ECONOMIC PROFITABILITY OF SITE-SPECIFIC PESTICIDE MANAGEMENT AT THE FARM SCALE FOR CROP SYSTEMS IN HAUTE-NORMANDIE (FRANCE).

O. Bourgain

Rural economy department
Esitpa, agricultural engineering collège
Mont Saint Aignan, France

M. Bécu, C. Duval

Défisol27
Evreux, France

J-M. LLorens

Technology transfert firm
Agrinovatech
Mont Saint Aignan, France.

ABSTRACT

Modern agriculture requires decision making criteria applicable to different scales of territory in order to reconcile productivity and respect of the environment. Our scale of final investigation is the farm unit. So we have established a methodology to study the profitability of site specific pest management (SSPM) of fungicides for cropping systems dominated by cereals in Haute-Normandie. We have simulated pesticide application for variable surface areas (95 ha, 145 ha, 240 ha) and for different heterogeneity levels of soil. The direct margins calculated for a uniform application and with precision agriculture (PA) show that, in our pedoclimatic conditions, SSPM is not profitable as such. In order to be profitable, it should be conceived as part of the global site specific crop management investment.
Key words: Site-specific pest management (SSPM), pest strategy, economic perspectives, agricultural policy.

INTRODUCTION

Modern agriculture requires decision making criteria applicable to different scales of territory to face the two dominant challenges of our present agricultural production systems which are maintaining productivity and respecting environment. Site specific crop management could reconcile these two challenges particularly for fertilizers (Bourgain and Llorens, 2009). SSCM could be used for numerous crop application techniques: pesticide management, seeding rates or irrigation. However, in many cases, the agro-environmental interest conflicts with economic profitability (Atherton et al., 1999) or socio-economic resistance to innovation (Robert, 2002).
In context of voluntary reduction of pesticide use it is important to be able to evaluate the economic benefits of this new technology.

Most of the time, the technical results obtained from previous studies were partially evaluated from an economic point of view: limited to increased profit, due to fertilizer reduction or gross profit margins. Moreover, these studies were carried out on specific crops, mainly wheat (Duval et al., 2007) or maize (Koch et al., 2004) and/or specific types of input, such as nitrogen (Dailey et al , 2006, De Vuyst and Halvorson, 2004 ; Koch et al, 2004 ; Link et al, 2006 ; Lobell, 2007). However, very few studies have been undertaken to analyse global crop systems (Sartori et al., 2005) or to evaluate the profitability of SSCM (Haefele and Wopereis, 2005), due to the complexity of the work involved.

Site-specific pest management (SSPM) is more than a simple technology, it allows us to increase the relevance of the agronomic decision making criteria (Swinton and Lowenberg-Deboer, 1998) according to the environmental management (Melakeberhan et Avendano, 2008). Thus it appeared important, in this work to have a global point of view at farm scale to better evaluate the economic efficiency of such techniques. Therefore, taking into account the costs of acquiring the information and the extra cost of equipment, profitability should be evaluated at the cropping system scale which aggregates the negative and positive interest of each crop.

A French voluntary political context : “le Grenelle de l’environnement”

These political measures will lead to a drastic reduction of all diffuse pollution, particularly, those linked to plant protection products. Firstly they concern the protection of water resources (Grenelle de l’environnement, 2007a). They propose to set an ambitious objective: to reach a good ecological for 2/3 of surface water. Concerning diffuse pollution (pesticides, nitrates, heavy metal…), There is general agreement for the reduction of their use, some drastic for ones and progressive but significant for others on the condition that it protects agricultural employment.

There are certain products which are pure and simply banned and the use of others is reduced to 50% in the medium term. Certain members of group III responsible for environmental respect of health thought that this approach it is only partial because it does not take into account the evaluation of benefits and risks. They considered it better to improve and develop new agricultural pathways through research and experimentation without setting precise figures (Grenelle de l’environnement, 2007b). Therefore, assuring a coherent global plan aiming to establish harmony between environment and health, group III propose developing an ambitious non mandatory policy of substitution and innovation. Our study is included in this policy context: site specific pest management could reduce the use of certain pesticides.

Our approach conforms to the objectives of the measures of the *“Grenelle de l’environnement”*. These measures imply a significant change of the crop systems and encourage agricultural research (Grenelle de l’environnement, 2007c).

Potential impact of an innovative technique such as precision agriculture

SSPM allows in theory, to apply the right dose in the right place based on soil potential in our pedoclimatic conditions. The agricultural decision making criteria for treatment is the density of plants in field zones. The high plant density zones where there is a higher risk of disease must be treated at the maximum level (100% of the dose). Dose reductions are possible in zones

where the plant density is lower. These dose reductions are based on the risk that the farmer is willing to take, particularly in the case of fungicides.
Few farmers use sprayers capable of doing site specific application of fungicides. Agricultural machinery manufacturers include very few of them in their catalogues. Developing this type of research is important to provide alternatives for an economically realistic future for agriculture in terms of new techniques for farmers, new economic data for policy makers and society in general.

For this study, we applied a similar methodology to that which we developed to evaluate the profitability site specific fertilizer management (Bourgain and Llorens, 2009) and to quantify anti-erosive agricultural measures to be taken (Bourgain and Michaud, 2006). We showed that decreases in fertilizers application rates were compatible with maintaining yield in Haute-Normandie. We restricted the study to silty soils very common in our region. Therefore precision agriculture should be conceived in a defined pedoclimatic context. In our case, it is the useful available water (UAW) that is the driving force of the yield potential heterogeneity. The UAW was determined by apparent soil electrical conductivity (Duval et al, 2007). The technical impacts on wheat and oil seed rape yields (OSR) were taken and analyzed using the results of modeling of earlier agronomic trials (Duval et al, 2007 et Bécu et al, 2008). Our final scale of investigation is the farm system as an economic unit.

Thus the two main aims of this project are

- firstly to elaborate a methodology including farming systems and to define relevant technico-economic indicators to estimate the profitability of SSPM for the total economic activities of the farm,
- Secondly, to apply this methodology to carry out profitability simulations for representative cropping systems of arable farms in Haute-Normandie.

MATERIAL AND METHOD

Survey scale

Our final scale of investigation is the farm system as an economic unit. One part of the economic and technical data is taken at the plot scale (Duval et al, 2007; Bécu et al, 2008) then it is aggregated at the level of the farm. For this we used farm unit type results from the economic observation network set up by the Chamber of Agriculture (Chambre d'agriculture, 2008). We used Three crop systems (cereals, sugar beet-flax and potatoes) were selected. Each system is composed of the rotation of seven or eight different crops. In fact, these types of farms represent 40% of the farms in Haute-Normandie. They are defined as being without milk production and a limited surface area of permanent pasture (less than 15% of the cultivated surface area). The turnover for livestock is less than 20% of the total.

In this study, among this typology, we chose to simulate cereal crop system profitability threshold (C1a, C2, C3, table 1). Indeed, it was on these crop systems that we had the most of experimental and technical data.
Information was collected concerning the technical practices of each crop and the current prices of required inputs.

This typology is based on three combined levels of the following factors:

- The percentage of land in cereals and OSR and protein crop, in sugar beet and flax, and in potatoes.
- Amount of labour
- Farm size
- The six cropping systems (table 1) represented 87% of the arable farms in Haute-Normandie ie 2800 farms. This typology is the synthesis of six years of observations (Rosace, 2005). Standard economic information taken from various sources was used to represent the farms in the region (Rosace, 2005, Agreste, 2008-2009, Chambre d'agriculture, 2008).

Table 1 : Typology of crop systems (Rosace, 2005) used in economic simulations with Olympe for precision agriculture in Haute-Normandie

Systems	Main caracteristics	Labour*	Average area (ha)	Farm Unit Type
Cereals	more than 80% arable land in cereals, oleo proteagineous + fallow	1	**95** (70-120)	C1a
		2	**145** (120-180	C2
		2	**240** (180-350)	C3
Sugar beet – flax	20 to 25 % arable land in sugar beet and flax	1	**110** (80-140)	BL1bis
		2	**200** (140-350)	BL2bis
Potatoes	More than 10 ha potatoes (25 ha average)	2 or more	**150** (more than 90)	PT

*Full Time Labour Unit

Technical referential:

We chose a five crop rotation (table 2). We identified the different technical procedures and inputs for each crop, we used recent necessary input prices (CER France, 2009) and operating costs.

Table 2 : Crop pesticide management for cereal systems in Haute-Normandie (Fertil info, 2009)

	Wheat		Barley		Oil Seed Rape		Peas	
<u>Product/ ha</u>								
Average yield (in t/ha)		8,5		7		3,5		5
<u>Variable costs/ha</u>	quantity (Kg ou l)		quantity (Kg ou l)		quantity (Kg ou l)		quantity (Kg ou l)	
Fertilizer								
Seeds								
Herbicides	Isoproturon (T1)	1,2	Chlortoluron (T1)	1,5	Colzor trio (T1)	3	Challenge(T1)	3
	First (T1)	0,5	First (T1)	0,5	Noval (T1)	2	**<u>Nirvana (T2)</u>**	1
	<u>Celio (T2)</u>	0,3			**<u>Centurion (T2)</u>**	0,4	**<u>Centurion (T2)</u>**	0,4
	<u>Starane (T2)</u>	0,6			**<u>Chrono (T2)</u>**	0,6		
Fungicides	**<u>Menara (T1)</u>**	0,4	**<u>Fandango (T1)</u>**	0,8	Menara (T1)	0,4	Chlorotalonil (T1)	1
	<u>Bravo 500 (T1)</u>	1	**<u>Bell (T2)</u>**	0,7	Bravo 500 (T1)	1	Chlorotalonil (T2)	1
	<u>Opus (T2)</u>	0,5	**<u>Comet (T2)</u>**	0,2	Opus (T2)	0,5	Chlorotalonil (T3)	1
	<u>Piros (T2)</u>	0,7			Piros (T2)	0,7		
	<u>Joao (T3)</u>	0,3			Joao (T3)	0,3		
Other pesticides								

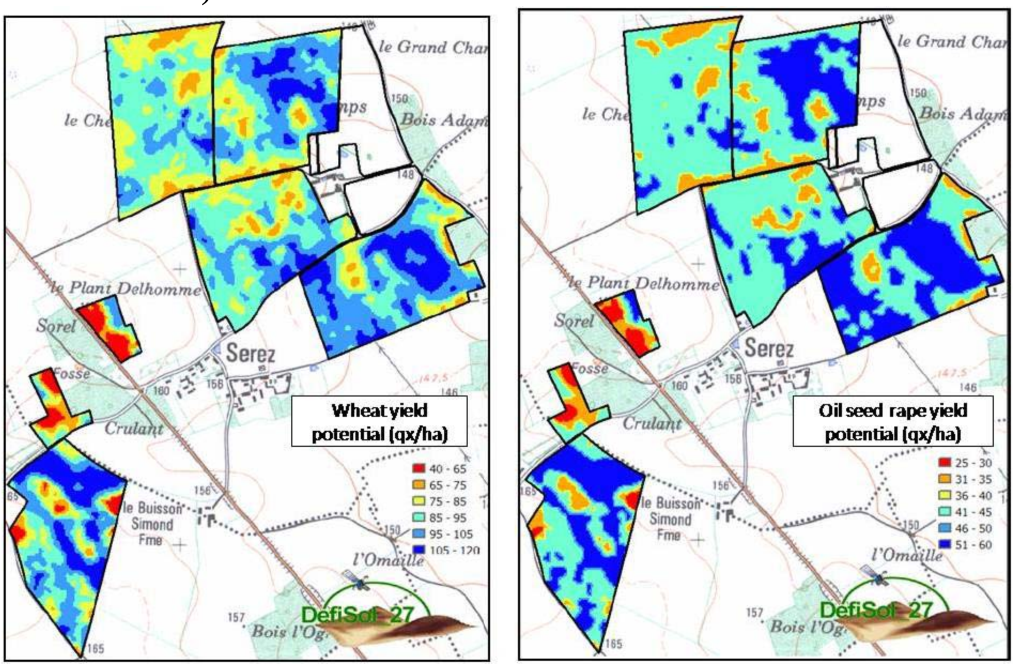
Underlined and bold pesticides are those on wich it is possible to apply SSCM

The yields of wheat and OSR were taken and analyzed using the results of modeling of earlier agronomic trials (Duval et al, 2007 et Bécu et al, 2008). For the other crops (barley and peas), yields were estimated using expert advice.

The soils of these fields are mainly silty over a layer of clay and flint. The intra field heterogeneity was determined by apparent soil electrical conductivity (EC_a). The amount of stone can be up to 50% in some shallow soils, on the other hand it is almost absent in deep soils.

Fungicides application rates vary according to soil heterogeneity. We defined three zones with different yield potentials[1] (High medium and low) based on the measures of soil electrical conductivity (figure 1).

Figure 1: wheat and OSR yield potential maps based on apparent electroductivity of silty soils in Haute-Normandie (Défisol27, personnal communication).



The fungicide rate reduction strategies were in relation to these different yield potential zones. In those where the yield of biomass is greater and the climatic

---

[1] For wheat, in our pedoclimatic conditions, yields above 9,5 t/ha are considered high. When they are between 7,5 and 9,5 t/ha they should be considered medium. Finally, below 7,5 t/ha is considered low.

conditions under vegetation cover is more favourable to the development of disease, the maximum treatment dose is applied (100%). In the zone of medium yield 90% to 80% of maximum dose is applied following the strategy. In the zones of low yield potential the dose reduction can reach 80% to 60% of maximum dose.
The two strategies tested here are therefore:

- Strategy N°1 (S1): 100% (Total dose), 90% and 80% of this dose.
- Strategy N°2 (S2): 100% (Total dose), 80% and 60% of this dose.

The fungicide treatments concerned (table 2) are those applied to wheat (T1, T2, T3) and on barley (T1, T2). The technical references of the used products (prices and doses) came from documents used by the agricultural advisors in our region (fertil'info, 2009).

Economic indicators:

The selected economic factors were production costs, specific pest materiel costs and direct profit margin (gross margin – specific fixed costs)
In our case, Crop Product indicator was established according to the following definition:

Crop Product (CP) = yield*sale price + direct crop subsidy

Variable costs and specific fixed costs for pesticide applying (VCSFCPA) = inputs (fertilizers, seeds, pesticides) + spreader + localisation equipment (GPS, software, electronic box) + maintenance cost of the localisation equipment + technical flowmeter + pressure sensor + site specific material assembly).

Direct Profit Margin (DFM) = CP – VCSFCPA

The spreader equipment could vary depending on the technique applied: pesticide uniform application (PUA) or SSPM. We chose to take into account this specific cost for which the depreciation had been calculated over a five years period. The site specific management material costs are provided by Défisol 27

Inputs and traction costs were calculated per hectare of crops. Those affected at the material used for the site specific pesticide applying were distributed over the total cultivated land (excepted for the spreader maintenance costs which are calculated per hectare). Therefore, the latter will be less significant as the surface area increases.
We chose to distribute the total specific costs throughout the surface area, for the two following reasons:

- Firstly, to work on a global farm unit.
- Secondly, to apply SSPM to various others crops

Economic simulations

Using Olympe (economic simulator software) we were able to work at different scales: field, crop system and farm (figure 2). Thus we simulated the economic profitability of SSCM equipment in the most common crop systems in Haute-Normandie.
Olympe is decision-support software with various functionalities. It can be used as a database, an accounting calculator and a simulator. Different

simulations can be carried out for a cropping system and be compared. In our study, they concerned:

1. Three levels of fungicide applied in relation to the soil heterogeneity.
2. Two dose reduction strategies of fungicide applied.
3. Five levels of fungicide prices.
4. Three surface areas of the cropping system (cereal production system in this case).

The first two points have been defined hereabove. About the third point, since 2005 an increase in fungicide prices has been observed (Agreste, 2010). We, thus, created a simulation of price increase up to the double (10%, 30%, 50%, and 100%). Indeed according to G. Couleaud, to reduce by 40% pesticide use the price must be doubled (Couleaud , 2009). It is, Therefore, imperative to vary fungicide prices in order to define profitability threshold. From this selected hypothesis we wish to reach the french policy objectives of the “Grenelle de l’environnement”.
For the point four, the three tested surface areas are obtained from Rosace (2005).

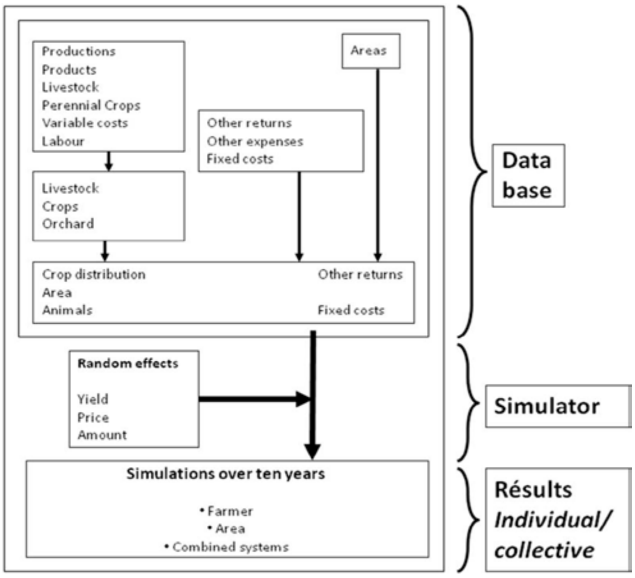


Figure 2: “Olympe” an economic research decision-making tool which is both a data base and a simulator (Attonaty et al., 2005)

In order to simulate the SSPM equipment profitability, the calculation hypotheses were the following:

- The only inputs included in terms of variables in the simulations are the quantities of fungicides on wheat and barley. The spraying costs are identical in PUA and SSPM. The farmers and advisors encountered in our collaboration with Défisol 27 indicated that there was no actual difference in the material need. The extra costs observed arise from electronic equipment specific to SSPM and the monitoring.
- Potential yield spatial variability is based on the ECa measures, since the water resource is the main limiting factor on yield (Duval et al., 2007).

RESULTS

Cereal systems in Haute-Normandie

Table 3 presents the average crop distribution for the 3 typical systems in Haute-Normandie and the details for each cereal production system studied. In these systems, grassland areas are not integrated into the rotation. Neither are these concerned by SSPM. Thus, their costs are unchanged whatever practice used.

Normandy soils are among the richest in France in terms of potential yields, particularly the deep silty soils (Duval et al., 2007). Thus the combination of crop and rotation generates a wide range of crop systems (table 3). The technico-economic profitability of SSPM is therefore complicated at the farm level. We have focused our study on cereal systems since the number of crops to be analyzed is more limited and three different surface areas are available.

These soils are characterized by the potential for upper average yield but also by a high intrafield variability. The apparent electroconductivity (ECa) measurements of the soils translate the variations of soil depth which as an influence on the water reserve available for the plants which affect yield. The depth can vary in the same field from 50cm (with a level of stone which can be high as 50%) to a soil of more than 2 meters of silt without any stones. This depth heterogeneity influences yield potential for OSR and wheat (figure 1). The lowest potential (in red) are between 4 and 6,5 t/ha for wheat and 2,5 and 3 t/ha for OSR. The highest exceed 10,5 t/ha for wheat and 5 /ha for OSR. Thus, the same silty soil plot can vary two fold in terms of yield (figure 1).

Table 3 : Average Crop distribution in 2001 for crop systems in Haute Normandie (%) and average crop distribution for cereal production systems used for simulation (ha). SB = Sugar beet, OSR = oil seed rape, Pt = potatoes, WB= winter barley, Pa = pasture, F=fallow, P =Pea.

crop system	Average Crop distribution in 2001 (%)								
	wheat	SB	flax	Pt	Pa	OSR	P	WB	F
Sugar beet – flax	40	14	12		7		11	8	8
Potatoes	42	7	13	17	7		7		7
Cereal	52				6	18	10	14	
Cereal	Crop distribution in 2001 (ha)								
	wheat	SB	flax	Pt	Pa	OSR	P	WB	F
C1a (95 ha)	49				6	17	10	13	
C2 (145 ha)	75				9	26	15	20	
C3 (240 ha)	125				14	43	24	34	

To this potential yield are associated plant biomass variations and therefore higher risks of diseases in the zones where the biomass is higher. In these zones it is necessary to apply the highest dose (100%) to protect the crop. On the contrary in the zones where the yield is lower, the biomass is lower and it is possible to reduce the maximum dose by 20 to 40% following the strategy applied. In the intermediary zones we can reduce the dose by 10 to 20%.

We have thus classified the soils in three level of soil potential that have been entered into the database (figure 2). For each yield level we have defined in table 4, three level of heterogeneity based on the results most encountered in our region) over a period of 10 years experimentation (70 farmers and 9000 ha analyzed by the GRCETA, unpublished data).

Table 4: Hypothesis concerning three levels heterogeneity of Haute-Normandie's soils (medium, minimum and maximum) in relation with soil depth and three levels of crop yield potentials (low, medium and high)

Soils of Haute-Normandie		Surface area (%) Low potential	Medium potential	High potential
Heterogeneity	maximum	17%	58%	25%
	medium	12%	68%	20%
	minimum	8%	74%	18%

The logic of the classification is the base for the calculations for the quantities of fungicide to be applied. In order to illustrate this methodology we have detailed the approach for the calculation for the quantities of "bravo 500" applied on wheat (S2 : 100-80-60) for a farm of 95 ha (table 5).

Table 5 : Example of calculation concerning Bravo 500 amounts applied for wheat on a 95 hectare farm in relation to the variation of the heterogeneity rates of soils and potential yields.

Crop	Fungicide	Soil Heterogeneity		Yield Potential	Surface area distribution (ha)	Fungicide quantity (en l)	price (€/l)	costs (€)
Wheat (surface area = 49 ha) Farm surface area = 95 ha	Bravo 500 Strategy 2	Maximum	25%	High	12	12	7	84,0
			58%	Medium	29	23,2	7	162,4
			17%	Low	8	4,8	7	33,6
		Medium	20%	High	10	10	7	70,0
			68%	Medium	33	26,4	7	184,8
			12%	Low	6	3,6	7	25,2
		Minimum	18%	High	9	9	7	63,0
			74%	Medium	36	28,8	7	201,6
			8%	Low	4	2,4	7	16,8

We have obtained the quantities and the total cost of this fungicide for wheat in relation to the surface areas concerned by the heterogeneity of the field: maximum and medium heterogeneity (40 kg Bravo 500 applied at a cost of €280) and minimum heterogeneity (40,2 kg Bravo 500 applied at accost of €281,4). The values obtained are almost the same

Diminishing quantities of fungicides with site-specific input management (SSIM) on cereals.

Contrary to the previous study (Bourgain and Llorens, 2009), SSPM does not generate yield variations. The latter are linked to the water reserve and mineral nutrition which determine variable yield potential areas. For reasons of simplification, we chose to focus on pesticides, independently of site specific fertilization management (SSFM). Indeed, SSFM generate yield increases and thus implying economic gains (Bourgain and Llorens, 2009). However the goal of SSPM is only to protect the crop and not to improve yield.

When we compare PUA and SSPM, S1 reduces fungicide doses by about 10% and S2 by about 20%. These can be explained, first by the fact, the heterogeneity levels are centered on the dose 90% for S1 and for 80% for S2. And secondly, by the heterogeneity characteristics where the zone of medium potential varies between 58% and 74% of the surface area. This is in contrast to what observed with SSFM (Bourgain and Llorens, 2009).

Technically only S1 is achievable at the present moment with the available equipment. S2 requires technical development in terms of the possibility of reducing the nozzle flow to 40%.

We wanted to simulate this hypothesis because it is agriculturally conceivable. However this implies risks relating to the weather, the variety used and the intensity of fungal diseases.

These risks can be estimated at 10 or 15% of yield loss (Poletti, personal communication).

Improved gross margin but reduced direct margin.

At 2009 prices, SSPM improves global farm gross margin per hectare thanks to the improvement of cereal gross margin of €5/ha for S1and €10/ha for S2. In our study, the different levels of heterogeneity do not influence gross margin.

At the farm scale the minimum gross margin gain (S1) is €453 for 95 ha and the maximum gain (S2) is €2379 for 240ha. These amounts are marginal, they represent only 1 to 2% of the total gross margin.

The hypothesis of prices doubling implies gross margins gains doubling because it is linked to the fungicide price variation.

Using 2009 prices, SSPM improve gross margin however taking into account specific equipment costs leads to a negative direct margin (table 7). Indeed, in relation to uniform application specific structure costs increases by €3290. The low gross margin gain is insufficient to cover the extra equipment costs. The direct margin loss is lower when surface area is larger. The extra cost linked to the use of this equipment is spread over à larger surface area (from -€30 to -€3 according to the two strategies and production systems).

Under the conditions of our working hypothesis where we are interested only in fungicides on cereals excluding all other inputs, SSPM was not profitable in 2009.

In the framework on strategy N°2, for the largest surface areas (240 ha), an increase of 30 to 50% in fungicide prices an economic balance could be reached (table 7). When the prices double a direct margin gain in the order of €6/ha can be obtained. Thus, SSPM could be profitable in the case where non negligible crop risks are taken in term of treatment strategy and for large cereal farms (240ha).

However, envisaged from an environmental point of view the improvement is significant: treatments are only done in zones where it is necessary, thus avoiding impacts on soil biodiversity (Brussard et al., 2007). These techniques are in accordance with the French policy objectives of reducing pesticides use (Grenelle de l’environnement)

Table 6 : Direct profit margin variation (in €/ha of farm area) between uniform application and site specific fungicide management application in relation with cereal system surface area, different rates of silty soils heterogeneity and different application strategies.

Direct Pofit Margin /ha of farm area				2009 price	+ 10 %	+ 30 %	+ 50 %	100%
			95ha	420	415	404	394	366
	Uniform Application	direct profit margin €/ha	145ha	437	432	421	410	383
			240ha	450	445	434	424	396
			95ha	-30	-29	-28	-28	- 25
		Minimum Heterogeneity	145ha	-18	-18	-16	-15	- 13
Strategy 1:			240ha	-8	-8	-7	-7	- 4
100-90-80	Site Specific fungicide		95ha	-30	-29	-28	-28	-25
	management : Direct Profit	Medium Heterogeneity	145ha	-18	-18	-16	-15	- 13
	Margin variation €/ha		240ha	-8	-8	-7	-7	- 4
			95ha	-30	-29	-28	-28	- 25
		Maximum Heterogeneity	145ha	-18	-18	-16	-15	- 13
			240ha	-8	-8	-7	-7	- 4
			95ha	420	415	404	394	366
	Uniform Application	direct profit margin €/ha	145ha	437	432	421	410	383
			240ha	450	445	434	424	396
			95ha	-25	-24	-22	-20	- 16
		Minimum Heterogeneity	145ha	-13	-12	-10	-8	- 4
Strategy 2:			240ha	-3	-3	-1	1	+ 5
100-80-60	Site Specific fungicide		95ha	-25	-24	-22	-20	- 15
	management : Direct Profit	Medium Heterogeneity	145ha	-13	-12	-10	-8	- 4
	Margin variation €/ha		240ha	-3	-3	-1	1	+ 6
			95ha	-25	-24	-22	-20	- 15
		Maximum Heterogeneity	145ha	-13	-12	-10	-8	- 4
			240ha	-3	-3	-1	1	+ 6

General discussion and perspectives

We limited ourselves in this study to the economic evaluation of fungicides on cereals for several reasons:

- To give economic answers to techniques used by farmers with equipment which presently exist on the market.
- To use techniques applied in the region studied.
- To limit it to fungicide on cereals because it would not be agriculturally appropriate to apply on Oilseed rape or peas.
- To situate it in the context of a farm ready to invest in this type of equipment

In these conditions, the localized application of fungicides is not economical as such mainly because of the high investment costs in equipment. However there are two possibilities which have not been explored and could increase the economic feasibility of this approach. The first is to apply to much larger surface areas using collectively owned equipment. The second is to consider the SSPM in the framework of the localized application of all inputs at farm scale, our previous work (Bourgain et Llorens, 2009) showed that SSFM improved the direct margin (from €35 to €45/ha).

Another area of improvement, in the reduction of pesticides in precision agriculture, is weed control. However, this only concerns post emergent treatments (table 2) because it will be necessary to have maps of weed infestation (Normeyer, 2006). One of the perspectives of this work is to simulate the reduction of herbicides using precision agriculture. Meanwhile, available equipment is only in the form of research prototypes whether for the detection of plants (Burgos-Artizzua et al, 2009) or for localized treatments which must be much more precise for fungicides (Slaughter et al, 2008) if significant reductions in doses are to be achieved. Technology transfer in relation to localized weed control remains to be done for it to be operational on the farm (Normeyer, 2006, Slaughter et al, 2008, Burgos-Artizzua et al, 2009).

The evolution towards reduced pesticide use, thanks to precision agriculture, will take time due to the fact that some technical problems still need to be resolved, nevertheless the process should be started now at three levels:

- In the long term (10 to 15 years), by launching as from now research programmes to develop the means of identifying (the development of specific sensors for weeds (Burgos-Artizzua et al, 2009) and diseases) and treating in a more precise way (Slaughter et al, 2008) the zones concerned (the development of sprayers capable of treating small areas or applying several products at the same time).
- In the medium term (5 years), research and development will be necessary to significantly improve the technical tools implicated in the manufacture of sprayers (increase the utilisation range of nozzles in order to decrease the application rates).
- For the credibility of the site specific pesticide management (SSPM), immediate measures (6 months) such as the establishment of technical references concerning precision agriculture based on technical guidelines for the major crops at the territorial level with all the stakeholders. The diffusion of these techniques will be necessary to demonstrate its efficiency from an economic point of view as well as technical (Jochinke et al, 2007).

Our methodology could be transferable to other regions in which there are silty soils with a substratum which induces differences in depth. The potential yields in function of soil heterogeneity should be defined in advance so that simulations can be adapted to the new reference pedo-climatic conditions.

The perspectives of this work are to simulate environmental externalities such as pollution potential from the excess of plant protection products.
Thus, our methodology using a simulation tool shows that it can be useful at different levels. Firstly, farmers or farm advisors can evaluate the profitability of the investment in site specific management equipment. Secondly for the equipment manufacturers in order to assess the development potential at territorial level (Normandy). Finally to define environmental and economic decision making criteria for policy makers in a framework of European policy to reduce pesticide use to 50% of present levels in 2018.

CONCLUSION

Our method, based on the modelling using Olympe has shown that economically this technique is not viable for the management of fungicides on cereals alone but it should be seen within the global farm context. In the pedo-climatic conditions in Upper Normandy by applying precision agriculture to all the inputs (fertilizer, fungicides and herbicides), their costs are reduced at the level of the cropping system and the direct margin is increased without affecting the yield. This is particularly relevant at a time when the price of inputs and food insecurity are increasing.

Beyond the important developments in agricultural practices in the last 10 years or so, it is indispensable to engage in an in depth process of transformation of agriculture globally and to review the foundations of conventional agriculture, to reconcile economic efficiency, robustness to climate change and to ecological reality. This modernisation of agricultural practices requires the participation of the knowledge and knowhow of all and to confront it to the new challenges and make them more efficient for research, experimentation, exchange and transfer of knowledge. Precision agriculture maybe one possible route towards improvement and our ambition is to offer a large number of decision making criteria for agricultural advisors, machinery manufacturers and policy makers

ACKNOWLEDGEMENTS

This work could not have been carried out without the experimental field trials undertaken by two French farmer groups (GRCETA de l'Evreucin and DEFISOL 27). We should, first of all, like to thank the advisors of GRCETA Vincent Debandt and David Mahieu for their comments and their expert agronomic advice. Finally, a special mention for Bill Edmonds for helping us to find the right words to create this document in English.

BIBLIOGRAPHY

AGRESTE, (2010), bulletin de conjoncture.

Atherton B.C., Morgan M.T. Shearer S.A., Stombaugh T.S., Ward A.D., (1999), Site-specific farming : a perspective on information needs benefits and limitations. Journal of soil and water conservation 54 (2), 455-460.

Attonaty J-M., Le Bars M., Allaya M., Le Grusse P., 2005. Olympe : manuel d'utilisation. CIHEAM-IAM, Montpellier, France,

Bécu M., Duval C., Debandt V., Taïbi S. et LLorens J-M. (2008). Influence of the past history of the addition of fertilizers on the intra field variability of the rate of P and K in the soil: potential of site-specific fertilization. Ageng 2008 - International Conference on Agricultural engineering & Industry Exhibition. Hersonissos – Crete 23-25 June 2008, Greece.

Bourgain O., Michaud M., (2006). Evaluation of the economic impact of agricultural practices aiming at limiting muddy flows : farmers from the Plateau du Neubourg (France). Workshop « the socio-economic aspects in the management of soil erosion » Strasbourg, France 7th – 8th April 2006.

Bourgain O. and Llorens JM. (2009). Methodology to estimate economic levels of profitability of precision agriculture : simulation for crop systems in Haute-Normandie. In EFITA Conferences 09, Wageningen Academic publishers p. 91-98.

Burgos-Artizzua X. P., Ribeiroa A., Tellaecheb A.,Pajaresc G., C. Fernández-Quintanillad (2009). Improving weed pressure assessment using digital images from an experience-based reasoning approach. Computers and electronics in agriculture 65, 176–185.

CER France, (2009). Gérer pour gagner, hors-série régional. 24 p.

Chambre d'agriculture Normandie, BCMA, CUMA, (2008), Coûts d'utilisation prévisionnels des matériels agricoles.

Brussaard, L., de Ruiter, P. C. and Brown, G. G. 2007. Soil biodiversity for agricultural sustainability. Agriculture, Ecosystems and Environment 121: 233–244.

Couleaud, G., (2009). Programme fongicide céréales – un investissement calqué sur le prix du quintal. http://www.terre-net.fr/dossier_special/Fongicides-Cereales-2009.
Dailey, A.G., Smith, J.U. and Whitmore, A.P. 2006. How far might medium-term weather forecasts improve nitrogen fertiliser use and benefit arable farming in the England and Wales? Agriculture, Ecosystems and Environment 117: 22–28.
DeVuyst, E. A. and Halvorson, A. D., (2004). Economics of Annual Cropping versus Crop–Fallow in The Northern Great Plains as Influenced by Tillage and Nitrogen. Agron. J. 96:148–153.
Duval C., Debandt V., Eveillé J-P., Mahieu D, Taïbi S., LLorens JM. (2007) Influence of the pedo-climatic variability in Haute-Normandie (NW France) on the intra field spatial variability on yields of wheat and oilseed rape. In Précision agriculture 07, Wageningen Academic publishers p. 87-94.
Fertil info (2009). special phyto 2010. Chambre d'agriculture de Seine-Maritime, 52p.
Grenelle de l'environnement (2007a). Synthèse du Groupe II – Préserver la biodiversité et les ressources naturelles. 7 pages.
Grenelle de l'environnement (2007b). Synthèse du Groupe III – Instaurer un environnement respectueux de la santé. 6 pages.
Grenelle de l'environnement (2007c). Synthèse du Groupe IV – Vers des modes de production et de consommation durables. 8 pages.
Haefele, S.M. and Wopereis M.C.S. 2005. Spatial variability of indigenous supplies for N, P and K and its impact on fertilizer strategies for irrigated rice in West Africa. Plant and Soil 270: 57–72.
Jochinke, D. C., Noonon, B. J., Wachsmann, N. G. and Norton R. M. (2007). The adoption of precision agriculture in an Australian broadacre cropping system—Challenges and opportunities. Field Crops Research 104: 68–76.
Koch, B., Khosla, R., Frasier, W. M., Westfall, D. G. and Inman D. (2004). Economic Feasibility of Variable-Rate Nitrogen Application Utilizing Site-Specific Management Zones. Agron. J. 96:1572–1580.
Link, J., Graeff, S., Batchelor W. D. and Claupein W. (2006). Evaluating the economic and environmental impact of environmental compensation payment policy under uniform and variable-rate nitrogen management. Agricultural Systems 91: 135–153.
Lobell D.B. (2007). The cost of uncertainty for nitrogen fertilizer management: A sensitivity analysis. Field Crops Research 100: 210–217.
Melakeberhan, H. and Avendaño, F. (2008). Spatio-temporal consideration of soil conditions and site-specific management of nematodes. Precision Agric 9: 341–354.
Nordmeyer H. (2006). Patchy weed distribution and site-specific weed control in winter cereals. Precision Agriculture 7, 219–231.
Robert, P. C., (2002). Precision agriculture: a challenge for crop nutrition management. Plant and Soil 247: 143–149.
ROSACE, (2003) Réseau d'observation des systèmes agricoles pour les conseils et les études.
Sartori, L., Basso, B., Bertocco, M., Oliviero, G., (2005). Energy Use and Economic Evaluation of a Three Year Crop Rotation for Conservation and Organic Farming in NE Italy. Biosystems Engineering 91: (2) 245–256.

Slaughter D.C. Giles D.K., and Downey D. (2008). Autonomous robotic weed control systems: A review. computers and electronics in agriculture 61, 63–78.

Swinton SM, Lowenberg-DeBoer J , (1998), Evaluating the profitability of site-specific farming, Journal of precision agriculture 11 (4), 439-446