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Potential of Sentinel-2 satellite images to monitor vine fields grown at a territorial scale

Nicolas Devaux[1], Thomas Crestey[2], Corentin Leroux[2-3], Bruno Tisseyre [2*]

[1] LISAH, Montpellier SupAgro, INRA, IRD, Univ Montpellier, Montpellier, France
[2] UMR ITAP, Montpellier SupAgro, Irstea, Univ Montpellier, France
[3] SMAG, Montpellier, France

Corresponding author: skoundou@agro.auth.gr

ABSTRACT

Aim: The aim of this short note is to provide first insights into the ability of Sentinel-2 images to monitor vine growth across a whole season. It focuses on verifying the practical temporal resolution that can be reached with Sentinel-2 images, the main stages of Mediterranean vineyard development as well as potential relevant agronomic information that can be seen on the temporal vegetation curves arising from Sentinel-2 images.
Methods and results: The study was carried out in 2017 in a production vineyard located in southern France, 2 km from the Mediterranean seashore. Sentinel-2 images acquired during the whole vine growing cycle were considered, i.e. between the 3rd of March 2017 and the 10th of October 2017. The images were used to compute the classical normalized difference vegetation index (NDVI). Time series of NDVI values were analyzed on four blocks chosen for exhibiting different features, e.g. age, missing plants, weeding practices. The practical time lag between two usable images was closer to 16 days than to the 10 theoretical days (with only one satellite available at the date of the experiment), i.e. near 60% of the theoretical one. Results show that it might be possible to identify i) the main steps of vine development (e.g. budburst, growth, trimming, growth stop and senescence), ii) weed management and inter-row management practices, and iii) possible reasons for significant inter-block differences in vegetative expression (e.g. young vines that have recently been planted, low-productive blocks affected by many missing vines).
Conclusions: Although this experiment was conducted at a time when Sentinel-2b was not fully operational, results showed that a sufficient number of usable images was available to monitor vine development. The availability of two Sentinel satellites (2a and 2b) in upcoming seasons should increase the number of usable images and the temporal resolution of the time series. This study also showed the limitations of the Sentinel-2 images' resolution to provide within-block information in the case of small blocks or blocks with complex borders or both.
Significance and impact of the study: This technical note demonstrated the potential of Sentinel-2 images to characterize vineyard blocks' vigor and to monitor winegrowers' practices at a territorial (regional) scale. The impact of management operations such as weeding and trimming, along with their incidence on canopy size, were observed on the NDVI time series. Some relevant parameters (slope, maximum values) may be derived from the NDVI time series, providing new insights into the monitoring of vineyards at a large scale. These results provided areas for further investigation, especially regarding the development of new indicators to characterize block-climate relationships.

KEYWORDS

vine growth, satellite images, large-scale monitoring, NDVI

INTRODUCTION

Multiple studies have shown the interest of remote sensing images for field or within-field management purposes in viticulture such as irrigation or fertilization monitoring (Acevedo-Opazo *et al.*, 2008; Carrillo *et al.*, 2016; Hall *et al.*, 2002; Johnson *et al.*, 2001). However, current limitations of most remote sensing acquisition platforms are their low temporal resolution (16 days for the LandSat8 platform) and their cost ($1.65/km² for Spot 6-7 new image acquisition with a minimum order of 500km² or $1.28/km² for RapidEye new image acquisition with a minimum order of 3500km²). It is acknowledged that unmanned aerial vehicle (UAV) and airborne platforms can be used intensively over time to monitor the temporal dynamics of vine growth or vine water status either at the field or at the within-field level (Hall *et al.*, 2011), but such monitoring approach is quickly limited by acquisition costs, making any commercial services unrealistic for most vineyards (Matese *et al.*, 2015).

The recent availability of Sentinel-2 images might be seen as an interesting opportunity to provide an affordable service to monitor vine growth over time. Indeed, the two satellites (2a and 2b) have particularly valuable features (ESA, 2012):

- a revisit period of 5 days that could enable the observation of significant changes in canopy growth (e.g. new phenological stage or biotic and abiotic stresses);
- 13 different spectral bands, 10 of which being - particularly interesting for the computation of vegetation indices [e.g. normalized difference vegetation index (NDVI) or soil-adjusted vegetation index (SAVI)] or soil-related indicators; and
- a free diffusion of the images, with multiple levels of correction (e.g. atmospheric correction, orthorectification, cloud masks, etc.).

Despite these advantages, Sentinel-2 images also present some drawbacks which, in viticulture and depending on the wine-growing regions, may limit the use of this new information source. First, the images' spatial resolution ranges from 10 to 20 m according to the wavebands, which may be limiting to record relevant information in small fields or in fields with complex boundaries such as those commonly found in southern France. Another limitation of this resolution lies in the impossibility of obtaining pure pixels of vine. Indeed, Sentinel-2 images are necessarily made up of mixed pixels (vines/soil or vines/cover crop when the inter-row is grassed). Second, depending on the location under study, cloudy weather conditions can be of great concern as they limit the number of usable images. Finally, it is stressed that the chain actually available to process, correct and supply Sentinel-2 images has not yet been tested in light of a possible new service for dynamic vine vegetation monitoring.

The main goal of this short note is to provide first insights into the ability of Sentinel-2 images to monitor vine growth across a whole season. The objective of this study is to answer the two main following questions: i) Which practical temporal resolution can be reached with Sentinel-2 images? ii) Can the main stages of Mediterranean vineyard development be seen on the temporal vegetation curves arising from Sentinel-2 images? Questions and concerns requiring further work with this new source of information are discussed.

MATERIALS AND METHODS

1. Study area

The study was carried out in 2017 in a production vineyard, called Domaine du Chapitre, located close to Montpellier (Villeneuve-lès-Maguelone, France 43°31'52.668"N, 3°51'51.597"W, RGF93), 2 km from the Mediterranean seashore.

The vineyard is composed of 40 blocks ranging from 0.1 to 4.69 ha (the mean block area is 0.8 ha). Vine blocks were planted between 1973 and 2016 and were subjected to a very classical training system in southern France (vertical shoot positioning with a 2.5 m inter-row and mechanical weeding). Vines are grown under Mediterranean climatic conditions characterized by a hot and dry summer. Precipitations mainly occur in autumn and spring. A high evaporative demand usually leads to significant water restrictions in summer. Blocks are mainly non-irrigated.

Four out of the 40 blocks were selected for the study (Figure 1). The latter were chosen for exhibiting different features, e.g. age, missing plants, weeding practices (Table 1). Note that all

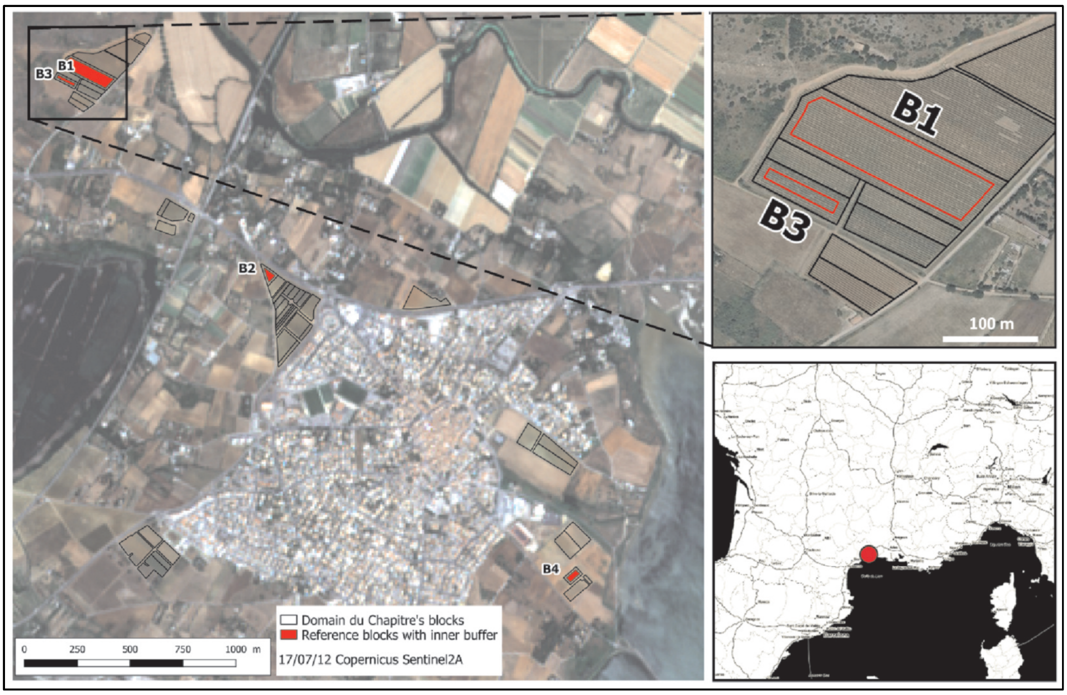

FIGURE 1. Location of the vineyard and the four blocks of interest
The red line inside the blocks is an inner buffer that is used to remove border effects (see the "Data processing" section)

TABLE 1. Main characteristics of the four blocks of interest

Block ID	Planting year	Area (ha)	Varieties	Specificities	Inter-row cover crop
B1	2000	1.91	Caladoc	Fully productive block (Reference)	None
B2	1973	0.41	Syrah	Old vines with 23% of missing vines	Present
B3	2002	0.84	Syrah	Fully productive block	Present
B4	2016	0.71	Muscari	Young vines (2 years old with limited canopy development)	None

the technical operations that were carried out on the blocks were filed in the farm management information system (Agreo, SMAG, Montpellier, France) by the vineyard manager. This made it possible to retrieve the date of each management operation inside each block.

2. Data acquisition

All the Sentinel-2 images that were used in this study were distributed by Copernicus with a level-2A processing provided by the National Centre for Spatial Studies (CNES) for the Theia data centre (Irstea, Montpellier, France)[1]. Level-2A correction incorporates several processes such as image orthorectification, and corrections for atmospheric and slope effects. In addition, Theia level-2A images are provided with cloud and shadow masks. Level-2A images are currently available within an interval of more or less 8 days after the raw images are acquired. Sentinel-2a images have 13 spectral bands (ESA, 2012) with a spatial resolution ranging from 10 to 20 m depending on the band. In this study, only the red band (665 nm ± 15 nm) and the NIR band (842 nm ± 52 nm) were used to compute the classical NDVI index (Rouse *et al.*, 1974). Both bands come with a 10-m spatial resolution. In this study, only the images acquired during the whole vine growing cycle were considered, i.e. between the 3rd of March 2017 and the 10th of October 2017.

https://www.theia-land.fr/fr/presentation/acc%C3%A8s-aux-donn%C3%A9es

3. Data processing

In this study, the whole processing included the following steps:

I Downloading Sentinel-2 images.

II In addition to cloud and shadow masks delivered with the images, carrying a visual check of each image on the four blocks of interest in order to identify any disturbance (haze, isolated cloud not detected, etc.) likely to affect the quality of the calculation.

III Cropping red and near-infrared bands with an inner buffer of 10m to avoid border effects (Figure 1).

IV Computing NDVI using the cropped red and near-infrared images.

V Extracting descriptive NDVI statistics (mean value) in each block boundary.

Image processing was performed with the QGIS software (version 2.18, QGIS Development Team, 2018 - Open Source Geospatial Foundation Project[2]). The processing of each image took less than 10 seconds with a computer equipped with a processor i5 7th generation with four cores and a 3.80 GHz base frequency.

RESULTS AND DISCUSSION

1. Practical temporal resolution of Sentinel-2 images

Figure 2 shows the NDVI temporal dynamics for block B1. During the experiment, Sentinel-2a was the only operational satellite to provide usable images. No images from Sentinel-2b could be used for the study period. As the revisit period of the Sentinel-2a satellite is 10 days, 22 images should have been potentially available over the experiment. After the elimination of cloudy images and the identification of images that were not acquired due to technical problems, a total of 14 images were found available to compute the NDVI temporal spectrum. Results show that the time lag between two usable images was closer to 16 days than to the 10 theoretical days presented (the practical time lag is near 60% of the theoretical one).

Figure 2 shows that the NDVI temporal dynamics created with Sentinel-2 images enable to identify the main stages of vine development. The budburst and growth phases corresponding to an increase in biomass (NDVI) are perfectly observed from early April to mid-June. After mid-June, the decrease in NDVI values is due to summer operations (trimming). After mid-July, a plateau corresponding to a stop in vegetation growth is observed. At veraison (August), the

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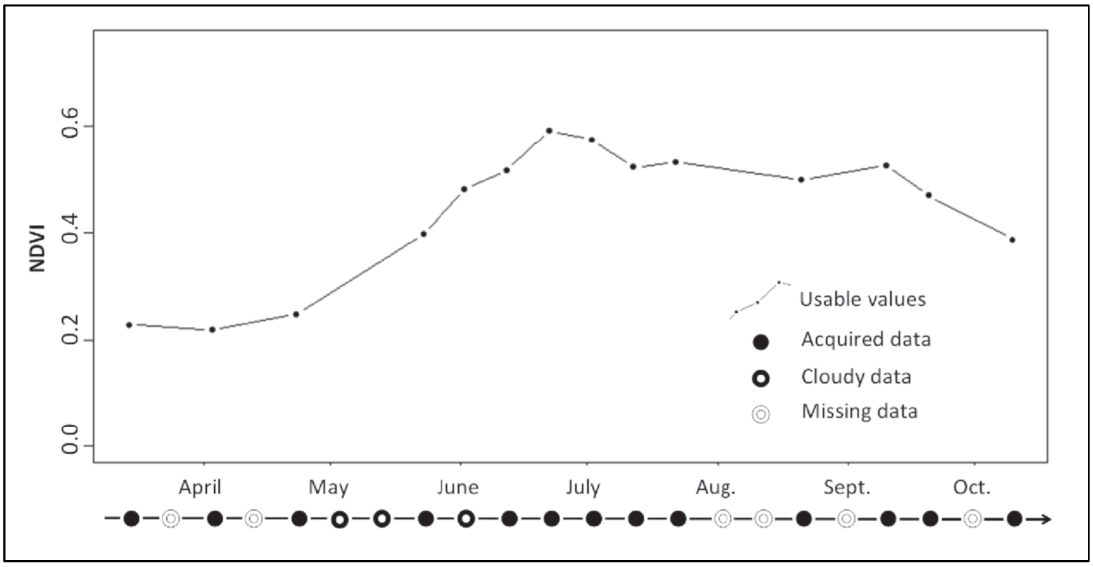

FIGURE 2. NDVI temporal dynamics on plot B1 between 2017/03/14 and 2017/10/10
Images are either Usable, Cloudy (it was not possible to calculate the NDVI due to climatic conditions) or Missing (images were not available on the CNES web platform).

NDVI values are near 0.5, which correspond more or less to the values observed at this stage in other vineyards trained in vertical shoot positioning and grown under similar conditions (Johnson, 2003; Johnson *et al.*, 2001). At the end of September, after harvest, the decrease in NDVI values corresponds to leaf senescence.

The study site benefits from a very high annual sunshine rate. Despite these advantageous climatic conditions, note the two successive cloudy images in May. Practically, this lack of images is problematical as this period corresponds to a period of high plant growth where more information is needed. Note also that six images were missing during the whole vine development (Figure 2), mainly due to technical problems in the processing chain of the images' providers. These technical problems have now been resolved, meaning that, theoretically, 20 images should have been available over the season. It is reminded that this study has only been performed with one single Sentinel satellite. The use of both satellites in upcoming seasons could certainly increase the number of usable images.

2. Sentinel-2 NDVI mapping

Figure 3 shows NDVI maps at the within-block level over four dates spanning the whole season. Figure 3 highlights i) an increase in NDVI values during the leaf development phase, from 2017/04/03 to 2017/06/22, ii) a maximum NDVI value in June, and iii) a decrease in NDVI values at the end of summer and early autumn as illustrated on 2017/10/10. Figure 3 also shows the advantages and limitations of Sentinel-2 images to observe either inter-block or within-block variability. It must be clear that the objective of this technical note is not to provide an explanation for the observed NDVI spatial variability. Much work has already been dedicated to this issue in the literature (Acevedo-Opazo *et al.*, 2008; Carrillo *et al.*, 2016; Hall *et al.*, 2002; Johnson *et al.*, 2001). The objective is rather to discuss what seems to be observable and provide areas for further investigation. Inter-

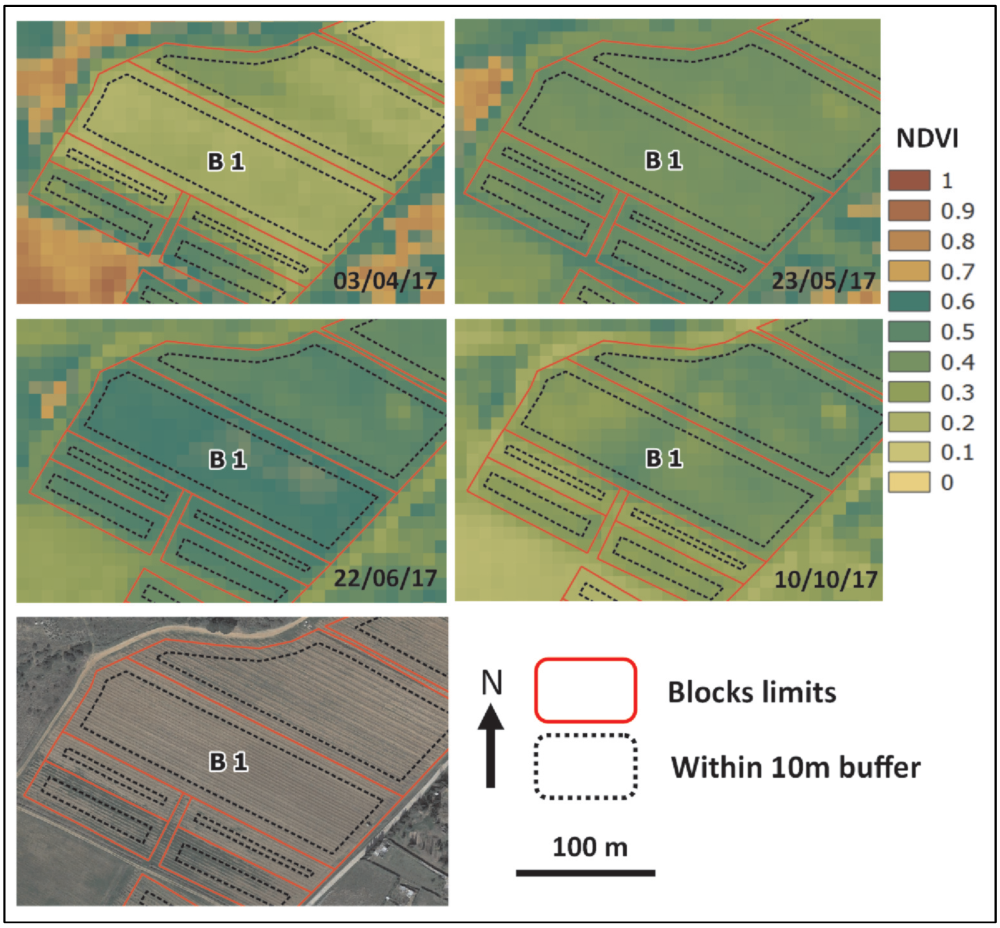

FIGURE 3. Within-block NDVI temporal dynamics in B1 and associated inner buffer

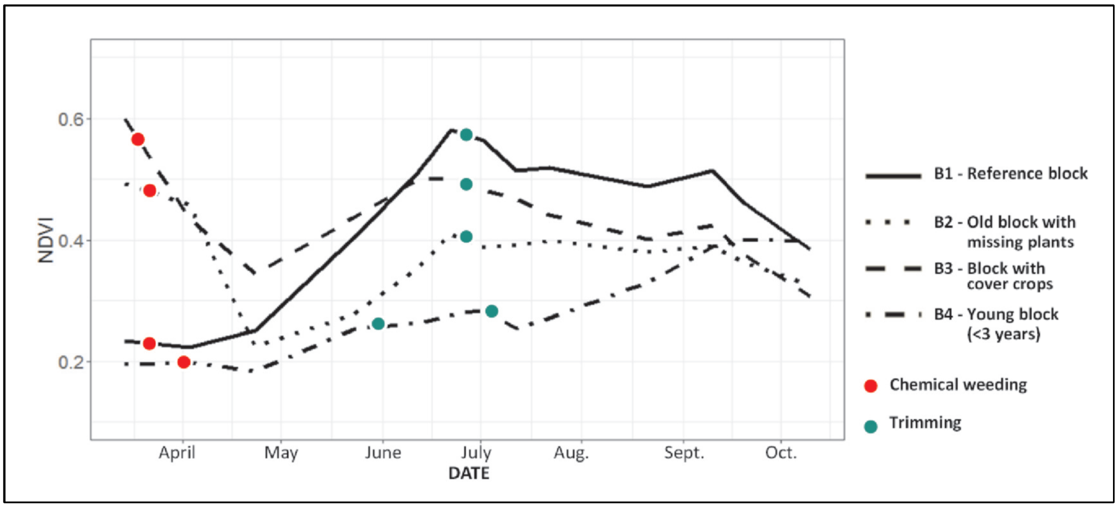

FIGURE 4. NDVI temporal dynamics for the four blocks of interest (B1, B2, B3, B4)
Main management operations related to weed and canopy management are displayed.

plot variability can be observed on the first image (2017/04/03), for example between block B1 and the block further north, certainly because of differences in cover crop, variety, training system, etc. On 2017/04/03, the resolution of the NDVI map allows to visualize some level of intra-block variability in the block further north to B1 that may be related to differences in vigor or in cover-crop development, etc. Lower NDVI values, corresponding to early canopy senescence, can also be observed in the western part the block on 2017/10/10.

Regardless of this interest to highlight within-block zones, the 10-m spatial resolution remains a strong limitation for most of the blocks, especially those south to B1. Indeed, in the case of small or narrow fields, very few NDVI values can be extracted, which means that the proposed methodology cannot apply to small blocks or blocks with complex boundaries. This constitutes a significant limitation for the use of Sentinel-2 images in some vineyards, especially small blocks in small farms as those found in southern France. Extreme care should therefore be paid to the vineyard blocks (size and shape) before recommending the use of Sentinel-2 images to map vine vigor throughout the season.

3. Monitoring vines' temporal NDVI dynamics with Sentinel-2 images

Figure 4 shows the NDVI temporal dynamics for the four blocks of interest whose characteristics are presented in Table 1. The four NDVI time series are particularly interesting because they highlight specific features of the vine development in each of the four blocks under study. At the beginning of the season (April), Figure 4 shows significant NDVI differences between the blocks with inter-row cover crops (B2 and B3) and the others (B4 and B1). At this date, the vines had not broken out yet, leading to higher NDVI values in blocks B2 and B3 because of the photosynthetically active biomass of the inter-row crop. Lower NDVI values for B4 and B1 were mainly due to low bare soil's reflectance. From April to mid-May, the decrease in NDVI values observed for blocks B2 and B3 originated from a chemical weeding operation and the destruction of the inter-row cover crop. The inter-row was then weeded as much as necessary until the summer, so any residual inter-row crop has a very small impact on NDVI values during the rest of the season for these blocks. At the beginning of May, the NDVI values were almost identical for B1, B2 and B4. Note, however, that higher NDVI values could be observed for B3 since weeding was carried out every two rows compared to the other block with inter-row cover crop, B2, for which weeding was done on each inter-row. From May to the end of June, the increase in NDVI values was due to classical vegetative growth. However, the four blocks differed in the maximum NDVI value that was reached at the end of the vine growth stage (beginning of July). The highest values ($0.5 < NDVI < 0.6$) were observed for the two blocks at full production, B1 and B3. For B2, the lower NDVI peak ($NDVI = 0.4$) was probably due to the higher number of missing vines (Table 1). The lowest NDVI peak that was found for B4 was the consequence of the presence of young vine plants with limited canopy development.

The trimming operation that was performed in July resulted in a slight decrease in NDVI values for the four plots under study. The NDVI values then remained relatively stable after the growth had stopped (after mid-July), especially for B1, B2, and B3. The plateau values observed from mid-July to mid-September were different for each of these three blocks because of differences in the overall biomass (vine canopy). Note, however, the particular behavior of B4 during summer with a constant increase in NDVI, which may be explained by a growth resumption of the young vines without any fruits. The last NDVI peak occurring in September, after harvest, was due to the specific Mediterranean climatic conditions that took place, i.e. autumn rains, which reduced summer water stress and revived plant growth. Senescence was observed simultaneously (mid-September) for the four blocks.

These results highlighted the potential interest of temporal sequences of Sentinel-2 images to characterize vineyard blocks' vigor and to monitor winegrowers' practices at a territorial (regional) scale. Indeed, given what was found in Figure 4, it might be possible to identify i) weed management and inter-row management practices, ii) the trimming date with the associated potential impact on canopy size, iii) possible reasons for significant inter-block differences in vegetative expression (e.g. young vines that have recently been planted, low-productive blocks affected by many missing vines), and iv) interesting pathways for developing new indicators of vine development for new consulting services or by growers themselves. For instance, the NDVI slope between bud break and growth stop could be a relevant indicator of vine vigor. The NDVI plateau may also constitute an indicator of the overall vegetative expression. It should be noted that such indicators could be used to cross-compare vintages in the near future when substantial historical databases will be set up. Similar researches are already underway for arable crops with software development that automatically estimates new indicators from NDVI time series (Eklundh and Jönsson, 2016).

CONCLUSION

This technical note demonstrated the potential of Sentinel-2 images to characterize vineyard blocks' vigor and to monitor winegrowers' practices at a territorial (regional) scale. As an example, the impact of management operations such as weeding and trimming, along with their incidence on canopy size, were observed on the NDVI time series. Some relevant parameters (slope, maximum values) may be derived from the NDVI time series, providing new insights into the monitoring of vineyards at a large scale. These results provided areas for further investigation, especially regarding the development of new indicators to characterize block-climate relationships as well as management operations performed by growers. New experiments have already been conducted in the study domain to test the relevance of these indicators. Although this experiment was conducted at a time when Sentinel-2b was not fully operational, results showed that, under Mediterranean growing and climatic conditions, a sufficient number of usable images was available to monitor vine development. It must be stated, however, that this study also showed the limitations of the Sentinel-2 images' resolution to provide within-block information in the case of small blocks or blocks with complex borders or both. One should be aware that any Sentinel-2-based service will necessarily depends on the quality of images' corrections and the velocity with which corrected images are provided to users. This last point may constitute important limitations.

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