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CONSEQUENCES OF HEAVY MECHANIZATION AND NEW ROTATION ON RUNOFF AND ON LOESSIAL SOIL DEGRADATION IN THE NORTH OF FRANCE.

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The impact of heavy mechanization on soil degradation raises considerable problems all over the world. The authors present some results of a light approach to this problem promoted by a committee of cultivators with the help of the Administration and some researchers in the North of France.

This approach combined regional investigations and field tests to evaluate the extension of erosion and the reasons for soil degradation. Sixty rainfall simulated tests were applied on 1m2 plots with the ORSTOM sprinkling infiltrometer to study the evolution of infiltration during an annual rainfall event (33mm in one hour) and soil erodibility. In spite of the low erosivity of the rainfall (Rmetric = 50), erosion is active in all the loessial area, but its intensity depends on the type of cultivation (covering in winter, residue management), soil degradation (acidification, crusting, compaction) and the intensity of soil tilling (dilution of organic matter and topsoil pulverization). The increase in erosion is related to the development of mechanization, the dissociation of breeding and farming and the extension of degrading industrial crops and not to an hypothetic modification of the rainfall pattern. Field tests showed that runoff is very high (40 to 85 %) in soils degraded by industrial rotation and mechanized farming (sealing crust and tillage pan). Subsoiling can only temporarily and partly remedy compacted pan. The more advanced the seedbed preparation is, the more considerable runoff is (5 to 66 %) and the greater the difficulties of germination for cereals. The authors conclude that it is necessary to reduce the number of tillage practices, to cover the soil in winter and to restore the balance between the rotation of degrading crops and restructurating ones. Therefore, terracing does not seem necessary.

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INTRODUCTION

In the earliest cropping systems, a long period of fallowing makes it possible for soils impoverished by a short period of cropping to recover both a certain level of chemical fertility and good physical properties. This system called shifting cultivation is still largely widespread in sparsely populated tropical zones (FAO, 1974). In Europe, a first agricultural revolution allowed to reduce the period of fallowing and to intensify the agricultural production through a close association between breeding and farming including tilling, manuring and rotation between degrading and restructurating crops (temporary grassland and cereals). In the early century, industrialization brought new modifications to agriculture. Mechanization helps to release manpower for the preparation of the seedbed, weeding and harvesting. Mineral fertilization contributes to plant nutrition, but crop rotation tends to produce more and more industrial crops which lead to soil degradation. Breeding is concentrated in special areas close to the farm where it becomes a pollutant. However, one is not long in observing that soil physical properties are only partly and temporarily improved by tilling.

Up to the present time, intensive mineral fertilizing and advanced plant breeding led to a very high productivity. However, as in many places over the world (TRIPLETT, MANNERING, 1978 ; BOIFFIN et al., 1982, KANWAR, 1982), one begins to observe stagnating and even decreasing yields despite large amounts of fertilizers and strong cultivation practices , the degradation of the soil physical properties, the surface waterlogging of the plateau loamy soils, the abundant runoff leading to the gully erosion of hillsides, frequent inundations and mud depositions in valleys occupied by villages. The frequency and intensity of these problems of erosion increased so much over the last ten years in the northern part of France that the cultivators themselves have called upon the help of the Agricultural department , a few researchers and the Rural Development Committee of the Val de

Canche in order to cope with the situation. (MASSON, PELLETIER, 1979 ; DOUAY et al., 1980).

The impact of mechanization on soil degradation is such a widespread problem all over the world that it seems necessary to describe here the results of a light approach to this problem in a country region.

METHODOLOGY

Cultivators are not interested in undertaking on a local basis highly sophisticated researches on processes of erosion. But they need to determine the extension and economic influence of erosion, the causes and factors of soil degradation. They would like to get the most adequate but the less demanding conservation practices with a view to the development of a modern and profitable agriculture. Therefore, we made successive approaches to the problem in order to specify it and modify gradually the reaction of cultivators towards the erosion risks and the possible changes in the current farming practices with a view to reaching a steady production which will be better adapted to the local ecological and socio-economic conditions.

Three investigations have been made successively :

E_1 at the level of the local administration of the Val de Canche in order to evaluate the extension of damages caused by erosion in the most affected zone of the department.

E_2 at the level of the cultivators and plots in order to look for the reasons for the change in the intensity of erosion since about ten years.

E_3 at the level of the North-Pas de Calais region by studying the historical, geomorphological and soil data related to phenomena of erosion visible in the field and in aerial photographs.

Simultaneously, various agricultural experts (INRA, ORSTOM and INA*)

INRA = Institut National de la Recherche Agronomique.

ORSTOM = Office de la Recherche Scientifique et Technique Outre Mer.

INA = Institut National Agronomique.

were asked to get into touch with cultivators in the field and make an evaluation of the situation. In addition to the classical Department of Agriculture, a special committee has been set up in order to give advice to farmers in the most affected region.

Finally, as problems and solutions seem to be clearer, field tests have been made with voluntary farmers in order to evaluate the influence of intermediate crops on the soil cover in winter or that of the excessive tilling on germination and the cereal production. Similarly, the Department of Water Management[x] undertook 65 rainfall simulated tests through the sprinkling infiltrometer developed by ORSTOM (ASSELINE and VALENTIN, 1978). These tests allow to study the evolution of infiltration (over 1m2) during an annual rainfall event (33mm in one hour) as well as soil erodibility in relation to various factors such as the soil type, the green cover, farming practices, surface roughness and structure and cropping systems. Two series of tests through the infiltrometer will demonstrate the impact of the change in the cropping system (rotation and mechanization) and the intensive tilling on the erosion risks.

STUDY ENVIRONMENT

Investigations were made in the Val de Canche which is situated in the north of France between Arras and Montreuil (cf. situation map). The landscape is composed of vast loessial plateaus (where large-scale farming is developing) interrupted by deep valleys with steep convex-concave slopes where are concentrated breeding and forests (cf. geomorphological cross-section). The most frequent soils are more or less leached acid brown soils on loess which are all the more sensitive to crusting as they have been exploited since centuries : their texture is loamy to sandy loamy, their organic matter content is low (often less than 1 %) and these soils become acid in the absence of liming. The advanced mechanization over 15 to 30 years led to the formation of a rather thick compacted pan (20 to 40cm) under a

X S.R.A.E = Service régional de l'aménagement des eaux.

ploughed horizon (30cm) (cf. description of a profile as an appendix). Simultaneously, the rotation which included two years of cereals and one year of sugar-beets has been increased with industrial plants whose soil cover is low, sowing is late and crop residues are small (sugar-beet, potatoe, maize and various vegetables for cannery). Intermediate crops, green manuring and temporary grasslands have been given up : only humid soils are exploited as permanent grasslands (MASSON, PELLETIER, 1979).

The region gets a rather moderate oceanic temperate climate. The mean minimum temperatures drop from 13°C in July to 1,4°C in January and maximum temperatures from 20,6°C to 6,4°C in the same periods. Mean annual rainfalls amount to 850mm and their annual distribution is steady with minimum monthly rainfalls amounting to 50mm from February to May and maximum ones amounting to 116mm in November (PETIT-RENAUD, 1980). The mean erosivity index of Wischmeier (1960) (R metric) is about 50 (PIHAN, 1978). Therefore, rainfalls are generally not heavy, apart from a few summer storms. Winter (not very heavy rainfalls over a long period of time on crusted bare soil or in the thawing period) and spring (storms on too pulverized soil in May-June) are critical periods for erosion.

RESULTS

A. Investigations

Investigations which were made with the country administration (E_1) and the farmers (E_2) allowed to observe that phenomena of erosion are largely found in the whole zone of loessial plateaus. However, their intensity varies with the type of cultivation (importance of soil cover in winter and spring, more or less considerable restitutions of organic matter to soil), with the soil degradation (acidification, sealing crusts, compacted tillage pan) and with the depth and intensity of tilling. As a matter of fact, the general deep tilling leads to the dilution of soil organic matter and reduces its structural stability all the more so as soils are pulverized in order to

prepare the seedbed. The increase in weight and the number of passes by the different kinds of equipment can only increase hydraulic discontinuities and the compactness of deep horizons. Since then, it seems that the increase in the intensity and frequency of phenomena of erosion in the north of France is related to the development of mechanization, the dissociation of breeding and cultivation and the increasing areas covered with degrading crops rather than to an hypothetic change in the rainfall pattern. Finally, the third investigation and the mapping of soil erodibility in the whole department showed that the organic matter content is the lowest and soils are the most degraded where the mechanized industrial cultivation has been introduced since a longer period of time, such is the case of the regions of ARTOIS and CAMBRAISIS. In the other sub-regions, sheet and gully erosion exist but are limited in space, either for geomorphological reasons (slopes are short or too gentle) or for reasons of land use practices (meadows, bush, hedges or old embankments which absorb or reduce runoff).

B. The infiltration tests in the field

A first serie of tests showed that the increase in runoff varies with the cropping system such as the old system where breeding is closely related to cultivation and the present system where heavy equipment is used to plant and harvest various industrial crops.

Table I clearly shows that runoff begins later and remains lower in the old cropping system where breeding is closely associated with cultivation than in the present industrial system which is highly mechanized and leads to the formation of tillage pans and sealing crusts.

Subsoiling (test 4) can cope partly with these difficulties, but it is expensive and all the less effective as the soil is instable (for instance, acid loamy soils). Tests 2 and 14 show how quick and abundant runoff is (hardly 15 % of rainfall percolate) in industrial crops whose harvest has just been made : the soil is crusted by rainfalls and compacted by tractors and

trailers.

In the second serie of field tests, a study was made on the influence of soil pulverization on the shooting of a cereal as well as on runoff during the preparation of the seedbed.

The results of Table II show that the more pulverized topsoil is through successive vibro-driven or rapid passes of various types of harrow, the higher runoff is and the less likely are the cereal seeds to germinate (asphyxia) and go through the sealing crust.

DISCUSSION

Despite the low erosivity of rainfalls (R = 50) and their homogeneous annual distribution, one can observe numerous phenomena of erosion, runoff and sedimentation in the zone of loessial plateaus in the North of France. They most often occur in winter on denuded and very saturated soils likely to be subject to alternations of frost and thaw ; sometimes, erosion occurs in spring (May-June) on hardly sowed fields when the soil has been too much pulverized. Similar phenomena occur in Belgium (De PLOEY, 1979, BOLLINE, 1982) and England (MORGAN, 1979).

These phenomena of erosion are not new in France since a survey made by HENIN and GOBILLOT (1950) revealed that 4 to 5 millions of hectares were subject to erosion. On the contrary, what is recent (since 10 to 20 years) is the frequency of inundations and gullying as well as the considerable damages resulting from : - the change in rotation (fewer residues in soil),

- a more advanced and heavier mechanization (as soils are degrading) and more frequent operations in order to remedy the increase in soil compactness (instable structure with low organic matter contents),

- an increase in the field area (destruction of hedges and downhill extension of plots),

- and finally the decreasing restitutions of organic

matter to soil (fewer cereals, burnt straws and dilution of organic matter by means of deep tilling).

In tropical regions, the disastrous effects of the highly mechanized crops occur more rapidly (G. MARTIN, 1963 ; CHARREAU and FAUCK, 1970) as a result of the more aggressive climatic conditions (ROOSE, 1977) and the more rapid mineralization of organic matter (ROOSE, 1980). Soils are compacted, waterlogged and give rise to sealing crusts over a few years. In Senegal, one could observe serious phenomena of erosion even on gentle slopes (< 2 %) two years after land clearing. In the forest zones of the Ivory Coast, mechanized cultivation raises similar problems (BLIC, 1976, BLIC and MOREAU, 1977).

However, it is obvious that it is not possible nowadays to consider the suppression of mechanization for socio-economic reasons. Therefore, one must try to reduce its degrading influence by limiting the number of passes and the weight of the different kinds of equipment and by using biological methods together with smooth mechanical methods in order to better exploit soils without degrading them. This solution is possible nowadays as long as soil has not been too eroded, which is generally the case in temperate regions where phenomena of erosion are less intense than in mediterranean or tropical regions.

CONCLUSIONS

Heavy agricultural mechanization degrades the soil physical properties on the surface and in depth and finally reduces soil productivity in tropical regions where degradation is very rapid or in temperate regions where it is slower. Mechanization often leads to use more and more frequently heavier and heavier equipment in order to achieve a deeper mellowing of soil whose structure is degrading. However, the resulting macroporosity does not last long in instable environments such as loess if the structure stability is not improved either by injection of flocculating ions (liming) or by the growth of deep rooted crops (temporary grassland of lucern or ray

grass).

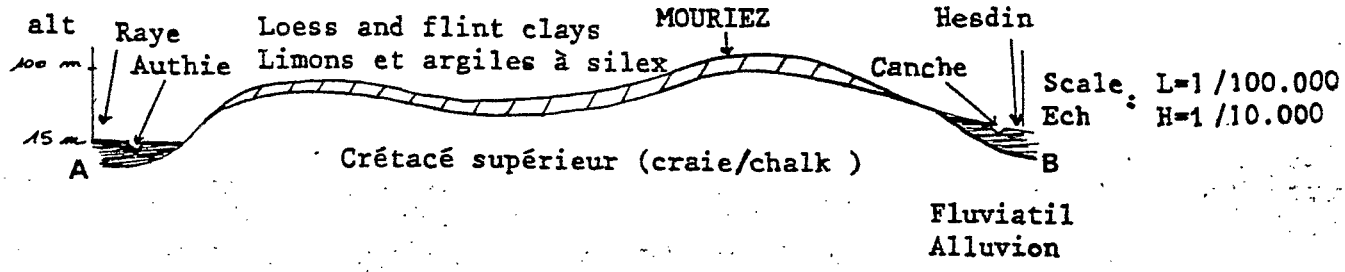
Finally, it will be necessary to restore the balance between the rotation of degrading plants and that of restructurating plants or to find out a new cropping system likely to regenerate the structure and macroporosity (temporary grassland, forage growing), to cover soil during the long cold season (winter grain, green manuring) and to limit the number of motorized operations. Heavy agricultural mechanization leads to the degradation of the environment, which does not question the socio-economic value of mechanization but requires some effort to adapt it to the physical conditions of the environment and to man.

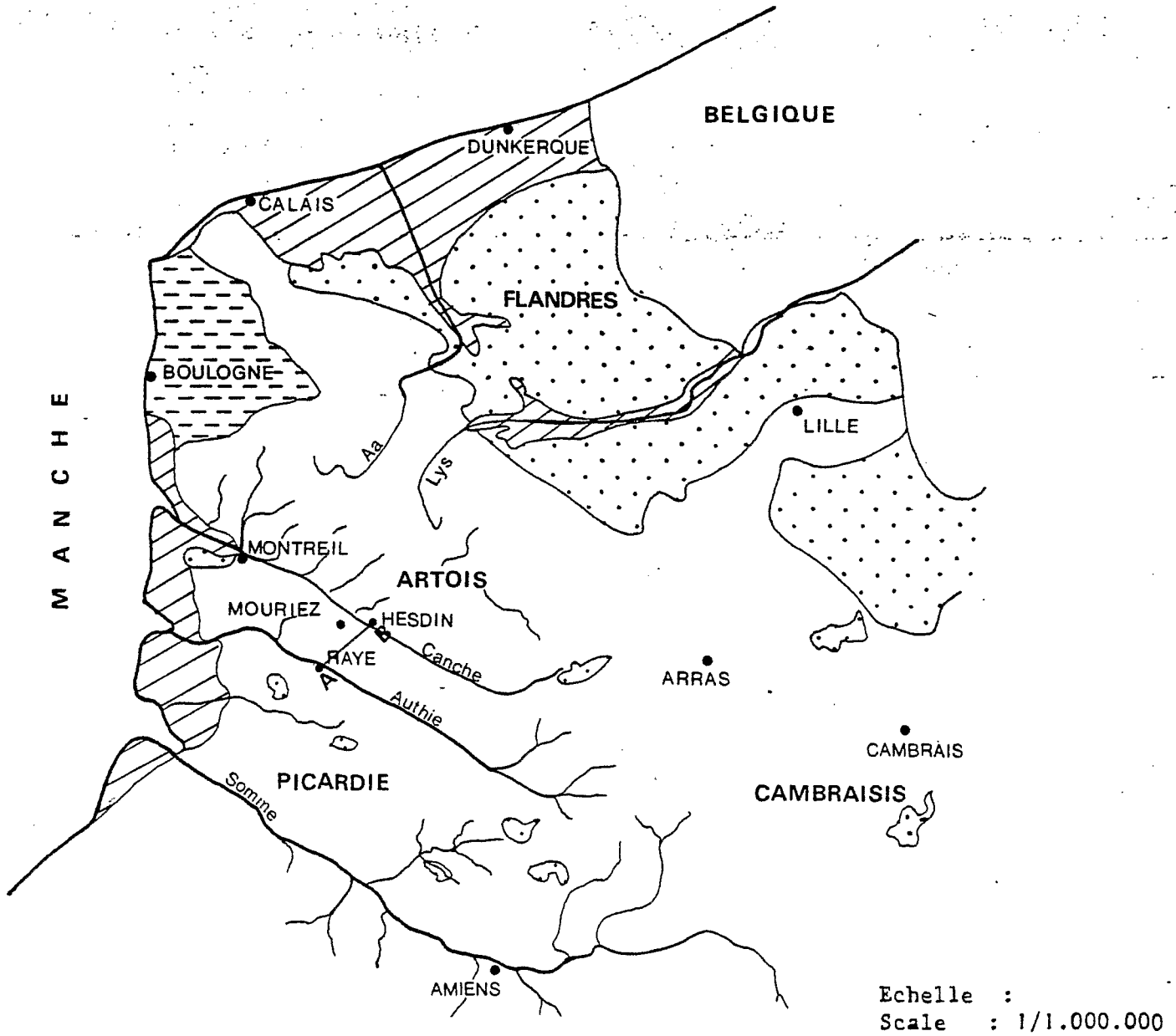
Table I : Influence of the cropping system on the soil degradation and runoff during a one hour simulated rain of 33mm in winter.

Treatments	Horsepower traction Winter barley	Permanent grassland	Broken grassland	Tilling Stubble ploughing Subsoiling	Tilling Stubble ploughing No subsoiling	Heavy equipment after harvesting	
						Endives	potatoes
Depth of ploughing	17cm	-	25cm	25cm	25cm	30cm	30cm
Tillage pan	0	0	+	+ (interrupted)	+ +	+ + +	+ + +
Soil surface conditions	cloddy	compacted over 15cm	small clods	small clods	small clods	crusted	crusted
Green cover	80 %	100 %	7 %	10 % Stubble	10 % Stubble	11 % Residues	11 % Residues
Runoff							
Delay in mn	69' *	16'	15'	15'	4'	1'	2'
Runoff in mm	0mm	2mm	9mm	5mm	14 mm	23mm	28mm
Mean KR in %	0 %	6 %	27 %	15 %	42 %	85 %	85 %
Final KR in % after 60mn	0 % *	24 %	48 % *	30 % *	73 %	91 %	98 %
Number of test	16	58	57	4	6	2	14

* The stable minimum infiltration rate has not been obtained after 60 minutes of rainfall. Rains are simulated on acid brown soils in loessial plateaus. The slope is lower than 5 % - KR = runoff coefficient = depth of runoff/depth of rainfall.

FIG .1. GEOMORPHOLOGICAL AND GEOLOGICAL DIAGRAM





Primaire + Jurassique + Crétacé inf.

Crétacé sup.+ Limons

Tertiaire Sableux

Quaternaire Fluviatile ou marin

Table II : Influence of the intensity of soil tilling on the shooting of wheat and on runoff during a one hour simulated rain of 33mm. Acid brown soil on loam : Campagne-lez-Hesdin , March 1982.

Treatment	Tilling + sowing	Tilling Harrow 4cm Coupled sowing	Tilling More rapid harrow 8km/h	Tilling 1 vibro-driven cultivator 1 sowing	Tilling 2 vibro-driven cultivators Sowing
Number of passes	2	2	2(more rapid)	3 (deeper)	4
Number of shootings/ m2 *	127	114	109	73	59
Runoff ** mm	1,6	9,1	12,5	18,8	21,7
Runoff ** %	5 %	28 %	38 %	57 %	66 %

Sources * DERANCOURT (1982) ** MASSON (1982)

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Annexe 1 - Quick profile description of a brown leached soil of the Mouriez plateau (North of France).

The description was made by Mr. MASSON in Marsh 1981 on a wet field of cereals, 4 % slope, on the plateau near Mouriez.

0 to 1 cm	Sealing crust (thick variation from 1 to 4 centimeters).
1 to 25 cm	Ap. horizon : brownish grey (7,5 YR 4/4), silty loam, low organic matter content (∿ 1 %), traces of calcareous improvements, medium polyedric structure, high porosity, fine roots. Distinct transition on the tillage bottom (around 22 to 30 cm).
25 to 50 cm	A2 horizon : yellowish brown (7 YR 5/6) loamy, rare traces of organic matter and calcareous improvements, prismatic to cubic structure becoming massive on the level of the tillage pan (15 to 25 cm thick, very compact) and below very rough polyedric structure. Very rare roots located on the structural sides and again dividing themselves under the compacted level. Transition rather distinct (around 50 to 75 cm).
50 to 85 cm and under	Bt horizon : brownish yellow (7 YR 4/6) clay loam, clay skins, rough to medium polyedric structure, better rooting and higher interstructural porosity ; less compact than above.