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Infiltration, runoff and drainage in the Sudano-Sahelian zone

W. B. HOOGMOED

Soil Tillage Laboratory, Agricultural University, Dierenweg 20, 6703 GW Wageningen, The Netherlands

M. C. KLAUJ & J. BROUWER

Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, BP 12404, Niamey, Niger

Abstract We present a brief overview of methods suitable for measuring or estimating infiltration, runoff or drainage. Since an exhaustive overview is not feasible in the context of this paper, the emphasis is on field methods which are not too complicated or expensive, and suitable for use in the Sudano-Sahelian zone. Methods for measurements over large areas, e.g. catchments, are not included. Obviously, for natural events where interception of rainfall by the vegetation can be ignored, infiltration and runoff together equal precipitation: only two of the three processes need be quantified to quantify the other. For each method a brief description is given, together with a suitable reference for further information.

INTRODUCTION

The water balance can be written in the form:

$$dS = P + G + R_{on} - E_t - D - R_{off} + Irr \quad (1)$$

where dS is the change in soil water content, P the precipitation, G the groundwater inflow, R_{on} the runoff or surface inflow, E_t the evapotranspiration, D the drainage, R_{off} the runoff and Irr the irrigation.

For non-irrigated agriculture, the input of water into the root zone is due to rainfall and possibly runoff. For the large majority of soil conditions in the Sudano-Sahelian zone, no upward flow takes place, so $G = 0$. Rainwater reaching the soil surface may *infiltrate*, if the rate of rainfall is lower than the infiltration rate of the soil. When the infiltration rate is lower than the rainfall intensity, the excess water starts to collect at the surface, and when the surface storage is exceeded, *runoff* will occur. At the bottom of the root zone water will leave the system as *drainage*. A brief description of infiltration, runoff and drainage processes is presented below. For further information reference is drawn to Burke *et al.* (1986), Klute (1986a), Lal (1988) and ASAE (1983).

INFILTRATION

Background

Infiltration is a dynamic process of water crossing the soil-air interface. The infiltration rate depends on the soil characteristic and on the rainfall intensity. In the Sudano-Sahelian zone this process is strongly influenced by the fact that rainfall is intense and erratic and soils are generally light, poorly structured and unstable. This implies that generally conditions change during the rainfall event (crusting, sealing, aggregate breakdown).

Methods

Basically, two systems are used to measure infiltration:

- water is applied to the infiltrating surface without any kinetic energy (i.e. by ponding or flooding),
- water is applied as drops (rainfall).

Infiltration of ponded water: ring infiltrometers The most common method used to measure surface infiltration rates is the cylinder infiltrometer; a metal cylinder, inserted a small distance into the soil. Of the various methods which use ponded water, the double ring infiltration method, using two concentrically placed rings, is preferred. Measurements are made on the rate of fall of the water level in the inner ring, while water infiltrating into the soil between the two rings ensures one-dimensional flow (FAO, 1979). However, the outer cylinder is effective only for those situations where there is a poor contact between cylinder wall and soil (crusts etc.). In other situations, the measured infiltration rate with or without outer cylinders is almost the same (Bouwer, 1986).

The method is not suitable for soils with macropores, where flow is not one-dimensional, or for soils with fragile surface crusts which will break when the rings are pushed into the ground. If layers with very different saturated conductivities occur near the surface, the pressure head gradient is unlikely to be equal to 1 m m^{-1} , which is a basic assumption of the method. The infiltration rates then obtained do, however, give an indication of the likelihood of runoff taking place due to a temporary perched water table rising to the surface.

The results obtained can be quite accurate, particularly as the (inner) rings can be quite large (30 cm diameter or more). The method is inexpensive, simple and very easy to learn and rings can easily be made locally, or even "on-the-spot" by ponding water in between small earthen dikes lined with plastic sheets.

Infiltration of ponded water: crust test For measuring the resistance of surface crusts and crust infiltration rates, a variation of the crust test for measuring saturated and unsaturated hydraulic conductivities can be used (Bouma et al., 1983). In the variation described by Falayi & Bouma (1975)

the crust is carefully cut with a razor blade, a few mm inside the infiltrometer ring, before the ring is pushed into the soil. The gap between the ring and the undisturbed crust is sealed with a gypsum paste, or, preferably, with a quick drying hydraulic cement. Water is applied from a burette with a mariotte device to control the suction. Sub-crust matric potential is measured with a small tensiometer. The method is suitable for crusts without too many rocks in them. It is accurate and quick.

Infiltration of simulated rain Rainfall hitting the soil surface may have a considerable effect on its condition. This is especially so when, as under the climatic conditions in the Sudano-Sahelian zone, rainfall is aggressive (Hoogmoed & Klaij, 1990).

To measure infiltration under rainfall, one could either utilize the natural rainfall, or try to duplicate the characteristics of a natural rainstorm. Using natural rain has some distinct advantages, the real situation is assessed and no equipment is required to produce rain. The disadvantages are that each rain event has a different characteristic, time and frequency of occurrence is not known and rain may come at inconvenient moments or not at all.

Various types of rainfall simulators or sprinkling infiltrometers have been developed to duplicate natural rainfall. To simulate rainfall, a major question is which characteristic should be approached most closely? Peterson & Bubenzer (1986), gave a comprehensive review of these devices and list the following criteria: drop size distribution, drop velocity at impact, rainfall intensity, uniform rainfall, total energy and reproductive storm patterns. The choice of a certain combination of drop size distribution, velocity and intensity is difficult, since measuring the natural rainfall to be simulated is not easy either. In addition, there is no clear picture of how certain parameters can be used to compensate others. This depends strongly on the type of effect rainfall has on the soil surface and on the infiltration process.

In particular on the light soils, the sealing effect of the aggressive rain is important, so a simulator used in the Sudano-Sahelian zone should produce realistically sized drops, hitting the soil surface at a realistic (i.e. terminal) velocity. Experiments in Mali on a sandy loam soil showed a very big difference in measured infiltration rate between low and high-energy infiltrometers (Hoogmoed, 1987)

Basically, two systems are used to produce raindrops: the nozzle and the drop-former type. The nozzle type is the most commonly used system; it can easily produce the correct drop size (distribution) and velocity, but complicated constructions had to be developed to bring the intensity down to a realistic level. The main disadvantage with the drop-former type is the fact that terminal velocity of large drops is reached only after a fall of more than approximately 5 m, thus making it impractical for field use. In units with lower drop heights, the lower velocity has to be compensated by creating larger-than-natural drop sizes. Small portable simulators of the drop-former type as described by Kamphorst (1987) are not recommended for use on the surface-sealing soils.

A general disadvantage of both systems is that simulated rainfall

intensity is fairly constant and the quick changes in intensity, typical of rainstorms in the region, cannot be simulated. It is also difficult to attain extremely high intensities, like, for example, over 300 mm h⁻¹ during 6 minutes as found by Hoogmoed (1986). Furthermore, the larger rainfall simulators, covering an area of 10 m² or more, are very cumbersome and require a lot of water as well as a large power generator. Despite these facts, rainfall simulation offers the best opportunity to evaluate the build-up of surface seals and to measure surface storage and detention. Seal formation is quantified by expressing the infiltration rate as a function of cumulative rain applied.

Water repellency Infiltration and runoff are often related to water repellency of soils, including sandy soils, although its effect on total infiltration may be small, as found in Mali by Rietveld (1978). The relative water repellency of a soil can easily be assessed by measuring Water Drop Penetration Time: drops of distilled water are placed on soil dried at 60° and passed through a 2 mm sieve, and the time until disappearance of the drops into the soil is measured (e.g. Hammond & Yuan, 1969, Dekker & Jungerius, 1990). The method is, however, only qualitative.

Examples for the Sudano-Sahelian zone

Use of small plots in combination with rainfall simulators is described by Valentin (1985) and Casenave and Valentin (1989), using 1 m² plots in Niger and Burkina Faso. Stroosnijder & Hoogmoed (1984) report work on 2.25 m² plots in Mali and Niger.

RUNOFF

Background

Runoff is a process where there is a flow of water over the soil surface, with:

$$R_{\text{off}} = P (+ Irr) - SSD - I \quad (2)$$

where SSD is the surface storage and detention, and *I* the infiltration. Three parameters are involved:

- rainfall reaching the soil surface,
- infiltration of water into the soil profile, and
- the static and dynamic storage capacity of the soil surface depending on slope and roughness/configuration of the surface.

These three parameters are dynamic and not independent from each other, for example, surface roughness and infiltration capacity may both decrease under rainfall.

Methods

Runoff can be measured by delineating a certain area of a field and collecting and measuring the volume of water passing the downslope border of that area. In view of the dynamic character of the process, the runoff rate will give the most useful information. The main differences in methods of measuring runoff are a matter of scale, the collecting area is the main determinant for the type of information, and for the required methodology. Runoff collecting areas in agricultural research may range from complete watersheds, down to areas of less than 1 m². In the first case, the information relates not only to soils, but also to surface shape and roughness, vegetation etc. Runoff collected from small areas provides more information on the soils and their behaviour under rainfall.

An extensive review and description of the installation and use of field plots for erosion and runoff studies is given by Mutchler *et al.* (1988). Basically, three classes of plot size may be distinguished: small plots, USLE (Wischmeier) plots and watershed type plots.

Small plots (1–2 m²) are used commonly in combination with rainfall simulators, but can also be used under natural rainfall. The processes studied are those that are directly tied to the effects of rainfall, like sealing or changes in surface storage due to aggregate breakdown etc., and not to processes induced by water flowing over the surface. These plots can be easily installed, they are cheap, all runoff water and sediment can be collected, but border or edge-effects (particularly important for erosion studies) may be serious. Since variability of the fields will have a much bigger influence, the choice of locations is more critical, and more replications may be needed.

Wischmeier or USLE plots The size of these plots is large enough to permit study of the combined processes of rainfall, runoff and erosion. Standard plots are 1.8 m wide and 22 m long. Such plots cover 0.04 ha and have the dimensions most commonly encountered by Wischmeier & Smith (1978), in the work leading to the formulation of the Universal Soil Loss Equation (USLE). While such dimensions are by no means magical, in particular standard lengths are to be preferred for reasons of comparison, with a width adapted to row crop distance and other agricultural practices (for example, working width of machinery). The runoff volume can be measured using large (e.g. 200 litre) vessels installed in a hole in the ground, with 1:9 flow dividers leading to further vessels to increase measurement capacity (Rawitz *et al.*, 1983). Continuous registration of runoff can take place using any type of discharge measurement method (see Bos, 1989). Care must be taken that silt and debris coming of the plots do not interfere with the measuring of the runoff.

Though construction of such plots is not all that expensive, their operation can be rather time consuming. Also very sizeable areas are required. The fact that the plot is cut off from the surrounding (upslope) area may influence the representativity of the measurements. If one is interested in the effects of surface storage or detention, as produced by

tillage, special attention must be given to the layout of the plot. For example, contour-ridging is difficult to evaluate, since the length of the ridges is limited by the width of the plot. Construction and maintenance are not very difficult, though plot boundaries may have to be removed to allow farm operations.

Watershed-sized plots These plots may comprise agricultural fields plus natural drainage ways. The field area may consist of cropped areas, or natural vegetation, or a combination of both. Preferably, the area should be under only one type of cover or treatment. The size and shape of a watershed permits the evaluation of conservation measures on a larger-than-field scale (terraces, "digues filtrantes" etc.). The major disadvantage is that the results obtained from these plots cannot easily be reproduced.

Unbounded runoff plots These are a recent development in overland flow measurement. Runoff collection troughs are installed in a cascade system in such a way that runoff to one unbounded plot may be considered to be the same as runoff into the adjacent upslope trough, located immediately to one side. Differences between runoff and runoff for a plot bounded only at its lower end can thus be calculated. The problem of bounding a plot at its upper end (and along its sides) is eliminated (Bonell & Williams, 1986; Williams & Bonell, 1987). Unlike conventional runoff plots, tillage farm operations along the contour are not restricted in unbounded plots. In all other respects an unbounded runoff plot is much like a conventional runoff plot.

Examples for the Sudano-Sahelian zone

The USLE type plots are in use at the ICRISAT Sahelian Center (ISC) to evaluate effects of soil tillage practices on runoff (this paper). Roose (1977) reports on work in West Africa including observations on plots of 250 m² with natural vegetation in Burkina Faso. The (semi) watershed sized plots have been used in experiments reported by Delwaulle (1973) in Niger, using entire farmers' fields as plots, sized between 3400 and 4800 m². Fields of 5000 m² were used in Burkina Faso. In these experiments, the effects of agricultural practices were evaluated (Roose, 1977).

DEEP DRAINAGE

Background

Deep drainage is very difficult to measure directly. It is often calculated by difference when all the other terms of the water balance are known, i.e. when precipitation, runoff, storage in the soil, evaporation and interflow are either measured or calculated directly, or are negligible. Deep drainage can also be calculated directly from groundwater piezometer data. Only in exceptional circumstances can such data be collected on the scale of an agricultural field,

and piezometer methods are not dealt with any further here. The use of artificial and natural tracers to measure recharge also falls outside the scope of this paper; relevant papers can be found in e.g. Simmers (1987).

Methods

Lysimetry is the only method available for direct measurement of deep drainage on a plot scale. Lysimeters can contain several cubic metres of soil, but may be as simple as 20 or 30 cm diameter tubes, sunk 10 to 50 cm into the ground. They can be lifted out regularly for weighing, or left with a solid plate at the bottom to induce (artificial) saturation and lateral flow into a collector in a pit (e.g. Agnew, 1982; Shawcroft & Gardner, 1983; Klocke *et al.*, 1985). Preferably, but not necessarily, lysimeters contain undisturbed soil. They can have a tension plate at the bottom to catch unsaturated drainage and avoid unnatural saturated conditions. Accuracy, cost and simplicity/complexity depend on lysimeter type, with low cost and simplicity usually accompanied by low accuracy.

Modelling computer models provide an alternative means of calculating deep drainage. The models themselves fall outside the scope of this paper, and we refer to Feddes *et al.* (1988) and Wierenga & Bachelet (1988). Simple models that do not require the use of computers are given by e.g. Rose & Stern (1965), McGowan & Williams (1980), Reddy (1983), Pygay (1985) and Maulé & Chanasyk (1987).

All the models, however, are generally dependent upon input of soil, crop and weather data. We would like to point out some of the pitfalls in the collection of the soil part of such data, in particular matric potential-water content relationships and matric potential-hydraulic conductivity relationships, as well as the determination of soil moisture profiles to check the calculations made with a model.

Matric potential-water content relationships These relationships are most easily and often determined using tension plates or sand bins (Klute 1986a; Burke *et al.*, 1986), a method which needs no further elaboration here. A warning note must be sounded, however, about the common practice of excluding the fraction >2 mm from the determination of water content at a matric potential of -1500 kPa (pH 4.2). As pointed out by various authors, quoted by Klute (1986b), the fraction >2 mm may well hold considerable amounts of water, particularly at low potentials. The studies quoted are concerned with rock fragments. It was found that ironstone (laterite) gravel from southeast Australia can contain more than 20% water ($\text{m}^3 \text{m}^{-3}$) at -1500 kPa (personal communication, J. Brouwer). Ignorance of this fact could lead to overestimating the available water holding capacity of the soil concerned by up to 6.6 volume percent, equivalent to up to 96% of the real water holding capacity. On gravelly soils in West Africa the same may well be true, and the consequences for modelling of the water balance will be obvious.

Other methods for determining matric potential-water content

relationships include the gas and vapour pressure methods (see Burke *et al.*, 1986) and a field method using tensiometers and a neutron probe (calibrated *in situ*) or gravimetric sampling (Vachaud *et al.*, 1978).

Saturated hydraulic conductivity This can be determined in a number of ways. Methods using large cylindrical samples of soil in the laboratory are described in Klute (1986a) and Burke *et al.* (1986). Methods using large gypsum- or cement-encased columns *in situ*, as developed by Bouma and colleagues, are also described in Burke *et al.* (1986). (Inversed) auger-hole methods, where the rate of rise or fall of the water level in an auger hole is measured, are described in Klute (1986a) and in Burke *et al.* (1986). The effect of slumping of hole walls (likely to happen in sandy Sahelian soils, unless a liner is used for the auger hole) on calculated conductivities is described by Topp & Zebchuk (1986).

Matric potential-unsaturated hydraulic conductivity relationships The oldest field method for determining this relationship is the *instantaneous profile method*, described by Rose *et al.* (1965). It uses simultaneous measurements of water content and matric potential for the necessary calculations.

The *crust method* is more recent, using artificial crusts of different thicknesses, rather than a natural crust, to induce different matric potentials in the soil under the crust, and thus different fluxes (Bouma *et al.*, 1983). This has been further refined by using only one crust in combination with a mariotte device to induce different potentials above and thus also below the crust (Booltink *et al.*, 1990). This latter refinement has the advantage over the suction infiltrometer of Perroux & White (1988), suitable for sandy soils, that it can also be used for soils with macropores and that it samples relatively large areas. A disadvantage is that it does not measure hydraulic conductivity at zero matric potential with full macropores, only with flow along the walls of the macropores (*cf.* Bouma, 1982). It also cannot be used at low conductivities (below about 10 mm day⁻¹).

The *one-step outflow method* is used to determine potential-conductivity relationships of small (300 cm³) undisturbed samples in the laboratory. The suction applied to the samples is lowered suddenly, and the subsequent outflow of water is monitored. The (change in) rates of outflow is used to calculate the potential-conductivity relationships (see Burke *et al.*, 1986). A disadvantage is the small size of the sample, and the relatively expensive equipment needed. In addition, the samples take 2-3 weeks to analyse. On the positive side, the full range of the potential-conductivity relationship can be calculated, rather than just the wet end as with the crust test.

Soil water profiles These are generally determined gravimetrically or with a neutron probe (which has to be calibrated *in situ* for accurate measurement; see e.g. Greacen, 1981). The technique of time domain reflectometry (TDR) (e.g. Topp, 1987) may become an interesting alternative for use in light and gravelly soils (Drungil *et al.*, 1989). These methods are not commented on further, except to say that flow through preferential

flowpaths, so-called "by-pass flow", is not picked up by any of these methods. Wherever such flow might take place, on all structured soils, but perhaps also on sandy soils, especially near saturation, neutron probe or gravimetric moisture data in themselves are not enough to calculate total deep drainage, only to calculate the unsaturated flow part of deep drainage. The situation regarding preferential flow on sandy soils in the Sahel is still being evaluated, but the occurrence of preferential flow on very sandy soils in Europe (see Dekker & Jungerius, 1990; and Van Ommen *et al.*, 1988) gives cause for thought. Methods to trace preferential flowpaths are described by Smettem & Trudgill (1983) and Van Ommen *et al.* (1988).

Examples for the Sudano-Sahelian zone

Research work to develop water balance models for the semiarid zone of West Africa has been carried out e.g. by IRAT, notably in Senegal (Franquin & Forest, 1977; Dancette, 1983; Dancette & Forest, 1986).

SOIL VARIABILITY

With all the above measurements, the extreme soil variability occurring over distances of only meters in West Africa (see e.g. Chase *et al.*, 1987), must be kept in mind. Such variability may require many more measurements than would normally be done in other regions, in order to obtain an accurate picture of local soil hydrology. Geostatistical techniques may be applied here to design optimal sampling schemes (Mulla, 1989). Scaling techniques to quantify the variability in hydraulic functions used in models are now available to improve the practical usefulness of these models (Wösten, 1990).

EXPERIMENTAL WORK AT THE ICRISAT SAHELIAN CENTER (ISC)

We evaluated rainfall infiltration characteristics from natural rainfall events on Wischmeier type runoff plots, and also using a small-plot rainfall simulator.

Runoff plots measuring 6 × 24 m were installed at the ISC on a "Laboucheri" soil series with a 3–4% slope. The soil surface is generally flat, with a yellowish red 30 cm deep surface horizon. The Bt horizon consists of weakly structured red sand to depths exceeding 2 m. The dominant clay mineral is kaolinite. The clay content of the topsoil is about 5%, gradually increasing to 6–8% at a depth of 1.5 m (West *et al.*, 1984).

Two soil management treatments: pre-sowing to a depth of 15 cm, and a non-tilled control, both fertilized and cultivated with pearl millet, were compared with a bare plot and a bush-fallow plot. From each plot total runoff per rainfall event was collected and transferred to a series of two simple divider vessels, the first one passed on about 10% of its excess water to the second and the second about 10% to an end-container. Runoff was estimated from the amounts of rainwater contained in the vessels. The

rainfall simulator was constructed according to the design of Morin *et al.* (1967). Simulation runs were made on fields of the "Laboucheri" soil series, using a 1.5 × 1.5 m plot size.

The deep sandy soils of the ISC maintain very high infiltration rates on cultivated plots. From 1984 to 1987, the maximum runoff measured from the non-tilled, millet cultivated, Wischmeier plot was 1.5%, with a 98 mm storm producing 1% runoff. In contrast, the bare plot developed a crust and produced up to 20% runoff for rainstorms ranging between 12 and 90 mm. The bush-fallow plot, featuring a grassy vegetation with a crusting soil, produced up to 30% runoff per storm in 1985 (after 1984, a rainfall deficient year). Apparently the shallow weeding executed at least twice a year on the non-tilled millet cultivated plot prevented the extent of crust formation which resulted in runoff from the bare and bush-fallow plots.

Rainfall simulator studies on the same soil type confirmed the high infiltration rates usually observed in fields. We subjected an initially dry, bare, 1.5 × 1.5 m plot with a 3% slope to a 100 mm h⁻¹ rainfall intensity. Two hours of continuous application failed to produce runoff. On a similar micro-plot ridges were formed in the direction of a 4% slope, over a mechanically compacted sub-soil. Even under these adverse conditions runoff produced did not exceed 4% after an application of a 75 mm h⁻¹ intensity rainfall over 12 minutes.

However, runoff does occasionally occur in cultivated fields, and usually originates from (abandoned) termite hills. Termite hills are typically somewhat elevated (about 0.5 m) and have four to eight-times the clay content of the surrounding soil to a depth of 1 m (West *et al.*, 1984). Using the rainfall simulator we measured runoff, and evaluated the effect of tillage produced macro-pores and surface roughness on a series of micro-plots ranging from the foot of a termite hill towards surrounding ordinary field conditions. What follows are the results from measurements on two plots.

The undisturbed soil in the plot located 3 m from the centre of the termite hill (78.3% sand, 4.1% silt, and 17.7% clay) produced runoff almost immediately when rain applied at a 88 mm h⁻¹ intensity began to exceed the infiltration rate (Fig. 1). The final infiltration rate dropped to about 20 mm h⁻¹. In the second plot at 6 m from the hill, the soil was slightly less clayey (82.3% sand, 3.3% silt, and 14.3% clay). In this case rainfall intensity used was 75 mm h⁻¹, and the undisturbed surface had an infiltration rate which decreased more slowly to a final rate of 30 mm h⁻¹ (Fig. 2). From the whole series of six plots it appeared that final infiltration rates increased from 20 to 40 mm h⁻¹ as the clay contents decreased from 17.7% to 12.9%. Reaching "normal" soil conditions with about 5% clay, infiltration rates would exceed the previously mentioned 100 mm h⁻¹.

To evaluate the effect tillage has on infiltration, the same plots were hand tilled using the "daba", a local digging scoop. The resulting increased soil surface storage delayed runoff in the first plot by 10 minutes equivalent to 12 mm rain. In the second plot, tillage delayed runoff by 18 minutes or 22 mm of rain. However, these rains reduced soil surface roughness and recompact the soil. As a result, a second rain simulator run produced runoff sooner while final infiltration rates were reduced to almost the final

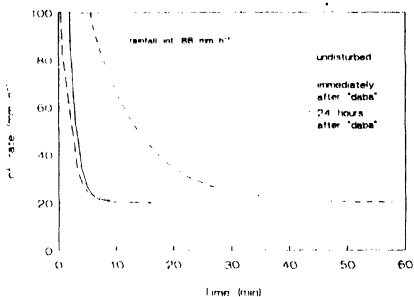


Fig. 1 Infiltration rate as a function of time under simulated rainfall of 88 mm h^{-1} (fitted curves). Centre of termite hill. ICRISAT Sahelian Center, Niamey, Niger.

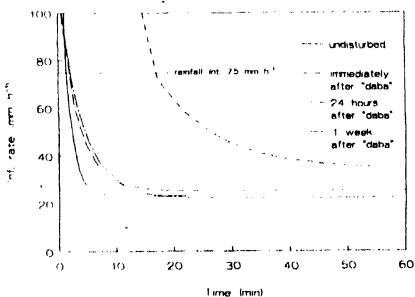


Fig. 2 Infiltration rate as a function of time under simulated rainfall of 75 mm h^{-1} (fitted curves). Six metres from centre of termite hill. ICRISAT Sahelian Center, Niamey, Niger.

rates (Figs 1 and 2). In both figures, runoff rate equals rainfall intensity minus infiltration rate.

The rainfall simulator used has been a very useful tool for evaluating the effects of tillage and or soil surface conditions on rainfall infiltration. On soils having a similar texture as those of the termite hill repeated tillage would be necessary to maintain higher rainfall infiltration.

CONCLUSIONS

Agricultural research in the Sudano-Sahelian zone has to deal with a large number of problems, among which soil and water conservation and crop water use efficiency are very important.

The development of improved management methods involves research of an applied nature. The underlying specific knowledge of physical, chemical and biological processes is often lacking when trying to explain observed differences between treatments in experiments. The availability of basic information on soil and soil water is even more important in field experiments covering a few seasons only, and it is indispensable when the phenomena under study are to be modelled.

Summarizing, with regard to *infiltration* we may say that measurements using ponded infiltration can easily be carried out, but rainfall simulators are required when changes in surface conditions are to be expected, natural rainfall being often too unpredictable. The choice of *runoff* plots will be based (apart from practical restrictions like available labour and capital) on the study subject, with small plots to study soil parameters and large plots to study field (watershed) and management parameters. *Drainage* can only be measured directly in lysimeters, which are costly and difficult to manage in this region. Calculation of drainage by analysing changes in the status of water in the soil profile require knowledge of soil-water characteristics which can be measured in the field or laboratory. Although laboratory methods are often attractive, measurements in a relatively undisturbed field situation may yield more reliable information. In view of the high soil variability, the application of the data to be collected should be carefully chosen. One piece of information missing may render an entire experiment virtually useless.

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