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Detection of Acid Rain Stress Effect on Plants Using Spectroradiometer - A Review

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ABSTRACT: This paper aims to use hyperspectral data to detect the spectral changes caused by acid stress on plants. Acid rain is causes due to air pollution in many developed countries mainly in USA and China. This is mainly causes due to the emission of sulphur dioxide and nitrous oxides through the combustion of fossil fuel. Due to the fall of acid through the rain it affects most of the environmental factors such plant growth and its development, water bodies and aquatic animals. As a result plant foliar structure changes and change can detect using its spectral reflectance by using spectroradiometer. Acid deposition causes significant change in concentration of chlorophyll content on leaves of a plant. The differences in chlorophyll concentrations caused by acidic stress are explicable to the different spectral reflectance patterns in the visible and near-infrared wavelengths. In some methods new chlorotic indices were utilized to explain the stress-caused leaf chlorosis. And comparing vegetation indices and PCA (principal component analysis) it would be possible to monitor the acid rain deposition stress effect on plants. In some methods remote sensing images such SPOT images are used to detect the emphasis of acid rain on forest region by applying various method in GIS.

KEYWORDS: Acid deposition; ***Acid rain;*** Continuum removal; PCA; Reflectance; Spectroradiometer; vegetation indices.

I. Introduction

Acid rain or acid deposition, mainly caused by sulphur dioxide (SO2) and nitrous oxide (NOx) through the burning of fossil fuels, has been a serious environmental problem worldwide in the past several decades until now. The gases may be deposited as dry deposition, which often dominates wet deposition in areas close to emission sources. In addition to wet and dry deposition, the total deposition may include a contribution from acidic mist (sometimes denoted occult deposition). Rainwater in equilibrium with carbon dioxide (CO2) in air (and with no other species affecting pH) is slightly acidic, with a pH of 5.6, while neutral water exhibits a pH of 7.0. However, even under pristine conditions, rain water is often more acidic due to natural emissions of SO2, NOx or organic acids. Typical pH values of acid precipitation caused by anthropogenic emissions may be in the range of 3.5–5.0 [1]. Possible emphasizes of acidic deposition on plants have been the topic of intensive research efforts all over the world. Acid intensiveness could affect plant physiology such as leaf surface wax layer, Chlorophyll and so on. It also affects the plants through soil and water by changing the contents of soil and pH value of the water. To study and detect the affected plant physiology, many methods have been discovered since last two decades. Traditionally, acid deposition was monitored by using wet chemistry method, which is expensive and time consuming, and always hard to extend to large spatial scale. The hyperspectral remote sensing, can endow us with the ability to quickly access the bio-chemical composition and health state of plants. Studies utilizing ground or aircraft based hyperspectral spectroradiometers have pointed out that stresses can result in a decreased chlorophyll content, which in turn will induce increased reflectance at visible wavelengths. Chlorophyll content is an important factor of study in order to monitor the plants health. In some studies, chlorophyll measured using a portable chlorophyll meter. Chlorophyll meter can quickly and non destructively assess the chlorophyll status of plants by simply clamping the meter over foliar tissue, then receiving an indexed chlorophyll content reading in less than 2 seconds. Using vegetation indices many methods have been used to measure chlorophyll

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content. Using hyperspectral data of the chlorophyll concentration measured within the different spectral reflectance patterns in the visible and near-infrared wavelengths, we can monitor the responses specific plant to acid stress.

II. Related work

Acid rains are dangerous ecological factor, which strongly influence on the decreasing of forest ecosystem productivity and reproduction. SONG Xiaodong et al. studied acid rain deposition on the plant *Pinus Massoniana*, which is widely found in china, using the hyeperspectral data. They used Continuum removal method to separate to isolate wavebands more responsive to stress in wavelengths 450–750nm. Two new chlorotic indices were simulated by them to explain the leaf chlorosis emphasis. After comparing the vegetation indices and principal component analysis (PCA), they found that it would be possible to monitor acid rain emphasis on forest plants from some wider spectral regions [2].

Acid rain has been a big worldwide environmental problem for decades but countries like China and Taiwan is one of the most serious acid deposition polluted regions in the world. How to effectively monitor acid deposition's intensiveness and spatial distribution has constituted a great challenge to the chemistry laboratory methodology, which is time consuming and more critical, used to monitor acid rain.

In the studies of Xiaodong Song et al., field and greenhouse experiments were performed separately to illustrate the influence of both natural and acid rain to the spectral reflectance and chlorophyll content of *Pinus Massoniana*. When they measured with a spectroradiometer and a chlorophyll meter, they found that spectral reflectance was a more sensitive indicator than chlorophyll content to indicate the intensiveness of acid emphasis. In most of their cases, the reflectance of *Pinus Massoniana* (both natural and greenhouse) was increasing with the intensiveness of acid emphasis in part or in the whole wavelength regions ranged from 400 to 800nm. Vegetation indices computed using simulated Landsat Thematic Mapper bands showed that light acid emphasis often caused higher indices' values. And it was suggested that multispectral image data might be used to monitor acid emphasis from a canopy level [3].

Naveen Dondapati et al., in India, studied a novel method for detecting acid rain patterns of SO2 and NOx using pH in image processing. To control acid rain pollution and to protect the ecological environment, it is a major need to identify the occurrence of acid rains. He represents in his paper a methodology for identifying the occurrence of acid rain using pH values calculated from normality by applying k-means clustering and Haar wavelet transform on the satellite imagery of water vapour, SO2 and NOx. If the computed pH value lies in the range from 1 to 5, then it is identified as acid rain and the resulted outcome indicates that the amount of rainfall with the concentration of SO2 and NOx have a strong influence on the occurrence of acid rains [4].

In Jilin University, china, He MENG et al. studied the emphasis of simulated acid rain (SAR) on growth and development in *Brassica campestris* L. without using hyperspectral data. In study, plants were exposed every two days after tenth day of emergence to 10 mm simulated rain at various levels of pH values as 3.0, 4.0, 5.0, 5.6 and 6.5 (CK). The results of this study indicated that influences on growth and development in rape were highly correlated with pH levels under treatment of acid rain. This impact mainly depended on the acidity of simulated acid rain, and then the time of rape suffered from simulated acid rain. The visible symptoms of rape injury were appeared at foliar injury of leaf such as chlorosis or necorsis. Acid rain emphasizes can cause plant height dwarf, lengths of stem and root reduce, and fresh and dry weights of edible portions and roots significantly decrease. With increasing acidity of acid rain, the growth and development of rape were remarkably inhibited. Under emphasis of the weak acid rain, growth of rape was partly affected [5].

To monitoring the response of vegetation to acid deposition in eco-regions of subtropical China, Jiaxin Jin et al. has studied based on SPOT/NDVI. His study aims to explore emphasis of acid deposition on vegetations in subtropical China through comparison inter/inter-annual and seasonal variations of NDVI in 11 eco-regions between intensiveness acid rain region and normal acid rain regions, based on the SPOT/VGT_10 Day_NDVI and precipitation pH from 1999 to 2001 [6]. The same author, Jiaxin Jin et al, has also studied for detecting responses of *Pinus Massoniana* to acid rain based on different soil conditions. For this study, monthly average pH and monthly average NDVI were obtained from precipitation acidity and NDVI data between 1992 and 2006 in China, based on both acidity levels and soil critical load of acid deposition, and then they used to analyze inter-annual variation by the improved sinusoidal fitting and linear regression analysis [7].

To explore responses of *Pinus Massoniana* to acid rain during a long time series in central China, Hong Jiang et al. used the interpolation dataset of acid rain and the Global Inventory Modeling and Mapping Studies (GIMMS) normalized difference vegetation index (NDVI) data to derive the monthly pH and NDVI trajectories based on acidity gradients from 1992 to 2006. Then he analyzed inter-annual and seasonal variation of vegetation growth by improved

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regression analysis and sinusoidal fitting [8]. In order to monitor the health conditions and acid rain issue with *chamaecyparis formosensis* in yi-lan area of Northern Taiwan, multi-view remote sensing has been used by Sheng-Yang Su et al. His study took a multiple-view approach with following steps: (1) to obtain SPOT and acid-rain data and form a GIS database; (2) to correct multi dates SPOT images using relative radiometric normalization; (3) to correct NDVI from relatively corrected SPOT images; (4) to detect a change detection on multi-date NDVI images; (5) to compare the distribution map of health conditions deteriorating Taiwan red cypresses (TRC) with acidic intensity distribution map; (6) to confirm the comparison results by high resolution ortho-rectified images [9].

Zhumar A.Yu et al. studied the influence of sulphuric acid solutions on the pine needles optical characteristics. The change of foliar structure of needle can be resulted by the emphasis of acid rain on a pine needle. The variation of pigment concentration influences on the leaf absorption. In his method, for simulation the influencing of acid rains on the needle pigments, mesophyll structure and its optical characteristics 0.1 %, 1 %, 5 % and 10 % water solutions of sulphuric acid (H2SO4) were used. Then needle reflectance spectra have been collected by spectrometer MSS-2 (spectral range 400-800 nm, spectral resolution 5 nm) and the needle chlorophyll concentration was measured by Arnon method. He model LIBERTY was used to simulate the reflectance of pine needles. The LIBERTY leaf model was designed to model and characterize conifer needles. The model performs a linear summation of individual absorption coefficients of the major constituent leaf bio-chemicals (chlorophyll, water, protein, lignin, and cellulose) according to their content per unit area of leaf [10].

In his study, It was found that the increasing of acid concentration results to the decreasing of the pigments content and reflectance of needle in the visible and near-infrared regions. The analysis of experimental and simulated by using LIBERTY model data has shown, that the decreasing of pine needle reflectance depends on the change of refractive index at cell wall-air and cell wall-water interfaces concerned with the reduction of intercellular air spaces in needle mesophyll.

One kind of acid rain measuring method for large ancient sites in the field based on IoT technology is researched and realized by Xiong Zhang et al. in the School of Information Science and Technology, Northwest University, China. For working principle of pH value detection is analysed and pH-value sensor conditioning circuits are constructed. In the field, automatic temperature compensation of pH-value sensor and conditioning circuit are conducted using AVR control panel carrying a temperature sensor and this circuit guarantees the precision of acid rain detection in intensive environment. Measuring results are uploaded into data management centre by wireless route, thus realizing the display and storage of data and the change trend of acid rain in the monitored area can be predicted according to historical data via data management platform designed by LabVIEW [11].

III. METHODOLOGY

In the studies by SONG Xiaodong et al, *Pinus Massoniana*, which occupies the largest forest area in the Three Gorges region, was selected as the research target for its acidic sensitive property. Samples' needles of 2 years old were collected in May 2006. Hyperspectral data were obtained with FieldSpec4 spectroradiometer manufactured by Analytical Spectral Devices Inc. (ASD). The spectral resolution of this instrument is 3nm for the region of 350–1000nm and 10nm for the region of 1000–2500nm. A portable chlorophyll meter, SPAD-502 was used to obtain relative chlorophyll concentrations in situ with the spectral measurement at the same time. The NBD was calculated as the band depth from the waveband of interest relative to the depth of the waveband at the centre of the absorption feature and that it is defined as below:

$$NBD = (1-(R/R_i))/(1-(R_i/R_{ic}))$$

where R is the reflectance of the sample at waveband of interest, Ri is the reflectance of the continuum line at the waveband of interest, Rc and Ric are the reflectance of the sample and the continuum line at the centre of the absorption feature, which is the maximum band depth. He also introduced chlorotic indices, R_{GY} and R_{GO}, defined as below:

$$R_{GY} = \frac{R_G}{R_Y} R_{GO} = \frac{R_G}{R_O}$$

Where R_G, R_Y and R_O are the average reflectances at green, yellow and orange wavebands respectively. Finally, he performed the comparison of simulated vegetation indices and principal component analysis (PCA).

In the study of using image processing, the inputs for the application are satellite imagery of water vapour, sulphur dioxide and nitrous oxide with noise or without noise. Naveen Dondapati et al. used clustering; clustering is the process of segmentation the data into several regions based on similarity measures using Euclidean distance. Image

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segmentation using k-means clustering is used to segment the data so that the objects in a cluster contain relatively similar data objects when compared with other clusters formed. K–means clustering algorithm is applied on water vapor precipitation image to form 4 segments, sulphur dioxide into 6 segments and nitrous oxide into 4 segments using Euclidean distance metric to provide local minima. The clusters are obtained after segmentation process on the satellite imagery of water vapour, sulphur dioxide and nitrous oxide. Here clustering is carried out using MATLAB 2011a tool box, which provide image segmentation algorithms and a comprehensive environment for data analysis, visualization and algorithm development. The feature extracted cluster images are selected for further analysis to convert into frequency domain. The haar wavelet is chosen here as it is an efficient technique, where decomposition is applied to the image in rows and columns by transforming from data space to wavelet space in frequency domain. As satellite images is an RGB image, Haar wavelet can automatically invert an RGB image into gray scale image which is later de noised and represented in one dimension. Now he needs to compute the pH value of rainfall; mean wavelength has to be estimated from the feature extracted images. Further, it is also required to compute ozone molecules, grams of solute, liquid molecules, litres of solution and normality is to be calculated using mathematical equations. Using these equations he computes ozone molecules, grams of sulphur dioxide, liquid molecules, litres of solution and normality. The pH value lies in the range of 1 to 5, justifying that the feature extraction images produce acidity; hence it is treated as acid rain.

He MENG et al. studied the emphasis of simulated acid rain (SAR) on *Brassica campestris* L. The study site area has a North Temperate Zone continental monsoon climate. The simulated rain contained a stock solution consisting of tap water to which had been added. Field was randomly divided into six groups, various pH levels and CK, with a 0.5 m buffer zone between each application avoiding interference from each group and simulated rain was applied with a pressured watering can with plastic body and copper nozzles. Before exposed to simulated rain, rape was irrigated with tap water. All plants were examined for acid rain foliar injury. The growth of rape was evaluated by measurement of plant height, stem length and root length and also the fresh and dry weights of roots and edible portions were recorded. Data were reported as mean standard deviation (SD) and were analysed by an analysis of variance (ANOVA). Least Significant Difference Test was used to test the significance of difference between means and Differences at P less than 0.05 were considered significant. The correlation coefficient was given via Pearson correlation analysis.

Jiaxin Jin et al. studied the detection of responses of *Pinus Massoniana* to acid rain based on different soil conditions. The Global Inventory Modeling and Mapping Studies (GIMMS) normalized difference vegetation index (NDVI) data sets were generated to provide a 25-year satellite record of monthly changes in terrestrial vegetation at a spatial resolution of 0.083. Ordinary kriging (OK) accounts for local fluctuations of the mean by limiting the domain of stationarily of the mean to the local neighbourhood and Kriging calculated variable values at unknown locations from a semi-variogram model and appropriately sampled data set. The kriged estimates are smoothed and are better when they are closer to the station. In his study, the best semi-variogram model was simulated using the software GSt (v7.0). Even though normality may not be strictly required in kriging, serious violation of normality, such as high skewness and outliers, can impair the simulation results. Thus, the power transformation of Box-Cox was performed to normalise positively skewed data sets, with the assistance of the software MINITAB (v14.0). Based on the acidity interpolation results, the acid rain was divided into 3 levels by multi-year average pH, including pH less than 4.8 (L1), pH between 4.8 and 5.0 (L2) and between 5.0 and 5.6 (L3). Based on the distribution of the *Pinus Massoniana*, the acidity level and the soil conditions in study area, monthly average pH and NDVI were obtained from the acidity interpolation data and GIMMS/NDVI data from 1992 to 2006 respectively for the analysis. For describing the inter-annual growing trend of *Pinus Massoniana* during the study period, he used the improved sinusoidal model to fit NDVI in each *Pinus Massoniana* pixel.

In study of *Yi-lan area of northern Taiwan* by Sheng-yang su et al., the datasets of study contained: four dates SPOT images, digital elevation model (DEM), 0.5 m × 0.5 m high-resolution orthophotos, and data of third forest recourses and land use inventory in Taiwan, also the basic information of the SPOT images. He inputted the DEM into ERDAS image program and used topographic analysis module to produce the slope image layer. Then he inputted SPOT images into ERDAS image program and selected the imagery that was acquired in 2005 as the base image. The other three images were corrected by histogram matching (HM) with respect to the base image. According to the NDVI values, he can estimate the health conditions of vegetation. Rouse et al. (1974) developed the general NDVI function:

$$NDVI = (RNIR - RR) / (RNIR + RR)$$

Further he inputted the post-HM SPOT images into ERDAS image program to obtain four-date NDVI images, and the four-date NDVI images and these are used for calculate NDVI change detection patterns, and he extracted the habitat patterns of TRC from the data of third forest resources and land use survey in ESRI ArcView 3.2 edition. He clipped

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the TRC NDVI patterns from NDVI images according to the TRC habitat pattern by using ERDAS image program. He conducted NDVI image change detection by subtracting the 2009 image from the 1994 image on the pixel-by-pixel base for TRC habitats. NDVI change equal to NDVI value of TRC habitat patterns in NDVI image of 2009 for each pixel. He concluded if the change detection result is positive, it means the TRC health-condition was ameliorating. In contrast, if the result is non-positive, it means the TRC health-condition was deteriorating. In the studies by Zhumar A.Yu et al., needle reflectance spectra have been collected by spectrometer MSS-2 (spectral range 400-800 nm, spectral resolution 5 nm) and the needle chlorophyll concentration was measured by Arnon method. The 10 series of experiments were made by him. The model LIBERTY was used to simulate the reflectance of pine needles. The LIBERTY leaf model (Leaf Incorporating Biochemistry Exhibiting Reflectance and Transmittance Yields) was designed to model and characterize conifer needles. The 10 series of experiments were made.

IV. RESULT AND DISCUSSION

SONG Xiaodong et al. compared the average NBD values at the wavelength of interest in the spectral region from 450 to 750nm for all samples in his studies. Studies have pointed out that due to decreased chlorophyll concentration caused by emphasizes; the chlorophyll absorption bands will absorb less incident visible light, especially in the blue and red wavelengths, so causing the increased reflectance in these spectral regions. He found that generally, the NIR reflectance decreases as the leaves senescing or under effects. His paper used hyperspectral data to detect the acid deposition effects on the acidic sensitive forest. Results from his investigation show that the different spectral reflectance patterns in wavelengths 450–750nm between two affected and non affected acid regions could be explained by the difference in chlorophyll concentrations and leaf thickness caused by the acid deposition induced effects. Also, two new chlorotic indices RGY and RGO were designed to explain leaf chlorosis caused by acid deposition effects.

In Naveen Dondapati et al. Research paper feature extraction from satellite images is main task main wavelength of satellite is to be calculated and If the collected satellite image represents rain then it is computed in terms of litres of solution. if it is an emissions image, it is computed in terms of grams of solute. The value obtain from (precipitation, SO2 and NO2 images) are used for the calculation of normality. Further, the value obtained from normality is used to determine the pH value of the rain. If its calculated pH value lies in the range established for acidity; hence it is an acid rain image. Also, if its calculated pH value does not lie in the range established for acidity, hence it is no acid rain image. He presented a methodology to find acidity in precipitation using sulphur dioxide and nitrogen dioxide imagery. This problem is addressed for the first time which is computationally efficient and adapt to as well with respect to measured pH value. Deming Dong et al. in his studies he found that direct damages of rape subjected to SAR were occurred on the leaves, which expressed as foliar chlorosis or necrosis. Injury spots were first observed on leaves after five times treatment of SAR pH 3.0. With the increasing times of application of SAR, new foliar injury spots generated; some injury spots gradually diminished or even disappeared because of continuing growth and repair of leaves; the others gradually preformed bigger ones. Finely, several injury spots linked together and formed larger injury spots. The effects of SAR on stem length and root length can be seen that they were reduced with the declining of pH of SAR. Finally it is found that Acid rain emphasizes can cause plant height dwarf, lengths of stem and root reduce, and fresh and dry weights of edible portions and roots significantly decrease. With increasing acidity of acid rain, the growth and development of rape were remarkably inhibited. Under effects of the weak acid rain, growth of rape was partly stimulated.

Jiaxin Jin et al. in his study, According to both the levels of acid rain and the soil critical load of acid deposition, he derived the NDVI respectively for curve fitting. In general, the curve fitting parameter shows that the stronger precipitation acidity was, the stronger inhibition to growth of pine was. At the end he concluded that in the same level of acid rain, the effects of different soil types to pine were different. In the study by Sheng-yang su et al. he worked with the help of satellite images. The standard deviations of the post-HM NDVI images are lower than those of the pre-HM NDVI images he found when he compared. Again the tendency of NDVI deteriorating patterns was contradictory to the acidic intensity tendency of acid rain. The tendency is decreases from northwest to southeast direction and result shows that acid rain may be not the key factor result in NDVI deteriorating, but increasing load in traffic resulted in TRC health-condition deteriorating. It was found that the enhancing of acid concentration results to the decreasing of the pigments content and reflectance of needle in the visible and near-infrared regions in the study by Zhumar A.Yu et al.

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V. CONCLUSION

From the above study it is cleared that acid rain emphasizes on the plant can be detected by using hyperspectral data. There are different methods to detect the responses of plant to acid rain. As we have studied that the chlorophyll content of leaves changes due to acid rain, so we can use either the stimulated chlorotic indices or the vegetation indices to detect the change in leaves. Satellite images are also performed main role to detect the acid rain emphasis. NDVI images can be use for calculating NDVI change detection patterns. Instead of using the traditional measuring techniques, the method of PH value measurement of acid rain based on the IoTs and the image processing and clustering methodologies by analysing the satellite images can be used.

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