Result-oriented versus input-oriented instruments: the case of pest resistance to pesticides

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Why use pesticides ?

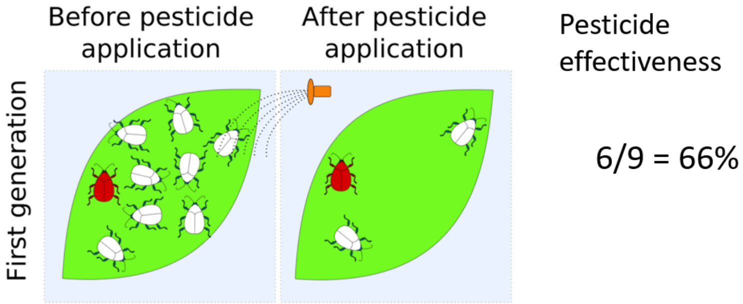
- Increase global agricultural production :
  - Reach food self-sufficiency
  - Increase farmers' profits
- Farmers use pesticides $\rightarrow$ chemical substances used for the prevention, control or elimination of unwanted organisms that harm crops.

Overuse of pesticides leads to air and water pollution

Source: https://www.indiamart.com/proddetail/agricultural-pesticides-21189530812.html

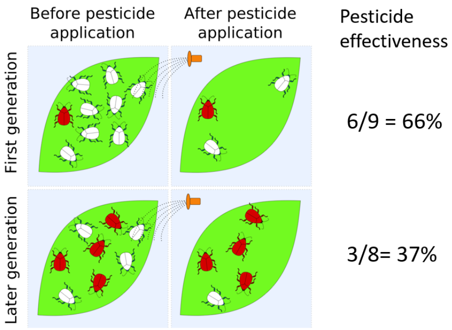
Source: https://www.bioaddict.fr/article/pesticides-alerte-a-la-contamination-des-cours-d-eau-a6089p1.html

Overuse pesticides leads to pest resistance



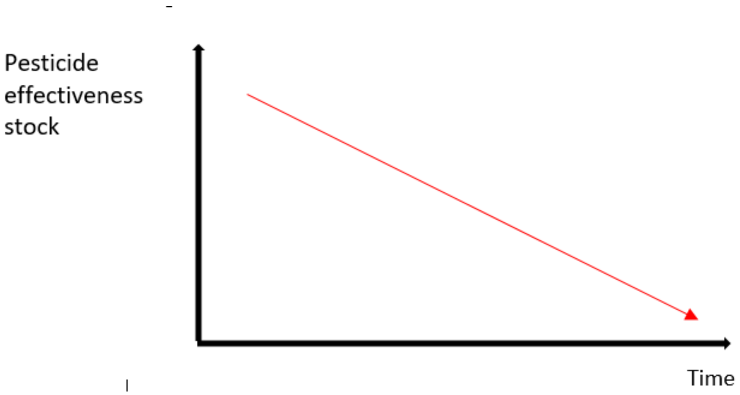
- 6 ⇒ Number of pests which die after pesticide application
- 9 ⇒ Total population before pesticides application.

Pest resistance : a dynamic phenomena



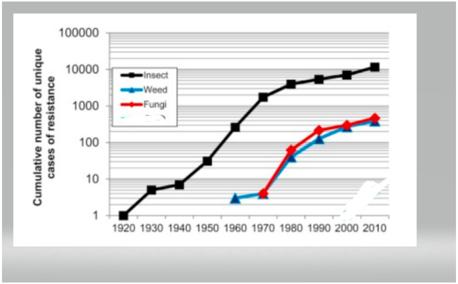
- After repeated applications, resistant pests constitute the majority of the population

Effectiveness of pesticides decreases over time



Cumulative increase in individual cases of resistance to insecticides, herbicides and fungicides

Source : Pesticide Biochemistry and Physiology 121 : 122-128



- With this graphics, the number of pest resistance to pesticides is increasing over time, which is worrying.

Resistant pests cause crop diseases : Case of wheat

SEPTORIA TRITICI BLOTCH (STB) CAUSED BY ZYMOSEPTORIA TRITICI (FUNGUS)

- Up to 50% yield losses during severe epidemics
- 70% of the estimated volume of fungicides used on cereals in Europe
- Increase the cost of pest control
- Reduces farmers' profits.

Fones and Gurr 2015 Fungal Genetics and Biology 79: 3-7

Definitions of some pest management

The social management is the part of the regulator where there is the possibility to cooperate and take into account all the externalities contrary to private management

Definitions of different pest management

Social management

Private management

Intertemporal production externalities in the form of pest resistance to pesticides

Solutions to reduce the use of pesticides

2020 European Green Deal & Farm to Fork strategy :

- Decrease the use and risk of chemical pesticides by 50% by 2030

The French National Action Plan : Ecophyto (Launched in 2008)

- 2018 : Reduce the use by 50% by 2025.

Instruments to reduce the use of pesticides

- Input-oriented instrument : tax each unit of pesticide purchased.
- Results-oriented instrument : farmers are rewarded with the provision of environmental goods such as the presence of certain birds in the field.

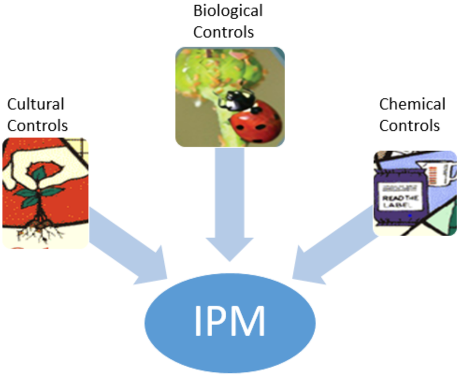
Integrated Pest Management (IPM)

Food and Agriculture Organization of the United Nations (FAO 2020) :

- « The careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human and animal health and the environment ».
- IPM ⇒ Sustainable Agricultural Practices

The principle of IPM

- Combine different chemical and non-chemical pest control strategies.



First contribution of the study

- We use **chemical + mechanical = IPM** to manage pesticide resistance, unlike **(Cornes et al., 2001, Elsa Martin, 2015) :** Chemical
- First study measuring the effect of IPM on pesticide resistance management in the presence of production externality

Second contribution of the study

- We use **results-oriented instruments** to solve the problem of pest resistance to pesticides which seem more effective in reducing pesticide use, therefore the supply of environmental goods (**Bredemeier et al., 2022 ; Drechsler, 2017 ; Burton and Schwarz, 2013**) contrary to,
- **Input-oriented instruments** which have shown their limits in the reduction of pesticides (**Skevas et al., 2012 ; Böcker and Finger, 2017 ; Ayoubaand Vigeant, 2020**)
- Literature on resistance management(**Regev et al., 1983 ; Ambec and Desquilbet, 2012 ; Martin, 2015), input-oriented instruments are used more.**
- First study using of results-oriented instruments to solve the problem of pest resistance to pesticides.

Discrete time model

- Two period model
- Two farmers i and j who are neighbours
  - They have the same meteorological conditions, land quality
  - The only difference between them is their pest control strategy
  . farmer i : chemical
  . farmer j : chemical + mechanical= IPM

Period 1 : production functions

$$f_1(x_{i1}, h_{i1}) = w x_{i1}^{\alpha} h_{i1}^{\beta_{hi}} \quad (1)$$

$$g_1(x_{j1}, h_{j1}) = w x_{j1}^{\alpha} h_{j1}^{\beta_{hj}} m_{j1}^{\beta_{mj}} \quad (2)$$

- h : chemical treatment
- x : other inputs
- w : meteorological index parameter
- m : mechanical treatement
- α : partial elasticity of other inputs
- β_{hi} and β_{mj} $\Rightarrow$ respectively the partial elasticity of the chemical and mechanical treatment.

Period 2 : production functions

$$f_2(x_{i2}, h_{i2}, h_{i1}, h_{j1}) = w x_{i2}^{\alpha} (h_{i2} - \theta [h_{i1} + h_{j1}])^{\beta_{hi}} \tag{3}$$

$$g_2(x_{j2}, h_{j2}, h_{j1}, h_{i1}) = w x_{j2}^{\alpha}\, m_{j2}^{\beta_{mj}} (h_{j2} - \theta [h_{i1} + h_{j1}])^{\beta_{hj}} \tag{4}$$

- Production in period 2 are negatively affected by the overall level of pesticide use in the first period $[h_{i1} + h_{j1}]$
- θ (0,1) : level of resistance to chemical treatment.
- θ tends to 1 $\Rightarrow$ production decreases

Production cost functions

$$C_{it} = c\,x_{it} + z_h\,h_{it} \tag{5}$$

$$C_{jt} = c\,x_{jt} + z_h\,h_{jt} + z_m\,m_{jt} \tag{6}$$

- t : period (1, 2)
- c : unit cost of other inputs
- z_h : unit cost of chemical
- z_m : unit cost of mechanical

Period 1 : profit functions

$$\pi_{i1} = w x_{i1}^{\alpha} h_{i1}^{\beta_h} - c x_{i1} - z_h h_{i1} \tag{7}$$

$$\pi_{j1} = w x_{j1}^{\alpha} h_{j1}^{\beta_h} m_{j1}^{\beta_m} - c x_{j1} - z_h h_{j1} - z_m m_{j1} + S \tag{8}$$

- S : subsidy granted to the farmer j thanks to the adoption of Integrated Pest Management

Period 2 : profit functions

$$\pi_{i2} = w x_{i2}^{\alpha} (h_{i2} - \theta [h_{i1} + h_{j1}])^{\beta_h} - c x_{i2} - z_h h_{i2} \tag{9}$$

$$\pi_{j2} = w x_{j2}^{\alpha} m_{j2}^{\beta_m} (h_{j2} - \theta [h_{i1} + h_{j1}])^{\beta_h} - c x_{j2} - z_h h_{j2} - z_m m_{j2} \tag{10}$$

- Profits of the second period are negatively affected by the overall level of pesticide use of the previous period $[h_{i1} + h_{j1}]$

Definition of Private Management

- Private Management ⇒ is such that in each period, farmers i and j choose their input levels to maximise their profits
- Each farmer thinks about his own profit, but ignores the impact of his pesticide use strategy on his neighbour's profit.
- Farmers don't take into account all the externalities

A difference between the chemical quantity of i and j

Period 1 :

Farmer i $$h_{i1} = \left(\frac{pw\,\beta_h}{z_h(1+\delta\theta)}\right)^{\frac{\alpha-1}{\alpha+\beta_h-1}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_h-1}}$$

Farmer j $$h_{j1} = \left(\frac{pw\,\beta_h}{z_h(1+\delta\theta)}\right)^{\frac{\alpha+\beta_m-1}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\,\beta_m}{z_m}\right)^{-\frac{\beta_m}{\alpha+\beta_m-1+\beta_h}}$$

- An important difference between farmers i and j is β_m (partial elasticity of the mechanical treatment)

β_m marks a difference between the chemical quantity of i and j

Period 2 :

Farmer i $$h_{i2} = \left(\frac{pw\,\beta_h}{z_h}\right)^{\frac{\alpha-1}{\alpha+\beta_h-1}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_h-1}} + \theta(h_{i1} + h_{j1})$$

Farmer j $$h_{j2} = \left(\frac{pw\,\beta_h}{z_h}\right)^{\frac{\alpha+\beta_m-1}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\,\beta_m}{z_m}\right)^{-\frac{\beta_m}{\alpha+\beta_m-1+\beta_h}} + \theta(h_{i1} + h_{j1})$$

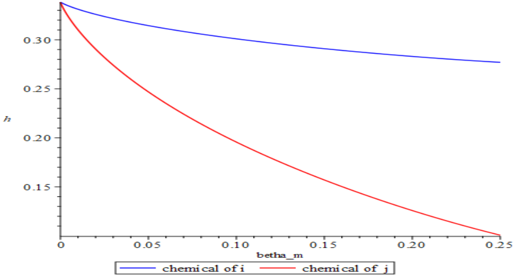
Importance of partial elasticity of mechanical treatment, β_m

- Key element of Integrated Pest Management
- It is supposed to reduce the use of chemicals, thus limiting the development of resistance, thus increasing production
- Measure its effect on the chemical quantity of farmers

IPM reduces overall level of pesticide use

Period2 :

Fig.2.The effect of betha_m on farmers' chemical quantities in private in the second period



- A lower application of pesticides in the second period helps to limit the development of pest resistance → increase production.

Definition of Social management

- Social planner maximises the discounted sum of farmers' profits.
- Takes into account the impact of farmer i's pesticide use strategies on farmer j's profit and vice versa.
- Chooses the socially optimal input levels for each farmer in each period

Chemical treatments are higher in private management than social management

Farmer i

Private: $$h_{i1} = \left(\frac{pw\,\beta_h}{z_h(1+\delta\theta)}\right)^{\frac{\alpha-1}{\alpha+\beta_h-1}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_h-1}}$$

Social: $$h_{i1}{}^{so} = \left(\frac{pw\,\beta_h}{z_h(1+2\delta\theta)}\right)^{\frac{\alpha-1}{\alpha+\beta_h-1}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_h-1}}$$

- The Difference is the 2 in social management where the social planner takes into account all externalities, unlike private
- $h_{i1} > h_{i1}^{so}$

Chemical treatments are higher in private management than social management

Farmer j

Private: $$h_{j1} = \left(\frac{pw\,\beta_h}{z_h(1+\delta\theta)}\right)^{\frac{\alpha+\beta_m-1}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\,\beta_m}{z_m}\right)^{-\frac{\beta_m}{\alpha+\beta_m-1+\beta_h}}$$

Social: $$h_{j1}{}^{so} = \left(\frac{pw\,\beta_h}{z_h(1+2\delta\theta)}\right)^{\frac{\alpha+\beta_m-1}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\alpha}{c}\right)^{-\frac{\alpha}{\alpha+\beta_m-1+\beta_h}} \left(\frac{pw\,\beta_m}{z_m}\right)^{-\frac{\beta_m}{\alpha+\beta_m-1+\beta_h}}$$

- $h_{j1} > h_{j1}^{so}$

Instruments

We used two instruments :

- Input-oriented instrument :
- Result-oriented instrument :
- Comparisons of input and result instruments

First instrument : Input-oriented instrument

- Tax on each unit of pesticide purchased, which increases the unit cost of the pesticide
- The first optimal tax regime , $\tau = z_h \theta \delta$.
- The optimal tax on pesticides, increases with θ.

$$\frac{\partial \tau}{\partial \theta} > 0$$

Indeed, when the level of resistance increases, the tax also increases to oblige farmers to reduce the use of pesticide.

Second instrument : Result-oriented instrument

- Tax the level of resistance

How to measure the level of pesticide resistance ?

This level of pesticide resistance could be measured, for example, by referring to the intensity of weeds present in the field after one dose of pesticide application against the weeds.

Expression of the optimal tax on result

- The second optimal tax regime , $\tau_1 = z_h$.
- The optimal tax on the result increases with the unit cost of the chemical input, $\frac{\partial \tau_1}{\partial z_h}$>0
- If the unit cost of chemical treatment increases, farmers may prefer to be taxed on the result rather than on the input.

The least costly policy is the one that is result-oriented

We compare of input and result instruments :

- The marginal cost ratio : $\frac{z_h(1+\theta\delta)+\tau}{z_h(1+\theta\delta)+\tau_1\theta\delta}>1$,
- Numerator we have the marginal cost with the input-oriented instrument and in the denominator the result-oriented one.
- This ratio shows that the least costly policy is the one that is result-oriented.

Summary

- Faced with the externality of production, IPM can reduce the overall level of pesticide use $\Rightarrow$ effective to limit the development of pest resistance
- Encourage farmers to adopt IPM
- Treatments are more intensive in private management than in social management
- Result-oriented taxation is a cost-effective way of solving this problem.

Thank you for your attention

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