# Precision viticulture and water status: mapping the predawn water potential to define within vineyard zones

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# Precision Viticulture and Water Status : Mapping the Predawn Water Potential to Define within Vineyard Zones.

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**Keywords :** Grapevine, predawn water potential, within field variability, mapping, zoning.

**Abstract**

**An experiment was carried out over two years (2003-2004) in order to monitor the spatio-temporal variability of the predawn water potential at a within field scale. The predawn water potential was measured on 49 points within a field of 1.2 ha. Respectively 7 and 6 measurements were performed at different times in 2003 and 2004. The main results of this work showed that the within field variability of the predawn water potential was significant. It also highlighted the temporal stability of the variability. The zoning performed according to the predawn water potential values was linked to other parameters such as leaf area, trunk circumference, soil resistivity, etc. The result confirmed the temporal stability of the within field variability. It also showed the opportunity to use high resolution data (remote sensing, monitoring systems mounted on conventional machinery) as decision support system to assess a similar zoning or to perform target sampling for a better assessment of the field water status.**

## INTRODUCTION

Many authors (Champagnol, 1984, Seguin, 1983, Dry and Loveys, 1998, Ojeda *et al.* 2002, 2004) showed that changes in grapevine water status have an effect on grape yield, grape vigor and quality. Zoning the vineyards on the water status basis would lead to a relevant decision support tool. Such a zoning requires the assessment of plant water status with a high spatial and temporal resolution.

This information would then bring a significant tool enable to manage the quality at a within vineyard scale. (ripening control, differential harvest, irrigation management, vigor management, etc.). Unfortunately, measuring the plant water status (assessed by the predawn water leaf potential) is hard to perform. This measurement requires a heavy device (pressure chamber, Scholander *et al.* 1965) and is time consuming. The assessment of the plant water status is then not realistic for the growers at a high spatial and temporal resolution during the growing period and the ripening.

An alternative approach would then lead to assess the spatial variability of the plant water status through other information that are easy to measure with a high resolution (remote sensing, monitoring system on board on conventional machinery, on the go measurement of the soil resistivity, etc.). These complementary data could provide basic information to characterize the within vineyard variability of the soil and the plant response (Tisseyre et *al*., 2001, Johnson et *al*., 2003, Bramley et *al*., 2004, Lamb et *al*., 2004). Zones of homogeneous changes in plant water status during the growing and ripening period could be considered. This zoning would bring a decision support system to perform target sampling of predawn water potential measurement or to propose a model describing changes of water status from zone to zone according to a field measurement reference.

This work constitutes a preliminary work in order to consider the opportunity to use high resolution data in zoning the vineyard according to changes in plant water status. This work aims at studying the within field predawn water potential variability in order to answer some preliminary questions :

What magnitude of variation of the plant water status (temporally and spatially) is expected at a within vineyard scale ? And is this magnitude significant enough to provide a relevant decision tool that the quality management would be based on ?

Is it possible to consider a zoning based on the plant water status and Is it relevant to assume that such a zoning corresponds to systematically low/medium/high water restriction areas over the growing period (time stability of the within field variability)?

Is the magnitude of variation of the quality high enough to justify such a zoning ?

Finally, is it possible to consider high resolution data to perform a zoning similar to the one that the plant water status is based on ? If yes, what are the most relevant data to rule such a zoning ?

## MATERIALS AND METHODS

### Experimental field and plant material description

Experiments were carried out on a vineyard located in southern France close to the town of Gruissan (INRA experimental centre of Pech-Rouge-Aude). It was a non-irrigated syrah vineyard of 1.2 ha. 49 sites of measurement were defined on a regular grid within the field. The sites were located with a differential GPS - Leica (Global Positioning System) allowing mapping and spatial analysis of the parameters.

### Parameter measurements

Parameters measured at a within field level (on the 49 sites) were related to the field description (elevation), the soil (electrical soil resistivity) but also to the plant, the harvest (quality and quality) and the plant water status. On every sample site, plant measurements were performed on 3 representative vines. The set of parameters collected over the two years (2003 and 2004) is summarized table 1, 2 and 3.

### Data analysis

### Data processing and clustering analysis

Data analysis was first conducted with a Principal Component Analysis P.C.A.). The PCA was followed by a second analysis based on the linear correlation coefficient (Pearson) calculated parameter by parameter. This analysis was conducted over the two years (2003 et 2004). Field zoning based on the plant water status was performed with an agglomerative hierarchical clustering method. Ward distance was used to drive the agglomeration process. Mean comparisons were performed with the Kruskal wallis non-parametric test. This test was used instead of the classical analysis of variance (ANOVA) because ANOVA normality assumptions did not apply on our data.

**Data mapping**

Data mapping was performed with 3Dfield software. The interpolation method used in this study was based on a determinist function (inverse weighting distance). The isocurves used to map the data correspond to :

- the class number when the map refers to the clustering result,
- expert classes when the map refers to plant water potential : the following classes were then considered ; [0 ; -2 bars[ no water restriction, [-2 ; -4 bars[ low water restriction ; [-4 ; -6 bars[ medium water restriction ; [-6 ; -10 bars] high water restriction ; < -10 bars, drastic water restriction.

## RESULTS AND DISCUSSION

**Within vineyard variability of the predawn water potential**

Figure 1 a) shows the changes in mean field predawn water potential (mean of the 49 sample sites). Figure 1 a) points out an average predawn water potential which decreases regularly over the growing period and the ripening. This is a logical result for a non irrigated vineyard in southern France. Figure 1 a) also shows that summer 2003 was hot and dry compared to summer 2004, resulting in a drastic water deficit and low predawn water potential at ripening in summer 2003. Figure 1 b) shows changes in field variance for both years of the experiment. It highlights an increasing variance over the summer for both years. Simultaneous analysis of figure 1 a) and b) shows that the field variance of the predawn water potential increases with the water restriction. To explain this increasing variance, a within vineyard variability due to soil variation and/or elevation was assumed. This within field variability may lead to consider different zones that may explain different trends of water restriction which may explain the increasing variance of the field. This preliminary result highlights the significant within field variability of the predawn water potential.

**Temporal variability of the plant water status at a within field scale**

Table 4 shows the results of the linear correlation coefficients for all the dates that the water potential was measured at. Table 4 highlights significant correlation (probability of 1 ‰ ) for most of the dates over both years. This results was confirmed by a PCA (not shown in this paper). It is noticeable that once the water potential reaches a significant value (after date 3 and date 4 respectively in 2003 and 2004), an increasing water restriction leads to a linear relationship between values observed at different dates. This means that at the within field level, there is a relationship between the plant status at date $t_i$ and the plant status at the date $t_{i+1}$.

Maps presented figure 2 highlight this phenomenon. Patterns of systematic significant water restriction (in dark grey or black, depending on the time) occur in the northern part of the field whatever the date for both years. Conversely, patterns of low water restriction (in white or light grey) occur in the center of the field at the same locations whatever the dates for both years.

These results highlight the presence of a parameter which may rule the plant water status at the within field level. This parameter leads to values systematically smaller or higher than the field mean depending on the location they belong to. This result is only noticeable once the predawn water potential reaches a significant level. Regarding the predawn water potential, it corresponds to a temporal stability of the within field variability. On a practical point of view, this result points out, once again, the importance of the sampling strategy to assess the plant water status. Depending on the sampling locations, field plant water status can lead to systematical under or over estimated values for the vineyard.

On a more theoretical point of view, these results show that the Z(s,t) water potential value measured at the location s and at the time t may :

- be assessed from data measured at the same location and at previous time,
- be modeled, at a within vineyard scale, on the basis of the parameter that the plant water status depends from. Such a model may be based on a field zoning described by the following relation :

$$Z(s,t) = \mu(t) + \sum_{k=1}^{K} \delta_k(s).\alpha_k(t) + \varepsilon \quad [1]$$

where $\mu(t)$ is the mean value of the field at time *t, K* is the number of zones which has to be considered on the field, $\delta_k(x)$ takes the values 0 or 1 depending on the belonging of the *s* location to the *k* zone, $\alpha_k(t)$ is the mean effect of the *k* zone at time *t* and $\varepsilon$ is a residual.

**Vineyard zoning**

A zoning of the vineyard was performed in order to validate the field zones assumption. Field zoning was performed with a hierarchical clustering method. Only predawn water potential data were considered in this process to avoid assumptions neither on the number of class to consider nor on the parameters which may rule the different zones. The clustering was performed with the entire water potential data set. Classes resulting from the agglomerative procedure were mapped in order to validate the clustering spatial relevancy and also to aggregate other spatial information according to the resulting zones. Map results are shown figure 3 a).

The clustering map highlights 4 different zones in the vineyard. Zone 1 presents systematic low water restriction whatever the dates and the year. Zone 4 corresponds to locations of systematic high water restriction. Zone 2 and 3 present medium values for all the dates. Compared to figure 2, the clustering map seems to be relevant since the clusters (zones) fit with the patterns of water potential which were previously identified on the northern and the center part of the vineyard. Figure 3 b) shows the mean water potential changes over the year (2003) for each zones. It clearly shows that the « water restriction path » is singular for each zone during the growing and the ripening. Similar results (not shown) were obtained in 2004.

**Relationship between zoning and qualitative parameters**

The mean values of qualitative harvest parameters were calculated on each. A non parametric test (Kruskal-Wallis) was used to determine statistical differences (Table 5). Significant differences between quality parameters for each zones were observed (Table 5). In 2003, zone 2 presents the highest sugar content, the highest level of pH, phenol and the lowest total tritable acidity (TTA). Whereas no statistical difference was detected for anthocyans content, zone 2 also presents the highest value regarding this parameter. Conversely, in 2004, the zone 4 presents the highest sugar content, the highest level of pH and anthocyans. It also shows the lowest TTA values. In 2003 climatic conditions, zone 2 was the highest quality zone whereas zone 4 was among the worst. Conversely, in 2004, the zone 4 was the highest quality zone. Results presented table 5 points out the relevancy of our zoning. These results also highlight the interaction between zones, climatic conditions, water restriction paths and fruits quality (see Ojeda et al., 2005 for a detailed study of these data).

**Relationship between zoning and other parameters**

The previous section showed how the zoning based on the water potential values at different time was relevant for quality management. Unfortunately, for growers, water potential measurements can hardly be performed with the frequency and the spatial resolution used in this experiment. This section aims at identifying easy to measure parameters which may be helpful to perform a similar and relevant zoning. This study focus on within field vigor measurement and soil data assessed by electrical resistivity (Table 6).

At first sight, table 6 shows that mean vigor and electrical resistivity change logically regarding the zones. Zone 1 (low water restriction) presents the highest average foliar area, trunk circumference, weight of wood. Conversely, Zone 4 (high water restriction) presents the lowest yield, trunk circumference, weight of wood and the highest soil resistivity. Zone 2 and 3 can be seen as intermediary regarding these parameters. Relationship between plant water potential zones (figure 6.a), foliar area (figure 6.b) and trunk circumference (figure 6.c) is also noticeable on the maps. Figure 6 shows that spatial patterns are similar for different parameters.

Zones present differences for soil (electrical resistivity) and also trunk circumference. This last parameter takes into account the vineyard history since plantation and especially water restriction history. This result is significant since it confirms the temporal stability of the zoning.

## CONCLUSION

The experimentation carried out in 2003 and 2004 on the water potential spatio-temporal within field variability highlighted some interesting clues. First it showed that the within field variability of the plant water potential is significant whatever the time and whatever the year on a non-irrigated vineyard. Results also showed that there was a significant temporal stability of the within field variability ; this means that high water restriction areas are always at the same locations of the vineyard and similarly for low water restriction areas. This conclusion leads to a within field zoning based on the water potential values measured at several times over two years. This zoning was used to rule differential harvest and also to analyze quantitative and qualitative parameters of the harvest.

Results highlighted a relationship between zones based on the water potential values and harvest quality parameters. Further tests and particularly wine testing from samples of the 4 zones are still on. Results also showed that vigor parameters such as weight of wood, trunk circumference, foliar area and yield had a relationship with the water restriction delineation of the vineyard. Similarly within field soil variability assessed by the electrical resistivity had also a relationship with the field delineation. This result is significant since it allows to consider a simplification of the sampling procedure for the next years. It also gives some clues to consider practical procedures for the growers since vineyard zoning based on vigor assessment seems to be relevant.

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**Table**

Table 1 : Measurement dates of the predawn water potential on all the points

| | Dates of predawn water potential measurement | | | | | | |
|---|---|---|---|---|---|---|---|
| year | date 1 | date 2 | date 3 | date 4 | date 5 | date 6 | date 7 |
| 2003 | 18 june | 26 june | 5 july | 16 july | 23 july | 30 july | 12 august |
| 2004 | 09 june | 05 july | 5 august | 18 august | 23 august | 10 sept. | - |

Table 2 Measurements performed at harvest on every points (2003-2004)

| | measurements performed at harvest | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| year | Anthocyans mg/kg of fruit | Weight of berries (g) | number of bunches /vine | yield (kg/vine) | pH | total titrable acidity (g/l) | Brix | Total phenol index |
| 2003 | X | X | X | X | X | X | X | X |
| 2004 | X | X | X | X | X | X | X | X |

Table 3 Measurements performed on the soil and the vines on every points

| | measurements performed on the field, the soil and the vines | | | | |
|---|---|---|---|---|---|
| year | soil resistivity (ohm.m) | elevation | foliar area | weight of wood (kg/vine) | trunk circumference (cm) |
| 2003 | - | - | X | X | X |
| 2004 | X | X | - | X | X |

Table 4 : Pearson correlation coefficient between water potential values at different time (* : P(|R| > r) = 0,001)

| | | linear coefficient of correlation (pearson) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | year 2003 | | | | | | | year 2004 | | | | | |
| | | date 1 | date 2 | date 3 | date 4 | date 5 | date 6 | date 7 | date 1 | date 2 | date 3 | date 4 | date 5 | date 6 |
| year 2003 | date 1 | 1.00 | 0.33 | 0.54* | 0.48 | 0.43 | 0.29 | 0.42 | -0.29 | 0.50* | -0.16 | 0.53* | 0.45 | 0.36 |
| | date 2 | | 1.00 | 0.74* | 0.75* | 0.54* | 0.69* | 0.63* | -0.03 | 0.38 | 0.18 | 0.33 | 0.36 | 0.36 |
| | date 3 | | | 1.00 | 0.88* | 0.67* | 0.74* | 0.78* | -0.15 | 0.61* | 0.13 | 0.56* | 0.57* | 0.52* |
| | date 4 | | | | 1.00 | 0.74* | 0.82* | 0.85* | -0.14 | 0.59* | 0.21 | 0.62* | 0.56* | 0.63* |
| | date 5 | | | | | 1.00 | 0.71* | 0.84* | -0.06 | 0.62* | 0.19 | 0.69* | 0.69* | 0.67* |
| | date 6 | | | | | | 1.00 | 0.84* | 0.02 | 0.52* | 0.25 | 0.57* | 0.66* | 0.66* |
| | date 7 | | | | | | | 1.00 | -0.04 | 0.58* | 0.26 | 0.63* | 0.68* | 0.65* |
| year 2004 | date 1 | | | | | | | | 1.00 | -0.34 | 0.13 | -0.26 | -0.10 | -0.22 |
| | date 2 | | | | | | | | | 1.00 | 0.06 | 0.65* | 0.68* | 0.67* |
| | date 3 | | | | | | | | | | 1.00 | 0.16 | 0.21 | 0.24 |
| | date 4 | | | | | | | | | | | 1.00 | 0.67* | 0.72* |
| | date 5 | | | | | | | | | | | | 1.00 | 0.77* |
| | date 6 | | | | | | | | | | | | | 1.00 |

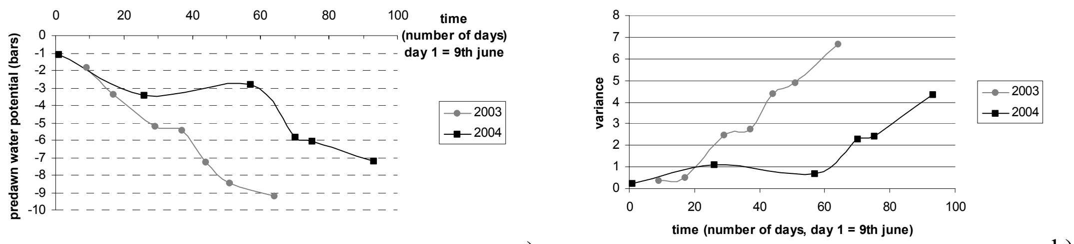
Table 5 Mean values of harvest quality parameters on each zones (a,b,c,d ; mean values significantly different 10% Kruskal-Wallis test)

| | mean value for each zone | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2003 | | | | | 2004 | | | | |
| | Brix (°) | pH | TTA (g/l) | phenol | anthocyans (mg/kg) | Brix (°) | pH | TTA (g/l) | phenol | anthocyans (mg/kg) |
| Zone 1 | 21.39 (a,b) | 3.72 (a,b) | 3.97 (a,b) | 32.6 (a,b) | 1182 (a) | 21.06 (a) | 3.79 (a) | 4.75 (a) | 37.7 (a) | 1754 (a) |
| Zone 2 | 22.55 (b) | 3.81 (b) | 3.54 (b) | 36.9 (b) | 1330 (a) | 22.33 (b) | 3.85 (a,b) | 4.52 (a) | 42.6 (b) | 1874 (a,b) |
| Zone 3 | 21.35 (a) | 3.69 (a) | 3.87 (a) | 33.69 (a) | 1239 (a) | 20.95 (a) | 3.83 (a) | 4.76 (a) | 36.1 (a) | 2077 (b) |
| Zone 4 | 20.89 (a) | 3.78 (a,b) | 3.99 (a) | 33.66 (a,b) | 1269 (a) | 22.51 (b) | 3.9 (b) | 3.84 (b) | 38.75 (a,b) | 2565 ( c) |

Table 6 : Mean values of main parameters on each zones (a,b,c,d ; mean values significantly different 5% Kruskal-Wallis test)

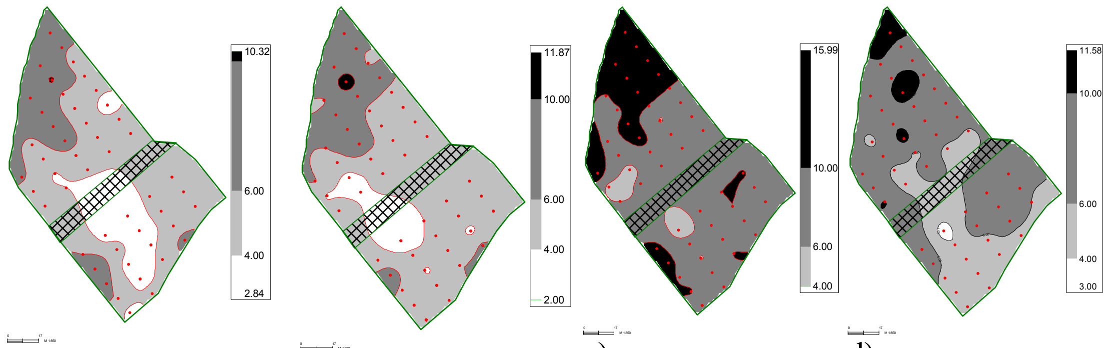
| | mean value for each zone | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2003 | | | | 2004 | | | | |
| | yield (kg/vine) | foliar area (m²) | trunk circumference (cm) | weight of wood (kg/vine) | yield (kg/vine) | trunk circumference (cm) | weight of wood (kg/vine) | soil resistivity 1 m. (ohm.m) | elevation (m.) |
| Zone 1 | 0.8 (a) | 1.9 (a) | 12.05 (a) | 0.96 (a) | 1.66 (a) | 13.96 (a) | 1 (a) | 309.8 (a) | 40.66 (a) |
| Zone 2 | 0.87 (a) | 1.54 (b) | 11.73 (a) | 0.73 (a) | 1.82 (a) | 13.46 (a) | 0.88 (a,b) | 283.7 (a) | 40.76 (a) |
| Zone 3 | 0.82 (a) | 1.16 ( c) | 11.33 (b) | 0.57 (b) | 1.53 (a) | 13.08 (b) | 0.79 (b) | 222 (a) | 38.76 (a) |
| Zone 4 | 0.45 (b) | 0.8 (d) | 9.8 ( c) | 0.36 ( c) | 1.23 (b) | 10.7 (c) | 0.43 ( c) | 672.4 (b) | 44.44 (b) |

## Figure



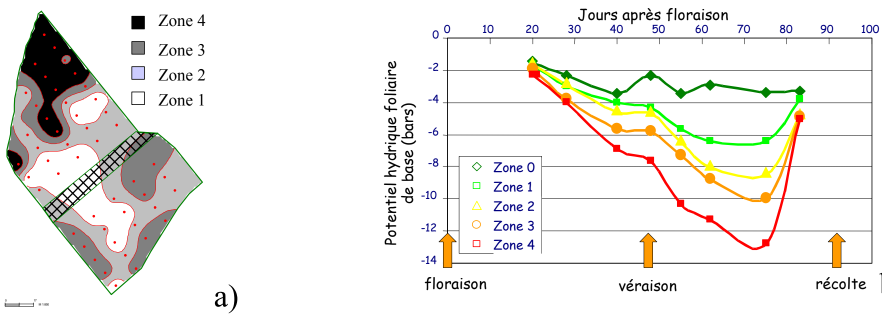

a) b)

Figure 1 a) Mean field predawn water potential changes during summer 2003 and 2004, b) changes in the field predawn water potential variance during summer 2003 and 2004.




a) b) c) d)

Figure 2 : maps of the predawn water potential at different times ; a) date 3 in 2003, b) date 4 in 2003, c) date 6 in 2003 and d) date 6 in 2004.




a) b)

Figure 3 a) Field zoning resulting from the clustering based on water potential values for all the data set. b) change in the mean water potential for each zone in 2003

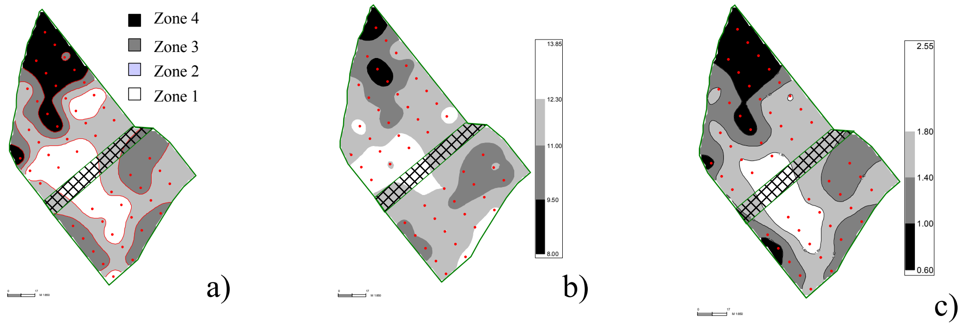



Figure 6 : a) map resulting from the plant water potential classification b) trunk circumference map in 2003, c) foliar area map in 2003.

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## *Viticulture de Précision et Etat Hydrique : Cartographie du Potentiel Hydrique et Intérêt pour le Zonage à un Niveau Intra-Parcellaire*

***Mots clés*** *: Vitis vinifera, potentiel hydrique de base, variabilité intra-parcellaire, cartographie, zonage.*

***Résumé***

*Une expérimentation a été conduite pendant deux ans (2003-2004) afin de suivre la variabilité spatio-temporelle du potentiel hydrique de base à une échelle intra-parcellaire. Le potentiel de base a été mesuré sur 49 points à l'intérieur d'une parcelle de 1,2 ha. Ces mesures ont été répétées à 7 et 6 dates différentes respectivement en 2003 et 2004. Les principaux résultats de cette expérimentation montrent que la variabilité intra-parcellaire du potentiel de base est importante. Ils mettent également en évidence la stabilité temporelle de la variabilité observée. Le zonage effectué sur la base du potentiel hydrique était lié à d'autres paramètres tels que la SFEp, la circonférence des ceps, la résistivité du sol, etc. Ce lien confirme la stabilité temporelle de la variabilité observée. Il permet également d'envisager d'utiliser des données à hautes résolution (télédétection, capteurs embarqués sur machines) pour effectuer un zonage similaire ou pour servir d'outils d'aide à l'échantillonnage orienté pour une meilleure estimation de l'état hydrique de la parcelle*

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