Tillage and fallow period management effects on the fate of the herbicide isoxaflutole in an irrigated continuous-maize field

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Abstract

The effects of two tillage treatments and two fallow period managements on water drainage and leaching of isoxaflutole were evaluated over a 4-year period (2005-2008). Tillage treatments were a conventional tillage (CT) with mouldboard ploughing and a conservation tillage (MT) with disk harrowing. Management of the fallow periods were bare soil (BS) or soil sown with a cover crop (CC) after maize harvest. Tillage and fallow period management had significant effects on water flow rate at 40 cm-depth. According to the year and cropping system, cumulated herbicide losses ranged from 2% under MT_CC in 2005 to more than 30% under CT_BS in 2006. Results showed that best agricultural practices, such as conservation tillage and cover crops during fallow period could be an efficient way to reduce herbicide losses at the field scale.
Keywords: conventional tillage, conservation tillage, cover crop, leaching, diketonitrile metabolite.

1 Introduction

Herbicides are among the most important nonpoint-source pollutants in Europe. The objectives fixed by the EU Water Framework Directive (Directive 2000/60/CE) to prevent and control groundwater pollution by herbicides involve a better assessment of environmental impacts of agricultural practices.

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Among these agricultural practices, reducing tillage intensity through the implementation of conservation practices is considered as a way to reach a more sustainable agriculture. Nonetheless the environmental impact of reduced tillage is not well-known because conservation techniques could induce strong changes in soil physicochemical properties and biological activity. In particular knowledge on the fate of applied pesticides under conservation tillage is scarce (Alletto *et al.* [1]). Implementation of conservation tillage generally induces both an increase in organic matter content at the soil surface and its gradual decrease with depth. This, in turn, leads to an increase of pesticide retention in the topsoil layer. Increasing retention of pesticides in the topsoil layer under conservation tillage decreases the availability of the pesticides for biological degradation and could thus lead to a higher persistence of pesticides in soils. Tillage effects on pesticides transport are also unclear. While, in most studies, runoff of pesticides is reduced under conservation tillage, leaching seems to be increased due to improved macropore connectivity (Isensee *et al.* [2]).

Another agricultural practice considered as a ‘best management practice’ is the introduction of cover crops during the fallow period (Ritters *et al.* [3]). Cover crops are grown specifically to protect the soil against erosion (Malik *et al.* [4]), reduce nitrate leaching (Justes *et al.* [5]), improve soil structure, enhance soil fertility and to control weeds, pests and pathogens (Swanton *et al.* [6]). Cover crops generally increase soil biological activity and organic matter content (Reeves [7]), what could thus influence herbicide retention, degradation and transport (Alletto *et al.* [1]). However, very little has been published on the effects of cover crops on pesticide transport in soils.

The main objectives of this 4-year study were (a) to evaluate the leaching potential of the herbicide isoxaflutole and its diketonitrile metabolite to groundwater during maize crop production and (b) to assess the effects of agricultural practices on the behaviour of this herbicide.

2 Materials and methods

2.1 Location, climate and soil

The experiment was conducted on a 15-ha agricultural field situated in the large alluvial corridor of the Garonne River, France. The soil was a Gleyic Luvisol (ISSS-ISRIC-FAO [8]). With low organic carbon contents and high silt contents, these soils are strongly sensitive to crusting. The slope of the field was low (< 1%) and water transport was mainly done by drainage. The field was in continuous maize (*Zea mays*) production irrigated with a centre pivot sprinkler.

2.2 Agronomy

Since 2000, the tillage systems consisted of a conventional tillage (CT) and a conservation tillage, called mulch till (MT) that leaves ≥ 30% of the soil surface covered with crop residues after planting. Moreover, since 2004, during the fallow seasons, each tillage plot was divided into two subplots. The subplots were maintained bare (BS) or were sown with cover crops (CC).

The herbicide, isoxaflutole (5-cyclopropyl-1,2-oxazol-4-yl-α,α,α-trifluoro-2-mesyl-*p*-tolyl ketone) at 75 g L^{-1} + aclonifen (2-chloro-6-nitro-3-phenoxybenzenamine) at 500 g L^{-1}, was sprayed 1 day after sowing in 2006 and 2007 and 3 days after sowing in 2005 and 2008.

2.3 Sampling

Soil. Each year, distribution and recovery of herbicide residues were determined from soil core analysis. Fractions of the soil profile were sampled to a depth of 80 cm before herbicide application and at several days after treatment (DAT). For each plot, sampling time and depth, ten soil samples were collected. These data were used to calculate half-lives ($t_{1/2}$) and migration depth under the different cropping systems.

Water. Distributed drainage through the topsoil horizon was measured using fibreglass wick lysimeters (two replicates per plot) installed at 40 cm-depth. Soil water samples were collected during the 4 years of experiment. The interval length between two sampling dates was adapted according to the amount and intensity of rainfall.

2.4 Herbicide analyses

Extracts from soil and water samples were analysed using a HPLC-MS-MS triple quadrupole (Thermo Electron Corp., Courtaboeuf, France) equipped with an electrospray ionisation source (ESI) operating in the negative or positive mode. The mobile phases for the HPLC analysis were: A, 90/10 and B, 10/90 (v/v) formic acid in water (0.1%)/methanol. Analyses were performed with a Hypersil Gold C18 from Thermo Electron Corp. (100 x 2.1 mm ID, 3.0 µm particle size). The characteristic ions used for analysis were m/z = 360 ($[MH]^+$), 251, and 85.5 for isoxaflutole and m/z = 358 ($[MH]^-$), 278, and 79 for diketonitrile. Quantification of DKN and BA was achieved using external standard calibrations.

2.5 Calculations and statistical analyses

Dissipation half-lives ($t_{1/2}$) of IFT were determined using a first-order dissipation model, $C_t = C_0 e^{-kt}$ where C_t is the measured soil concentration in IFT at time t, C_0 is the initial concentration measured immediately after herbicide application, and k is the first order rate constant. The time at which the concentration reaches half the initial concentration is referred to as the half-life ($t_{1/2} = \ln 2/k$).

Herbicide mass leached was calculated from herbicide concentrations in water and corresponding percolate volume. These data were used to calculate percentage loss of herbicides of each cropping system.

An analysis of variance (ANOVA) was performed on drainage volumes and herbicides loss collected in the lysimeters to reveal the effects of tillage treatment, fallow period management and the interactions between these two factors. The threshold of significance for the statistical test was 0.01.

3 Results

3.1 Persistence of isoxaflutole

In 2005, dissipation data were well described using a first order kinetic ($r^2 > 0.95$). Whatever the cropping system, isoxaflutole degradation was fast (≤ 1 day) (Table 1), and 7 DAT, IFT was not detected in soil samples. The amplitude of variation of IFT concentration at each sampling date was related to a spatial variability of spraying and of soil degradation capacities within each cropping system.

Table 1: Dissipation half-life $t_{(1/2)}$ of isoxaflutole under conventional (CT) and conservation (MT) tillage with (CC) or without (BS) cover crop during the fallow period during the four year of experiment.

	Dissipation half-life ($t_{1/2}$) in days (in hours)			
	2005	2006	2007	2008
CT_BS	0.9 (22)	1.7 (42)	1.8 (43)	1.9 (46)
CT_CC	0.9 (23)	1.6 (38)	2.1 (50)	2.1 (50)
MT_BS	0.5 (11)	1.3 (32)	1.5 (36)	1.4 (34)
MT_CC	1.0 (24)	2.1 (50)	1.6 (38)	1.5 (36)

In 2006, 2007 and 2008, IFT half-lives were slightly higher than in 2005 and ranged from 32 to 50 h. In 2006, 28 DAT, IFT was still detected in some surface soil samples (0-5 cm-depth), while for the other years, 15 DAT, IFT was not detected in soil samples.

Whatever the year, no difference in half-lives among the four cropping systems was found.

3.2 Drainage and herbicide leaching

2005. From 25 DAT water samples were collected under the cropping systems with volumes ranging from 30 to 75 mL. At the end of June, significant differences between the tillage systems were identified with water volumes collected 51 DAT under MT 35 times lower than under CT. For the other sampling dates, this difference was less important but still identified. Finally, at the end of the growing season 2005, cumulated water drainage was two times lower under conservation than under conventional tillage (with ≈ 7 L under MT plots and 14 L under CT plots) and no effect of the fallow period management was found.

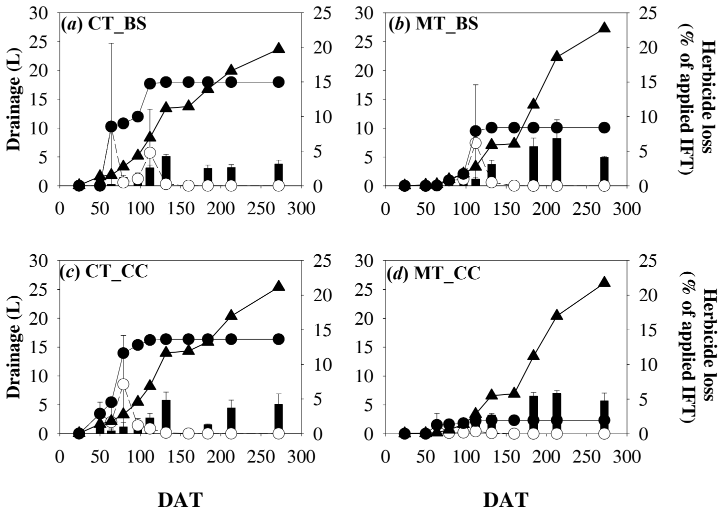

Figure 1: Leachate volumes and DKN concentration under the different cropping systems in 2005 (in days after treatment, DAT). Vertical bars are leachate volumes (L), black triangle (▲) are cumulative leachate volumes (L), open circles (○) are DKN concentrations expressed as % of applied IFT and black circles (●) are cumulated loss of herbicide.

Isoxaflutole has not been detected in water samples. Diketonitrile started to be quantified 50 DAT under CT_CC (1.3 µg L^{-1}). A maximum loss of 8.5 ± 12.0% of applied IFT was measured 65 DAT under CT_BS (32 µg L^{-1}) (Fig. 1). Under CT_CC, the concentration peak was measured later, 80 DAT (3.4 µg L^{-1}). From 160 DAT, herbicide was not detected in water samples. Cumulated losses of herbicide reached 14.3 ± 12.3% of applied dose under CT. Under MT, 8.4 ± 9.1% of applied dose were found in water samples in the plot without cover crop while 1.9 ± 2.1% were found in the plot with cover crop. However, difference between the cropping systems was not significant in 2005.

2006. The first water samples were collected 20 DAT and ranged from 230 to 580 mL under CT and from 430 and 960 mL under MT with significant effects of tillage system and of the interaction 'tillage x fallow management' at this date. During the other sampling dates, no difference was found between the tillage treatments and water volumes were higher than those collected in 2005 for a similar period. A significant effect of the presence of a cover crop on water drainage was found from 78 DAT with lower volumes collected under the plots with a cover crop (Fig. 2). At the end of the maize growing season 2006, cumulated water volumes reached 27 ± 3, 19 ± 0.5, 28 ± 2, and 17 ± 3 L under CT_BS, CT_CC, MT_BS and MT_CC respectively. Water drainage was thus reduced by approximately a factor 1.5 under cover cropped plots.

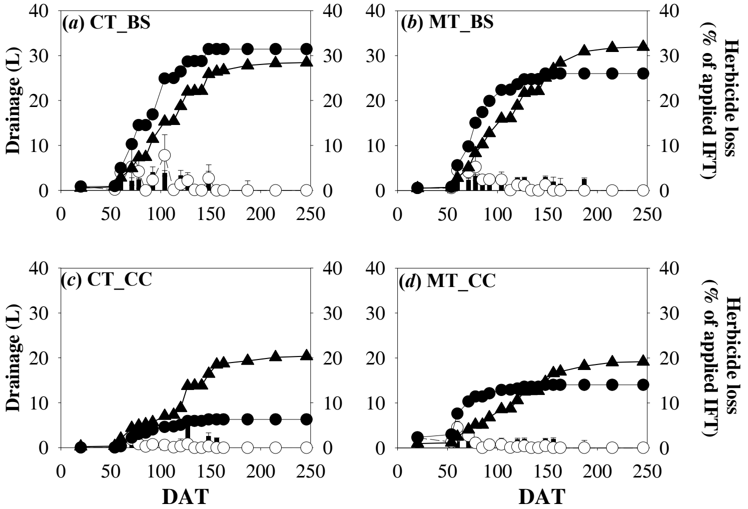

Figure 2: Leachate volumes and DKN concentration under the different cropping systems in 2006 (in days after treatment, DAT). Vertical bars are leachate volumes (L), black triangle (▲) are cumulative leachate volumes (L), open circles (○) are DKN concentrations expressed as % of applied IFT and black circles (●) are cumulated loss of herbicide.

Isoxaflutole was detected in water samples until 92 DAT in all the cropping systems, with a maximum concentration of 0.14 μg L^{-1} under MT_BS 60 DAT. Cumulative losses of applied herbicide in IFT molecular form were however low and reached 0.7 ± 0.05% under CT_BS, 0.1 ± 0.1% under CT_CC, 0.8 ± 0.4% under MT_BS and 0.4 ± 0.1% under MT_CC. Diketonitrile started to be quantified 20 DAT under the different cropping systems. Under CT_BS, two concentration peaks were quantified 71 and 104 DAT and represented 5.2 ± 4.0 and 7.8 ± 4.6% of applied herbicide respectively. Under CT_CC, only one peak was observed representing 1.8 ± 0.0% of applied herbicide 71 DAT. Under MT, the greatest losses were measured between 60 and 78 DAT. After 246 DAT, cumulated losses of herbicide reached 31.5 ± 15.1% under CT_BS, 26.0 ± 6.9% under MT_BS, 14.0 ± 13.0% under MT_CC and 6.3 ± 2.0% under CT_CC of applied herbicide. From 71 DAT until the end of the following, herbicide losses were significantly lower under the cover cropped plots.

2007. From the first sampling date (4 DAT), tillage treatment had a significant effect on water drainage with the lower volumes collected under MT (1.2 ± 0.3 L under CT_BS, 1.4 ± 0.3 L under CT_CC, 0.7 ± 0.1 L under MT_BS, 0.9 ± 0.0 L under MT_CC). This effect was identified during the entire growing season and led, at the end of the growing season to cumulated water drainage of 18.2 ± 1.7 L under CT_BS, 19.8 ± 0.6 L under CT_CC, 14.1 ± 1.0 L under MT_BS and 13.9 ± 0.3 L under MT_CC.

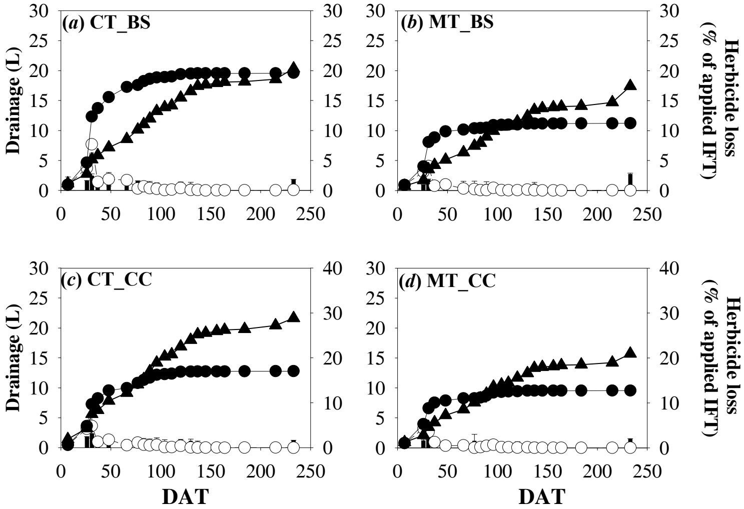

Figure 3: Leachate volumes and DKN concentration under the different cropping systems in 2007 (in days after treatment, DAT). Vertical bars are leachate volumes (L), black triangle (▲) are cumulative leachate volumes (L), open circles (○) are DKN concentrations expressed as % of applied IFT and black circles (●) are cumulated loss of herbicide.

Isoxaflutole was detected in water samples until 77 DAT but the cumulative loss in this molecular form did not exceed 1% of applied herbicide. Diketonitrile started to be quantified 6 DAT under the different cropping systems (Fig. 3). Whatever the cropping system, a concentration peak of DKN was detected 30 DAT. At this sampling date, herbicide losses reached 7.7 ± 0.2% of applied dose under CT_BS, 4.9 ± 2.7% under CT_CC, 4.0 ± 0.0% under MT_BS and 4.2 ± 1.8% under MT_CC. Herbicide was still detected in some water samples 232 DAT but losses were lower than 0.1% of applied dose. At the end of 2007, cumulative losses of herbicide reached 20.0 ± 2.4% of applied dose under CT_BS, 17.9 ± 2.0% under CT_CC, 11.5 ± 1.4% under MT_BS and 12.7 ± 2.6% under MT_CC. A significant effect of soil tillage was found from 65 DAT with higher losses under CT than under MT.

2008. From the first water sampling date (37 DAS), water volumes collected from the lysimeters were significantly lower under the plots with cover crop (Fig. 4). This effect was identified until 82 DAS, and at this date, cumulated water volumes reached 4.4 ± 0.4 L, 3.2 ± 0.1 L, 3.7 ± 0.4 L and 2.8 ± 0.2 L under CT_BS, CT_CC, MT_BS and MT_CC respectively. After 115 DAS, tillage treatment had a significant effect on drainage with lower volumes collected under MT. This effect was identified until this end of the sampling period.

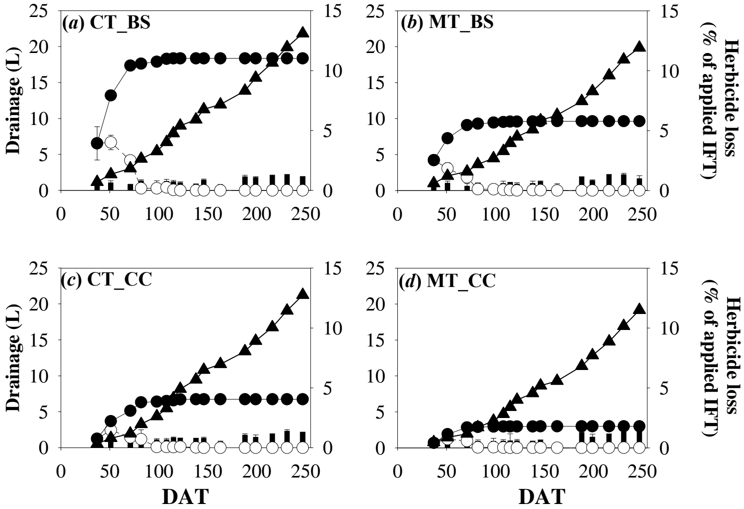

Figure 4: Leachate volumes and DKN concentration under the different cropping systems in 2008 (in days after treatment, DAT). Vertical bars are leachate volumes (L), black triangle (▲) are cumulative leachate volumes (L), open circles (○) are DKN concentrations expressed as % of applied IFT and black circles (●) are cumulated loss of herbicide.

Both IFT and DKN were quantified in water samples from the first sampling date (34 DAT). Cumulative losses of herbicide 71 DAT represented 10.6 ± 2.0% of applied dose under CT_BS, 3.8 ± 0.3% under CT_CC, 5.5 ± 0.6% under MT_BS, 1.7 ± 0.6% under MT_CC with significant effects of tillage and fallow period management (Table 7). These differences were identified until the end of the sampling period and 244 DAT, losses of herbicide represented 11.0 ± 2.0% under CT_BS, 4.0 ± 0.3% under CT_CC, 5.8 ± 0.6% under MT_BS, 1.8 ± 0.6% under MT_CC.

4 Discussion and conclusion

From this four-year experiment under continuous maize cropping, using cover crop during the fallow period and reducing tillage intensity were found to be efficient to reduce water drainage and herbicide leaching. Whatever the year and the cropping system, isoxaflutole had a rapid degradation and a very limited migration in soil. Its metabolite had a more important mobility and was detected in soil solution. Difference in diketonitrile leaching under conservation tillage plots or cover cropped plots could be explained by a lower drainage and faster degradation than under conventional tillage or bare soil plots (Alletto *et al.* [9]). Higher drainage under conventional tillage was explained by a greater infiltration capacity due to more intensive tillage operations (Alletto *et al.* [10]). According to these results, innovative agricultural practices were efficient for maintaining environmental quality and protecting groundwater from pesticides pollution.

References

[1] Alletto L., Coquet Y., Benoit P., Heddadj D. & Barriuso E., Tillage management effects on pesticide fate in soils. A review. *Agronomy for Sustainable Development*, **30**, pp367-400, 2010a.

[2] Isensee A.R., Nash R.G. & Helling C.S., Effect of conventional vs. no-tillage on pesticide leaching to shallow groundwater. *Journal of Environmental Quality,* **19**, pp434-440, 1990.

[3] Ritter W.F., Scarborough R.W. & Chirnside A.E.M., Winter cover crops as a best management practice for reducing nitrogen leaching. *Journal of Contaminant Hydrology*, **34**, pp1-15, 1998.

[4] Malik R.K., Green T.H., Brown G.F. & Mays D., Use of cover crops in short rotation hardwood plantations to control erosion. *Biomass Bioenergy,* **18**, pp479-487, 2000.

[5] Justes E., Mary B. & Nicolardot B., Comparing the effectiveness of radish cover crop, oilseed rape volunteers and oilseed rape residues incorporation for reducing nitrate leaching. *Nutrient Cycling in Agroecosystems*, **55**(3), pp207-220, 1999.

[6] Swanton C.J., Shrestha A., Roy R.C., Ball-Coelho B.R. & Knezevic S.Z. Effect of tillage systems, N, and cover crop on the composition of weed flora. *Weed Science,* **47**, pp454-461, 1999.

[7] Reeves D.W. Cover crops and rotations. In: Advances in soil science: Crops residue management, (Hatfield JL, Stewart BA, eds). Boca Raton, FL:Lewis.1994.

[8] ISSS-ISRIC-FAO. World Reference Base for Soil Resources. ISSN 0532-0488, O.C. Spaargaren - Wageningen/Rome ed.,1998.

[9] Alletto L., Benoit P., Bergheaud V. & Coquet Y., Temperature and water pressure head effects on the degradation of the diketonitrile metabolite of isoxaflutole in a loamy soil under two tillage systems. *Environmental Pollution*, **156**, pp678-688, 2008.

[10] Alletto L., Coquet Y. & Roger-Estrade J., Two-dimensional spatial variation of soil physical properties in two tillage systems. *Soil Use and Management*, **26**, pp432-444, 2010b.