# HOW TO IMPROVE THE SUCCESS OF DEAD VINE REPLACEMENT: INSIGHTS INTO THE IMPACTS OF YOUNG PLANT'S ENVIRONMENT

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**Context and purpose of the study -** Grapevine faces multiple biotic and/or abiotic stresses, which are interrelated. Depending on their incidence, they can have a negative impact on the development and production of the plant, but also on its longevity, leading to vine dieback. One of the consequences of vine dieback on production is the increased replacement rate of dead or missing vines within a parcel. Replacements can be very costly and time consuming for the vinegrower, especially because success (i.e. defined by the survival and growth of the young vine planted in place of the dead plant) is not guaranteed every year. Factors influencing the success of this replacement can be grouped into two main categories: the plant environment and the vinegrower practices. The aim of this study was to quantify plant mortality after such a replacement in different vineyards over several years, and the influence of the plant's environment on this mortality

**Material and methods -** For four years, plants replacements were carried out in production vineyards. A set of 83 batches distributed in 44 parcels corresponding to more than 7500 replacement plants were monitored. The year and density of planting, rootstock, and variety as well as soil type and maintenance were recorded for each parcel. Plant survival was monitored twice a year.

**Results -** As the plants were coming into production, the average survival rate was 83% of the initial batches of plantings**.** However, survival rates varied greatly depending on plot characteristics. Multi-year monitoring of plant survival showed that 60% of mortality occurred within the year following plant replacement. Over the study period, the average first-year mortality rate of replaced plants ranged from 7.4 to 17.1%, highlighting a vintage effect. In the second and third years after replacement, mortality was found to be higher in late winter than during the growing season. Thus, one hypotheses proposed is that the reserve status of the plant material may be more critical to the survival of these plants than the impacts of tillage or lack of water during the growing season. Nevertheless, mortality during growing season accounted for one-third of total mortality in a given year, which could potentially be reduced through better care of the young plants. Statistical analyses revealed no variety effect of and no date of the first plantation effect of the initial parcel while a significant soil effect was detected. This experimental monitoring should make it possible to provide answers on the impact of the environment of the replacement plant on its survival over time, its development and its production. These results highlight perspectives to improve the survival of replacement plants in vineyards.

**Keywords**: Grapevine, survival, mortality, stresses, dieback

## 1. Introduction

Vineyard decline, defined as a multi-year decrease in vine yield or its premature, sudden or gradual death, threatens viticulture worldwide (Riou *et al*., 2016). Vineyard dieback is a major concern in French viticulture. Over the past 10 years, decline has resulted in annual yield losses of approximately 4.6 hl/ha, i.e. around 10% of vine plantations at the national level (BIPE, 2015). Many complex factors and interactions lead to vineyard dieback. These are distinguished between biotic stresses, such as viruses (Fush, 2020) or trunk diseases (Dewasme *et al*., 2022) and/or abiotic stresses (Darriaut *et al*., 2020, Calvo-Garrido *et al*., 2021, Bortolami *et al*., 2021).
The practice of replacement of dead plants (i.e. co-plantation) can be very costly in case of failure, especially since the vine replacements will reach full production more slowly later than the young plants of a completely renewed parcel. Success, defined by the survival and good growth of the young vine planted in place of the dead vines, is not guaranteed every year. Co-plantation is a tricky technique because healthy adult vines are adjacent to the replacement plants and compete for resources. The factors influencing this replacement success are grouped into two main categories: the environment of the plant and the vinegrower's practices. However, no precise data on mortality rates during this replacement operation are available and very few studies have been carried out about success factors (Shavadze & Papunashvili, 2020, Dewasme *et al*., 2020).
The aim of this study was therefore to quantify plant mortality after co-plantation in different vineyards over several years, and to explore how the plant environment would affect it.

## 2. Material and methods

***Plant material and growing conditions***
The experiment was carried out in the Bordeaux region on the southwest side of the Garonne river in a oceanic climate. A set of 83 batches of plants distributed over 44 parcels were planted either in Cabernet-Sauvignon (59 batches) or in Merlot (24 batches). The date and density of the plantation, rootstock and variety, as well as soil type and its maintenance, were recorded for each parcel. Eleven types of soil have been identified but several of them are poorly represented with less than 5 batches set up onto them (ARENOSOL, CALCISOL, PELOSOL, PLANOSOL, REDOXISOL and REDUCTISOL) while 5 soils are well represented among the batches (BRUNISOL, PEYROSOL, CALCOSOL, LUVISOL, COLLUVIOSOL).The first replacements were made in 2018 with 24 batches and then each year trought 2021 with 31, 14 and 14 batches per year, respectively. All plants were bare roots and plant replacement practices were the same for all 44 parcels.

***Plant mortality assessment***
A total of 7 500 replacement plants were individually monitored between 2018 and 2021 over more or less long periods depending on the year of replacement. Twice a year, in the spring and fall, the replacement plants survival was evaluated.

***Statistical analysis***
Two models were developed to infer differences in mortality caused by environmental cofactors / parcel characteristics: one model predicting the mortality rate observed during the growing season immediately following replacement and one model predicting the mortality from one to four years after replacement evaluated before and after each growing season / twice a year. Negative-binomial mixed-effects generalized linear models (GLM) were fitted to the data using the R package *lme4*, to account for overdispersion caused by frequent null values. Fixed effects included variety, parcel age, soil type, vintage of replacement, years since replacement and observation period for the second model. Parcel was introduced as a random effect to account for batch repetition. For each model, deviance analysis was conducted on fixed effects to identify factors contributing statistically to the mortality rates (5% error rate, according to type 3 Wald $\chi^2$ tests). Significant fixed effects were further analyzed by calculating estimated marginal means (EMM), i.e. predictions over the mean values of the other predictors present in the model, using the R package *emmeans.* Significantly different marginal means were identified by pairwise Tukey comparisons. Data analysis was performed in R Studio (R version 4.1.2).

## 3. Results and discussion

**3.1.** *Most mortality occurs over the first leaf*

As the plants were coming into production, the average mortality rate was 16.1% (±2.4 %) of the initial batches. This is defined as a fairly good rate in the context of previous literature (Shavadze & Papunashvili, 2020). However, the average hides the large disparity of mortality across parcels. The mortality of replacement plant before coming into production ranged from 0 to 90% with a quarter of the batches at less than 5% mortality but an equal amount exhibited more than 20% mortality. Multi-year monitoring of plant survival revealed that 60% of mortality occurred within the year following plant replacement followed by 23% and 10% in the second and third leaf (Fig. 1 A). At the end of the first year, 14% of the batches showed no dead plants and 39% had a mortality rate of less than 5%. The average mortality within batches is 11.3 % (± 1.6%). Then, in the second and third seasons following plantation, the average mortality rate decreases with 7.5% (± 1.3%) and 3.6% (± 0.6%) respectively (Fig.1 A). This result highlights the importance of care to given to replacement plants, particularly during the year of their planting, both in terms of treatments against diseases and in terms of providing irrigation to mitigate water and heat stress.

Intra-annual variability in mortality rate was also observed. After the first year, there is a significant difference in mortality depending on the time of year (Fig. 1 B). Mortality at the end of the growing season (GS) is significantly lower than the mortality corresponding to the absence of budburst at the end of winter (WR). This result could be attributed to a lower availability of reserves by some plants. This unexpected result is interesting because growers mainly attribute plant mortality to high water deficit or to tillage when the soil is mechanically worked.

***3.2.*** *A significant effect of both vintage and soil type*

There was a significant effect of the vintage between the batches set up in 2019 with the lowest mortality (EMN =4.8%) and the batches set up in 2021 with the highest mortality (EMN=17.3%) (Fig. 2 A). The climatic conditions during the growing season could explain these differences. Spring 2021 was particularly rainy. In the contrary, 2019 is the least rainy of the four years from January to October with only 454 mm in 2019 while the amount of rainfall over the same period was 641 mm in 2021. In 2021, the cumulative rainfall was 50% higher between April and June compared to the 30-year average and could have involved root asphyxiation leading to increased mortality of replacement plants.

On the other hand, the age of the parcel in which the replacement plants were set up, did not seem to have any impact on the mortality rate in the first year, contrary to the conventional wisdom that competition with older vines would prevent the replacement success. However, there was only a few batches set up in young vines of less than 15 years old in our study. No effect of the grape variety was demonstrated (Fig. 2 B).

A significant effect of soil type was highlighted among the 5 most represented soils in our study. The first year following the replacement plant, mortality is 5 times greater on CALCOSOLs than on COLLUVIOSOLs (Fig. 3). The mortality is also greater on LUVISOLs but the difference is not significant. Concerning CALCOSOLs, we could make an hypothesis concerning the amount of clay in these soils and the temporary water logging in particular during the rainy years. The water logging induced by the clay on CALCOSOLs could have provided root asphyxiation and reduced nitrogen mineralization.

## 4. Conclusions

Effects of parameters surrounding the vine during plant replacement were studied and a significant effect of the vintage and the type of soil was highlighted. This experimental monitoring should make it possible to provide answers regarding the impact of the environment of the replacement plant on its survival over time, its development and its production. It was shown that the care provided in the first year is crucial to obtain a good success rate. However, this success of replacement plant is a combination of many factors whose respective influence is not well understood yet. Further studies should be set up to improve our knowledge concerning soil texture and spring weather influence on co-plantation success. However, these results open up prospects for improving the survival of replacement plants in a vineyard in production.

## 5. Acknowledgments

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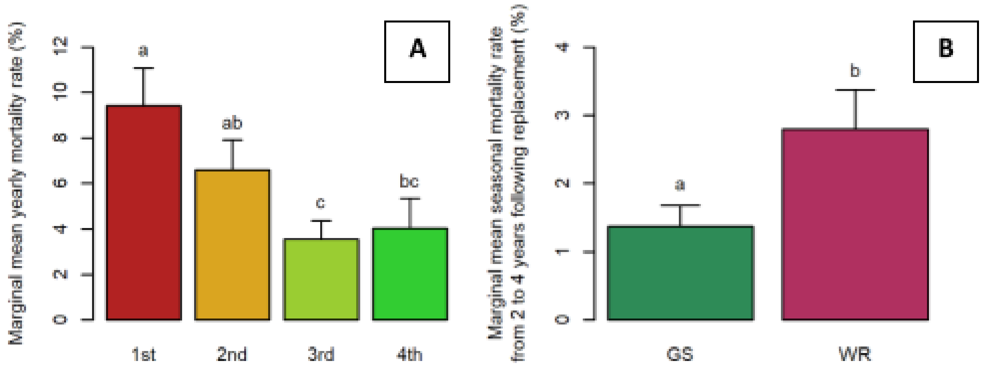


**Figure 1**: Replacement plant mortality rate from their year of planting (1st) to the year following their first theoretical year of production (4th) (df = 3, $\chi^2 = 22.7$, $p < 0.001$) **(A)** and depending on the time of year (excluding the first leaf) by separating the growing season (GS) from the winter rest (WR) (df = 1, $\chi^2 = 15.9$, $p < 0.001$) **(B).** The different letters above the barplots indicate significant differences between modalities.

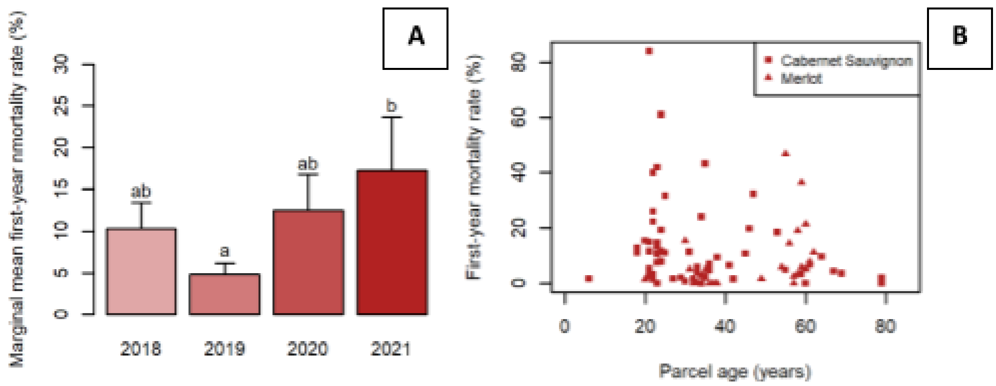


**Figure 2**: Replacement plant mortality rate in the first leaf according to the vintage (df = 3, $\chi^2 = 10.9$, $p = 0.01$) **(A)** and according the age of the parcel (df = 1, $\chi^2 = 0.03$, $p = 0.86$) and the variety (df = 3, $\chi^2 = 1.4$, $p = 0.23$) **(B).** The different letters above the barplots indicate significant differences between modalities.

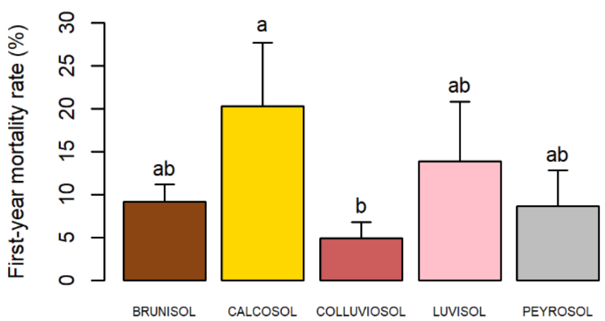


**Figure 3**: Replacement plant mortality rate in the first leaf according to the soil (df = 4, $\chi^2 = 9.1$, $p = 0.06$). The different letters above the barplots indicate significant differences between modalities.