Mapping intra-plot topsoil diversity of Burgundy vineyards (Aloxe- Corton, France) from very high spatial resolution (VHSR) images

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Emmanuel CHEVIGNY[1,2,*], Amélie QUIQUEREZ[1], Christophe PETIT[3], Pierre CURMI[2]

[1]*UMR 6298 ArTeHiS, Université de Bourgogne, 6 bd Gabriel, F-21000 Dijon, France*
[2]*AgroSup Dijon,UMR 1347 Agroécologie, BP 86510, F-21000 Dijon, France*
[3]*UMR 7041 ArScAn, Université Paris 1 Panthéon La Sorbonne, 3rue Michelet, F-75006 Paris, France*
[*]*Corresp. author : CHEVIGNY, Email: emmanuel.chevigny@u-bourgogne.fr*

ABSTRACT
In this work, we present a method based on very high spatial resolution (VHSR) aerial images acquired in the visible domain and that map soil surface diversity at the hillslope scale with a spatial resolution of a few centimeters. This method combines aerial VHSR image classification with local soil sampling. Principal component analysis (PCA) and non-supervised classification was performed on image characteristics to define soil surface characteristic classes (SSC). Then soil surface mapping was combined with soil surface descriptions and soil profiles to define soil types by physical and chemical characteristics.

Key Words: Soil mapping, vineyards, unmanned aerial vehicle, very high spatial resolution, soil surface characteristics

1 INTRODUCTION

The Burgundy vineyards have been recognized for their high diversity of Terroirs, controlled by complex interactions between natural processes, historical parameters and soil management practices. Determining simple relationships between these factors and the quality of wine production is yet not possible. However, a better understanding of the Terroirs diversity and of their spatial distribution is necessary for the sustainable management of vineyard soils.

This work aims at improving our understanding of Terroir soil spatial distribution from the mapping of soil surface characteristics.

Our approach combined local soil sampling, VHSR images, permitting soil surface heterogeneities to be identified at a centimetre spatial scale, and image classification [1, 2]. The spatial distribution of these soil surface classes is then mapped at the hillslope scale, allowing soil types to be visualised. In this work, we first describe the aerial image classification and then the soil mapping obtained from this classification combined to local soil descriptions by physical and chemical analyses.

2 MATERIALS and METHODS

2.1 Study area

The selected site is located on the hillslopes of Aloxe-Corton vineyards, in the Côtes de Beaune area (Burgundy, France). The hillslopes, shaped by the Bressan rifting, form the eastern border of the Burgundy plateau [3]. These hillslopes are covered by silty-clayey soils that develop on Jurassic marly limestones, where white stones contrast with the dark matrix. Slopes vary from 12° upslope to 1° downslope, and evolve from a convex to concave and then planar morphologies. The landscape is characterized by a vine monoculture where the parcellar limits, i.e. paths, road and walls between parcels form the only discontinuities on the hillslope. The studied area extends from the Corton wood downslope to the road "RN74" that marks the limit of the extension of the Côtes de Beaune vineyards.

2.2 Topsoil mapping from Very High Spatial Resolution (VHSR) image processing

VHSR images were acquired in April 2009 by the unmanned helicopter DRELIO [4] (Universities of Lyon 1 and Western Brittany, France) at a 2 cm spatial resolution (Fig. 1). The helicopter is equipped with a reflex digital camera Nikon D700 with a 35 mm equivalent focal lens, an automatic piloting system and an onboard GPS giving the geographic position during the flight. Images were acquired at a 70 m flying altitude during early spring, to avoid leaf and plant cover.

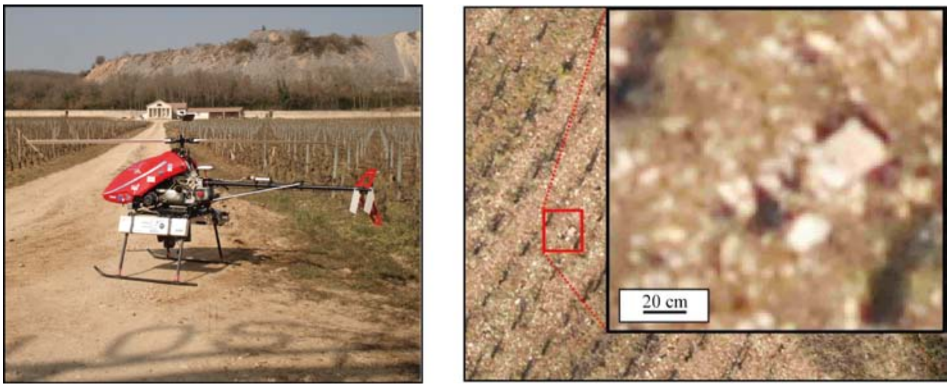

Figure 1: Helicopter DRELIO with Nikon D700 camera. Very High Spatial Resolution image with a pixel resolution of about 2 cm.

Image pre-processing consists in the construction of a mosaic from more than 100 images. The mosaic was georeferenced and pseudo-orthorectified, using control points obtained from differential GPS measurements acquired on the hillslope. The artefacts obstructing soil information (roads, vinestocks and their shadow) were masked. Then this mosaic was resampled to a 25 cm resolution to reduce time computing while still enabling intra-plot topsoil diversity to be visualised at the hillslope scale.

Finally, a principal component analysis (PCA) was performed on the resulting mosaic to produce uncorrelated bands and to maximize data variance reflectance. The three eigenbands were classified using a non-supervised classification to produce a map of soil surface classes (SSC).

2.3 Topsoil and soil characteristics of the soil surface classes from laboratory analyses

The obtained map allows distinguishing four soil surface classes. For each class, local soil surface descriptions and soil profiles were performed to precise the soil types. Thus, eighteen soil surface samples were collected in the 0-10 cm soil layer in the inter-row over a 0.25 m^2 surface along the hillslope. Among them, thirteen auger holes were performed. Samples on each identified horizon were collected. Complementary data coming from six soil pits on contiguous plots were also available. On these samples, physical (stoniness, grain-size distribution, matrix colour using the Munsell Soil Chart) chemical (total carbonates, organic carbon and nitrogen contents) and clay mineral analyses were done to define the topsoil and soil characteristics.

3 RESULTS

Figure 2 shows that the type of the soil surface classes evolves along the hillslope. The SCC1 (red class) located in the upper part of hillslope, evolves gradually in the middle of the slope towards SSC2 (yellow class). Downslope, SSC3 (blue class) is distributed spatially with SSC4 (cyan class).

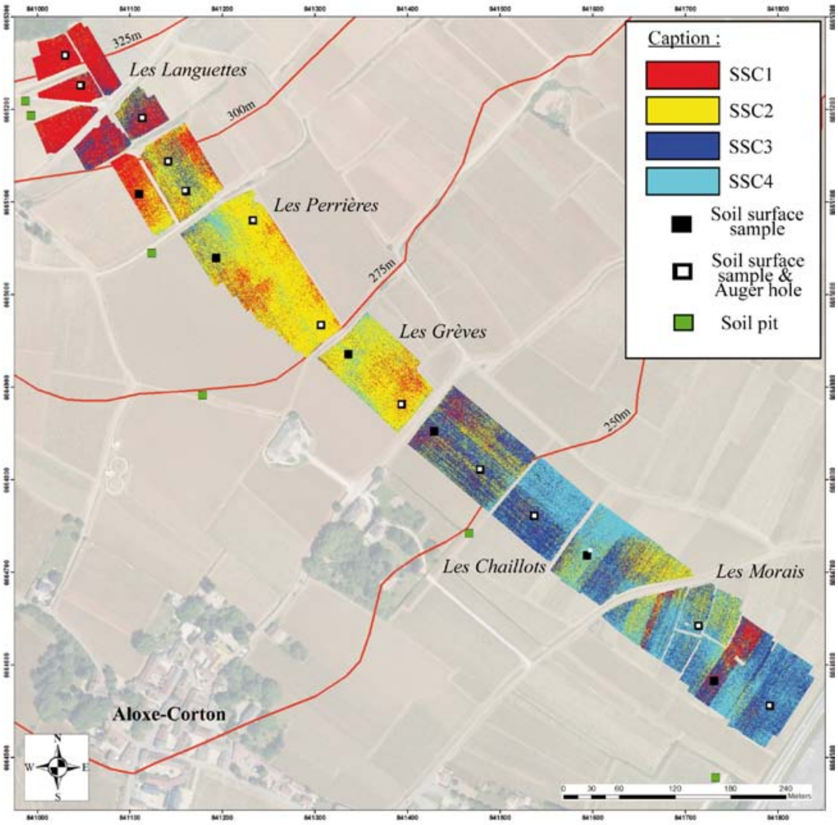

Figure 2: Distribution of four soil surface classes along the hillslope of Aloxe-Corton.

The auger holes and soil pits dug into the different SSC mapped with image processes allow to distinguish four SSC regrouped into three soil types (Table 1).

SSC1 and SSC2 may be defined as Calcosols developed on marly-limestone and limestone respectively with soil depths varying from 40 to 150 cm. They are characterized a high gravel content and a high carbonate and organic contents. They differ mainly by their carbonate content, texture (silt-loam to clay) and the clay mineralogy assemblage that is dominantly vermiculite and illite-smectite for SSC1 and illite-smectite and illite for the SSC2.

SSC3 and SSC4 may be defined as Calcisol on chert clays and display deep thickness (>160 cm) deposed on limestone in the middle of the slope and on carbonated marls donwnslope. They are characterized by a clay-loam texture, a high stoniness and very low carbonate content. They display various clay mineralogy assemblages from illite-smectite, to illite but also kaolinite and chlorite. Difference of reflectance values between these classes only reflects two management practices.

This SSC succession (Fig. 2) highlights a downslope decrease of the carbonate and organic matter contents that is correlated to a downslope evolution of soil colour from brown (SSC1) to reddish-brown (SSC2) to strong brown (SSC3 & 4) (Table 1). This trend is also associated to downslope evolution of the clay assemblages that are dominated upslope by the vermiculite and illite-smectite, by illite and illite-smectite in the middle of the slope, while the highest values of kaolinite and chlorite have been observed downslope.

	Samples	Gravel ⌀ > 2cm	Fine gravel 2 cm to 2mm	Colour			
				L	a	b	Munsell
SSC1	5	15 (4)	19 (5)	53 (3)	11 (2)	26 (3)	Brown
SSC2	6	18 (3)	11 (2)	46 (5)	15 (2)	30 (2)	Reddish-brown
SSC3	4	23 (12)	8 (5)	45 (2)	11 (2)	27 (2)	Strong brown
SSC4	3	22 (5)	5 (3)	45 (3)	9 (0)	26 (1)	Strong brown

	Texture	$CaCO_3$ (%)	C org (%)	N (%)	C/N
SSC1	Silt Loam	35 (8)	2.5 (0.6)	0.12 (0.03)	22 (4)
SSC2	Clay	10 (7)	1.9 (0.4)	0.10 (0.02)	18 (2)
SSC3	Clay Loam	1 (0)	1.7 (0.3)	0.12 (0.01)	15 (1)
SSC4	Clay Loam	0 (0)	1.6 (0.2)	0.11 (0.01)	15 (1)

	Clay mineralogy (%)					Soil type
	Vermiculite	Illite-Smectite	Illite	Kaolinite	Chlorite	
SSC1	11	40	33	9	7	Calcosol on marl
SSC2	0	56	37	7	0	Calcosol on limestone
SSC3 & 4	0	51	22	13	15	Calcisol on chert clays

Table 1: Physical, chemical and mineralogical characteristics for the four Soil Surface Classes analysed on topsoil samples (Mean and (mean Standard deviation))

This work shows that the stacking of the local and hillslope scales permits to distinguish fine differences of textural, mineralogical and agricultural management of the soil surface. This method can be used to identify both abrupt changes (agricultural practices), continuous evolution (related to surface sediment dynamic) and changes of soil composition (related to substratum).

4 CONCLUSIONS

This research presents a simple, highly efficient approach to map soil surface diversity at a high spatial resolution in Burgundy vineyards. This approach relies on the combination between very high resolution aerial data at the hillslope scale and local observations. VHSR aerial image processing establishes a precise mapping of the spatial distribution of soil surfaces. This map associated with soil sampling is an interesting tool to define soil typology by physical and chemical characteristics. Further investigations on clays and oxides characterizations using near infrared spectrometry (NIRS) should help to differentiate soil types.

By allowing the visualisation of soil distribution at a very high spatial resolution, this approach offers new insights and possibilities for documenting soil patterns and for exploring and predicting soil evolution through space and time on hillslopes, and so could be used for precision viticulture.

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