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# Economic Viability of Companion Planting in the Face of Virus Yellows in Sugar Beet

Martial Phélippé-Guinvarc'h and Jean Cordier

## Abstract

Following the EU decision to ban neonicotinoids in 2018, several alternative solutions have emerged from the dedicated French national research project initiated in 2020. Companion crops, such as barley or oats, sown at the same time as beet, have a repellent effect and reduce aphid numbers on sugar beet plants. This paper examines the sustainability of implementing these ecosystemic plantings to reduce the economic risk of virus yellows infection in sugar beets. We show that while the companion plant may be effective in repelling aphids, the strict economic impact of aphid number reduction is mainly negative under benefit/costs assumptions currently accepted. Our analysis is based on the incidence model developed by Qi et al. Planting oats or barley hinders the optimal development of sugar beet and, according to experts, reduces its production level by a minimum of 3%. To mitigate this negative effect, it is necessary to destroy the companion plant at the 2-6 leaf stage, inducing additional costs to the planting costs. Finally, the expected reduction in aphid numbers is about 35%, which does not necessarily translate into a 35% reduction in virus yellows losses. As a consequence of our analysis, it is required to develop research in two directions, (1) analyse the potential of additional benefits of ecosystemic plantings to the strict impact on aphid number reduction and (2) analyse the potential benefit of synergy between this measure and other ecosystemic methods.

## Introduction

Following the European Union's (EU)<sup>1</sup> decision to ban neonicotinoids in 2018, the agricultural sector has proactively explored alternative strategies. In particular, National Plan for Research and Innovation (PNRI), initiated in January 2021, aims to explore alternative solutions to neonicotinoids. One notable approach involves companion planting, where crops like barley and oats are sown concurrently with sugar beets, presenting potential solutions to repel aphids and mitigate their impact on sugar beet plants.

Jaworski et al. (2023) explain that intercropping refers to the simultaneous or relay cultivation of multiple crops during a growing season in the same field. This includes companion planting, strip cropping, and relay intercropping. Crop diversification strategies may include trap cropping, agroforestry, and landscape diversification. They show that recent literature has addressed the benefits of crop diversification for arthropod pest control, examining essential ecological mechanisms, tools, and scales for implementing diverse cropping systems.

Sarkar et al. (2018) elucidate the functioning of companion planting in Figure 1. In their comprehensive literature review, the authors recognize that the development of an effective trap crop system is a costly process and often entails a secondary product with minimal market value. While biocontrol with natural enemies may offer favorable long-term outcomes, obtaining the desired results is typically a gradual process, demanding much more time than the straightforward application of pesticides on trap crops.

Our investigation is prompted by recent findings from 84 trials examining sugar beet companion plants to fight against aphid, responsible for virus yellows, conducted by the French Agronomic Sugar Services and the participating agricultural high schools. As elucidated by Audrey Fabarez in 2023

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<sup>1</sup><https://food.ec.europa.eu>

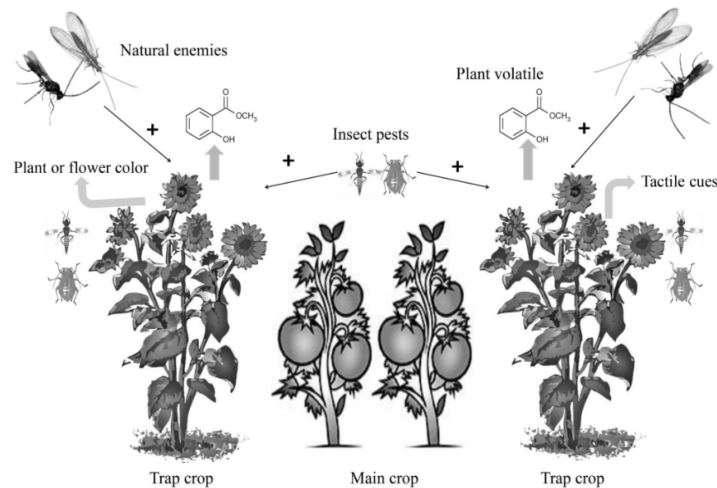


Figure 1: From Sarkar et al. (2018). 'Role of trap crop to attract insect pests and natural enemies in a farming system.'

(detailed results on [www.itbfr.org](http://www.itbfr.org)), various species were evaluated over the three-year research period (2021-2023), with grasses like spring oats and barley exhibiting the most promising outcomes.

This study delves into the feasibility and sustainability of implementing these companion planting approaches as ecosystemic measures to mitigate the economic risk associated with virus yellows infections in sugar beets. It builds on these trials results and on the paper of Phélippé-Guinvarc'h and Cordier (2023), itself based on papers by Dewar and Qi (2021), by Qi et al. (2004), by Werker et al. (1998) and by Luquet et al. (2023) to name only those.

While the efficacy of companion plants in averting aphids is acknowledged, our review found that, based on current cost-benefit assumptions, the economic implications of reducing aphid numbers are often unfavorable. Our argument has three parts. First, we determine the point at which a loss becomes economically advantageous, based on cost and efficiency assumptions. Second, we explain that the impact of a reduction in aphid numbers is not linear. This means that a 35% decrease in aphid numbers does not reduce the incidence or the loss by 35%. Finally, we use detailed simulations to estimate how often the reduction in incidence due to companion plants is enough to be economically profitable.

## 1 Three reasons for economic non-viability

### 1.1 The cost relative to largest losses

Assuming an expected crop yield of 80 tons/ha with a price of €45/t, resulting in a total expected revenue of €3600/hectare. According to Fabarez's findings, the introduction of a companion plant led to a 5% reduction of production in trial fields (€180/ha), while the ITB Institute aims for a more conservative reduction of €108/ha (€108/ha). ARTB additionally estimates a cost of €93/hectare (2.6%) for planting and removing companion plants.

In this stage of the reasoning, we make the assumption that 35% fewer aphids means a 35% reduction in crop yield losses. Based on the maximum impact of the companion plant, with losses reduced by 35%, the break-even loss would be 201€/ha (108+93€/ha, 5.6% of expected revenue per ha) divided by 35%, or about 574€/ha of loss (16%).

In our model, the maximum yield loss concerns early inoculation of plant and reaches 30% for BMV and 50% for BYV. Plants inoculations in field is not immediate. As the consequence, the whole plot is not contaminated to the same degree of loss, even if the whole plot is eventually infected *in fine*.

Our model run with MPI climatic data, RCP 8.5 scenario, never exceeds 16% for the BMV, but is possibly above that level for BYV. The model provides 10.5% of probability of occurrence, for the

period 2025-2100 (weighted by expected crop value). Then, it looks like, under our assumptions, that the companion plant measure has no positive economic impact when the plant is infected by BMVYV.

Certainly, assuming a 35% reduction in winged aphids directly translates to a 35% reduction in losses is ambitious. However, our rationale holds if we can establish that the rate of loss reduction, based on the rate of aphid reduction, can be encapsulated by a linear function. Furthermore, this conclusion becomes even more valid if the rate of loss reduction is equal to or less than the rate of abundance reduction, as explained in the following sub-section.

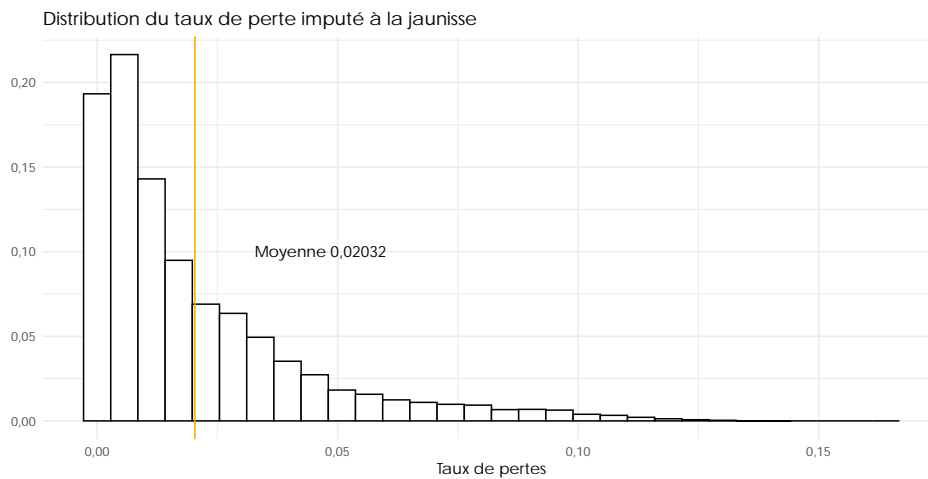


Figure 2: BMVYV Density Loss 2025-2100 (weighted by expected crop value)

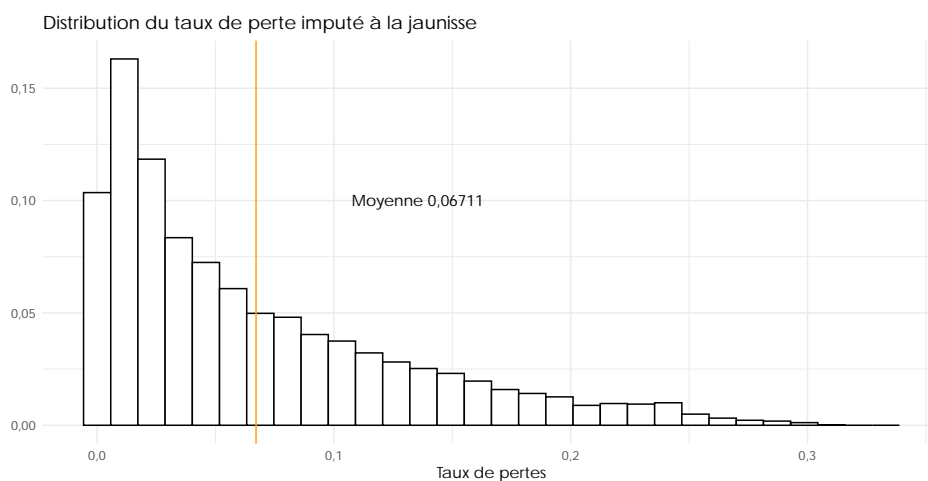


Figure 3: BYV Density Loss 2025-2100 (weighted by expected crop value)

## 1.2 The abundance reduction impact

### 1.2.1 Incidences assumptions

This sub-section only recalls the elements of the article of Phélicpé-Guinvarc'h and Cordier (2023). The model of Werker et al. (1998) is the reference. The observed proportion increase over time of plants exhibiting symptoms of virus yellows infection (denoted as  $Y$ ) can be attributed to two sources of inoculum, namely primary infection ( $P$ ) and secondary infection ( $S$ ). This increase is a result of the interplay between the proportion of disease free plants ( $1 - Y$ ) and these two sources of infection.

Considering that the total proportion of diseased plants is given by  $Y = Y_p + Y_s$ , the combined rate of change of the total proportion of diseased plants with respect to time is given by

$$dY/dt = (r_p P + r_s Y)(1 - Y)$$

The primary inoculum, represented by the variable  $P$ , is defined as the number of migrant viruliferous aphids that land on the crop and feed on it. The determination of  $P$  is based on the total number of aphids migrating in the spring, which is assessed using suction traps from the Rothamsted Insect Survey. The relationship between  $P$  and  $N$ , the total number of spring migrating aphids, is set by the equation:

$$P = 1 - e^{-pN} \quad (1)$$

This equation corresponds to the multiple infection transformation and involves the constant of proportionality denoted as  $p$ . The use of this transformation is necessary to stabilize the values of  $P$  since the number of migrating aphids ( $N$ ) exhibits significant variations from one year to another.

In this investigation the infection cycle is initiated at time  $t_0$ , then  $Y_0 = 0$  and the solution are:

$$Y = \frac{1 - e^{-(r_p P + r_s)(t-t_0)}}{1 + \frac{r_s}{r_p P} e^{-(r_p P + r_s)(t-t_0)}} \quad (2)$$

Time  $t_0$  coincides with the start of the spring migration of the aphid species *Myzus persicae*, and at this point, the proportion of infected plants, denoted as  $Y_0$ , is assumed to be zero.

### 1.2.2 Abundance impact on incidence

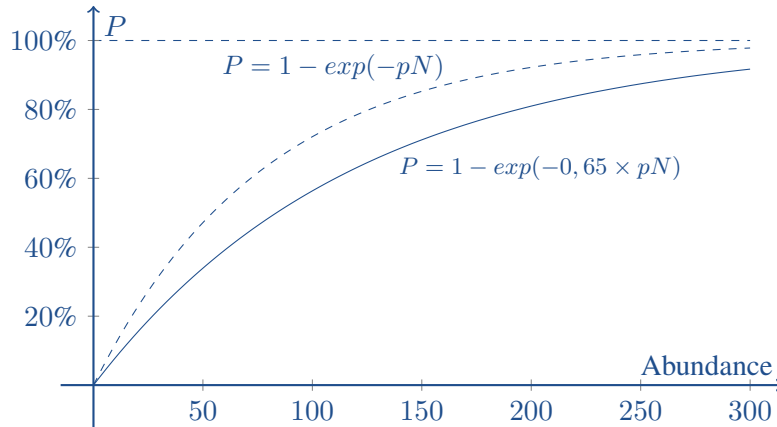


Figure 4: Impact of abundance on  $P$  factor ( $p = 0,01276$ )

As we see on figure 4, the  $P$  factor depends on abundance, through the negative exponential function. Reducing the number of aphids does reduce the  $P$  factor (eq. 1), and reduce the incidence, but not proportionally.

A 35% decrease in aphid abundance has an impact close to 35% of the crop loss when abundance is close to 0. This impact is decreasing asymptotically to 0 for higher abundances. These statements may be easily understood. The greater the abundance of aphids, the more plants should be inoculated. In situations where aphid abundance is already exceptionally high, additional aphids only inoculate plants that have already been contaminated, possibly multiple times. Consequently, even with a significant reduction in the number of aphids, the number of infected plants does not decrease, or decreases only minimally.

For example, to reach the break-even loss ratio at 16% on  $P$ , we need an abundance below 156, given the assumption of Qi for the north region, where  $p$  is estimated at 0.01276 (85,9% of occurrence, 2025-2100 (weighted by expected crop value)).

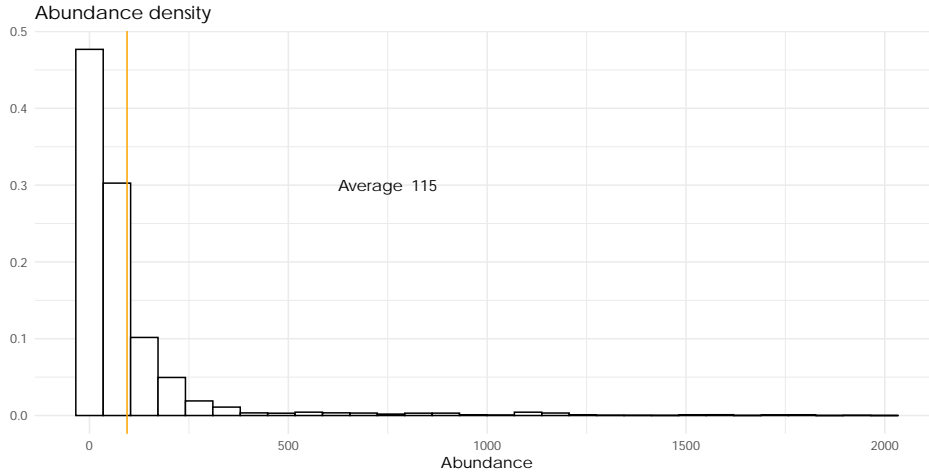


Figure 5: Abundance density 2025-2100 (weighted by expected crop value)

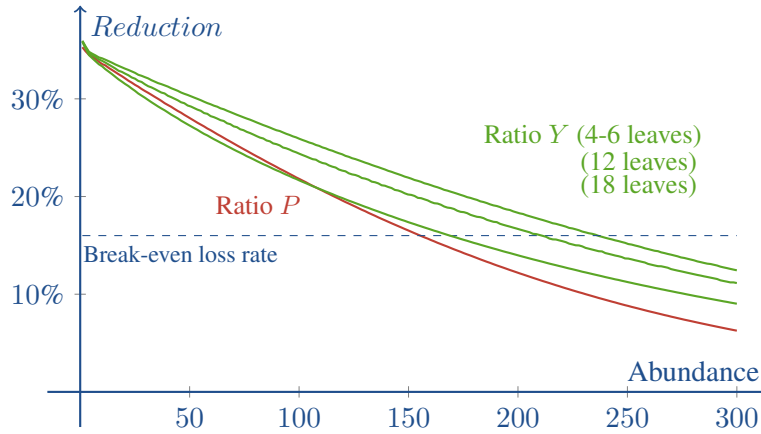


Figure 6: Impact of abundance on  $P$  factor and on incidence  $Y$  ( $p = 0,01276$ )

If we carry out the same exercise on the  $Y$  incidence (eq. 2), we observe a similar result. The figure 6 is based on average dates for future years 2025-2100. The graph is based on average dates for future years 2025-2100. It can be seen that a 35% drop in aphid numbers has a greater impact at the 5-leaf stage than at the 18-leaf stage.

So 35% fewer aphids does not mean 35% less loss, it means less, or even much less. The higher the abundance, the lower the reduction in loss rate.

### 1.3 Targeted use of companion planting

Suppose the farmer receives information that BYV is prevalent. In such rare instances, could the companion plant genuinely prove effective? The farmer might contemplate its use as a preventive measure under these specific circumstances.

For the entire MPI scenario (IPCC 8.5), we calculate the companion plant impact ( $CPI$ ) by multiplying the loss rate without companion planting by one minus the incidence at the 5-leaf stage divided by the incidence at the 5-leaf stage without the companion plant. We then verify that the gain from the loss exceeds the 5.5% cost. The  $CPI$  can be expressed as follows:

$$CPI = \ell \times \left( 1 - \frac{Y(0.65 N)}{Y(N)} \right)$$

where  $\ell$  represents the loss rate without companion planting, and  $Y$  estimates the incidence in the field at the 5-leaves stage using abundance and dates provided by the model, as detailed in Phéllippé-Guinvarc’h and Cordier (2023). The 5-leaves stage is chosen in relation to the figure 6, and overate impact on incidence, which, if multiplied by the maximum loss rate, overate the result. The probability of this possibility occurring for future years (2025-2100), i.e.  $CPI > 5.5\%$ , is 0.09% (weighted by expected crop values).

## 2 Discussion

Our cost/benefit analysis of planting companion crops as an ecosystemic measure for managing the economic risk of virus yellows infection in sugar beets is negative under assumptions currently validated. Only few circumstances of infection by the BYV may present a positive economic result.

This result is based on two basic concepts, first “there is no need to spend preventive money when you don’t expect loss” and second “there is no need to hang a man who has already been shot”. More practically, the reasoning is the following:

- Under conditions of strong winter conditions, and therefore low expected aphid abundance, the expected economic loss is low and below the cost of implementing efficiently the planting ecosystemic measure. Therefore, there is no need to spend the costs of planting and later to destroy the companion plants, and in the mean time to decrease the normal yield of the sugar beet if there is no or low expectations of technical and economic losses due to virus yellows infection.
- At the opposite, under conditions of mild winter conditions, and therefore high expected aphid abundance, the technical impact of 35% decrease of aphid abundance is close to zero as the high initial abundance is sufficient for affecting the whole plot with quite full economic loss due to virus yellows infection. Therefore, the direct effect of 35% decrease is not implying a 35% decrease in yield and economic losses. Under this condition, the implied full cost of the measure is not offset by its benefit.

Of course these results are conditional to the quality of the Qi model and to the quality of the main assumptions of the cost-benefit approach. The Qi model as used for the analysis may be theoretically questioned but cannot for the present analysis as the model is widely used for many projects of the national research program. The assumptions used in terms of implied full cost of the measure are set at a minimum critical level, so that the reality of practical conditions could be more unfavorable than these minimum levels.

Please note that our results are in line with previous studies. For example, in 2020, the Beet Technical Institute (ITB, France) declared, ‘Despite research endeavors, no chemical or natural solutions that can match the efficacy of neonicotinoids have been identified.’ Similar conclusions are drawn in the earlier work by Hauer et al. (2017). Recently, Chauvin and Soubeyrand (2022) used machine learning to identify risk factors for virus yellows in sugar beet. It was surprising to find that the presence of aphids was only the 11th most significant factor (out of 154). The authors argue that since winter severity variables are excellent predictors of aphid abundance, the role of the abundance variable is overshadowed in the statistical analysis. Although this argument is relevant, our analysis demonstrates that the non-linear relationship between abundance and losses may also explain Chauvin and Soubeyrand’s findings. The article’s originality lies in its provision of a cost/benefit analysis that is based on modeling and quantification.

However, additional intrinsic benefits from companion plants may exist within the relationship between the development of both plants, the sugar beet and the companion plants, increasing potentially the impact of the measure on the yield loss of the sugar beet. It is necessary to develop research on these potential additional benefits both in the conditions of mild or strong winters.

In the other hand, the companion plant measure should also been explored in synergy with other ecosystemic measures, for instance repulsive odor measures. All consulted literature emphasizes syner-

gies among ecosystemic measures. However, as of now, these solutions have not yielded economically testable results (see for example Francis et al. (2022), Sarkar et al. (2018), Jaworski et al. (2023)).

One final point to consider in this discussion is the variability in the performance of companion plants. The results from Fabarez that prompted the writing of this article, as well as the results of the trials reported in the literature cited, show that the methods considered produce highly variable results. However, this variability reduces the expected utility of the change for the farmer, or increases the challenge of finding effective ecosystem measures.

## Conclusions

The complex issue of designing optimal measures for dealing with virus yellows infection is far from straightforward. The paper asserts that companion plants are not a economic solution when looking at the sole benefit of reducing the aphid abundance and whatever the climatic winter conditions. The paper is therefore an alert and an incentive to develop research on supplemental intrinsic benefits of the planting measure as well as research of synergy with other ecosystemic measures as developed in the French national research program.

### 2.1 Acknowledgment

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### 2.2 Funding

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