WHITHIN-FIELD TEMPORAL STABILITY OF SOME PARAMETERS IN VITICULTURE : POTENTIAL TOWARD A SITE SPECIFIC MANAGEMENT

B. TISSEYRE, C. MAZZONI and H. FONTA

UMR ITAP, Montpellier SupAgro/Cemagref, Bât. 21, 2 place Viala, 34060 Montpellier, France

Abstract

Aims: The goal of this paper is to present the results of a study run over 7 consecutive years which aims at characterising the Temporal Stability of Within-Field Variability (TSWFV) for the most routinely measured vine parameters. In the context of precision viticulture TSWFV is of importance to know whether or not it is relevant to use the within-field variability of the year « n » to design a site-specific management strategy for the year « n+1 ».

Methods and results: The experiment was based on 6 vine parameters measured at 30 sites located within a non-irrigated vineyard block. Parameters measured included indicators of a vine capacity to produce biomass (pruning weight, yield and size of the canopy) as well as indicators of harvest quality (sugar content, pH and Total Titrable Acidity). For each parameter a significant temporal variability of the field average was observed from one year to another. This temporal variability led us to define the TSWFV as the occurrence of consistently high value or low value zones within the field. The definition of high and low values is done according to the average field value of the year for each parameter.

Conclusion: TSWFV analysis allows the parameters to be classified into two distinct types. Type 1 parameters (pruning weight, yield and canopy size) which present a significant TSWFV and type 2 parameters (sugar, Total Titrable Acidity and pH) which present no TSWFV.

Significance and impact of study: For precision viticulture management these results are significant. They show that yield or vigour (pruning weight, size of the canopy) maps of the previous years are relevant in designing site-specific management strategies in the year « n+1 » or subsequent years. Conversely, maps of quality parameters from previous years are not useful in determining how to manage harvest quality in the year « n+1 ».

Key words: *Vitis vinifera*, within vineyard variability, temporal stability, precision viticulture.

Résumé

Objectif : Cet article présente les résultats d'une expérimentation réalisée sur sept années consécutives sur une parcelle de vigne non-irriguée. Cette expérimentation a pour objectif d'étudier la Stabilité Temporelle de la Variabilité Spatiale au niveau Intra Parcellaire (STVSIP ou TSWFV en anglais) de quelques principaux paramètres viticoles. Dans le domaine de la viticulture de précision, l'étude de la TSWFV est importante pour savoir s'il est pertinent d'exploiter la variabilité intra parcellaire observée l'année « n » afin d'effectuer une modulation des intrants ou des pratiques l'année « n+1 ».

Méthodes et résultats : L'expérimentation est basée sur le suivi de six paramètres mesurés sur 30 placettes distinctes à l'intérieur d'une parcelle. Les paramètres choisis sont des paramètres quantitatifs (rendement, poids des bois de taille, surface de la canopée,) mais aussi des paramètres de la qualité de la vendange (sucre, acidité totale et pH). Quel que soit le paramètre considéré, une importante variation de la moyenne parcellaire a été observée d'une année à l'autre. Cette variabilité temporelle nous a conduit à définir la TSWFV comme la présence de motifs spatiaux, stables dans le temps, correspondant à des valeurs fortes et faibles. La notion de zone forte et faible devient donc relative à la moyenne parcellaire observée pour chaque année et chaque paramètre.

Conclusion : L'analyse de la TSWFV a permis de mettre en évidence deux classes de paramètres. Les paramètres de type 1 (poids des bois de taille, rendement et surface de la canopée) qui présentent une stabilité temporelle importante de la variabilité spatiale et les paramètres de type 2 (sucre, pH et acidité totale) dont la variabilité spatiale ne présente pas de stabilité temporelle.

Signification et impact de l'étude : Les cartes issues de la mesure des paramètres quantitatifs, considérés comme les plus prévisibles, pourront constituer une base pour mettre en place une modulation spatiale des intrants et des pratiques. À l'inverse, la cartographie des paramètres de la qualité de la vendange semble plus difficile à utiliser pour mettre en place des pratiques de gestion de la qualité.

Mots-clés : *Vitis vinifera*, variabilité spatiale, stabilité temporelle, viticulture de précision.

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*Corresponding author:tisseyre@ensam.inra.fr

INTRODUCTION

Recently, precision agriculture and site-specific management (Plant, 2001) has become increasingly popular for many crops such as wheat (Yamagishi *et al.*, 2003), corn (Kravchenko *et al.*, 2005), cotton (Boydell and McBratney, 2002), sugar cane, etc. This is mainly due to the use of emerging technologies such as real-time sensors, airborne imagery and differential global positioning system (Auernhammer, 2001, Stafford, 2000). The spatial variation of crops assessed with these technologies constitutes a new approach in agriculture and it has convinced researchers and farmers that uniform management may not be appropriate for all circumstances (McBratney and Whelan, 1999).

These emerging technologies have also been used more recently on perennial crops, especially winegrapes, to characterise the spatial variation in the production systems. Many projects located around the world have focused on site-specific management in viticulture : (Bramley, 2001; Tisseyre *et al.*, 2001; Taylor *et al.*, 2002; Ortega *et al.*, 2003; Lamb *et al.*, 2004; Arnó *et al.*, 2005). According to all these papers, winegrapes are assumed to present a good opportunity for site-specific management. The two major reasons presented for this hypothesis are:

- The perennial aspect of grape vines. In this regard vines differ significantly from broadacre crops. There is no rotation and the same vine is always at the same location over time periods of 30 years or more. As a result vine development is an integration of the local soil and micro-climate conditions over time. This may mean that a yield map, a sugar map, or another production parameter map which highlights the within-field variability of the year n, may be useful for predicting or assessing the variability of the same parameter at the year n+1. In other words, due to its perennial nature, the within-field variability of vineyards is assumed to present a significant temporal stability.

- Some site-specific management strategies are already regarded as highly valuable particularly regarding quality management. The spatial variability of yield, sugar, titrable acidity and other parameters of year « n » could be a relevant information source to plan a differential harvest in order to optimise the quality at harvest in year « n+1 ». Another possible significant application is the control of the vigour through differential fertilization, irrigation and/or canopy management. Differential management is already being conducted in some vineyards around the world.

For most of these applications, a knowledge of the within-field variability at year « n » is considered as significant to the adoption and the design of a site-specific management strategy in year « n+1 ». In this context, it seems to be relevant to perform a study of the temporal stability of the main vine production parameters in viticulture. The goal of this paper is to present the results of a study run over 7 consecutive years which aimed at characterising the temporal stability of the within-field variability for the most common vine parameters. This knowledge will contribute significantly to knowing (i) whether or not it is relevant to use the within-field variability of year « n » to design a site-specific management strategy in year « n+1 » and (ii) whether all the parameters present the same temporal stability. The first part of this paper will present the experimental field, the sampling strategy and the methods used to process and analyse the data. The second part of this work will present the main results and will discuss the potential to adopt site-specific management on the basis of data collected in previous years.

MATERIALS AND METHODS

1. The experimental field

This experiment was conducted in Southern France on the research vineyard of INRA at Pech Rouge (Gruissan-Aude-France). The experimental field is a 1.2 ha of non-irrigated Syrah variety trained in Royat cordon. It is located near Gruissan, Aude, France (RGF93 datum, Lambert93 coordinates: E:709800, N:6226840), on the Clape limestone massif. This field was chosen as it is typical of vineyards in the area in terms of its soil type, vine density (4,000 vines.ha^{-1}) and trellising (1.7 m training height with 3 wire levels).

At the beginning of the study, in 1999, the vineyard was 8 years old. The mean elevation is 68 m above sea level, the row direction is approximately East-West and the general aspect is easterly (see figure 1a). Like many vineyards in this area, it was assumed to have significant within-field soil variability. Although, the soil was heavily cultivated prior vineyard establishment (deep ripping at 70 cm depth), the different soil layers were noticeable from the top soil (figure 1b).

Figure 1c shows the result of soil gravel measurements. The percentage of element of a size higher than 12.5 mm confirms the difference between marls, limestone with clay and limestone.

2. Measurements

a- Sampling location

It was assumed that the main source of vine variability was due to soil variation. A stratified sampling scheme was designed according to soil observations. Thirty sites were defined within the field in order to take into account the soil variability and the different elevations of the field. Figure 1c shows the final sampling scheme which has been used. The number of samples assigned to each soil type was approximately proportional to the area of the soil type (11 sites for limestone with clay, 12 sites for marls, and 7 sites on limestone). The field border and the different sites were geo-located with a differential global positioning system (Leica Geosystems GS 50 and Omnistar corrections). The elevation was measured with a laser tachymeter (Leica TPS 1100).

b- Sampling considerations and sampling scheme

The sampling design was constructed bearing in mind that the ability to perform a selective harvesting operation is determined by the « footprint » (resolution) of the grape harvester. This means that the spatial variability that our experiment had to consider was at least determined by the area that the grape harvester operates over at any given time. (i.e. 1 row width over 4-5 m. along the row). These considerations lead to the design of a sampling scheme which takes into account the size of the machine. It was chosen to measure the variability at a site which occurs over 5 m. A site of measurement was then considered as a succession of five vines along a row. According to our plantation density (1 vine every 0.9 m along a row), this definition matches with the size of the machine (4.5 m along a row). For a considered sampling site :

- Yield, pruning weight and canopy size were measured individually on the 5 vines in a row for each site. The mean and the variance were then systematically computed and attributed to the site of measurement.

- The quality parameters (sugar content, titrable acidity and pH) were assessed through a sample of 200 berries picked as regularly as possible along the five vines at the sample site.

For mapping purposes, the spatial coordinates of the measurements were attributed to the central vine at a site.

c- Measurements

Between 1999 and 2005, several measurements were systematically carried out on the 30 sample sites.

Yield and pruning weight were manually measured with scales. In 2001 and 2002, the yield was measured with the Pellenc S.A. prototype yield monitoring system embedded on a grape harvester. This measurement lead to systematic yield sampling on the whole field with a rate of approximately 2400 points.ha^{-1}.

Canopy size was assessed by image analysis. Images were taken with a digital camera (Olympus 1.4 Mpixels) once the canopy growth had stopped and after the last summer pruning operation. Images were also grabbed before the occurrence of yellow leaves due to water deficit (which is common in Syrah vines on these soil types in this area). The images were collected and processed with Matlab (Mathwork inc. software) using the method of Souchon *et al.* (2001).

The harvest quality parameters, sugar content, pH and total titrable acidity, were measured on 200 berries picked on the 30 sites on the day that the block was harvested.

Table 1 summarizes the history of the trial and the different measurements carried out on the grape field since 1999. Canopy size measurements stopped in 2002 because this parameter was particularly difficult to measure properly. Moreover, despite a low correlation with pruning weight (r = 0.7), canopy size highlighted the same within field spatial patterns (figure 2).

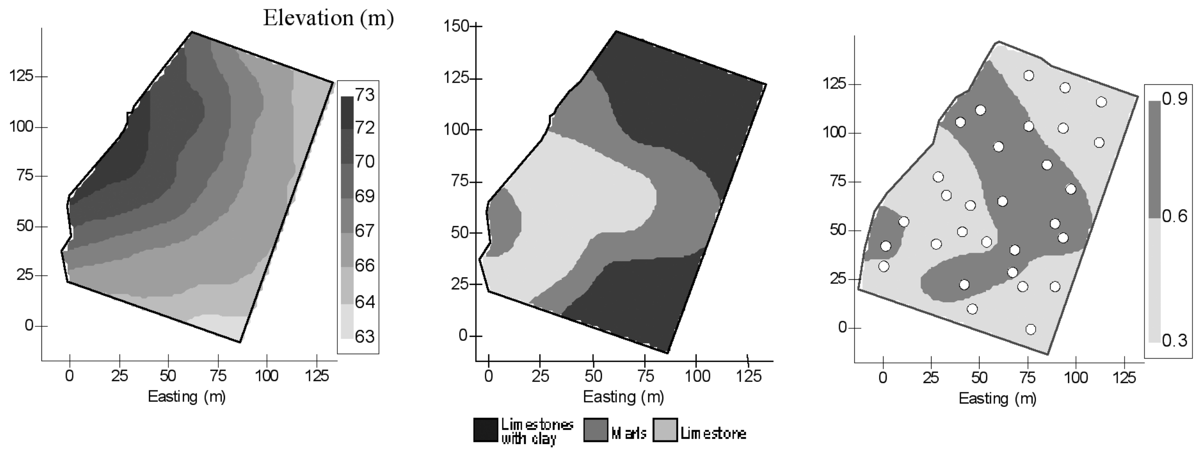


Figure 1 - a) Elevation (in m) map of the experimental field, b) Map of the top soil according to a soil survey, c) Map of soil gravel content (percentage of elements with a size more than 12,5 mm) and final sampling scheme.

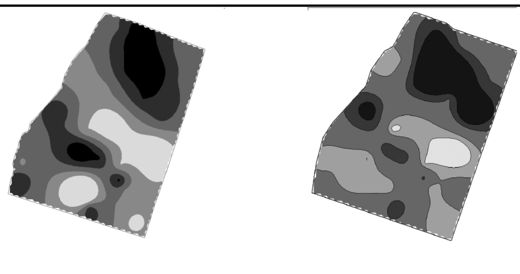
Table 1 - Measurements carried out on the 30 sites of the experimental field (O : available data, « - » : not available)

	1999	2000	2001	2002	2003	2004	2005
Yield - manually measured -	O	O	O	-	O	O	O
Yield - with the Pellenc monitoring prototype (grape harvester)	-	-	O	O	-	-	-
Canopy size	O	O	O	-	-	-	-
Pruning weight	O	O	O	O	-	O	-
Sugar	O	O	O	O	O	O	O
Titrable acidity	O	O	O	O	O	O	O
PH	O	O	O	O	O	O	O

3. Data analysis

a- Data mapping

In this study, maps were only used as a tool to visualize the results and to confirm statistical analysis. Data mapping was performed with 3Dfield software. The interpolation method used in this study was based on a determinist function (inverse distance weighting) due to the small number of measurement points (n = 30). For a given parameter, data were mapped in 20 % quantiles for each year. This removed absolute differences between years and makes the interpretation of maps over several years easier and highlights the potential stability of zones of high/low and medium values. For each map, the class « very small » (white) corresponds to the 0-20 % quantile, the class « very high » (black) corresponds to the 80-100 % quantile and the class « medium » (gray) corresponds to 40-60 % quantile of the data centered on the median, etc.



a) b)

Figure 2 - Comparison between map of canopy and map of pruning weight in 1999. a) Canopy size map, b) Pruning weight map.
Each of the 5 greyscale classes correspond to 20 % of the data. Classes are ranked from white for the lowest values to black for the highest values.

b- Temporal stability analysis

- Temporal stability between pairs of years

Temporal stability analysis was performed to verify whether the same part of the vineyard systematically presents high, medium or low values from year to year. Testing the temporal stability of a parameter can be summarized by a correlation analysis of the values observed on all the sites in year « n » versus the values of the same parameter observed in year « n+1 ». To conduct such an analysis, a rank correlation analysis based on the Spearman rank method was chosen over classical linear correlation (e.g., Pearson). This choice was made in order to limit the assumptions on the type of relationship between the same variables at different dates (over several years). The Spearman rank method doesn't require any assumptions on the linearity of the relationship or on data distribution. Moreover, this method matched the aim of our study which was to assess whether the same part of a field systematically presents high, medium or low values from year to year.

The Spearman coefficient (r_s) was computed according to equation 1 (see Saporta, 1990; for more details).

$$r_s = 1 - \frac{6.\sum_{i=1}^{n}\left(R\left(X_{k,t_1}\right) - R\left(X_{k,t_2}\right)\right)^2}{n.\left(n^2-1\right)} \qquad \text{[eq 1.]}$$

Where :

n: number of sites of measurement on the field,

X_{k,t_1}: is the value of the parameter X on the site k and the year t_1,

X_{k,t_2}: is the value of the parameter X on the site k and the year t_2,

$R(X_{k,t_1})$: is the rank of the value among all the values of the year t_1,

$R(X_{k,t_1})$: is the rank of the value among all the values of the year t_2.

Table 2 - Mean field values and coefficient of variation observed on each parameter for the seven years of the trial (NA : not available)

Year Annual Mean	1999	2000	2001	2002	2003	2004	2005	Mean (all years)	coefficient of variation (mean field) CV (%)
PH	3.42	3.73	3.55	3.37	3.72	3.59	3.53	3.56	3.84
Sugar ($g.l^{-1}$)	186	200	228	208	218	227	202	210	7.33
Titrable acidity ($H2SO4\ g.l^{-1}$)	4.83	4.16	3.94	4.95	3.84	3.23	4.58	4.22	14.48
Pruning weight ($Kg.vine^{-1}$)	0.80	0.82	0.63	0.76	NA	0.62	NA	0.73	12.98
Yield ($Kg.vine^{-1}$)	2.40	2.22	1.75	1.23	1.54	1.38	2.23	1.75	26.49
Canopy size (m^2)	0.81	2.08	1.92	NA	NA	NA	NA	NA	NA

r_S varies from -1 to 1. $r_S = 1$ implies that all the values present exactly the same rank in both series, which would denote, in our case, a strong temporal stability of the values between two successive years. Significance of r_S is given by a low probability. Three levels of significance were chosen in our work : 1 %, 5 % and 10 %.

b. Temporal stability analysis over the whole experiment

A more global analysis was conducted in order to quantify the temporal stability of the different spatial patterns over the seven years. The goal of this analysis was to give an index that allows the parameters to be ranked according to their temporal stability. This analysis was conducted with Kendall's coefficient of concordance (W). W coefficient was originally developed to quantify the agreement between several judges in their assessments of a given set of n objects. Such a test was used in this study because it didn't require any assumptions either on the distribution of the values or on the type of relationship (i.e. linearity) between data series. W only focuses on the rank of the values and provides an assessment on how the rank given by several judges fits between the different objects. In this study, the *n* objects were the 30 sites of measurement, and the 'judges' were the different years. For each parameter, the analysis was then conducted on a matrix where the lines referred to the sites of measurement and the columns to the year. W varies from 0 in case of total disagreement (i.e. no temporal stability) to 1 in case of total agreement. The equation to compute W is given by equation 2. (after Saporta, 1990).

$$W = \frac{\sum_{i=1}^{n}(R_i - \overline{R})^2}{\frac{1}{12}k^2(n^3 - n)} \quad \text{[equ. 2]}$$

with

$$R_i = \sum_{t=1}^{k} R(X_{i,t}) \quad \text{and} \quad \overline{R} = \frac{\sum_{i=1}^{n} R_i}{n}$$

Where :

n: is the number of sites of measurement,

k: is the number of year,

$\overline{R}$: is the average rank of the measurement site over all the considered year.

RESULTS AND DISCUSSION

1. Mean field variability over time

Table 2 presents summary field statistics for each parameter and for each year of our trial. Focusing on the yield, the mean field value varies from 1.23 $kg.vine^{-1}$ in 2002 to 2.4 $kg.vine^{-1}$ in 1999. This result highlights a significant temporal variability in the average yield in non-irrigated conditions with a potential two-fold difference in yield within a seven year period. The other parameters in Table 2 also show similar results to yield. A significant temporal variability of the mean field is observed over the seven years for pH (varying from 3.42 in 1999 to 3.73 in 2003), sugar content (varying from 186 $g.l^{-1}$ in 1999 to 228 $g.l^{-1}$ in 2001), TTA (varying from 3.23 $g.l^{-1}$ in 2004 to 4.95 $g.l^{-1}$ in 2002) and pruning weight (varying from 0.62 $kg.vine^{-1}$ in 2004 to 0.82 $kg.vine^{-1}$ in 2000). Variation observed on canopy size between 1999 and 2000-2001 is due to a change in the measurement procedure. The 2000 and 2001 data included a calibration procedure to convert the canopy size into m^2. In 1999, the size of the canopy was measured in percentage of green pixel in the image frame. This change largely explains the observed variability which is not only due to year effect.

The observed temporal variability is largely explained by specific climatic conditions in each year which strongly affect average values at the field scale. This effect is observed on both quantity parameters (yield and pruning weight) and harvest quality parameters (sugar content, pH and TTA). In table 2, the temporal coefficient of variation (computed from annual means over the seven years) is particularly significant for the yield (CV = 26.49 %). Conversely, the temporal coefficient of variation of pH and sugar content (respectively 3.84 % and 7.33 %) are the lowest. This result was expected since average field values of pH and sugar drive the date of harvest. For these parameters, the potential temporal variability due to climatic conditions of the year is offset by the choice of the harvest date.

2. Annual Within-field variability

Figure 3 presents median values and boxplots summarizing the distribution of values observed for each parameter and for each year. Boxplots are centred on the median value. The size of the box represents the limit of the upper and the lower quartiles (75 % and 25 % of the distribution respectively). The whiskers represent the 5 % - 95 % percentiles of the distribution.

For each parameter, the median values present the same trend as the mean value presented in table 2. Figure 3 also shows the large range of variation around the median regardless of the year or the parameter. Focusing on the yield, figure 3 shows that the range of variation (5 % - 95 % of the distribution) is at least of 2 kg.vine^{-1} whatever the year (which is twice the range in mean yield observed in table 2). This equates to at least of 8 Mkg.ha^{-1} variation within-field yield. However this range of variation is not constant over time; with a yield range of more than 4 kg.vine^{-1} in 1999 and around 2 kg.vine^{-1} in 2004. Similar results were observed for all the parameters (figure 3).

A more detailed analysis of the within-field variability is presented in table 3 including the coefficient of variation (CV) computed for each parameter and each year. The CV statistic summarizes the variability observed at a within-field level. It corresponds to the standard deviation normalised by the mean and gives the percentage of the mean value that the standard deviation corresponds to. CV is usually used to compare the magnitude of variation of different parameters. In this work, it is important to note that CVs values are highly dependant on the considered parameter : pH presents the lowest CV (average of 4), pruning weight and yield present the highest CV with an average of 38.6 % and 47 % respectively. In general the results highlight a significant spatial variability of quantity parameters like yield and pruning weights and a less significant spatial variability for harvest quality parameters. Similar results have already been observed in other parts of the world (Bramley *et al.*, 2004, Taylor *et al.*, 2005). Whatever the parameter, the CV also vary drastically from one year to another. During the seven years this experiment lasted, results show that CV can almost double for most of the parameters. This is particularly true in the case in pH, where CV varies from 3 to 5, sugar content (7-15), TTA (7-14) and, pruning weight (26-40). Yield seems to present a relatively more stable CV over time.

3. Discussion on the within field variability

The results presented in sections 3.1 and 3.2 are based on non-spatial descriptive statistics. Nevertheless they highlight variability in space (at a within field level) and

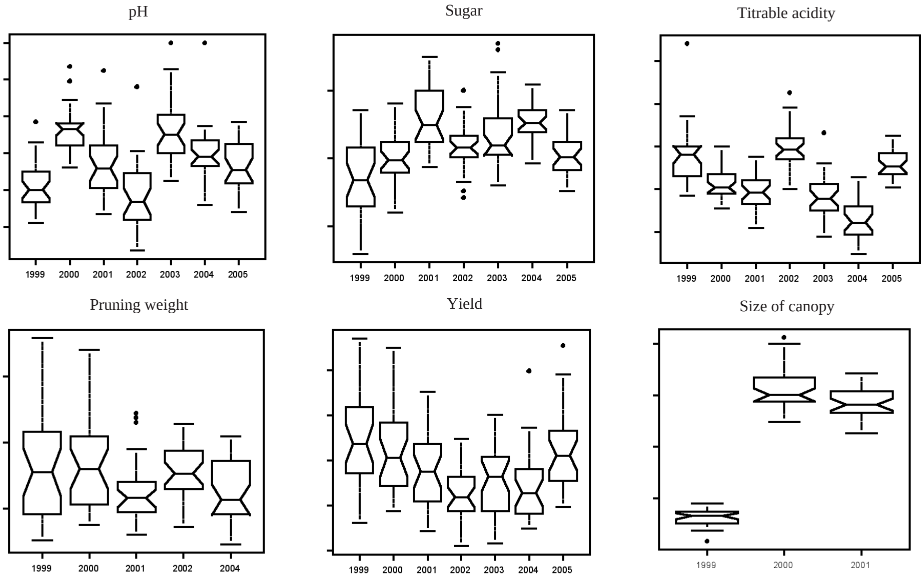


Figure 3 - Temporal variation of yield, pruning weight, canopy size, sugar, titrable acidity and pH.
The 25 %-75 % percentiles are represented by the size of the box, the median is represented by the horizontal line, the 5 %-95 % percentiles are represented by the « whiskers » and the outliers are represented by « o ».

Table 4 - Rank Correlation Coefficient r_S of Spearman computed between years for all the paramaters (* p>0.1, ** p >0.05, *** p > 0.01) « - » corresponds to a not significant r_S .

Year Coefficient of variation (%)	1999	2000	2001	2002	2003	2004	2005	Average spatial coefficient of variation $\overline{CV}_S$ (%)
PH	4	3	5	5	5	5	4	4.4
Sugar (g.l^{-1})	15	9	10	9	12	7	7	9.8
Titrable acidity (H2SO4 g.l^{-1})	14	9	10	10	13	13	7	10.8
Pruning weight (Kg.vine^{-1})	47	40	40	26	NA	40	NA	38.6
Yield (Kg.vine^{-1})	43	44	48	47	51	54	42	47
Canopy size (m^2)	10	10	8	NA	NA	NA	NA	9.3

in time for the most common parameters in viticulture. Some of these parameters present a significant variability in space or time, particularly the quantity parameters of yield and pruning weight, and can be designated as « type 1 » parameters. Conversely other parameters present less significant variability either in space or in time: e.g. harvest quality parameters like sugar, pH and TTA, and these parameters can be designated as « type 2 ».

One of the most significant goals of precision viticulture is to use the spatial variability observed in year « n » to provide site-specific management options in the vineyard in year « n + 1 ». In this context, our results raise several questions which have to be addressed:

- Firstly, regarding the magnitude of spatial variation, managing within-field variability of type 1 parameters may be more interesting than type 2 parameters. This conclusion comes from the analysis of a very simplistic statistic based on the coefficient of variation which doesn't take into account other considerations like profit margin, winery requirements, etc. In other locations and with a similar magnitude of spatial variation of type 2 parameters, Bramley *et al.* (2005) concluded that site-specific management of grape quality was profitable for the growers.

- Secondly, regarding the significant temporal variability observed, especially for type 1 parameters, it seems redundant to consider managing the spatial variability if it is masked by the temporal variability. Nevertheless, if the spatial variability exhibits consistent patterns over the years then it may possibly be managed despite the temporal variability. This assumption is of importance since it allows the consideration of consistent zones at a within field scale. Verifying the occurrence of zones would then require to identify locations which have a uniform response over the years. This definition include the possibility for a zone to be high one year and to be low the next year (i.e. to have flip flop effects). The spatial resolution of our data set is not large enough to test such a proposition. The following realistic assumption is then made : the average level of the different zones would change over the time, nevertheless, zones which present highest, medium, and lowest values compared to the mean of the field would then have the same locations in the field. Figure 4 provides an illustration of such an assumption. Figure 4 shows a hypothetical field with three zones. The zones are consistent over the time since they are at the same location two years in a row. Hypothetical boxplots of the field zones illustrate our assumption for the two years : a significant temporal variability is observed since average field value can change drastically from a year to another. Nevertheless, the spatial pattern remains consistent across both years since the zones of high, medium and low values remain at the same location. Considering this the Temporal Stability of the Within-Field Variability (TSWFV) is interesting in the frame of our work. Indeed, it allows the user to know whether it is possible or not to consider the within field variability of the previous year in the management of the field in the subsequent year(s).

The analysis presented in the next section aims at verifying the assumption of TSWFV as defined in this section. Parameters of type 1 and type 2 were considered and processed in the same way.

4. Analysis of the Temporal Stability of the Within Field Variability (TSWFV)

a- Results of correlation rank

Table 4 summarizes the values of r_S (Spearman's rank correlation coefficient) observed on the entire data set. Spearman's r_S was computed for each possible pair of years and each available parameter. Like the Pearson's

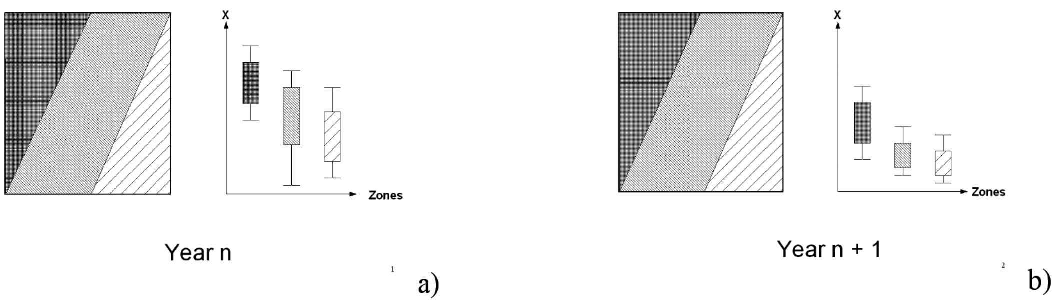


Figure 4 - Hypothetical field with three zones of high, medium and low zones two years in a row. a) year n with high average values. b) same hypothetical field the year n+1 with a low average value but consistent patterns of low, medium and high values

linear correlation coefficient, Spearman's r_S gives the strength that two series of values are linked with.

Table 4 shows that two classes of parameters can be considered. This distinction follows the one made in section 3.3 (« type 1 » and « type 2 » parameters) :

- « Type 1 » parameters always present high and statistically significant values of r_S. This is the case for yield, pruning weight and to a lesser extent for canopy size. Focusing on pruning weight, this parameter shows r_S values varying from 0.45 (for the pair 2000-2002) and 0.84 (for the pair 1999-2004). For all (10 over 10) the available pairs of years, r_S values are statistically significant for the pruning weight. Yield, with 19 pairs of years over the 21 considered, presents high and statistically significant r_S values. For canopy size, only three pairs of years were available, nevertheless, the three of them were significant. Significant r_S values are not necessarily observed between years in a row. They are observed between 1999 and 2004 (r_S = 0.84) for the pruning weight or between 1999 and 2003 (r_S = 0.70) for the yield. These results show that a strong TSWFV is observed for these parameters and that this TSWFV is also relevant on the long term.

- « Type 2 » parameters always present small and not necessarily statistically significant values of r_S. This is the case for TTA, sugar and to a lesser extent for pH. Focusing on TTA, r_S values are statistically significant for only 4 pairs of years among the 21 considered. Significant r_S remains small for this parameter (maximum r_S = 0.515 for the pair 1999-2004). For sugar and pH, with 7 and 9 years over the 21 considered respectively, despite a number of r_S values higher than that observed for the TTA, results are similar. Again, it is interesting to note that correlations between years does not necessarily appear between two years in a row; significant correlation is, for example, observed between years 1999 and 2004 for TTA, between years 2000 and 2005 for pH and sugar. These results show that a very weak TSWFV is observed for these parameters.

b- Maps analysis

The maps presented figures 5, 6 and 7 confirm the results highlighted by the Spearman's rank correlation coefficients (r_S) in table 4. Figures 5, 6, 7 only shows maps of pruning weight, yield and TTA obtained over the seven years of the experiment. Sugar and pH maps were not presented since they exhibit similar characteristics to TTA. For each map, black zones correspond to high values and white zones to low values in respect to the mean values for each particular year.

Maps of pruning weight highlighted consistent patterns regardless of the year. The field consistently has one zone of high pruning weight in the northern part and two zones of low values (south east and south west) separated by a thin long zone of high values. Because of the interpolation method and sampling rate, the thin zone of high values did not appear clearly in every years (especially in 2002). Pruning weight maps of 1999, 2001 and 2004 present very similar patterns in the field and correspond to years which had the highest r_S correlation coefficient (see table 4).

Maps of yield also presented consistent patterns over the years. Nevertheless, this consistency is less obvious than with the pruning weight. This result was expected since r_S correlation coefficients were slightly smaller for this parameter. Yield maps always showed one or two zones of high yield in the northern part of the field. These zones are sometimes separated with a thin zone of low yield (especially in 1999, 2000 and 2004). A zone of low yield consistently appears in the southern part of the field. Once again because of the interpolation method and the sampling rate, the contour of this low yield zone changes slightly from one year to another. The yield maps of 1999, 2001 and 2003 present very similar spatial patterns. This result was expected since these years correspond to the years with the most significant r_S coefficient (table 4). An analysis of spatio-temporal relationships between parameters was not the purpose of this work, nevertheless, it is interesting to see that high and low pruning weight zones often match with high and low yield zones, respectively .

Table 4 - Rank Correlation Coefficient r_S of Spearman computed between years for all the paramaters (* p>0.1, ** p >0.05, *** p > 0.01) « - » corresponds to a not significant r_S.

	2000	2001	2002	2003	2004	2005
PH						
1999	-	-	-	-	-	-
2000		-	-	0.454 *	0.345 *	0.487 *
2001			-	0.464 *	-	0.438 *
2002				0.549 **	-	0.377 *
2003					0.329 *	0.501 *
2004						-
Sugar						
1999	0.343 *	0.492 *	-	-	-	-
2000		0.480 *	-	-	-	0.419 *
2001			-	-	-	0.466 *
2002				-	-	-
2003					0.313 *	0.374 *
2004						-
Titrable acidity						
1999	0,343 *	-	-	-	0,515 *	-
2000		-	-	-	0,363 *	0,424 *
2001			-	-	-	-
2002				-	-	-
2003					-	-
2004						-
Pruning weight						
1999	0,657 ***	0,840 ***	0,578 ***		0,842 ***	
2000		0,799 ***	0,454 *		0,585 **	
2001			0,727 ***		0,822 ***	
2002					0,527 **	
2003						
2004						
Yield						
1999	0,598 ***	0,576 **	0,619 ***	0,702 ***	0,401 *	0,565 **
2000		0,441 *	-	0,408 *	0,606 ***	0,509 *
2001			0,388 *	0,711 ***	0,579 **	0,445 *
2002				0,567 **	-	0,540 **
2003					0,546 **	0,665 ***
2004						0,490 *
Canopy size						
1999	0,556 **	0,419 *				
2000		0,521 **				
2001						
2002						
2003						
2004						

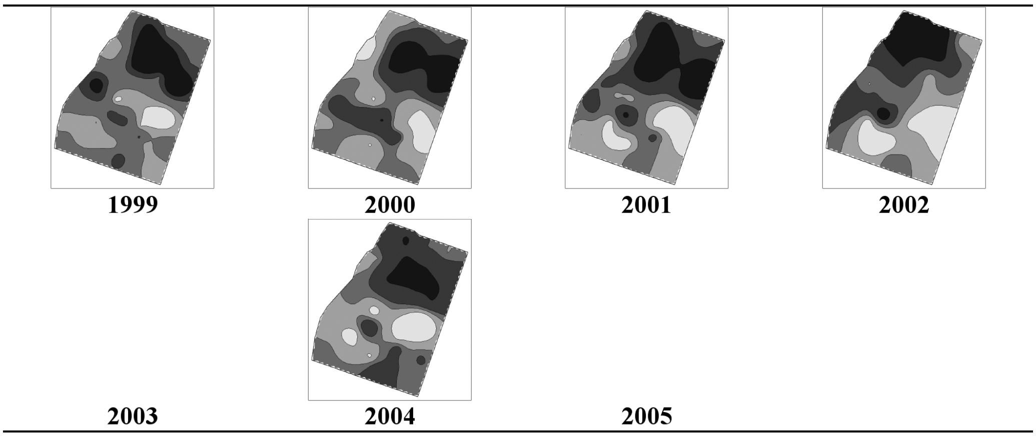


Figure 5 - Pruning weight maps. Each of the 5 greyscale classes correspond to 20 % of the data.
Classes are ranked from white for the lowest values to black for the highest values.

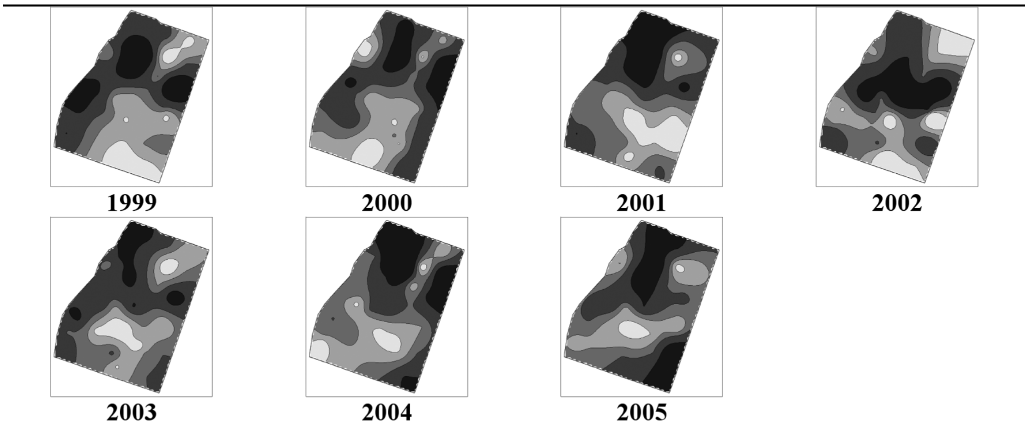


Figure 6 - Yield maps. Each of the 5 greyscale classes correspond to 20 % of the data.
Classes are ranked from white for the lowest values to black for the highest values.

For TTA, consistent zones are difficult to identify with several maps showing almost inverse responses, e.g. the 1999 and 2005 maps. This result confirms that TTA present a weak TSWFV. Sugar and pH maps present similar characteristics.

A visual analysis of the maps confirms the results presented table 4 and highlights the relevance of our analysis, in particular the use of the Spearman's r_s coefficient to assess the time stability of the within-field variability. Maps show consistent zones of yield and pruning weight and a knowledge of this consistent pattern may be a significant decision support when considering future site-specific management of the fields.

5. Temporal stability over the whole experiment and discussion

The previous section (section 3.4) focused on a year per year analysis of the time stability either through the Spearman's r_s coefficient or the maps. Nevertheless, a more global analysis over the entire period of the experiment is required to confirm this conclusion. This global analysis will be necessary to provide an objective index for ranking each parameter from the most to the least time consistent. This section aims at providing such an analysis.

Table 5 presents the Kendall's coefficient of concordance (W) of each parameter computed over the seven years of the experiment. W illustrates to what extend a parameter can be considered as time stable considering all the years together. Again, table 5 allows two types of parameters to be considered :

- « Type 1 » parameters which present high Kendall's W values ; pruning weight (W = 0.76) , size of the canopy (W = 0.71) and yield (W = 0.59),

- « Type 2 » parameters which present low Kendall's W values ; pH (W = 0.37), sugar (W = 0.35) and TTA (0.29).

Table 5 confirms the results presented in the previous two sections. The within-field variability of type 1 parameters can be considered significantly time stable. Among these parameters, pruning weight presents the highest TSWFV. Despite a high W value, the non significant result observed for canopy size is mainly due to the small number of years (three) available for this analysis. Yield can be considered as time stable over the seven years. Nevertheless the smaller W value observed for this parameter, compared with pruning weight and canopy size, probably means a less significant TSWFV. This confirms the results from table 4 that a significant TSWFV was not consistently observed between all years (2 over 21 comparisons are not significant). Table 5 confirms that « type 2 » parameters don't present any TSWFV for pH, sugar or TTA.

These results are relevant since « type 1 » parameters (and especially pruning weight) are strongly related to water and nutrients availability. They largely depend on soil characteristics (soil texture, soil depth, etc.) and topography (water flow) that differ little from year to year. The non-irrigated condition in the vineyard studied may further emphasise these results. The smaller TSWFV observed for yield compared to pruning weight may be due to its less significant link with time stable field attributes. Disease problems, climatic anomalies, or other anomalies which may affect yield may explain this smaller TSWFV level. This result is of importance in the context of precision viticulture. It means that pruning weight (or other vigour assessment) and yield maps to a lesser extent may constitute relevant decision supports to manage the within-field variability for future years. Regarding the results of this study, variability observed either in pruning weights or a yield map remains relevant for at least seven years. Variable rate operations (irrigation, fertilisation, pruning) could therefore be driven by the spatial variability observed in pruning weights or yield in previous years. A first simple relevant application could be to optimise yield assessment by a target sampling procedure based on the spatial variability of previous yield or vigour maps.

Conversely, the lack of TSWFV observed in « type 2 » parameters indicates that there is no obvious relationship between time stable vineyard attributes, like physical soil properties and topography, and these parameters. Quality maps (pH, sugar and TTA) of the previous years are therefore of little value to drive either quality assessment or differential harvest of the quality for the years to come. Once again, non-irrigated conditions may be emphasising this result. The results also highlight that within-field variability of « type 2 » parameters is much more complicated to predict. In irrigated conditions results may be different. On two irrigated blocks (4 years and 3 years of measurements), within field measurements reported by Bramley (2005) showed consistent patterns for each attribute (sugar content, pH, total titrable acidity and phenols).

Plant water status may have a significant contribution to quality at the within field level. Experiments run by Ojeda *et al.* (2005) tended to show that harvest quality results from a strong interaction between the climate of the year and water availability (mainly explained by soil

Table 5 - Kendall's coefficient of concordance computed over seven years.

	Kendall W	*Significance ($p<0.01$)*
Pruning weight	0.76	***
Size of canopy	0.71	**Ns**
Yield	0.59	***
pH	0.37	**Ns**
Sugar	0.35	**Ns**
Total acidity	0.29	**Ns**

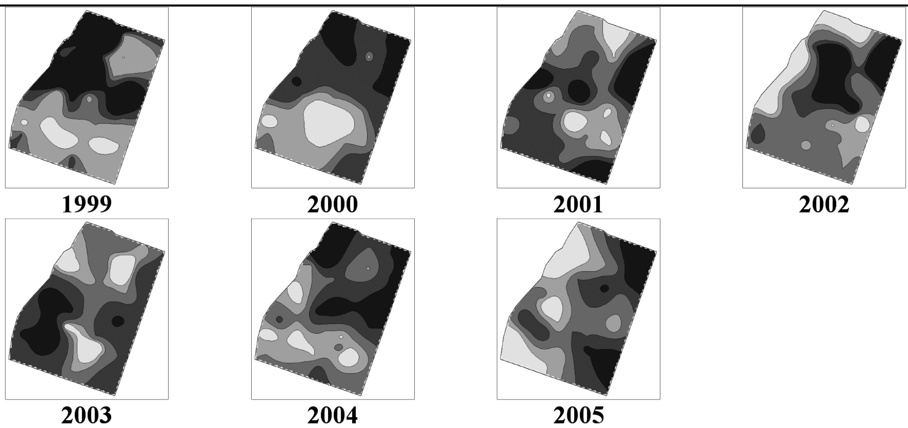


Figure 7 - Titrable acidity maps. Each of the 5 greyscale classes correspond to 20 % of the data.
Classes are ranked from white for the lowest values to black for the highest values.

attributes). Depending on climatic factors and the within-field variability of soil attributes, this interaction may lead to very different spatial patterns in non-irrigated conditions.

CONCLUSION

The aim of this paper was to present the results of a study run over 7 consecutive years to characterise the Temporal Stability of the Within-Field Variability (TSWFV) for the most common vine parameters. In the context of precision viticulture, TSWFV is of importance to know whether or not it is relevant to use the within-field variability of the year « n » to design a site-specific management strategy on the year « n+1 ». The experiment was based on 6 parameters measured on 30 sites located within a non irrigated vineyard. Parameters measured the vines capacity to produce biomass (pruning weight, yield and size of the canopy) as well as harvest grape quality (sugar content, pH, Total Titrable Acidity).

Whatever the parameter, a significant temporal variability of the mean response was observed from one year to another. This temporal variability lead to the definition of the TSWFV as the occurrence of consistent high values or low values patterns over the years. High and low values were defined in relation to the mean vineyard value of the year for each parameter. TSWFV analysis allows the parameters to be classified in two distinct types. Type 1 parameters (pruning weight, yield and canopy size) which present a significant TSWFV and Type 2 parameters (sugar, TTA and pH) which present no TSWFV. This result may indicate a strong relationship between Type 1 parameters and several time stable field attributes like soil texture, soil depth, topography and the resulting water and nutrients availability. Non-irrigated conditions may serve to emphasise such a relationship. Conversely, Type 2 parameters present a more erratic within field distribution over the years. For these parameters, it was hypothesised that a strong interaction between the climate of the year and water availability (mainly explained by soil attributes) may lead to inconsistent zones at the within-field scale.

For precision viticulture management, these results are significant. They show that yield or vigour (pruning weight, size of the canopy) maps of the previous years are relevant in designing site-specific management strategies in the year « n+1 » or subsequent years. For the vineyard used in the study, a vigour map (pruning weight) remained relevant over 6 years. Conversely, maps of quality parameters from previous years are not useful in determining how to manage harvest quality in the year « n+1 ».

Nevertheless, on the basis of these results many questions still need to be addressed in future work :

- The possibility of designing an optimised targeted sampling scheme based on the amount of within field variability observed in previous years. An early assessment of the yield is often required by wineries for management purpose and harvest logistics. Improved harvest logistics will assist both growers and wineries alike.

- The possibility to use « type 1 » parameter maps and soil maps in association with climatic data or plant water status data to predict within-field quality variability. This hypothesis needs to be investigated to determine if quality can be predicted as a season progresses.

- The relevance of airborne imagery or ground based sensors in assessing the within field variability of « type 1 » parameters. Information provided by such sensors should remain relevant over a number of years. Experiments specifically dedicated to study the temporal stability of information provided by airborne imagery and its link with ground truth information are yet to be investigated.

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