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Consequences of two tillage systems on Vertisol evolution and on working costs.
Influence de deux techniques culturales sur l'évolution d'un Vertisol et des coûts d'exploitation.

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The installation of an irrigated area in the South of Martinique (F.W.I.) in the late 70's, permitted the development of intensive market gardening crops on Vertisol. In order to loosen this clayey soil and to ensure optimal conditions for plant growth, deep ploughings (cross sub-soiling, ploughing at 40 cm depth) and numerous workings down were adopted by farmers. That conventional tillage (CT) induces a rapid decrease of soil organic carbon content and a consequent increase of soil erodibility which imperils the sustainability of agriculture in this region. In order to propose less destructive and more sustainable tillage systems, a field experiment was realised in an experimental farm. It consists in a comparison of selected soil parameters (indicators of soil quality), melon yields and variable costs (economical indicators) for two treatments : (1) a conventional tillage (CT, described above) and (2) a reduced soil tillage (RT) using a spading machine which loosen only the upper 10 cm of soil. Results are given for two successive melon croppings seasons. In comparison with CT, the reduced tillage RT allowed a better drainage, limited the decrease of carbon content, preserved the earthworm activity and did not induce a yield decrease. Motorizing and labour variable costs were threefold higher in CT than in RT. A survey led in a farm whose farmer uses both CT and RT confirmed those results and showed that motorising costs were 40% less for RT than for CT.
The adoption of RT by farmers would lead to a better conservation of the environment (low soil erodibility), would give the farmers a better flexibility in tillage timetable and would allow a better profitability. As a conclusion, the intensive market gardening croppings in the South of Martinique could be sustainable if reduced tillage was adopted by farmers.

Keywords : vertisol, reduced tillage, conventional tillage, economical costs, soil conservation, soil organic carbon, earthworms
Mots clés : vertisol, travail simplifié, travail profond, coûts économiques, conservation du sol, carbone du sol, vers de terre

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Introduction

Vertisols are traditionally used as grasslands or pluriannual crops because they are difficult to manage (strong when dry and sticky when wet). More intensive food croppings are possible only with mechanical implements and irrigation. Yule & Willcocks (1996) noticed that with introduction of tractors, farmers tended to plough deeper and more often. This intense ploughing aims at obtaining an increase of porosity and consequently an improvement of water drainage, of rooting development and finally of yields.
Soil loosening can be obtained only if the soil is dry enough (below plastic limits) in the whole tilled depth; on the other hand, tillage in humid conditions results in deleterious effects on the by-pass porosity and, as a consequence, on water flow and aeration (McGarry & Daniells, 1987). These soil degradations can decrease the productive potential of the soil for the next harvests (McGarry, 1987). In the humid tropics, the number of days during which mechanical tillage is possible is generally low, and thus the compaction risk is important. Moreover, mechanical tillage often leaves the soil uncovered when rains are heavy and Vertisols tend to be highly eroded (Albrecht et al., 1992).
At the end, those deep tillages are unsuited to humid tropics because they decrease the productive potential of the Vertisols, both at long- and short-term. Shallower tillages could minimize the soil degradation with the same economical results (lower yields but also lower inputs) and with less environmental degradations. In order to test this hypothesis a long-term pasture (16 years) whose soil has a high productive potential has been tilled with i) a conventional tillage (CT), i.e., moulboard ploughing at 40 cm deep, or ii) a reduced tillage (RT), i.e., spading machine loosening the upper 10 cm of soil. The pedological evolution was monitored with 3 quantitative parameters : the water content before tillage (which determines the compaction risk), the organic matter content (which determines the soil erodibility) and earthworm activity (which is a global indicator of soil quality).

Alternative techniques will be adopted by farmers only if they are economically profitable. Thus we also monitored economical indicators (motorizing and labour variable costs and yield to evaluate the outputs) on the experimental plots and in a farm near the experimental station. Melon crop was chosen because of its economical importance in the French West Indies (Koussoula-Bonneton, 1993). This paper presents the results after 2 years of experiment.

Materials and methods

Study plots

The plots are located in an experimental station (Station d'Essais en Cultures Irriguées, SECI) in the South of Martinique (14°25N, 60°53W). The mean annual rainfall on the station is 1580 mm (1981/1995) and the potential evapotranspiration (Piche) is 1080 mm (Fig. 1); the interannual rainfall variability is very important.

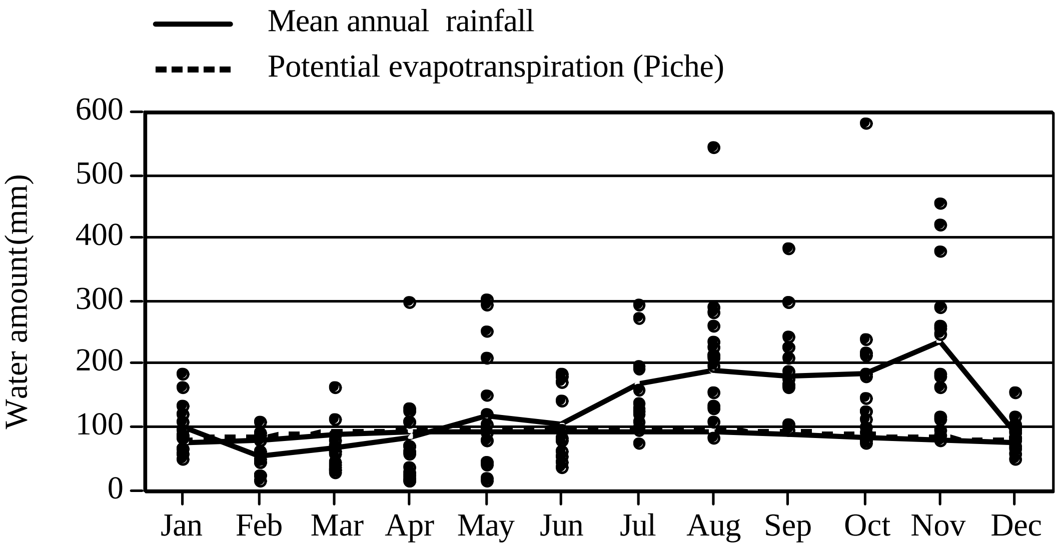

Fig. 1. Potential evapotranspiration (mean) and rainfall (monthly and mean values) at the experimental station (1981-1995).

In Martinique, Vertisols have a 'structure large dès la surface' (Colmet-Daage & Lagache, 1965); they would now be called 'weakly self-mulching'; in the US Soil Taxonomy they are classified Leptic Hapludets (Eschenbrenner, comm. pers.). The clay content is approximately 60 % on the whole profile (80 cm), the pH is ca. 6.5, the exchangeable sodium percentage (ESP) increases with depth from 5% (0/10 cm) to 12 % (30/40 cm).

The pasture was planted with *Digitaria decumbens* in 1979, since then it has always been fertilized, irrigated and grazed by sheep. In the 0/10 cm the soil organic carbon content is 35 $mgC.g^{-1}$ soil and the specific air volume is 0.164 $cm^3.g^{-1}$. In January 1995, two experimental plots (30 x 10 m each, separated by a 2.5 m track) were tilled as described below :

- conventional tillage (CT): first cultivation inverting soil layers with a 40 cm depth mouldboard plough towed by a 100 HP (75kW) wheeled tractor. In order to obtain a correct seedbed, ploughing was completed with 3 operations: a tine cultivator (100 HP tractor), a spading machine (20 HP (15 kW) tractor) and a rotovator (20 HP tractor);
- reduced tillage (RT): topsoil (0/10 cm) loosening with a spading machine (2.5 m wide) powered by a 100 HP wheeled tractor.

In order to plant melons at the same date for both treatments, soil preparation for RT started 2 weeks after that for CT. Each experimental plot contained 6 rows and 50 plants on each row.

Once the musk melon (cv. Alpha F1, Tézier) was planted, the management technics were identical on both plots: a plastic mulch to avoid weed control operations, trickle irrigation, fertilizers in the irrigation water, chemical pest control by spray.

The first cultivation started in January 1995 and was harvested in April. The plots were under natural fallow until the next soil tillage in January 1996 where the same tillages were conducted on the same plots. The second harvest was also in April.

Soil analyses

Disturbed samples were taken with an auger every 10 cm until 60 cm depth, they were then oven-dried (105°C) in order to calculate the mean water content for each plot (10 replicates). The organic carbon content was measured in the 0/10 cm layer (3 replicates) in each plot using a CNS microanalyser (Carlo-Erba Instruments). Earthworms were hand-sorted from 30x30x30 cm monoliths (3 to 5 replicates in each treatment).

Economical measurements in the experimental station and in a farm

As the management (irrigation, fertilizers,...) is the same for both experimental plots, only the time of soil preparation and induced costs were calculated.

The labour cost is ca. 39 French Francs (FF) per hour, that is approximately 7 $US (5.6 FF ≈1$US). The duration of tractor use was recorded and the motorizing variable cost was calculated from the fuel consumption per hour (1 l = 1.77 FF). Two tractors were used, depending on the implement : for the 100 HP tractor the fuel consumption is 22 $l.h^{-1}$ and the cost is 38.94 $FF.h^{-1}$, for the 20 HP tractor the fuel consumption is 6 $l.h^{-1}$ and the cost is 10.62 $FF.h^{-1}$.

The duration of tillage is high on the experimental plots because of their small size which induce numerous manoeuvring of tractors. To obtain more representative data, an investigation was conducted in a farm where both deep ploughing and reduced tillage with a spading machine are used. The farmer uses only a 100 HP wheeled tractor for tillage and other operations. The variable costs (labour and motorizing) are estimated to 95 $FF.h^{-1}$.

Musk melon yield measurements

The external rows were not used for the yield measurement; only the 200 central plants were harvested, i.e., 40 groups of 5 successive plants. The melons of 5 plants were weighed (even those which cannot be marketed) and the mean yield of the plot was calculated (Mg.ha-1).

Results

Water content profile

The water content for the MT plot was lower than that for CT; the difference was particularly significant the second year (Fig. 2).

Carbon content

Cultivation induced a decrease of carbon content since the first cultivation (Fig. 3). This decrease was more rapid for CT (28 % in one year and 37 % for 2 years) than for RT (17 % in one year and 23 % for 2 years).

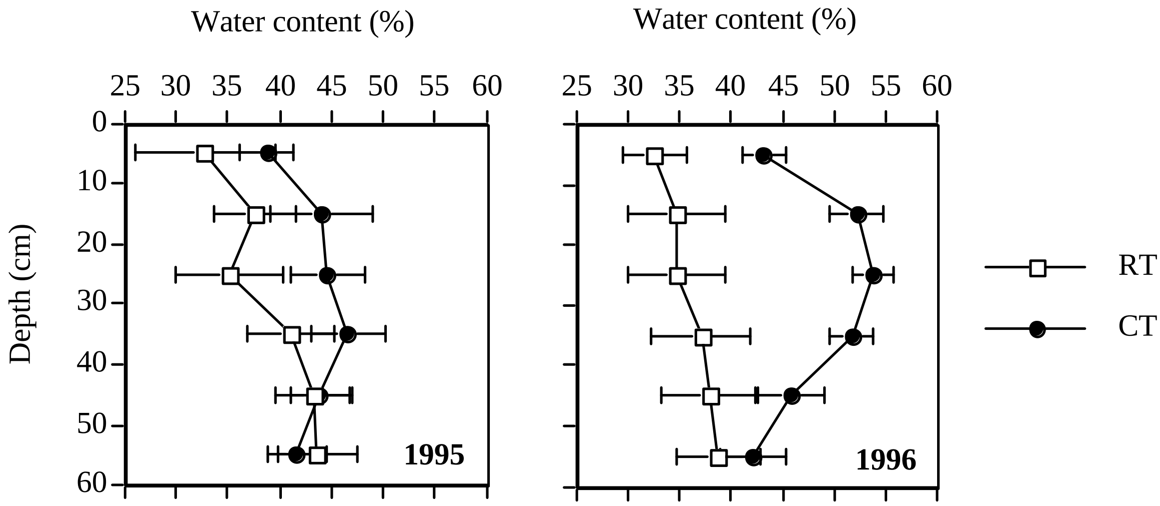

Fig. 2. Soil water profiles in December after one and two cropping seasons (respectively December 1995 and 1996) for CT and RT treatments (means and confidence intervals $P<0.05$, $n=10$)

Earthworm biomass

Compared to the initial pasture (37.3 $g.m^{-2}$), there was a higher decrease of the earthworm biomass in CT (0.78 $g.m^{-2}$) than in RT (8.48 $g.m^{-2}$) after the first year of cultivation (Fig. 4). Later, the biomass gradually increased again in both plots. In RT this increase was particularly important as the values in May and Dec. 96 were higher than that of the pasture before tillage; the presence of numerous adults of *Polypheretima elongata* explains this high biomass.

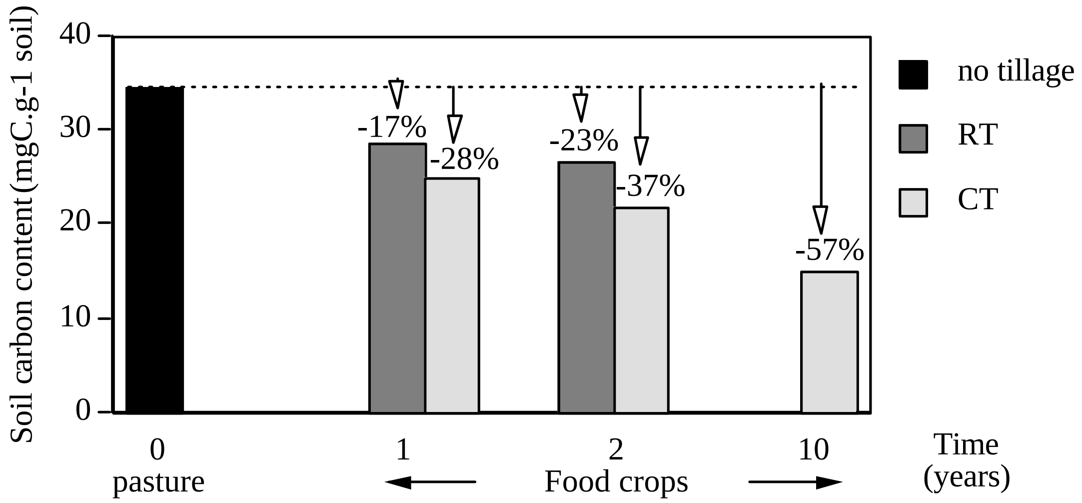

Fig. 3. Effects of RT and CT on the evolution of the carbon content (0/10 cm). Comparison with the carbon contents of a long-term pasture (left) and of a long-term (10 years) food cropping plot (right).

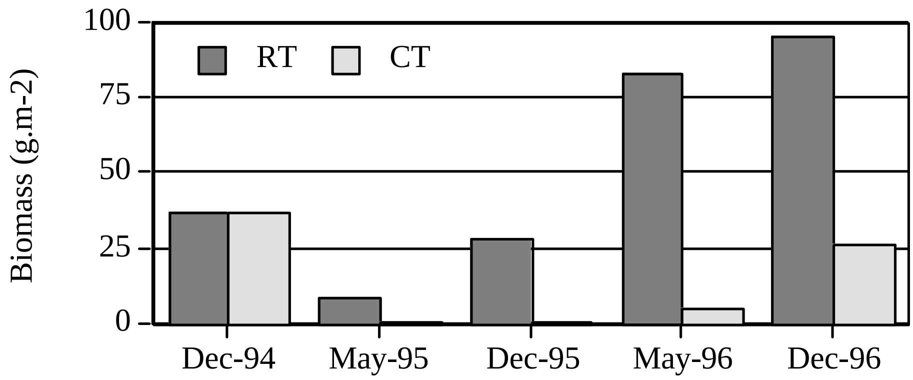

Fig.4. Evolution of the earthworm biomass in CT and RT, in comparison with the pasture before tillage (Dec-94).

Comparison of labour and energy inputs in CT and MT

Table 1. Working time and variable motorizing costs in an experimental station. Values are given for one experimental plot (300 m^2).

	CT	RT
Working time (mn)	110'30	38'20
Labour cost (FF)	72	25
Fuel cost (FF)	40	14
Total variable costs (FF)	**112**	**39**

Table 2. Tools (implements) and working time in an agricultural farm. Calculation of variable motorizing costs for one ha (100 HP wheeled tractor for both treatments).

Treatment	CT		RT	
Working time ($h.ha^{-1}$)	Three furrow plough	7.5	Spading machine (2.50 m)	5.5
	Disc harrow	2.0		
	Rotovator-ridger compound machine	6.0	Rotovator-ridger compound machine	6.0
Total ($h.ha^{-1}$)	15.5		11.5	
Variable costs ($FF.ha^{-1}$)	1 208.5		896.5	

Musk melon yield

There was no relation between melon yield and tillage system. As compared to CT, the yield of the RT plot was higher in 1995 (not significant) and became lower in 1996 (significant). The internannual variability was very important despite of the same soil tillage technique in 1995 and 1996.

Table 3. Musk melon yield ($Mg.ha^{-1}$) on the experimental plots.

treatment	CT	RT
1995	21.0	23.5
1996	36.7	30.6
Mean ($Mg.ha^{-1}$)	28.85	27.05

Discussion

Influence of tillage system on biological and physical soil properties

As compared to a deep ploughing CT, reduced tillage RT (i) limits the decrease of carbon content in the upper horizons, (ii) permits a better conservation of earthworm populations. A subsequent and rapid reconstitution of the earthworm population in RT may be explained by a weak transformation of soil properties (structure, organic matter, moisture, aeration...) and thus by a weak disturbance of earthworm environment. Earthworm conservation may be especially effective if soil surface is dry and earthworms are deep in the soil when the tillage is realized. In fact, a superficial tillage maintains a better drainage than a deep ploughing and thus the soil is characterized by better moisture conditions, especially at the time of the next cultivation. At that time, the less the soil is moist, the better is the conservation of biological activity and the less are compaction risks (McGarry & Daniells, 1987). Those risks are also reduced if machines (tractor and implements) are light.

Influence of tillage system on cultivation costs

In experimental station as well as on-farm, motorizing variable costs are higher for CT than for RT because (i) the progression speed is lower and (ii) the secondary operations are numerous. In experimental station, variable costs are 2.9 times higher for CT than for RT. On-farm, variable costs are only 1.3 times higher for CT. Savings realised on-farm are lower because the farmer used a rotovator-ridger compound machine after the spading machine which doubled his working time and his variable costs; without this operation, costs would have been only 429 F (instead of 896.50 F), i.e., 35% of CT costs. Thus, this working down is really expensive and it is not sure that yields would increase in the same proportion. Moreover, it is likely that a better use of the spading machine would have given the same soil fragmentation than spading machine + rotovator-ridger compound machine.

When RT is realized with a wide (2.5 m) spading machine, machine investments are equal to those for CT. In small farms, a most narrow spading machine powered by a lighter tractor would allow a 40% decrease of the machine investment.

Influence of tillage system on yields

Results obtained in experimental station showed that the tillage system had no influence on the melon yields. For vertisols, it seems that irrigation control is the main factor which limits plant yield (Cabidoche & Ney, 1987). Thus, the time saved in RT soil preparation could be used (1) in other technical managements which seem more determinant for yields, for instance irrigation or pests and diseases control, or (2) in marketing. Results obtained with musk melon should be verified with other plants which are more sensitive to structural properties, in relation with a deep root system, and which are more sensitive to diseases (tomato for instance).

Sustainable agriculture on Vertisols

When a soil under pasture is tilled for food cropping, biological and physical degradations occur. Nevertheless the rapidity and intensity of degradations are dependent on soil tillage system. With a RT, physical degradations are less important and soil organic carbon and earthworm populations are much more preserved than with a CT. With time, differences between CT and RT would probably accentuate.

Furthermore, it seems that there is no relationship between tillage system and yields for melon and other shallow root system crops. However motorizing variable costs could be

highly reduced for RT. When crop surface is less than a few ha (majority of market gardening farms in Martinique), a 45 HP tractor would be enough to power a narrow (1.2 m) spading machine; in CT a 100 HP tractor is necessary irrespective of the crop surface and of the furrow number. In RT, if a 2.5 m wide spading machine is chosen, a 100 hp tractor is needed and thus the investment is equal to that of CT ; in that case, savings are realised in manpower and fuel. RT is economically more efficient that CT.
The reduction of time needed for the soil preparation and the increase of trafficable days allow a better flexibility in tillage timetable, which is necessary in humid tropical areas characterised by unforseeable heavy rains. Moreover, the saved time could improve the life conditions of farmers.

Conclusion

The analysis of soil biological and physical parameters, yields and variable costs showed that a reduced tillage (i) preserves the soil and its productive potential, (ii) permits lower investments, (iii) reduces the number of labour days which permits the farmer to intensify controls on irrigation and plant diseases. This study realised in Martinique on market gardening crop gives same results than those of a study realized in Guadeloupe on sugar cane (Guillaume, 1997, pers. comm.).
Those results need to be confirmed in experimental station through the use of a deep-rooting plant as tomato and on-farm through surveys with farmers which invests in spading machines.

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