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Normalized difference vegetation index obtained by ground-based remote sensing to characterize vine cycle in Rio Grande do Sul, Brazil

Índice de vegetação por diferença normalizada obtido por sensor remoto de superfície para caracterização do ciclo de videiras no Rio Grande do Sul, Brasil

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ABSTRACT

The normalized difference vegetation index (NDVI) obtained by remote sensing is widely used to monitor annual crops but few studies have investigated its use in perennial fruit crops. The aim of this study was to determine the temporal NDVI profile during grapevine cycle in vineyards established in horizontal training systems. NDVI data were obtained by the ground-based remote sensing Greenseeker in Chardonnay and Cabernet Sauvignon vineyards located in the Serra Gaúcha region, Rio Grande do Sul, Brazil, from September to June in the 2014/2015 and 2015/2016 vegetative seasons. The grapevine canopies were managed in horizontal training systems (T-trellis and Y-trellis). The results indicated that the temporal NDVI values varied during the grapevine cycle (0.33 to 0.85), reflecting the changing in vigor and biomass accumulation that resulted from the phenological stages and management practices. The temporal NDVI profiles were similar to both horizontal training systems. The NDVI values were higher throughout the cycle for Cabernet Sauvignon compared to Chardonnay indicating Cabernet Sauvignon as the cultivar with greater vegetative vigor. The NDVI obtained by ground-based remote sensing is a fast and non-destructive tool to monitor and characterize the canopy in real time, compiling into a single data several parameters related to vine development, like meteorological conditions and management practices that are difficult to be quantified together.

Index terms: *Vitis vinifera*; Greenseeker; precision viticulture.

RESUMO

O índice de vegetação por diferença normalizada (NDVI), obtido por sensoriamento remoto, tem sido amplamente empregado no monitoramento de culturas agrícolas produtoras de grãos, porém poucos são os estudos em fruticultura. O objetivo deste trabalho foi caracterizar a evolução temporal do NDVI obtido por sensor remoto de superfície ao longo do ciclo de videiras em sistemas horizontais de condução do dossel vegetativo. Dados de NDVI foram obtidos com sensor remoto Greenseeker em vinhedos na região da Serra Gaúcha, Rio Grande do Sul, Brasil, de setembro a junho nas safras 2014/2015 e 2015/2016. Os vinhedos das cultivares Chardonnay e Cabernet Sauvignon eram conduzidos em sistema horizontal (latada e lira). Os resultados indicaram que houve variabilidade temporal do NDVI ao longo do ciclo (de 0,33 a 0,85), a qual refletiu as alterações no acúmulo de biomassa e vigor vegetativo decorrentes das principais etapas fenológicas e práticas de manejo. A evolução temporal do NDVI foi semelhante nos sistemas latada e lira, ambos caracterizados pela condução horizontal do dossel vegetativo. Os valores de NDVI para 'Cabernet Sauvignon' foram superiores aos de 'Chardonnay' ao longo do ciclo, independe da safra avaliada e do sistema de condução, indicando 'Cabernet Sauvignon' como a cultivar de maior vigor vegetativo. O NDVI, obtido por sensor remoto de superfície, é uma forma rápida e não destrutiva de monitoramento e caracterização do dossel vegetativo em tempo real, compilando em uma única informação o desenvolvimento da videira, o qual é resultado de diversos fatores, edafo-climáticos e de manejo, dificilmente quantificados conjuntamente.

Termos para indexação: *Vitis vinifera*; Greenseeker; viticultura de precisão.

INTRODUCTION

Viticulture is the main agricultural activity in the municipalities of Serra Gaúcha in Rio Grande do Sul, an important Brazilian wine-producing region (Protas; Camargo, 2011). The region has 32,952 ha established with vineyards, 80% of the vineyard area in the state (Mello et al., 2013). The *Vitis labrusca* and *Vitis vinifera* varieties are destined for juice, table and wine production (Protas; Camargo, 2011). The implementation of the Vale dos Vinhedos Indication of Origin (IO), recently promoted to Designation of Origin (DO), has focused on the *Vitis vinifera* cultivars, which are used for producing fine quality wine (Protas; Camargo, 2011). The Serra Gaúcha climate is classified as humid, hot temperate, with temperate nights, according to the Multicriteria Climatic Classification System, distinguishing the region and providing typicality to the wines (Tonietto; Fialho, 2012).

The modern and sustainable viticulture requires strategies to improve wine quality by characterizing the variability between vineyards and between plants of the same vineyard, in the precision viticulture context (Drissi et al., 2009; Mazzetto et al., 2010; Ray-Caramés et al., 2015). Techniques and remote sensing tools can contribute to precision agriculture since they allow characterizing the spatial and temporal variability of biophysical parameters by quantifying and analyzing the electromagnetic energy reflected by the vegetation. Therefore, remote sensing data are used to study vegetation behavior using indices, such as the Normalized Difference Vegetation Index (NDVI). The NDVI relates the reflectance in the red and near-infrared wavelengths, being considered an indicator of vegetation growth and green biomass accumulation. In vineyards, studies have shown that the NDVI allows interpreting the spatial patterns of leaf area index (Johnson et al., 2003; Drissi et al., 2009), biomass accumulation (Tardáguila et al., 2008; Stamatiadis et al., 2010), diseases (Mazzeto et al., 2010; Di Gennaro et al., 2016) and chlorophyll and nitrogen contents in leaves (Taskos et al., 2015).

The NDVI obtained from orbital remote sensing (satellite images) was used to characterize the spatiotemporal variability of vegetative vigor and parameters such as leaf area index (LAI) and duration of vine growth season (Johnson et al., 2003; Badr et al., 2015). Images collected by orbital remote sensing allow simultaneous interpretation of spatial vegetation patterns in large areas. However, spatial resolution incompatible with the vineyard area or temporal resolution not suitable for management decisions may compromise the applicability of the images in precision viticulture (Mazzetto et al., 2010). Ground-based remote sensing has emerged as an important source of data collected in the field in real time. In Brazil, temporal NDVI profiles, obtained by orbital or ground-based remote sensing, have been widely used to monitor biomes (Kuplich; Moreira; Fontana, 2013, Wagner et al., 2013; Junges et al., 2016) and characterize vegetation growth in annual crops (Junges; Fontana, 2011, Bredemeier et al., 2013; Fontana et al., 2015; Klering et al., 2016; Pinto et al., 2016). However, the use of precision agriculture technologies applied to perennial crops is incipient in the country (Bassoi et al., 2014), with few studies published on the monitoring of fruit crop cycle using remote sensing techniques. Also, international studies on the potential use of the NDVI in viticulture to characterize the vegetative vigor have been developed in vineyards with vertical training system, the most widely used in wine regions over world (Mandelli et al., 2003). In the Serra Gaucha region, the vineyards are traditionally conducted in horizontal training systems, such as T-trellis and Y-trellis.

The vegetation indices, related to plant green biomass accumulation, can be used to monitor the cycle by characterizing the response patterns of vegetation cover. This study aims at characterizing the NDVI obtained by active ground-based remote sensing, during the cycle of the vine (*Vitis vinifera*) conducted in horizontal training systems in Rio Grande do Sul, Brazil.

MATERIAL AND METHODS

The studied vineyards located in Veranópolis, in the Serra Gaúcha region, Rio Grande do Sul, Brazil were established with Chardonnay and Cabernet Sauvignon cultivars. The region climate is classified as humid subtropical, Cfb according to Köppen (1948), with average air temperature lower than 22 °C in the hottest month of the year. In Rio Grande do Sul, Chardonnay occupies the largest cultivated area (12.5%) among the grapes destined to produce fine or sparkling white wines. Whereas, Cabernet Sauvignon occupies the largest area (20.3%) among those destined to produce fine red wines (Mello et al., 2013).

The studied vineyards were north-soul (NS) oriented and the soil was classified as a typical Dystrophic Lithic Udorthent. The grapevine canopies were managed using horizontal training systems, raised 1.8 meters from the soil surface by wires (T-trellis and Y-trellis), spaced between 2 and 2.5 m between rows and 1.5 and 2 m between plants. The four treatments evaluated were Chardonnay (CHLI) and Cabernet Sauvignon (CALI) in Y-trellis systems, and Chardonnay (CHLA) and Cabernet Sauvignon (CALA) in T-trellis systems. The average area of vineyards is 0.45 ha, ranging between 0.28 ha (CHLI) and 0.75 (CALI).

The NDVI data were obtained by the Greenseeker Handheld HCS-100 Trimble that uses red (650 nm) and near infrared (770 nm) radiation emission diodes to calculate the vegetation index. The sensor was manually positioned 60 cm above the vegetative canopy, using an extensor bar. The NDVI data were obtained from ten plants in each vineyard, during the vegetative cycle (from budding to leaf fall), from September to June, in the 2014/2015 and 2015/2016 vegetative seasons. The NDVI measurements were conducted on four marked branches (one per quadrant) on each plant to determine instantaneous and mean NDVI per plant. The mean values of the 10 plants were used to define the temporal NDVI profile of each vineyard and season and to analyze data variability by standard deviation.

The temporal NDVI profile was expressed in calendar time (fortnights) and degree-days. The accumulated degree-days was calculated according to Villa Nova et al. (1972) (Equations 1, 2 and 3), from the beginning of leaf development, corresponding to the first leaf unfolded and spread away from the shoot (phenological code 11 in BBCH scale for grapes) (Lorenz et al., 1995). The meteorological data (air temperature) were provided by the weather station of the Agricultural Research State Foundation in Veranopólis.

$$GD = \left(Tm - Tb\right) + \frac{TM - Tm}{2}, \text{ for } Tm > Tb \quad (1)$$

$$GD = \frac{\left(TM - Tb\right)^2}{2\left(TM - Tm\right)}, \text{ for } Tm < Tb \quad (2)$$

$$GD = 0, \text{ for } Tb > TM \quad (3)$$

Where GD = degrees per day; TM = daily maximum temperature (ºC); Tm = daily minimum temperature (ºC) and Tb = basal temperature for grapevine (10 ºC).

The dates of grape main phenological stages according to BBCH scale (Lorenz et al., 1995) and management practices that changed the vegetative canopy were recorded to follow the vine cycle.

Differences between cultivars were determined by the temporal behavior of the vegetation index and the area below the profile curve calculated by the trapezoidal method. Furthermore, differences between training systems were compared by the t-test ($p<0.05$).

RESULTS AND DISCUSSION

Mean temporal NDVI profiles

The mean NDVI profiles of Chardonnay and Cabernet Sauvignon vines indicated that the vegetation index ranged from 0.33 to 0.85 throughout the cycle (Figure 1).

The highest NDVI (between 0.80 and 0.83 to Chardonnay and 0.85 and 0.86 to Cabernet Sauvignon)

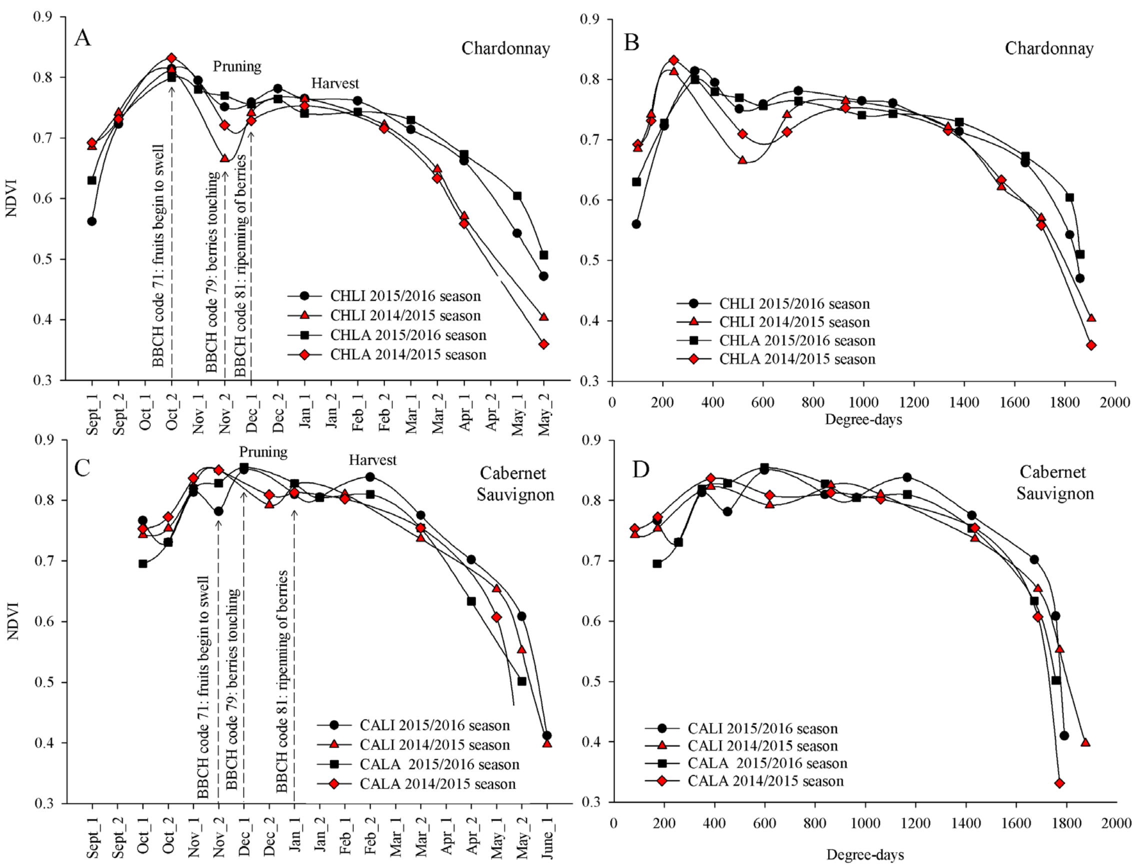

Figure 1: Temporal Normalized Difference Vegetation Index (NDVI) profiles of Chardonnay (A and B) and Cabernet Sauvignon vines (C and D) established in horizontal training systems T-trellis (LA) and Y-trellis (LI), from September to June in 2014/2015 and 2015/2016 vegetative seasons.

occurred in the beginning of fruit set corresponding to the phenological code 71 of the BBCH scale (young fruits begin to swell, remains of flowers lost). The lowest NDVI (0.30 to 0.50) occurred in the senescence, in the phenological stage of leaf discoloration and fall. The grapevine, when cultivated in subtropical areas such as the study region, has a deciduous habit, with vegetative cycles followed by dormancy periods (Mandelli et al., 2003).

The NDVI varied between 0.56 and 0.69 for the Chardonnay cultivar (Figure 1A and 1B) in the first half of September, at the beginning of the vegetative cycle (Figure 2B), when six (2015/2016 season) to nine (2015/2016 season) unfolded leaves per branch were observed. It was not possible to obtain NDVI data during the previous stages, in the beginning of leaf development (August, Figure 2A) because canopy porosity and leaf density affected the signal received by the sensor. The NDVI values increased and reached a maximum in the second half of October (0.80 to 0.83) (Figure 1A and 1B). The increasing NDVI reflected the expanding leaf area per plant

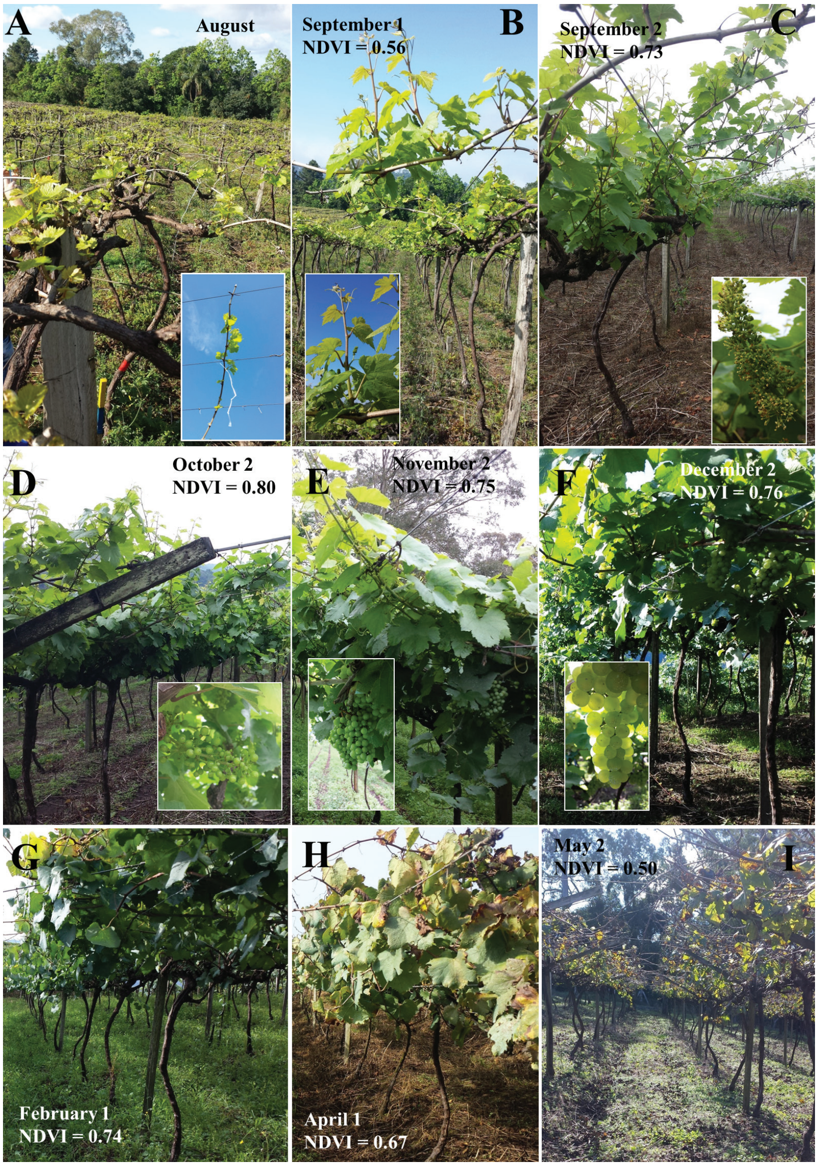

Figure 2: Photographs and Normalized Difference Vegetation Index (NDVI) values in Chardonnay cycle established in horizontal training system.

and canopy closing. NDVI peaked in the same fortnight and phenological stage (young fruits begin to swell) in both seasons (Figure 2D), at 245 and 330 degree-days.

After peaking, the temporal NDVI profiles decreased in the second half of November (0.66 to 0.72 in the 2014/2015 season, 0.75 to 0.77 in the 2015/2016 season) (Figure 1A and 1B). This reduction observed in the phenological stage 79 (majority of berries touching) (Figure 2E) was associated with the summer pruning. In fruticulture, summer prunings are intended to reduce plant vigor, promote the balance between vegetative and productive parts, provide aeration to the vegetative canopy and reduce the likelihood of diseases, especially bunch rot (Mandelli et al., 2009).

After the NDVI drop due to summer pruning, the vegetation index increased again, especially in the 2014/2015 vegetative season, remaining between 0.74 and 0.76 in December and January (Figure 1A and 1B), in the berry ripening (berries begin to develop variety-specific color: from green to yellow-green in the case of Chardonnay) and harvesting (Figure 2F) stages. This NDVI increase was associated with the green biomass accumulation resulting from the continuous expansion of the leaf area, especially in the upper vegetative canopy. After harvesting, mean NDVI values remained close to 0.70 until the first half of March (1,400 degree-days), indicating conservation of vegetative canopy leaf area. Subsequently, from the second half of March, the NDVI of the Chardonnay cultivar decreased gradually, reflecting leaf discoloration and fall due to senescence, reaching between 0.36 and 0.50 (Figure 1A and 1B) in the end of the cycle (May) (Figure 2I).

Temporal NDVI profiles were similar for Cabernet Sauvignon and Chardonnay cultivars. Because Cabernet Sauvignon is a late cultivar that comparatively requires more chilling hours to bud burst (Mandelli et al., 2003), the cycle was monitored from the first fortnight of October, when vines had between 8 to 9 unfolded leaves and mean NDVI values varied between 0.69 and 0.76 (Figure 1C and 1D). The increasing NDVI peaked (between 0.83 and 0.85) due to leaf expansion and increasing number of leaves per branch (Figure 1C and 1D). It is noteworthy that the Y-trellis vineyard initial NDVI of 0.76 decreased to 0.73 in the posterior evaluation in the 2015/2016 season (Figure 1C and 1D). This rapid NDVI change did not result from phenology, but from the thinning of nonproductive branches in the vegetative canopy, performed specifically in this vineyard and season.

The NDVI peaked in different fortnights in the Cabernet Sauvignon vineyards for the studied years. In the 2014/2015 vegetative season, the NDVI peaked (0.82 and 0.83) in the second half of November, at 400 degree-days and phenological stage 71 in BBCH scale (young fruits begin to swell, remains of flowers lost), like Chardonnay. On the other hand, in the 2015/2016 season, the NDVI peaked (0.85) in the first half of December at 600 degree-days, in the phenological stage 79 (majority of berries touching) (Figure 1C and 1D). In the 2014/2015 season, after peaking, the NDVI dropped due to summer pruning, as verified for the Chardonnay cultivar. In the 2015/2016 season, summer pruning occurred in the same fortnight and phenological stage (415 degree-days), as shown by the NDVI drop in the temporal profile, especially for the Y-trellis Cabernet Sauvignon vineyard. However, the NDVI increase between the second fortnight of November and the first fortnight of December in the 2015/2016 season indicates increased vegetative vigor that required a new pruning during the berries touching stage. This result was associated with rainfall higher than the historical average for November (+47 mm) and December (+143 mm) in 2015. Also, the high average monthly air temperature (+1.5 ºC) in December 2015, may have favored the vegetative development, especially of branches characterized by long internodes of fast growth, excessive vigor and few fertile buds (Mandelli; Miele, 2003).

Thus, differences in the Cabernet Sauvignon NDVI temporal profiles reflected the interannual variability of meteorological conditions and the need to adapt management practices to such variability. This fact is especially true regarding the NDVI drop that resulted from the management practices that promoted interventions in the vegetative canopy to reduce biomass, such as pruning, thinning and defoliation.

After the NDVI peaked, the Cabernet Sauvignon and Chardonnay NDVI profiles behaved similarly over time. At ripening (berries begin to develop variety-specific color: from green to purple-blue in the case of Cabernet Sauvignon) and harvesting (second half of February) of berries, indices were close to 0.80 and remained high (0.73 to 0.77) until the second fortnight of March (1,400 degree- days). After that, the NDVI decreased gradually to 0.33 and 0.50, in May and June (CALI), due to senescence.

The NDVI values obtained in this study were higher compared to the values cited in the literature. Tardáguila et al. (2008) studied a vineyard (cultivar Tempranillo) in Spain using the Greenseeker remote sensor and reported values between 0.55 and 0.70 at the maximum vegetative development and between 0.65 and 0.75 at the beginning of berry ripening. Higher NDVI values were expected in the horizontal training systems due to greater vegetative vigor. Because the area available for branch growth and development is larger, the number of productive branches and bud loads are greater in horizontal training systems compared to vertical ones. For example, in the study region, the recommended bud load is between 120 and 140 and between 65 and 80 thousand buds ha^{-1} in the T-trellis and the vertical training system (VSP), respectively (Miele; Mandelli, 2003).

The temporal NDVI profile adequately reflects vineyard vegetative vigor and the changing biomass accumulation due to the phenological stages of the grapevine cycle, which promote the greatest variations in NDVI values and confer the typical temporal pattern. Because the remote sensor was positioned near the canopy, the temporal NDVI profiles also indicate green biomass decrease that resulted from the vineyard management practices, especially summer pruning. Although NDVI drops due to pruning were lower, in numerical terms, than those due to phenology, they indicate the potential use of the ground-based remote sensor Greenseeker as tool for the non-destructive quantifying of the vegetative vigor of vineyards.

Variability of NDVI data

Throughout the cycle, NDVI values varied between plants of the same vineyard in the same date. The lowest NDVI means had higher standard deviations, which were associated with senescence in the end of the vegetative cycle (Figure 3). This results from the fact that leaf fall does not occur homogeneously in the vineyard, as it is dependent on both natural senescence and the occurrence of foliar diseases.

Mandelli et al. (2003) also attributed to leaf diseases and meteorological conditions, especially the early frost occurrence, the higher variability in the dates of the phenological stage of beginning of leaf fall among the years, compared to the other sub-periods of the vine cycle in the Serra Gaúcha region. Therefore, the NDVI could be used to identify spatial and temporal variability of post-harvest leaf area maintenance, important information for temperate fruit trees such as the vine. The presence of leaves at the end of the cycle is related to reserve accumulation in the tissues, which favors initial budding in the next cycle. Most of the carbohydrates transported to the leaves and branches at the beginning of vegetative growth originate from the reserves accumulated in the post-harvest of the previous cycle (Anzanello; Souza, 2015).

The lowest standard deviations were observed for higher NDVI values, especially for the Cabernet Sauvignon cultivar (Figure 3), demonstrating that, in the studied vineyards, for NDVI close to 0.8, the green biomass variability between plants was lower (standard deviation of 0.01). This lower variability may also be due to index saturation, indicating that probably the NDVI values underestimate the accumulated biomass. Bourgeon (2016) reported a NDVI saturation trend in Chardonnay, Pinot Noir and Meunier cultivars in France at the end of the vegetative cycle, also with values close to 0.80. Stadiamatis et al. (2010) indicated that, in the ripening of Merlot berries, the NDVI values did not distinguish plants with high vegetative vigor (more than 1.3 kg plant^{-1} biomass removed at pruning) due to index saturation.

Difference between vineyards: training systems and cultivars

Between training systems

NDVI behaved similarly over time for the same cultivar, regardless of training system, both characterized by horizontal canopy. In the Chardonnay vineyards, the differences are related to the larger area per plant (5.2 m^2) and lower average number of productive branches (73) in the

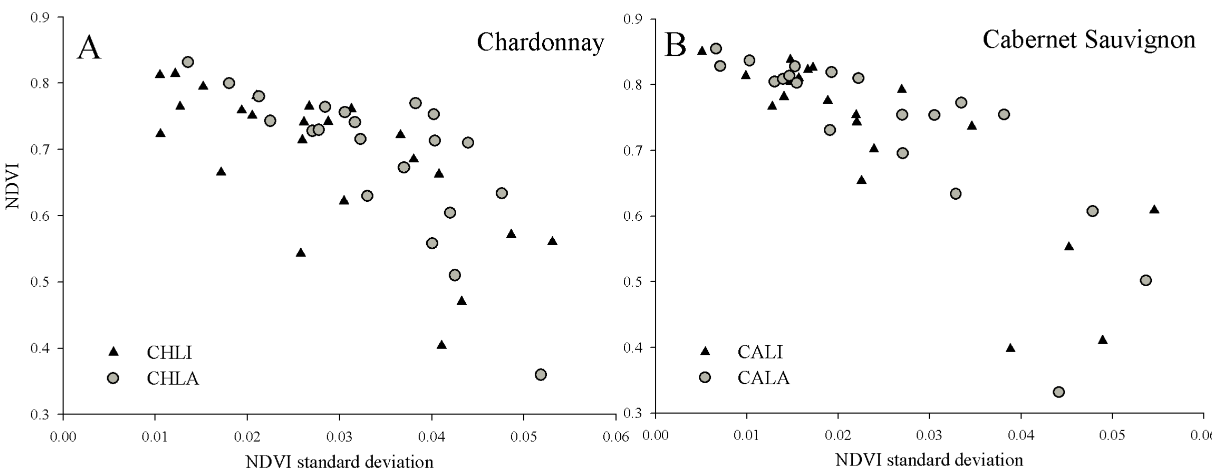

Figure 3: Relationship between mean and standard deviation of Normalized Difference Vegetation Index (NDVI) from Chardonnay (A) and Cabernet Sauvignon (B) vines established in horizontal training systems.

Y-trellis compared to the T- trellis (3.8 m^2 and 82). However, different training systems did not result in different green biomass accumulation since average NDVI values were similar for both systems in each fortnight (Figure 4).

Furthermore, NDVI was higher in the Y-trellis Cabernet Sauvignon vineyard from the second half of April onward (Figure 4), the only vineyard in which evaluations could be performed until the first half of June. The leaf area was preserved for a longer period in Y-trellis vineyard, which could be due to greater vegetative vigor, given the higher number of productive branches (110) compared to T-trellis (70). However, the higher NDVI values were not observed throughout the cycle in the Y-trellis system, as would be expected, since this vineyard had the highest number of productive branches, but only at the end of the cycle during senescence (NDVI lower than 0.70). This result supports the previously discussed possibility of NDVI saturation, indicating that NDVI differences are more associated with vegetative vigor than the training system itself, given that the number of branches is defined in the winter pruning, following the criteria adopted by the producer, such as cultivar, rootstock and soil-climate aspects.

The similar behavior of NDVI temporal profiles for the studied training systems may be explained by the similarity between the canopies, especially from the sensor position to obtain the NDVI data (above the canopy). Thus, the NDVI obtained in this study are representative of the horizontal training systems adopted in the vineyards of the Serra Gaúcha region.

Between cultivars

The NDVI temporal profiles were similar for Chardonnay and Cabernet Sauvignon along the cycle (Figure 5). Due to different chilling requirements, Chardonnay bud burst is precocious compared to Cabernet Sauvignon, therefore, the NDVI data were collected early September and early October, respectively. The cultivars in the Serra Gaúcha region are classified regarding budding period as precocious (e.g. Chardonnay) for budding occurring until September 10; average (e.g. Cabernet Sauvignon) between September 11 and 20; and late (e.g. Trebbiano and Moscato Branco cultivars) after September 20 (Mandelli et al., 2003). The temporal NDVI profiles reflected the different cycle and phenology between cultivars, with an interval of 30 to 45 days between NDVI peak and NDVI drop due to summer pruning or beginning of leaf discoloration and fall (Figure 5).

Therefore, real-time monitoring of grapevine development using ground-based remote sensors is possible since the temporal NDVI profiles represented the green biomass accumulation in the cycles of distinct cultivars due to phenological stages. Also, the possibility of using the temporal NDVI profiles to identify the fortnightly periods when NDVI differences are maximized between cultivars is useful for the monitoring and mapping of vineyards

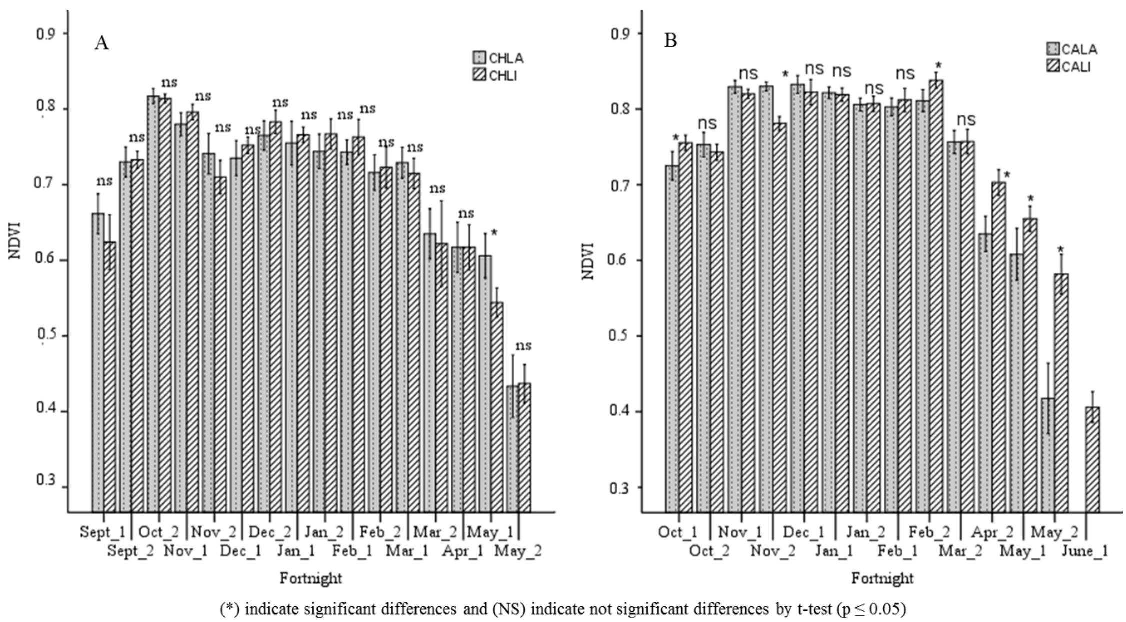

Figure 4: Mean Normalized Difference Vegetation Index (NDVI) for Chardonnay (A) and Cabernet Sauvignon (B) vines conducted in horizontal T-trellis (LA) and Y-trellis (LI) systems from September to June.

using orbital remote sensing. As Greenseeker is an active remote sensor that obtains NDVI data in diverse lighting condition, it is not possible to use these values to determine quantitative differences in data obtained by orbital images. For this purpose, NDVI should be measured simultaneously on surface and by satellite, under the same lighting conditions, to generate the data necessary to eliminate atmospheric interference. Even so, the Greenseeker sensor can be used to generate data about the spatial and temporal NDVI variability, which can assist the identification and interpretation of the targets in the images.

The NDVIs were higher for Cabernet Sauvignon throughout the cycle, regardless of the year and training system, indicating that Cabernet Sauvignon is a cultivar of greater vegetative vigor (Figure 5). This result was corroborated by the area below the curve of the Cabernet Sauvignon NDVI profile (Figure 6). Cabernet Sauvignon is a very vigorous and moderately productive cultivar while Chardonnay has average vigor and productivity, under the cultivation conditions of the Serra Gaúcha region (Carmargo, 2003). It is noteworthy that the integration of NDVI values is an indicator of net primary productivity of vines throughout the cycle, and is directly related to the vegetative cycle duration (Badr et al., 2015). The largest area below the curve for Cabernet Sauvignon temporal profiles also resulted from the fact that leaf area was preserved for a longer period, allowing monitoring the cycle via NDVI until the first half of June.

Differences in the temporal NDVI profiles between vineyards of the same cultivar may be associated with the variable vegetation development due to meteorological conditions. In this sense, a higher accumulated rainfall, which resulted in lower solar radiation, associated with higher air temperatures (Figure 7) may have favored vegetative growth and plant biomass accumulation in the 2015/2016 season. Generally, the NDVI values and the area below the curve of the temporal NDVI profiles were greater in 2015/2016 compared to 2014/2015 (Figure 6). The higher average temperatures recorded in 2015, in September (+1.4 ºC), December (+1.5 ºC), January (2.2 ºC), February (2.7 ºC) and April (+2.7 ºC) may have favored the vegetative plant development and green biomass accumulation while leaf area was preserved for a longer period at the end of the cycle. Autumn temperatures affect the length of the vegetative cycle because lower air temperatures or the occurrence of frosts accelerates leaf fall. Also, rainfall was higher than the historical average in the 2015/2016 season, during almost the entire vegetative cycle, with emphasis in September (+173 mm), October (+246 mm), December (+143 mm) and March (+306 mm) (Figure 7).

The temporal NDVI profiles reflected the interannual variability of green biomass accumulation, which can be associated to the varying meteorological conditions during the cycle. An inherent characteristic of vegetation indices is the reduced volume of data to be analyzed since practically all vegetation information is summarized in only one numerical value, indicating that NDVI obtained by ground-based remote sensor can be inserted as an independent variable to adjust models for growth simulation and vegetative vigor estimation.

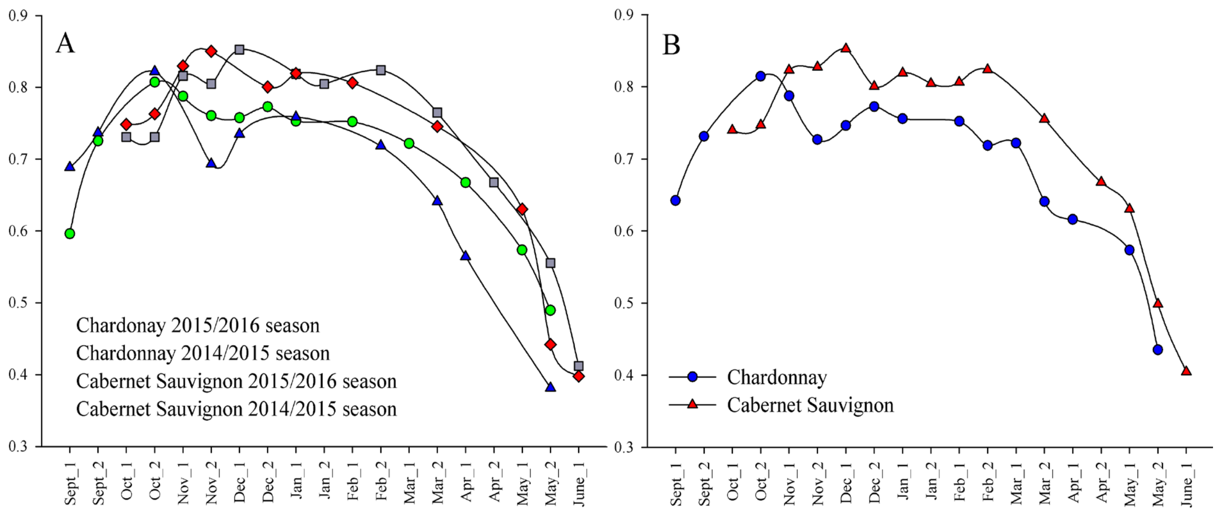

Figure 5: Temporal Normalized Difference Vegetation Index (NDVI) profiles of Chardonnay and Cabernet Sauvignon vines in 2014/2015 and 2015/2016 vegetative seasons (A) and in the mean of studied seasons (B).

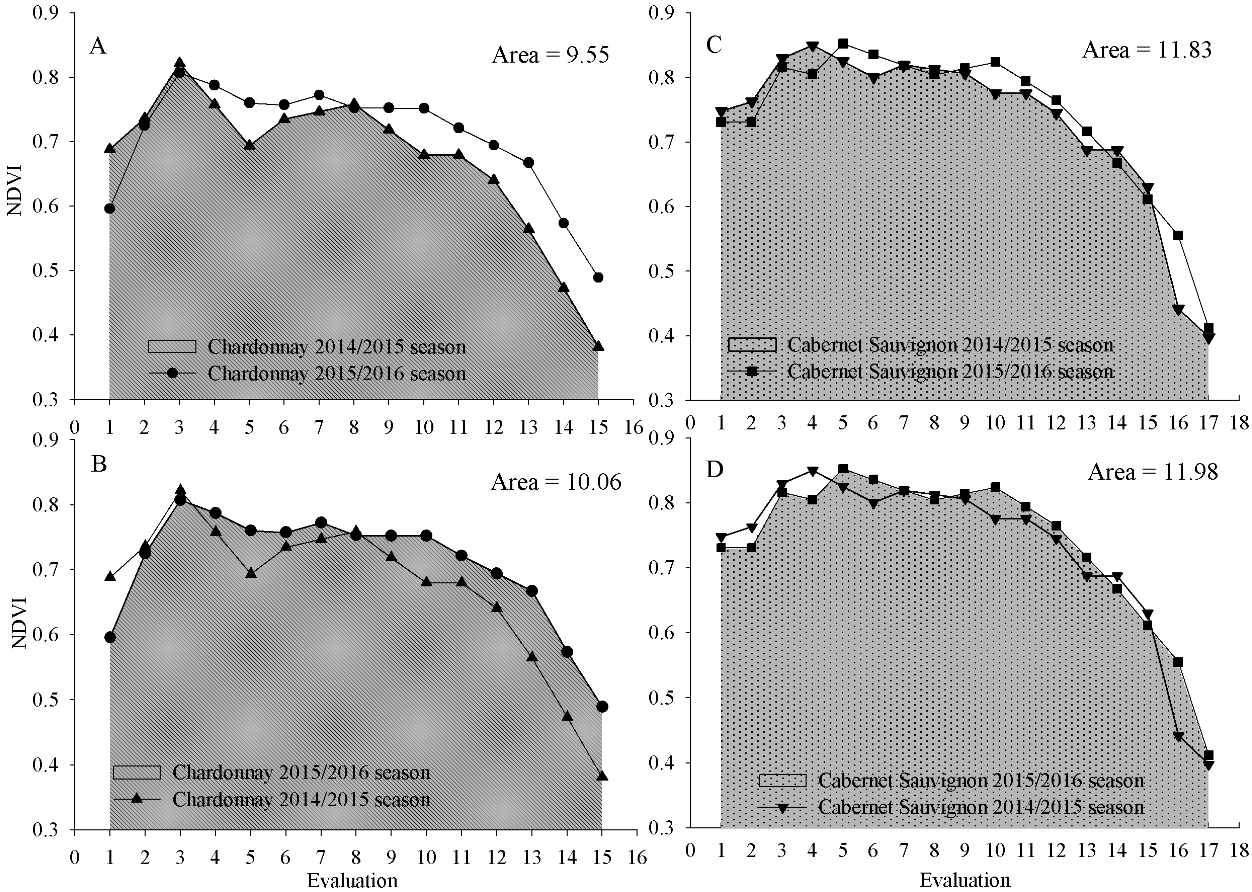

Figure 6: Area below the curve of the temporal NDVI profile for Chardonnay in 2014/2015 (A) and 2015/2016 (B) and for Cabernet Sauvignon vines in 2014/2015 (C) and 2015/2016 (D) vegetative season.

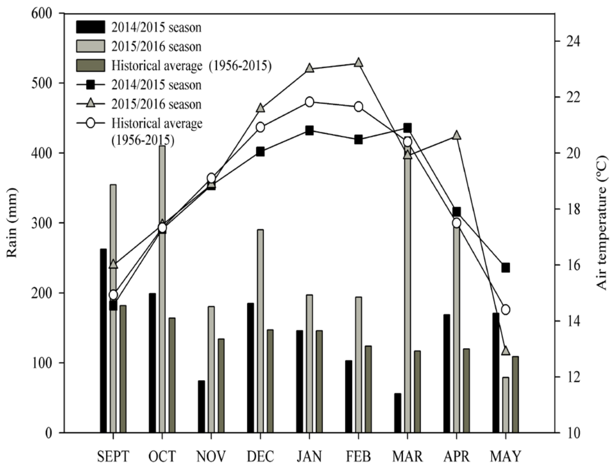

Figure 7: Monthly average air temperature (°C) and rainfall (mm) during the vine cycle from September to June, in the 2014/2015 and 2015/2016 vegetative seasons and the historical average (1956 to 2015).

CONCLUSIONS

The temporal NDVI profiles obtained by ground-based remote sensor reflects the accumulation of green biomass over the vine cycle in the typical grape production system of the Serra Gaúcha region. The temporal NDVI profiles allow monitoring plant growth and development during the phenological stages and changes in the canopy resulting from management practices (summer pruning). The NDVI obtained by remote sensing can be used to characterize the vegetative canopy vigor in vineyards with horizontal training systems, compiling into a single information grapevine development, which results from several factors, such as meteorological conditions and management practices that are difficult to be quantified together. Therefore, it is possible to use the remote sensor Greenseeker as a fast and non-destructive tool in precision viticulture and to support the information collected by orbital remote sensing.

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