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Consequences of heavy mechanization and new rotation on runoff and on loessial soil degradation in northern France

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In the most primitive 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 widely used in sparsely populated tropical zones (*10*).

An early agricultural revolution in Europe permitted a shorter fallow period and intensified agricultural production through an integration of animal raising and farming. The cropping systems included tilling, manuring, and rotation between degrading and restructuring crops (cereals and temporary grassland).

Early in this century, industrialization brought new modifications to agriculture. Mechanization helped to release manpower for the preparation of the seedbed, weeding, and harvesting. Mineral fertilization contributed to plant nutrition, but crop rotation tended to produce more and more industrial crops that lead to soil degradation. Animal breeding was concentrated in special areas close to the farm where it became a pollutant. But it did not take one long to observe that soil physical properties were only partly and temporarily improved by tilling.

Today, intensive mineral fertilizing and advanced plant breeding are used to maintain very high productivity. But despite large amounts of fertilizers and intensive cultivation practices many parts of the world (*4, 12, 21*) are experiencing stagnating and decreasing yields, degradation of soil physical properties, surface waterlogging of plateau loamy soils, runoff leading to gully erosion on hillsides, and frequent inundations and mud

depositions in valleys. The frequency and intensity of these erosion problems increased so much over the last 10 years in northern France that farmers have called upon the help of the Agricultural Department, researchers, and the Rural Development Committee of the Val de Canche in order to cope with the situation (*9, 14*).

Mechanization's impact on soil degradation is such a widespread problem throughout the world that it seems necessary to describe the results of a small approach to this problem in a rural region.

Methodology

Farmers are not interested in undertaking, on a local basis, highly sophisticated research on erosion processes. But they need to determine the economic influence of erosion and the causes and effects of soil degradation. They would like adequate but less demanding conservation practices leading to the development of a modern, profitable agriculture. Therefore, we made successive approaches to the problem in order to specify it and modify gradually the reaction of farmers toward the erosion risks and the possible changes in current farming practices with a view to reaching a steady production that will be better adapted to local ecological and socioeconomical conditions.

Three investigations were made successively:

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

E_2, at the level of the farmers and plots, to look at the reasons for change in the intensity of erosion over about 10 years.

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

Simultaneously, various agricultural experts—INRA, ORSTOM, and INA[1]—were asked to get in touch with farmers in the field and evaluate the situation. In addition to the classical Department of Agriculture, a special committee was set up to advise farmers in the most affected region.

Finally, as problems and solutions seemed clearer, field tests were made with volunteer farmers to evaluate the influence of intermediate crops on soil cover in winter or that of excessive tilling on germination and cereal production. Similarly, the Department of Water Management[2] undertook 65 simulated rainfall tests with the sprinkling infiltrometer developed by ORSTOM (*21*). These tests permitted the study of infiltration (over 1 m^2)

[1] INRA, Institut National de la Recherche Agronomique; ORSTOM, Office de la Recherche Scientifique et Technique Outre Mer; INA, Institut National Agronomique.
[2] S.R.A.E., Service Regional de Lamenagement des Caux.

during an average annual rainfall event (33 mm in 1 hour). Soil erodibility in relation to various factors, such as soil type, green cover, farming practices, surface roughness and structure, and cropping systems also were studied. Two series of infiltrometer tests demonstrated the impact of the change in cropping system (rotation and mechanization) and intensive tilling on erosion risks.

Study environment

Val de Canche is situated in northern France, between Arras and Montreuil (Figure 1). The landscape consists of vast loessial plateaus (where large-scale farming is developing) interrupted by deep valleys with steep slopes. Animals and forests abound (Figure 1). The most frequent soils are mostly leached acid brown soils on loess, which are sensitive to crusting because they have been exploited for 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 40 cm) under a plowed horizon (30 cm).[3] Simultaneously, the rotation that included 2 years of cereals and 1 year of sugar-beets was increased with commercial plants the soil cover of which is low, sowing is late, and crop residues are small (sugar-beet, potato, maize, and various vegetables for canning). Intermediate crops, green manuring, and temporary grasslands have been eliminated; only humid soils are left to permanent grasslands (*14*).

The region has a moderate oceanic temperate climate. Mean minimum temperatures drop from 13°C in July to 1.4°C in January. Maximum temperatures move from 20.6°C to 6.4°C in the same period. Mean annual rainfall is 850 mm. Its distribution is steady, with minimum monthly rainfall amounting to 50 mm from February to May and maximum rainfall amounting to 116 mm in November (*17*). The mean erosivity index of Wischmeier (*22*) (R metric) is about 50 (*18*). Therefore, rainfall is generally not heavy, apart from a few summer storms. Winter (not very heavy

[3]Abbreviated profile description of a brown leached soil of the Mouriez plateau (northern France). The description was made by Masson in March 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.

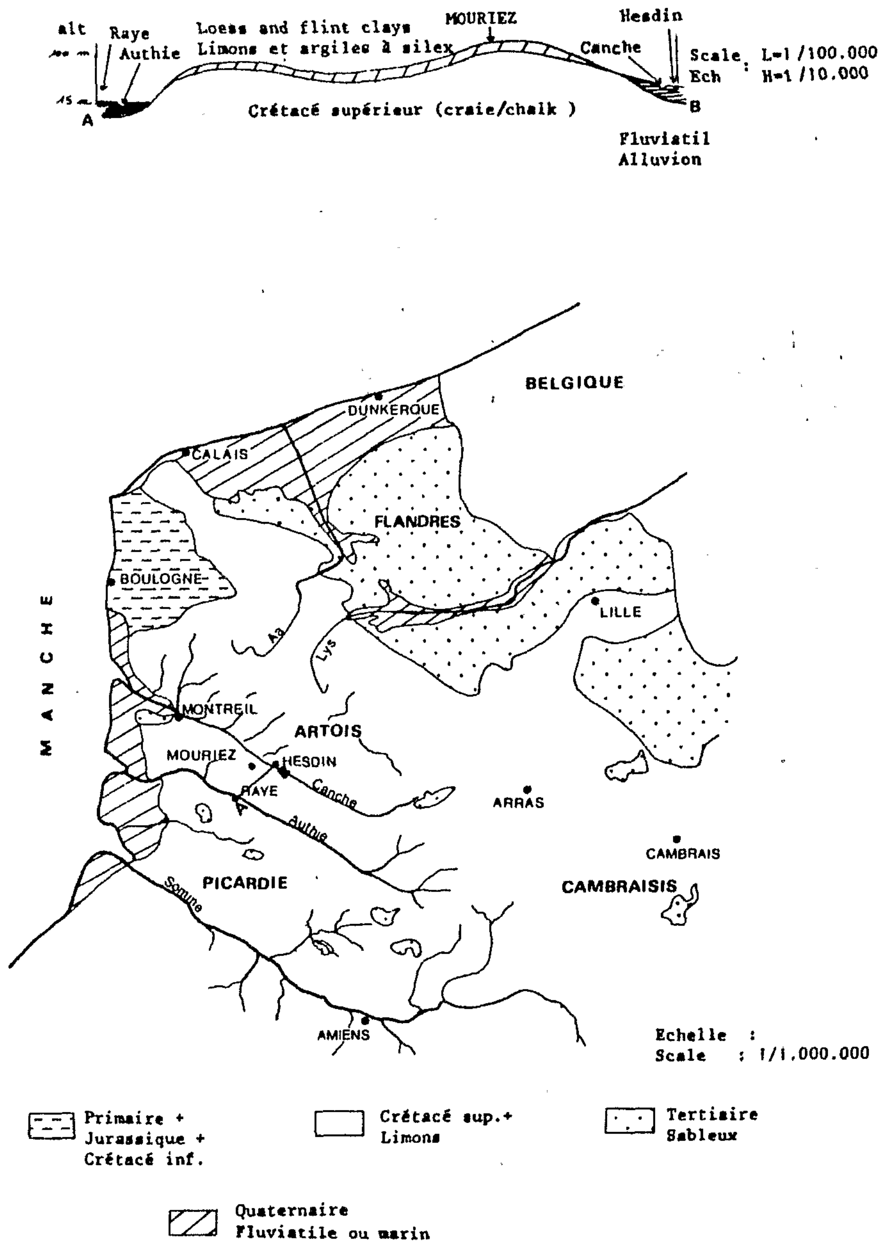

Figure 1. Geomorphological and geological diagram.

rainfall over a long period of time on crusted, bare soil or in the thawing period) and spring (storms on pulverized soil in May-June) are critical periods for erosion.

Results

Investigations. Investigations made with country administration (E_1) and farmers (E_2) revealed that erosion occurred mainly in the zone of loessial plateaus. However, erosion intensity varied with the type of cultivation (importance of soil cover in winter and spring, more or less considerable restitutions of organic matter to soil), with soil degradation (acidification, sealing crusts, compacted tillage pan) and with the depth and intensity of tilling. Deep tilling led to the dilution of soil organic matter and reduced its structural stability as soils were pulverized during seedbed preparation. Increase in weight and number of passes by different kinds of equipment can only increase hydraulic discontinuities and the compactness of deep horizons. Therefore, it seems that the increase in erosion's intensity and frequency in northern France relates to the development of mechanization, the dissociation of animal raising and cultivation, and the increasing areas covered with degrading crops, rather than to any hypothetic change in rainfall pattern.

Finally, the third investigation and mapping of soil erodibility in the whole department showed that organic matter content was the lowest and soils were the most degraded where mechanized cultivation has occurred for a longer period of time, as in the regions of Artois and Cambraisis. In other subregions, sheet and gully erosion occur but they 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 that absorb or reduce runoff).

Field infiltration tests. The first series of tests showed that the increase in runoff varied with cropping system. In the old system animal raising is closely related to cultivation and in the present system heavy equipment is used to plant and harvest various commercial crops.

Table 1 clearly shows that runoff began later and remained lower in the old cropping system than in the current commercial system.

Subsoiling (test 4) can cope partly with these difficulties, but it is expensive and less effective in unstable soils (for instance, acid loamy soils). Tests 2 and 14 show how quick and abundant runoff was (hardly 15% of rainfall infiltrated) in commercial crops after harvest. The soil was crusted by rainfall and compacted by tractors and trailers.

In the second series 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 seedbed preparation.

Table 1. Influence of cropping system on soil degradation and runoff during a 1-hour simulated rain of 33 mm in winter.

	Horsepower Traction			Tilling Stubble Plowing		Heavy Equipment After Harvesting	
Treatments	*Winter Barley*	*Permanent Grassland*	*Broken Grassland*	*Subsoiling*	*No Subsoiling*	*Endives*	*Potatoes*
Depth of plowing	17 cm	-	25 cm	25 cm	25 cm	30 cm	30 cm
Tillage pan	0	0	+	+ (interrupted)	+ +	+ + +	+ + +
Soil surface conditions	cloddy	compacted over 15 cm	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	0 mm	2 mm	9 mm	5 mm	14 mm	23 mm	28 mm
Mean KR in %	0%	6%	27%	15%	42%	85%	85%
Final KR in % after 60 mn	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.

Table 2. Influence of the intensity of soil tilling on the shooting of wheat and on runoff during a 1-hour simulated rain of 33 mm. Acid brown soil on loam, Campagne-lez-Hesdin, March 1982.

Treatment	*Tilling + Sowing*	*Tilling Harrow 4 cm Coupled Sowing*	*Tilling More Rapid Harrow* 8 km/h	*Tilling 1 Vibro-driven Cultivator* 1 Sowing	*Tilling 2 Vibro-driven Cultivators* Sowing
Passes	2	2	2 (more rapid)	3 (deeper)	4
Shootings/m²*	127	114	109	73	59
Runoff†					
mm	1.6	9.1	12.5	18.8	21.7
%	5%	28%	38%	57%	66%

*Derancourt (*8*).
†Masson (*13*).

The results in table 2 show that the more pulverized topsoil was as a result of successive vibro-driven or rapid passes of various harrow types, the higher runoff was and the less likely were the cereal seeds to germinate (asphyxia) and push through the sealing crust.

Discussion

Despite low rainfall erosivity (R = 50) and homogeneous annual distribution of rainfall, one can observe much erosion, runoff, and sedimentation in the zone of loessial plateaus in northern France. These processes occur most often in winter on denuded and saturated soils subject to alternate freezing and thawing. Sometimes erosion occurs in spring (May-June) on newly seeded fields where the soil has been pulverized too much. Similar phenomena occur in Belgium (*5, 7*) and England (*16*).

Erosion is not new in France. A survey by Henin and Gobillot (*11*) revealed that 4 to 5 millions hectares are subject to erosion. What has increased over the last 10 to 20 years is the frequency of inundations and gullying as well as the considerable damage resulting from the change in rotation (fewer residues in soil). Also, more advanced and heavier mechanization (as soils are degrading) and more frequent operations to remedy the increase in soil compaction (unstable structure with low organic matter contents), an increase in field area (destruction of hedges and downhill extension of plots), and finally, the decreasing additions 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 highly mechanized crop production occur more rapidly (*6, 15*) as a result of climatic conditions (*19*) and more rapid mineralization of organic matter (*20*). Soils are compacted, waterlogged, and give rise to sealing crusts over a few years. In Senegal, one can observe serious erosion, even on gentle slopes (< 2%) 2 years after land clearing. In the forest zones of the Ivory Coast, mechanized cultivation creates similar problems (*2, 3*).

However, it is not possible today to consider the suppression of mechanization for socioeconomic 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, to better exploit soils without degrading them. This solution is possible so long as soil has not been too severely eroded, which is generally the case in temperate regions, where erosion is less intense than in mediterranean or tropical regions.

Conclusions

Heavy agricultural mechanization degrades soil physically and reduces soil productivity in both tropical regions, where degradation is rapid, and in temperate regions, where it is slower. Mechanization often leads to more frequent use of heavier equipment to achieve a deeper mellowing of soil the structure of which is degrading. However, the resulting macroporosity does not last long in unstable environments, such as loess, if stability is not improved either by injection of flocculating ions (liming) or by the growth of deep-rooted crops (temporary grassland of lucern or rye grass).

Finally, it will be necessary to restore the balance between the rotation of degrading plants and beneficial plants or to find 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 socioeconomic value of mechanization but requires some effort to adapt it to the physical conditions of the environment and to man.

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