Sediment and the Environment (Proceedings of the Baltimore Symposium, May 1989)
IAHS Publ. no. 184, 1989.

Cropping systems effects on runoff, erosion, water quality, and properties of a savanna soil at Ilorin, Nigeria

R. Lal
Department of Agronomy, The Ohio State University
Columbus, Ohio 43210

ABSTRACT Effects of five cropping systems and tillage methods on runoff, erosion and soil properties were investigated for a savanna soil on field runoff plots from 1983-1985. Treatments consisted of traditional farming, no-till, plow-till, alley cropping and bush fallow control. The mean annual runoff was traces, 38, 29, 36, and 77 mm in 1983 and traces, 44, 11, 61, and 39 mm in 1984 for bush fallow, traditional farming, no-till, plow-till and alley cropping treatments, respectively. The annual soil erosion ranged from traces, 779, 319, 984, and 1520 kg/ha in 1983 compared with traces, 1139, 133, 3318 and 172 kg/ha in 1984 for the treatments in the order listed above. Soil physical and hydrological properties and crop yields were satisfactory in the traditional farming system. Vehicular traffic caused soil compaction in other treatments. Runoff and erosion were less in no-till compared with other treatments.

INTRODUCTION

Soil erosion and land degradation are severe problems in some ecological regions of tropical Africa. In West Africa, soil erosion by water can be severe on mismanaged lands in the semi-arid and sub-humid region (Dregne, 1978; 1982; Talbot and Williams, 1978; Adu, 1972; and Lal, 1984; 1985). These regions have a mean annual rainfall of 500 to 1000 mm and a prolonged dry season of five to nine months. The high erosivity of tropical rains is obviously an important factor. These regions are characterized by a 1-h maximum rainfall intensity of 50-75 mm h^{-1} (Jansson, 1982). Localized rainfall intensities exceeding 100 mm h^{-1} substained for 10-15 minutes are frequently observed (Wilkinson, 1975a; Kowal & Kassam, 1976; and Lal 1981a). High intensity rains can cause severe damage especially at the beginning of the rainy season when the soil has been denuded of its scanty vegetation cover.

Susceptibility to erosion is also related to detachability and transportability. Soils of the African savanna have low organic matter content, low-activity clay and low structural stability against impacting force of raindrops and shearing force of runoff. Erodibility factor K of some soils can be as high as 0.57 (Vanelslande et al., 1987). In addition to physical factors, severity of soil erosion and its impact on crop production depend on antecedent conditions, rooting depth and inherent soil fertility. Some soil and crop management systems can drastically reduce erosion. These systems include mulch farming, conservation tillage and multiple cropping (Lal, 1976; Roose, 1977; Aina et al., 1977; 1979; and Wilkinson, 1975b). For soils of hard-setting characteristics, however, mechanical loosening by deep plowing is necessary to reduce erosion (Charreau, 1969). In such environments, tied ridges and other mechanical devices are necessary for judicious water management (Lal, 1986). For many of these marginal soils, the soil loss tolerance (T value) can be as low as 0.5 t/ha/yr.

The objective of this experiment was to evaluate the effects of cropping systems and tillage methods of runoff, erosion and on mechanical and hydrological properties of a savanna soil. This experiment was aimed at comparative evaluation of traditional versus new cropping systems.

MATERIALS AND METHODS

Field experiments were established at the research farm of the Ilorin Agricultural Development Project at Alateko, near Ilorin in the Kwara State of Western Nigeria. The experimental site selected in January 1983 was under savanna vegetation of trees, shrubs and grasses. The tree density (trees exceeding 15 cm girth at 1 meter height) ranged from 50-100 trees per hectare. Most of the trees were small. Soil of the experimental site is derived from the basement complex rock and is characterized by plinthite pan at shallow depth. The top soil above the plinthite layer consists of a course-textured colluvial material. The texture is sandy loam with a large proportion of sharp angular quartz sand. In its natural state, the top soil is easily compacted and sets hard due to ultra-desiccation caused during the long dry season.

The vegetation was cleared in March 1983 using a front-mounted shearblade on a D-8 track-type tractor. The cleared biomass was pushed off the plot and burnt in a windrow. The average slope was 3 to 4%. The mean annual rainfall of Ilorin is about 1100 mm received over a single growing season from May to October.

There were four cropping systems and tillage treatments. In addition to uncleared bush fallow control, runoff and soil erosion were monitored for traditional farming, no-till, plow-till, and alley cropping treatments. All treatments were replicated twice. Each plot, 50 x 20 m, was confined by earthen dikes to prevent run-on and to concentrate runoff through a well-defined exit. The runoff rate was measured through a 1 H-flume and an FW-1 water stage recorder. A composite sample of runoff was obtained for every erosive rainstorm event using a Coshocton Wheel Sampler. The sample was stored in a galvanized tank located in a covered concrete sump.

The traditional farming treatment was implemented through contractual arrangements with a local farmer. The decisions about seeding rate, date of sowing, cropping patterns and method of seedbed preparation were made independently by the farmer. The cultural practices involved in traditional farming included constructing ridges up-and-down the slope with a native hoe and sowing maize and yams in a mixed-cropping pattern.

The plow-till treatment consisted of disc plowing to about 20 cm depth followed by harrowing before sowing. In the no-till treatment, maize was sown without primary or secondary tillage. Weeds in the no-till treatment were controlled by two applications of paraquat (1, 1 -dimethyl-4, 4 bipyridinium ion) at 0.5 kg a.i. ha^{-1}. The first application was made one week before sowing and the second just after planting. The alley cropping treatment was planned on the basis of establishing hedgerows of <u>Leucaena</u>

leucocephala on the contour every 4-meters apart. The establishment of Leucaena in this ecological region, however, proved to be unsatisfactory. In lieu of Leucaena, therefore, contour hedges were established with pigeon peas (cajanus cajan).

Infiltration rate was measured during the dry season using a double-ring infiltrometer. Soil bulk density was measured for 0-5 cm and 5-10 cm depths using core samplers. The penetrometer resistance was measured using a pocket penetrometer. Soil moisture retention characteristics were evaluated using a combination of tension table and pressure plate extractors.

Surface runoff, erosion and soil hydrological properties were monitored for 1983 and 1984 using maize as a test crop in all treatments. Maize received 120 kg/ha N as urea (1/3 at planting and 2/3 at 4 weeks after planting), 20 kg/ha P as single superphosphate and 30 kg/ha K as muriate of potash. Fertilizers were not applied for the first cropping cycle after land clearing. Runoff and soil erosion data were summed up for the entire year and are presented as annual total.

RESULTS AND DISCUSSION

Runoff and Soil Erosion

The runoff losses from a brush fallow control were negligible in both 1983 and 1984. The mean annual runoff in other treatments ranged from 29 to 77 mm in 1983 and 11 to 61 mm in 1984 (Table 1). The lowest runoff and erosion among cropped plots were recorded for the no-till treatment. The alley cropping treatment was more effective in runoff and erosion control in the second than in the first year.

Table 1 Cropping systems effects on water runoff (mm) and soil erosion (kg/ha) during 1983 and 1984

	1988		1984	
Treatments	Runoff	Erosion	Runoff	Erosion
Bush fallow*	T	T	T	T
Traditional farming	37.9	779	44.1	1139
No-till	28.8	319	10.9	133
Plow-till	35.8	984	60.5	3318
Alley cropping	76.9	1520	39.0	172
LSD (.05)	63.6	1583	49.3	2351

T - Runoff = < 5 mm T - Erosion = < 100 kg/ha
*Based on measurements made on one replication only.

Because of the ridges made up-and-down the slope in the traditional farming treatment, sediment density in water runoff was generally high (Table 2). In contrast to plow-till and traditional farming, lower sediment concentrations were recorded for surface runoff from no-till and alley cropping treatments.

Soil Hydrological Properties

Both accumulative infiltration and equilibrium infiltration rate were high for the traditional farming treatment (Tables 3 and 4). This was especially the case in the second and third year after land clearing. Mechanized farm operations and vehicular traffic were responsible for low infiltration in plow-till, no-till and alley cropping treatments. Lal (1985)

Being coarse textured, the soil has low water retention capacity (Table 5). The moisture retention ranged from 10 to 14% at field capacity and 3 to 4% at the wilting point. The plant-available water reserves are low. Because of the short duration of the experiment, there were no drastic differences in moisture retention characteristics among the treatments. In general, however, moisture retention was more in no-till and traditional farming compared with other treatments.

Soil Mechanical Properties

Effects of cropping systems and tillage methods on soil bulk density and penetrometer resistance are shown in Tables 6 and 7, respectively. In accord with the infiltration data, soil bulk density was generally lower in the traditional farming compared with other treatments.

Table 2 Some examples of cropping systems effects on sediment density (g/liter) and water quality for 1984 rainy season

Date of rainstorm event	Treatments: Traditional farming	No-till	Plow-till	Alley cropping
14 May	3.69	0.01	8.08	0.01
24 May	1.23	0.01	2.83	0.01
24 June	4.92	0.83	7.27	0.76
5 July	5.82	0.70	24.79	0.73
23 July	3.13	0.75	3.06	0.59
5 August	2.95	0.01	2.36	0.65
19 August	3.28	2.11	7.58	0.23
23 August	4.42	0.31	1.78	0.38
8 September	3.58	0.53	3.97	0.31
24 September	3.23	0.01	0.92	0.18
3 October	3.37	0.01	0.70	0.01

Table 3 Cropping systems effects on accumulative infiltration (cm/2hr) measured at different times after land clearing

Treatment	Time after land clearing (yrs): 1	2	3
Bush fallow	55.6	82.1	122.5
Traditional farming	47.8	149.1	209.6
No-till	76.8	66.8	117.7
Plow-till	51.4	102.8	72.6
Alley cropping	100.9	88.7	122.5
LSD (.10)	71.4	37.4	68.6

Table 4 Equilibrium infiltration rate (cm/hr) as influenced by different cropping systems

	Time after land clearing (yrs)		
Treatment	1	2	3
Bush fallow	25.1	34.6	53.0
Traditional farming	23.1	101.3	63.6
No-till	33.9	20.8	51.2
Plow-till	19.2	34.9	35.8
Alley cropping	36.8	38.9	35.4
LSD (.10)	22.8	43.0	49.9

Table 5 Tillage and cropping systems effects on soil moisture retention (%, by weight) at different suctions (M Pa) one year after land clearing in April 1984

	Soil moisture suction (M Pa)							
Treatment	0	0.003	0.006	0.01	0.05	0.1	0.5	1.5
			A 0-5 cm depth					
Bush fallow	28.8	19.4	13.2	11.3	6.0	4.7	4.6	3.7
Traditional farming	30.4	19.5	14.1	12.6	6.8	5.6	4.2	3.6
No-till	28.8	21.2	13.2	11.7	6.2	5.3	3.6	3.0
Plow-till	27.2	19.8	12.5	11.1	5.5	4.3	3.4	2.9
Alley cropping	27.9	17.9	12.2	9.9	5.0	4.4	3.3	2.6
			B 5-10 cm depth					
Bush fallow	31.1	14.9	10.2	9.9	5.1	4.5	3.4	4.0
Traditional farming	29.3	19.6	13.9	12.1	6.9	6.2	4.5	4.1
No-till	27.8	18.7	13.3	11.9	6.3	5.2	3.9	3.1
Plow-till	27.5	18.4	11.6	10.0	5.3	4.5	3.0	2.6
Alley cropping	29.7	16.9	10.9	9.8	5.1	4.7	3.5	2.8
LSD (0.1)								
i) Tillage (T)	2.0	1.7	2.3	1.6	0.7	0.7	1.1	0.9
ii) Depth (D)	0.5	0.5	0.5	0.3	0.2	0.2	0.4	0.2
iii) T x D	1.1	1.1	1.1	0.6	0.5	0.4	0.9	0.5

Similar trends were observed in the penetrometer resistance. Once again, vehicular traffic is a likely factor responsible for surface soil compaction observed in intensively managed compared with traditional farming treatments. In traditional farming treatment, water transmission properties were more favorable at the ridge top than in the furrow (Fig. 1).

Sustainability and Land Degradation

Grain yields of maize for three consecutive years are shown in Table 8. Yields were satisfactory even in the traditional farming treatment. The soil loss: grain yield ratio was 0.58, 0.21, 0.66 and 1.05 for 1983 and 0.47, 0.04, 1.09 and 0.075 for 1984 for traditional farming, no-till, plow-till and alley cropping treatments, respectively. In 1984, when treatments were more effective than in 1983, the least soil loss: grain yield ratio was observed for the no-till treatment followed by that for the alley cropping system.

Table 6 Effects of cropping systems and tillage methods on bulk density (g/cm^3) for 0-5 and 5-10 cm depths for different duration (years) after land clearing.

	2 Years		3 Years	
Treatment	0-5 cm	5-10 cm	0-5 cm	5-10 cm
Bush fallow	1.42	1.46	1.45	1.49
Traditional farming	1.52	1.41	1.26	1.26
No-till	1.53	1.55	1.35	1.46
Plow-till	1.52	1.51	1.31	1.38
Alley cropping	1.51	1.57	1.32	1.38
LSD (0.1)				
i) Tillage (T)	0.08		0.04	
ii) Depth (D)	0.02		0.06	
iii) T x D	0.04		0.03	

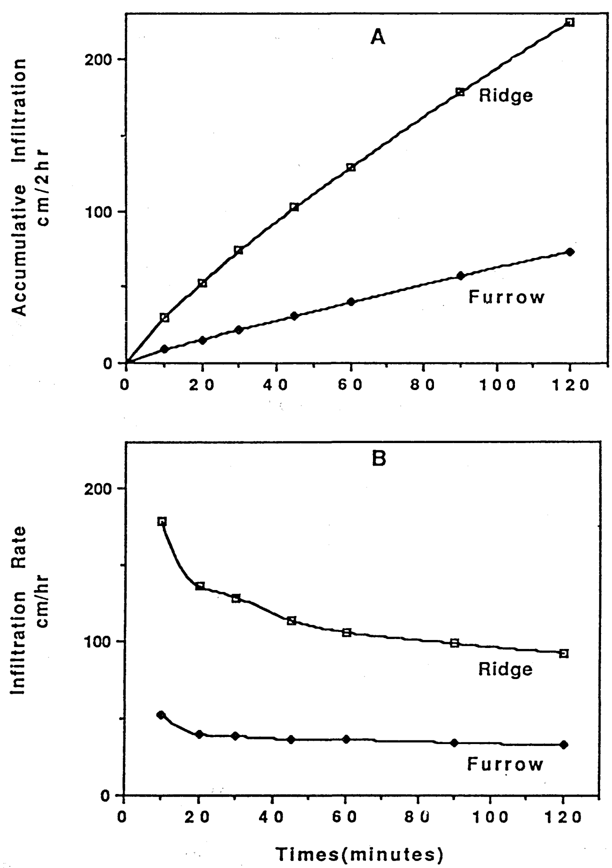

Fig. 1 Effects of ridge/furrow systems on (A) accumulation infiltration and (B) infiltration rate.

Table 7 Effects of cropping systems and tillage methods on penetrometer resistance (kg/cm^2) measured at different duration (years) after land clearing

Treatment	2 Years		3 Years	
	0-5 cm	5-10 cm	0-5 cm	5-10 cm
Bush fallow	0.5	3.6	3.2	3.8
Traditional farming	2.3	1.5	1.3	1.5
No-till	0.7	2.1	4.7	4.8
Plow-till	1.4	1.6	4.3	4.7
Alley cropping	0.7	1.6	4.5	4.5
LSD (0.1)				
i) Tillage (T)	0.8		1.6	
ii) Depth (D)	3.5		0.2	
iii) T x D	7.8		0.4	

Table 8 Cropping systems effects on grain yield of maize during the first three years after land clearing.

Treatment	Maize grain yield (t/ha)		
	1983	1984	1985
Traditional farming*	1.35	2.40	3.95
No-till	1.55	3.45	3.20
Plow-till	1.50	3.05	3.90
Alley cropping	1.45	2.30	2.75
LSD (.10)	0.15	1.12	1.53

* In addition to maize, the yield of yam tubers ranged from 15 to 20 t/ha/yr.

CONCLUSIONS

1. The traditional farming treatment produced satisfactory yields and had more favorable soil physical and hydrological properties than intensively managed systems.
2. Vehicular traffic due to the mechanized farm operation in no-till, plow-till and alley cropping treatments resulted in soil compaction and low infiltration rate.
3. High sediment density in the surface runoff from the traditional farming treatment was due to construction of ridges up-and-down the slope.
4. The least soil loss: grain yield ratio was observed for the no-till treatment. Considering the total yield (including yams), however, the least soil loss: production ratio was observed for the traditional farming treatment.

ACKNOWLEDGEMENTS Help received from P. Reid, B. Dawtry and other staff of IADP, Ilorin is gratefully acknowledged.

REFERENCES

Adu, S. V. (1972) Eroded savanna soils of the Navrongo-Bawku area, northern Ghana. Ghana J. Agric. Sci. 5:3-12.

Aina, P. O., Lal, R. & Taylor, G. S. (1977) Soil and crop management in relation to soil erosion in the rainforest of western Nigeria. In: Soil Erosion: Prediction and Control. SCSA Special Publication **21**:75-84.

Aina, P. O., Lal, R. & Taylor, G. S. (1979) Effects of vegetal cover on soil erosion on an alfisol. In: Lal, R. & Greenland, D. J. (eds) "Soil Physical Properties and Crop Production in the Tropics," J. Wiley & Sons, U.K:501-508.

Charreau, C. (1969) Effect of cultural practices on runoff and erosion in Casamance (Senegal). L'Agron, Trop. (Paris) **24**: 836-842.

Dregne, H. E. (1978) Desertification: Man's abuse of the land. J. Soil Wat. Conserv. **33**:11-14.

Dregne, H. E. (1982) Historical perspective of accelerated erosion and effect on world civilization. ASA Special Publication **45**: 1-14.

Jansson, M. B. (1982) Land erosion by water in different climates. Uppsala Univ., Dept. of Physical Geography, UNGI Rapport 57.

Kowal, J. M. & Kassam, A. H. (1976). Energy and instantaneous intensity of rainstorm at Samaru, northern Nigeria. Trop. Agric. **53**:185-198.

Lal, R. (1976) Soil erosion problems on an alfisol in western Nigeria and their control. IITA Monographs 1, Ibadan, Nigeria.

Lal, R. (1981a) Soil erosion problems on an alifsol in western Nigeria. VI Effects of erosion on experimental plots. Geoderma **25**:215-230.

Lal, R. (1981b) Deforestation of tropical rainforest and hydrological problems. In: Lal, R. & Russell, E. W. (eds) "Tropical Agricultural Hydrology," J. Wiley & Sons, UK:131-140.

Lal, R. (1984) Soil erosion from tropical arable lands and its control. Adv. Agron. **37**:183-248.

Lal, R. (1985) Mechanized tillage systems effects on properties of a tropical alfisol in watershed cropped to maize. Soil & Tillage Res. **6**:149-162.

Lal, R. (1986) Soil surface management in the tropics for intensive land use and sustained production. Adv. Soil Sci. **5**:1-105.

Roose, E. J. (1977) Adaptation of soil conservation techniques to the ecological and socio-economic conditions of West Africa. Agron. Trop. **32**:132-140.

Talbot, M. R. & Williams, M. A. J. (1978) Erosion of fixed dunes in the Sahel, Central Niger. Earth Surface Processes **3**:107-114.

Wilkenson, G. E. (1975a) Rainfall characteristics and soil erosion in the rainforest area of western Nigeria. Expl. Agric. **11**:247-255.

Wilkenson, G. E. (1975b), Canopy characteristics of maize and the effect on soil erosion in western Nigeria. Trop. Agric. **52**:289-297.

Vanelslande, A., Lal, R. & Gabriels, D. (1987) The erodibility of some Nigerian soils: A comparison of rainfall simulator results with estimates obtained from the Wischmeier Nomogram. Hydrological Processes **1**:255-265.