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Vitis vinifera SPECTRAL RESPONSE TO THE INCREASE OF CO_2

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Abstract

Hyperspectral remote sensing (HRS) is a useful method to monitor spectral changes in vegetation. HRS contains significant spectral information for detecting plant stress. The specific aims were: (1) to assess the changes in Vitis vinifera plant chlorophyll content due to the leakage of CO_2 into the plant-air environment, and (2) to analyze an vegetation index derived from the first derivative reflectance values for use in detecting *Vitis vinifera* plant stress due to elevated concentrations of air CO_2. Spectral reflectance was measured between 336 and 1045 nm with a spectral resolution of 1 nm, covering visible and near-infrared portions of the electromagnetic spectrum. ***T***he amount of chlorophyll decreased about 50% in the open top chamber modified (OTC modified) + CO_2 injection when compared to natural condition. The difference in chlorophyll between OTC modified + no CO_2 injection and natural condition was 24%. The concentration of chlorophyll a and b decreased and concentration of carotenoids increases of *Vitis vinifera* in initial stage of growth, with increase in CO_2 to 550 ppm. In the end, the remote sensing hyperspectral presents itself as a great tool to assist in studies of global climate change and its impacts on the biomes of the world.

Keywords: Hyperspectral, global climate change, biomes, pigments, vegetation, semiarid, Brazil**.**

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1. Introduction

Much has been discussed about global climate change, greenhouse gases, global warming, and its possible effects in Brazilian agriculture. A recent study coordinated by Pinto & Assad (2008), indicates that the increase in temperature can cause, in general, a decrease in regions with lower climate risk for the grain cultivation and significant economic losses (Coltri et al. 2009).

One of the potential options to mitigate the contribution of fossil fuel emissions to global warming problem is to CO_2 capture and store (Lakkaraju et al., 2010; IPCC, 2005). However, associated with the knowledge on CO_2 storage the extent of the CO_2 leakage is one of key questions related to integrity of storage (Lakkaraju et al., 2010; Hepple and Benson, 2005).

Solar radiation interacts with vegetation through the leaves, first with leaf surface and then with mesophyll; and this leads to integration between cells, tissues, pigments, secondary compounds of cellular metabolism, energy in the light photon, and incidence angle of rays (Pimentel, 2010).

While it has long been known that photosynthetic pigments control the visible reflectance properties of leaves, only recently, techniques have been developed to estimate the concentrations of individual pigments within leaves, using high spectral resolution (hyperspectral) reflectance measurements (Blackburn, 1998; Chappelle et al., 1992; Peñuelas et al., 1995).

The distribution of pigments within a leaf is associated with format and size of cells and number and size of intracellular spaces. Palisade cells have a much greater number of chloroplasts in relation to the amount of these structures found in the foam, making the palisade a tissue with higher absorbance values in the mesophyll. Consequently, the larger the area occupied by cells of palisade in mesophyll, it is expected that a higher absorbance value is obtained in this leaf (Pimentel, 2010).

Hyperspectral remote sensing (HRS) is a useful method to monitor spectral changes in vegetation. HRS contains significant spectral information for detecting plant stress (Lakkaraju et al., 2010; Carter, 1994; Carter, 1998). Spectrometry imaging has been used by De Jong (1998) to detect CO_2 seepage indirectly, using vegetation spectral reflectance.

Photosynthetic pigments such as chlorophyll a and chlorophyll b (which absorb photons that energize the reactions of photosynthesis) and carotenoids (which protect the photosynthetic reaction centers from the light excess) dictate the photosynthetic potential of a leaf and relate strongly to the physiological status of plants (Blackburn, 1998).

Wine production in Brazil had considerable increase from the nineteenth century with the arrival of Italian immigrants in the Rio Grande do Sul state. The Brazilian viticulture has evolutes in a extraordinary way in the two last decades, with a considerable increase in area planted with *Vitis vinifera*, giving to Brazil an international visibility as a producer of fine wines.

Among the crops growing commercially in the São Francisco River Valley, the vine appears as the third most important crop in terms of planted area, with an estimated area of 8,000 hectares in 2002, surpassed only by the areas planted with mango and coconut (Silva & Correa, 2004). It is worth mentioning the scarcity of statistics on horticulture in the region. The vine crop is of special economic and social importance, with involves a large annual volume of businesses directed to internal and external markets and stands out among the irrigated crops in the region such as those that present the highest coefficient generating direct and indirect jobs (Silva & Correa, 2004).

Remote sensing data in situ are often colleted by researchers simply to obtain information about the material spectral characteristics of terrestrial surface. Additional knowledge on the materials can be obtained submitting to various treatments (e.g. applying different amounts of CO_2 in the air to evaluate the response of *Vitis vinifera*) and determining whether treatments result in different patterns of spectral reflectance. The several treatments and their characteristics can be monitored over time to get additional information.

In situ reflectance data from nearly pure materials of Earth's surface can be used to locate endmembers for use during the analysis of hyperspectral or multispectral data (Jensen, 2009).

Remote sensing of chlorophyll absorption in vegetation canopy represents a biophysical variable fundamentally useful for various types of biogeographical researches. The absorption characteristics of vegetation canopies can be associated with other remote sensing data to identify their stresses, productivity, and other hydrological variables of vegetation. Thus, many studies of the remote sensing are focusing on monitoring of what happens with the photosynthetically active radiation (PAR) when it interacts with the individual leaves or the vegetation canopy. The use of imaging and non imaging spectroradiometer is particularly useful for measuring characteristics of absorption and reflectance of photosynthetically active radiation (Jensen, 2009).

The aim of this study was to use hyperspectral remote sensing techniques to investigate the spectral responses of *Vitis vinifera* to increased CO_2 concentrations in atmosphere air, where CO_2 was injected into air of the OTC modified, which show 2 m of diameter and 1,2 m height. The specific aims were: (1) to assess the changes in *Vitis vinifera* plant chlorophyll content due to the leakage of CO_2 into the plant-air environment and (2) to analyze an vegetation index derived from the first derivative reflectance values for use in detecting *Vitis vinifera* plant stress due to elevated concentrations of air CO_2.

2. Materials and methods

2.1 Location and Climate

The experiment was carried out at the Embrapa Tropical Semiarid Experimental Field (09º09 'S latitude and 40º22' W longitude), located in Petrolina municipality (Figure 1) in 15th November 2010.

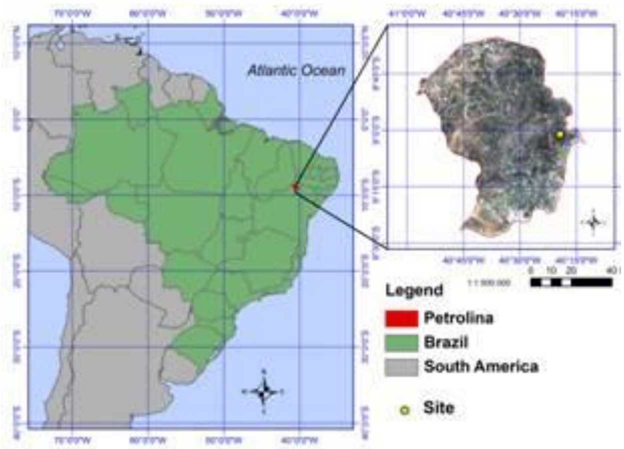

Figure 1 – Spatial location of the site.

The Petrolina municipality presents spatial and temporal irregular precipitation, with annual average of 531.0 mm (www.cpatsa.embrapa.br), which occurs practically from December to April (81% of the annual total). The average monthly air temperature for this region is 26.1^{o}C, ranging from 23.8^{o}C in July to 27.8^{o}C in November (Figure 2).

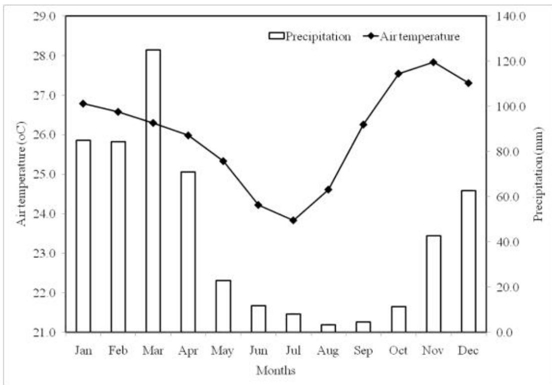

Figure 2 – Climatology of the air temperature and precipitation for Petrolina municipality, Pernambuco State, Brazil.

2.2 Experimental design

The experiment was conducted in structures called OTC modified (Open Top Chamber modified). The OTC modified are circular structures, framed with aluminum rods and side of PVC film (polyvinyl chloride), with 2 m diameter and 1.2 m height, Figure 3. The CO_2 concentration of was measured by infrared gas analyzers (IRGA, infrared gas analyzer), which provided information to a controller that regulated opening of valves for injection of CO_2 in the OTC modified. The CO_2 release was at a constant rate.

Figure 3 – Open Top Chamber modified (OTC modified) installed on the experimental site,

Petrolina, Brazil. Picture from: Galvíncio, 2010.

The studied crop was table grape cv. Italy stand on rootstock 572, planted into OTC modified on 10 of November 2010. The vines were summit to CO_2 treatments from 550 ppm.

The weather conditions were monitored by a CR23X datalogger (Campbell Scientific INC.) programmed to measure the sensors each second and to record data each minute. It was measured temperature and air humidity (HMP45C, Vaisala), global solar radiation (CM3, Kipp & Zonen), photosynthetically active radiation (LI-190, Li-Cor), wind speed (05103, Young), and rainfall (TB4, Hydrological Services).

2.4 Spectral reflectance measurements

Spectral reflectance was measured between 336 and 1045 nm with a spectral resolution of 1 nm, covering visible and near-infrared portions of the electromagnetic spectrum. Fieldspec HandHeld (ASD, Boulder, USA) fitted with a fiber optic probe having a 25° field of view was used. The spectroradiometer was optimized using reference white plate.

2.3 Spectral data analysis

Spectral data were colleted in 15 of November of 2010. The criterion of selection of the day was that it was on beginning of stage of plant growth. Once this stage is that where there is greater differentiation in the spectral signatures, it would be easier to highlight the differences of the treatments used. Measurements were obtained without interference from environmental conditions (e.g. no wind, no rain, etc) but was not controlled atmospheric effects (e.g. temperature, water vapor, etc). In order to estimate the change in chlorophyll content of the leaves due to leakage of CO_2, reflectance band ratios related to chlorophyll content were calculated. Variations in background reflectance properties, contributions from non-photosynthetic canopy components and the effects of leaf layering and canopy structure may weaken the relations between reflectance values in single wavebands and pigment concentrations. Pigment indices which use ratios of reflectance at different wavelengths may overcome such difficulties (Blackburn, 1998). In this study, structural independent pigment index (SIPI) (Eq. (1)) (Penuelas et al., 1995), chlorophyll normalized difference index (Chl NDI) (Eq. (2)) (Richardson et al., 2002), pigment specific simple ratios for chlorophyll a (PSSRa) (Eq. (3)) and chlorophyll b (PSSRb) (Eq. (4)) (Blackburn, 1998) were used to estimate the change in chlorophyll content of the plants and these indices were used to analyze the impacts of CO_2 increase in air on the photosynthetic pigment amount of plants.

In the visible spectral region, the high absorption of radiation energy is due to leaf pigments; primarily the chlorophylls and carotenoids (Knipling, 1970) and therefore it would be possible to track changes in chlorophyll content by calculating vegetation indices in the visible spectrum. Since SIPI compares carotenoids with chlorophyll a, Chl NDI is an indicator of total chlorophyll content and PSSRa and PSSRb are the indicators of chlorophyll a and chlorophyll b, these indices were chosen to estimate changes in the concentrations of carotenoids, total chlorophyll, chlorophyll a and chlorophyll b.

$$SIPI = (R_{800} - R_{445})/(R_{800} - R_{680}) \quad (1)$$

where R_{445}, R_{680} and R_{800} are the spectral reflectance values at 445, 680 and 800nm, respectively.

$$ChlNDI = (R_{750} - R_{705})/(R_{750} + R_{705}) \quad (2$$

where R_{705} and R_{750} are the spectral reflectance values at 705 and 750 nm, respectively.

$$PSSR_a = R_{800} / R_{675} \quad (3)$$

$$PSSR_b = R_{800} / R_{650} \quad (4)$$

where R_{650}, R_{675} and R_{800} are the spectral reflectance values at 650, 675 and 800 nm, respectively.

PRI – Photochemical reflectance Index is obtained by correlation with the expoxidation state of xanthophyll cycle pigment and photosynthetic radiation use efficiency, proposed by Gamon et al. (1992):

$$PRI = (R_{531} - R_{570})/(R_{531} + R_{570}) \quad (5)$$

where R_{531} and R_{570} are the spectral reflectance values at 531 and 570 nm, respectively.

SR_{705} – Simple Ration is used for estimation of chlorophyll content, proposed by Sims & Gamon (2002):

$$SR_{705} = R_{750} / R_{705} \quad (6)$$

where R_{750} and R_{705} are the spectral reflectance values at 750 and 705 nm, respectively.

mSR_{705} – Modifed Simple Ration is used for estimation of chlorophyll content, proposed by Sims & Gamon (2002):

$$mSR_{705} = (R_{750} - R_{445})/(R_{705} + R_{445}) \quad (7)$$

where R_{750}, R_{705} and R_{445} are the spectral reflectance values at 750, 705 and 445 nm, respectively.

New Vegetation Index – NVI

$$NVI = (R_{777} - R_{747}) / R_{673} \quad (8)$$

where R_{777}, R_{747} and R_{673} are the spectral reflectance values at 777, 747 and 673 nm, respectively.

The difference of NVI in relation to other indices is that excludes the absorption band of water vapor.

and red edge index

$$R(red\ edge) = (R_{670} + R_{780}) / 2 \quad (9$$

where R_{670} and R_{780} are the spectral reflectance values at 670 and 780 nm, respectively.

Derivative spectra were calculated by differentiating the spectral reflectance with respect to wavelength. The wavelengths at which the first derivative spectra reach maximum and minimum values were used to derive a vegetation index to quantify the difference between CO_2 stressed and control vegetation. In the first derivative spectra, for CO_2-stressed vegetation, the minimum (negative) was found to locate between 575 nm and 580 nm and maximum (positive) was between 720 nm and 723 nm. The wavelengths at these two features (minimum and maximum) were selected manually and used to obtain the Normalized difference First Derivative Index (NFDI). The averages of the first derivative values of spectral reflectance between 575nm and 580nm were then taken. The averages of the first derivative values of spectral reflectance between 720 nm and 723 nm were also calculated. NFDI was calculated as follows, based on these average values:

$$NFDI = (dR_{720-723} - dR_{575-580})/(dR_{720-723} + dR_{575-580}) \quad (10)$$

where $dR_{575–580}$ is the average of the absolute first derivative values between 575 nm and 580 nm, and $dR_{720–723}$ is the averaged first derivative values between 720 nm and 723 nm. The percentage difference between stressed and control vegetation was calculated to assess the percentage impact of CO_2 injection in plant.

A Incoterm digital laser thermometer was used to measure the temperature of leaf surface.

The spots were located with a GPS (Garmin III Plus) and camera with GPS of Ricoh.

The results were presented by averaged spectral curve for each treatment. Three treatments (with CO_2 and without CO_2 in the OTC modified and control (attestant) were used. For each treatment were collected nine measurements.

3. Results and discussion

Figure 4 presents the daily trend of air temperature and relative air humidity in minute-scale measured in 15th November 2010 at OTC modified plots in Petrolina municipality, Pernambuco State, Brazil. It can be observed that the for that day, the minimal air temperature was 22.78°C at 08h35min (Greenwich) and the maximal one was 34.64°C at 15h03min (Greenwich).

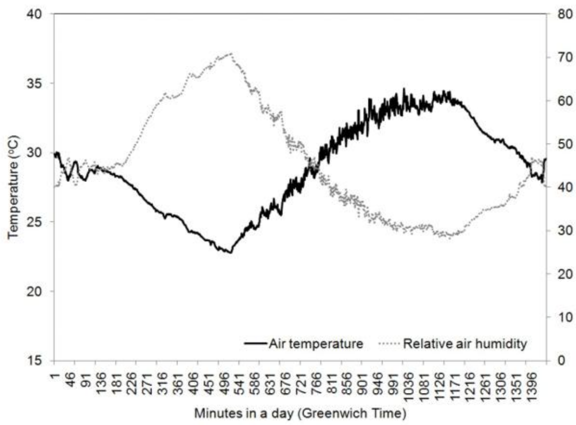

Figure 4 – Air temperature and relative air humidity in minute-scale measured in 15th November 2010 at the OTC modified plots in Petrolina municipality, Pernambuco State, Brazil.

The relative air humidity presents opposite behavior, and the maximal value was 71% occurred at the same time of the minimal air temperature, while the minimal relative air humidity was 28.3% at 19h17min (Greenwich).

Figure 5 presents the daily trend of energy flux density of global solar radiation (Sr, W m^{-2}) and photossynthetically active radiation (PAR, W m^{-2}) measured in minute-scale for 15th November 2010 at the OTC modified plots. According to the Sr data, with the values rising up to 1196 W m^{-2}, this studied day was characterized by a great occurrence of clouds. Field measurements of the spectral data were done at a clear time of the day. PAR behavior is similar to solar global radiation, and by considering sunny day, the ration between photossynthetically active radiation and solar global radiation is around 50%.

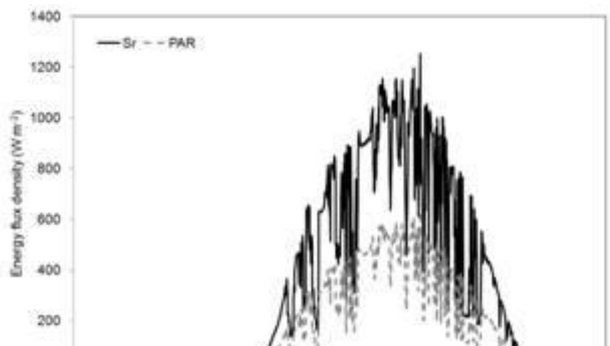

Figure 5 – Energy flux density of global solar radiation (Sr, W m^{-2}) and photossynthetically active radiation (PAR, W m^{-2}) measured in minute-scale for 15th November 2010 at the OTC modified plots in Petrolina municipality, Pernambuco State, Brazil.

According to Moura et al. (2009), these values of air temperature and air relative humidity are between the optimum range for grape in this phenological phase, being excellent weather condition to grape growth, and avoiding the main disease for grape in this region – downy mildew.

The values of leaf surface temperature and air temperature for studied treatments (T1 - natural condition, T2 – OTC modified + no CO_2 injection and T3 - OTC modified + CO_2 injection) are showed in Figure 6. These values were obtained at the time of spectral analyses in field. Can be observed that the spectral measurements for natural conditions (T1) occurred when the air temperature (30.3^{o}C) was higher that of the grape leaf (28 ^{o}C). On the other hand, the spectral observations for T2 and T3 treatments were made when the grape leaf surface temperature was higher than that of the air, respectively 3.6 ^{o}C and 7.0 ^{o}C (Figure 6). Galvíncio et al. (2010) found 5^{o}C in difference between the air temperature and leaf temperature for a native species (Jurema Preta – *Mimosa Tenuiflora*) of Caatinga in natural semiarid condition in Paraiba State of Brazil.

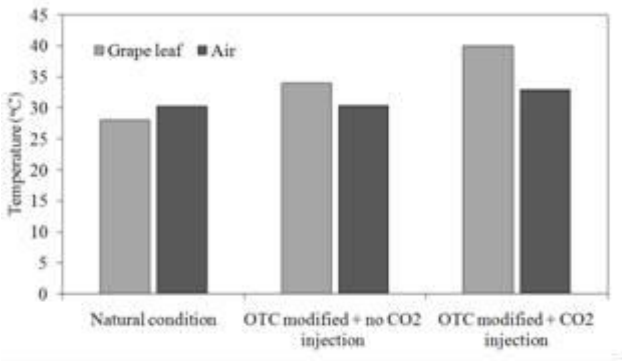

Figure 6 – Grape Leaf surface temperature and air temperature at the spectral measurements time in vines growing in natural condition (T1), in OTC modified + no CO2 injection (T2) and, in OTC modified + CO2 injection (T3), in Petrolina municipality, Pernambuco State, Brazil.

Note that leaf temperature around 40 ^{o}C is too high to photossynthessis process; and for this instance, the gas exchange between leaf and air may be reduced. The air temperature affects photosynthetic activity of plants. The reactions of photosynthesis are less intense at temperatures below 20ºC; grow with increase of this climatic parameter, reaching a maximum between 25 and 30^{0}C, to drop again when approaching 45°C. The resistance limits are between 38 and 50ºC. The average temperature range considered ideal for production of table grapes is between 20 and 30ºC, (Teixeira, 2004).

Figure 7 shows the spectral response in visible region of Italy *Vitis vinifera* variety in three treatments: OTC modified + CO_2 injection, OTC modified + no CO_2 injection and natural condition.

Note that the plastic affects spectral behavior little and that CO_2 injection caused a greater change in spectral characteristics of the plant. OTC modified + CO_2 injection, there was an increase in reflectance in the wavelength range from 540 to 700 nm. Regarded to characteristics of different pigments, the absorption of radiation is more pronounced in wavelengths of 480 nm (chlorophyll "b") and 680 nm (chlorophyll "a"), through a very low absorption between 540 and 620 nm, Figure 7. The reflectance curve with CO_2 by 680 nm is greater than with OTC modified + no CO_2 injection. There was a decrease in chlorophyll a with CO_2 injection. By 480 nm there was also the higher reflectance with OTC modified + CO_2 injection when compared with OTC modified + no CO_2 injection. This indicates decrease in chlorophyll b.

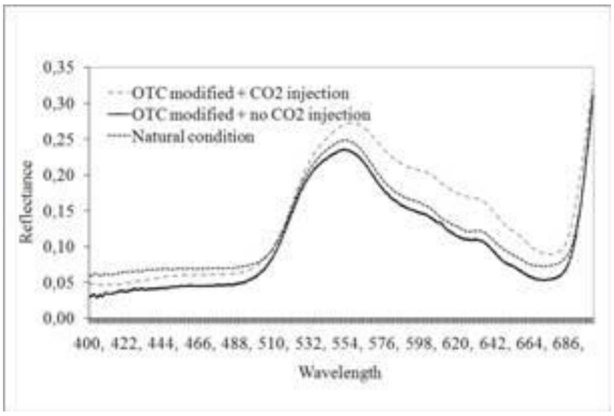

Figure 7 – Spectral response in visible region of cv. Italy *Vitis vinifera*.

The PSSRa index was 8.51 with OTC modified + CO_2 and 16.52 with OTC modified + no CO_2 injection Table 1. There was a decrease in chlorophyll a with CO_2 injection.

The PSSRb was 6.10 with OTC modified + CO_2 and 11.89 with OTC modified + no CO_2. There was a decrease of chlorophyll b with CO_2 injection. Blackburn (1998) applied a correlation between a data set of chlorophyll a and b with the indices of PSSRa and PSSRb, and found a strong correlation with a coefficient of determination from 0.93 to 0.94 for chlorophyll a and chlorophyll b, respectively. According to the author, PSSR index is used to minimize effects of interaction of radiation with the leaf surface and internal structure in the mesophyll, (Blackburn, 1998).

The SIPI was 1.05 on OTC modified + CO_2 injection and 1.02 on OTC modified + no CO_2 injection, (Table 1). In the OTC modified + CO_2 injection there was an increase in amount of SIPI, i.e. an increase in ratio between chlorophyll a and carotenoids. There was a decrease in the concentration of chlorophyll a and increase in the concentration of carotenoids. The SIPI is an index that minimizes the effects of leaf structure and has been used to estimate the ratio between carotenoids and chlorophyll (Peñuelas et al. 1995). The results of Blackborn (1998) corroborate those obtained in this study. The PRI is an index that reflects plant photochemical conditions and represents correlation between the epoxidation state of xanthophylls cycle pigments and photosynthetic radiation use efficiency. PRI for OTC modified + CO_2 injection was negative, (Table 1). The PRI index nearest of zero was the one of natural condition. The natural condition treatments show a higher capacity of light utilization by photosynthesis, and thus greater should be the efficiency of the plant in doing it. This result occurred because the plant is fully exposed to sunlight, as shown in Figure 8. The better radiation use the higher photosynthesis, the higher the possibility of plant to use CO_2 for photosynthetic processes and thus store CO_2. Importantly, this index varies throughout day, with the differences in light intensities. Overnight, indexes inverse, since the plants breathe without the presence of light (Rahman et al. 2001; Coltri et al. 2009).

Figure 8 – Natural condition.

Table 1- Spectral indices value computed in this study.

Indices	Miniface + CO_2	Miniface + no CO_2	Natural condition
PRI	-0.070	0.005	-0.004
NVI	0.140	-0.680	-0.460
Red Edge	0.420	0.460	0.470
SIPI	1.053	1.023	1.010
PSSRa	8.505	16.518	12.287
PSSRb	6.056	11.893	9.750
SR705	1.819	2.135	2.220
mSR705	1.954	2.259	2.466
Chl NDI	0.290	0.362	0.379

The values of PRI were negative for natural condition and OTC modified + CO_2 injection, and ranged between -0.07 and -0.004 (Table 1). The vegetation was performing photosynthesis with efficiency in the use of active radiation at the moment of collection. Thus, due to realization of photosynthesis, it is clear that the *Vitis vinifera* was using CO_2 with high efficiency. When collecting data on OTC modified + no CO_2 injection the vegetation was not performing photosynthesis, but showed a greater capacity of light utilization by photosynthesis when compared with the vegetation of OTC modified + CO_2 injection, and yet, the vegetation of OTC modified + no CO_2 injection showed a greater efficiency in photosynthesis. It is suggested that CO_2 interfere in the efficiency of plant photosynthesis.

Indices SR705, mSR705 and Chl NDI which are indices to estimate the chlorophyll content showed the same trends, i.e., the OTC modified + CO_2 injection values decreased, (Table 1), confirming the results of the indexes PSSRa and PSSRb. In the analysis of Chl NDI there was a decrease in the rate of normalized difference chlorophyll with CO_2 injection. The Chl NDI is used to measure the fraction of Photosynthetically active radiation and coverage of green vegetation when used for large geographical scales (Kumar & Monteith, 1981, Gamon et al. 1995; Blackborn, 1998).

Figure 9 shows the contents of chlorophyll a and b *Vitis vinifera* of the three treatments on November 15th, 2010. Note that the amount of chlorophyll decreased about 50% in OTC modified + CO_2 injection when compared to control vegetation. The difference in chlorophyll between OTC modified + no CO_2 injection and natural condition was 24%.

Smith (2002) found that barley above the leaking gas pipeline showed a decrease between 16 and 56% and Smith et al. (2005) found that chlorophyll content in gas exposed to high concentrations of soil natural gas was decreased by 30%. In addition, Ketel (1996) found that the chlorophyll content of leaves, but treated with 25% lethat dose of glyphosate was equal to that of control leaves, but that when lower doses of the herbicide were used, the chlorophyll content was greater that of control leaves.

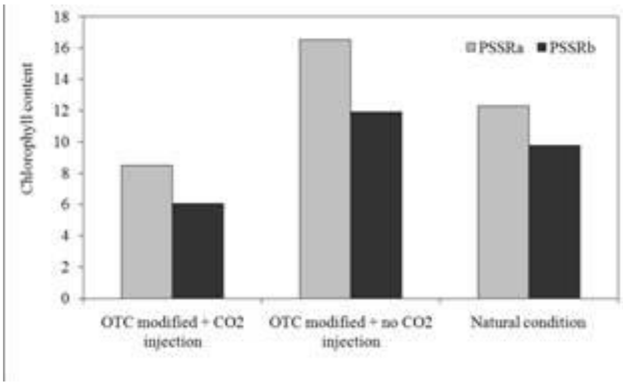

Figure 9 – Change in chlorophyll content in three treatments and measured on November 15, 2010.

In Lakkaraju, (2010) as CO_2 seeps to the ground surface, it could deplete oxygen in the soil atmosphere and could cause stress in the local vegetation. The primary cause of the stress, in response to natural gas leaks, is believed to be displacement of oxygen from the soil atmosphere, which thereby inhibits root respiration that provides energy for root growth and uptake of nutrients from the soil (Hoeks, 1972a; Gilman et al., 1982; Arthur et al., 1985). Displacement of soil oxygen has negative effects on plant growth which are expressed as reduced root, shoot growth and dry weight (Drew, 1991). For instance, Noomen and Skidmore (2009) found that increasing soil CO_2 concentrations decreased plant height, leaf chlorophyll content and dry weight of maize plants. Boru et al. (2003) reported that a 50% CO_2 concentration at the root zone has shown either death of soybean plants or severe symptoms of chlorosis, necrosis and root death. Compromising to the health of plants due to stress is often associated with an increase in spectral reflectance in the visible region and a decrease in the near-infrared (NIR) region. This results in a shift of the slope between red and NIR, called ‘red-edge position’, towards shorter wavelengths. Since it is known that the changes in spectral reflectance are often a stress induced response of plants (Macek et al., 2005; De Jong, 1998), these changes in spectral reflectance could be used as a proxy indicator of CO_2 leakage.

First derivative analysis was applied to determine how red edge position was affected by air increase of CO_2. Figure 10 shows the first derivate of reflectance for the *Vitis vinifera* with and OTC modified + no CO_2 injection. The injection of CO_2 caused stresse in plant. Note difference on reflectance between the response of *Vitis vinifera* with CO_2 and without CO_2, especially in Red Edge region (region by 700nm). The indice Red Edge, (Table 1), shows lowest value in plant with CO_2 injection. In OTC modified + CO_2 injection occurred a increase relative compared with the natural condition in first derivative between 520 and 580 nm and a relative decrease in derivative between 630 and 660 nm. Similar result can be in Smith et al., (2005). Smith et al., (2004) examine the response of vegetation to the increase of methane and obtained a decrease of reflectance in the infrared.

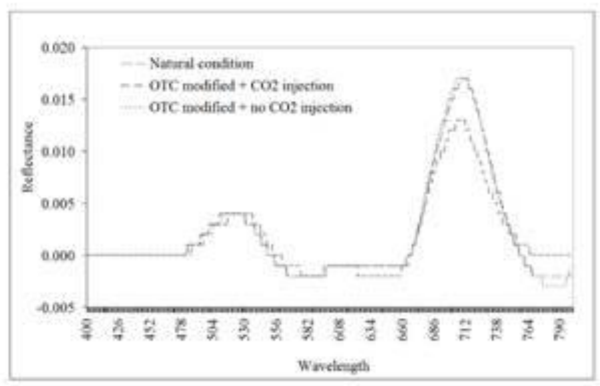

Figure 10 – First derivative of reflectance.

Figure 11 shows the NFDI of OTC modified + CO_2 injection and natural condition. Note that the NFDI was less at and had a 9% difference. The NFDI was sensitive to stress of vegetation. According to the results, it is suggested that there is a negative correlation between increased CO_2 and NFDI. This information is of paramount importance for monitoring and forecasting of the impacts of increasing CO_2 in the air over the *Vitis vinifera*. Lakkaraju et al. (2010) found a high negative correlation (r =- 0.93) between increased CO_2 in soil and NFDI and a low positive correlation (r = 0.33) between natural condition and NFDI.

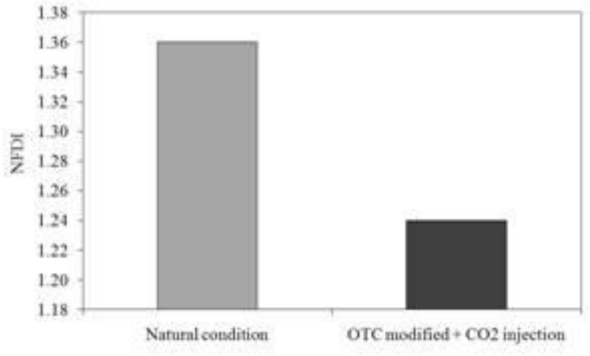

Figure 11 – NFDI of the *Vitis vinifera* with CO_2 in air and natural condition.

Most of the methods used for displacing oxygen from air increases plants reflectance at all visible wavelengths when compared with the control plant. Other researchers have also found increases in the reflectance in visible wavelengths in response to plant stress (Smith et al., 2004). Carter (1993) used various stresses and plant species to detect changes in reflectance and found that visible reflectance increased consistently in response to stress. Carter and Miller (1994) found that reflectance within the 690 – 700 nm range was particularly sensitive to early stress-induced decreases in leaf chlorophyll content.

Of course, CO_2 enters the leaf from atmosphere through tiny pores, which are located mainly in lower epidermis. The plants have adapted their internal and external structure to carry out photosynthesis. This structure and its interactions with the electromagnetic energy has a direct impact on how leaves and plant canopies appear when registered using spectral remote sensing instruments, (Jensen, 2009).

The IPCC (2005) states that it is expected that increasing concentration of CO_2 in the atmosphere resulting from burning of coal reserves, oil, gas and forests, affect radiation balance, causing a rise in temperature on planet. The analysis of air bubbles in glaciers (Neftel et al. 1985) showed since 1800 the concentration of CO_2 in the atmosphere increased from 280 to 330 ppm today. The model of Manabe et al. (1990) for year 2060 envisages an increase of 2.5^{o}C in global average temperature, based on the trend that concentration of CO_2 equivalent of "greenhouse gases" (CO_2, methane, nitrous oxide, ozone and chlorofluorocarbons) and continue increasing double by year 2060 over current levels. Other models (see Mason 1990) show similar trends. According to Orlóci (1994), this increase in average global temperature will cause in the higher latitudes of the northern hemisphere an increase of up to 12^{o}C in mean annual temperature, which will likely determine collapse of vegetation such as the Tundra and Forest.

4. Conclusions

The spectral indices used in this study proved to be excellent for estimating concentration of photosynthetic pigments (such as chlorophyll a and b and carotenoids) and they were sensitive to increased CO_2 and its impact on response of *Vitis vinifera*.

Increasing in CO_2 to 550 ppm, the concentration of chlorophyll a and b decreased and carotenoids increased of *Vitis vinifera* in initial stage of growth,.

During collection, the plant was at peak of photosynthesis and CO_2 affected the efficiency of plant photosynthesis. With the increase of CO_2 there was a decrease of almost 50% in amount of chlorophyll as compared to natural condition. The increase in CO_2 caused stress on plant. With CO_2 a relative increase occurred, when compared with control in first derivative between 520 and 580 nm and decrease in relative derivative between 630 and 660 nm.

NFDI was sensitive to the stress of vegetation. There was a negative correlation between increasing CO_2 and NFDI. This information is of paramount importance for monitoring and forecasting the impacts of increasing CO_2 in air on *Vitis vinifera*.

Many of the spectral indices used in this study have similar functionality and therefore, presents spectral autocorrelation. Anyway, the results indicate that certain combinations of spectral indices and bands are more sensitive and more effective than others in some situations depending on the pigment concentration. It is important to investigate these spectral indices used here in large spatial and temporal scales for possible collection of spectral curves at leaf level, canopy cover, and area.

Finally, the hyperspectral remote sensing presents itself as a great tool to assist in studies of global climate change and its impacts on the biomes of the world.

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