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Soil & Tillage Research, 16 (1990) 85-103
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

Soil Management for Crop Production in the West African Sahel. I. Soil and Climate Parameters

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(Accepted for publication 20 July 1989)

ABSTRACT

Hoogmoed, W.B. and Klaij, M.C., 1990. Soil management for crop production in the West African Sahel. I. Soil and climate parameters. *Soil Tillage Res.*, 16: 85-103.

To obtain a basis for a proper development of improved soil management methods in the West African Sahel, soil and rainfall characteristics of a millet growing area close to Niamey, Niger were determined. In laboratory tests, the coarse sandy soil of the area shows a mechanical behavior which is extremely dependent on the moisture content at the time of soil handling. Therefore, the workability range is very narrow. Rainfall in this region is aggressive; even small storms may fall with high intensities. In the region studied, the number of days available for planting millet is extremely small, on average around 11 for the season. Therefore, time-efficient soil preparation and planting methods are required.

INTRODUCTION

The world's attention continues to be drawn to food shortages in the Sahel region of West Africa. Although drought periods generally are the direct cause of disasters, agricultural research has shown that the problems of insufficient food crop production are not just due to these adverse climatic conditions, but to a combination of environmental and socio-economic factors (Matlon, 1987). In this and following papers of this series, we will describe the research on soil and water management of typical West African soil types, which is carried out at ICRISAT (International Crops Research Institute for the Semi Arid Tropics) Sahelian Center near Niamey, Republic of Niger.

In this paper a report is given on investigations concerning the two most important environmental parameters that affect soil management, i.e. soil and rainfall.

0167-1987/90/$03.50

GENERAL DESCRIPTION OF THE AREA

In West Africa, the vegetation zones closely follow the isohyets of annual rainfall, which run virtually east–west and show a substantial increase in annual precipitation when moving south, away from the Sahara desert. The Sahelian and Sahelo-Sudanian zones are bordered by average annual rainfall limits of 100 mm $year^{-1}$ in the north (approximately the northern limit of cultivation) and 600 mm $year^{-1}$ in the south, from where the Sudanian and Sudano–Guinean zones extend to the south to the maximum rainfall limit of about 1200 mm $year^{-1}$.

The single-peak rainy season is in the period from May to September, with the remainder of the year virtually dry. The length of the rainy season ranges from 60 days at the 250 mm $year^{-1}$ isohyet to 120 days at the 750 mm $year^{-1}$ isohyet. Rainfall is irregular and comes in the form of high-intensity storms, with strong implications for soil management and soil and water conservation.

Generally, productive arable farming is not possible in regions with < 400 mm $year^{-1}$ rainfall. In these regions, agricultural production is based on cattle (meat and milk products), often in a nomadic herd system. Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is grown throughout the semi-arid zone, but it is dominant in the 250–750 mm $year^{-1}$ zone. Millet is often intercropped with cowpea or niebe (*Vigna unguiculata*). The production of sorghum (*Sorghum bicolor* (L.) Moench) is concentrated in areas with 650–1000 mm $year^{-1}$ rainfall.

Crop production in the Sahelian region is hindered by a large number of unfavorable factors. The soils have a low fertility and an unstable structure, the climate is harsh and unpredictable, and the means of the farmer in terms of capital, energy and economic infrastructure are extremely limited. Traditional crop production is almost entirely based on hand labor. Animal traction is used to some extent (mainly in Senegal and Mali) in the production of the typical subsistence crops millet, cowpea and sorghum. Mechanization by using tractors is limited to a few large-scale operations producing cash crops.

For a typical Sahelian farm, soil management forms a very important part of the energy input. Seedbed preparation may constitute the biggest energy-consuming activity, but manual weeding may form the most serious labor bottleneck of all activities.

THE EXPERIMENTAL SITE

The ICRISAT Sahelian Center (ISC) is situated in the south-western part of Niger, at 13°15′ N latitude and 2°18′ E longitude, about 40 km south-east of the capital Niamey, and about 7 km from the Niger river.

The soils in the Niamey region, having moist conditions for 98 consecutive days, are classified as Ustic. Mean annual soil temperature is 31.5°C, and the temperature regime was classified as Isohyperthermic (van Wambeke, 1982). The hottest period, however, is in April–May and not in the summer months. Thus, because of larger differences between extremes, Hyperthermic would be the best classification (Soil Survey Staff, 1975). The most important soil series at the center, the Labucheri, is classified as a Psammentic paleustalf (West et al., 1984).

The experimental site has a rather flat topography: slopes are generally around 1–2%, with a maximum of 4%. The soil profile is deep, ranging from a minimum of 2 m up to more than 8 m at the bottom of a slope. The main characteristics of the soil are given in Table 1. On a micro-scale, with locations no more than 10–20 m apart, variations in crop growth and yield are appreciable. The reason for this extreme variability is not well understood, but is thought to be caused by both chemical and physical differences. Research on the chemical aspects of this variability has been reported by Scott-Wendt et al. (1988).

The typical conditions of soil and climate make it difficult to grow crops successfully. Millet is planted immediately after the first substantial rain, but the young seedlings frequently are killed, either by lack of water because of a dry spell after the first rain, or by sand blasting or burying by sand as a result of strong winds accompanying the rains early in the season.

TABLE 1

Soil characteristics at ISC

Characteristic	Depth (cm)		
	0–5	5–10	20–25
pH (KCl)	5.2	4.7	4.5
Organic matter (%, w/w)	0.5	0.6	0.5
Texture (%, w/w)			
0–2 μm	3.1	3.1	6.2
2–16 μm	1.3	1.6	1.1
16–50 μm	3.3	3.2	2.7
50–105 μm	19.8	19.7	18.3
105–150 μm	14.4	13.9	14.4
150–2000 μm	58.1	58.5	57.3
Particle density (g cm^{-3})	2.66	2.66	2.66
P_2O_5 (mg l^{-1})	6.5	5	5.5
K_2O (mg 100 g^{-1})	2.5	2	2
pF values (%, w/w)			
2.0	6.1	6.1	6.2
2.3	3.1	3.3	3.8
2.7	2.2	2.4	3.0
3.4	1.4	1.5	2.3
4.2	1.1	1.2	1.8

Soil physical characteristics

In the Niamey region, the texture of the soil is very light without any natural aggregation. Thus, the soil shows a typical behavior: when it is dry, manipulation in the field (by traffic, tillage, etc.) may result in a very loose top layer which easily blows away. However, when the soil is moist, its appearance and behavior are completely different: the soil surface is resistant to wind, and relatively stable aggregates can be formed by tillage. This leads to a limited number of moisture-dictated conditions, where the surface soil may be successfully modified by tillage operations.

To supply a basis for further investigations, the following soil characteristics were determined: (1) particle size distribution, organic matter, P and K contents; (2) moisture retention curve, saturated and unsaturated conductivity; (3) mechanical behavior of the soil, in response to tillage activities and traffic. The effects of the tillage-induced structure modification on soil strength, bulk density and wind erosion susceptibility, were assessed.

Rainfall

Two aspects were investigated in more detail, as these have the highest impact on the actual choice of tillage and planting activities: (1) the aggressiveness of the rainfall, as affecting the physical condition of the soil, in particular the surface layer; (2) the rainfall distribution.

The kinetic energy of the falling drops, which is primarily responsible for erosion and runoff phenomena in the field, is strongly related to the intensity of the rain. Rainfall intensity also influences the water balance: the infiltration capacity may be decreased by seal formation, and surface storage may be reduced by a smoothening of the soil surface.

In the Niamey region, the rainfall distribution has some characteristics which are particularly important for soil management. (1) Rainfall early in the season is very erratic. Single showers may wet the soil sufficiently for planting, but may be followed by a long dry period (Sivakumar et al., 1979). (2) Highest crop yields were found when the crop was planted just after the first showers. One of the possible causes is the so-called "N-flush", i.e. a process of nitrification in the soil by microbial activity, initiated when the soil is wetted after a long dry period (Birch, 1960). (3) Rainy days may be immediately followed by days with high evaporative demand. In view of the very low moisture-holding capacity of sandy Sahelian soils, crop management decisions following a rainfall event should be made very quickly.

By analyzing daily rainfall data, the number of workable and plantable days was calculated, based on assumptions derived from observations in the field.

MATERIALS AND METHODS

Basic soil data

Particle size distribution
Particle sizes < 0.05 mm were determined by the pipette method, the larger sizes by sieving (Gee and Bauder, 1986).

pH, organic matter, P and K
The pH was determined using the KCl method (McLean, 1982); organic matter content (total C content) was determined by the dry combustion method (Nelson and Sommers, 1982). In addition, K (soluble in oxalic/hydrochloric acid) and P (soluble in water) contents of the soil were determined.

Particle density
This characteristic was determined by the pycnometer test (Blake and Hartge, 1986).

Data relating to water balance and water movement

Moisture retention curves
The following methods were used (Richards, 1965): sand beds (suction range 1–10 kPa), sand–kaolin beds (20–50 kPa) and pressure-plate equipment (100–1500 kPa). Curves were determined for two dry bulk densities (1.40 and 1.60 g cm^{-3}), which were obtained by compaction of dry, structureless sand in sample rings. The rings were left to saturate for 48 h before applying the consecutive suctions.

Saturated hydraulic conductivity (K_{sat})
The constant-head method was applied (Klute and Dirksen, 1986), using core samples of about 10 cm high, with an internal diameter of 5 cm. The hydraulic head difference with the bottom of the sample was about 12 cm. Tests were carried out for a range of soil bulk density values.

Unsaturated hydraulic conductivity
For the determination of the unsaturated hydraulic conductivity (K) as a function of moisture content, the so-called "hot air method" (HAM) was used (Arya et al., 1975; Van Grinsven et al., 1985). The structureless sandy soil allows cylinders to be filled quite accurately and uniformly. However, moisture contents higher than field capacity (about 10%, w/w) cause non-uniform distribution of water in the sample. Therefore only a small moisture range can be analyzed, but this is the most interesting range in water balance calculations.

Data relating to the mechanical behavior of the soil

Mechanical compaction

The response to mechanical compaction was assessed for: (1) samples of the original soil; (2) samples of the same soil with increased organic matter content. This increase was obtained by mixing old, well-decomposed farmyard manure (FYM) with 15% dry matter with the soil at a rate of 75 t ha^{-1} (dry matter). The mixture of soil and FYM was left for 2.5 months and then the larger remaining parts such as straw were removed. Testing according to the potentiometric Kurmies method (Houba et al., 1979) showed that organic matter content had increased from 0.12 to 0.38% (w/w).

All samples were wetted to two moisture content levels: 5 and 10% (w/w). The moist soil was placed in cylindrical PVC containers (diameter 11.6 cm, height 4 cm) with a fixed bottom. Then the soil was subjected to piston pressures of 15, 34 and 53 kPa, respectively, for about 30 s.

In a second series of tests, the indoor soil bin of the Tillage Laboratory was used. This model soil bin consists of eight 50-cm long, aluminium U-profiles with a height and width of 0.2 m, laid together to form an uninterrupted length of 4 m. Soil was wetted to moisture contents of 4, 6 or 8% (w/w) and then placed in the soil bin. A standardized precompaction procedure resulted in a homogeneous dry bulk density of 1.35 g cm^{-3}.

Compaction of the top soil was achieved with a smooth steel roller (diameter 20 cm, width 19 cm) which can be moved with adjustable forward speed. Both the pressure exerted on the soil by the roller and the rotational speed of the roller can be adjusted. A forward speed of 0.2 m s^{-1} and rotational speeds of 20, 30 and 45 r/min, respectively, resulted in 0, 30 and 55% positive slip. Effective load of the roller was 2.5 or 6.5 kg. Since the depth of the rut formed by the roller could not be measured exactly, the resulting pressures (2 and 4 kPa) could only be approximated.

Measurements

Tensile strength

The tensile strength was assessed by means of the "Brazilian test" (Dexter and Kroesbergen, 1985). After soil compaction, small brass sample rings (diameter 35.6 mm, height 13 mm), with a cutting edge on one end, were pressed into the moist surface of the soil in the bin, which was then placed under heating light bulbs to attain soil surface temperatures of about 50°C, simulating drying under strong sunlight. The samples were left under the lamps until the top layer was air dry. The brass rings were then lifted out of the surface layer and cylinders of dried soil were carefully pushed out of these rings. The soil cylinders were (placed on their side) subjected to loading until failure occurred.

Bulk density

Bulk density was measured using parts of the broken soil cylinders after the measurement of tensile strength. The density of these clods was determined by immersion in kerosene (McIntyre and Stirk, 1954).

Cone index (CI)

The CI, defined as measured penetration resistance (N)/cone base area (m^2), is a mechanical characteristic which depends on soil moisture content, bulk density and strength of the bonds between the mineral parts. In clay soils, cohesion is the most important parameter; in sandy soils, the internal friction. Penetration speed in the tests was 10 mm min^{-1}. The cone used had a top angle of 60° and a base area of 0.2 cm^2. The CI was taken as the peak value recorded for the first 5 mm of penetration.

Wind erosion susceptibility of the treated soil surface

For these experiments, a simple wind tunnel (2.5 m long, cross section 0.2×0.2 m) in the Tillage Laboratory was used. The model soil bin was placed under an opening in the bottom of the tunnel, to ensure that the surface of the soil was in line with this bottom. Since the process of abrasion by soil particles present in the air stream is primarily responsible for soil detachment and transport, 400–500 g min^{-1} of soil material (<1 mm) was brought in the air stream before it passed the soil surface. During the standard 2-min duration of the test a wind speed of 7.5 m s^{-1} was maintained.

Rainfall

Information on rainfall characteristics was collected and analyzed for five locations in the typical millet-growing regions of Niger, and for one comparable location in India. Details of the locations are given in Table 2.

Intensities

To determine the intensity of each rainfall event, charts from recording rain gauges which depict cumulative rainfall as a function of time were used. The slope of the line on the chart indicates the intensity. Using a FORTRAN computer program, each rainfall event was divided into segments of uniform intensity. Events were separated by rainless periods of at least 12 h. Kinetic energy and various indices, based on their empirical relationship with rainfall intensity were calculated. These indices are the following:

the kinetic energy (E_k) of the rain (Dexter, 1977; Wischmeier and Smith, 1978)

$$E_k = 13.3 + 9.8 \times \log I \ (\mathrm{J\ m^{-2}\ mm^{-1}})$$

TABLE 2

Details of the data available for rainfall analysis

Location	Lat. (N) °	′	Long. (E) °	′	Intensity analysis: Period	Number of years	Number of storms	Total rain (mm)	Workable days: Period	Number of years	Mean annual rainfall (mm)
Tahoua	14	54	05	15	-	-	-	-	1921–1984	64	384
Zinder	13	48	09	00	1969–1983	15	335	5474	1905–1984	76	473
Niamey Ville	13	29	02	10	1971–1983[1]	12	343	6171	1905–1984	79	559
Niamey Aerop.	13	29	02	10	1970–1983[1]	13	370	5963	-	-	-
Maradi	13	28	07	05	1970–1983[2]	13	305	4626	1931–1984	50	573
Gaya	11	59	03	30	1970–1983[3]	12	537	9289	1931–1984	54	825
Pantancheru, India	17	27	78	28	1974–1983	10	377	7377	-	-	-

[1]1979 missing.
[2]1980 missing.
[3]1971 and 1972 missing.

with intensity I in mm h^{-1}; intensities >75 mm h^{-1} are regarded as being 75 mm h^{-1} only;

the EI_{30} erosivity index (Wischmeier and Smith, 1978)

$$EI_{30}=E_k \times I_{30} \ (\text{J m}^{-2}\text{ h}^{-1})$$

with I_{30} as the highest intensity over 30 min in a particular storm;

the $E_k>25$ index, as proposed by Hudson (1971) as an adaptation of the Wischmeier index to the more aggressive conditions in Africa; here the kinetic energy is calculated using only those segments with intensities >25 mm h^{-1};

the AI_m (mm h^{-1}) index proposed by Lal (1976), which basically is a weighted average intensity, since it is the summation of the product of intensity and volume of rain for each intensity class.

Workable periods

The assumptions used in the calculation of the number of workable days are based on field observations and measurements on sandy soils (Table 3). Basically, it is assumed that soil can be tilled satisfactorily when the topsoil is sufficiently moist. However, moisture content will drop quickly under dry weather after rain. In the analysis, the length of the workable period depends on the volume of rainfall falling in 1 day or in 2 consecutive days. Although many variations are possible, two different lengths of workable periods were evaluated, and only one length of plantable period, since the decision to plant is more critical than the decision to till. Table 3 shows that Scenario 2 is somewhat more optimistic about the number of workable days after a certain amount of rain has fallen than Scenario 1.

TABLE 3

Rainfall threshold values (rainfall in mm, falling in 1 or 2 consecutive days) and assumed number of workable and plantable days after the rainfall event

Rain[1] (mm)	Assumed number of workable days[2] "1"	"2"	Rain[3] (mm)	Assumed number of plantable days
Rain<6	0	0	Rain<11	0
6≤rain<14	2	3	11≤rain<19	1
14≤rain<21	3	4	19≤rain<26	2
Rain≥21	4	5	Rain≥26	3

[1]In 1 day; for 2 days, threshold values plus 2 mm.
[2]"1" = Scenario 1; "2" = Scenario 2.
[3]In 1 day; for 2 days, threshold values plus 5 mm.

The analysis was carried out over the soil preparation and planting period that is typical of the location. The period began on 1 May for all locations and ended on 28 June for Tahoua and on 18 July for the other locations. Planting after this period was assumed to leave too short a growth period to expect any harvest. Planting and tillage activities were assumed to take place the day(s) after the first day with sufficient rainfall, even when it rained again on that particular day.

RESULTS AND DISCUSSION

Soil

The basic soil physical characteristics are given in Table 1. In the upper 10-cm layer, clay and silt contents total no more than 5–7% (w/w). The dominant clay mineral is kaolinite (West et al., 1984). The coarse sand fraction occupies almost 60% (w/w) of the total. Organic matter content is very low (0.4–0.6%, w/w).

The moisture retention curves for two bulk densities, the saturated hydraulic conductivity (K_{sat}) as a function of bulk density and the relationship between unsaturated hydraulic conductivity (K) and moisture content, are shown in Figs. 1, 2 and 3, respectively. The results indicate that the soil at ISC is a typical coarse sandy soil, with a very small water-holding capacity. Therefore, in the field soon after rainfall soil moisture values quickly drop to levels under 10% (w/w), as the water drains quickly from the large pores.

Changes in soil bulk density under load are shown in Fig. 4. A higher organic matter content clearly reduces the increase in bulk density after loading, in-

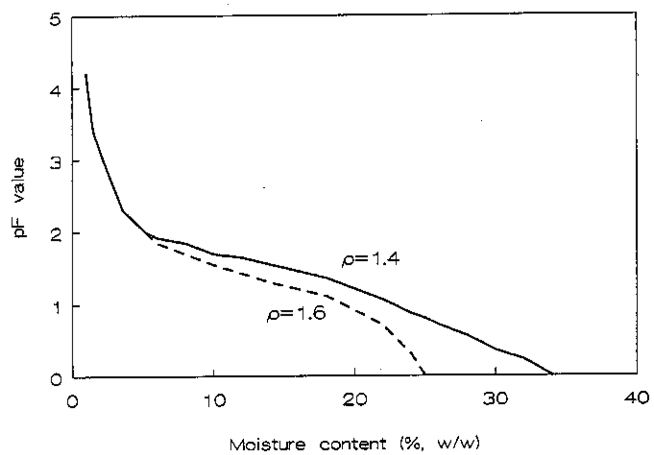

Fig. 1. Moisture retention curve for two bulk densities (ISC soil).

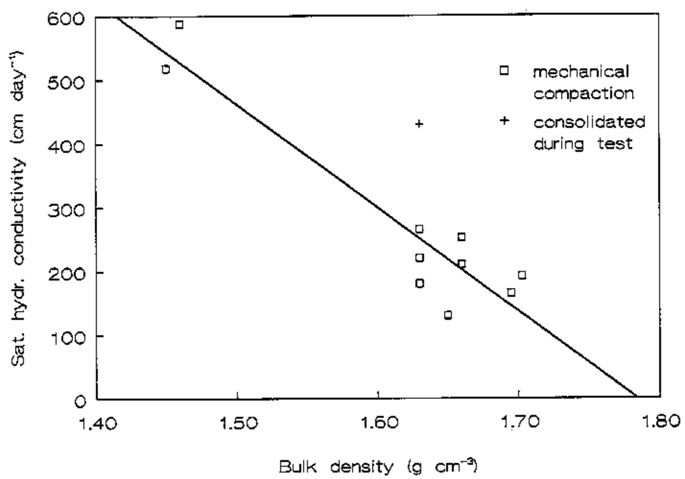

Fig. 2. Effect of bulk density on saturated hydraulic conductivity (ISC soil).

dicating that the soil becomes less susceptible to compaction. In all cases a higher moisture content at compaction results in a higher bulk density.

Figure 5 shows the tensile strength of the soil, as manipulated by various methods. The effect of a roller with positive slip (imitating a sliding movement of a metal tool over the soil) is compared with a static load, applied at different moisture levels, for an otherwise untreated soil. A higher moisture content at the time of manipulation leads to higher tensile strength. The effect of positive slip is very large, since a load of only 4 kPa but with 30% slip causes the same tensile strength of the soil top layer, as does a load of 53 kPa without slip at an even higher moisture content. Most probably this effect can be explained by

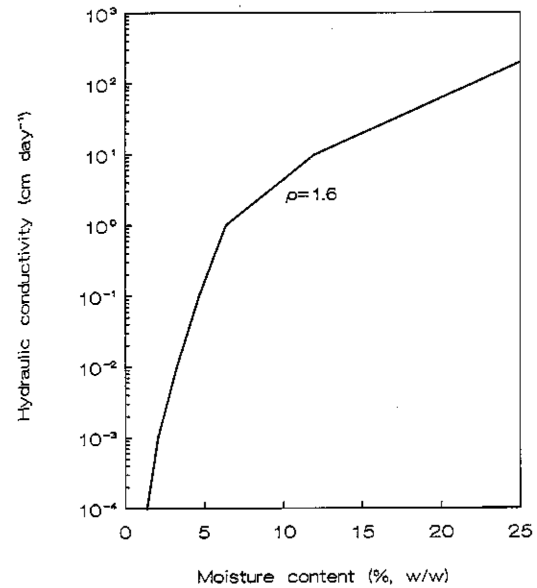

Fig. 3. Hydraulic conductivity as a function of soil moisture content (ISC soil).

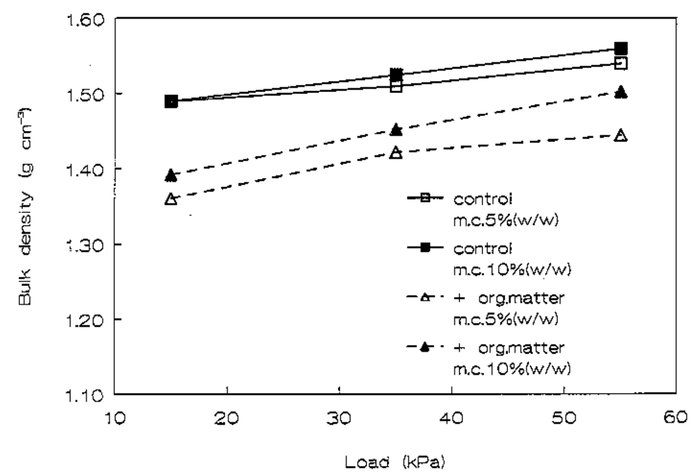

Fig. 4. Influence of moisture content and increased organic matter content on the effect of static loading (ISC soil).

the fact that slip causes a more intimate contact between the soil particles (rearrangement).

The load- and slip-induced increases in tensile strength and bulk density cause higher resistance to penetration (Fig. 6). Soil detachment from the sam-

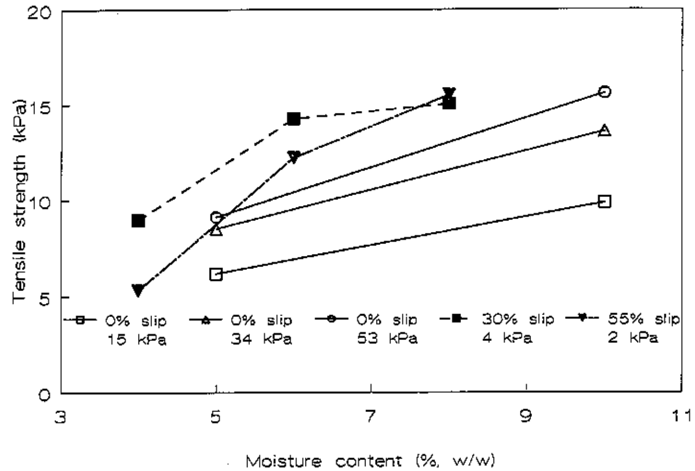

Fig. 5. Effect of load, slip and moisture content on tensile strength of the top layer (ISC soil).

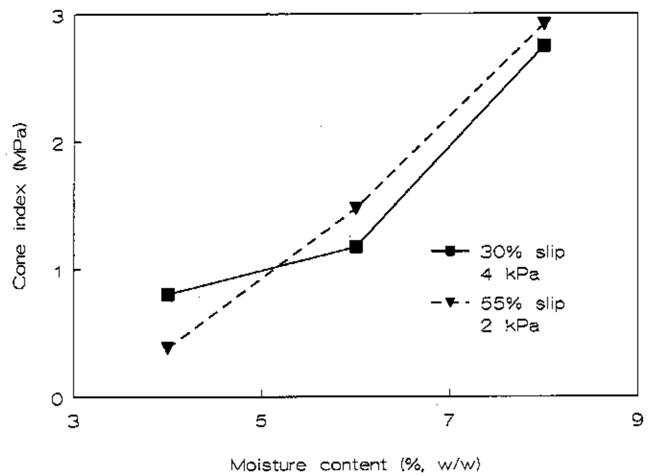

Fig. 6. Effect of load, slip and moisture content on penetration resistance (cone index; ISC soil).

ples subjected to wind loaded with sand was reduced considerably when the surface was smeared and compacted with the driven roller (Fig. 7).

These results of the smearing and compaction experiments show that the best quality of work can be achieved by tillage operations in wet soil. Clods or ridges made in a soil with a moisture content near field capacity will remain more stable. The effects of sliding of a tool over the soil surface also show that a stable and strong surface layer does not require a strong compaction of the

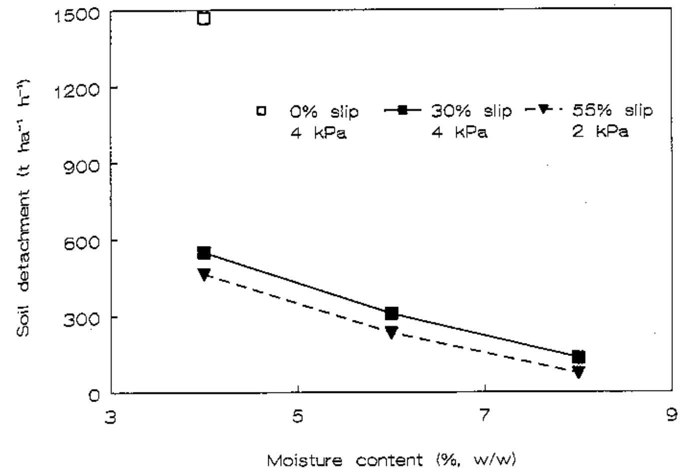

Fig. 7. Effect of load and slip treatments on wind erosion susceptibility, expressed as soil detachment (ISC soil).

soil, i.e. simple implements (bed shaper, ridger with wing attachment) may be considered to protect the soil surface to wind erosion, by sealing it.

Rainfall intensities

Here, the most important results of the analysis will be given; a detailed discussion of the data may be found in Hoogmoed (1986). Figure 8 shows that 50% of the rain in Niger falls with intensities $>$ 30 mm h^{-1}, against 15 mm h^{-1} in India. This means that although the region of study in Niger and the area around Patancheru (Andhra Pradesh) in India both have a semi-arid tropical climate with about the same total rainfall, there is considerable difference in rainfall intensity. In the analysis, rainstorms were divided into three classes: $<$10 mm, 10–20 mm and $>$20 mm. For Niamey, Niger, the clear differences in intensity distribution between small and large storms are shown in Fig. 9.

The various indices, based on the intensity (distribution) of the rainstorms, are summarized in Table 4. These values are expressed per mm rainfall, and may thus be considered as an indication of rainfall aggressiveness. For all storms, Table 4 indicates a small difference between locations in Niger, the lower rainfall areas having higher index values, and confirms the (aforementioned) big difference between Niger and Patancheru, India. The indices, expressed per mm rain, are clearly higher for the storms $>$ 20 mm. However, although the storms $>$ 20 mm have a larger proportion of high-intensity rain than the storms $<$ 10 mm, regression analysis showed a very poor relationship between storm size and energy per mm rainfall. The other indices also showed

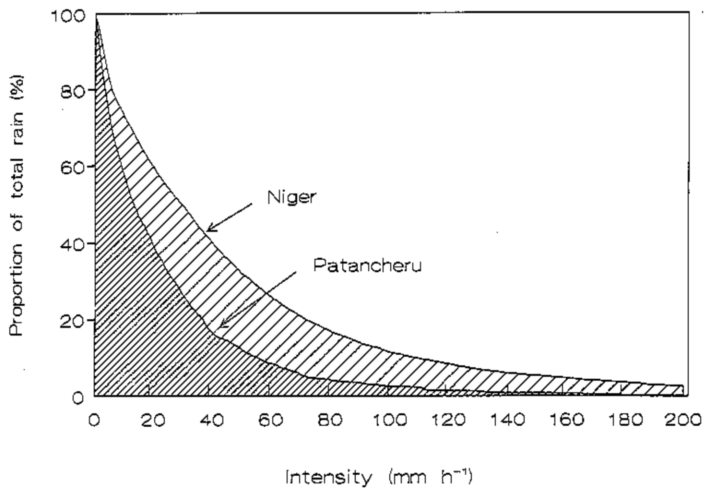

Fig. 8. Difference in intensity distribution between the Niger locations and Patancheru, India. Average values for all storms analyzed.

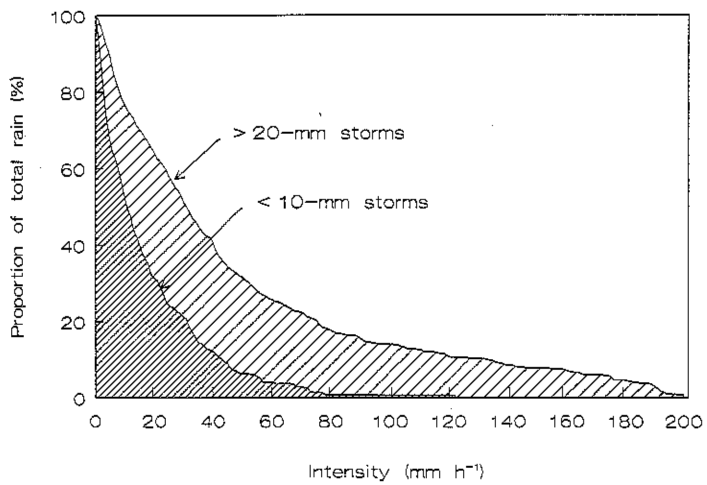

Fig. 9. Intensity distribution of small (< 10 mm) and large (> 20 mm) storms for Niamey (Ville), Niger.

poor fits (Table 5). This means that a large variation exists between individual storms. On the other hand, the total kinetic energy (E_k) showed a good linear correlation with rainstorm size, which is not surprising in view of the origin of the calculation. So, larger storms are not always more aggressive than smaller ones, but they will have a larger influence on the water balance, since total erosivity is higher. For most of the indices, a linear fit was best. The following equation was found for Niamey

$$E_k = -40.5 + 25.67 \times \text{rain (mm)} \quad (r^2 = 0.988)$$

and for Patancheru

$$E_k = -24.2 + 22.14 \times \text{rain (mm)} \quad (r^2 = 0.982)$$

As part of the analysis, possible runoff was calculated for each storm, assuming various combinations of infiltration capacity and surface storage capacity. These soil characteristics were assumed to remain constant during the storm, which is of course not quite true, but results give an indication of what may happen under different rainfall regimes. Figure 10 shows that large storms will cause higher runoff losses, or require higher surface storage values to keep these losses low.

Rainfall – workable periods

Further analysis of the rainfall data showed that the variability of the rainfall is highest in the locations with the lowest rainfall (Table 6). This analysis,

TABLE 4

Energy and erosivity indices expressed per mm rainfall for five locations in Niger and one location in India

Location	All storms				Storms < 10 mm				Storms > 20 mm			
	E_k	EI_{30}	$E_k>25$	AI_m	E_k	EI_{30}	$E_k>25$	AI_m	E_k	EI_{30}	$E_k>25$	AI_m
Niamey Ville	23	1050	15	51	20	254	6	19	25	1378	18	64
Niamey Aerop.	23	888	14	45	20	285	7	18	24	1145	16	55
Zinder	24	1059	17	58	21	350	8	22	25	1376	19	74
Maradi	23	833	14	42	21	267	7	19	24	1098	16	50
Gaya	23	824	13	40	20	231	5	15	23	1045	15	48
Patancheru, India	21	667	8	23	18	152	3	10	22	829	10	26

Units: E_k = J m^{-2} mm^{-1}; EI_{30} = J m^{-2} h^{-1}; $E_k>25$ = J m^{-2} mm; AI_m = mm^{-1} h^{-1}.

TABLE 5

Goodness of fit (r^2 values) regression analysis of indices versus storm size for locations shown in Table 4

Type of fit	Index				Index per mm rainfall			
	E_k	EI_{30}	$E_k>25$	AI_m	E_k	EI_{30}	$E_k>25$	AI_m
Linear	0.98	0.75	0.79	0.60	0.21	0.52	0.23	0.28
Power	0.98	0.85	0.75	0.79	0.29	0.55	0.01	0.39

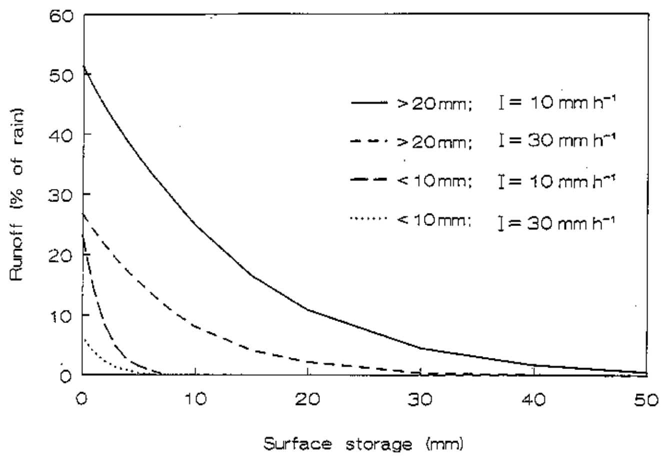

Fig. 10. Calculated effect of surface storage on runoff values under small and large storms (<10 mm and >20 mm), for two infiltration rates (I=10 and 30 mm h^{-1}) for Niamey (Ville), Niger.

TABLE 6

Characteristics of the rainfall in the periods analyzed

Location	n	Mean (mm)	S_x (mm)	Min. (mm)	Max. (mm)	Skewness	SE (skew)	80% confidence[1]	
								Min. (mm)	Max. (mm)
Tahoua	63	68	40	5	171	0.80	0.30	16	120
Zinder	74	143	67	25	318	0.45	0.28	57	229
Niamey Ville	79	192	68	32	402	0.11	0.27	105	279
Maradi	49	174	68	57	314	0.33	0.34	87	261
Gaya	53	298	87	131	518	0.27	0.33	187	409

[1]Assuming normal distribution.

TABLE 7

Calculated number of workable and plantable days based on rainfall analysis

Location	n (years)	Work days[1]			Plant days		Probability (%) of zero days to	
		"1"	"2"	S_x (%)	All	S_x (%)	Work	Plant
Tahoua	64	8.6	11.1	60	3.2	90	8	19
Zinder	76	16.4	20.0	44	7.6	58	1	5
Niamey	79	22.6	27.1	31	10.7	41	1	1
Maradi	50	19.6	23.6	38	9.3	50	2	2
Gaya	54	32.3	37.5	22	17.4	33	0	0

[1]"1"=Scenario 1; "2"=Scenario 2 (cf. Table 3).

however, does not account for the size or distribution of the individual storms. This information was used to calculate the average number of work days (for two scenarios) and planting days per location (Table 7). The driest location (Tahoua) shows very small numbers of available days, with an average of only 8.6 workable days for the most pessimistic scenario ("1"), and a 19% probability of not having any planting day. These values are more favorable for the wetter locations, although the average number of plantable days in the 500–600-mm zone (Niamey, Maradi) does not exceed 11. In addition to the planting days, the farmer may have 5–15 days available for preparatory tillage.

Farmers practice

The above mentioned conditions justify efforts to try to plant as early as possible, since at failure losses are small compared to the probable increase in yield. At this time of the year manpower is not required for other purposes and the loss of seed for planting is small (a few kg ha^{-1}). As will be shown in the next paper of this series, crop yields are greatly improved by appropriate management systems, including tillage, fertilizer application and the use of improved varieties.

CONCLUSIONS

From the laboratory experiments and rainfall analyses, the following conclusions may be drawn.

(1) The soil at ICRISAT Sahelian Center (ISC) is a structureless sand, with a high percentage of coarse sand particles, and a low organic-matter content.

(2) Mechanical treatment of the soil is effective only when the soil is moist. An external load compacts the soil, but only when the moisture content is sufficiently high.

(3) The soil surface can be made stronger, i.e. more resistant to wind erosion, particularly by smearing. In the early part of the season, this may be a practical option to protect the field against aggressive rain preceded by strong winds.

(4) In Niger, rainfall is very aggressive because intensities are high. This implies high energy impacts on the soil surface.

(5) Generally, the intensities of large storms are higher, but between the size of the storm and its intensity (or erosivity index derived from this intensity) no significant correlation was found when intensity was expressed per unit rainfall.

(6) For the sandy soil conditions as found at ISC, the number of days suitable for planting millet is on the average no more than 11. This situation demands a very efficient planting method and does not allow much room for elaborate, time-consuming seedbed preparation activities.

ACKNOWLEDGMENTS

The rainfall charts for Niger were made available by the Meteorological Services of the République du Niger; the charts for Patancheru, India were supplied by the Resource Management Program of ICRISAT, India. Mr. A. Boers of the Tillage Laboratory, Wageningen, took care of most of the laboratory analyses reported.

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