The challenge for precision spraying

B. Bonicelli, O. Naud, S. Rousset, C. Sinfort, V. de Rudnicki, Jean-Marie Lescot, B. Ruelle, L. Scheyer, Eric Cotteux

▶ **To cite this version:**

B. Bonicelli, O. Naud, S. Rousset, C. Sinfort, V. de Rudnicki, et al.. The challenge for precision spraying. AgEng 2010: International Conference on Agricultural Engineering, Sep 2010, Clermont-Ferrand, France. 11 p. hal-00650005

HAL Id: hal-00650005

https://hal.science/hal-00650005

Submitted on 9 Dec 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

The challenge for precision spraying

B. Bonicelli[1], O. Naud[1], S. Rousset[2], C. Sinfort[3], V. de Rudnicki[1], JM. Lescot[2], B. Ruelle[1], L. Scheyer[4], E. Cotteux[1]

(1) Cemagref[1] UMR ITAP, 361 rue Jean-François Breton 34196 Montpellier Cedex 5
(2) Cemagref UR ADBX, 50 avenue de Verdun, 33612 CESTAS Cedex
(3) Supagro[2] UMR ITAP, 2 Place Pierre Viala 34000 Montpellier
(4) EPLEFPA Montpellier-Orb-Hérault [3], 3224, Route de Mende 34093 MONTPELLIER Cedex 5

Abstract

With contamination of water, soil and air by pesticides, agricultural practices are increasingly being suspected. Inadequate practices can indeed induce point or diffuse pollution. The point source pollution is easier to identify and also to solve by implementing best practices, technologies or infrastructures. Diffuse pollution is more difficult to analyze and to reduce because of the difficulty in defining its exact source, Depending furthermore of each geographical and technical situation. Given a situation, the level of contamination is the result of a set of complex mechanisms that depend on many stakeholders, weather and bioclimatic events. It is even more complex to evaluate due to the many compounds and metabolites which are involved. This paper deals with the knowledge on the levels of losses, their technical causes, the possible improvements and the economic determinants of precision farming in order to develop efficient mitigation measures.

Keywords: pesticides, spraying, precision

1. Introduction

Agricultural practices are increasingly being suspected with contamination of water, soil and air by pesticides (IFEN 2006). Inappropriate practices and equipment can indeed induce point or diffuse pollution. Point source pollution, due to inadequate operations or prevention measures, is easier to solve at the farm scale as shown in the European Life[4] Projet Topps[5] (Roetelle 2008).

In accordance with the national rules, mitigation by improving practices, technologies and infrastructure is efficient if the level of knowledge of the stakeholders is adequate. This means a need of information, training and diagnosis actions at the different levels of decision. Depending on each geographical and technical situation, the source and consequence of diffuse pollution is more complex to identify, to analyse and to reduce. At the scale of a catchment, the water pollutant pressure is the result of a set of complex mechanisms coupled to variable technical and bioclimatic events. At the mesoscale (10-100km), the air contamination is more difficult to measure due to the many compounds and metabolites involved. For air, soil or water pesticides contamination, a voluntary reduction of pesticide use seems very desirable.

Precision Farming (PF), by providing methods and tools to optimize agriculture practices, could bring solutions to this objective. Massive data acquisition and analysis should make it possible but as discussed in the literature (Reichardt 2009, Vaculik 2008), the practical adoption of PF into daily practices is a problem of knowledge dissemination and economical possibilities for adoption.

The implementation of precision farming requires three specific tools:

[1] Cemagref: Public Agricultural and Environmental Research Institute (http://www.cemagref.fr)
[2] SupAgro: French International for Higher Education in Agricultural Siences (http://www.supagro.fr)
[3] EPLEFPA : French Horticultural and Landscaping School of Montpellier (http://www.epl.agropolis.fr)
[4] LIFE: U's financial instrument supporting environmental and nature conservation projects throughout the EU
[5] TOPPS: Train operators to prevent point source pollutions

- Positioning systems (e.g. GPS receivers) to localize recorded data, to guide or to control the farm machines,
- Geographic information systems (GIS) to represent the information on intelligible maps,
- Farm machinery able to perform variable rate actions like seeding, spreading, spraying, harvesting.

With more and more powerful machines, many examples of PF (Agco, John Deere, RDS, Dikey-John, Trimble, Teejet) exist for annuals crops: spreading modulation is carried out using recommendation maps, automatic guidance for large width sprayer is common, like hydraulic section management. In the same way, some automated devices have been tested in vines and orchards: ultrasonic device to determine the dimension of trees and to adjust the spray shape (Durand-Wayland), vigour site specific modulation for selective grape harvesting (New Holland). Giles (2003), Molto (2001), Balsari (2005), Solanelles (2006), Stover (2007), GilPinto (2007), Gil (2007) describe these smart devices: retrofit of air-blast sprayers to canopy density, sensors to adjust the spray to canopy shape or slope, recording tools to analyse the practices. These devices demonstrate significant possibilities to save pesticide (Gil 2002, Raynal 2008).

This paper covers the knowledge on the levels of losses, their technical causes, the possible improvements and the economic determinants to develop efficient mitigation measures.

2. What is the exact knowledge on losses during spraying ?

A lot of studies were dedicated to reduce the risks due to diffuse pollution. The more significant deal with the pesticide spray drift out of the plots (ISO22866 method). But few of them consider the whole aspect of the spray partition in the different compartments of the concerned environment (soil, plants and air). Consequently, some technical responses on a given criterion can produce unwanted “collateral effects”: for example a minimisation of the losses on soil generally increases losses in air and vice versa. To solve this question Cemagref proposed a methodology to evaluate this partition (Sinfort 2007). Based on field and lab tests, these tests show the influence of different parameters: the spraying mechanism, the machine setting, the weather conditions and the canopy density of the crop (i.e. the LAD - Leaf Area Density).

In accordance with the ISO22866 standard this partition measurement was based on the use of a fluorescent dye (Brilliant Sulfo Flavine) trapped on different kind of collectors fitted to each evaluated compartment (PVC lines for air, leaves for plant, PVC plates for soil). After water extraction and dilution, the amount of deposit was obtained through spectro-fluorimetry analysis. To ensure a good statistical estimation the efficiency of collectors was previously tested in laboratory conditions and the implementation of the collectors within the test plots was optimized. Fig 1 shows an example of experimentation to quantify air and soil losses.

Fig 1: experimental tests on artificial vines (source: Cemagref)

These experiments were carried out on vineyard with various equipment and weather configuration (Sinfort 2009). For the same sprayer, they showed a large variation in the percentage of losses: 10 to 40% of on the soil, 30 to 40% in the air (see fig 2).

Fig 2: spray partition during treatment (source: Cemagref 2009)

In terms of variability, considering the soil deposits, the level of losses is directly dependent on sprayer configuration and on the stage of development of the vegetation (see fig 3).

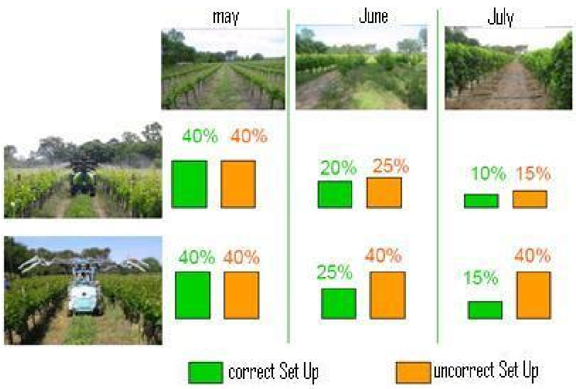

Fig 3: comparison of soil depositions in various conditions (Source Cemagref 2009)

The wind condition should also be taken into account: using an axial air-assisted standard sprayer (Fisher Turbo 561 - Berthoud Ltd., France) GilPinto (2007) showed the high variability of air losses in horizontal and upward direction for different droplet size (fig 4).

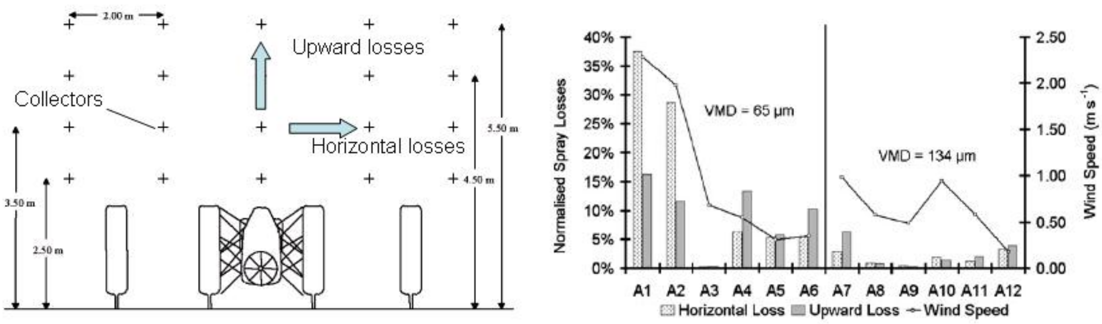

Fig 4: normalised air losses for 12 tests on artificial vines (© Cemagref 2006)

In conclusion, it is clear that the percentage of losses during spraying operations is generally high and could be drastically reduced. This is confirmed by tests conducted by the French

Institute of Vine (Codis 2009): with appropriate sprayer configuration and setting a reduction of 30% (0,7 nominal dose) of the applied dose doesn't change the agronomic efficiency (fig. 5).

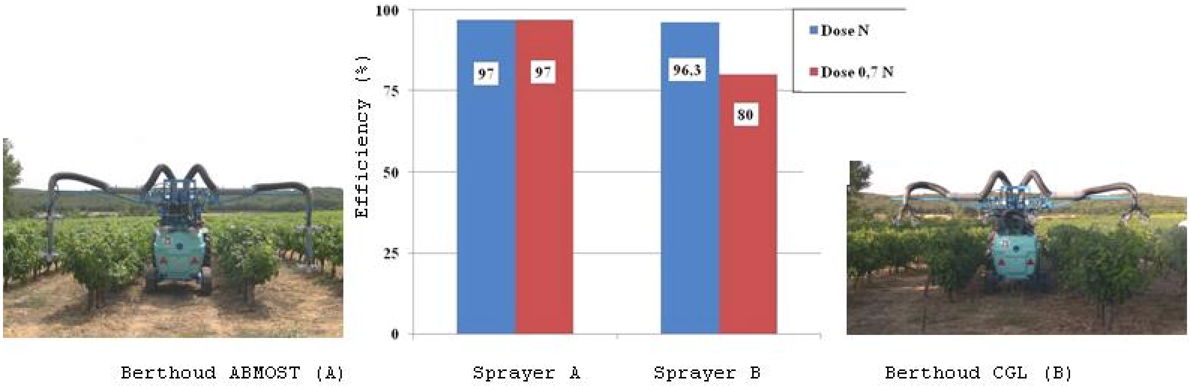

Fig 5: comparison of efficiency for two sprayer configurations (source: IFV[6] 2009)

Dealing with all these phenomena, it is also interesting to discuss weather conditions increasing the losses:

- The possibility to start spraying by inadequate weather conditions (i.e. strong wind during a long period with a high disease pressure)
- The general difficulty to stop spraying operations whereas the climatic conditions are changing (any plot must be finished - all tank content must be used)

3. What is the possible progress?

Current state of researches indicates that to reduce significantly diffuse pollution during pesticides application, the emphasis must be placed on tools and methods for agricultural professionals. Three key aspects are involved:

- to optimize the agronomic decisions
- to control the precision of the applications
- to record the work performed

Optimizing agricultural decisions means a decrease of the number of interventions or a site specific dose adjustment based on the level of infestation and the growth stage of the crop. Disease-specific protocols are required to specify appropriate observations or measurements. Bioclimatic information and weather forecasts are necessary for decision. In France, two methods are currently proposed (fig 6): the reduction of treatment events (GrapeMilDeWS or *Mildium* in French) and the modulation of the doses (Optidose).

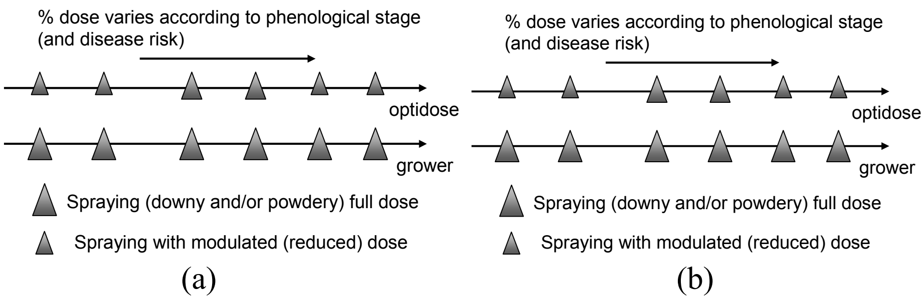

Fig 6: synthetic schematics for GrapeMilDeWS(a) and Optidose (b)

[6] IFV: French Institute for Vines and Wine

GrapeMilDeWS is a decision workflow for the protection against the two major pathogens of grapevine (Léger et al, 2010). The workflow terminology for a decision system acknowledges the fact that process, timings, tactics to adapt spraying to actual epidemics and bioclimatic context, play a major role in achieving reduced phytosanitary input without risking the year's harvest. Several years of experiment at the plot scale have shown the benefits of this decision protocol (see fig 7) and the experiment network is as of today very active and still growing. Ugaglia, (2008) discussed the determinants to diffuse this innovation. The research effort is now shifting on the possibility to apply or adapt the method to the farm scale.

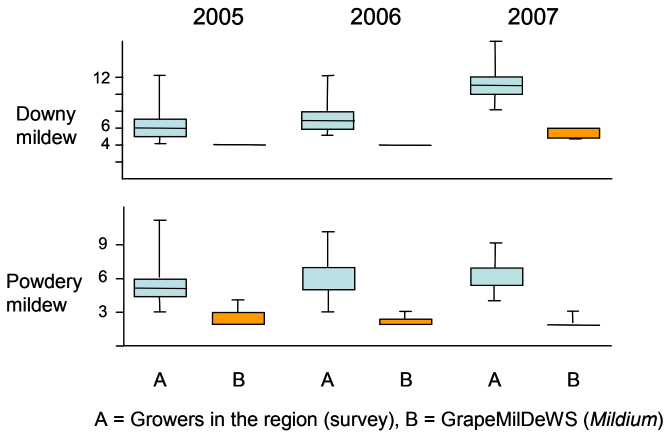

Fig 7: number of sprayings with Grapemildews compared to usual practice (source INRA[7])

Optidose enables to adjust the dose during the vine growing while maintaining an adequate protection of the crop (Raynal 2003). This method, tested over several years, shows large possible savings: up to 50% in 2002 (see fig 8). However, it is important to have a high quality spraying to keep a correct dose deposition on the target (leaves or fruits).

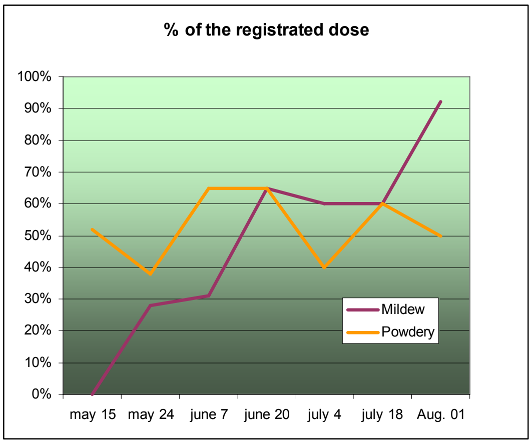

Fig 8: Optidose decision support and possible pesticides saving (source: IFV 2002)

Beyond the performance of each type of spraying device, their continuous set-up optimization is a key element to improve the deposit of chemical products on target pests.
The air or soil losses are generally caused by the inadequate position of the nozzles at the top and bottom of the vegetation. For orchards, the use of ultrasonic sensors allows

[7] INRA: French National Institute for Agricultural Research

modification of the sprayed pattern well adapted to the crop structure. This induces a significant reduction in spray volume while maintaining coverage and penetration rates similar to conventional methods (Molto 2001, Escola 2002, Gil 2007, Balsari 2009). Measuring the distance to the crop Ultrasonic sensors can also easily determine the presence or not of the crop and to stop spraying between plants or at the end of each crop line. Recent results from field trials have shown possible improvements for vineyards of up to 30% increase in deposition on targets, 75% reduction in drift and 40% reductions in pesticide (Landers 2009), by using canopy sensors, optimizing nozzle orientation and adjusting air speed and hydraulic pressure.

Some devices can lead spectacular progresses.
For example, the containment of sprays (cf. recovery panels, electrostatic) eliminates almost all the air and soil losses, up to 90% (Doruchowski 2000, Celen 2009). However the characteristics of these devices create operative problems, which constitute the most important barrier to their adoption.

Other losses can be avoided with traceability tools and specific devices aiming at detecting common dysfunctionning.
Error of dose setting, inaccuracy of instrumentation, hydraulic regulation problems, time delay to stop spraying or hydraulic sections, etc., are other dysfunctions to mitigate. At the field or at the farm scale, that means tools to analyze the technical accuracy of the couple operator/sprayer working. Through the European LIFE AWARE[8] results, Ruelle (2009) showed how sprayer setting, inadequate operations, or incidents can decrease the spraying quality. The onboard system (see fig 9) measures and records, second by second, geo-referenced application parameters (flow rates, tank volume, meteorological information). Application map clearly shows under (in blue) and over (in red) dosing at the border of the plot. Comparison on automated / manual traceability information shows others discrepancies inducing up to 10 to 15% over use of pesticides.

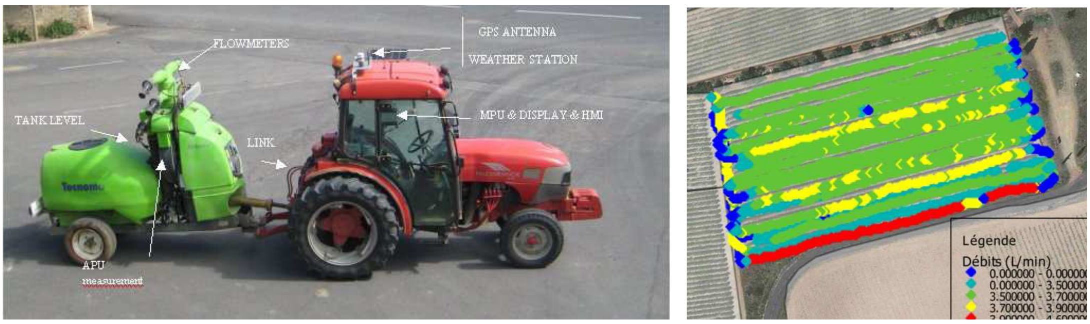

Fig 9: Traceability equipment and application map (source: cemagref 2008)

4. Determinants of the improvements

With contrasted situations (regions, productions, practices, equipments), even if the technical potential for chemical products savings can be important, three main causes could impede the progress at production level: (i) the possible extra time (or organisational load) to devote to their implementation, (ii) level of investment needed for their development, (iii) aversion to risk and difficulty to evaluate it.

The collective scientific expertise Cemagref/INRA (Aubertot et al. 2005) and the socio-economic studies on the use of the pesticides underlined two key points for the evolution of the practices:

[8] A Water Assesment to Respect the Environment

- the low cost of plant protection in comparison with the gross margin,
- the importance of risk awareness .

Several aspects can then be discussed:

- capacity for evolutions,
- conditions for implementing optimized agronomic practices,
- contribution of Information and Communication Technologies,
- economical feasibility.

In terms of awareness, the analysis of the opinion of actors on point source pollution at the European scale highlights the convergences (Vaçulik 2008). The reduction of pollution concerns a better knowledge of the possible improvements. Each step of spraying process is to consider in terms of possible profit: before (compound choice, sprayer maintenance and preparation of the sprayer, time management), during (continuous settings, tank management and incident detection), after (tanks and sprayer cleaning, residue mitigation). In these conditions the implementation of tools or training session for analysis and diagnosis is to promote.

Addressing agronomic decision, recent results on Mildium and Optidose (Davidou 2009) showed important savings at the field scale due to a good quality of spraying. These approaches will require procedures to connect each tactical decision to a more general strategy of pesticide reduction at the farm scale and for a whole season. The success of these methods will also depend on the quality of observations, or canopy sensor measurements, for appropriate decisions in real time as well as in delay time. To further demonstrate the benefits of these innovations, research should be continued from field to farm and to catchment scales.

At the catchment scale, the use of automatic recording systems (De Rudnicki 2008 and De Rudnicki 2009) associated to analysis tools for data-processing gives possibilities for improvements concerning both practices and equipment. Thus, it is possible to discuss the improvements at the farmer or at the adviser scales in order to optimize the choices and the priorities: the setting procedure for the sprayer for example. In other words, it is by giving to the operators the means of a better control over the spraying quality, that introduction of innovations will be possible and the pesticide savings will be effective.

In economic terms, reducing pesticide use may influence the quality of the grapes and finally of the wine production. Thus, risk may affect the strategies adopted for crop protection (Pannell, 1991). In these conditions, economic optimization models can provide useful guidance in assessing system changes to policies instruments and adoption factors for precision spraying. Nevertheless, given the complexity of the pest control problem, model outcomes should be used carefully, as was shown in (Tozer 2009) for a grain farm case. For example, a simple analysis based only on input savings produced results which were very favourable to the technology, but a more complete representation of the problem resulted in a distinctly adverse conclusion. This suggests that an accurate representation of the risk-related aspects of PF technologies may be critical in evaluating accurately their potential. Most of research on pesticides-saving technology deals with the adoption of integrated pest management (IPM). In tab 1 we summarize the survey carried out on many crops by Aubertot et al. (2005) and integrate other PF references on tools like sensor-based Variable Rate Application (VRA), remote sensing and Geographic Information System (GIS). Results show that, operators of larger farms are more likely to adopt innovations because those farms are generally the most profitable and they can more easily bear the risk of technological changes. In most cases, farmer education is also positively correlated with the adoption of IPM or PF. The positive effect of extension and consultants confirms the importance of human factor for a better control of techniques but the hypothesis that off-farm employment may present a constraint to adoption is not confirmed (Femandez-Comejo, 1998). Besides, the age of farmers rarely has a significant effect. Interestingly, in two studies on PF, the perception of field variability has statically a positive effect on adoption (Sevier and Lee, 2005; Walton et al., 2008).

Concerning public policy, there have been few attempts so far to evaluate instruments to achieve pesticide usage reductions taking into account technological change. Most of Mathematical Programming Models (MPM) built to evaluate policies focus on the allocation of crops and other farming activities (Arfini and Donati, 2008). At the farm scale, bio-economic models, usually MPM integrating information coming from biophysical models (Reynaud, 2009), may embody new technology allowing easier, lower-cost adjustment to lower-pesticide-input crop practices. However, an important drawback of many models is that pesticides are aggregated into a single input, and substitution between different types of pesticides cannot be taken into account. Bio-economic modelling of perennial crops is especially difficult. For polycyclic diseases like mildews of grapevine, a major difficulty is to evaluate dynamically and cumulatively over the season the effect on yield quantity and quality of spraying or not spraying a given pesticide at a given moment. In (Bazoche 2008), the relevancy of the model is checked against expertise of epidemic scenarios.

Reference	Country (States), period	Production	Pesticides-saving technology	Education	Off-farm work	Farm size	Age, experience	Ownership of farm	Soil quality, land productivity	Technical assistance, consultant	Pesticides as % of crop revenue	Farm income	Others
Caswell et al.(2001)	USA (NE, IN, PA, WA, VA, GA, IL, IA, ID, TX, MI, MS, AR, CA) 1991/93	corn, cotton, potatoes, soybean, wheat	IPM : crop rotations	n.s.	n.s.	n.s.	n.s.	-	+	+			
			IPM : biological controls	+	n.s.	+	-	n.s.	+	+			
			IPM : scouting	+	n.s.	+	-	-	n.s.	+			
Fernandez-Cornejo (1996)	USA (CA, FL, GA, MI, NC, MS, NJ, NY, TX) 1992/93	tomatoes (fresh)	IPM : scouting (insecticides)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+			risk aversion (-)
			IPM : scouting (fungicides)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+			
Fernandez-Cornejo (1998)	USA (CA, MI, NY, OR, PA, WA) 1993/94	grape (wine 80%, raisin 10%, juice 10%)	IPM : scouting (insecticides)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.			
			IPM : scouting (fungicides)	+	-	+	n.s.	n.s.	n.s.	n.s.			wine grapes (-)
Fernandez-Cornejo and Castaldo (1998)	USA (CA, FL, MI, PA, NY, OR, WA, NC) 1993/94	fruits	IPM : scouting	n.s.		n.s.	n.s.				-		income per ha (+)
			IPM : biological controls	ns		n.s.	n.s.				n.s.		
Fernandez-Cornejo and Jans (1996)	USA (FL, CA) 1993/94	oranges (fresh)	IPM : scouting (insecticides)		n.s.	+							crop price (+)
		oranges (proc.)	IPM : scouting (insecticides)		-	+							
Fernandez-Cornejo and Kackmeister (1996)	USA (CA, FL, IL, MI, MN, NJ, NY, NC, OR, WA, WN) 1992/93	horticulture	IPM : scouting	+		n.s.	n.s.				+		
			IPM : biological controls	+		n.s.	n.s.				-		
Fuglie and Kascak (2001)	USA (NE, IN, PA, WA, VA, GA, IL, IA, ID, TX, MI, MS, AR, CA) 1991/93	corn, soybean, cotton, wheat, potatoes	IPM : scouting, biological controls, cultural controls	+					+			+	
Mcnamara et al. (1991)	USA (GA) 1985	peanuts	IPM : scouting	+	-		+		n.s.	+			yield (+)
Wiebers, Mandcalfe and Zilberman (2002)	USA (CA) 1990	tomatoes	IPM : scouting by farmer	+	+	-	n.s.						
			IPM : dealer assistance	n.s.	n.s.	n.s.	n.s.						
Amponsah (1995)	USA (NC) 1991	all	PF : computers	+		+	n.s.					+	
Batte et al. (1990)	USA (OH) 1997	grain, dairy, mixed livestock	PF : computers	+		+	-	n.s.					grain farm ( )
Daberkow and McBride (1998)	USA (IL, IN, IA, KA, MI, MN, MS, NA, NC, OH, PA, SC, TX, WI) 1995	corn	PF : sensor-based variable rate application, remote sensing, GIS	n.s.		+	-	n.s.	+			+	
Daberkow and McBride (2003)	USA (all) 1998	all	PF : variable rate application, yield mapping, remote sensing	n.s.	-	+	n.s.	n.s.					vegetables, nuts, fruits (+)
Khanna (2001)	USA (IL, IN, IA, WI) 1997	all	PF : nitrogren variable rate application	+		+	+	-	+				contracts based on quality (+)
Putler and Zilberman (1988)	USA (CA) 1986	all	PF : computers	+		+	n.s.						
Sevier and Lee (2005)	USA (FL) 2003	citrus	PF : sensor-based variable rate applicators, remote sensing, GIS	n.s.		n.s.	-			n,s			in-grove variability (+)
Walton et al. (2008)	USA (AL, AR, FL, GA, LA, MI, MS, SC, NC, TE, VI) 2005	cotton	PF : soil sampling	+		+	-	+		+			field yield variability (+)

IPM : Integrated Pest Management PF : Precision Farming

Tab 1: Main factors in pesticides-saving technology adoption.

In order to asses the decision factor, as Aplan et al. (1993) we have developed a discrete stochastic programming model where consideration of disease pressure is based on information from the last ten years. Data coming from the French Farm Accountancy Data Network (FADN) is used to study a panel of winegrowing farms. Different strategies against powdery and downy mildew for reducing spraying application are evaluated.

5. Conclusion: what is the challenge for precision spraying ?

All recent studies show a significant potential for reducing pesticide use: the emphasis should be placed on tools and methods to optimize decisions concerning the use of pesticides and the quality of applications. The importance of economic conditions for adopting precision technologies has been put forward in different regions and between types of production. The question of specific investment, whether in equipment, training, or innovation in management, may delay the process of improvement in vine estates. Therefore, even if pesticides reduction can reduce the costs, means to trigger this investment are relevant topics for further research about precision spraying techniques.

From our collaborative research, we have acquired the conviction that collective and individual perception of environmental issues for the development of “cost effective” smart sprayers can still be improved. This raises the question of the environmental qualification of equipment and practices to implement incentives encouraging the replacement of obsolete sprayers and improving spraying practices. In this regard, some questions addressed to different scientific communities remain on the research agenda:

- How to define and implement acceptable environmental labels for “environment friendly” equipments or practices?
- What kind of national or regional incentives systems are necessary to promote efficient improvements?
- Which diagnostic tools and advice can offer practical solutions to each farmer?
- Which monitoring indicators are needed to secure progress?

References:

Aplan J., Hauer G. (1993). Discrete stochastic programming: concepts, examples and a review of empirical applications. *Staff Paper, University of Minnesota, St. Paul, MN,* 41 pages.

Arfini F., Donati M. (2008). Health check and farm efficiency : a comparative assessment of four european agricultural regions. *109th EAAE Seminar, Viterbo, Italy. November 20-21,* 20 pages.

Aubertot et al.(2005). Pesticides, agriculture et environnement: réduire l’utilisation des pesticides et en limiter les impacts environnementaux. *Expertise collective, Editions Quae INRA-Cemagref*, 117 pages

Balsari, P., P. Marucco, et al. (2005). Adjustment of an air assisted sprayer in a peach orchard to optimise applications against oriental fruit moth (Cydia molesta). *Sprayfruit Cuneo Proceedings,* pp.187-193.

Balsari, P., P. Marucco, et al. (2009). A crop identification system (CIS) to optimise pesticide applications in orchards. *Journal of Horticultural Science & Biotechnology ISAFRUIT Special Issue*, pp. 113–116.

Bazoche, P., P. Cartolaro, et al. (2008). Réduire les pesticides utilisés en vitiulture: à quel prix. *Revue des Oenologues N°129 (spécial),* 4 pages.

Celen, I. K., M. R. Durgut, et al. (2009). Effect of air assistance on deposition distribution on spraying by tunnel-type electrostatic sprayer. *African Journal of Agricultural Research 4 (12)*, pp. 1392-1397,.

Codis, S. and B. Ruelle (2009). Optimisation de la pulvérisation pour améliorer l'utilisation des intrants phytosanitaire en viticulture. *Les rencontres Qualimed Montpellier 6 nov*: 14 slides.
Davidou L. (2009). Protection de la vigne : bilan des expérimentations 2008 en Gironde. *Brèves N°30, Chambre d'Agriculture de Gironde*, 7 pages
De Rudnicki, Ruelle B., Douchin M., Bellon-Maurel V. (2008). Reducing pesticide-related water pollution by improving crop protection practices: The use of embedded ICT technologies. *AGENG 2008 Conference, Hersonissos (GRC)*, June 23-25, 2008.
De Rudnicki, V., Ruelle B., Douchin M., Sinfort C. (2009). Maitrise de l'application des produits phytosanitaires : utilisation des NTIC embarquées. *Congrès du Groupement Français des Pesticides, Toulouse,* 12 pages
Doruchowski, G., Holownicki,R., (2000). Environnementally friendly spray techniques for tree crops. *Crop protection. 1,* pp. 617-622.
Escola, A., Solanelles,F.,Planas,S.,Rosell,JR. (2002). Electronic control system for Proportional spray application to the canopy volume in tree crops. *International Conference on Agricultural Engineering, Budapest. Paper n°02AE010,* 8 pages
Fernandez-Cornejo J. ; Castaldo C. (1998). The diffusion of IPM Techniques among Fruit Growers in the USA. *Journal of Production Agriculture, vol. 11, n° 4,* p. 497-506.
Gil Pinto, Y., C. Sinfort, et al. (2007). Atmospheric loss of pesticides above an artificial vineyard during air assisted spraying. *Atmospheric Environment. 41,* pp. 2945-2957.
Gil, E. (2002). Crop adapted spraying in vineyard. Leaf area distribution and uniformity of deposition as a tools to evaluate the quality of application. *International Conference on Agricultural Engineering, Budapest.* 8 pages
Gil, E., A. Escola, et al. (2007). Variable rate application of plant protection products in vineyard using ultrasonic sensors. *Crop Protection 26(8)*, 1287-1297.
Giles, D. K., Downey D. (2003). Quality control verification and mapping for chemical application. *Precision Agriculture Volume 4 , Number 1,* pp.103-124.
IFEN (2006). Les pesticides dans les eaux. données 2003 et 2004, IFEN.
Landers, A. (2009). New tehnology in vineyard spraying. *New England Vegetable & Fruit Conference, Manchester, USA*, 4 pages.
Léger B., Naud O., Delière L., Cartolaro P., Gouache D. (2010). Contribution of formal modelling and field experiment to leverage knowledge and expertise for designing crop protection guidelines. *AgEng 2010 Clermont Ferrand,* Sept 6-8,
Molto, E., B. Martín, et al. (2001). PM—Power and Machinery: Pesticide Loss Reduction by Automatic Adaptation of Spraying on Globular Trees. *Journal of Agricultural Engineering Research 78(1)*, pp. 35-41.
Pannell, D., (1991). Pests and pesticides, risk and risk aversion. *Agricultural Economics 5 (4),* pp. 361-384.
Raynal, M., Claverie M (2003). "Application de produits phytosanitaires: quelles pistes pour améliorer la pulvérisation." Banque de données des matériels viti-vinicoles, Chambre d'Agriculture de Gironde - IFV, 4 pages.
Raynal, M. (2008). Agriculture de précision: un potentiel technologique au service de la maitrise qualitative et environnementale de la production viticole. *Lettre d'Actualité Matevi N°37, ENTAV-IFV,* 4 pages.
Reichardt, M., C. Jürgens, et al. (2009). Dissemination of precision farming in Germany: acceptance, adoption, obstacles, knowledge transfer and training activities. *Precision Agriculture 10(6)*, pp. 525-545.
Reynaud A. (2009). Adaptation à court et à long terme de l'agriculture au risque de sécheresse: une approche par couplage de modèles biophysiques et économiques. *Revue d'études en agriculture et environnement, vol. 90, n° 2,* pp. 121-151.
Roetelle, M., P. Balsari, et al. (2008). Technical deficits that restrict full adoption of best management practicies to prevent losses of plant protection products to water. *AGENG 2008 Conference, Hersonissos (GRC)*, 13 pages.

Ruelle B., de Rudnicki V., et al. (2009). AWARE : A Water Assessment to Respect the Environment . *LIFE AWARE projet technical report,* 58 pages.
Solanelles, F., Escola A., Planas S, Rosell JR, Camp F, Gracia F (2006). An Electronic Control System for Pesticide Application Proportional to the Canopy Width of Tree Crops. *Biosystems Engineering* 95, pp. 473–481.
Sevier B.J. ; Lee W.S. (2005). Precision Farming Adoption by Florida Citrus Producers: Probit Model Analysis. *Department of Agricultural and Biological Engineering, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida,* 6 p.
Sinfort, C., Y. Gil, et al. (2007). "Influence of sprayer technologies on losses to the air and on the ground during typical vine spraying." *Suprofruit Malmö, swenden 12-14/09- Book of abstracts, pp.* 40-41.
Sinfort, C., Cotteux E., Bonicelli B., Ruelle B. (2009). Influence des conditions et matériels de pulvérisation sur les pertes de pesticides au sol et dans l'air en viticulture languedocienne. *Congrès du Groupement Français des Pesticides, Toulouse,* 4 pages
Stover, E. (2007). Sensor-Controlled Spray Systems for Florida Citrus. *University of Florida extension service,* 8 p.
Tozer P.R. (2009). Uncertainty and investment in precision agriculture – Is it worth the money? *Agricultural Systems, vol. 100,* p. 80-87.
Ugaglia-Alonzo, A., B. Del'Homme, et al. (2008). Determinants of pesticides reduction in grape growing farms." *DIME International Conference "Innovation, sustainabilty and policy 11-13 September 2008, GREThA Université Montesquieu, Bordeaux IV, France,* 15 pages.
Vaçulik, A., Bonicelli. B., Palagos B., Laplana R. (2008). Réduction des pollutions des eaux par les produits phytosanitaires agricoles. Premiers enseignements d'une enquête auprès de professionnels européens. *Ingenieries,* 15 pages
Vaculik, A., Bonicelli B., et al. (2008). Proposal on a sustainable strategy to avoid point source pollution of water with plant protection products - *Life Topps Project report,* 156 p.
Walton J.C. ; Lambert D.M. ; Roberts R.K. ; Larson J.A. ; English B.C. ; Larkin S.L. ; Martin S.W. ; Marra M.C. ; Paxton K.W. ; Reeves J.M. (2008). Adoption and abandonment of precision soil sampling in cotton production. *Journal of Agricultural and Resource Economics, vol. 33, n° 3,* pp. 428-448