This paper was peer-reviewed for scientific content.
Pages 300-304. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Influence of Cultural Practices on Sheetflow, Sediment and Pesticide Transport: The Case of Corn Cultivation Under Plastic Mulching

C. Gascuel-Odoux, F. Garnier and D. Heddadj*

ABSTRACT

Corn cropping represents only 25% of the arable land in the western part of France while high concentrations of corn herbicides are frequently observed in the rivers of this region. The highest concentrations are found shortly after application. Following these observations a comparative assessment of environmental impacts of different practices for weed control with corn cultivation was performed, taking into account sheetflow, sediment and herbicide transport. This study focuses on the effects of plastic mulching for corn cultivation that concerns about 10% of the corn cultivation in this region. Field measurements were performed under natural rainfall on two slope positions (eight rainfall events generating runoff), and then under simulated rainfall (4 meter long plots, 3 successive rainfalls), by using collectors intercepting runoff separately from plastic bands and soil bands. Under natural rainfall, runoff is low on plastic bands and high on the soil bands, with strong variability from band to band and high erosion. The herbicide outflow was roughly equal with plastic mulching than without it when herbicides were applied before plastic mulching. It was much higher when herbicides were applied after plastic mulching, due to a quick washing out of herbicides by the first rainfalls.

INTRODUCTION

Water contamination by corn herbicides is frequently observed in France, particularly in the western part of France (Brittany) where the corn cropping represents 25% of the arable land, 70% of corn being used for silage. Atrazine, an herbicide mainly used for corn cultivation is commonly detected in stream water. Weekly samples of five rivers in western France showed that 93% and 81% of samples between 1990 and 2000 atrazine is respectively, detected and showed concentrations exceeding 0.1 $\mu g\ L^{-1}$ (European standard for drinking water). The highest concentrations, up to a few tenths of a $\mu g\ L^{-1}$, were found shortly after application. A comparative assessment of environmental impacts of different practices for weed control used for corn cropping is necessary. Three weed control practices were evaluated: i) the traditional whole chemical weed control, with or without tillage using bandwise mulch planting or bandwise decompacting; ii) the combined strategy, combining a chemical application on 20 cm wide bands in the vicinity of the corn plants row and a mechanical weed control between these bands; iii) and plastic mulching where herbicides were applied before or after plastic mulching. While the first two practices have been analyzed in many case studies (Baker and Laflen, 1983; Barrioso et al., 1991; Felsot et al., 1990; Wauchope, 1987), the effects of plastic mulching for corn cropping on runoff, sediment and herbicide transport have been only studied in a few case studies (Clark and Smajstrla, 1998; Delahaye, 1992). The study is important as herbicides might be incorporated in plastic composition in future. The present study focuses on impacts of plasticulture with corn cropping under different conditions of herbicide application.

Plasticulture for corn began in France in 1970, but has really developed since 1985. Now the proportion of plasticulture is estimated to 2% and 10% of corn for silage, (i.e. about 70,000 and 25,000 ha) in France and Brittany, respectively. The proportion varies highly from year to year according to the stores of the fodder in farms. Plasticulture ensures a minimum crop yield in areas where constraints of temperature could occur.

In corn plasticulture, field is tilled and shaped into bed rows. Impermeable and photo-labile plastic film bands cover all the crop rows and one inter row out of two. Two crop rows are located at each side of the plastic band. Seeds are regularly sown through slots in the plastic film. Soil inter rows differ from one another. One out of two soil inter rows is deeper and smoother due to the central wheel of the machine using for sowing and plastic mulching. Beds are often designed and laid out following the steepest slope, so that runoff and erosion were frequently observed in the first weeks of cultivation during high intensity rainfall events. Plastic breaks up progressively after 6 to 8 weeks. Herbicides are applied commonly before plastic mulching, but sometimes also after plastic mulching.

The aim of the present study is to identify the main factors that control flow and sediment transport in corn field and to provide first elements for predicting herbicides transport. The case study is a field with a low aggregate stability especially susceptible to runoff and erosion like many others in this northwestern part of Europe.

MATERIALS AND METHODS

The field study was located near Rennes, in northwestern of France and was extensively described in Heddadj and Gascuel-Odoux (1999). The soils are loamy textured (70 %

*C. Gascuel-Odoux, F. Garnier and D. Heddadj, INRA, Unité de Sciences du Sol et d'Agronomie de Rennes-Quimper, 65, Route de Saint-Brieuc, 35042 Rennes Cedex, France. *Corresponding author: chantal.gascuel@roazhon.inra.fr.

silt) (Distric and Aquic Eutrochrepts) and well drained. Organic matter is low (1.8%). The slopes are gentle. A mid-slope section approximately 200 m long sloping at 4.5%is gradually changing to 1.5% in the last 50 meters, resulting in a concave downslope section. Corn was planted at the beginning of May. Sowing direction corresponded to the main slope direction. One part of the field was cultivated using plasticulture. The remainder was cultivated conventionally and was considered as the reference. Two approaches were used to quantify the effect of plasticulture on surface flow.

The first method consisted in a field monitoring of water and sediment transport under natural rainfall events. A network of sixteen unbounded, non-overlapping plots with simple collectors that allow easy runoff and sediment transport measurements was used. Each collector intercepted overland flow from crop interrows. Detailed descriptions of the runoff collection procedure were given by Gascuel-Odoux et al. (1996). Each collector was connected to a 60 L container. When over-spilling, water volume (under-estimated) and concentrations (over-estimated) were not exactly known. On the sixteen collectors, eight were located at midslope, and eight at toeslope. For each topographic position, six collectors were located on plasticulture and two on reference: i) three collectors on plastic inter row; ii) three collectors on the plasticulture soil inter row out of which one was on the track of the central wheel of the plastic mulching machine; iii) two collectors on reference, one without traffic, the other trafficked by farm machinery. The six inter row on plasticulture on one hand and the two inter row on reference on the other hand were contiguous (Fig. 1). These plots were monitored for two months, in May and June 1997. The amount of water and sediment was measured after each rainfall event, while the amount of herbicides was measured

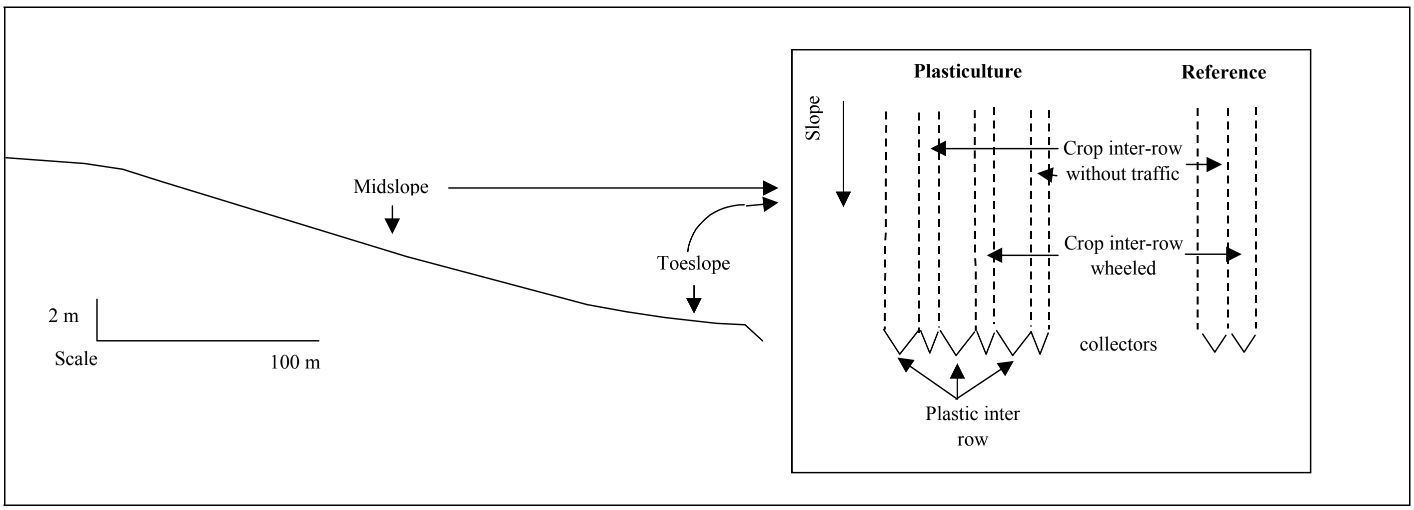

Figure 1. Field spatial sampling design under natural rainfall.

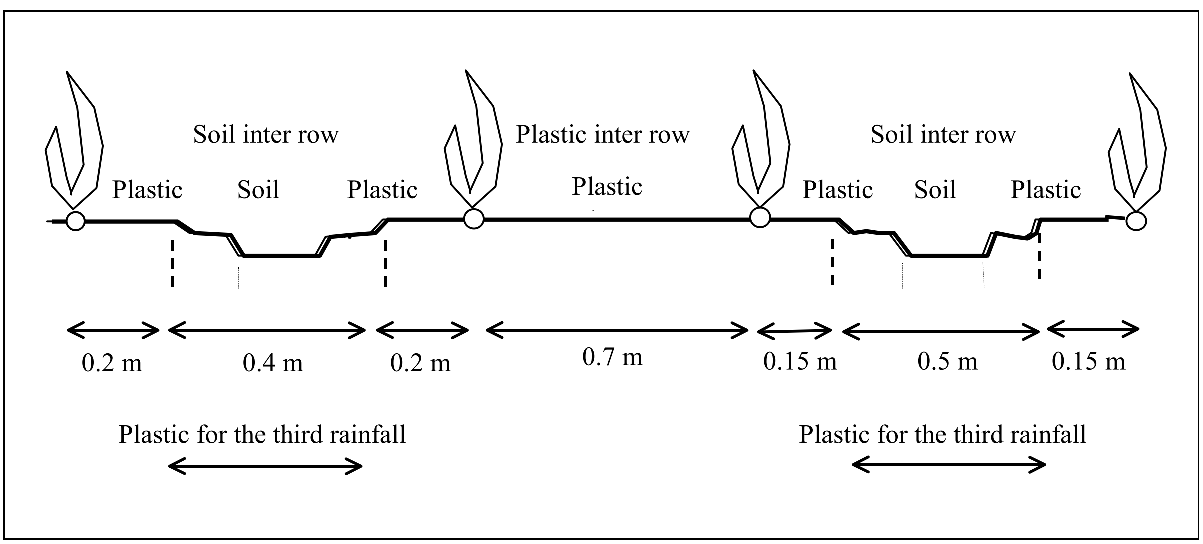

Figure 2. Experimental design under simulated rainfalls. For the first and the second rainfall the surface conditions are not modified. For the third rainfall, the entire soil surface is covered by plastic in order to quantify infiltration in slots and water flowing from the central inter row to the two adjacent ones.

only after three rainfall events. For this first approach, the herbicides were applied just before plastic mulching, as it is the most usual. An application of 1000 g ha^{-1} of atrazine (Half life of 60 days) was performed.

The second approach consisted of using a rainfall simulator. The rainfall simulator was a calibrated watering jet, placed 4 meters over the target surface. A motor imparts a motion to the jet, following a front and back sway with a frequency of 50 swings a minute. Three rainfalls of intensity of 30 mm h^{-1} for first one, 60 mm h^{-1} for the two following ones were applied with a duration of one hour for the first, thirty minutes for the two others. The return period of such rainfall is about 10 years in this part of France. Drainage period was of one hour between the first, the second, and the third simulation. The simulation plot was 4 m long. Three contiguous inter rows in plasticulture were studied, one with plastic at the middle, the two others adjacent and with soil. For the third rainfall simulation, a plastic film was applied on the two soil inter rows and fixed with a rubber band in order to cover all the soil surface and to allow soil infiltration only to slots perforated for sowing. This third rainfall simulation was realized to calculate the water balance of the plastic inter row and distinguish the part of water that went away from the plastic inter row to the two adjacent inter rows from that infiltrated in the slots perforated for sowing (Fig. 2). For this second approach, the herbicides were applied after plastic mulching. An application of 450 g ha^{-1} of Bromoxynil (Half life of 7 days) was performed as it is also frequently used by farmers. The rainfall simulation was realized 3 days after the herbicide application. This second approach quantifies the effect of plasticulture under serious conditions in terms of rainfall and cultivation practices involving water contamination.

RESULTS

Under natural rainfall

A total of eight rainfall events with a rainfall amount and a rainfall intensity for each higher than 7 mm and 20 mm/h respectively generated runoff (Fig. 3). Results were similar on midslope and toeslope and only illustrated here by midslope results. In plasticulture, the highest and the most frequent runoff was observed on the soil inter row with the wheel track. There was quite always overspilling of this collector. On the soil inter row without the wheel track, runoff was highly variable from rain to rain and from one inter row to another. On plastic inter row, runoff was always low. For the highest rainfall intensity, low runoff may result from lateral water outflow from plastic band to adjacent soil inter rows. When the flow depth on plastic increased and exceeded a threshold, the water running on plastic film is partly diverted according to the local topography as described by Delahaye (1992). The comparison with the reference shows that runoff was higher on the inter row under wheeling with plasticulture than on the reference under wheeling, itself higher than on the reference without wheeling.

The same trends were observed for erosion. It was very high on plasticulture, particularly on the soil inter row with wheeling. For moderate rainfall intensity, erosion occurred only on the soil inter row with wheeling whereas it was on all the inter rows for the highest rainfall intensities. The erosion computed on the eight rainfall events was four times higher on plasticulture than on the reference.

Herbicide outflow was low on plastic inter row due to low runoff. For the soil inter rows on plasticulture, two stages can be distinguished. For the first rainfall event, herbicide outflow was higher on soil inter row on plasticulture than on reference whereas it was the opposite for the following rainfall events. For the following rainfalls, the highest runoff and erosion on the soil inter rows on plasticulture correspond to the lowest herbicide concentrations because plastic and soil areas were quickly and highly washed out by the first runoff. Finally, when herbicides were applied before plastic mulching, the total amount of herbicide computed on the three rainfall events was not significantly different in plasticulture (1%) compared to the reference (1.5%).

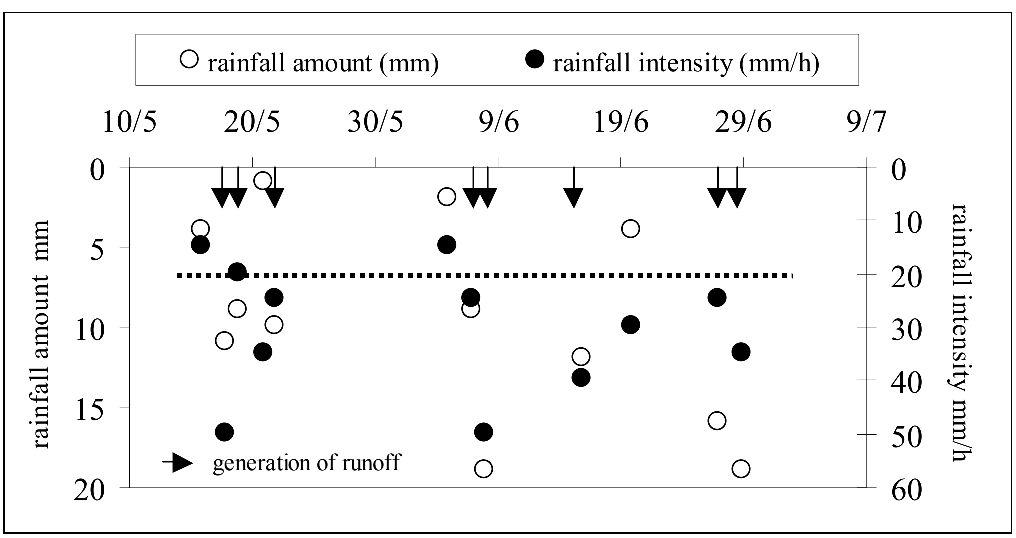

Figure 3. Characteristics of the rainfall events during the study period. The dotted line is the limit from which runoff is generated.

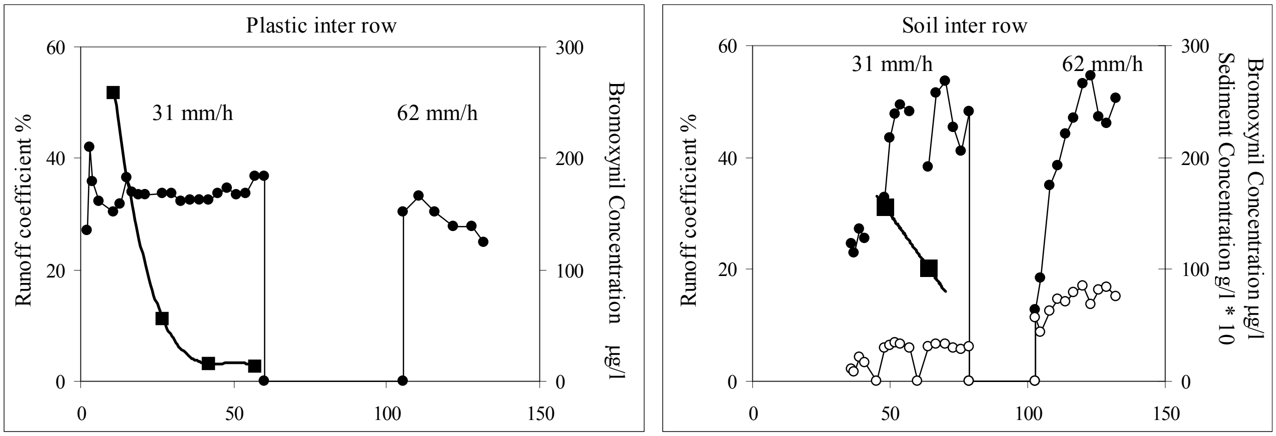

Figure 4. Runoff, erosion and herbicides outflow for the runoff events.

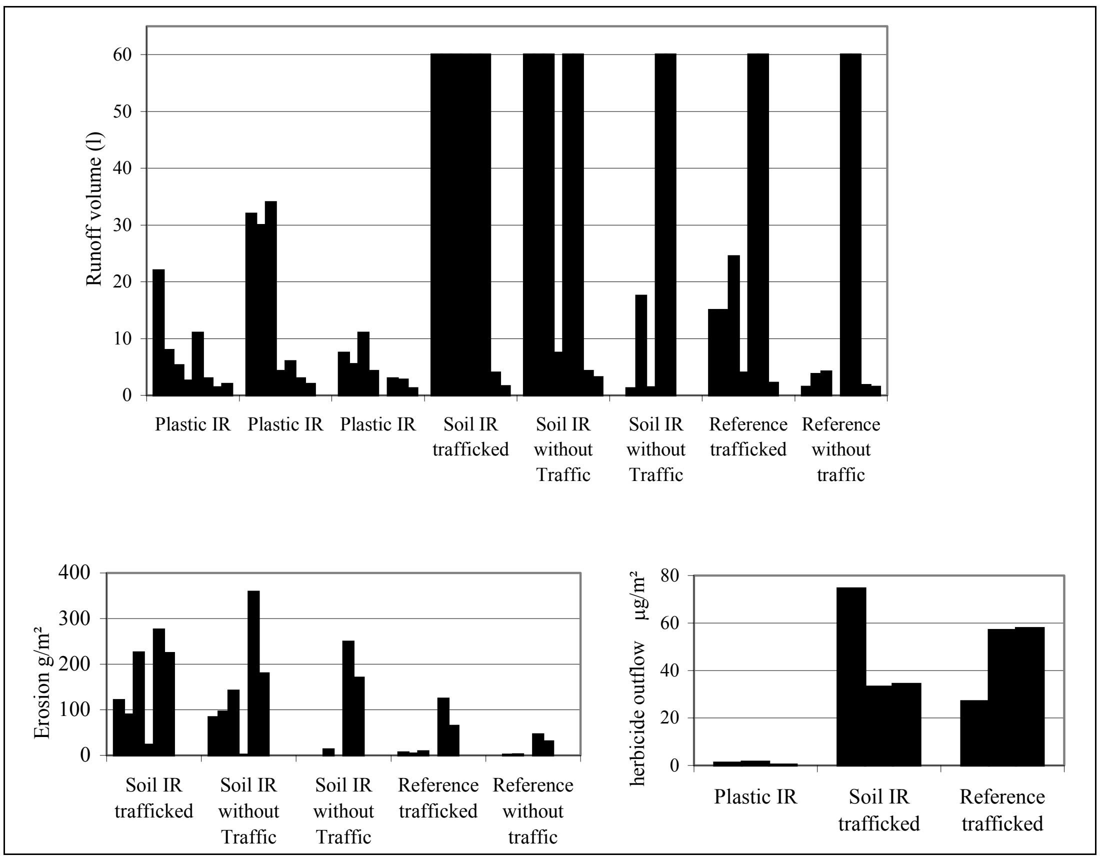

Figure 5. Runoff(●), sediment (❍) and herbicide concentration (■) for the two successive simulated rainfall events.

The temporal variations of the concentration slightly differed, with higher concentrations in the first rainfall events on plasticulture than on the reference.

Under simulated rainfall

An important part of water ran on the plastic inter row, i.e. about 30% of the input on this inter row. This ratio is important compared to the field observations. Seventy percent of water is so assumed to infiltrate in soil by slots perforated for sowing or to flow away to the two adjacent soil inter rows. Runoff on the soil inter row was highly variable: it was nil on one soil inter row whereas it corresponded to 50% of the input on the other one. The runoff coefficient was roughly the same from one rain to the following one, both on the plastic and the soil inter row, whereas rainfall intensity was twice higher.

The third rainfall simulation with plastic film on the two soil inter rows allowed to calculate the water balance of a plastic inter row. This experiment showed that one third of water flow down slope on plastic, one third flows laterally and preferentially to an adjacent soil inter row according to the local topography, and the remaining infiltrated into soil though slots where corn was planted.

Sediment concentration varied from 3 to 7g L^{-1} from first rain to the second one, due to a two-times higher runoff, but it was much lower than at the field scale. Bromoxynil concentrations were higher at the beginning than at the end of the rainfall simulation. It decreased more abruptly on plastic inter row than on soil inter row.

DISCUSSION AND CONCLUSION

The experiment under simulated rainfalls allowed the identification of the dominant processes controlling runoff at local scale. Three main processes were showed. First, water on the plastic inter row flows preferentially to one the two adjacent inter rows according to small and local variations of the topography. Second, an important part of water infiltrated within slots where corn was planted. We can assume that this local process is also effective at the field scale, but depends on the flow on plastic and, consequently, on the rainfall characteristics. Third, we observed a high and quick washing out of the herbicides on plastic if they were applied after plastic mulching.

The experiment under natural rainfalls allowed the identification of the dominant processes at the field scale. The sediment and herbicides outflow were under estimated due to frequent overspillings of collectors. Two processes were described. First the preferential flow from the plastic inter row to one of the two contiguous inter rows was higher at the field scale than at local scale. It would show that topographic effects are higher at the field scale than at the local scale. As the flow depth on plastic inter row exceeds a threshold, that depends on the slope length, some water flows laterally to the adjacent soil inter rows, and preferentially to one of them as function of the local topography. Second the central wheel traffic, where the inter row was deep and smooth and only tested at field scale, has a major effect. It induces a high runoff in the soil inter row that partly explains the high sediment concentration in the soil inter row at the field scale. These two effects induced concentrated erosion in some soil inter rows. They explain the high erosion rate observed in the study field, and more generally observed in corn cultivated with plastic mulching.

The herbicide outflow depended on the duration time between the herbicide application and the first runoff. When chemicals were applied before plastic mulching, despite higher runoff and erosion, the herbicide outflow was not very different between plasticulture (1%) and reference (1.5%) in the study case because the contributing area of the herbicide outflow is quite different. As it is bounded to soil surface of the field with plasticulture, i.e. two third of the field surface, it corresponds to all the surface of the field in reference. The herbicide concentrations were high both on plasticulture and on reference, ranging from 30 to 170 mg L^{-1}, due to high runoff and erosion, but slightly higher on plasticulture than on reference for the first rain. We cannot conclude in the same way when herbicides were applied after plastic mulching. Despite local data that do not allow any extrapolation at the field scale, we showed that the herbicide of the plastic inter row were quickly washed out both to soil inter rows and slots when herbicides were applied after plastic mulching. The herbicide concentrations in water flowing on the soil inter row with plasticulture was very high in the first rainfall, clearly much higher in this case than in the previous one. A high amount of herbicide was quickly washed out of plastic to the soil inter row and added to the quantity properly due to the soil inter row. High infiltration of very contaminated water through slots, i.e. a small area of a few square centimeters, might also induce the contamination of plants or ground water due to preferential flow in these little areas. These aspects were studied in detail in Clark and Smajstrla (1998).

Finally, plasticulture for corn cultivation would not be recommended due to the high risk of water contamination when herbicides are applied after plastic mulching particularly. At the opposite, herbicide application before plastic mulching do not induce significant herbicide outflow compared to a reference. In any case, the main negative effect of corn cropping plasticulture remains erosion that is much higher with plastic mulching than in reference. These research findings must contribute to limit the extension of such agricultural practices in sloping areas particularly.

REFERENCES

Baker, J.L., and J.M. Laflen. 1983. Water quality consequences of conservation tillage. J. Env. Qual. 8:602-607.

Barrioso, E., R. Calvet and B. Cure. 1991. Incidence de la simplification du travail du sol sur le comportement des produits phytosanitaires: conséquences sur les risques de pollution. p. 105-124. *In:* G. Monnier, G. Thevenet and B. Lesaffre (eds.) Simplification du travail du sol. INRA Editions.

Clark, G.A. and A.G. Smajstrla. 1998. Design considerations for vegetable crop drip- irrigation systems. Seminar Proceedings, Vegetable Production Using Plasticulture. ASHS. 10-15.

Delahaye, D. 1992. Approches spatialisées et analyses expérimentales des phénomènes de ruissellement et d'érosion des sols. Ph.D. diss. Caen Univ., France.

Felsot, A.S., J.K. Mitchell and A.L. Kenimer. 1990. Assessment of management practices for reducing pesticide runoff from sloping cropland in Illinois. J. Env. Qual. 19:539-545.

Gascuel-Odoux, C., S. Cros-Cayot and P. Durand. 1996. Spatial variation of sheet flow and sediment transport on an agricultural field. Earth Surf. and Landform Proc. 21:843-851.

Heddadj, D. and C. Gascuel-Odoux. 1999. Annual and topographic variations of hydraulic conductivity at the field scale. Europ. J. of Soil Sci.50:275-283.

Logan T.J., J.M. Davidson, J.L. Baker and M.R Overcash. Chelsea, MI, USA: Lewis Publ., 205-21.

Wauchope, R.D. 1987. Effects of conservation tillage on pesticide loss with water. In: Effects of conservation tillage on groundwater quality.