# Influence of No-Tillage on Soil Conservation, Carbon Sequestration and Yield of Intensive Rotation Maize-Cotton: Research on Sandy Alfisols of Cameroon and Mali

**Drissa Diallo, Zachée Boli and Eric Roose**


## Abstract

To compare conventional tillage to various direct drilling systems (no-tillage or tooth tillage reduced to the sowing line), two sets of runoff plots (100 m²) (57 in Cameroon and 17 in Mali) were built on fragile sandy Alfisols under Sudanese savannah areas. After 3 to 4 years with 900 to 1500 mm of annual rainfall, it was clear that the litter/legumes/weeds cover on no-till reduced the runoff (–20%) and erosion risks (to 1/3) compared to the conventional tillage system. Although mineral fertilizers were applied intensively, the highest yields were observed from the plowed fields (30 to 50% more of maize grain and + or – 10% for cotton). It seems that cotton is less sensitive to well drained soils and nitrogen leaching than maize during the first 2 months of growth. Carbon sequestration by the direct drilling system was not systematic on very sandy soils but more important if the clay content is over 25%. The direct drilling system with glyphosate herbicide was quickly adopted by small farmers as a labor-saving system during the sowing and weeding period, but the soil surface was not well covered with mulch because of the traditional African habits of free grazing and bushfire incidence during the dry season.


## Introduction

In many countries of the world, researchers and farmers have applied various plowing systems in order to improve the structure of the topsoil and infiltration, to increase root density and resistance to droughts, to control weeds and to insure homogenous development of the crops (Charreau and Nicou, 1971). Therefore, in the wet Sudanese savannah of northern Cameroon and southern Mali, cotton and maize are grown in an intensive cropping system using conventional tillage, mechanical weeding and ridging, mineral fertilization, application of insecticides and improved varieties.

However, this intensive cropping system does not prevent soil productivity from declining. Lands where inputs are no longer profitable are abandoned and new fields are opened from savannah bush fallow. In a first survey, Boli et al. (1991) noticed that soil organic matter (SOM) degradation and erosion were major causes of the continuous yield decline. To better understand how the malfunctioning of the "soil-plant intensive system" occurs on various tilled and no-tilled systems, two experimental designs were set up with 57 runoff plots (100 to 1,000 $m^2$) in northern Cameroon (1991-94) and 17 runoff plots in southern Mali (1997-99) on new or old fields. On these fragile, sandy Alfisols the soil evolution is very fast in relation to the low soil organic matter (SOM) content and the warm climate. In this note we present some findings that researchers have accumulated from plots in order to better understand how reduced tillage combined with mulch cover may reduce erosion and degradation problems on some tropical cropped soils.

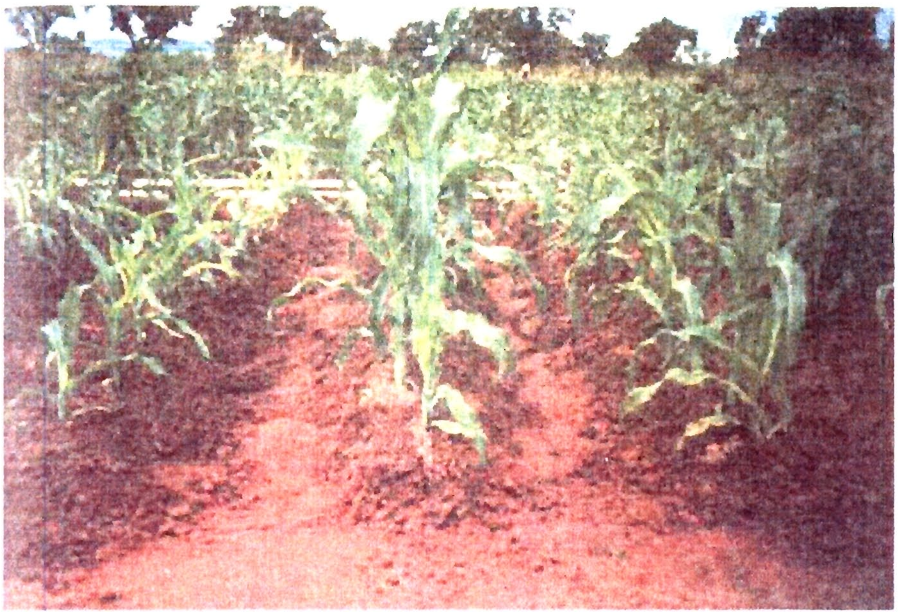
## Material and Method

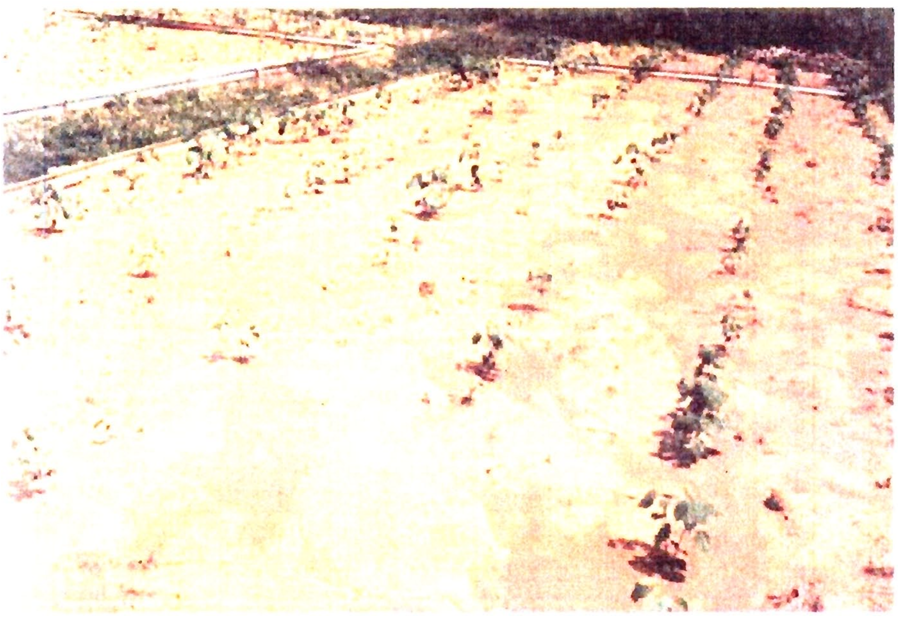
The comparative studies of savannah, tillage and no-tillage systems have been made in the African cotton belt near the village of Mbissiri (8°23"N, 14°33"E) in northeastern Cameroon and in the Djitiko watershed (12°03"N and 8°22"W) in southern border of Mali, near the Niger river. These stations are located in the Sudanese savannah area with two contrasting seasons, a rainy season from April to October and then 5 to 6 months of very dry and hot weather. Annual rainfall varies from 900 to 1,500 mm and the average during the study periods was 1,311 mm in Mbissiri and 1,175 mm in Djitiko. The annual erosivity index of Wischmeier and Smith (1978) varied from 400 to 780 in U.S.A. units (tonnes-foot per acre x inches/hour).

Sandy Alfisols are the typical soils for rainfed farming in these regions (Brabant and Gavaud, 1985). The Mbissiri soils, developed on sandstone, have an upper 15 cm plow horizon low in soil organic matter (<1.2%), very low in clay (kaolinite) content (<10%) and cation exchange capacity (CEC = 1 to 3 meq/100 g). In the Djitiko basin, the geological substratum is Precambrian granite and schist covered with weathered materials 15 to 35 m deep. The red Alfisols are richer in clay (26%) and silt (56%), with a CEC of 27 meq/100 g, pH of 6, but also low in SOM (1.2 to 1.9%), nitrogen (C/N>14) and available phosphorus. Both soils are structurally fragile and quite erodible.

The annual cropping period covers 4 to 6 months. Natural vegetation is a bush savannah with trees (*Vitellaria paradoxa, Parkia biglobosa, Isoberlinia doka, Combretum* sp.) and a dense cover of grasses (e.g. *Andropogon* sp., *Pennisetum purpureum).* From the beginning of the rainy season to the end of the cropping period the litter plus vegetation covered surface increased from 34 to 74% for the annually burned and grazed savannah, from 8 to 64% for tillage cropping system and from 11 to 91% for the no-tillage system. Therefore the first rainstorms of the season found the field surface rather bare and covered by sealing crusts. The slope varied around 2 ±0.5%.

Runoff, erosion, yields and SOM changes are compared for two situations: (1) on fields recently deforested in Mbissiri, and (2) on degraded fields cropped (or grazed) for more than 5 to 20 years in Djitiko and Mbissiri. The basic experimen-





tal unit is a runoff plot of 100 m² (5 x 20 m) with two storage tanks and a divisor allowing measurements of runoff volume, fine particles in suspension and the coarse sands eroded after each rainfall. The details of the device are described in Boli et al. (1993). The treatments compared were:

- an old bush savannah burned and grazed each year at the end of the rainy season;
- an intensive cropping system with soil plowed by a tractor or with oxen to a 12-15 cm depth, sowing, mechanically weeded twice and molding up six weeks after sowing with mineral fertilizers to cotton and maize: N115, P20 (P), K15 (K), S6 + B1 (S + B) kg $ha^{-1}yr^{-1}$ + 5 kg $ha^{-1}$ of zinc sulphate for maize;
- a no-tillage system: herbicide burn down, sowing one week later with 'double head hoe' (digging one hole for fertilizers and the second for two seeds) on soil covered by crops residues and weeds (> 30%) or after 2 years of Calopogonium legume fallow (*Calopogonium mucunoides*). Photos 1-4 show experimental plots during the trial periods.

**Table 1.** Impact of no-tillage on average annual runoff rate (%), average soil loss (t $ha^{-1}yr^{-1}$), clay + loam content (A+L %) and soil organic carbon content (SOC %) in the topsoil (10 cm) of sandy Alfisols of southern Mali and northern Cameroon.

| Site | Clay + Loam | Soil Organic Carbon | Runoff Till/No-Till | Soil Loss Till/No-Till |
|---|---|---|---|---|
| | % | % | % | t $ha^{-1}$ $yr^{-1}$ |
| Djitiko, old fields | 26 | 0.69/0.87 | 45.2/24.8 | 18.4/7.4 |
| Mbissiri, old fields | 8 | 0.20/0.30 | 23.5/4.4 | 11.4/4.2 |
| Mbissiri, new fields | 19 | 0.25/0.35 | 23.1/4.4 | 9.2/3.1 |

## Results

### Rainfall

Annual rainfall varied from 900 to 1,500 mm, with some deficits and some excessive rains during the cropping period. Intensive rainstorms (I= >60 mm $hr^{-1}$ during 30 min) occur at the beginning of the season and long rains of more than 100-200 mm over 3 days in July or August when the soil is not well covered (vegetative cover <50%). The risks of runoff or excess drainage are high almost every year in these wet Sudanese areas. The annual rainfall erosivity index of Wischmeier and Smith (1978) varied from $R_{usa}$ = 400 to 750 in relation with the rainfall amount.

**Runoff**

The maintenance of a litter cover during the whole cropping period considerably reduced the runoff risk. The average annual runoff coefficient (%) varied in Mbissiri from 23% (tillage) to 4.4% (no-tillage) and in Mali from 45% (tillage) to 25% (no-tillage) on sandy Alfisols (Diallo et al., 2005, Table 1). Therefore direct drilling systems on a litter nicely improved the infiltration capacity, even during the most intensive rainstorms. Water storage in the topsoil and the base flow could be increased during the wet season.

During the wettest rainy seasons in Mbissiri, the decrease of the runoff involved a high drainage rate which increased the nitrogen leaching and reduced the young maize plant vigour, so that we were obliged to apply an additional 20 kg $ha^{-1}$ of nitrogen on fields after the most intensive rainy periods. The cotton crops seemed not to be as sensitive to the excessive drainage. On one silty clay brown Vertisol field of the Djitiko basin, which is more resistant to rainfall energy, the difference of runoff (27 & 26%) due to tillage was negligible (Diallo et al., 2005). In the drier area of Djitiko no negative effect of excessive infiltration on the crops was observed.

**Erosion and carbon losses**

On each of the sites, soil loss by erosion was 2.5 to 3 times higher under conventional tillage than under no-tillage systems (Table 1). The differences were similar for the eroded carbon (390 to 60 kg C $ha^{-1}$ $yr^{-1}$) (Diallo et al., 2005). These erosion differences are related to the litter covered soil surface during the cropping period (CV=64% for tillage and 91% under no-tillage) (Diallo et al., 2004). The increasing rate of runoff and erosion under plowing systems is a consequence of the degradation of the structure of the topsoil submitted to numerous cultural practices and left exposed to the kinetic energy of raindrops and runoff.

**Yield of maize and cotton**

Aina (1993) found the yields of tested crops were generally higher under plowed plots than in direct drilling and no-till plots. Nevertheless these situations were depending on crop types and excess rainfall periods during the first 2 months of cropping (Boli and Roose, 1998). In Mbissiri on very sandy and fragile soils, the cotton yields on direct drill and reduced tillage plots in relative dry years were equal to or even better (10 to 20%) than the plowed fields.

The better infiltration rate under no-tillage would reduce the deficit of rainfall in the sandy soils. On the farmer's fields, it is observed that the difference in yields between the two systems is diminishing with the introduction of legume fallows, and over time. It takes 2 to 3 years to observe an improvement of the biological activity between the litter of weeds and crop residues and the topsoil (Lal, 1979).

**Table 2.** Crop production under no-tillage systems on degraded sandy soils in Mbissiri (after Boli and Roose, 1998).

| Treatments | Cotton yield ($t\ ha^{-1}$) | Maize grain yield ($t/\ ha^{-1}$) |
|---|---|---|
| Conventional tillage | 2.0 | 4.8 |
| No-tillage (control) | 1.4 | 2.8 |
| No-tillage after loosening | 1.9 | 3.6 |
| No-tillage after 2-year fallow | 2.1 | 3.6 |

The litter of the no-tillage system was not sufficient to improve the SOC, except after 2 years of legumes fallow or under the living hedges of *Cassia siamea*. The difference in structure of the topsoil was noticed by the surface crusting. After one 35 mm storm after sowing, the surface was 86% crusted on tillage treatments and only 2% under direct drilling with mulch cover. Before molding up (215 mm of rainfall), the crusted surface was 93% on new fields that had been plowed and only 18% on new fields with direct drilling. The improvement of structure seemed linked to earthworm activities which was five times greater in a no-tillage field than the adjacent tilled field (Boli et al., 1993; Boli and Roose, 1998). Tillage operations (plowing, two weedings and ridging) were more deleterious to the earthworms than applying 3 liters/ha of a systemic herbicide (Boli et al., 1993).

In Djitiko, after 3 years of direct drilling in the litter of crop and weed residues, the SOC increased from 0.69% for tillage to 0.87% with no-tillage, and the water-stable macro-aggregates increased from 150 to 300 $g\ kg^{-1}$ if tillage operations are reduced (Diallo et al., 2004).

Thus with no-till or reduced till, if the mulch is sufficient or after a legume fallow, the SOC, the structure stability and infiltration are all increased and runoff is decreased. Because the soil surface is covered by mulch, new crop residues or weeds, the kinetic energy of raindrops and runoff is reduced as are the soil losses by erosion (Barthès et al., 2000).

## Discussion

The surface mulch, weeds and legumes all increased the fauna activity, the macro-porosity open to the soil surface and the stability of the macro-aggregates. Likewise, the interception of rainfall and runoff reduced their energy levels. Even if the litter does not cover the soil surface completely, it is efficient in reducing runoff and erosion (Lal, 1974; Roose, 1996).

Because the runoff risk is reduced so much, there is no longer a need to build heavy mechanical structures to safely remove the excess rainwater from the hill-

Photo 3. Maize sowed [illegible] killed by glyphosate herbicide reduced runoff [illegible] plots than in tilled plots (Mouser mulch plots).

Photo 4. [illegible] legumes were sown [illegible] rows. They will grow fast [illegible] die at the end of the dry season. The legume seeds will grow very fast after the [illegible] rains and produce a thick carpet to easily direct drill [illegible] cotton.

## Soil organic carbon of the topsoil and soil aggregate stability

[illegible] four years after clearing the natural bush savannah, the SOC of the [illegible] layer decreased [illegible] under fallow to 0.38% under no-tillage, [illegible] under tillage and 0.26% [illegible] plowed bare fallow on new fields. The SOC [illegible] old fields.

sides. A living hedge (each 25 to 50 m) along the contour line is sufficient to reduce soil losses adequately. Therefore, in the fields around the research station of Mbissiri, it was not necessary to dig conventional drainage terraces and waterways to manage the excess runoff.

The improvement of yields is essential. Yield increase is assisted by opening the compacted soil, by using a tooth to loosen the soil along the intended seed row for maize (which roots are very sensitive to compaction) and by introducing a short fallow of legumes (like *Calopogonium mucunoides*, *Stylosanthes*, etc.) sown under the maize 30 to 60 days later. Mineral fertilizer needs can be reduced if good manure is spread on the seed row perpendicular to the slope.

The adoption rate of these new systems was very rapid because the labor requirements were reduced at plowing and weeding time, two very busy periods for farmers. After a herbicide treatment for weed control, the no-till or mini-till systems reduced activity to the seed row (strip till), requiring less labor and equipment. This labor saving allows the extension of the sowing period and thus a larger area could be cropped. However, this can result in a problem later when the farmers cannot complete the last weeding and they choose to abandon some weedy fields.

A problem in West Africa is that, traditionally, just after the grain and cotton harvest the fields are invaded by all the village cattle resulting in very little crop residue remaining on the fields for the beginning of the rainy season. One solution could be to underseed maize to non-palatable legumes. If the forage grows long enough to produce seeds, even if the legume will die during the dry period (5 to 6 months), the seeds will grow after the first rains and produce a nice carpet which cotton can be directly drilled into.

The other solution where no legume seeds are available is to wait until the weeds reach 20 cm and kill them with a herbicide before planting cotton (generally such cover will not be as even as with legumes).

At both sites the trials were abandoned after 3 to 5 years on the runoff plots. No systematic differences were observed of erosion or yields between plot sizes ranging from 100 to 1,000 $m^2$; there was no plot size effect. The larger size is similar to the quarter hectare fields generally planted to cotton by small farmers. However, the no-tillage system requires 3 to 5 years to become completely competitive with the conventional tillage system. The difference of yields and SOC decreased with time and these studies must be continued beyond the "thesis intensive trials" with the farmers in their own fields.

## Conclusions

At both research stations, rainfalls were very intense and were representative of the Sudanese tropical areas. The succession of extremely rainy weeks during the beginning of the cropping period (June to August) had a negative effect on the development of maize, more than on cotton (because of the latter's stronger root system) on no-tillage fields.

The various direct drilling (no-till or reduced tillage) systems significantly reduced the runoff (20% less) and the erosion (65% less), but increased the drainage and the fertilizer leaching.

The best yields were observed on plowed fields for maize (+ 30 to 50%) and sometimes for cotton (+ 10 to −10%). Nevertheless, the differences decreased after using a legume fallow and during the 'dry' years. The studies were too brief to know if these differences will decrease over time or if the SOC and structural properties continuously improve with direct drilling in a sufficient level of crop residue. The effect of the no-tillage system on the carbon sequestration was not evident – it depends on the clay content of the topsoil.

Nevertheless, in Sudanese Africa, this direct drilling system will be difficult to generalize in present conditions of small farming with the traditional habits of annual bush fire and post harvest, unrestricted, free grazing. To get sufficient mulch, a solution could be to sow legume between the maize rows one month later or to wait for weed growth to reach 20 cm before killing them with a herbicide (burn down).

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*The Authors:*
**Dr. Drissa Diallo** is a professor to the Institut Polytechnique Rural (IPR) de Katibougou, BP 6 Koulikoro, Mali. drdiallo@ird.fr

**Dr. Zachée Boli** is at the Institut de Recherche Agronomique pour le Développement (IRAD); BP. 2123 Yaoundé, Cameroun. bolieric@wanadoo.fr

**Dr. Eric Roose** is a research director emeritus UR SeqBio, à l'Institut de Recherche pour le Développement (IRD) BP 64501, F 34394, Montpellier, France. Eric.Roose@ird.fr