

**Distribution of imidacloprid residues in two sandy soils of portneuf (Quebec) under potatoes (*solanum tuberosum*) culture**

**ABSTRACT**

**Aims:**The goal of this work was to confirm the results of leaching and dissipation of the imidacloprid obtained with intact soil columns and draining lysimeters.

**Methodology:** A study on the distribution of imidacloprid (insecticide) residual deposit was carried out on two potatoes (*Solanum tuberosum*) farms of Portneuf (Quebec). Two farms (PNF47 and PNF51) were selected in the county of Portneuf located at 25 km in the west of the town of Quebec (Canada). The soil was sampled once before and four to five times after imidacloprid application. Imidacloprid residues analysis was performed using HPLC.

**Results:**The results obtained show that the average concentration of imidacloprid after application is lower or equal to the theoretically expected values. The imidacloprid was recovered in the soil 2 to 6 days after foliar application at rates varying between 23.2 to 23.6%. The heterogeneity of active ingredient distribution on the soil at application, differential dissipation of this one and foliar interception explain these results. The coefficients of variation of the concentrations observed in the layer 0 to 5 cm, 2 to 6 days after application vary from 76 to 96 %. The soil contamination after harvest is insignificant compared to the amount of imidacloprid applied. The vertical distribution profiles of the residual concentrations of imidacloprid after application show that, these vertical profiles of distribution vary from a sampling point to another. The residual concentrations in the deep layers of the soil are independent of the concentrations in the surface layers (absence of correlation).

**Key words:** imidacloprid, soil, potato, residues distribution.

**1. INTRODUCTION**

One of the principal problems in the field study of the leaching and dissipation of pesticides is the great variability of residual deposit at application and its dissipation with time [1]. This space variability of the residual concentrations results from the lack of uniformity in pesticides application, variability of soil properties and vegetable biomass [2, 3, 16]. The heterogeneity of distribution of the active ingredient in field can also result from errors of calibration of certain pulverizers used in potatoes farms of Portneuf, erroneous mixtures, variability of the advance speed of equipment and overlapping of application bands [4, 6].

Imidacloprid was sold and used for the first time in Canada in 1995 for the control of the Colorado potato beetle in the eastern of Canada. Nowadays, imidacloprid is an insecticide with active

ingredient used to control sucking insects, such as aphids, leafhoppers, psyllids, thrips, whiteflies and beetles in agricultural crops, to control white grubs in lawns and turfgrass, as well as to control domestic pests such as fleas and cockroaches [17]. The knowledge of the space variability of the residual concentrations of pesticides in farms is of particular interest for digital simulation models of deterministic type which use average values relating to a given surface as entry variables. Numeric models of simulation development require a combination of theoretical concepts and empirical data resulting from laboratory and field studies [3]. These empirical data; particularly those obtained from field reality are used for the confirmation of digital simulation models. The numerical and empirical approaches in the study of pesticides leaching and dissipation in the soil profile are thus complementary. The difficulties and the cost associated with pesticides residues analysis justified the development of digital simulation models which require data resulting from farming reality for their calibration and validation [7, 9]. All these reasons determined the choice of the empirical approach adopted in this study to evaluate leaching and time-space variability of the residual concentrations in the soil profile. The imidacloprid which is an insecticide widely adopted by farmers and having a high leaching potential according to the Gustafson index was retained as reference molecule.

This work followed upon the detection of pesticides residues (metribuzine, aldicarbe, carbofuran, atrazine and linuron) in wells located in the vicinity of potato farms in the counties of Portneuf and Lanaudière [10]. It contributes to elucidate the origin of this contamination (accidental discharge or leaching beyond the rhizosphere of treated farms) and confirm the results of leaching and dissipation of the imidacloprid obtained with intact soil columns and draining lysimeters. In fact, in a previous experimentation, undisturbed soil columns (65cm high X15 cm diameter) were used in a greenhouse experiment to study the effect of rainfall and mode of application on leaching of imidacloprid. These results showed that imidacloprid was leached in trace amount below 65 cm soil columns. Under field conditions, imidacloprid was detected in percolated water below 1m depth lysimeters at concentration less than 3µg/L [18]. In a specific way, the study aims to evaluate the homogeneity of the residual deposits after application; the vertical movement and dissipation of the imidacloprid; and the concentration variability in the soil profile from one point of the farming-field to another at various moments after application.

## 2. MATERIALS AND METHODS

### 2.1 Study farms description

Two farms (PNF47 and PNF51) were selected in the county of Portneuf located at 25 km in the west of the town of Quebec (Canada). The farming succession and cultivated varieties are described in the table 1. The various cropping operations and phytosanitary treatments were carried out by the farmers according to their usual practice, in order to be able to collect data reflecting as much as possible realities.

**Table 1. Description of farming succession, varieties and their yield in the two potatoes farms**

| Farm <sup>a)</sup> | Typical farming succession                      | Varieties      | Plantation | Average Yield <sup>c)</sup><br>(g ha <sup>-1</sup> ) |
|--------------------|-------------------------------------------------|----------------|------------|------------------------------------------------------|
| PNF47              | 2years.P <sup>b)</sup> /1 year oats<br>+mustard | Kennebec       | 21 may     | 9.1± 3.8                                             |
| PNF51              | 2years.P/2years cereals + hay                   | Superior ronde | 13 may     | 5.96 ± 1.4                                           |

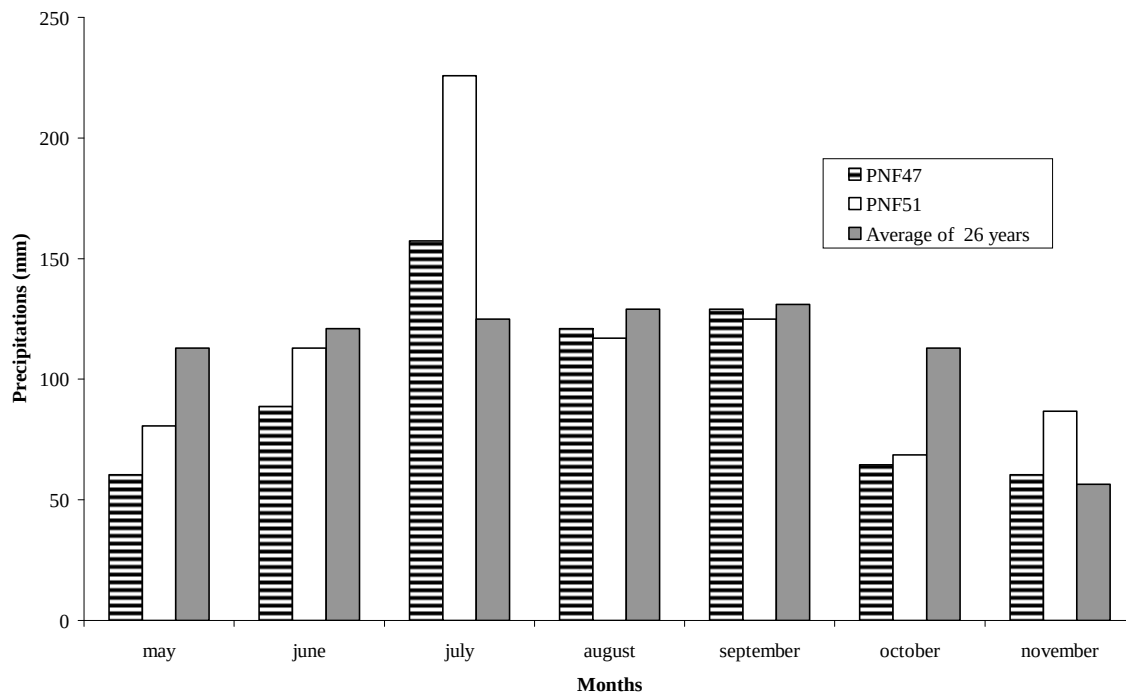
<sup>a)</sup>: the various farms belong to various producers

<sup>b)</sup>: P = potato

<sup>c)</sup>: average dry yield for three plots of 8 m<sup>2</sup> per farm.

## 2.2 Rainfall and soil properties

Figure 1 represents monthly precipitations of the two farms as well as the 26 years average for the May-November period. The monthly data of Rainfall (except for July with exceeding Rainfall) are comparable with the average monthly data over one 26 years period. In the Portneuf County, potato is cultivated on sandy soils. The soils of the two selected farms belong to the Morin series.



## 2.3 Pesticides choice and application

The imidacloprid was selected on the basis of its adoption by the farmers, its leaching potential and the need for knowledge on its behaviour in the sandy soils under potato culture of Quebec (table 2). The imidacloprid (Admires<sup>R</sup> 240 g a.i.l<sup>-1</sup>) in fluid paste form was applied in foliar

72 treatment at the rate of 48 g ha<sup>-1</sup> in the farms PNF47 and PNF51 respectively on July 6/17 and June  
73 30. The foliar application took place approximately one month after the potato lifting.

74 **Table 2. Physico-chemicals characteristics of Imidacloprid [15]**

| Physico-chemicals characteristics |                                                                                     |
|-----------------------------------|-------------------------------------------------------------------------------------|
| Commercial names                  | Admire®, Confidor®, Gaucho®, Premier®, remise®, provado®, Marathon®                 |
| Class                             | Insecticide                                                                         |
| Active ingredient                 | Imidacloprid<br>[1-(6-chloro-3-pyridimylmethyl)-Nnitroimidazolidine-2-ylideneamine] |
| Chemical family                   | Nicotine derivative                                                                 |
| Formulation                       | Fluid paste                                                                         |
| Application mode                  | Foliar pulverization                                                                |
| Solubility (mg/L)                 | 510-750                                                                             |
| Half-life in soil (days)          | 140-180                                                                             |
| K <sub>oc</sub>                   | 160-400                                                                             |
| GUS <sup>a)</sup>                 | High (H)                                                                            |

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76 <sup>a)</sup>: Gustafson Index of potential leaching = Log(half-life in soil) x (4-log(K<sub>oc</sub>))

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## 78 **2.4 Soils sampling**

79 The soil was sampled once before and four to five times after imidacloprid application.  
80 Twenty soil samples separated by distances of ten meters on the farms diagonal (surface of  
81 1 and 3 ha) were taken at different depth (0-100 cm). Rows sampling was retained to avoid  
82 the disturbances of soil in the between-rows because of cropping operations like weeding.  
83 The sampling points were marked with stakes at the time of the first passage after  
84 application. Subsequent samplings took place in a radius of 1 m either on the same row, or  
85 on an adjacent row. All the samples were preserved in a refrigerator containing ice during the  
86 sampling period and laboratory transport. In laboratory, the samples were then put drying at  
87 free air during 48 hours. After drying, the samples were filtered (sieve of 2 mm) and were preserved  
88 at - 20 °C in plastic bags until extraction taking place less than two months later. The extracts were  
89 preserved at - 20 °C until the analysis.

## 90 **2.5 Imidacloprid residues analysis**

91 The soil was dried by free air during 48 hours and extracted with acetonitril. A 10 g  
92 soil sample in a screwing stopper tube of 50 ml is extracted with 20 ml of acetonitril during 30  
93 minutes (160 rpm) in an automatic agitator (Standard Innova 2000). After sedimentation, 10  
94 ml of the supernatant are transferred in a dry tube and evaporated under nitrogen jet in a  
95 water bath at 70 °C. The residue was included in 1 ml of aqueous solution of sulfonic acid 1-  
96 pentane 5 mM at pH 2.2, followed agitation and filtration to the syringe with filters Nylon  
97 Acrodisc® 13 (0.45 µm certified HPCL) before injection in HPCL (High Performance Liquid

Chromatography). The chromatographic apparatus (HPCL) used for proportioning is of type WATERS™.

This apparatus includes a system of control Millennium 2010; a pump WATERS™ 600 MS; an automatic sampler WATERS™ 717, and one sweeping detector of wavelength (PDA) WATERS™ 996. The software Millennium 2010 allows carrying out the spectral analysis and peaks integration. A Spherisorb column ODS C-18 (4.6 mm X 250 mm, 25 µm) was used for the separation of the imidacloprid using a gradient of elution obtained from an aqueous solution (5 mM) of sulphonic acid 1-pentane at pH 2.2 (SAP) and tetrahydrofurane (THF) as solvent of the mobile phase.

### 3. RESULTS AND DISCUSSION

The data obtained show that, in farm PNF47, imidacloprid was recovered until the layer 20-35 cm 6days, 12days and 23 days after application while 113 days after application imidacloprid was only recovered until the layer 5-20cm (table 3). In farm PNF51, imidacloprid was detected in the layer 80-100 cm, 120 days after application. In the same farm, the pesticide was detected in the layer 65-80 cm 10 and 27 days after application (table 4).

The observations done in different soil layers of farms as a function of sampling position and time after application showed that that the vertical profile of residues distribution varied from one point to another in the farm diagonal at various sampling moments after application (figures 2 and 3). For example in the farm PNF47, 12 days after application of imidacloprid, in the layer 0-5 cm, we have about 10 ppb of imidacloprid in the position 1, about 20 ppb in the position 2, about 12 ppb in the position 6 and 10 and 5 ppb in the position 19 (figures 2 and 3).

**Table 3. Statistical parameters<sup>a)</sup> of imidacloprid<sup>b)</sup> concentration variation in various soil layers different days after application (DAA) in farm PNF47<sup>c)</sup>**

| Soil<br>layers<br>(cm) | 6 DAA |            |            |                 | 12 DAA |             |            |            | 23 DAA |            |            |            | 116 DAA |            |            |            |
|------------------------|-------|------------|------------|-----------------|--------|-------------|------------|------------|--------|------------|------------|------------|---------|------------|------------|------------|
|                        | Min   | Max        | Av         | C.V             | Min    | Max         | Av         | C.V        | Min    | Max        | Av         | C.V        | Min     | Max        | Av         | C.V        |
| 0-5                    | <2.2  | <b>9.6</b> | <b>5.3</b> | <b>96</b>       | <2.2   | <b>21.4</b> | <b>5.1</b> | <b>123</b> | <2.2   | <b>4.6</b> | <b>0.8</b> | <b>175</b> | <2.2    | <b>2.6</b> | <b>0.1</b> | <b>600</b> |
| 5-20                   | <2.2  | <b>6.2</b> | <b>2.6</b> | <b>73</b>       | <2.2   | <b>6.06</b> | <b>0.5</b> | <b>300</b> | <2.2   | <b>4.6</b> | <b>0.5</b> | <b>180</b> | <2.2    | <b>3.2</b> | <b>0.3</b> | <b>260</b> |
| 20-35                  | <2.2  | <b>5.0</b> | <b>0.6</b> | <b>250</b>      | <2.2   | <b>2.8</b>  | <b>0.1</b> | <b>600</b> | <2.2   | <b>2.2</b> | <b>0.1</b> | <b>500</b> | <2.2    | <2.2       | <2.2       | -          |
| 35-50                  | <2.2  | <2.2       | <2.2       | - <sup>d)</sup> | <2.2   | <2.2        | <2.2       |            | <2.2   | <2.2       | <2.2       |            | <2.2    | <2.2       | <2.2       | -          |
| 50-65                  | <2.2  | <2.2       | <2.2       | -               | <2.2   | <2.2        | <2.2       |            | <2.2   | <2.2       | <2.2       |            | <2.2    | <2.2       | <2.2       | -          |
| 65-80                  | <2.2  | <2.2       | <2.2       | -               | <2.2   | <2.2        | <2.2       |            | <2.2   | <2.2       | <2.2       |            | <2.2    | <2.2       | <2.2       | -          |
| 80-100                 | <2.2  | <2.2       | <2.2       | -               | <2.2   | <2.2        | <2.2       |            | <2.2   | <2.2       | <2.2       |            | <2.2    | <2.2       | <2.2       | -          |

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138 <sup>a)</sup>: Min. = minimum ( $\mu\text{g kg}^{-1}$ ); Max. = maximum ( $\mu\text{g kg}^{-1}$ ); Av. = average ( $\mu\text{g kg}^{-1}$ ) of 20 samples for 0 – 35 cm  
 139 layers and 5 samples for 35 – 80 cm layers; C.V. = coefficient of variation (%); the values lower than the limit of  
 140 detection are considered null

141 <sup>b)</sup>: Limit of detection =  $2.2 \mu\text{g kg}^{-1}$

142 <sup>c)</sup>: Two applications of 48 g of a.i.  $\text{ha}^{-1}$

143 <sup>d)</sup>: not estimated

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159 **Table 4: Statistical parameters<sup>a)</sup> of imidacloprid<sup>b)</sup> concentration variation in various soil layers**  
 160 **different days after application (DAA) in farm PNF51<sup>c)</sup>**

| Soil<br>layers<br>(cm) | 2 DAA |             |            |                 | 10 DAA |             |            |            | 27 DAA |            |            |            | 120 DAA |            |            |            |
|------------------------|-------|-------------|------------|-----------------|--------|-------------|------------|------------|--------|------------|------------|------------|---------|------------|------------|------------|
|                        | Min   | Max         | Av         | C.V             | Min    | Max         | Av         | C.V        | Min    | Max        | Av         | C.V        | Min     | Max        | Av         | C.V        |
| 0-5                    | <2.2  | <b>28.4</b> | <b>9.4</b> | <b>76</b>       | <2.2   | <b>12.3</b> | <b>4.9</b> | <b>67</b>  | <2.2   | <b>2.2</b> | <b>0.1</b> | <b>500</b> | <2.2    | <b>3.8</b> | <b>0.6</b> | <b>200</b> |
| 5-20                   | <2.2  | <b>7.4</b>  | <b>1.7</b> | <b>129</b>      | <2.2   | <b>4.4</b>  | <b>1.6</b> | <b>94</b>  | <2.2   | <b>3.4</b> | <b>0.9</b> | <b>133</b> | <2.2    | <b>5.5</b> | <b>0.6</b> | <b>266</b> |
| 20-35                  | <2.2  | <b>2.2</b>  | <b>0.2</b> | <b>300</b>      | <2.2   | <b>4.4</b>  | <b>1.5</b> | <b>100</b> | <2.2   | <b>3.8</b> | <b>0.4</b> | <b>260</b> | <2.2    | <2.2       | <b>0.3</b> | <b>266</b> |
| 35-50                  | <2.2  | <2.2        | <2.2       | - <sup>d)</sup> | <2.2   | <2.2        | <2.2       | -          | <2.2   | <2.2       | <b>0.8</b> | <b>150</b> | <2.2    | <b>2.2</b> | <b>0.8</b> | <b>150</b> |
| 50-65                  | <2.2  | <2.2        | <2.2       | -               | <2.2   | <2.2        | <b>0.9</b> | <b>140</b> | <2.2   | <2.2       | <b>0.4</b> | <b>225</b> | <2.2    | <b>2.6</b> | <b>1.4</b> | <b>92</b>  |
| 65-80                  | <2.2  | <2.2        | <2.2       | -               | <2.2   | <2.2        | <b>0.4</b> | <b>225</b> | <2.2   | <2.2       | <b>0.4</b> | <b>225</b> | <2.2    | <b>2.8</b> | <b>1.4</b> | <b>95</b>  |
| 80-100                 | <2.2  | <2.2        | <2.2       | -               | <2.2   | <2.2        | <2.2       | -          | <2.2   | <2.2       | <2.2       | -          | <2.2    | <b>2.6</b> | <b>1.4</b> | <b>92</b>  |

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162 <sup>a)</sup>: Min. = minimum ( $\mu\text{g kg}^{-1}$ ); Max. = maximum ( $\mu\text{g kg}^{-1}$ ); Av. = average ( $\mu\text{g kg}^{-1}$ ) of 20 samples for the  
 163 layers of 0 – 35 cm and 5 samples for the layers of 35 – 80 cm; C.V. = coefficient of variation (%); the  
 164 values lower than the limit of detection are considered null

165 <sup>b)</sup>: Limit of detection =  $2.2 \mu\text{g kg}^{-1}$

166 <sup>c)</sup>: Two applications of 48 g of a.i.  $\text{ha}^{-1}$

167 <sup>d)</sup>: not estimated

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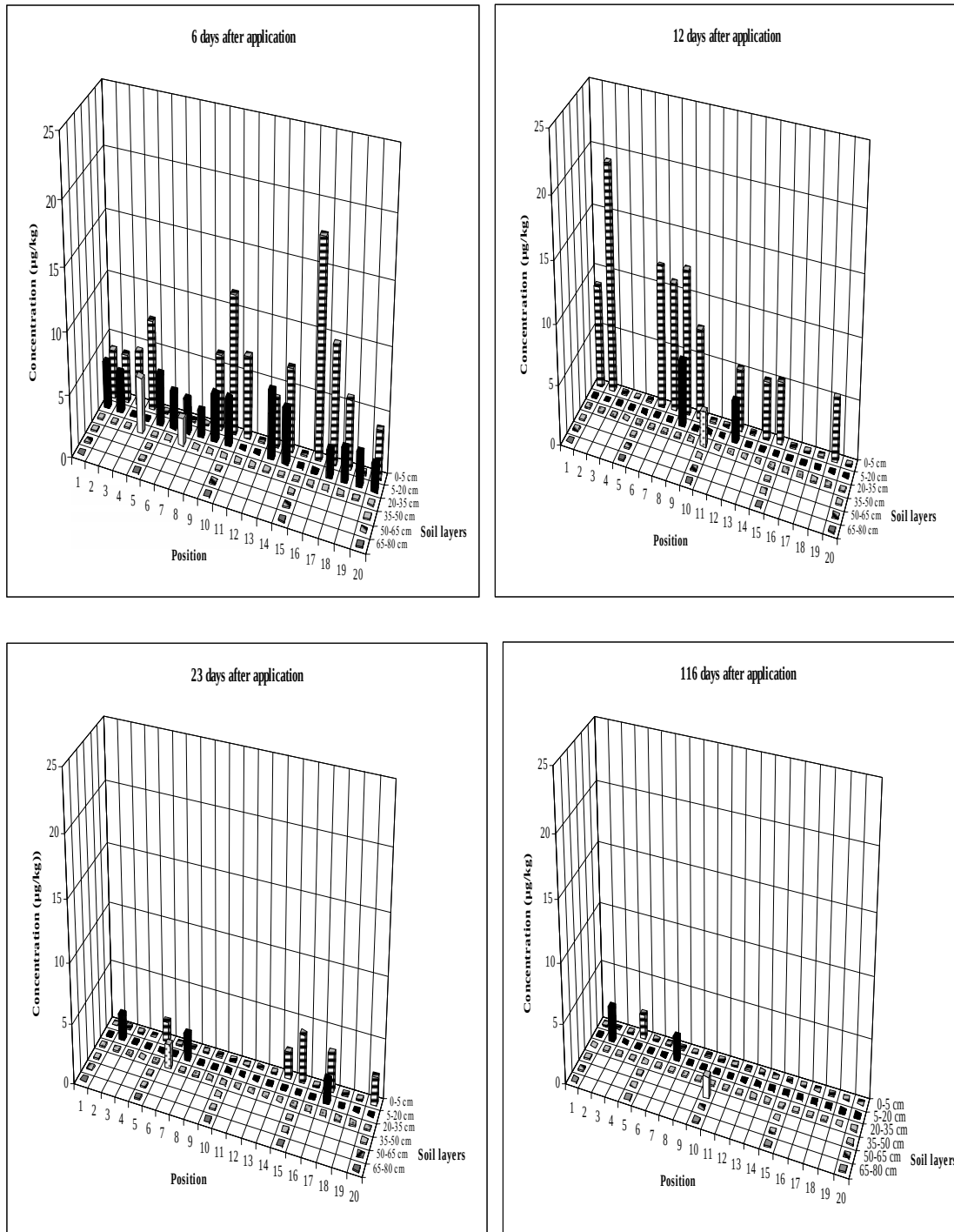


**Figure 2. Vertical distribution of imidacloprid residues (µg/kg) in different soil layers of farm PNF47 as a function of sampling position and time after application**

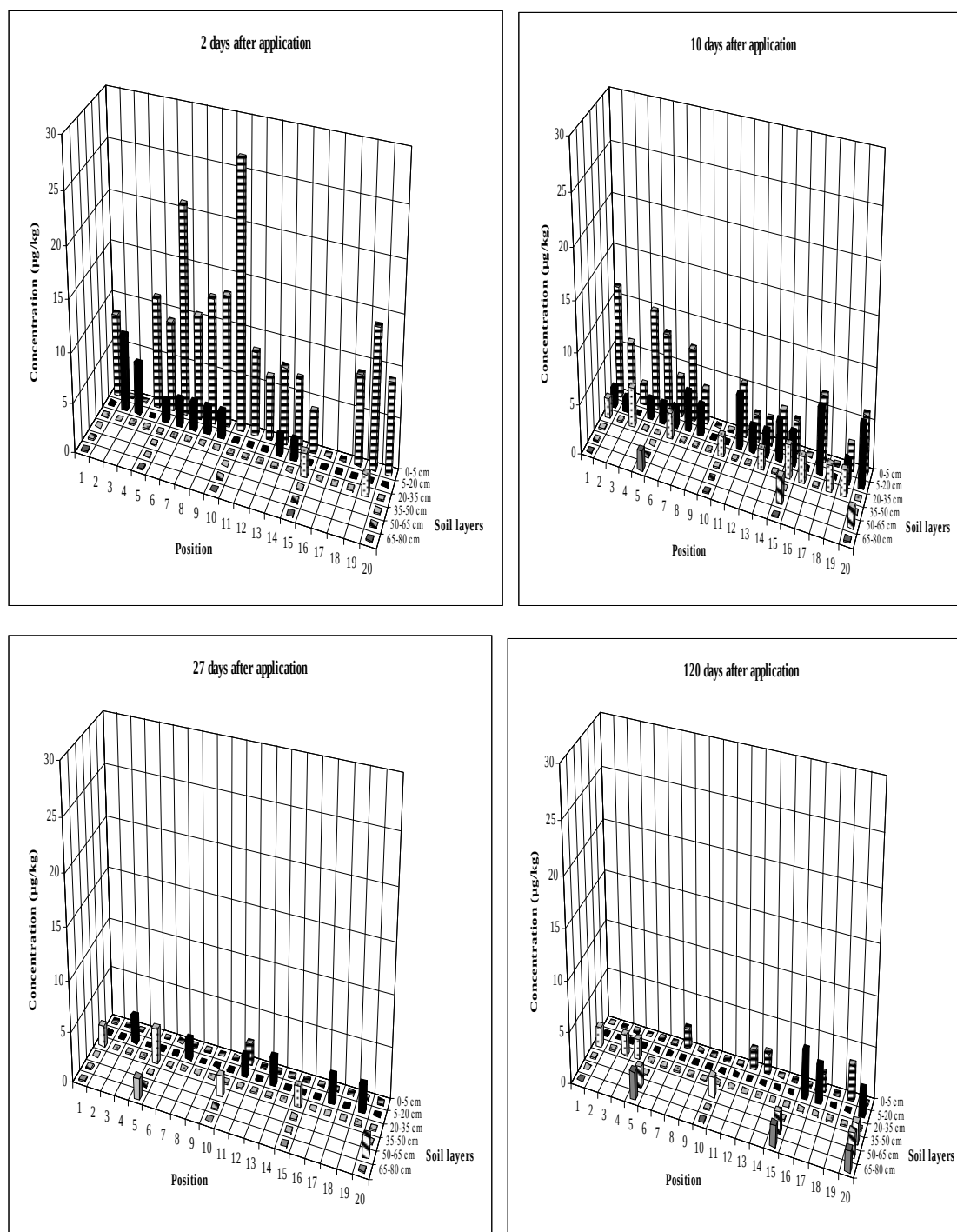


**Figure 3. Vertical distribution of imidacloprid residues (µg/kg) in different soil layers of farm PNF51 as a function of sampling position and time after application**

The imidacloprid is an insecticide widely adopted by farmers and have a high leaching potential according to the Gustafson index. The residual quantities recovered after application are 23.2% of the applied mass, 6 days after application in farm PNF47 and 23.6% of the applied mass, 2

days after application in the farm PNF51. The insecticide is relatively mobile in the soil since it can be detect beyond 20 cm of soil, 2 days after application (tables 3 and 4). Its dissipation in the surface layers of soil results from dilution of the active ingredient in the soil volume by in-depth migration. One can detect residues of the active ingredient until some 80-100 cm depths after harvest (figures 2 and 3). Similar results were obtained by Bonmatin et al. [21] in the study of method of analysis of imidacloprid in soils, in plants and in pollens. These results showed that with the limit of detection  $0.1 \mu\text{g kg}^{-1}$ , imidacloprid recovered in soils, plants and pollens at levels of a few micrograms per kilogram.

The residual deposit after application is heterogeneous. This residual deposit heterogeneity is reflected by the high values of the coefficients of variation of the average concentrations or by the high relative differences between minimum and maximum concentrations detected (tables 3 and 4). The figures 2 and 3 show that the vertical profile of residues distribution varies from one point to another in the farm diagonal at various sampling moments after application. However, the contamination of the soil by imidacloprid residues remains insignificant after harvest.

Xie et al. [11] studied the interception of pulverization deposit of fenoxaprop and imazamethabenz on the oats plants (*Avena fatua*) according to environmental conditions. They obtain rates of interception varying from 68 to 89% for fenoxaprop and from 75 to 97% for imazamethabenz. The imidacloprid solubility is  $510 \text{ mg l}^{-1}$  and its leaching potential is considered high according to Gustafson index (1989) [11]. In New Brunswick and Prince-Edouard island, Julien et al. [12] studied the potential of imidacloprid to being transported by run off waters and to contaminate rivers adjacent to potato farms. The authors report concentrations of imidacloprid varying between  $0.1$  to  $4.4 \mu\text{g l}^{-1}$  and  $0.06$  to  $0.052 \mu\text{g g}^{-1}$  from rivers and from rivers sediments respectively [12]. These data confirm the tendency of the imidacloprid to be transported out of the application site by water movement. Felsot et al. studied imidacloprid vertical distribution after application in a sandy loam of United States. They reported that residues of the insecticide were detected until 75 to 90 cm depth [13]. However, Rouchaud et al. could not highlight an unspecified leaching of the imidacloprid beyond 20 cm under the depth of sowing of beet seeds (*Beta vulgaris*) treated with insecticide [14]. This result tends to show that the insecticide mobility in soil depends on the cropping and environmental conditions. This corroborates the results of Chris (2007) and Chai et al. (2009), who worked on similar experiments. In fact the experiment done by Chris (2007) showed that the presence of vegetation had little effect on activity of imidacloprid in the soil. Results obtained by Chai et al. (2009) in the study of the dissipation and leaching of acephate and chlorpyrifos showed that high dissipation of acephate was in part attributed to precipitation and preferential flow.

#### 4. CONCLUSION

The residual deposits of imidacloprid after application are heterogeneous. This deposit heterogeneity is maintained or developed with time because of the dissipation and differentials migration of active ingredient from one point of the farm to another. The development of the simulation models of the imidacloprid behaviour in the soil must take account of the field reality. These results also call for certain moderation during field extrapolation of the results obtained in laboratory or station with relatively controlled and homogeneous conditions. The quantities of imidacloprid leached beyond

the rhizosphere as their remanence after harvest does not seem to pose a relevant risk of pollution. The respect of adequate pulverization practices and cropping rotation can however decrease this risk considerably.

## REFERENCES

- [1]. C.Vischetti, M. Businelli, M. Marini, E.Capri, M. Trevisan, A. Attilio, L. Donnarumma, E. Conte and G.Imbroglini, "Charac-terization of spatial variability structure in three separate field trials on pesticide dissipation," *Pestic Sci*, vol. 50, pp. 175-182, 1997.
- [2]. P. S. C. Rao and R. J. Wagenet, "Spatial variability of pesticides in field soils: Methods for data analysis and consequences," *Weed Sci*, vol.33, no 2, pp. 18-24, 1985.
- [3]. C. N. Smith and R. S. Parrish, "A field study to evaluate leaching of aldicarb, metolachlor, and bromide in a sandy loam oil," *J Environ Qual*, vol. 22, pp. 562-577, 1993.
- [4]. H. E. Ozkan, "Sprayer performance evaluation with microcomputers," *Applied engineering in Agriculture*, vol. 3, no 1, pp. 36-41, 1987.
- [5]. R. D. Grisso, E. J. Hewett, E. C. Dickey, R. D. Schneider and E. W. Nelson, "Calibration accuracy of pesticide application equipment," *Engineering in Agriculture*, vol.4, no 4, pp.310-315, 1988.
- [6]. G. D. Leroux, E. Cormier et M. H. April, "Pomme de terre : Ajustez votre appareil de pulvérisation, " *Bulletin des agriculteurs*, Mars 1997, 2924 boul. Taschereau, Québec J4V 3P1, pp. 59-63, 1997.
- [7]. S. A. Sichani, B. A. Engel, E. J. Monke,J. D. Eigel and E. J. Kladvko, "Validating GLEAMS with pesticide field data on a Clermont silt soil," *Transactions of the ASAE*, vol. 34, pp. 1732-1737, 1991.
- [8]. E. Behl , "Computer models for fate assessment during the registration process: data needs," *Weed Technol*, vol. 6, pp. 696-700, 1992.
- [9]. S. Zacharias and C. D. Heatwole, "Evaluation of GLEAMS and PRZM for predicting pesticide leaching under field conditions," *Transactions of the ASAE*, vol. 37, no 2, pp. 439-451, 1994.
- [10]. I. Giroux, "Qualité de l'eau: contamination de la nappe par les nitrates et les pesticides dans la région de culture de pommes de terre, " *Ministère de l'environ- nement et de la Faune Québec Canada*, 45 p., 1995.
- [11]. S. H. Xie, B. C. Caldwell, A. I. Hsiao, W. A. Quick and J. F. Chao, "Spraying deposition of fenoxaprop and imzamehabenz on wild oat (*Avena fatua*) as influenced by environmental factor," *Weed Sci*, vol. 43, pp. 179-183, 1995.
- [12]. G. R. Julien, L. M. Edwards and P. L. Stewart, "Field and test studies of dispersal of imidaclopride (Admire) in NB and PEL (1995)," *Environment Canada Atlantic Region Darmouth, NS. EPS-5-AR-98-3*, 51 p., 1996.
- [13]. M. Felsot, "Experimental evidence of transport of pesticides through field soils," A report submitted to Ciba Ltd, Basel, Switzerland, 54 p., 1994.

- [14]. J. Rouchaud, F. Gustin and A. Wanters, "Soil biodegradation and leaf transfer of insecticide imidacloprid applied in seed dressing in sugar beet crops," *Bull Environ. Contam Toxicol*, vol. 53, pp. 344-350, 1994.
- [15]. B. McRae, "Caractérisation et identification des pesticides susceptibles d'être lessivés et des zones potentielles de contamination de l'eau souterraine par les pesticides au Canada," Article de documentation 89-01, Agriculture Canada, 35 p., 1989.
- [16]. D. Jennifer, M. James, L. Jerry, and C. Barbara, "Imidacloprid Application in low and high elevation eastern hemlock stands in the southern appalachians: movement in soils and impacts on soil microarthropods," Fifth Symposium on Hemlock Woolly Adelgid in the Eastern United States, pp. 30-40, 2010.
- [17]. Anonym, "Canadian water quality guidelines: imidacloprid, Canadian Council of Ministers of the Environment," Canada, 8 p., 2007.
- [18]. B. Ndongo, G. Leroux et J. Fortin, "Transport du linuron, de l'imidaclopride et du bromure au travers de colonnes de sol et de lysimètres drainants," *Biotechnol. Agron. Soc. Environ.*, vol. 4 no 1, pp. 33-40, 2000.
- [19]. J. Chris, "Imidacloprid mobility and longevity in soil columns at a termiticidal application rate," *Pest Manag Sci*, vol. 63, pp. 1124-1132, 2007.
- [20]. L. Chai, T. Mohd, S. Hansen and C. Hansen, "Dissipation and leaching of acephate, chlorpyrifos, and their main metabolites in field soils of Malaysia," *J Environ Qual*, vol. 38, no 3, pp. 1160-1169, 2009.
- [21]. J. Bonmatin, I. Moineau, R. Charvet, C. Fleche, M. Colin and R. Bengsch, "A LC/APCI-MS/MS Method of Analysis of imidacloprid in soils, in plants, and in pollens," *Anal Chem*, vol. 75, pp. 2027-2033, 2003.