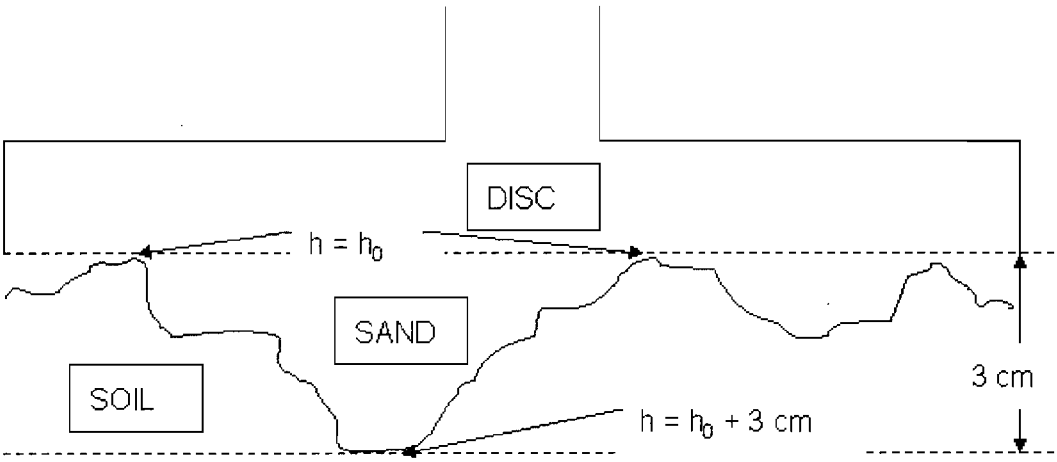

Figure 1 – *Schematic representation of the soil microrelief and its consequences on the applied pressure head.*

Figure 2 – *Tube guide for the 7 infiltrating tubes.*

Figure 3 – *Cotton wool ensuring contact between the infiltrating tubes and soil*

Figure 4 – *The new infiltrometer functioning*

Figure 5 – *The new infiltrometer with tripod on a 67.5% slope.*

Figure 6 – *Wet cotton wool after infiltrometer removal.*

Figure 7 – *Wet cotton wool after infiltrometer use and tube guide removal. Note the well separated infiltration zones.*

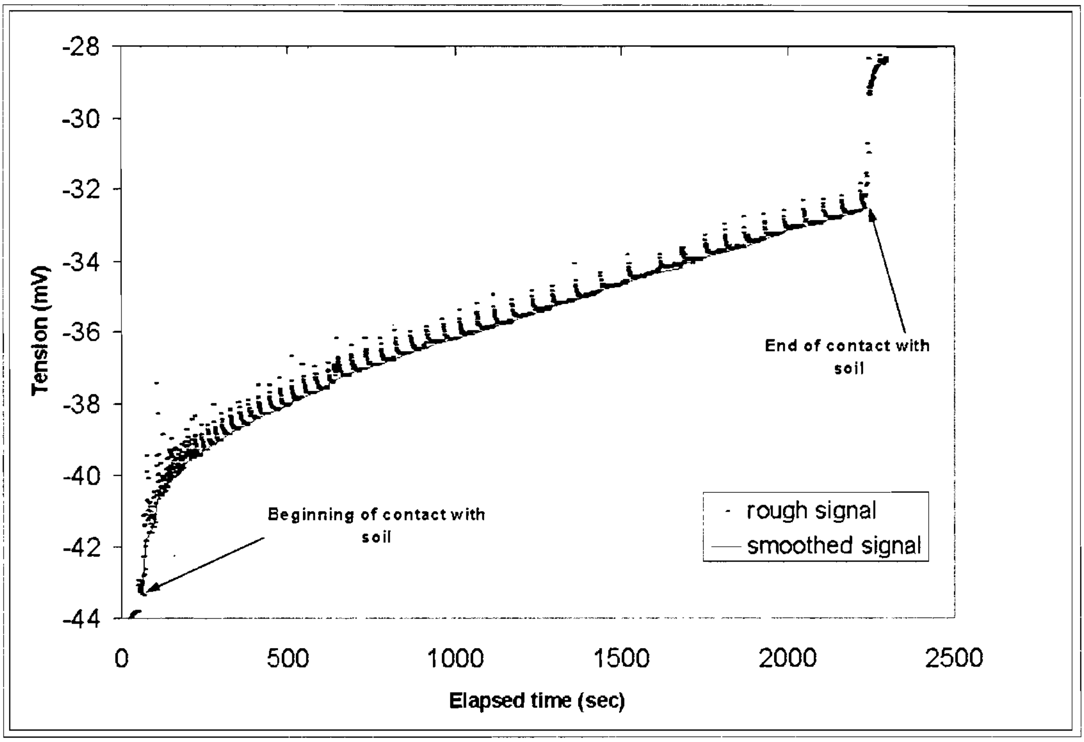

Figure 8 – *An example of water level recording by pressure sensor, rough signal (points) and smoothed signal (plain line).*

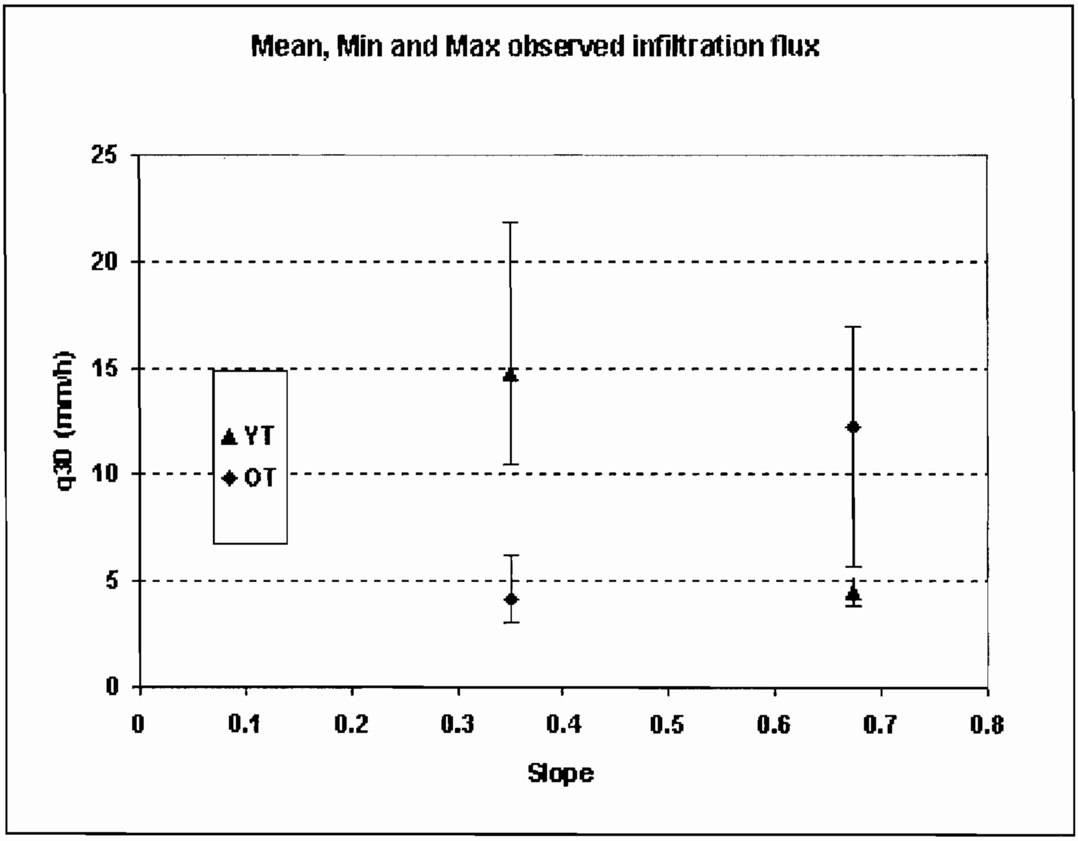

Figure 9 – *Mean, maximum and minimum steady infiltration flux measured within the old teak (red squares) and young teak (blue triangles) stands as a function of the slope.*

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IRD Institut de recherche pour le développement

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ອອກແບບ ແລະ ຈັດໜ້າ ໂດຍ: ຂັນຄໍາ ອ້ວນອຸດົມ, ສູນຂໍ້ມູນຂ່າວສານ, ສຄກປ