# SOIL TILLAGE AND WATER CONSERVATION IN SEMI-ARID WEST AFRICA

R. NICOU and C. CHARREAU[1]

The pedoclimatic conditions of the semi-arid West African zone are such that it is very difficult for annual crops to grow. The physical properties of the soil, in particular, impair crop root development.

In other respects, due to the extreme climatic irregularities, one of the first problems which the farmer needs to solve is that of providing water to his annual crops. As soils are very prone to degradation, infrequent but large and intense rains cause runoff and erosion. Thus, more than 50% of the rain water may be lost.

Agronomic research in many countries has, for a long time, striven to find solutions to these problems. It appeared that one of the means to succeed in so doing was to use good cropping techniques. Therefore, we are going to examine the major results obtained in soil tillage and water conservation in semi-arid West Africa.

## MAJOR CLIMATE AND SOIL CHARACTERISTICS

The climate. The climate of the tropical zone of semi-arid West Africa is characterized by the strong contrast between a rainy season which lasts two to three months in the North and five to six months in the South between May and October; and a totally dry season.

Annual rainfall varies roughly between 200 and 1,300 mm; isohyets are irregularly parallel to the equator and rainfall shows a strong increase gradient from North to South. This gradient is more pronounced in western Senegal than within the zone.

Because of the extreme irregularity of rainfall, the rainy season is often a succession of rainy periods and dry periods, the latter becoming more and more frequent northward. It is a fact that since 1966, a period of drought has prevailed all over this zone and that most isohyets have decreased by 200 mm (Dancette, 1977). The zone is under a very strong evaporative demand: annual potential evapotranspiration (PET) roughly ranges between 2200 mm in the North and 1600 mm in the South.

There are two other important characteristics in the physical properties of the soil:

(1) the absence of frost: temperatures rarely drop below 10. The phenomena of strong frost which are important in the northern countries are totally absent here;

(2) the very high intensity of rains and their erosive power. All calculation methods have demonstrated the very strong aggressivity of the climate throughout the zone. This aggressivity is the origin of the very strong hydric erosion that exists everywhere, especially in the South.

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1 Soil Physicist and Director of IRAT-CIRAD in Burkina Faso, Ouagadougou and Agro-Pedologist, Director of IRAT-CIRAD, Nogent du Marne, France.

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Other climatic factors are more favourable to crop production. In general, temperature is not a limiting factor for plant growth and solar radiation is high. The result is a high potential of production which stands in contrast with the present very low productivity.

The soils. Roughly speaking there are a number of soil units with respect to rainfed agriculture (Charreau, 1974). There are:

(1) sub-arid modal brown soils and red brown soils (CAMBORTHIDS) located between isohyets 200 and 500 mm. They develop mostly on aeolian sediments of the Quaternary and form a 200 km wide belt in the north of the zone,
(2) slightly leached tropical ferruginous soils (USTOPEPTS) which are mostly on the aeolian sediments under an annual rainfall ranging between 500 and 900 mm,
(3) leached ferruginous tropical soils (USTALFS). They are the most common in the zone. They are found on varied rock residus (granitogneiss, sandy and sandy-clayey rocks) and they have very differentiated profiles,
(4) poor and slightly unsaturated latosols (ALFIC EUTRUSTOX). They are not very common in the zone except in the south of Senegal and in the south-west of Burkina where they are associated with leached tropical ferruginous soils,
(5) vertisols and other complex associations with a montmorillonitic base. They are generally associated with materials of basic origin in Burkina,
(6) hydromorphic mineral soils (TROPAQUENTS, TROPAQUEPTS, etc.) are scattered in the zone. Some are used for rainfed agriculture but most of them form the major parts of the important alluvial plains of the main rivers; they are irrigated and temporarily flooded,
(7) lateritic cuirasses. The great extension of lateritic cuirasses (most of them being old) is one of the most common features of semi-arid West Africa. Most of them are located in the 500 and 900 mm isohyets.

Although the zone is characterized by a uniform rainy season and by a flat relief, the soils show variabilities with predictable consequences for cropping.

## NEED FOR SOIL TILLAGE

In the traditional systems of semi-arid Africa, tillage by hand is the only practice. Soil preparation is generally very superficial. Animal traction was introduced at the beginning of the 20th Century and it developed differently according to the regions. Now it is used by farmers for seeding and weeding operations and very irregularly for soil preparation. By contrast, in another semi-arid region such as India, oxen traction tillage is the general rule.

The opinion of the agronomists on this matter vary. Some believe that deep tillage and especially ploughing has beneficial effects on soil an crops and should be generalized. Others consider that these effects are not important or regular enough to assure a good return for the costs that this practice entails for farmers. They also note that soil deep ploughing may have negative effects over a long period of time, such as

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increased erosion and accelerated burning of the organic matter. They recommend zero or minimum tillage.

To shed light on the subject under discussion, it is necessary to review first of all the role of the physical properties of the soil in semi-arid West Africa as a limiting factor of plant growth; then to review tillage as the most ancient technique and the most commonly used for soil preparation; and finally to review other soil tillage techniques and their effects on the soil and the crops (Charreau, 1972).

Soil physical properties in semi-arid Africa. The soils with clay content exceeding the 20% threshold and which are swelling minerals in the clayey fraction are generally considered by soil physicists as structurally active. The phenomena of swelling and shrinking in temperate region alternating with frost create or regenerate a fragmentary structure. The roots of plants, especially of grasses, are capable of improving the structure of the soil (Charreau, 1974).

Below this threshold and especially when the clayey fraction contains few or no swelling materials, the soil is structurally inert. Plant roots are not capable of improving the structure by themselves.

For structurally active soils, soil tillage may not be required or its frequency may be reduced. For inert soils, soil tillage might make it possible to compensate the inefficiency of natural factors and to create a structure.

It may be noted that the threshold of 20% clay content roughly corresponds to the limit between coarse loamy and fine soils in the USDA (18%) textural triangle.

From that point of view, the soils of the West African semi-arid zone fall into two catagories. Vertisols and comparable soils clearly belong to the category of structurally active soils. Some hydromorphic soils and latosols may also fall into this category, but these soils have a limited extension in this zone as compared to structurally inert soils.

The prevailing feature of tropical sub-arid and ferruginous soils is the poor clay content of superficial horizons. This results both from the sandy nature of the original material (aeolian drifts) for slightly leached tropical sub-arid or ferruginous soils and, from the pedogenesis for tropical ferruginous soils and latosols.

Whatever the causes may be, generally the upper horizons of these soils tend to be sandy-clayey. Furthermore, the clayey fraction is mainly made of amorphous iron kaolinite and hydroxides in ferruginous soils and latosols, whereas montmorillonite prevails in sub-arid soils but with a very low clay content (1 to 10%).

Given these textural and clayey characteristics, the main physical properties of the upper horizons of these soils may be listed as follows:

(1) very weak fragmentary structure (if any);
(2) rather low porosity, not more than 40% to 43%;
(3) very low structural porosity (porosity related to root penetration and to water circulation);

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(4) high propensity to compaction and to hardening during the dry season;
(5) infiltration capacity varying according to the soil and to the original materials; high in soils made of aeolian sediments, often limited in the other soils, with a propensity towards forming a superficial crust;
(6) rather low water reserve, depth of water storage may also be limited by concretions or by the lateritic cuirass;
(7) susceptibility to erosion ranging from weak to average: the Wischmeier index varies from 0.05 to 0.1 in the first years of cropping, from 0.2 to 0.30 after 3 or 4 years of cropping (Roose 1974), Wischmeier, 1959.

The physical properties of the soil, limiting factors of plant growth. Many positive correlations (Charreau and Nicou, 1971; Nicou and Chopart, 1979) between total root weight or root density in g/dm3 and the yields of various crops (groundnut, sorghum, maize, rainfed rice) have been shown in the West African semi-arid zone (Fig. 1).

This seems to be a general rule for soils with sandy-clayey superficial horizons and can be explained by the fact that in these soils where water availability is limited and uncertain, and where the content of available mineral elements is poor, deep root establishment is essential for water and mineral nutrition.

In soils such as vertisols where water and mineral salts availability is high, the correlation between root establishment and crop yields may not exist.

Close relations between total porosity or apparent density and root density have been found in the sandy-clayey soils in various horizons and for different crops of Senegal (Fig. 2). Root weight or root densities rapidly decrease when density increases in accordance with a function which, most often, is linear and depends on the crop and the experimental conditions (Blondel, 1965; Nicou and Chopart, 1979).

In the vertisols or similar soils, the major limiting factor for plant growth is most often the insufficient infiltration and the water logging of the deep horizons, especially in the degraded vertisols.

The effects of the low porosity on root establishment may be explained mainly by two reasons:

(a) insufficient aeration of roots,
(b) mechanical resistance to root penetration into the soil.

The first explanation is not satisfactory for these soils because macroporosity is always high and the risks of temporary water logging are low in the upper horizons. On the contrary, the second reason is likely to be the most important one. The increase of porosity leads to a greater proportion of large pores through which roots can easily find their way.

Whatever the reasons may be, this low total porosity which results from an unadapted structure is often a limiting factor for plant root establishment and growth in these sandy-clayey soils of the dry tropical zone. The practices of soil development must increase porosity in order to obtain the best yields.

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Green matter, t/ha

Grain, kg/ha

Dry wt of aerial part,

Fig.
spec
(c)
rice

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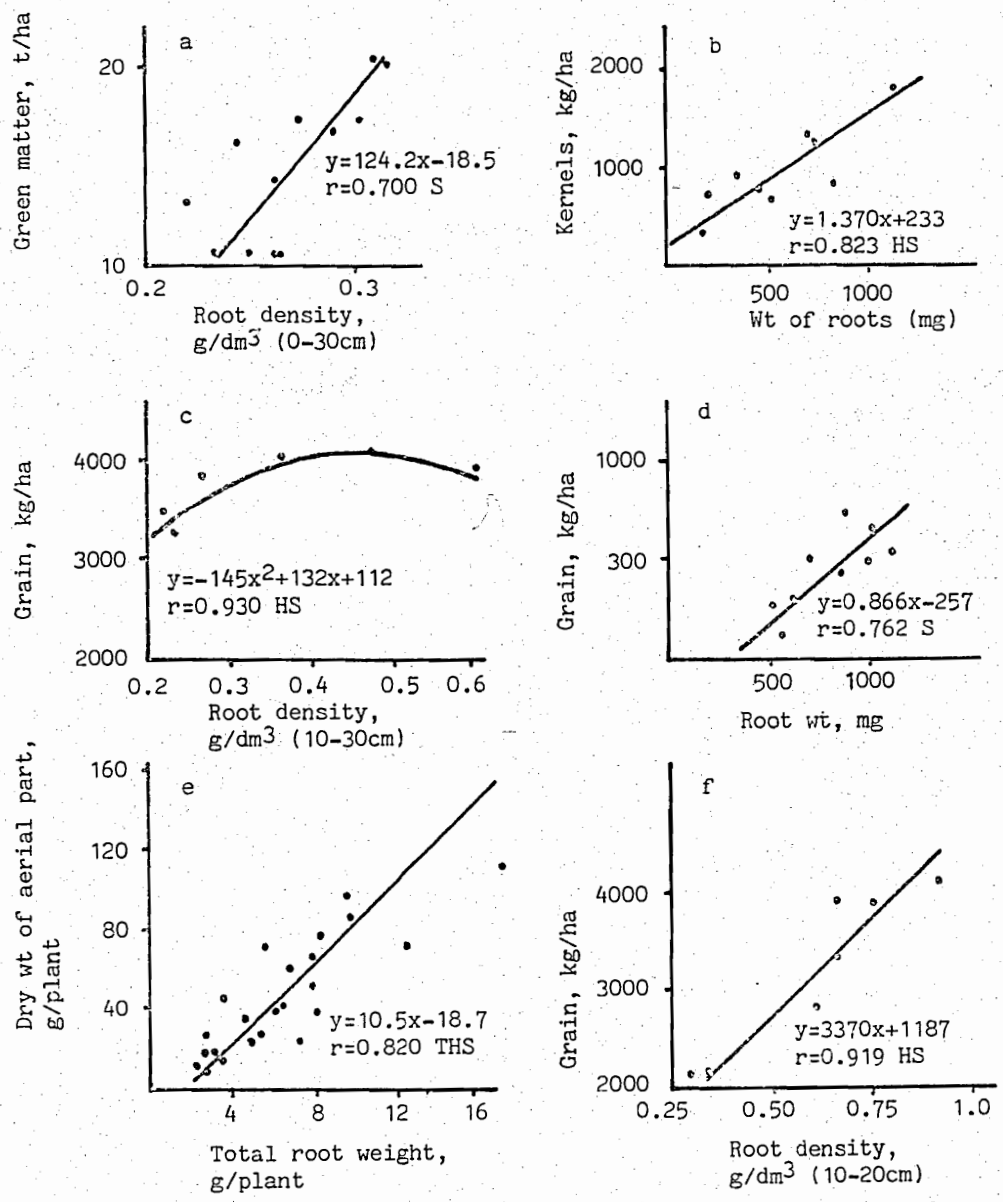


Fig. 1. Relations between root development and yield for different plant species in Sénégal. (a) Fallow, Bambey ; (b) Groundnuts, Bambey, 1964 ; (c) Sorghum, Nioro de Rip, 1967 ; (d) Sorghum, Bambey, 1964 ; (e) Rainfed rice, Séfa, 1970 ; (f) Maize, Séfa, 1969.

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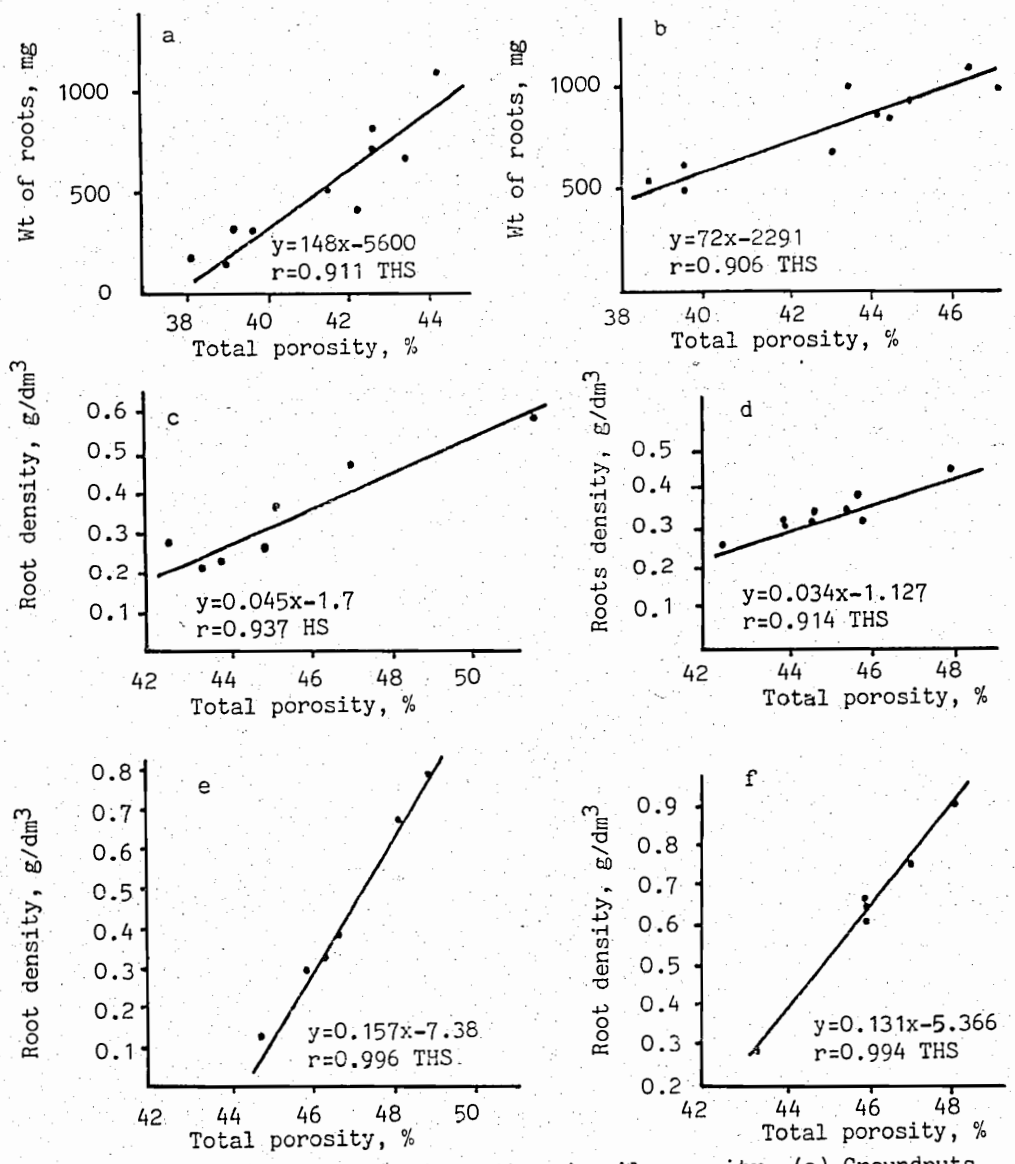


Fig. 2. Relations between root growth and soil porosity. (a) Groundnuts, Bambey ; (b) Sorghum, Bambey ; (c) Sorghum, Nioro de Rip (10-30 cm) ; (d) Maize, Sinthion-Malème (10-30 cm); (e) Rainfed rice, Sefa (10-30 cm); (f) Maize, Sefa (10-20 cm).

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## THE EFFECTS AND CONSTRAINTS OF TILLAGE

Tillage has many effects on the soils that have sandy-loamy and sandy-clayey surface horizons. The most important ones concern the structure of the soil, the hydric regime, the organic matter and microbial activity and consequently the yield of crops.

The structure of the soil. Tillage increases the total porosity of superficial horizons whatever the conditions of realization. It takes the earth, breaks it and turns it by dividing it more or less slenderly in accordance with its humidity and therefore with the intensity of the mass take-off. Thus it creates an artificial cleft which does not exist under natural conditions. Morphological observations of soil profiles after tillage show an important difference in the macrostructure between superficial horizons and deep-seated horizons.

In Table 1, we have gathered a few field measurements in a range of representative conditions (Nicou, 1977).

Table 1. Example of the effects of tillage on soil porosity.

| Village | Type of soil | Total porosity | | Statistical Comparison |
|---|---|---|---|---|
| | | Control | | |
| | | % | | |
| Bambey | Leached tropical ferruginous soil on sand-hills (DIOR) | 38.9 | 43.4 | ++ |
| | | 38.1 | 44.5 | ++ |
| | | 40.8 | 43 0 | ++ |
| | | 40.8 | 47.5 | ++ |
| | Sandy-clayey soil (DEK) | 39.2 | 46.0 | ++ |
| | | 40.0 | 46.4 | ++ |
| Nioro du Rip | Leached tropical ferruginous soil on sandy-clayey sandstone | 43.4 | 47.2 | + |
| | | 42.6 | 47.2 | ++ |
| | | 41.9 | 47.5 | ++ |
| | | 43.0 | 46.8 | ++ |
| Sinthiou Malem | Leached tropical ferruginous soil on sandy-clayey sandstone | 40.8 | 44.2 | ++ |
| | | 43.4 | 47.5 | ++ |
| Sefa | Leached ferruginous soil | 43.4 | 51.3 | ++ |
| | | 44.9 | 47.9 | ++ |

++ Highly significant difference
\+ Significant difference

Clod porosity also increases, especially where the organic matter has been incorporated. It has been shown that when tillage was well carried out in good conditions of soil moisture the changes of structural porosity affected not only the big clods but also the small aggregates of one to two cm of diameter (Nicou, 1974).

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This increase in total porosity that may appear to be limited (10 to 20%) has, nevertheless, very important consequences particularly on annual plant root development. We have seen that there exist relations between root density an global porosity, but it is the whole dynamics of root establishment which is favourably modified (Chopart, 1975):

(1) pace of progression of the root front,
(2) maximum depth and total length,
(3) deep root density,
(4) average distance between two roots.

A number of data assessed in figures appear in Table 2 as an example (Chopart and Nicou, 1976).

Table 2. Effects of tillage on some characteristics of crop root establishment

| Characteristic | Control | Tillage |
|---|---|---|
| Pace of growth: rainfed rice root weight at 25-30 cm | | |
| After 25 days, g | 6 | 45 |
| After 45 days, g | 54 | 64 |
| Characteristics of rainfed rice root establishment at 92 days | | |
| Total length, m | 36.2 | 96.2 |
| Distance between main roots, cm | 4,14 | 2.55 |
| all roots, cm | 0.66 | 0.48 |
| Total weight, g | 4.10 | 8.48 |
| Diametral surface, $cm^2$ | 550 | 1676 |
| Characteristics of sorghum root establishment at blossoming | | |
| Total length, m | 36.4 | 49.6 |
| Distance between main roots, cm | 12.8 | 10.1 |
| all roots, cm | 0.63 | 0.57 |
| Diametral surface, $cm^2$ | 9.45 | 12.36 |
| Indepth root weight by plant (mg) | | |
| Millet 100 - 150 cm | 532 | 1225 |
| 150 - 200 cm | 91 | 308 |
| Groundnut 50 - 110 cm | 4010 | 5700 |
| Sorghum 40 - 90 cm | 2370 | 3910 |

The hydric regime of the soils. Tillage also affects the hydric regime of soils strongly. This is one of its most beneficial effects in semi-arid tropical zone. It is frequently observed that crops support dry periods better when they are planted after tillage.

Three mechanisms must be taken into consideration for this improvement of the hydric regime:

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(1) improvement of infiltration, tillage affects infiltration:
   (a) by increasing the porosity of surface horizons;
   (b) by creating obstacles to the partial or total circulation of water at soil surface, this obliges it to penetrate: cloddy superficial structure, modification of land pattern.

   This action has been checked under numerous circumstances, that is, (IRAT, 1982, 1983, 1984):
   (a) by hydric profiles at the beginning of the cycle (Fig. 3)
   (b) by measurements on runoff particularly with the help of erosion compartments (Southern Senegal, Center Burkina, Northern Nigeria).

   In that respect, the proper efficiency of tillage is mainly perceptible at the beginning of the cycle. Later on, it is the more important development of the vegetation cover that ensures better protection of the soil by intercepting the rains.

(2) Use of the stored water by the plant. This effect is linked to the development of the root system. Thanks to a more rapid and better utilization of the soil by the roots, the water reserve made available to the plant is more important (Table 3).

   Numerous monitorings of hydric profiles performed during periods drought have made it possible to find that plants cultivated on tillage explored the hydric reserves of the soil better (Charreau and Nicou, 1971).

Table 3. Differences of water stocks between control and tillage during millet cultivation in Bambey and rainfed rice cultivation in Sefa (Senegal).

| Millet, Bambey | | | Rainfed Rice, Sefa | | | |
|---|---|---|---|---|---|---|
| Differences of water stocks, mm Control-tillage | | | Differences of water stocks, mm Control-tillage | | | |
| Depth in soil | 1970 | 1973 | Depth in soil | 1968 | | 1969 |
| 0 - 50 cm | - 1.5 | + 1.8 | 0-30 cm | + 6.5 | 0-40 | - 17 |
| 50 - 100 | + 9.1 | + 6.5 | 30-50 | + 10.3 | 40-80 | + 14.9 |
| 100 - 150 | + 9.2 | + 11.1 | 50-100 | + 15.2 | 80-200 | + 17 |
| 150 - 200 | + 17.5 | + 18.4 | | | | |
| 0 - 200 | + 34.3 | + 37.8 | 0-100 | + 32 | 0-200 | + 14.9 |

Whereas consumptions at surface are equivalent, in depth the plant consumes more on a tilled soil and uses the reserves better.

(3) Conservation of stored water. If performed after cropping, soil work makes it possible to reduce evaporation during the dry season, by breaking of the capillary front and suppression of all surface vegetation. If there is water left in the soil after harvest (short cycle cropping) and if the texture allows

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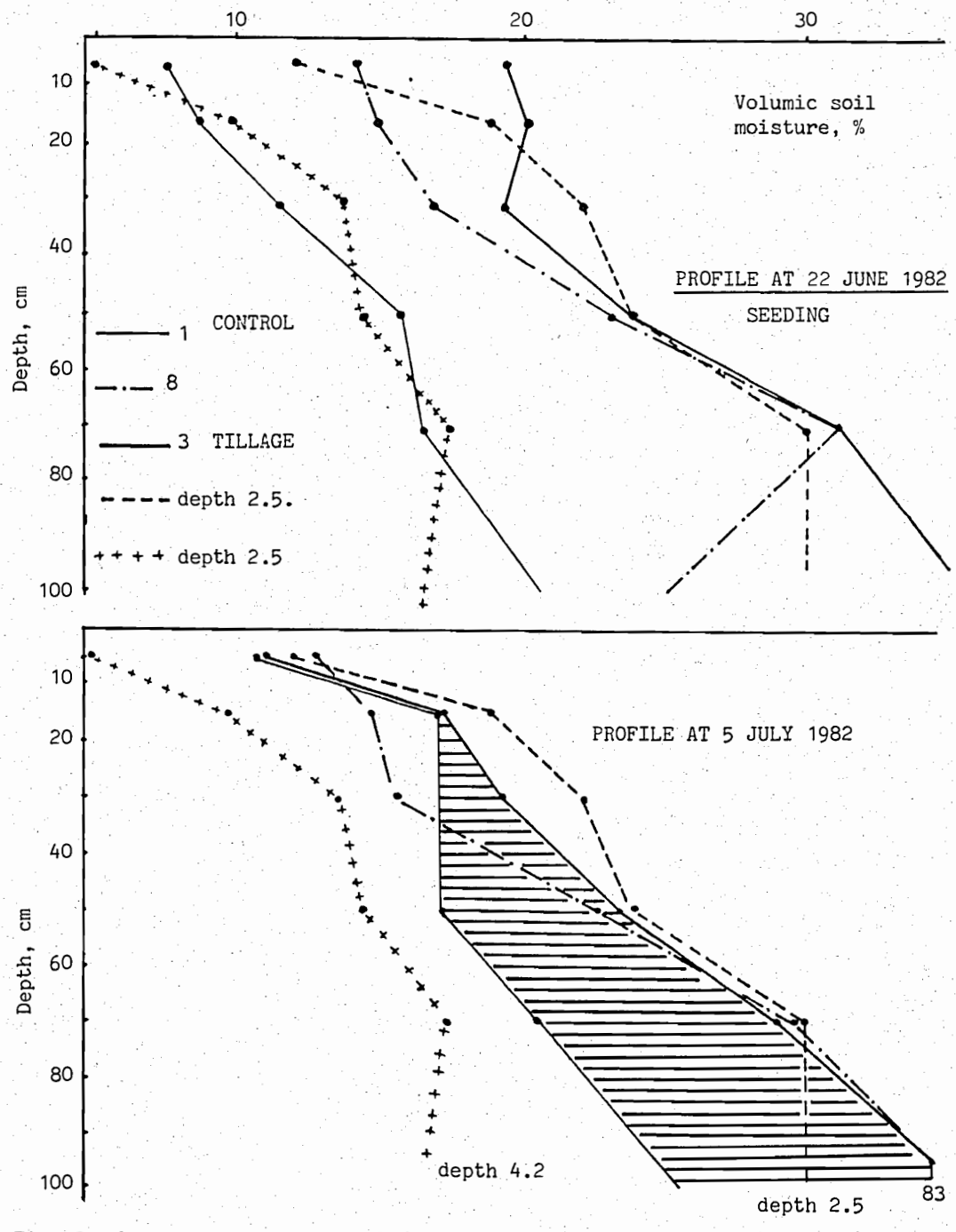


Fig. 3. Water conservation techniques hydric profiles at Gampela, Burkina Faso.

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it, this water may thus be preserved during the dry season and be used at the beginning of the cycle of the following year (Dancette and Nicou, 1974).

Table 4. Variations of water stocks (mm) over 2 m during the dry season after different treatments.

| Treatments | 30 November 1972 | 29 June 1973 |
|---|---|---|
| | mm | |
| Millet harvested, straw left on the spot, unweeded soil | 34 | 3 |
| Millet harvested, mulched, without weeds | 71 | 30 |
| Millet harvested, mulched, with weeds | 5 | 2 |
| Tillage at end of cycle, incorporation of straw into the soil early October | 52 | 40 |
| Tillage at end of cycle, incorporation of straw into the soil late October | 57 | 53 |

The organic matter and microbial activity. As regards the organic matter, repeated tillage is reputed to accelerate the oxidation and mineralization of humus and to modify microbial activity and biochemical processes. In semi-arid West Africa, the decrease of humus rate is not evident. On the other hand, in the soils of Senegal it was demonstrated that tillage might increase nitrogen mineralization significantly during the rainy season (Ganry, 1977), which increases cereal yields.

Tillage may also have important effects on the symbiotic activity of rhizobiums. Groundnut yields may thus be increased by 50% in very sandy soils, due to increased nitrogen fixation, as has been measured in Senegal (Wey and Obato, 1984).

Crop yields. The modifications of the physical properties of the soil, due to tillage and particularly its effects on the hydric regime of the soils have very important consequences on the yield of the major plants cultivated. We have many data for French speaking semi-arid West Africa. In Table 5, we have shown the averages recorded in a large part of pre-extension field trials.

These are the effects of tillage only, without taking into consideration the incorporation of organic matters that may modify the percentages in relation to the nature of the organic matter.

Cereals are very sensitive to the effects of soil tillage which increase when one moves from millet to sorghum, then to maize and to rain-fed rice. In fact, this depends, to a large extent, on the hardiness of the species and on its adaptation to the aridity of the climate.

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Table 5. Effect of tillage on the yields of the major plants cultivated annually in semi-arid West Africa.

| | Number of annual results | Yield | | Gain of tillage |
|---|---|---|---|---|
| | | Control | Tillage | |
| | | kg/ha | | % |
| Millet (grain) | 38 | 1558 | 1894 | + 22 |
| Sorghum (grain) | 86 | 1691 | 2118 | + 25 |
| Maize (grain) | 31 | 1893 | 2791 | + 50 |
| Rainfed rice (paddy) | 20 | 1164 | 2367 | +103 |
| Cotton (cotton gr.) | 28 | 1322 | 1550 | + 17 |
| Groundnut (pods) | 46 | 1259 | 1556 | + 24 |

We have also recorded residual effects of tillage; they may be relatively important and, most often they depend on rotation. Thanks to their clustered root establishment, cereals preserve the macrostructure created in the soil better whereas often after groundnut there is nothing left. This makes it possible to envisage tillage over periods of two or three years and therefore the distribution of the work over the whole field.

Finally, it must not be forgotten that tillage has a very marked effect on the growth of weeds. It has been demonstrated that a tillage correctly performed would make it possible to reduce the number of weedings significantly and, at any rate, to postpone the date of the first intervention; which is important for the crop calendar of the farm.

The difficulties and obstacles for tillage extension on-farm. The effects of tillage are not as marked everywhere because they depend on:

(1) the nature of the soil: we have said enough with respect to this subject and need not dwell on it,
(2) the climate and the vegetation.

In an environment of heavy rains, erosion control prevails. Furthermore, the presence of a long dry season is an obstacle to any efficient action of the mesofauna (earthworms):

(3) the plant cultivated,
(4) the cultural history of the plot.

On a recently cleared piece of land, it is often preferable not to upset the upper horizons whereas on a piece of land cultivated over a long period they must be tilled:

(5) the quality of the performance,
(6) the cultural manners of recovery: recoveries are often necessary when tillage is badly performed.

Tillage requires that the farmer should have an adequate force of traction (animal traction, motorization), that is, means of production.

In the case of ox traction, four to five days are required for tilling a hectare of land. The problem of crop calendar is especially serious at the beginning of the rainy season, when there is competition between soil preparation, seeding and weeding and when the state of health of the yokes of oxen is far from satisfactory after a long dry season.

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Tillage is often accused of increasing erosion. Numerous results show that this is not true, if tillage is correctly performed at a low pace as is the case with ox traction. Often, there is confusion between depth and intensity of soil work. In particular, the use of disk ploughs working at high speed on sloping soils must be condemned (Charreau, 1969). A means to prevent tillage from being erosive is to associate it to the organic matter.

Despite all the positive results obtained in trials, and the efforts of the extension services, it may be demonstrated that tillage is still relatively in little use among farmers of semi-arid West Africa. Even in some zones of western and southern Mali where it is used to a large extent, it is often used in an incorrect manner. This situation strongly contrasts with what exists in other semi-arid regions such as India, where tillage by animal traction has been largely and correctly used over centuries, despite the use of quite primitive instruments. It would be interesting to analyze the reasons for this opposition.

We have seen that in semi-arid West Africa there are numerous constraints to the adoption of tillage by the farmers. Among those constraints, the most significant one is the lack of the time required for performing this operation at the beginning of the cycle, due to the brevity of the rainy season and to the imperative need to seed early. The competition between cultural practices, seeding and weeding is particularly marked in the West where rains start suddenly. But inland, where a number of early rains of April and May may be used for tillage, this is not done without very clear reasons (Tradition prevails).

At the end of the dry season, the soils are too hard (taken as a whole) in order for work to be carried out with animal traction. After a short cycle cropping, the farmer may have a limited time to till at the end of the cycle. But here again, one is faced with a number of habits and practices, particularly that of taking a rest between the harvest of short cycle crops and that of long cycle crops.

All the drawbacks taken individually are not insurmountable, but their combinations explain the difficulties encountered in the introduction of this technique to the farmers of semi-arid West Africa.

## OTHER TECHNIQUES OF SOIL TILLAGE

Soil tillage with tines or pseudo-tillage. Soil tillage with tines makes it possible to prepare the soil without turning it up. Its purpose in particular is to get rain water to penetrate without upsetting the surface of the soil. It may have different forms (Nicou, 1978):

(1) Shallow cultivation of dry land: performed with different types of tines; it makes it possible to split the soil (Canadian, pick-mattock, diamond point, etc.). Performed with animal traction, it is necessarily limited in width and depth by the force of traction and most often it is very localized and superficial.

The yield increases obtained are very irregular and depend, to a large extent, on the volume of soil really affected by the modifications of structure. Experimentally, the yield increases may range between 0 and 15%.

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(2) Passage of tines on moist land: the tillage is deeper, faster and covers more surface. The use of parts known as "goose-feet" may be very efficient. But this work must be performed after the beginning of rains and therefore it competes with seeding. Yield increases have reached 23 % (whereas ploughing in the same conditions yielded + 39%).
(3) A chisel can only be used with a tractor. On a dry land, its depth of tillage is most often limited because of the hardness of the soils, but the surface cultivated may be important.
(4) Deep ploughing splits the soil more indepth, but the force of traction must be high. However, as the passages of tines are spaced by 1 m to 1.50 m, this reduces labour time. It is faster to use a deep-plough on a dry land than to plough 1 ha of moist soil with a tractor. Its efficiency depends a lot on the nature of the soil. If too sandy, splitting is inadequate and the modifications of structure tend to disappear rapidly. If clay content is inadequate, the effect may last at least two years.

An experiment conducted at Gampela (Burkina) over four years has led to very interesting results (Table 6). After Herblot, 1985.

Table 6. Effects of soil tillage with tines on cereal yields.

| Treatment | Sorghum 1982 | Groundnut 1983 | Sorghum 1984 |
|---|---|---|---|
| | kg/ha | | |
| Control | 950 | 1284 | 523 |
| Chisel | 1020 | 1186 | 652 |
| Chisel/deep ploughing previous year | 1200 | 1659 | 1050 |
| Deep ploughing the current year | 1390 | 1567 | 1841 |
| Tillage with gang plough | 1340 | 2000 | 1020 |

The efficiency of tillage with tines varies a lot:
(1) In terms of water economy, the deeper the tillage and the closer the passages the better the infiltration is. A deep ploughing that leaves big clods at soil surface may be very efficient at the beginning of the cycle. But a simple shallow cultivation remains very risky. The interest of these techniques is that as they are performed during the dry period they make it possible to store a more or less important part of the first rains.
(2) Action on root establishment is limited to the tilled area. If seed rows are found on the passage of the tines, there is a preferential penetration and an unquestionable efficiency. Between the tines, there is no visible effect, therefore, root penetration is very irregular.
(3) Tillage with tines alone does not play any role in evaporation control. But it may be efficiently combined with the mulch of crop residues.

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Ridging and mounding. Ridging consists in making rectangular spaced embankments with a plough, a mounding body or a hand tilling instrument. The earth is taken from the space between two crop rows to an untilled part. The plants are seeded on top or on the side of the ridges that need to be banked up during the cropping cycle.

The principle of this technique is to trap rain water, to prevent runoff and to keep the maximum of this water at the disposal of the plant. In fact, this is possible only if:

(1) the ridges are made perpendicularly to the direction of the slope,

(2) the slope is gentle or low. If this is not the case, the water runs out faster carrying away the thin elements. This erosion is then facilitated by the fact that ridging work grinds the earth.

Furthermore, if the previous conditions are met, the water will be truly available to the plant only if the texture of the soil makes it possible and if the root establishment of the crop is adequate.

In the zones of West Africa where this technique is traditionnally used, tillage is performed by hand and, in general, seeding is delayed. Ridging is particularly useful for controlling weeds at the beginning of the cycle. This being so, contour ridging may effectively limit runoff.

However, it must be noted that in sandy soils, the ridges are gradually destroyed by rains. A layered structure which is unfavorable to crop root development may develop in the furrows in which the sedimentation occurs. This was particularly observed in the south of Senegal (Seguy, 1971).

Finally, it must be pointed out that when the soil is sandy or gravelly, that is leaching, the water does not remain in the body of the ridge. In case of seeding followed by a period of drought, the plant does not resist. But if it rains a lot at the beginning of the cycle, the system avoids water logging, which may be an advantage for some crops such as maize.

An experiment conducted over the last three years in Burkina (Table 7) in several different pedoclimatic situations makes it possible to compare flat ploughing and ridging (IRAT, 1982, 1983, 1984).

Table 7. Average yield of sorghum and maize.

| | Number of annual results | Control | Flat ploughing | Ridging |
|---|---|---|---|---|
| | | kg/ha | | |
| Sorghum | 20 | 730 | 1126 | 1090 |
| Maize | 5 | 1893 | 2791 | 2323 |

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Generally, there is no significant difference between the two, as flat ploughing is superior in average. The interest of ridging is particularly marked when the slope becomes important. But its operation may be considerably improved by tying which will be discussed later on.

Mounding: it consists in taking the earth from the space between two rows to the plants being cultivated. The work may be performed by hand, by animal traction or even by motor traction. The seeding is performed on flat soil and it is only when the plant has reached a certain height that mounding can be carried out.

The purpose of the operation in terms of water preservation may be compared to that of ridging: to trap rain water and facilitate its infiltration. However, the result obtained may vary in relation to what happened before mounding and to what will happen after mounding.

If seeding was carried out after flat ploughing, one may expect to cumulate the effects of tillage and those of mounding. The same applies if there has been tillage with tines. This is important particularly concerning the development of the root system. However, mounding gives rise to a number of problems:

(1) To perform it, one must wait until the plant has grown enough. In regions with poor rainfall, when there is a period of drought at the beginning of the cycle, one must wait for a long time before getting the possibility of mounding. Therefore, the efficiency of the technique may then be questioned.
(2) When mounding, one may have to cut off a number of roots which are in the space between two rows. Some negative effects have been observed on millet.
(3) Seed lines must be perpendicular to the line of greater slope.

As in the case of ridging, the efficiency of mounding may be consierably improved by tying.

Tied ridges. The technique of tied ridges consists in making embankments with regular space between the ridges, in such a way as to prevent the runoff of water and to create basins for water microcatchment. This technique makes it possible to practically suppress runoff in the plot and, to put all the rain water that falls down at the disposal of the plant.

This technique which traditionally is in little use in West Africa is widely used in South America, it has recently been the subject of surveys by the IITA-SAFGRAD Agronmy Team on maize and cowpea in Burkina and, by the ICRISAT Team on millet and sorghum; its on-farm application has been initiated by the FSU/SAFGRAD Team. IRAT-CIRAD, under IBRAZ, has undertaken over the last three years a regionalized comparative study on all water conservation techniques which will make it possible to determine the most adapted techniques in relation to the pedoclimatic context. The efficiency of the tied ridge depends on numerous factors;

(1) distance between the ridges,
(2) date of ridging or of tied ridging,
(3) nature of the soil,
(4) position on the toposequence.

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In a study carried out at the Kamboinsé station (Burkina), ICRISAT has compared different sizes of basins of microcatchment with or without complementary straw, for reducing evapotranspiration. For sorghum, a microcatchment basin of 0.50 $m^2$ was significantly better in terms of yields: this corresponds to a spacing of 1 metre between the ridges for seed rows spaced by 50 cm, (Zaongo, 1983).

Concerning the date of tying, several possibilities must be envisaged:

(1) Direct seeding at the outset on the tied ridges manually or mechanically. In that case one does without the effects of soil tillage such as tilling on crop root establishment.
(2) Flat seeding after preparation and tied mounding about three weeks or one month after seeding.
(3) Flat seeding, mounding at the beginning of plant growth and tying some time afterwards.

The efficiency of the tied ridge will then depend upon the distribution of rains with respect to the date of tying and also to the nature of the soil.

If the soil is too sandy, the device might not resist severe rains and it will be necessary to bank up regularly (hence additional work). It is, therefore preferable to perform tying rather late so that it can be efficient at the period of ear emergence or blossoming, a very stress sensitive period of plant growth.

If the soil is clayey enough and if the tied ridge is solid, it is preferable to make it early, but if one wishes to utilize all of the water of the profile by a deep root establishment, it is better to plough beforehand. The IITA-SAFGRAD experiment has shown that in that case, the device could be kept for two years without being banked up.

The regionalized IRAT trials of 1984 have shown that the best date for tying the ridges varies in relation to the site (IRAT, 1984).

Table 8. Effects of the ridge in relation to its date of construction on sorghum yield.

| Location | Control | Ploughing + tied ridges 1 month | Ploughing + ridging, 1 month + tying, 2 months |
|---|---|---|---|
| | Kg/ha | | |
| Sabouna | 1 | 330 | 118 |
| Kolbila | 288 | 611 | 531 |
| T O | 876 | 1461 | 1219 |
| Gampéla | 109 | 1683 | 2594 |
| Saria Haut | 523 | 1410 | 1337 |
| Saria Bas | 259 | 1561 | 1790 |
| Kassou | 698 | 884 | 825 |

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It must also be pointed out that when the soil is sandy or gravelly, the water may seep and not be used by the plant. Therefore, it is necessary to develop a deep root establishment.

The example of Saria Haut is a typical one in this respect (sorghum, kg/ha)

| | |
|---|---|
| Control | 523 |
| Flat tillage | 1083 |
| Flat tillage + tied ridging at 1 month | 1410 |
| Direct tillage + tied ridging 1 month | 959 |

Concerning toposequence, an important study is being conducted by IITA-SAFGRAD at Kamboinsé. Fig. 4 shows the results obtained in 1983. They reveal the effect of the position of the crop, along the toposequence, on the yield of maize. Tied ridging every other row or every row has increased yields on all positions except the bottom lands, (IITA-SAFGRAD, 1983).

Therefore, tied ridges appear as a very interesting water conservation technique that may be combined with other techniques (soil tillage, mulch).

However, if ridging may be done with animal traction and maintained in the same way, so far tying required considerable work from the farmer. The creation by SAFGRAD of an adapted tool gives rise to hopes in that respect.

It is a fact that mechanical weeding between the rows is no longer possible, everything must be done by hand. We believe that flat seeding (preferably after soil preparation) followed by tied ridging three weeks afterwards, will make it possible to solve the problem of weeds, as the effect of mounding is to limit the number of weedings. Thus only one manual intervention would suffice until harvest.

It must also be pointed out that another technique has been tested by IITA-SAFGRAD. It consists, after flat seeding, in digging small holes (about 40 cm long x 20 cm wide x 10 cm deep) at the same time as the first weeding. The holes are dug between the rows without mounding the plants. The system has had a very highly significant effect on the yields of maize in 1983 at Kamboinsé; 624 kg/ha without holes compared to 1272 kg/ha with holes. The average yield increase is higher than the opportunity cost of labour. If this is confirmed, this operation must be mechanized, (IITA-SAFGRAD, 1983).

Mulching. Mulching consists in leaving on the soil surface all or part of crop residues. The objectives of this technique are many (LAL, IITA, 1983):

(1) to protect the soil:
   (a) by limiting runoff and, limiting erosion as a consequence,
   (b) by reducing evaporation;
(2) to reduce soil tillage by avoiding to turn up the surface horizons;
(3) to enrich the soil with organic matters and increase the activity of the mesofauna (earthworms).

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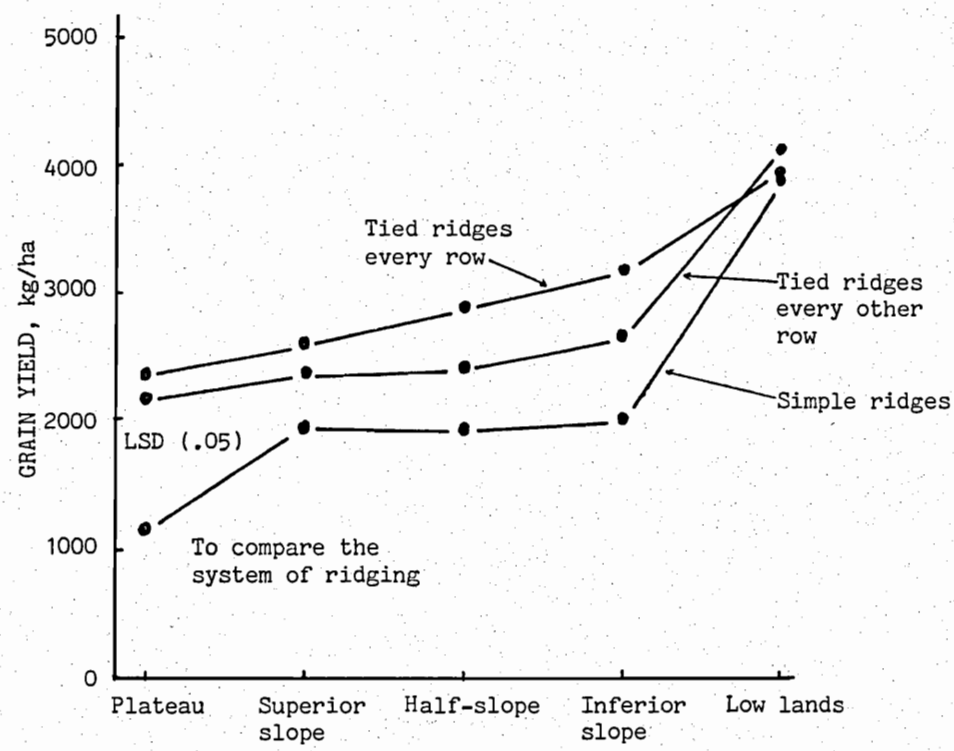


Fig. 4. Effect of the position of the crop along the toposequence and the tied ridges on maize grain yield at Kamboinsé, Burkina, 1983. Average of two seeding dates.

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Many data have been produced particularly at IITA and more recently at ICRISAT. They show clearly that mulching reduces runoff and facilitates infiltration.

This is certainly the most spectacular effect of this technique. However, it must be noted that its efficiency depends on the quantity of straw present on the soil. If the harvest of the previous year has been poor, the quantity of straw will be poor and the protection will be reduced. In case of heavy rains, on a sloping soil, this straw may be carried away. Thus it was demonstrated in Senegal that a harvest of 1500 kg/ha of millet yielding 4 t/ha of straw is not enough to ensure adequate protection and that the tonnage must be doubled with contributions from outside. In general, the coverage is adequate in humid zones, whereas in the dry zones where the role of infiltration is primordial, it is difficult to produce the quantities required (Chopart, Nicou and Vachaud, 1976).

To be efficient in terms of moisture conservation and evaporation control mulching must be associated with weeding.

During the cropping cycle, it is somewhat efficient in reducing evaporation as compared to bare soil; it also makes it possible to store water, but it may favour deep seeping inasmuch as the root system of the plant is not adequately developed, which is the case in the absence of tillage on soils with mediocre porosity.

The drawback of mulching when used alone is that it does not allow for semi-deep plough with turning over. Therefore, the roots are at the surface, which make the plant even more sensitive to drought. In order to mitigate this drawback, one tries to associate it to techniques of soil tillage on the row but the results are far from being convincing.

Theoretically, one could think of taking the residues out of the field, tilling and then bringing the residus back. But this would require too much work and it is preferable under these conditions to make manure, compost or simply to incorporate the residues directly into the soil.

The presence of this layer of undecayed organic matter at the soil surface gives rise to other problems.

(1) the problem of weeding: one must resort to different herbicides, that is, to certain technologies,
(2) the problem of mechanical seeding which can be settled only by motor traction,
(3) finally, the farmer must have an adequate quantity of straw. But in the semi-arid West African zone, straws are used as animal feed, as fuel or as construction material. Therefore it is in the zones where the problems of hydric supply are the most crucial that this technique is less likely to be put in use. But it remains very interesting for zones recently cleared, in tropical humid environments on soils with good structure.

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## CONCLUSIONS

We have tried to recapitulate in one table (Table 9) the efficiency of different techniques on water conservation, for each of the following objectives:

(1) to improve infiltration,
(2) to facilitate the use of stored water,
(3) to preserve water.

We have assessed in a very simple manner how each technique would help meet those objectives:

- = no action,
+ = not very efficient,
++ = efficient,
+++ = very efficient.

We have added a fourth column in which we highlight the problems raised by the application of the technique.

This has been done on the basis of experimental data at our disposal, with much objectivity. A rapid reading of this table makes it possible to determine the most efficient interventions and to think a priori of the most interesting combinations. However, the experimental results may moderate this trend by highlighting the importance of pedoclimatic conditons.

We can see that most soil tillage and water conservation techniques are relatively efficient in terms of rain water collection (reduction of runoff, increase of infiltration), but that they do not have the same effects on the use of this stored water by plants.

The essential difference, in terms of their efficiency, lies in their capacity to facilitate the development of the crop root system, particularly at the beginning of the cycle, and in their capacity to allow for the presence of a deep and extensive root system to ensure the hydric nutrition of the plant during dry periods.

But it must be noted that no technique is universal and that each of them must be adapted to the context. Indeed, it is observed that each of them depends on:

(1) the soil (texture, structure, depth, fertility),
(2) the climate (total rainfall, distribution),
(3) the vegetation, and
(4) past farming practices.

Finally, the socio-economic context plays a major role in the possibilities of application.

For example, it is illusory to talk of mulch in a country where all the residues are used or of deep ploughing when motorization is a luxury not very widely distributed.

Flat tillage requires minimal equipment and time available for work. Tied ridging requires an important effort from the farmer.

Therefore, a judicious choice must be made in relation to the situation which one is undergoing.

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Table 9. Effects of different techniques and problems raised by their application.

| | Shallow cultivation | Dry deep ploughing | Flat tillage | Tillage in ridges | Mounding | | Tied ridges | | Mulching |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Without tillage | With tillage | Without tillage | With tillage | |
| Improves infiltration, reduces runoff | + | ++ | ++ | ++ | ++ | ++ | +++ | +++ | +++ |
| Facilitates the use of stored water by the plant | + | ++ | +++ | + | - | ++ | + | ++ | - |
| Helps preserve infiltrated water | - | - | ++ | - | - | - | + | + | ++ |
| Problems raised by the application of the technique | - Force of traction | - Requires heavy motorization<br>- Cost | - Animal traction equipment<br>- Period of realization | To be done perpendicular to the slope<br>- Problem of mechanical seeding<br>- Labour time if done by hand | - Seed rows must be perpendicular to the slope<br>Damage to toots<br>- Mounding date dry zone<br>- Labour time | | Tying: Labour time for tying<br>- Weeding | | - Straw availability<br>Weeding<br>- Mechanical seeding |


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ICRISAT Annu 1984.

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