OPEN JOURNAL SISTEMS
ISSN:2237-2202

Available on line at Directory of Open Access Journals

Journal of Hyperspectral Remote Sensing v.6, n .1 (2016) 72-81
DOI: 10.5935/2237-2202.20160007

Journal of Hyperspectral Remote Sensing
www.ufpe.br/jhrs

Precision Agriculture using Advanced Remote Sensing techniques for peanut crop in Arid Land

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Received 06 February 2016; accepted 21 April 2016

ABSTRACT
Precision agriculture involves studying and managing crop variations within fields that can affect crop yield. In precision agriculture farmers are adapting technology and advanced remote sensing techniques with different software to relieve decision making. Hyperspectral ground measurements can be used for giving timely information about crops in specific areas and thereby providing valuable data for decision makers. In this paper field spectroscopy measurements measured by ASD field Spec4 spectroradiometer were used to monitor the spectral response and differences of peanut crop vegetation cover reflectance due to bio-physical plant variables. The results of Tukey's HSD showed that blue, Red and NIR spectral zones are more sufficient in the monitoring differences between peanut growth stages than green, SWIR-1 and SWIR-2 spectral zones. The results of physiological spectral indices of growth stages showed significant correlations between varied classes productivity and spectral similarity measures, indicating that similarity between the samples' spectra decreases as the pigments concentration in the plant leaves increases. Furthermore, electromagnetic peanut crop mapping was successfully employed to simulate vegetation healthy effect on canopy structure and final yield.

Keywords: Precision agriculture, peanut, field spectroscopy measurements.

1. Introduction

Precision Agriculture is an environment helpful system solution that optimizes production quality and quantity while lowering cost of inputs (Blackmore, 1999; Stombaugh, et al., 2001). Remote sensing can be used as a quick and minimizing cost tool in precision agriculture. One of the most important retrieved information from remote sensing are the vegetation indices derived from multispectral data, which have been extensively used for monitoring and detecting vegetation and land cover changes (Liu and Kafatos, 2005; Aparicio et al. 2002). But a multispectral data is processed into a limited number of bands. The barrier of limitation of multispectral data is broken with hyperspectral data, which allows accurate and potential use of entire range of electromagnetic spectrum recorded in extremely narrow wavebands. VNIR bands along with Yellow Edge, and Red Edge bands can be used to identify different types of crops, crop health, various kinds of stresses, weeds, biomass, LAI, and other parameters that can be used for precision agriculture applications including site specific pesticide and fertilizer applications, smart or directed soil sampling, yield estimation, and others. The collection capacity of WV-2 allows for regional crop assessments for commodities markets (Yang and Chen, 2004). Hyperspectral crop reflectance data is a precision agricultural tool that can be used to improve crop productivity. It could also be used to reduce the amount of nutrient loadings into both surface and underground water bodies since fertilizer would be applied only in areas with less soil nutrients, which can be computed from foliage reflectance data. Hyperspectral technology with narrow spectral bands may be crucial for providing additional information with significant improvements over broad bands in quantifying crop biophysical characteristics and yield prediction (Gong et al., 2003; Bernstein et al., 2005; Darvishzadeh et al., 2006; Nguyen et al., 2006). Arafat et al. (2013) discriminated between two winter crops (Wheat and Clover) and two summer crops (Maize and Rice). This is considered as a first step to improve crop classification through satellite imagery in the intensively cultivated areas in Egypt. Using field hypespectral remotely sensed data NDVI is usually assumed to be broadly indicative of crop photosynthetic activity and therefore associated with greenness and thus above-ground dry matter production Moreover; additional studies have shown that various spectral vegetation indices, calculated from visible and near-infrared (NIR) reflectance data, are linearly related to canopy light interception (Rouse et al., 1974). In addition to more research showed a strong relationship between Landsat normalized difference vegetation index (NDVI) and Percent of pixels representing green vegetation for multiple horticultural crops. As such, it appears that indices such as NDVI can potentially track canopy development and light interception, (Sarkar and Kafatos, 2004). Generally, soil background effects can be reduced using indices such as the soil adjusted vegetation index (SAVI) (Huete, 1988), especially for agricultural crops or homogeneous plant canopies. SAVI is more significant when agricultural crops on widely varying soils are studied (Rondeaux et al., 1996; Lawrence et al., 1998). Accurate information concerning the spatial variability within fields is very important for precision farming of specialty crops (Lee et al., 2010). However, this variability is affected by a variety of factors, including crop yield, soil properties and nutrients, crop nutrients, crop canopy volume and biomass, water content, and pest conditions (disease, weeds, and insects). These factors can be measured using diverse types of sensors and instruments such as field-based electronic sensors, spectroradiometers, machine vision, airborne multispectral and hyperspectral remote sensing, satellite imagery, thermal imaging and machine olfaction system, among others. Sensing techniques for crop biomass detection, weed detection, soil properties and nutrients are most advanced and can provide the data required for site specific management. On the other hand, sensing techniques for diseases detection and characterization, as well as crop water status, are based on more complex interaction between plant and sensor, making them more difficult to implement in the field scale and more complex to interpret. Peanut (*Arachis hypogaea* L.) one of the main cultivated summer crops in Egypt, has been studied for identifying Peanut growth stages by various systems; the most common is (Boote, 1982). This system divides plant development into vegetative and reproductive stages. Egypt is a major peanut exporting country of which 68% peanut products head to the European market (FAO, 2011). Egyptian Peanut production is estimated 0.2 million tons for 2015/16 same as last year. Planted area is estimated similar to last year at 0.6 million hectares while area harvested is estimated at 0.59 million hectares. Planted and harvested hectares are both up 5% the previous crop year. The increase in planted acreage for 2015 was mainly due to lower corn and soybean prices (USDA, 2015). The current study mainly focus on using advanced remote sensing techniques on the geo-referenced site specific or precision agriculture practices by determining whether peanut pigments, chlorophyll, carotenoids, anthocyanin's and water content can be discriminated based on their spectral characteristics, by establishing a relationship between potential yields and peanut crop spectra and by testing if variations in the spectra of potential yields samples are statistically significant.

2. Materials and methods

2.1. Study Area

The study area is located between 30° 29′ 00″ N and 30° 30′ 00″ N latitude and 31° 56′ 00″ E and 31° 57′ 00″ E longitude, and situated at the eastern Nile Delta, Ismailia governorate, Egypt. The study area represented by one pivot within area about 67 hectares, cultivated with peanut crop and irrigated by center pivot system using Nile River water that characterized by Total Dissolved Salts (TDS) of 544 mgL^{-1} as it shown in Figure (1).

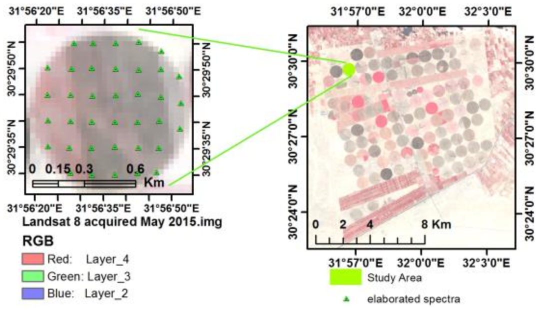

Figure 1 - Location of study area and elaborated spectra.

The climate in the area is arid Mediterranean type with an average annual precipitation of about 20 mm and temperature 18 c°. The climate is mainly dry and rarely rainfall throughout the year. During the summer, the sun brightness hours increases and the solar radiation getting stronger that mainly increases the rates of evapotranspiration and plant water consumption.

2.2. Field data canopy reflectance measurements

Thirty seven peanut samples were elaborated by using Analytical Spectral Devices (ASD) FieldSpec4 spectrometer. The method of symmetric random sampling was applied, with interval of 30 days starting from 30 days after plantation representing initial growth stage, 60 days after plantation representing the middle growth stage of season and 90 days after plantation represents the late season growth stage. Figure 1 show places of elaborated spectra with Lat/long coordinates, which were entered on GPS to be used on the field investigation.

The ASD FieldSpec is hyper-spectral sensor that was used to measure the reflection of the peanut plants in a full optical spectral range starting from 350 nm to 2500 nm with 1 nm interval output data. The sampling interval is different at 350-1050 nm and 1000-2500 nm 1.4 nm and 2nm respectively. These are the intervals, which the device is capturing the reflectance the device itself making an interpolation for the data automatically and gives the final data output with 1nm interval for the all spectrum range 350-2500 nm. The sensor's field of view was 15°. Noise at both ends of the spectrum limited the useful data range to between 350 and 2500 nm in this study. Data were collected on cloudless days with solar elevation angles ranging from 50 to 55°, in order to minimize external effects of the atmospheric conditions and changes in solar position. The spectral measurements were collected ±2 h from solar noon, under clear sky, and in nadir orientation. The spectrometer was programmed to automatically calculate the average of 10 readings that were taken at each sampling point. The measurements were collected 100 cm above the top of the soil, generating an instantaneous field of view about 0.40 m^2. During the season, as the height of the crops increased. Pressed and smoothed barium sulfate ($BaSO_4$) powder was used as a white reference for peanut spectral data collection (Hatchell, 1999). Immediately after the white standard radiance measurement, two spectra of the peanut canopy were recorded by a sensor located directly over the center of two rows on a ridge and other sensor located directly over the furrow. The mean of the two spectra was then determined to provide a single spectral value. This procedure was repeated 10 times over each plot to obtain representative spectral data by their mean values. Preprocessing the spectral data included eliminating atmospheric water absorption regions, namely 1.35–1.42 and 1.80–1.96 μm, as mentioned by Pimstein et al. (2009) as well as linear interpolation of the data to 1 nm and 2 nm narrow bands.

Two statistacl analyses were employed in this study according to (Mason et al., 2003), one way ANOVA and tukey's significant difference procedure. One way ANOVA used to comparing means from measured spectra and tukey's significant difference procedure was used for multiple comparisons when all averages are based on the same number of observations.

3. Results and discussion

The results of Continuous spectra of peanut crop samples showed that continuous spectrum of the wavelength of 350- 2500 nm, is characterized by high reflectance variation through the different growth stages (Figure 2). The non-uniformity of spectral reflectance of a peanut canopy may due to of incident solar radiation, plant content, leaf areas, shadows, and background reflectivity. In general results of continuous spectra of peanut crop samples showed that continuous spectrum of the wavelength of 350-2500 nm, is characterized by high reflectance variation through the different growth stages. The non-uniformity of spectral reflectance of a peanut canopy may due to of incident solar radiation, plant content, leaf areas, shadows, and background reflectivity. The wavelength region of visible light (350- 700 nm) is mainly marked by an obvious reflectance peak at 533 nm that may be used to differentiate peanut, at the initial stage growth, from other crops. It is also remarkable that the continuous spectra of peanut crop samples have a narrow variation of reflectance range (1.0-2.5 µm). On contrary peanut crop, in all growth stages, gives the higher reflectance values through the spectrum region of 710 nm (near infrared to1330 nm). The reflectance, of spectrum, has three peaks at the wavelengths of 838, 1082 and 1265 nm. Theses peaks have tendency to decrease with the increasing of the wavelength. All peanut crop samples recorded moderate reflectance, between the spectrum region between 1326 nm and 387 nm that has a distinguished peak at wavelength of 1692 nm. Peanut plants have again a low reflectance, through wavelength range of 1936 -2500 nm; at the late stage growth has a noticeable peak at wavelength range of 2210 nm. Chlorophyll is the most obvious important factor in photosynthetic and plant food production, carotenoids, brown pigments and other accessory pigments are additionally driving reasons of high yield. The majority of these pigments are sure to economic yield. Patterns of chlorophyll distribution influence water movement and nutrient dynamics the variation of economic yield. We have endeavored to build up a statistical relationship between the in situ chlorophyll and remote sensing at different wavelength bands for example, 550 and 680 nm for improving the precision of chlorophyll retrieval. Furthermore, low reflectance of the visible light (350- 700 nm) represented the initial stage growth. This region of wavelength is mainly marked by an obvious reflectance peak at 533 nm that may be used to differentiate peanut, at the initial stage growth, from other crops. It is also remarkable that the continuous spectra of peanut crop samples have a narrow variation of reflectance range (1.0-2.5 µm). On contrary peanut crop, in all growth stages, gives the higher reflectance values through the spectrum region of 700nm (near infrared to1326 nm. The reflectance, of spectrum, has three peaks at the wave lengths of 838, 1082 and 1265 nm. Theses peaks have tendency to decrease with the increasing of the wave length. All peanut crop samples recorded moderate reflectance, between the spectrum region between 1326 nm and 387 nm that has a distinguished peak at wave length of 1692 nm. Peanut plants have again a low reflectance, through wavelength range of 1936 -2500 nm; at the late stage growth has a noticeable peak at wavelength range of 2210 nm.

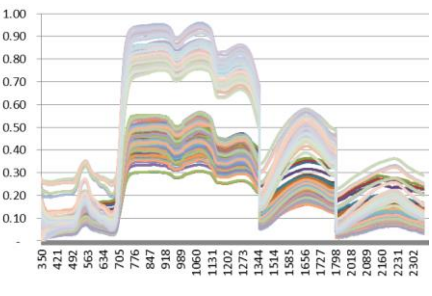

Figure 2 - Continuous spectra of peanut crop through the wavelength of 350- 2500 nm at different growth stages.

The results of Averaged spectral data of peanut crop sample indicated that the means of spectral measurements, of peanut crop, through three stage growth, were calculated to identify the averaged spectral behavior. Moreover, the calculation of the averaged spectra of peanut crop samples enabled to compare (a) the spectral behavior through the different growth stages m and (b) test the significance of spectral variation of peanut's different growth stages . The graphical presentation of the spectral means indicated that the region of near infrared and infrared has the higher values Figure 3.

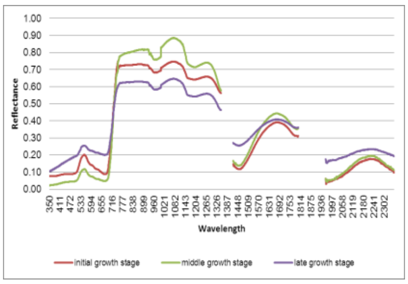

Figure 3 - Mean hyper-spectral signature, of the different growth stages**,** of peanut crop

Tests the significance of spectral variations, of peanut different growth stages**,** were elaborated through all the range spectrum of 350- 2500 nm that was divided into different regions; visible (350 -700 nm), NIR (701-1300 nm), shortwave infrared (SWIR1: 1300-1800 nm) and (SWIR2: 1801-2500 nm). The visible region 350- 700 nm was divided into three sub-regions; blue (350-449 nm), green 450-549 nm, and red (550-700 nm). The spectral division might enable to elaborate more accurate interpretation of the spectral data of the green canopies of Peanut crop (figures 4, 5 and 6, and tables 7 and 8). Figure (4) that represented the spectral behavior of peanut's at different growth stages reflectance, through blue region, indicated that spectral variations had a more wide range in the late growth stage than the initial and middle growth stages. This wide range of variation was graphically represented by a wider considerable confidence period. In addition, Figure (4) showed obviously that the late growth stage had a higher mean reflectance 0.133 (Table 1) that may due to spectral response affected by chlorophylls a and b, carotenoids, brown pigments , and other accessory pigments. The elaboration of One-way ANOVA analysis Tukey's HSD proved the significance of spectral variations, through spectrum of blue (350-449 nm), of peanut different growth stages, (Table 1). Letter A, B and C designed to the means of spectral reflectance, of the three peanut growth stages, according to their values, where letter (A) was assigned to the greater mean.

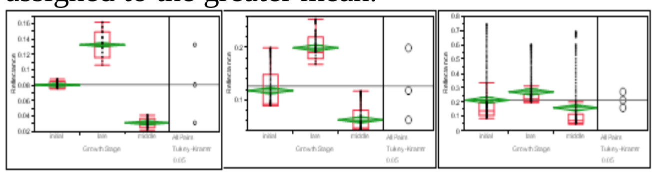

Figure 4 - Whisker box (plot) of reflectance**,** through for blue, green and red ranges respectively, of Peanut's growth stages (Tukey's method).

Table 1 - Significance spectral difference, through blue spectrum range, of peanut growth stages (Tukey's method)

Growth Stages	Mean Reflectance		Summary of Fit for means comparisons for all pairs	
initial	0.08	C*	Rsquare	0.93
middle	0.03	B*	Adj Rsquare	0.93
late	0.13	A*	RMSE	0.01
*Levels not connected by same letter are significantly different			Observations (or Sum Wgts)	300

The reflectance measurements of canopies Peanut's growth stages, through the spectrum green 450-549 nm, were presented by figure (4). The great diameters of the three circles, located at the side left of figure (4), showed graphically that all growth stages had high internal spectral variations. Figure (4) indicated also that Peanut canopies had a reflectance wider range at the late growth stage, while the other stages had more or less the same moderate wide spectral variation. In addition, the figure showed that the middle growth stage has the highest mean reflectance of 0.201 (table, 2). The reflectance means were significantly different; therefore they were designed by different three letters; (a), (B) and (C), table (2). These highly significant spectral variation was expressed by the high value of root mean square error (0.0314), they were graphically represented by greater distance between the three circles located at the side left of figure (4).

Table 2 - Significance spectral difference, through green spectrum range, of peanut growth stages (Tukey's method)

G. Stages	Mean Reflectance		Summary of Fit for all pairs means	
initial	0.12	C*	Rsquare	0.76
middle	0.06	B*	Adj Rsquare	0.76
late	0.20	A*	Root Mean Square Error	0.03
*Levels not connected by same letter are significantly different			Observations (or Sum Wgts)	300

Table 3 - Significance spectral difference, through red spectrum range, of peanut growth stages (Tukey's method)

G.Stages	Mean Reflectance		Summary of Fit for all pairs means	
initial	0.219	B*	Rsquare	0.07
middle	0.163	C*	Adj Rsquare	0.07
late	0.277	A*	Root Mean Square Error	0.16
*Levels not connected by same letter are significantly different			Observations (or Sum Wgts)	600

The results of testing significance of spectral variations, through spectrum of infrared NIR range 701- 1000 nm of peanut's different growth stages. In the meantime, Table 4, 5 and Figure 5 illustrate the differences between all growth stages reflectance at the near- infrared NIR range 701- 1000 nm, where the middle season growth stage was the highest reflectance, where it is highest vegetative stage. The late growth stage was lower as result of low vegetation cover and plant leaves still in the developing phase that result less reflection at the NIR range. Furthermore, the reflectance of the late season growth stage at the NIR range was the lowest because of changes in leaves structure. Baret and Guyot (1991**)** obtained a similar result, they stated that internal structure of the leaf controls the reflectance and the transmittance on the whole spectrum, but this appears more clearly where the absorption is low, especially in the near infrared domain.

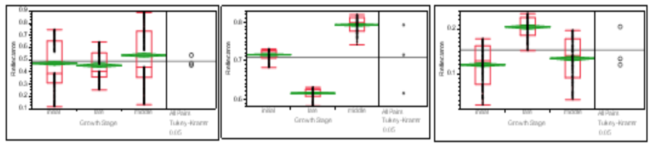

Figure 5 - Whisker box (plot) of reflectance, through NIR, SWIR1 and SWIR2 spectrum range respectively, of Peanut's growth stages (Tukey's method).

Table 4 - Significance spectral differences, through NIR spectrum range, of peanut growth stages (Tukey's method)

G. Stages	Mean Reflectance		Summary of Fit for all pairs means	
initial	0.794	B*	Rsquare	0.94
middle	0.717	A*	Adj Rsquare	0.94
late	0.617	C*	Root Mean Square Error	0.02
*Levels not connected by same letter are significantly different			measurements (or Sum Wgts)	753

Moreover, the results show in Tables (5 and 6) also illustrated in Figures (5) that difference between growth stages reflectance along the shortwave infrared (1001-1800 nm) and (1801-2500 nm) represent SWIR1 and SWIR2, respectively. The reflectance values at SWIR1 in the different growth stages were similar and almost had the same trend. On the other hand, the reflectance varies along SWIR2 depending on plant water content and water stress.

Table 5 - Significance spectral difference, through SWIR1 spectrum range, of peanut growth stages (Tukey's method)

G. Stages	Mean Reflectance		Summary of Fit for all pairs means	
initial	0.540	A*	Rsquare	0.03
middle	0.473	B*	Adj Rsquare	0.03
late	0.458	C*	Root Mean Square Error	0.19
*Levels not connected by same letter are significantly different			Observations (or Sum Wgts)	2184

Table 6 - Significance spectral difference, through SWIR2 spectrum range, of peanut growth stages (Tukey's method)

G. Stages	Mean Reflectance		Summary of Fit for all pairs means	
initial	0.205	C*	Rsquare	0.46
middle	0.134	B*	Adj Rsquare	0.46
late	0.121	A*	Root Mean Square Error	0.04
*Levels not connected by same letter are significantly different			Observations (or Sum Wgts)	1197

The comparison of reflectance value of the different spectrum's regions generally indicated that, A plant leaf typically has a low reflectance in the visible spectral region because of strong absorption by chlorophylls, a relatively high reflectance in the near-infrared because of internal leaf scattering and no absorption, and a relatively low reflectance in the infrared beyond 1.3 µ because of strong absorption by water. Furthermore, when disease and physiological stresses directly affect the reflectance properties of individual leaves, the most pronounced initial changes often occur in the visible spectral region rather than in the infrared because of the sensitivity of chlorophyll to physiological disturbances. The reflectance measurements, through fixed wavelengths, were recorded to interpret the physical and physiological status of peanut. The means of this reflectance value were calculated to present physiological spectral indices of growth stages of different peanut productivity classes (table, 7).

The values of the different vegetation indices were calculated to compute the their means at the peanut's growth stages (table, 8) .The adventage of these means due to their potentailty of crop yield producation . In addtion, they are referenced values es to classify the soil into differen productivity classes .

The indices general means arranged, in ascending order, the different vegetation indices as follows:

Mean $NDVI_{705\ mean}$ → Mean $NDVI_{spec\ mean}$ → Mean $SAVI_{spec\ mean}$

This arrangement order can simply intpreted by the following two facts, the mean $SAVI_{spec}$ is affected by soil shaddow and the mean $NDVI_{705\ mean}$ is more , inversly affected by spectral at the wavelength of 705 water absorption.

Table 7 - Physiological spectral indices of growth stages of varied - classes productivity

Productivity Classes	Reflectance (%) Wave length (nm)						
	430 -445	531- 570	550–680	700–800	800 - 900	970	800–900
	Plant Parameters						
	carotenoids	xanthophyll	chlorophyll	brown pigments	structure	water	green biomass
(1-Initial Growth Stage)							
H.P	0.097	0.188	0.131	0.603	0.728	0.68	0.728
M.P	0.087	0.18	0.121	0.593	0.718	0.67	0.718
L.P	0.077	0.17	0.091	0.563	0.688	0.64	0.688
(2- Middle Growth Stage)							
H.P	0.05	0.107	0.07	0.603	0.808	0.76	0.808
M.P	0.04	0.099	0.06	0.593	0.798	0.75	0.798
L.P	0.03	0.089	0.03	0.563	0.768	0.72	0.768
(3- Late Growth Stage)							
H.P	0.143	0.248	0.22	0.535	0.628	0.58	0.628
M.P	0.156	0.239	0.21	0.525	0.618	0.57	0.618
L.P	0.176	0.229	0.18	0.495	0.588	0.54	0.588

*H.P: high production, M.P: moderate production and L.P: low production

Table 8 - Peanut's vegetation indices (Mean $NDVI_{spec\ mean}$, mean $SAVI_{spec\ mean}$ and Mean

$NDVI_{705\ mean}$) of different Peanut's canopies (high , moderate and low production) of growth stages (initial , middle and late)

Productivity Classes	Peanut's Vegetation Indices								
	Mean $NDVI_{spec\ mean}$			Mean $SAVI_{spec\ mean}$			Mean $NDVI_{705\ mean}$		
	Peanut's growth Stages			Peanut's growth Stages			Peanut's growth Stages		
	Initial	Middle	Late	Initial	Middle	Late	Initial	Middle	Late
High production	0.83	0.91	0.53	0.76	0.85	0.49	0.51	0.64	0.36
Moderate production	0.78	0.89	0.51	0.73	0.83	0.48	0.73	0.80	0.63
Low production	0.76	0.87	0.50	0.72	0.82	0.47	0.50	0.63	0.36
General Mean	0.79	0.89	0.51	0.74	0.83	0.48	0.58	0.69	0.45

The interpretations of spectral diagnosis of peanut's growth stages by vegetation indices showed that the calculated NDVI and SAVI from hyper-spectral data show the similarity of these values to the calculated values from multi–spectral data. The results, also, show that NDVI and SAVI values decreased at the initial growth period and ascending increased to reach highest values at middle season growth stage, while these values decreased to reach lowest at late growth stage.

Figures (6 and 7) represent the differences between $NDVI_{spec}$ and $SAVI_{spec}$ values for each growth stage. The values of both NDVI and SAVI of hyperspectral hand held spectroradiometer data were higher than those calculated from multispectral satellite data. That is may be return to the atmospheric influence that results distortion on either the incident electromagnetic wave or reflected amount of energy from the plant surfaces. Furthermore, the field of view that has diameter about 30 cm using the handheld spectroradiometer, which give the opportunity to take the reflectance of plant canopy to the individual plant's level. Moreover, the SAVI values were lower than NDVI values in all growth stages. That returns to the rule of SAVI for minimizing the soil reflectance influence from spectral vegetation indices that involving red and near-infrared (NIR) wavelengths. The soil has a high reflection along the red wavelength contrary to the vegetation, which has a high reflection along the NIR wavelength. The results display that the correlation between NDVI and SAVI values increases along the peanut crop vegetation cover development, that is in agreement with Rondeaux et al. (1996) stated that soil contribution decreases but may still remain significant, depending on plant density, row effects, canopy geometry, wind effects, soil background and *etc*. along the crop growth.

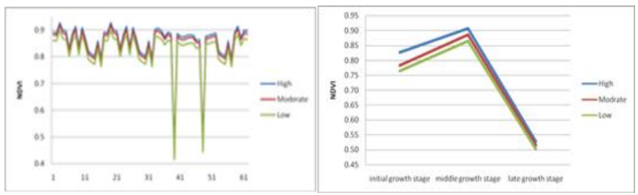

Figure 6 - NDVI $_{spec}$ and $NDVI_{spec\ mean}$ of different Peanut's canopies production levels of diferente growth stages.

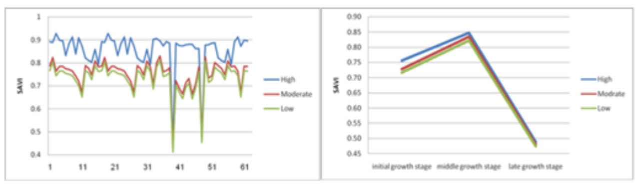

Figure 7 - SAVI $_{spec}$ and $SAVI_{spec\ mean}$ of different Peanut's canopies production levels of diferente growth stages.

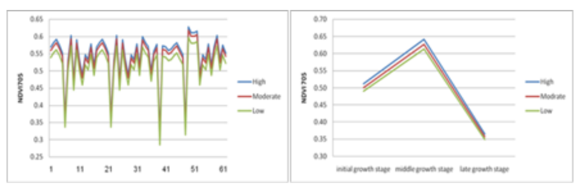

Figure 9 - NDVI $_{705}$ and $NDVI_{705\ mean}$ of different Peanut's canopies production levels of diferente growth stages.

4. Conclusions

The conclusions drawn from this study indicate that, physiological spectral indices of growth stages have significant correlations between varied classes productivity and spectral similarity measures, indicating that similarity between the samples' spectra decreases as the pigments concentration in the plant leaves increases, which offer as a precision agriculture tool to manage crop variations within fields that can affect crop yield. In the range of 350–1000 nm, the red-edge (705-750 nm) is the most sensitive spectral region for assessing vegetation healthy, for peanut spectral. However, the degree of importance is determined by the specific band formation of the hyperspectral sensor as well as the crop. The results of Tukey's HSD showed that blue, green and NIR spectral zones are more sufficient in the discrimination between peanut growth stages than red, SWIR-1 and SWIR-2 spectral zones. Furthermore, electromagnetic peanut crop mapping was successfully employed to simulate vegetation healthy effect on canopy structure and final yield.

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