SPECTRAL RESPONSE ANALYSIS OF SELECTED PHILIPPINE AGRICULTURAL SOILS IN VARYING NUTRIENT CONDITIONS

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ABSTRACT

Three major soil orders commonly used for agricultural purposes in the Philippines are Alfisols, Inceptisols and Ultisols. Representative samples were collected for these soil orders composed of dry and wet and with the introduction of increasing levels of elemental nutrient such as nitrogen (N), phosphorus (P), and potassium (K). The measurement of spectral reflectance was carried out in the laboratory using a spectrometer at a wavelength interval of 400 to 850 nanometers. Mean spectral reflectance values were computed and plotted as spectral curves for each soil order and at varying levels of N, P and K. The spectral responses of each soil order and the spectral behavior of the elemental nutrients were analyzed using analysis of variance (ANOVA); spectral derivative analysis; and spectral resampling technique to sensors of selected satellite images. ANOVA was used to determine whether the soil orders and the different nutrient levels differ significantly in reflectance responses. Derivative analysis established the most responsive wavelength and the degree of differences in reflectance values among the samples. Spectral resampling matched the measured spectral data using the spectral sensitivities or filter windows of the sensors of Landsat TM/MSS, ASTER and SPOT along the electromagnetic spectrum. The central wavelength absorption by soil order and nutrient conditions was derived for the respective bands of the satellite sensors. Spectral curve were plotted to the corresponding bands of Landsat TM/MSS, ASTER and SPOT.

The ANOVA proved that there is a significant difference in the mean reflectance values of soil order and moisture content. Correspondingly, the increasing levels of N, P and K by soil order demonstrated significant differences in the mean reflectance values. Spectral derivative analysis confirmed that Alfisols, Inceptisols and Ultisols are distinguishable in wavelength ranges 0.45-0.52 μm, 0.52-0.60 μm, and 0.63-0.69 μm of the electromagnetic spectrum. Spectral response of phosphorous among the soil orders is distinct in the 0.76-0.85 μm, 0.45-0.52 μm, and 0.52-0.60 μm for Alfisols, Inceptisols and Ultisols, respectively. The analysis of spectral responses of the soil orders and elemental nutrients examined, in relation to other soil attributes opens up possibilities for development of spectral libraries which can support image analysis particularly for soil related studies.

INTRODUCTION

Soil is formed by weathering of exposed rocks and minerals of the earth's crust and by decomposition of organic matter deposited by flora and fauna which makes it a complex material extremely variable in chemical and physical properties. Soil has nutrient components which are essential elements needed by plants for proper growth and productivity improvement. These nutrients are categorized as macronutrients and micronutrients. Macronutrients are the major elemental nutrient namely; nitrogen (N), phosphorous (P) and potassium (K) while micronutrients are boron (B), copper

(Cu), manganese (Mn), iron (Fe), calcium (Ca), magnesium (Mg), sulfur (S) and zinc (Zn) among others. The assessment of these elements would evaluate the level of soil fertility which could be the basis for fertilizer recommendations and other input management of a given farming area.

On the other hand spectral reflectance is a result of the interaction of the electromagnetic energy with the surface of the earth aside from absorption and transmission (Lillesand and Keifer, 1987). The interaction of the incident energy with the atomic structure of soil, rocks, plants, bodies of water and man-made objects governs how much energy is absorbed and how much is reflected (Keller, 2000). Each of this surface materials have a distinctive reflectance spectra which can be measured by a laboratory or field portable spectrometer.

Utilizing the potentials of spectral analysis and evaluation, Nielsen et al. (1995) identified several important soil fertility attributes, including available soil nitrogen, other macro and micro plant nutrients, relative position and slope of the terrain and soil organic matter content that could be mapped and managed for improved yield. Malley et al. (1999) were able to predict pH, electrical conductivity (EC), phosphorus (P), sulfur (S), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), and manganese (Mn) by scanning the soil samples along the 400 to 2500 nm wavelength range. Sudduth and Hummel (1993) used the ultraviolet-visible-near infrared diffuse reflectance spectroscopy technique to predict several important soil fertility parameters including pH, electrical conductivity (EC), organic carbon, total nitrogen (N), ammonium nitrogen (NH4-N), nitrate nitrogen (NO3N), phosphorus (P), sulphur (S), cation exchange capacity (CEC), exchangeable calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), calcium and magnesium ratio (Ca:Mg), exchangeable sodium percentage (ESP) and other micronutrients. He et al., (2005) used the NIR spectroscopy to estimate nitrogen (N) and organic matter (OM) content of the soil which was proved to be a good tool for precision-farming application. Also, Kamrunnahar et al (2005) proved the potential of VIS-NIR soil spectral libraries for predicting and mapping soil properties such as soil organic carbons; total nitrogen and cation exchange capacity.

The main objective of the study is to determine the spectral responses of selected agricultural soils to different levels of macronutrients such as N P K. Specifically the study (1) measures with a spectrometer the spectral reflectance of the three major agricultural soil orders with varying levels of soil nutrient; (2) evaluates the different spectral responses of the selected soils with the introduction of increasing levels of N P K; and (3) examines the potential for the detection of the measured reflectance spectra in each soil order and nutrient condition from selected remote sensing instruments.

METHODOLOGY

Collection of Soil Samples

Guided by a soil map classified according to the USDA Taxonomic Classification, representative soil samples were collected for Alfisols, Inceptisols and Ultisols represented by soil series Quingua silt loam (*Subgroup:Typic Hapludalfs*), Buenavista clay loam (*Subgroup:Aeric Tropaquepts*) and Sampaloc clay loam (*Subgroup:Typic Kandiudlts)* respectively. Soil samples were taken from the topsoils within the 0-15 cm soil depth, air dried, pulverized, sieved and placed in labeled containers. Samples were analyzed in the laboratory using the standard methods for macronutrients and trace elements.

Spectral Reflectance Measurement

Three spectral measurements were done for the set of samples prepared by soil order and at varying levels of nutrients (Figure 1). For the first measurement, six sets of samples each weighing 100 ml were placed in a black container to represent dry and wet samples for each soil order and elemental nutrient. The wet samples were added with equal amounts of 90 ml water and set aside in room temperature for two weeks before measurement was done. After the first spectral measurement, all base dry samples were added with inorganic fertilizers to augment the elemental nutrients N P K labeled as N1, P1 and K1 for the three soil orders. Fertilizer applications were based on the recommended levels resulting from the laboratory analysis done and the crop requirement following the ratios 100-25-25 kilograms/hectare; 90-60-60 kilograms/hectare and 80-100-100 kilograms/hectare for Alfisols, Inceptisols and Ultisols respectively. The source of elemental nitrogen was urea (46-0-0); phosphorous (P_2O_5) was supplied by solophos (0-18-0) and potassium (K_2O) was taken from potassium chloride, KCL (0-0-60). The same samples used in the second measurement were added with the double rate of fertilizer recommendation which composed the third set of measurement referred as N2, P2 and K2 for each soil order (Figure 1).

The Ocean Optics S2000 Miniature Fiber Optic spectrometer was used in the spectral measurement carried out at laboratory conditions. The equipment was set up with the spectrometer head mounted permanently on a tripod. Samples were placed at about 15 cm from the head of the optics and illuminated with a 500 watts lamp positioned at about 45 degrees zenith angle placed directly opposite the sample. The equipment was set to read for five seconds and for a total of six readings recorded within the wavelengths interval from 400 to 850 µm. A white reference material was also measured aside from the target sample for every measurement done.

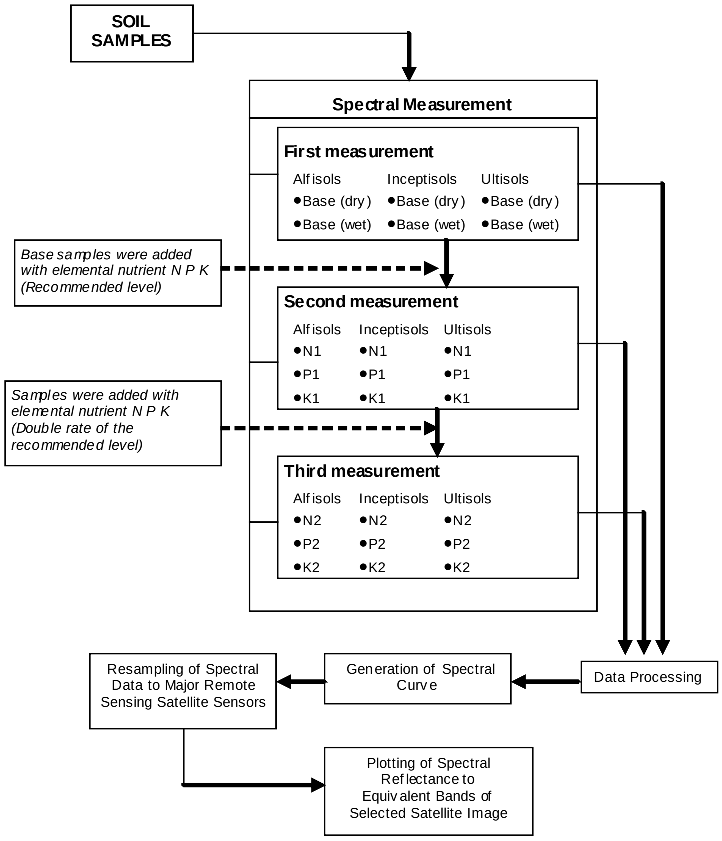

Figure 1. Schematic diagram in establishing spectral curves for different soil orders in response to increasing levels of elemental nutrients (NPK)

Data Processing

The recorded spectral data were processed and organized using the software MsExcel. The mean for the six readings recorded both for the target soil samples and white reference was computed by dividing the spectral response of the target material by that of a reference white sample. This was done to mathematically eliminate all parameters that are multiplicative in nature, such as the spectral irradiance of the illumination source and the optical throughput of the field spectrometer, present in both the spectral response of a reference sample and the target material (ASDI, 2001).

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Generation of Spectral Curve and Data Analysis

Spectral curves were generated using the *Spectral Library Builder* of Environment for Visualizing Images (ENVI) 4.0 package. The created reflectance curves were save as spectral library. It was displayed and enhanced using the standard ENVI image display and analysis routines.

Analysis of data was done using the analysis of variance (ANOVA), the spectral derivative analysis and the spectral resampling technique. The ANOVA package was used to evaluate whether there are differences between the mean reflectance values among soil order in dry and wet conditions and with the increasing level of N P K. It determined whether the three soil orders and the different nutrient levels differ in reflectance curve and which of the samples gave the highest mean reflectance value relative to the wavelength of the spectrum. The spectral derivative analysis was done to determine the most responsive wavelength and the degree of difference in reflectance values among the samples using the formula:

$$(R_2-R_1)/(\lambda_2-\lambda_1)$$

where :

R$_2$ the highest mean reflectance value

R$_1$ the mean reflectance value following the highest mean reflectance value

λ_1 the first wavelength value recorded in the spectral data

λ_2 the second wavelength value recorded in the spectral data

The Spectral Library Resampling menu of ENVI 4.0 was used to resample the spectral data file of the samples. The spectral data inputs were resampled to match the response of the instruments of Landsat TM, Landsat MSS, and SPOT and ASTER satellite sensors. ENVI assumes critical sampling and uses the Gaussian model. The resampling done used the filters of the Landsat TM (4, 5 & 7), Landsat MSS (4 & 5), SPOT (1, 4 & 5) and ASTER.

RESULTS AND DISCUSSIONS

The results of the statistical analysis using analysis of variance proved that there was a significant difference in mean reflectance value among soil type as indicated by a very small p-value of less than 0.0001. The same p-value of less than 0.0001 was attained for the wet and dry soils among the soil types. A p-value of less than 0.05 indicates that the correlation is significant at more than 95% level. In general, reflectance values of the samples measured significantly differs as a function of soil type and moisture condition. Comparisons of samples between soil types and the condition of moisture using the T-test Least Square Difference (LSD) at 5% level concluded a dissimilar response pattern. Based on the computed difference between means, Ultisols (dry) has the highest mean reflectance value of 0.0278 followed by Inceptisols (dry) and Alfisols (dry) 0.0215 and 0.0079, respectively. Correspondingly, the increasing levels of N, P and K by soil order demonstrated significant differences in the mean reflectance values. The generated curves by soil order and varying nutrient levels are indicated in Figure 2a, Figure 2b, Figure 2c and Figure 2d. Phosphorous treated samples exhibited distinct curves compared to those of nitrogen and potassium in all the soil orders. Similarly, proves the work of Maleki et al (2006) where he used the VIS-NIR sensor based to detect the extractable phosphorous and from the measured spectra, elemental P requirements were determined.

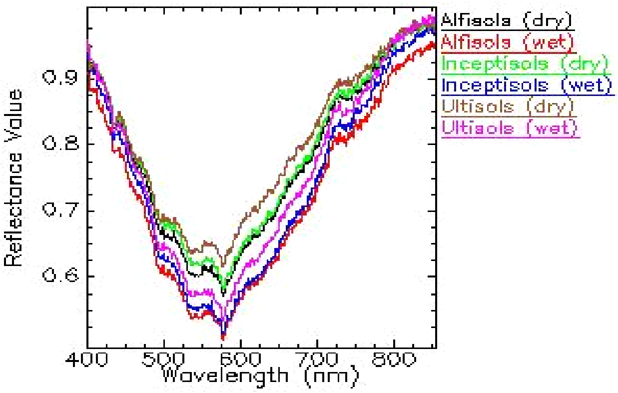

Figure 2a Spectral reflectance curve by soil order

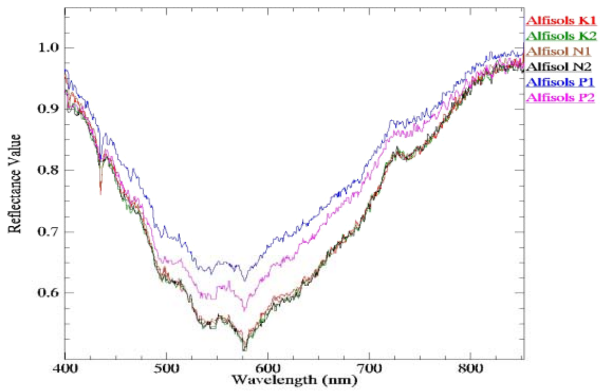

Figure 2b Spectral reflectance curve of varying soil nutrients in alfisols

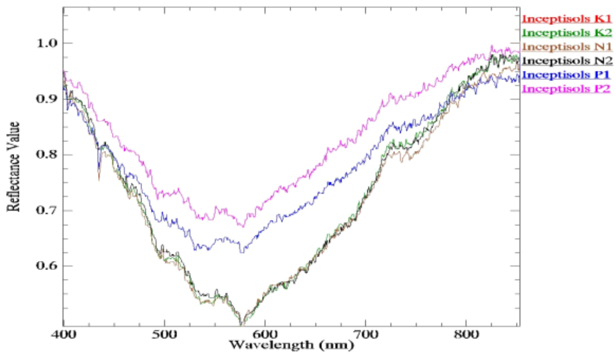

Figure 2c Spectral reflectance curve of varying soil nutrients in inceptisols

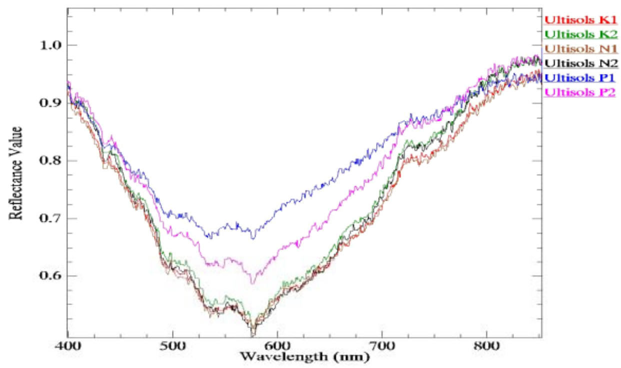

Figure 2d Spectral reflectance curve of varying soil nutrients in ultisols

The derivative analysis was done to establish the most responsive wavelength and the degree of differences in reflectance values among the samples. The Landsat TM spectral bands were the reference used for band assignment of the spectral data measured per sample ranging from 400-850 nm. Based on the derivative analysis done, the three soil orders are distinguishable in bands 1, 2 and 3 of Landsat TM. Ultisols and Alfisols have the highest possible separability in band 2 while Inceptisols and Alfisols are distinguishable in band 1. Band 4 did not show potential separability of the three soil orders. Spectral response of phosphorous in all the soil orders has the probability of being distinct in all the bands however distinguishability is high in bands 4, 1 and 2 for Alfisols, Inceptisols and Ultisols, respectively. Reflectance response of nitrogen and potassium is discernible in band 4 for Alfisols and bands 1 and 3 for Ultisols. No possible separation was obvious in all the bands for phosphorous in Inceptisols. The graph of derived differences by soil order and corresponding nutrient levels are depicted in Figure 3a, Figure 3b and Figure 3c.

The resampling technique showed similarity in results with the derivative analysis wherein various soil orders illustrated distinctive patterns of spectral response in all the bands used. Phosphorous in all the soil types indicated a different spectral curve compared to nitrogen and potassium which showed overlaps in all the bands. The three soil orders appeared to be of the same central wavelength absorption feature and almost similar in the reflectance values for SPOT, Landsat and SPOT in band 1, band 2 and band 3. This shows that the three satellite images would provide similar spectra for Alfisols, Inceptisols and Ultisols. The curves and central absorption wavelength are shown in Figure 4a, Figure 4b and Figure 4c. The spectral curve for each soil order is noticeable in all the satellite images. Common to all soil orders are the unique spectral curves of P1 and P2 which indicate dissimilar reflectance values in spectral data as compared to levels of N and P. The levels of N and P overlap in band 1, band 2 and band 3 of ASTER, SPOT and Landsat which indicates that the three nutrients would give similar reflectance values in all the bands of the satellite sensors used in the resampling process.

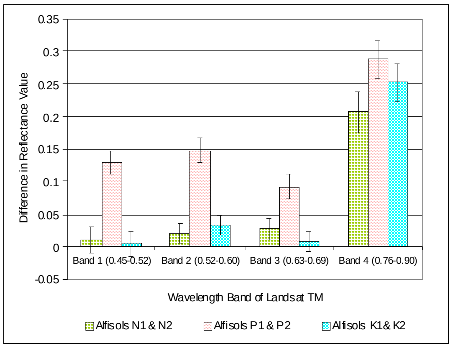

Figure 3a Derived differences in reflectance values of NPK in alfisols

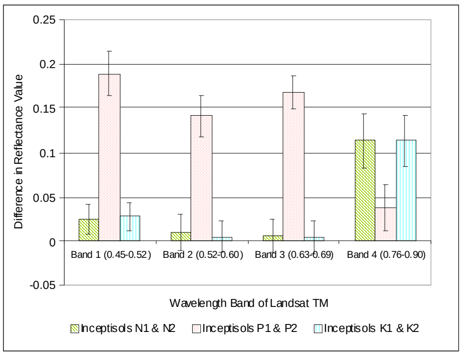

Figure 3b Derived differences in reflectance values of NPK inceptisols

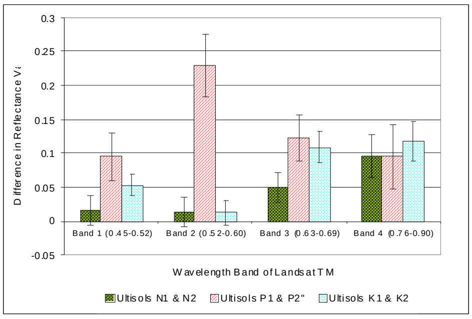

Figure 3c Derived differences in reflectance values of NPK in ultisols

The results of the spectral resampling to satellite sensors and the spectral derivative analyses are comparable. The separability obtained in the analysis was observable in the resampled spectral data as illustrated in the figures of the curves for each soil type relative to the satellite sensors used. The locations of wavelength absorption and reflectance response are diverse among soil orders and nutrient conditions. However, similarities were observed for nitrogen and potassium as indicated by the overlaps in wavelength locations in contrast to phosphorous common to all satellite sensors used.

CONCLUSIONS AND RECOMMENDATIONS

Spectral curves for the three soil orders and elemental nutrient have proven to be distinct along the 400 to 850 nm of the electromagnetic spectrum. Phosphorous-treated samples showed a remarkable difference in the spectral response in all the soil orders as compared to those of nitrogen and potassium. However, the absorption pattern along the different absorption feature in the electromagnetic spectrum should be further analyzed by relating the different soil properties to soil nutrients. The derivative analysis established the most responsive wavelength and the extent of difference in reflectance values displayed the degree of separability between soil order and nutrient condition. The outcome of the resampling technique done has given comparable results with the spectral derivative analysis; both have provided similarities in spectral patterns in all the soil type and nutrient condition at specific wavelength in the visible region of the electromagnetic spectrum. The spectral data measured can be identified and the reflectance response varies in the different bands which illustrated the distinguishability of the soil order and nutrient conditions in the visible bands of SPOT, ASTER and Landsat sensors.

The established reflectance curves could support image classification analysis relative to soil studies. However, further validation and refinement of the established spectral curves should be carried out. Validation is crucial using other techniques such as field measurements or satellite image analysis. Spectral measurement should extend along the mid infrared to the thermal infrared of the electromagnetic spectrum to attain good relationships between soil properties and the absorption features. Comparison between bands would provide better analysis as to the reflectance properties of the soil order and nutrient conditions. Other analysis techniques such as discriminant analysis and similarity index should be explored in order to possibly enhance or further qualify the results. The possibilities for the development of spectral database specific for Philippine soil is recommended to support image analysis particularly for soil related studies.

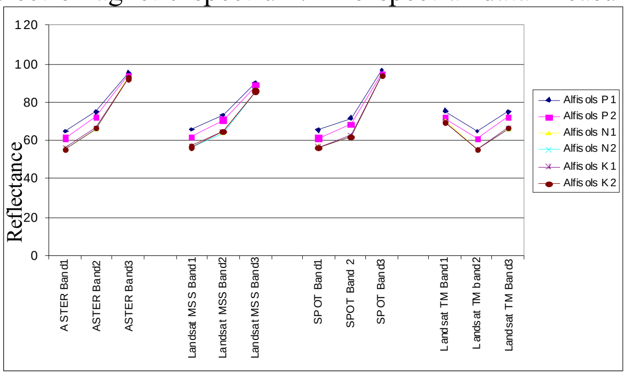

Figure 4a Summary of spectral responses of N P K in Alfisols relative to selected satellite sensors

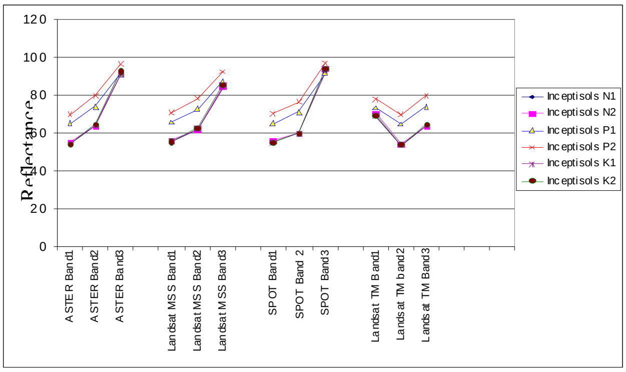

Figure 4b Summary of spectral responses of N P K in Inceptisols relative to selected satellite sensors

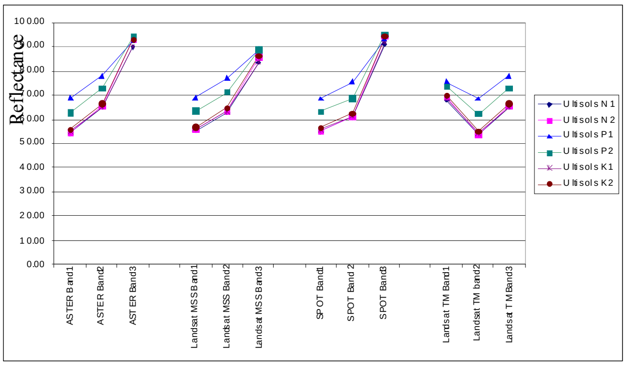

Figure 4c Summary of spectral responses of N P K in Ultisols relative to selected satellite sensors

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