Water pollution
The impact of soil cultivation on pesticide transfer

Minimum tillage modifies soil characteristics in many ways: porosity, biological activity, ground cover… Trials carried out in Western France helped assess the amount of molecule leakage depending on the cropping techniques used. When applied in spring and summer, active ingredients are less mobile in minimum tillage systems, but with autumn and winter applications, on almost saturated soils, ploughing is more beneficial.

By destroying water pathways, ploughing slows down the infiltration process deep into the soil and vertical transfer of pesticides applied in the autumn.

The use of minimum tillage has greatly increased in countries like the United States, Brazil and Australia. This is partly due to the wish to reduce production costs and to make more efficient use of manpower. Soil protection was another reason for choosing minimum tillage, especially direct drilling. Erosion (from wind and rain) caused serious problems in those countries: soil deterioration, pollution… From as early as the 1930s, the United States began an important soil preservation programme (direct drilling, layout of fields and landscape…). The most infamous case of erosion is the Dust Bowl, resulting from catastrophic wind erosion after the silty soils of the American South West were brought under cultivation. In Brazil, the technique of sowing into cover crops (continuous direct drilling with green covers) has been developing rapidly in the last few years, in order to protect fragile tropical soils damaged by cultivation practices combined with a very aggressive climate.

The situation is of course quite different in France. Erosion, even if it can be serious in places, is not a major problem at national level. However, in fields, run-off is a vehicle for pollutants (pesticides, phosphorus…) which may alter the quality of surface water. Leaching can also lead to the transfer of pesticide residue in shallow soils or through drainage networks in fields which have them.

Different water flow

Soil cultivation has a bearing on the way water flows in the ground. Indeed, minimum tillage tends to limit run-off in soils susceptible to capping and encourages the flow of water deep into the ground.

Crop residue on the ground after harvest protects the earth clods from the "splash" effect of raindrops, which may cause them to disintegrate and result in capping, in turn leading to hortonian overland flow. A surface mulch forms, greatly reducing capping and creating a coarser surface that does not encourage run-off. This mulch increases water infiltration and reduces water evaporation. In addition, residue and associated humus rich substances increase the water capacity of the field. In minimum tillage systems, the top soil is wetter than when the ground is ploughed, and this remains true throughout the cropping season. Finally, all the specialists have noticed an increase in the level of organic matter in the top five centimetres of soil. So, when, in 1987, ploughing stopped on the La Jaillière research station site, the level of organic matter in the T5 field scored 2.2% between 0 and 10 cm. Thirteen years later, in 2000, it had reached 3.6% between 0 and 5 cm and 3.0% between 5 and 10 cm.

Higher level of biological activity

Moreover, biological activity on the surface is more intense in minimum tillage systems than in ploughed fields. Therefore minimum tillage helps achieve a much higher level of earthworm biomass than ploughing, which in turn has numerous consequences in terms of water and pesticide residue transfer. Earthworm activity helps to break fresh organic matter down and, in the long-term, helps crop residue decompose.

The micro-mixing of the soil by earthworms also helps microbial inoculation, which on the whole improves the quality of the arable layer. Apart from earthworms, we also noted an increase in micro-arthropod populations where minimum tillage was used. Earthworm activity affects water flow. Earthworm burrows certainly improve soil structure on the surface and help water infiltration deep into the ground. They are not destroyed in minimum tillage systems, whereas ploughing destroys water pathways. The "pan" created by ploughing breaks up the continuous permeability of the soil. The latter does not let water seep in so easily. Several authors *(Hall et al., 1991; Hall et al., 1989; Isensee et al., 1990, Gaston and Locke, 1996)* have noted how, in minimum tillage situations, the level of transfer has increased through drainage of molecules such as triazines or metolachlore.

Conversely, minimum tillage boosts organic matter concentration levels in the top soil, in the medium and long term, which encourages the absorption of molecules on the surface, as well as their decomposition.

Molecule transfer in the La Jaillière trial		1	
		Min till (T5) drainage	Ploughed (T3) drainage
1996-97	Q in mm	172	189
	Atrazine in mg/ha	1200	3378
	*DFF in mg/ha**	173	65
1997-98	Q in mm	210	221
	*Atrazine in mg/ha**	79	248
	DFF in mg/ha	30	3
1998-99	Q in mm	202	279
	Atrazine in mg/ha	469	1215
	*Epoxiconazole in mg/ha**	81	121

Pesticide applied during the season

Significant differences in run-off levels

Trials carried out at the Kerguéhennec Research Station (Chambre d'Agriculture of Brittany) since 2000 involve non-hydromorphic sandy-clayey silts prone to natural compaction. The trial is situated on a medium slope. This long-term experiment was established in 1999-2000. The rotation alternates grain maize and wheat. Differences in ground conditions have been noted between soil cultivation techniques, in terms of run-off, concentration and active substance transport levels. Min till techniques in wheat crops tend, in autumn and winter, to lead very quickly to soil saturation and therefore increase the risk of transfer. Conversely, they help greatly delay the deterioration of the soil surface (presence of mulch, coarse surface) in spring and summer in maize crops. The amount of active ingredient transfer is then a lot higher in fields that were ploughed.
Hydric conditions and physical properties of the ground seem determining factors when it comes to explaining differences in run-off levels, and therefore in the transport of active ingredient. Those measurements will continue since with minimum tillage techniques the soil may change over the years. During the first years, and in certain soil and weather conditions, the risk of winter run-off and therefore of pesticide transfer is pretty significant with min till techniques. Hence the implementation of such techniques should be combined with technical precautions, such as selecting adequate tools, using cover crops, destroying green covers mechanically, or choosing appropriate pesticides.

Results of trials carried out at the Kerguéhennec Research Station (Chambres d'Agriculture of Brittany) since 2000.		2	
		Min till (superficial cultivation)	Ploughing
1999-2000 (maize) [1]	Run-off level in mm	1.1	24.1
	Sulcotrione in mg/ha	74.6	3170
2000-2001 (wheat)	Run-off level in mm	17.8	8.8
	Isoproturon in mg/ha	1916.4	44.5
2001-2002 (maize) [2]	Run-off level in mm	1.7	15.7
	Sulcotrione in mg/ha	193.7	7492
2002-2003 (wheat)	Run-off level in mm	7.9	3
	Isoproturon in mg/ha	565	229

[1] Measurements under simulated rain, taken 3 weeks after herbicide treatment (intensity: 50 mm/h for 2.5 hours).
[2] Measurements under simulated rain, taken 24 hours after herbicide treatment (intensity: 50 mm/h for 1 hour).

This is how *Levanon et al. (1993)* explain the reduction in atrazine, carbofuran, diazinone and metolachlore transfer by leaching, which they noticed in minimum tillage systems. Other authors *(Dao, 1995; Weed et al., 1995; Fernamich et al., 1996)* share this opinion. Finally, other studies *(Starr and Glofelty, 1990)* showed no differences between the two cultivation methods.

Reduced run-off

In addition, minimum tillage has a recognized impact on the reduction of run-off levels as well as of associated pesticide residue transfer. This has been highlighted in several studies *(Hall J.K., 1991; Brown et al, 1985; Felsot et al., 1990; Glenn and Angle, 1987; Hall et al., 1984). Fawcett et al. (1994)* showed in a five-year study of catchment areas, that on average the amount of herbicide gathered by run-off water was reduced by 70%. The concentration in run-off water may be higher with minimum tillage, but volumes of run-off water being lower, the flow of residue is reduced. However, the authors think that, with minimum tillage, such transfer can be considerable in extreme conditions such as very heavy rain following herbicide application. In France, experiments carried out in small fields by ARVALIS - Institut du végétal at Bignan (Morbihan, Brittany), Spechbach (Haut-Rhin, Alsace) and La Jaillière (Loire-Atlantique, Western Loire Region)* highlighted a reduction in run-off volumes and herbicide transfer when direct drilling was used for maize. For wheat, results are mixed: they are conclusive at la Jaillère and negative at Bignan. Likewise, preliminary results from a large-scale experiment led by ARVALIS- Institut du végétal in partnership with ARAA and Syngenta in Geispitzen (Alsace), show that minimum tillage in maize reduces run-off levels by 55% and herbicide transfer by 80%.
Two fields, equipped with drainage systems, included in the "cropping practices and water quality" trial at La Jaillière* have been monitored since 1989. The T3 field, equipped with a drainage system as well as a run-off trap, is ploughed.
The T5 field, also equipped with drains, is in a minimum tillage system (superficial cultivation only occasionally coupled with subsoiling). Apart from soil cultivation, cropping is conducted the same way in both fields each year (maize/wheat rotation), with the same crop protection programme. Throughout the three seasons studied, similar quantities of water were drained: 189 mm with ploughing and 172 mm with minimum tillage in 1996- 97, 221 mm and 210 mm in 1997-98, with however a lower level of drainage with minimum tillage in 1998-99, 201 mm compared to 278 mm.
In Western France, run-off may be due to capping, especially in the spring, but it is usually the result of saturation in winter in fields with hydromorphic soils. It is saturation-induced run-off.

Low levels of transport when products are applied in the spring

In the soil and climatic conditions of La Jaillère, very low levels of atrazine residue transfer have been noted in the spring: water drainage and saturation-induced run-off have stopped. Apart from rainy spells which may start the drainage process again with a small water flow, we noted that 91 to 99% of transfers of that herbicide occur during the winter following the treatment, i.e. when the fields are in wheat. For instance, in 1997-98, transfer occurred before the maize was established and is due to atrazine being applied in May 1996. The comparison of the atrazine flux coming out of the two fields during the 1996-97 season, shows that transfer levels from the min till field are on average 64% lower than those from the ploughed field *(figure 1 & 2)*.

This phenomenon can be explained by the fact that the herbicide is placed on a surface richer in organic matter. The active ingredient is then fixed more efficiently on the clay-humus combination of the min till field than on the surface of the ploughed field.

In addition, biological activity on that top soil is probably more intense than on the ground of the ploughed field. The herbicide present in the soil solution is therefore more rapidly degraded.
Over the three seasons studied, a 60% drop in atrazine transfer levels was recorded in the min till field, with comparable quantities of water drained in both fields.

The same sort of pattern was noted for epoxiconazole applied to wheat in the spring. Residue from this active substance is translocated when the drainage process resumes in the field in the autumn, with nonetheless a more moderate drop in flux in the min till field than in the ploughed one.

30 years of minimum tillage

Minimum tillage techniques appeared in the 1970s in France, although they were not really widely used until the 1990s, especially in clayey chalky soils with autumn crop based rotations. At that time, work organization, as well as the wish to reduce machinery costs, greatly contributed to the development of those techniques. Between the mid 90s and the end of the decade, min till techniques started being used more often in deeper soils with rotations including more spring crops. Agronomical reasons also started emerging, such as reducing capping, run-off and erosion in weakly structured soils. Nowadays, minimum tillage applies to around 20% of cropped land.

Heavier flux of products applied in the autumn

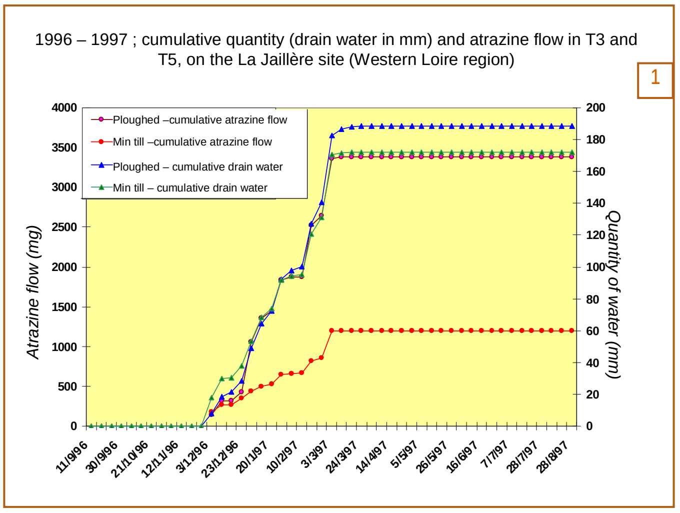
The behaviour of autumn herbicides is very different. Diflufenican (DFF) applied in autumn or winter, just before or during the drainage season, creates a situation where the flow is heavier with minimum tillage. How can we explain this? In a minimum tillage system stabilized for several years, we note a change in the way water infiltrates the ground, due to the higher number of macropores. Readings made by ARVALIS - Institut du végétal following the first rains of the season, highlighted overall larger volumes of drain water with min till than with ploughed soil: 18 mm compared to 10.5 mm in 1996-97 and 9.9 mm compared to 6.3 mm in 1997-98. Additionally, if, following the first rains, DDF concentration was similar in 1997-98, it was five times higher in the min till field in 1996-97.

A higher volume of drain water and a similarly high concentration - if not higher - explain higher transfer levels *(tables 3 and 4)*. In the ploughed field, the top soil acts as a homogenous sponge filling up before releasing the water which infiltrates the ground deep down. The plough destroyed the preferential flow formed in the summer, such as shrinkage cracks. Water infiltration is slower. Conversely, it is likely that continuous preferential flow (earthworm burrows or roots, fissures) encourage quicker transfer of water into drainage networks in min till systems.

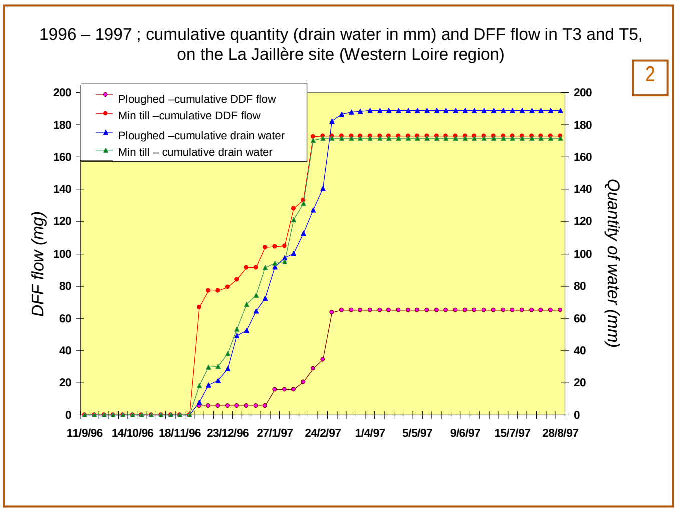
Adapting soil cultivation to the level of run-off risk

In cases where rain falls very hard (storms or heavy showers witnessed in spring and summer), hortonian overland flow is encouraged by the formation of a capped crust and a smooth soil surface. All measures aiming to limit the formation of fine soil to maintain a coarsely structured surface (cover crops residue covering the ground, no rolling, removing tracks behind drill wheels…) should be given priority. T*able 4* lists some solutions to the problem of molecule transfer in maize/wheat rotations in a silty soil.

In cases of high rainfall levels in winter, saturation run-off can appear on compacted or hydromorphic soils. This type of diffuse run-off is not always easy to spot. It is less spectacular than hortonian overland flow which is often linked to erosion. However, it can easily be contained, for instance by avoiding leaving a field with numerous wheel tracks after harvest. In hydromorphic soils, deep cultivation (ploughing, subsoiling to a depth of 20-30 cm), with the level of permeability it creates, can also encourage deep water infiltration and improve water capacity before reaching saturation *(table 3)*.



When atrazine is applied in April, the flux occurs when water drains away the following winter. There are significant differences between min till/ploughed fields.



With autumn applications, in the minimum tillage field, the transfer occurs soon after pesticides are applied.

Making reasoned choices regarding cropping techniques used in minimum tillage systems

In a drained field and in minimum tillage systems, it is important to make reasoned choices regarding crop protection. As soon as the field has reached water capacity and the start of the drainage season is approaching, certain herbicides should be avoided. It has been noted that when products such as isoproturon or DFF are used before the start of the drainage period, their transfer level is low, whereas it can be very high, especially in the case of isoproturon, when they are applied during the drainage period. When weed control measures must however be taken during the drainage season, less mobile herbicides must then be used or they must be used in smaller doses, as advised by the CORPEN diagnostic approach. Obviously, it is even more essential to follow those recommendations in minimum tillage systems.

Impact of farming practices on pesticide transfer Autumn-winter period 3		
WESTERN FRANCE - SILT ON SCHIST - MAIZE/WHEAT ROTATION		
Risk of transfer Autumn-winter period	Treatment in question	Possible solutions
High risk of rapid transfer by drain water. Risk of run-off, especially in hydromorphic soils. This risk is however lower in the case of glyphosate applied on thick cover (little of the product reaches the soil). Min till may accentuate transfer by drain as well as saturation run-off water.	Weed control in wheat (15/11-15/03)	• It is impossible to control weeds in wheat at any other time. In order to limit transfers, the choice of moderately mobile molecules is recommended, or low dose applications. This choice is even more crucial in min till systems. • In min till systems, a cropping programme including subsoiling to a depth of 20 cm at the time of sowing the wheat crop, can minimize saturation-induced run-off (soil porosity can cope with higher water capacity) and transfer through preferential flows. This is particularly important if the soil was compacted during the previous harvest.
	Destruction of cover before maize (01/02-15/03)	• A cover crop is very useful to prevent capping during the intercropping season and therefore minimize run-off. Favour easily destroyed covers (mustard, phacelia, sunflowers) and mechanical destruction methods (stubble tilling, chopping) when frost is not an option. In min till systems, the cover crop can also be destroyed chemically with a view to sowing maize into a cover. Little of the product will reach the soil under a strong cover. A strong ground cover under a maize crop will be very successful in controlling run-off and erosion later on, especially on slopes. • Total herbicide application a few days prior to sowing is only justified in the case of perennial weeds (like false oat-grass) or min till sowing (to control weeds which would require an increased use of herbicides in the crop).
	Weed control before sowing wheat crop (20/10-15/11)	• Non-selective herbicides are not justified before ploughing. • With min-till, one application can be justified to destroy weeds which would require an increased use of herbicides in the crop.

Impact of farming practices on pesticide transfer Spring-summer period 4		
WESTERN FRANCE - SILT ON SCHIST - MAIZE/WHEAT ROTATION		
Risk of transfer Spring-summer period	Treatment in question	Possible solutions
Minimal risk of transfer through drain water at that time of year. High risk of run-off on capped soils and on slopes. Min till reduces run-off and transfer through drain water the following winter.	Weed control in maize	• In the case of slopes encouraging run-off on capped soil, in maize cropping programmes including ploughing, a few measures can be taken to partially offset the absence of ground cover: one pass cultivation on ploughed land, using no power tools (to avoid creating fine soil), fit track eradicators behind the wheels of the drill and avoid rolling afterwards (to preserve the coarseness of the soil), hoeing (to break capped crust). To preserve the organic matter content of the soil, it is advisable to limit ploughing depth to 20 cm. • In maize cropping programmes with minimum tillage, the stronger the ground cover is, the less capping, run-off and erosion there will be. The cropping techniques, which will leave a more or less dense ground cover, can be determined in view of the run-off risk (slopes, field layout, capping, climate…). For instance, cropping techniques including sowing into a cover usually result in a level of ground cover 2 to 4 times stronger than that obtained on a soil superficially recultivated in the spring. Long-term minimum tillage also creates a level of organic matter concentration on the surface which encourages water infiltration under a crop of maize. • When sowing maize at close spacing (cereal direct drilling drills), the ground cover is more regular (no bare inter-row), which helps reduce run-off water.

To trap run-off water, it is essential to improve the layout of the fields. Changes to the way land is divided up into fields, during land consolidation exercises for instance, may have created run-off problems in regions where this was previously a rare occurrence. Some simple measures can help reduce this problem, such as the creation of an 8 to 10 m grass margin adjacent to watercourses or ditches. The banks of the ditches must retain a green cover and be mechanically maintained. When run-off is a frequent occurrence, field layout and use must be improved: this involves, for instance, alternating between an autumn and a spring crop across a slope. Buffer strips (grass margins, ditches or hedges) can also be established across the slope and in valleys, to reduce run-off or gullies.

Finally, we must not forget the effect of pH on the stability of the soil structure. If necessary, calcareous supplements will have to be applied (chalk, lime…), either routinely or as part of a corrective programme.

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* The La Jaillière site, as well as ARVALIS - Institut du végétal's Parisot (Tarn, South West), Magneraud (Charente-Maritime, Centre West) and Geispitzen (Haut-Rhin, Alsace) sites, bring together, within the "Agricultural practices and water quality" scientific interest group: ARVALIS - Institut du végétal, INRA, Cemagref, the University of Angers, ESA, ENSAT and Cetiom.

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