Climate change mitigation to restore water resources:

The contribution from vineyards management to reduce greenhouse gases.

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Abstract

Climate change is a reality that is already producing damage. Human activities have been raising the concentration of greenhouse gases and, therefore, increasing global warming. Nearly 15 percent of these gas emissions come from agricultural activities through the burning of fossil fuels, the decomposition of organic matter and the burning of biomass. The modern viticulture brought an increase of emissions and higher costs, mostly from the control of fungal diseases. Furthermore, we have to consider the concern of consumers about the negative effects of agrochemicals on product quality, health and the environment. Therefore, it is necessary to integrate new technologies that allow the simultaneous reduction of emissions, the use of agrochemicals and costs. Using simulation analysis, the purpose of this work is to present and quantify the ecological and economic advantages of cultivate vineyard with low-input management practices: the use of vines resistant to major diseases (the powdery and downy mildews) and the minimal pruning system. The hybrids from the first crossing between the European *Vitis vinifera* with the American *Muscadinia rotundifolia* and successive back-crossing with quality wine varieties, have advantages that are not only environmental (lower greenhouse gas emissions) but also economic (by reducing costs of agrochemical products). The hybrids are obtained by conventional methods, without genetic engineering, which has the advantage of keeping them out of the current debate about genetically modified organisms. Minimal pruning is a trellis system developed in Australian whose main objective is the reduction of the grape production costs of hectare. The researches carried out at the INRA Experimental Unit of Pech Rouge showed that the use of both technologies allow to reduce in 44 % the Carbon dioxide emissions, in 57 % the use of agrochemicals, in 64 % the cost of vineyard operations and in 56 % the time of manual labours employed during the vine's growth.

Keywords: Climate Change; Emissions; Costs; Grapevine; Hybrids; Minimal pruning

Introduction

There is scientific evidence that the average temperature of the earth's surface is increasing because of the greater concentration of carbon dioxide and other greenhouse gases in the atmosphere. This is due to human activity, to the burning of fossil fuels, to changes in the use of the earth and to agriculture. In the 21st century, if measures are not taken, the temperature will go up by between 1.5 and 5.5º C and sea level will rise by around 0.5 m (Houghton, 2001).

The consequences of climatic change are many: a decrease of agricultural productivity due to extreme climates, droughts and water shortage, a loss of biodiversity, a rise in sea level, more extreme climatic phenomena, etc. Not all regions will be affected in the same way but, in Mediterranean countries, it is forecast that summer rainfall will be between 20 and 40% lower in 2080, which will affect agriculture and forest fires (Mestre F., 2003; Medio ambiente para europeos, 2005).

Carbon dioxide is the principal component of the greenhouse gases (GHG) derived from human activities. Its concentration in the atmosphere has grown from 200 ppm in the last ice age (approximately 20,000 years ago.), to the current 371 ppm. If adequate policies are not adopted to limit and reduce the emissions of these gases, the concentration of carbon dioxide could increase to between 540 and 970 ppm in 2100 (IPCC 2001).

CO_2 is responsible for two thirds of the increase of the greenhouse effect (Houghton, 2001). A decrease in the emission of this gas in Spanish vine cultivation would be an important contribution at the global level because, of the 4,310,000 ha cultivated in Europe, 1,200,000 ha belong to Spain, the country with the largest cultivated area in the world (www.areadelvino.com data from FAO, 2003).

The use of news technologies reducing significantly the use of machineries in vine production can be an effective tool to decrease the emission of CO2. In this way, the consumption of fuel and the emissions of gas will also decrease in the vineyard with the integration of low-input management practices (Tristram et al., 2002)

There are two types of technologies that allow approaching this target: i) the use of vines resistant to major diseases (the powdery and downy mildews) and ii) the light pruning techniques (minimal pruning).

The downy mildew, (*Plasmopara vitícola)* exists in most countries where the vine is cultivated. A native of North America, it was introduced into Europe at the end of the 19th century. The European vine, *Vitis vinifera*, sensitive to this disease, gave rise to its spreading throughout European vineyards. Nowadays, it is one of the most destructive vineyard diseases. It mainly affects the leaves, but also the grapes, and lowers the quality of the wine. It causes defoliation, reduces the quantity and quality of the grapes and dries new shoots. When the climatic conditions for its development are favourable, the illness can destroy between 50 and 75 % of the harvest (Agrios, 1997). Most European varieties need to be protected through the use of fungicides for an adequate control of the disease. In Spain, mildew is an endemic disease in the northern vineyards where rainfall is higher (López Fernández J.A., 1998).

The powdery mildew, (*Uncinula necator)* also from North America, appeared in Europe before downy mildews. In Spain it is widespread in vineyards and its severity is increasing mainly because of the generalisation of the use of sensitive varieties like Tempranillo, Cabernet Sauvignon, Chardonnay, Mazuelo and Merlot (Pérez de Óbanos, 1996). The damage that this disease causes can be seen on the surface of the green organs of the plant. It attacks leaves, vine shoots, and fruit, causing most damage to the latter. Although it can attack pre-flowering fruit, the optimum receptivity is for grapes of 5-7mm diameter. The fruit ceases to grow, turns whitish at first before later blackening, and tends to burst before reaching phase of beginning of maturity. The conditions favourable for this fungus are a lack of ventilation, with high relative humidity and temperatures of around 25ºC (López Fernández J, 1998).

As well as management practices to reduce the effects of the disease (variety, watering regimes, elimination of the leaves, etc.) and advances in biological control (e.g. the antagonist *Ampelomyces sp*.), the most utilised method of control is the use of fungicides. The control of powdery and downy mildews is efficient with sulphur and copper, which, in France in 1999, cost approximately 152 million euros, with an average of eight treatments annually (Bouquet *et al.*, 2000). The efficacy of the fungicides has been annulled by the appearance of resistant species of this fungus. Furthermore, the overuse of copper and sulphur has harmful effects on the environment and on the biology of the soil. Therefore, the substitution of these treatments by varieties that are completely or partially resistant to some diseases may be beneficial to viticulture and environmentally friendly.

At worldwide level, the qualitative improvement of grape varieties for wine production has been accomplished by two distinct and supplementary ways: clonal selection within the traditional grape varieties (Audeguin *et al.*, 1998 ; Audeguin *et al.*, 1999), and crossing between these grape varieties, resulting in new varieties, usually called "métis" in France (Bouquet and Boursiquot, 1999 ; Bouquet *et al.*, 2001).

At the same time, selection was also orientated to the parasites resistant grapevine varieties and notably to both the most important fungus diseases, the powdery and downy mildews.

From the end of the XIXth century, there were created varieties, direct producer hybrids, from interspecific hybridization between *Vitis vinifera* European species and different American species used as sources of resistance (Galet, 1988). One of these crossbreeding was carried out at the beginning of the 20th century in the USA between a cultivar of *Vitis vinifera* and an autochthonous species, *Muscadinia rotundifolia* (Detjen 1916). Half a century later, it was recovered in France to initiate a new way in breeding for disease resistance (Bouquet, 1980). The American species *Muscadinia rotundifolia* is genetically distant from the species *V. vinifera*, and their hybridisation is complicated because they have a different number of chromosomes (2n=38 in *Vitis vinifera* and 2n=40 in *Muscadinia rotundifolia*). The F1 hybrids show little similarity between the genomes, which implies a genetic imbalance in the plants, and leads to anomalies in their development and fertility.

Since 1974, the INRA has been carrying out a breeding based on successive back-crossing of this F1 hybrid with different cultivars of *Vitis vinifera* to select resistant genotypes to powdery and downy mildew. At each stage/In each crossing/generation, the *Muscadinia* part is reduced by 50 % with respect to the previous one, thus increasing the percentage of *Vitis vinifera*. After six back-crossings, total resistance to powdery mildew has been achieved in *Vitis vinifera*. The resistance to powdery mildew comes from a dominant gene called *Run* 1 (Resistant to *Uncinula necator*), which is expressed in the same way in leaves, fruit and branches. Resistance shows as a hypersensitive reaction that isolates the fungus, surrounding it with dead cells that impede its development. The resistant plants, R5 (obtained in the fifth back-crossing), are being tested in the field to evaluate their growing characteristics and the organoleptic qualities of their wine, and various R6 descendants are in the nursery/seedbed after having demonstrated their partial resistance to downy mildew. Work is in progress to introduce in *V. vinifera* other genes of *M. rotundifolia* conferring high resistance to downy mildew and some authors suggest that this resistance is conferred by a unique major gene named Rpv1 (Merdinoglu *et al.*, 2003). Moreover, Rpv1 was shown to be tightly linked to the dominant gene conferring resistance to powdery mildew, Run1.

At present there are next to 1200 resistant genotypes which are located on INRA units from Languedoc-Roussillon (Vassal and Chapitre). On the base of all these works, nowadays the INRA develops a selection program for traditional wines, low alcoholic wines and grape juices production (Figure 1).

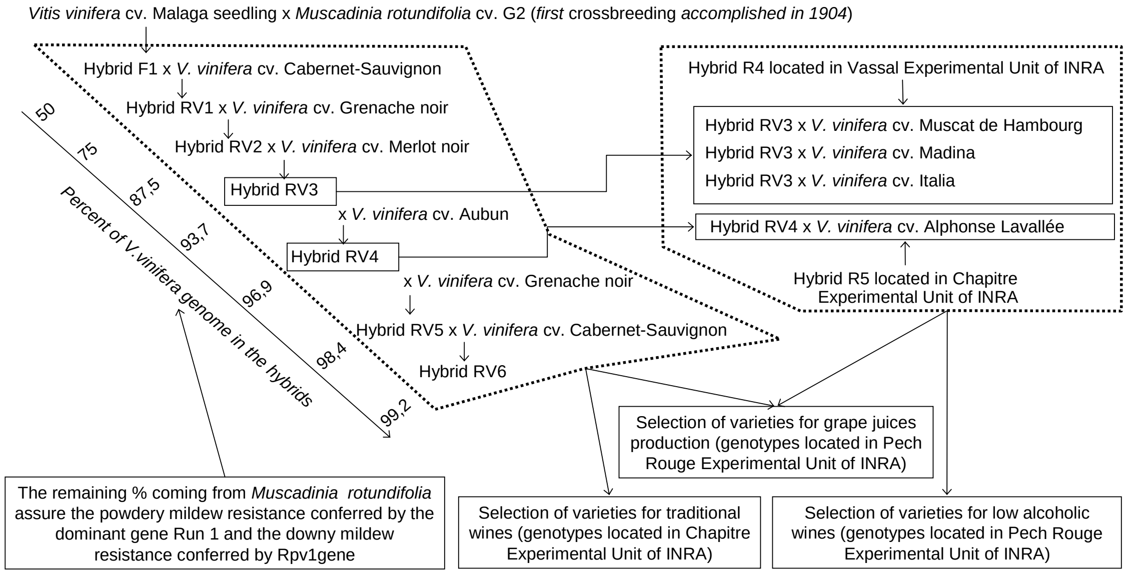

Fig. 1. Scheme of selection program and genealogy of the varieties resistant to powdery and downy mildew carried out by INRA geneticist from successive back-crossing of F1 hybrid of *Muscadinia rotundifolia* with different cultivars of *Vitis vinifera*.

Though, at present, there is no work being done on the subject, if the gene could be isolated and its sequence known, it could, in the future, be introduced directly into *Vitis vinifera***.** In this way, it could transform the genetics of highly sensitive varieties like Tempranillo, Cabernet Sauvignon and Chardonnay, while conserving their morphological and organoleptic characteristics (Bouquet *et al.* 2000).

At the moment there is widespread debate about genetically modified organisms (GMO). Genetical engineering projects are seeking diverse objectives, among them that of reducing production costs with the introduction of genes that are resistant to plagues or disease and that of increasing the quality of the product. The same objectives are sought with the use of hybrids though much more time is required and the costs are higher. Both techniques involve the transfer of genes, but through hybridisation this process is brought about naturally.

A decrease in the application of agrochemical products in the cultivation, as well as being important environmentally, would bring significant economic benefits. The cultivation of the vine in Spain occupies an important surface area, only surpassed by cereals, fruit trees and olive groves. The most relevant illnesses of the vine, both, from the epidemiologic point of view and from economic side, are mildew, which costs 11 million euros per year (53 %) and powdery mildew, which costs 7.5 million (36.8 %). Together they account for almost 90 % of the cost of controlling the problems caused by pathogenic fungi (López Fernández J. A., 1998).

Another low-input agronomic practice that allows reducing the use of machinery is the Minimal pruning (MP). MP is a trellis system developed in Australian whose main objective is the reduction of the grape production costs of hectare (Clingeleffer, 1984, 1992; Possingham, 1996; Martinez de Toda and Sancha, 1999, Poni *et al*., 2000; Reynolds and Wardle, 2001). Minimal pruning is based on the principle that a minimally pruned vine may become self-regulating in term of balance between the vegetative growth and the yield. This trellis system, that allows the elimination of pre-pruning, pruning, and the majority of green operations in vineyard, was studied in the southern of France with very promising results due to its productive and qualitative performances, notably in moderate vigour conditions (Deloire et al. 2004, Ojeda et al. 2007). In this situation TM allows an economy of production costs near of 20% (Rousseau et al. 2007).

The principal aim of this work is to present and quantify the ecological and economic advantages of cultivate vineyard with the integration of two low-input agronomical practices that allows to reduce significantly the use of fungicides, the costs of production and the emission of CO_2: the use of grapevines genotypes resistant to powdery and downy mildews and the Minimal pruning system.

2. Materials and methods

2.1. Experimental site

This research was carried out at the Experimental Unit of Pech Rouge (INRA), in Gruissan, France, on seven plots that are representative of the different zones and varieties that exist in the Experimental Unit (Table 1). The soil and mesoclimate characteristics are represented by three different zones: “Littorale”, “La Clape” and ”Les Colombiers“.

- The *Littorale* zone, with 12 ha of vineyard, lies along the coast with an average altitude of 2 m above sea level. Its soils are between clay-loamy and sandy, and it does not belong to any *Appellation D’origine Contrôle* (AOC). The roots are not very deep because of the presence of a saline stratum and the crop yield does not exceed 50hl/ha (6000 kg/ha).
- The *La Clape* mount belongs to the AOC Corbières. It has an average altitude of 40 m and its soils are calcareous, of good structural stability and very stony. The crop yield does not exceed 35 hl/ha (4500 kg/ha).
- ¨*Les Colombiers*¨ is at an altitude of 100-120 m and is also within the AOC Corbières. Its soils are stony and calcareous-loam-sandy. They are relatively deep, which allows adequate crop yields.

Table 1

Main characteristics of different plots selected for the study

Plot number	Zone	Surface (ha)	Variety	Clone	Rootstock	Year of plantation
55	Littoral	1,23	Viognier	642	SO4	1996
63	La Clape	1,14	Syrah	99	140 R	1990
69	La Clape	1,65	Mourvèdre	collection	140 R	1990
74	La Clape	0,38	Carignan	collection	R 110	1998
76	La Clape	1,73	Syrah	174	140 R	1993
81	La Clape	1,43	Chardonnay	141	140 R	2000
96	Les Colombiers	0,70	Grenache N.	collection	SO4	1975

2.2. Simulation conditions

Using the traceability data from the 2004 and 2005 campaign, different comparisons was made by simulation studies changing the *Vitis vinifera* cultivated varieties by resistant grapevines cultivated with conventional management (trained on a vertical trellis and pruned as bilateral cordon) or with minimal pruning (with the elimination of pre-pruning, pruning, and a big part of green operations in vineyard).

The emissions of CO2 were calculated with the method proposed by R. Lal (2004). In the case of product application, we take the emissions produced by the use of machinery and, in the case of pesticide, those that come from the process of manufacture. To make the data easier to compare, the results are unified and converted to kilograms of carbon equivalent (kg.CE). A comparison of the economic costs of the management practices and the pesticides products has also been carried out (€/ha), and the time spent on culture practices (h/ha) per plot has been calculated.

The same treatment was done, comparing pure *Vitis viniferas* with hybrids resistant to the fungal diseases. In the cultivation of the resistant varieties the application of products against powdery and downy mildews were eliminated, and only applications against *Botrytis bunch rot*, insecticide and herbicide treatments were carried out (Table 2). In the products application, those corresponding to powdery and downy mildews control were eliminated, maintaining without any alterations the rest. To obtain the total benefits, it has been considered reductions in both applications and manufacture of products. In the same way, the effects of resistant genotypes trained on Minimal pruning trellis system was compared, with the elimination of pre-pruning, pruning, and the majority of green operations in the vineyard.

Table 2:

Vineyard labors comparing *Vitis vinifera* cultivate varieties and resistant genotypes with conventional management (trained on a vertical trellis and pruned as bilateral cordon) and resistant genotypes vineyards trained in Minimal pruning trellis system.

Labor	*Vitis vinifera* + conventional management	Resistant hybrids + conventional management	Resistant hybrids + minimal pruning
Pre-pruning (mechanical)	yes	yes	no
Pruning (manual)	yes	yes	no
Product applications to powdery and downy mildews control (mechanical)	yes	no	no
Product applications (other than powdery and downy mildews) (mechanical)	yes	yes	yes

soil labors (mechanical)	yes	yes	yes
Divers green operations (manual and mechanical)	yes	yes	partially
Divers fertilizations (soil and foliar) (mechanical)	yes	yes	yes
Harvesting (mechanical)	yes	yes	yes

3. Results and discussion

3.1. Emissions

According to the traceability data, the simulation in each of the vineyard plots selected considering the greenhouse gases emissions corresponding to the pesticides application (Figure 2), showed an average reduction of 43.3 kg CE/ha (-57.1 %) by the use of resistant genotypes in comparison to the *Vitis vinifera* cultivate varieties. There were no differences between the conventional management and minimal pruning because the products applied in each situation are similar (data no showed).

The agro-ecological conditions of each plot determine the differences on CO2 emission. In fact, the plot # 69, cultivated with the variety Mourvèdre, shows the highest emissions because it is sensitive not only to powdery and downy mildews, but also to infection by the fungus *Botrytis cinerea* and to the attacks of mites and insects. In short, Mourvèdre needs more chemicals applications. Another similar case is the plot # 74 cultivated with Carignan, variety particularity sensitive to powdery mildew. An opposite case is the Syrah (plots # 63 and 76), less sensitive than others varieties.

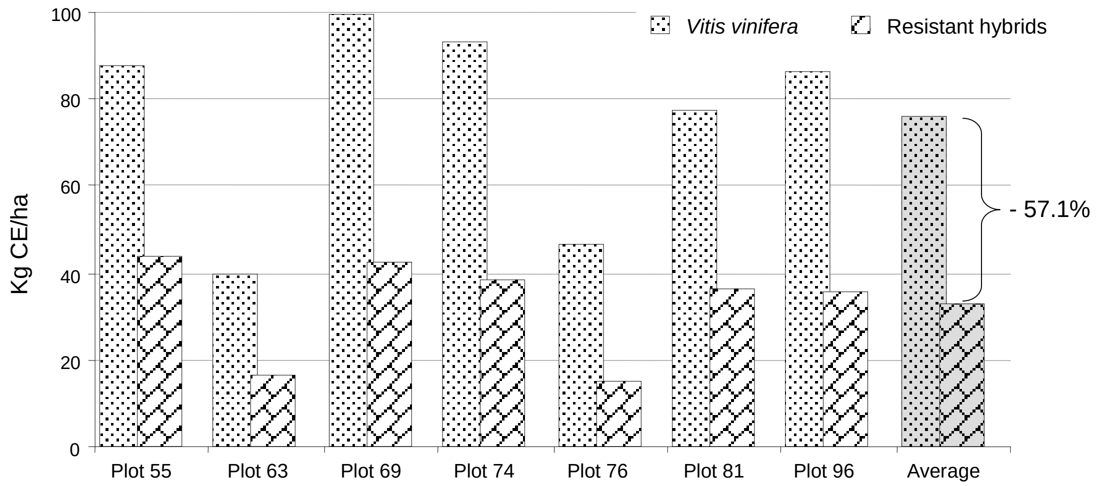

Fig. 2. Emissions (kg CE/ha) due to the products application comparing *Vitis vinifera* cultivate varieties and resistant genotypes with conventional management.

The emissions by the use of agricultural machines (without considering the product applications) were considerably lower (-39.7 kg CE/ha) to the vineyards training on minimal pruning compared to conventional management (trained on a vertical trellis and pruned as bilateral cordon) (Figure 3). The elimination of pre-pruning, pruning and some green operations in minimal pruning system reduce significantly the machine employment (-35.4%).

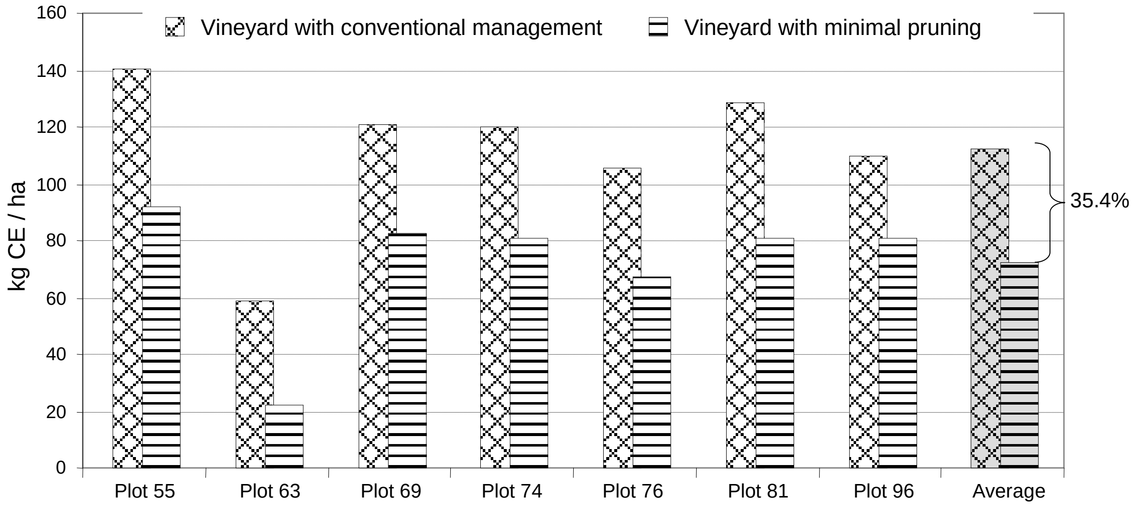

Fig. 3. Emissions (kg CE/ha) comparing the vineyards with Minimal pruning and with conventional management.

With the integration of both low-input management practices (*Vitis vinifera* cultivate varieties with conventional management and resistant genotypes vineyard trained in minimal pruning trellis system), the carbon emissions by the use of machineries decreased even more significantly: the global reduction was of -48.5 kg CE/ha (-25.8 %) for the use of resistant genotypes and increases to -83 kg CE/ha (-44.1 %) incorporating the minimal pruning (Figure 4).

The number of culture practices and the quantity of pesticides applications vary according to the agro-ecological conditions of each plot, principally the variety and the soil type. In plot 63 the emissions are low because in this plot the soil labours are not frequent (calcareous rock soil), the pest treatments are few, and the elimination of pruning and the reduction of shoots positioning interventions bring about a more than 60 % reduction in the carbon emission in relation of plots average.

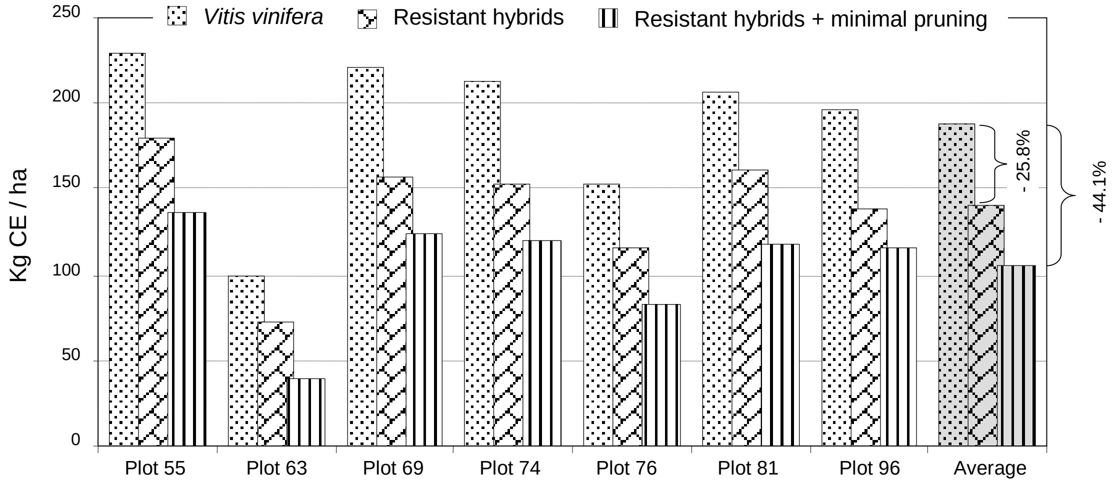

Fig.4. Emissions (kg. CE/ha) produced by the use of agricultural machines comparing *Vitis vinifera* cultivate varieties (trained on a vertical trellis and pruned as bilateral cordon) and resistant genotypes vineyard trained in Minimal pruning trellis system.

3.2. Costs

Using resistant hybrids it's possible to reduce about 50 % (- 498.5 € / ha) the cost of total fungal control (products + applications) (Fig. 6) the equivalent to 21 % of global cost per hectare (Fig.7). Integrating minimal pruning the global reduction of costs can arrive at 64.4 % (- 1277.3 € / ha).

This reduction by the use of minimal pruning is explained principally by the elimination of manual pruning, obligatory in conventional management, but also for the partial reduction of manual green operations (green pruning and trellising). The average time of manual labours employed is 156 hours/ha/year with the *Vitis vinifera* varieties with conventional management. This time falls to 144 hours/ha/year (-7 %) using the resistant hybrids and it drops up to 69 hours/ha/year (-56 %) with the incorporation of minimal pruning (Fig. 6). These reductions are very close to previous estimations realised for vineyard of the southern of France (Carbonneau 2005, Rousseau *et al.* 2007).

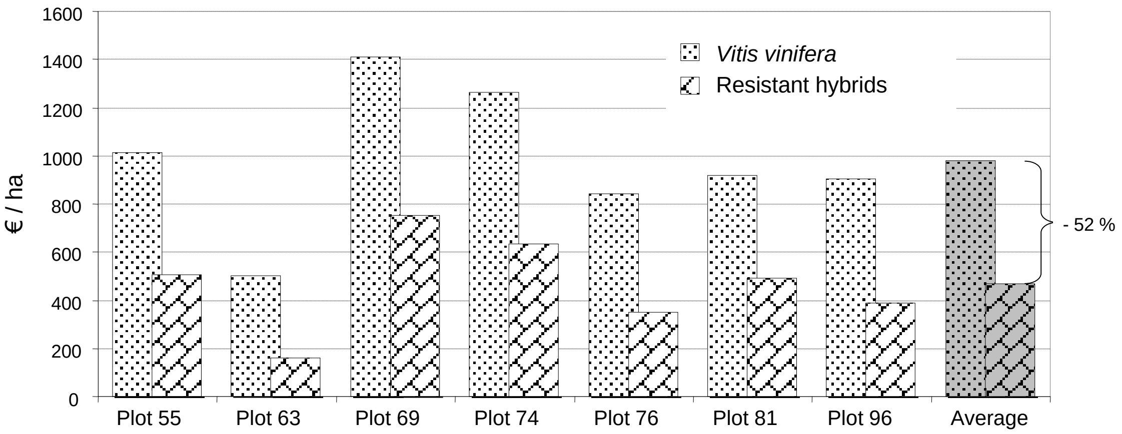

Fig. 5. Cost (€/ha) of the pesticide treatments (product + applications) comparing *Vitis vinifera* cultivate varieties and resistant genotypes.

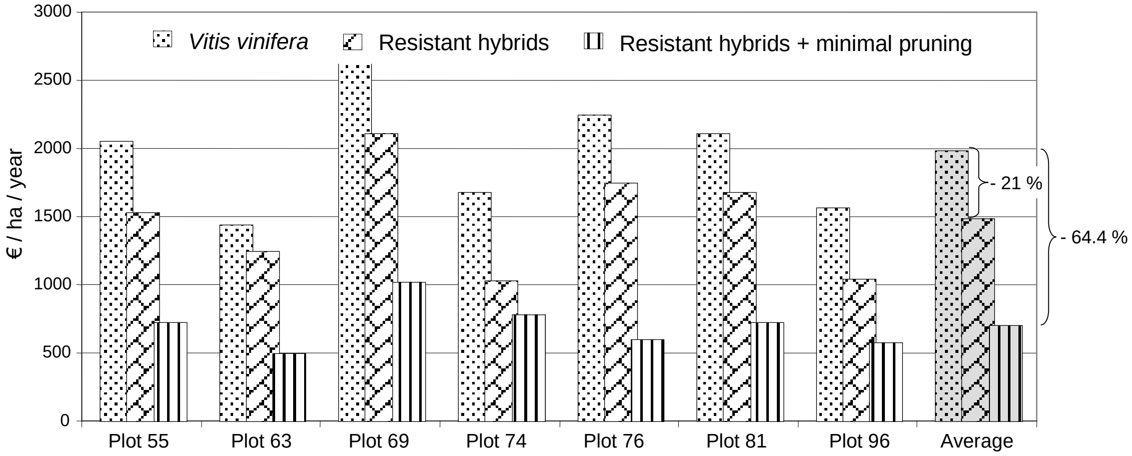

Fig. 6. Total cost in vineyards (in euros per hectare per year) comparing *Vitis vinifera* cultivate varieties, resistant genotypes and minimal pruning.

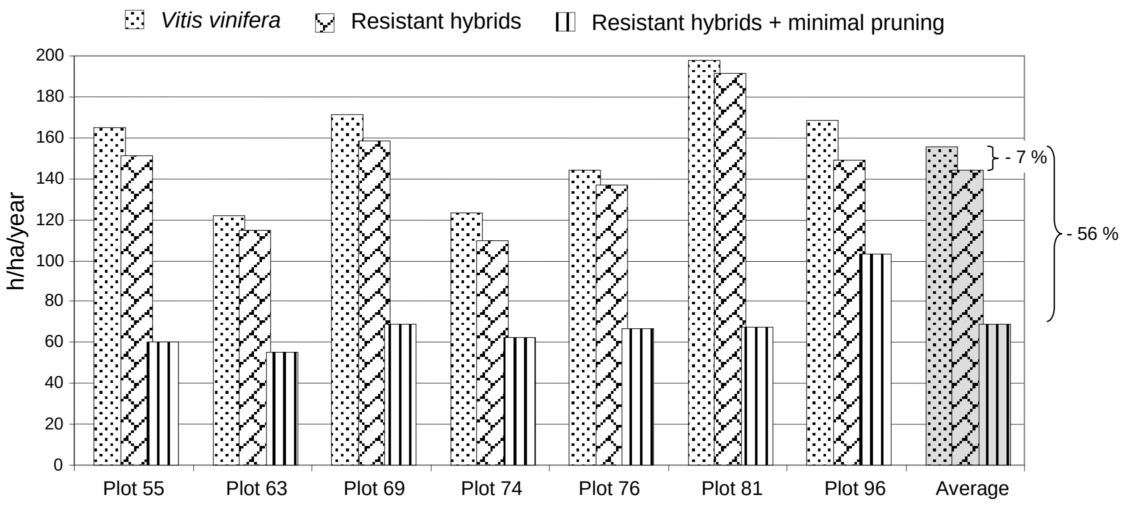

Fig. 7. Time of manual labours employed (in hours per hectare and per year) comparing *Vitis vinifera* cultivate varieties, resistant genotypes and minimal pruning.

4. Conclusions

The technology proposed in this paper is a contribution to fight against the climate change.

The use of vine hybrids resistant to fungus diseases allows reducing the quantity of agro-chemicals necessary for vine cultivation, the use of machine necessary for their application and the consumption of fossil fuels (both as fuel and as the raw material for the energy in the manufacturing process of the products). Minimal pruning system contributes significantly in the realization of this target increasing also the economic benefits.

Both technologies allows to reduce in 44 % the Carbon dioxide emissions, in 57 % the use of agrochemicals, in 64 % the cost of vineyard operations and in 56 % the time of manual labours employed during the vine's growth.

These are only two examples of how the agriculture and, particularly, the viticulture can find solutions to contribute against the climatic change problem with a parallel economic benefit.

This proposition avoids the debate about genetically modified organisms (GMO) because the vine varieties resistant to the powdery and downy mildews are obtained by conventional methods of hybridization.

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