

Linear spectral unmixing to monitor crop growth in typical organic and inorganic amended arid soil

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Abstract. The soils of the GCC countries are dominantly sandy which is typical of arid regions such as the Arabian Peninsula. Such soils are low in nutrients and have a poor water holding capacity associated with a high infiltration rate. Soil amendments may rehabilitate these soils by restoring essential soil properties and hence enable site revegetation and revitalization for crop production, especially in a region where food security is a priority. In this study, two inorganic amendments; AustraHort and Zeoplant pellet, and one organic locally produced compost were tested as soil amendments at the experimental field of the International Center for Biosaline Agriculture in Dubai, UAE. The main objective is to assess the remote sensing ability to monitor crop growth, for instance Okra (*Abelmoschus esculentus*), having these amendments, as background with the soil. Three biomass spectral vegetation indices were used namely; NDVI, TDVI and SAVI. Pure spectral signatures of the soil and the three amendments were collected, using a field spectroradiometer, in addition to the spectral signatures of Okra in two growing stages (vegetative and flowering) in the field with a mixed F.O.V of the plant and amended soil during March and May 2015. The spectral signatures were all collected using the FieldSpec® HandHeld 2 (HH2) in the spectral range 325 nm – 1075 nm over 12 plots. A set of 4 plots were assigned for each of the three amendments as follow: three replicates of a 1.5 by 1.5 meter plot with 3kg/m² of each amendment and 54 plants, one plot as control and all plots were given irrigation treatments at 100% based on ETc. Spectra collected over the plots were inversed in the range of 400-900 nm via a Linear Mixture Model using pure soil and amendments spectral signatures as reference. Field pictures were used to determine the vegetation fraction (in term of area of the F.O.V). Hence, the Okra spectral signatures were isolated for all plots with the three types of amendments. The three vegetation indices were then calculated and compared in the vegetation fraction of the entire F.O.V. The key outcome of this analysis was that a considerable bias was induced when using a mixed F.O.V. In fact, the compost as an organic soil amendment containing dead vegetation affects similarly the sensitivity of the three vegetation indices in the vegetative stage of Okra compared to AustraHort and Zeoplant pellet amended plots. However, the TDVI is very sensitive to vegetation presence even with unmixed crop spectra. AustraHort amendment led to better status of Okra both in March and May with values of 0.19 and 0.28 respectively. Bias induced by some soil amendments can be misleading when upscaling spectral information to satellite imagery with low spectral and spatial resolutions. The results obtained are encouraging for further use of spectral information for crop monitoring in soil containing amendments.

1. Introduction

The strength of remote sensing in agricultural applications has been refining ever since the emergence of this field. From satellite based, airborne imagery or terrestrial imaging systems, myriad of research



and publications have come to assert an eminent contribution in all aspects and stages of agricultural practices. Climate change impact and increasing global demand of food and other commodities called for innovations in agricultural research especially to improve water and nutrients use efficiencies which are major limiting factors in crop production in the Arabian Peninsula (AP). The soils of AP in general and the GCC countries in specific are coarse textured and have low fertility status. High temperature and poor soils necessitate daily irrigation for crop production. Improving the water use efficiency through innovative technologies such as climate smart agriculture may be an option. In this regard, a number of organic and inorganic amendments have been used by various researchers to improve water and nutrient use efficiencies. However, little has been done in this respect on U.A.E, and hence this subject has formed the focus of this study, involving two inorganic amendments, namely AustraHort and Zeoplant Pellet, and compost as an organic amendments. The remote sensing component of this study targeted to integrate close range sensing techniques to assess the impact of using soil amendments on crop production. The aim was to propose a time and cost effective method to measure vital bio-physical parameters in a perspective of large scale farming practice. This study contributes to build the preliminary and necessary in field remote sensing knowledge and subsequently the models that fits the studied soils, used soil amendments and crops. It is a crucial step before any remote sensing upscaling to use satellite imagery, airborne or even UAVs based earth observation imagery. Proposing to farmers a way to improve the soil capabilities and water efficiency is as important as giving them the tools to monitor the state of the crop during various stages of the phenological cycle. While soil amendments is proposed in this study to reach a better use of water in poor soils in U.A.E, the remote sensing component paves the way to an intelligent tracking of the state of the crops using less day to day resources and avoiding long and fastidious field work especially in arid zones and harsh weather conditions.

Myriad of spectral vegetation indices are used to assess various aspects of vegetation in general and agriculture in specific [1, 2, 3, 4]. Many of these indices relies on the spectral information collected in the near infrared and visible bands and the most popular, and not necessary the most effective, is the normalized difference vegetation index (NDVI) [5]. The NDVI has been used for numerous application including leaf area index [6], biomass and yield [7], evapotranspiration [8], Chlorophyll content estimation; [9, 10], Nitrogen content [11, 12], etc. Other reflectance indices are also evaluated and used to estimate other parameters such as growth, productivity and water status, *inert alia*, Enhanced Vegetation Index, the Normalized Difference Water Index, Simple Ratio Index, Atmospherically Resistant Vegetation Index, Moisture Stress Index, Normalized Difference Infrared Index, etc. are few example of such indices. In this study, three vegetation indices were selected, namely, NDVI (as one of the most spread vegetation indices), TDVI (Transformed Difference Vegetation Index) and SAVI (Soil Adjusted Vegetation Index). The three indices rely on the spectral information collected in the near infrared and visible portions of the electromagnetic spectrum, for which equivalent multispectral bands are available in most Earth Observation Satellites, including U.A.E national E.O satellites program (e.g. Dubaisat-1, DubaiSat-2 and coming Khalifa Sat).

2. Material and methods

The plots trial was conducted at ICBA station using sandy soil dominant in UAE. Two inorganic amendments; AustraHort and zeoplant pellet, and a locally produced compost were used (Figure 1). These three amendments are referred to respectively in the text and figures as A1, A3 and A5. Standard fertilizer rates were used ($N=150$ kg/ha, $P_2O_5=300$ kg/ha and $K_2O=150$ kg/ha) as a first dose applied two weeks after germination. The second dose of fertilizer ($N=150$ kg/ha, and $K_2O=75$ kg/ha) was applied three weeks later. Treatments were triplicated in Randomized Complete Block Design (RCBD). The plot size was 2.25 m^2 (1.5m by 1.5m) and the distance between plants is 0.25 meter between lines and 0.30 meter between plants. At sowing two seeds per hole were placed and after germination seedling were thinned to 1 plant. A set of 4 plots were assigned for each of the three amendments as follow: three replicate of a 1.5 by 1.5 meter plots with 3 kg/m^2 of amendments and 54 plants, one plot as control and all plots were given irrigation treatments at 100% based on ETC.



Figure 1. The three used amendments and plots preparation at ICBA.

It is clear visually that these three amendments are very different in their colour as the Zeoplant pellet is the lighter, the compost is the darker, while the AustraHort is just in between. The three amendments and their mixtures with soil at a rate of 3kg/m^2 were used to determine water retention at 1/10 and 15 bar using pressure membrane apparatus (Table 1).

Table 1. Water retention at 0.1 and 15 bars by pure amendments, native sand soil of UAE and their mixtures at 3kg/m^2 .

Amendment/ Soil mixture	1/10 bar water retention (%)	15 bars water retention (%)
Pure Amendments		
AustraHort	48.20	40.60
Zeoplant pellet	27.48	22.40
Compost	75.50	57.11
Soil:amendment mixtures		
AustraHort @ 3.0 kg /m^2	4.40	1.27
Zeoplant pellet @ 3.0 kg /m^2	3.55	2.39
Compost @ 3.0 kg /m^2	3.32	2.90
Native UAE sand soil (ICBA)	5.59	1.72

Table 1 and figure 2 show the distribution of water retention at 0.1 and 15 bars pressure. Among the amendments the compost shows the highest water retention relative to other amendments, which is expected from an organic material. Among the inorganic amendments, AustraHort is showing better water retention than zeoplant pellet.

Figure 2 depicts a general overview of the methodology adopted to achieve the objectives set using close range remote sensing. For this, pure spectral signatures were collected in the range of 400 to 900 nm of the selected U.A.E soil and the three soil amendments mixed with soil at the rate of 3kg/m^2 used in this study. Furthermore, mixed spectral signatures of crop, soil and amendments were collected at two growing stages (vegetative and flowering) of Okra (*Abelmoschus esculentus*). The spectral signatures were all collected in a zenith angle [13,14] of the sun-target-sensor geometry near Nadir ($\theta_s = \theta_v = 90^\circ$), Field of View (FOV) of 25° and constant height of 0.5 meter for soil and amendments measurements and 1.5 meter for vegetation measurements in plots. White and dark current calibration were performed for each single spectra to avoid discrepancies related to slight solar zenith angle variation in time of collection. The FieldSpec® HandHeld 2 (HH2) spectroradiometer (figure 3) was used to collect spectral signature in the 325 nm – 1075 nm spectral range. With a wavelength range of 325 nm – 1075 nm, an accuracy of $\pm 1\text{ nm}$ and a resolution of $<3\text{ nm}$ at 700 nm. The software used with the Handheld 2 is R3 for accurate data visualization. Integration time in the field was set to 534 ms, because of the harsh field conditions and the big number of spectra to collect

while the sun is in the zenith. Table 2 presents the different dates of spectral signatures collection at ICBA experimental farm.

The pure collected spectral signatures of soil were used (1) to compare the spectral behaviour of different amendments vs soil between 400-900 nm. (2) to inverse the spectra and isolate the crop signature from the mixed spectral signatures by using a basic Linear Mixture Model [15] (equation 1) and knowing the fraction of the FOV occupied by vegetation collected, and (3) to calculate three spectral vegetation indices, namely; Normalized Difference Vegetation Index (NDVI), Transformed Difference Vegetation Index (TDVI) and Soil Adjusted Vegetation Index (SAVI). Moreover, a combination of the soil and amendments spectral signatures using the same linear spectral mixture model was performed to assess the effect of that mixture on vegetation indices, in this case NDVI. Table 3 present the three used vegetation indices.

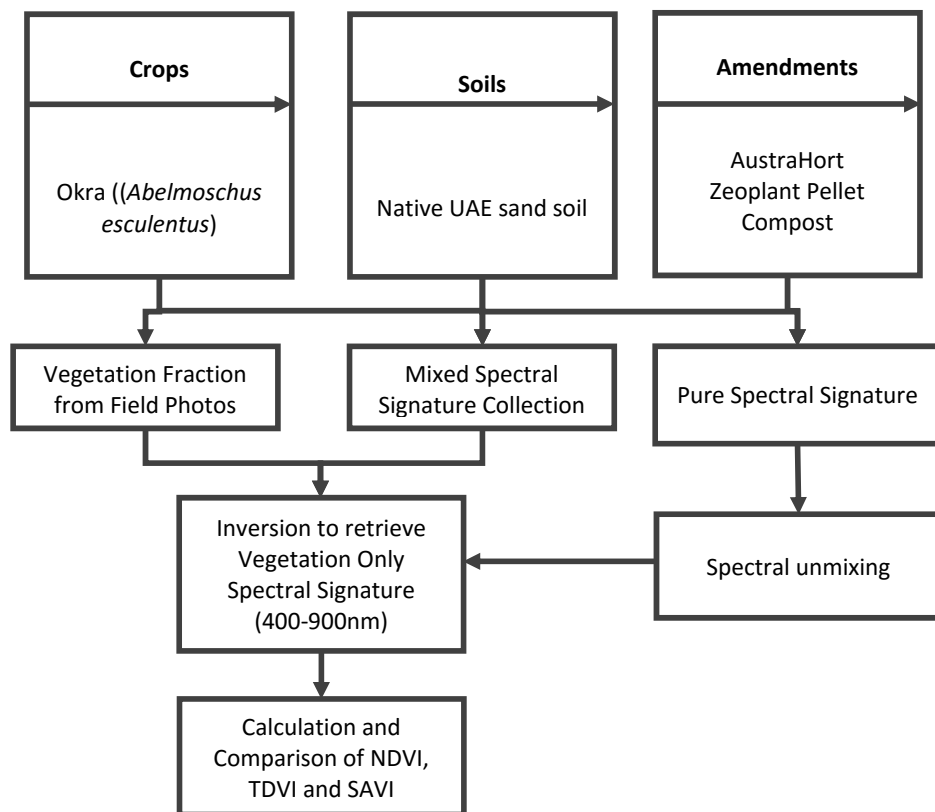


Figure 2. General overview of Remote Sensing Methodology.

$$R_i = \sum_{j=1}^n f_{ij} r_j + \varepsilon_i \quad (1)$$

where:

R_i is the resulting reflectance in wavelength I for a given FOV (value from 0 to 100%)

r_j is the reflectance of any given pure surface element “ j ” within the FOV (value from 0 to 100%)

f_{ij} is the fraction of area that the surface element “ j ” occupied in the FOV in the wavelength I (Values from 0 to 1)

ε_i is an element of error related to all intrinsic and extrinsic factors

Table 2. Spectral Vegetation Indices used in the study.

Normalised Difference Vegetation Index	$NDVI = \frac{R_{850} - R_{680}}{R_{850} + R_{680}}$	Most widely used vegetation index. Difference between the high chlorophyll absorption and the reflection of leaf cellular structure
Transformed Difference Vegetation Index	$TDVI = 1.58 \left(\frac{R_{850} - R_{680}}{\sqrt{R_{850}^2 + R_{680} + 0.5}} \right)$	Similarly to NDVI, the TDVI used difference between the high chlorophyll absorption and the reflection of leaf cellular structure but is more robust in case of sparse and low density vegetation
Soil Adjusted Vegetation Indices	$SAVI = \frac{1.5 \times (R_{850} - R_{680})}{(R_{850} + R_{680} + 0.5)}$	Help to reduce the effects from background soils, Coefficient L is considered as equal to 0.5 in this study accordingly with the density of crop.

Table 3. List of fieldwork visits and dates.

Period	location	Purpose
26-29 January 2015	ICBA-UAE	Collection of spectral signatures of pure amendments, .soil, and bare plots experiments
15-19 March 2015	ICBA-UAE	Collection of spectral signatures at field of plots experiments with vegetation (Okra) before blossom stage
12-14 May 2015	ICBA-UAE	Collection of spectral signatures at field of plots experiments with vegetation (Okra) after blossom stage



Figure 3. The FieldSpec® HandHeld 2 used to collect spectral signatures.

3. Results and discussion

As described above, visually the three used amendments show clearly a significant distinction of the colour ton. In fact, figure 4 shows that the Zeoplant Pellet (A3) which is the clearer one has a distinctive spectral signature with relatively high reflectance values, in the range 400-900nm compared to AustraHort (A1) and Compost (A5). Figure 5 presents the spectral signatures of the native U.A.E soil which present a typical sand signature. All the signature of amendments and soil represent the normal trend of soils spectral signatures. It is clear from figure 5(b) that the mixture rate of 3kg/m² applied of amendments to the soil does not affect significantly its reflectance.

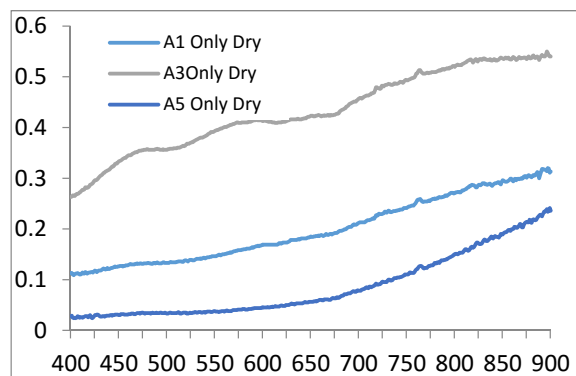
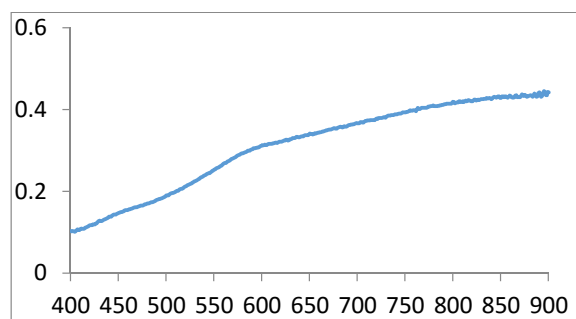
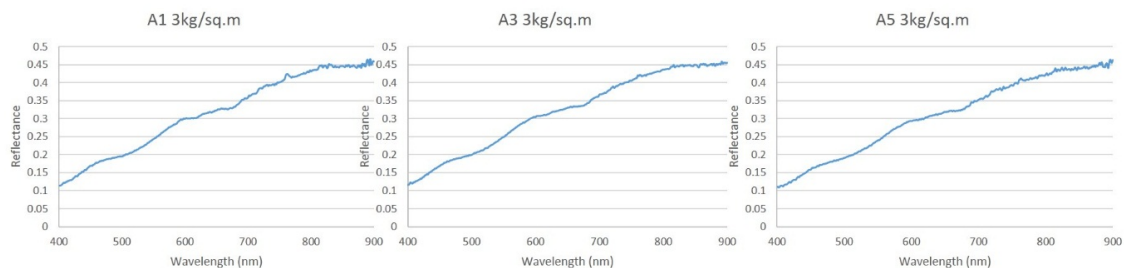


Figure 4. Spectral Signature of the three used soil amendments using in dry conditions.



a)



b)

Figure 5. Spectral Signatures (reflectance from 400-900 nm) of (a) UAE used soils and (b) mixture of the three amendments with the soil at 3 kg/sq.m.

As explained above, before using spectral vegetation indices to infer any relation between them and vegetation status, it is primordial to understand the soil amendments impact on such indices even without the presence of any vegetation (on bare soil). The following figure 6, depicts the theoretical effect of a mixture of A5 Amendment (compost) with UAE soil on the Normalized Difference Vegetation Index (NDVI). A5 amendment was selected because it is a compost and contains remains of dead vegetation. To realise this curve, the LMM was used to combine gradually, in term of surface, the A5 curve presented in figure 4 and the soil curve in figure 5. While no crop is present, the NDVI values are very high, starting from 20% of Compost mixture with soil, and this bias induced can be misleading when upscaling spectral information to satellite imagery with low spectral and spatial resolutions.

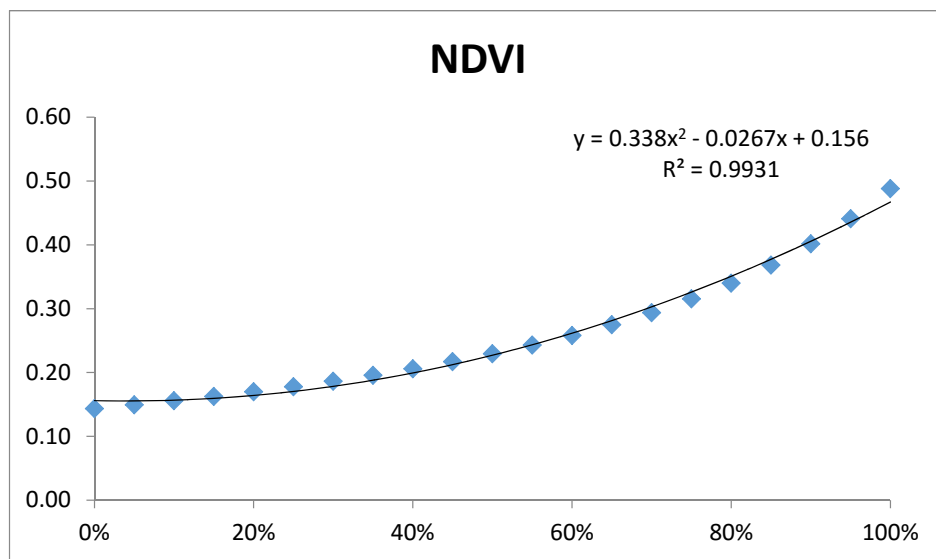


Figure 6. Effect of A5 mixture with UAE soil (passing from 0% to 100%; X axis) on NDVI values.

Unmixing collected field spectra to get only the vegetation spectral response is necessary. For this purpose, spectral signature of bare soil and amendments collected on January 2015 is needed as reference. In fact, this spectral signature, for each plot, is giving the spectral response of the soil and amendments only, while the subsequent spectral signatures collected in March and May 2015 contain additional information on vegetation as well. Figure 7 shows the FOV of the HH2 spectroradiometer which includes, vegetation, soil, amendments, irrigation pipes and shadow of vegetation.

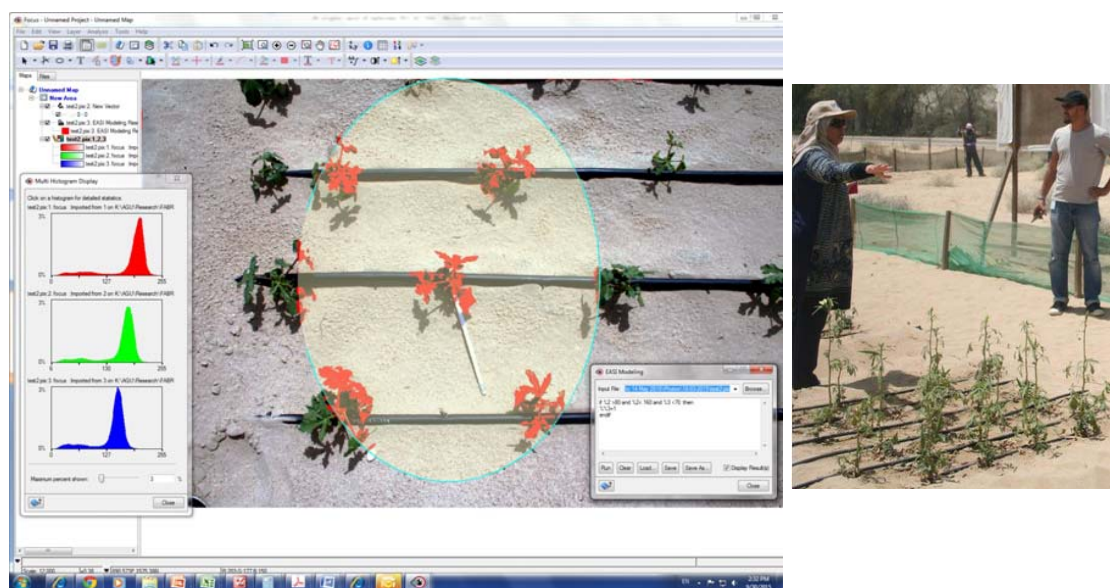


Figure 7. Isolation of vegetation (illustrated in red color) using a simple Histogram Thresholding technique via Geomatica 2015.

Figure 8 present an example of different spectral signatures collected in the field with various height values of the spectroradiometer (HH2). It is clear that plant signature (yellow) and the soil one (red) are mixing when got together; blue and green curves. The idea is how to retrieve from a mixed signature such as the one shown in figure (24), the vegetation one. As mentioned earlier, using the linear mixture model presented in equation 1 above, and knowing the reference spectral signature of soil and amendment for each single plot an endmembring is possible to extract only vegetation signature. A nominal surface of vegetation of 30% of the FOV is used for this purpose, based on

analysis of field photos. Figure (9) shows the same signatures presented in the previous figure (10) but with the retrieved vegetation one (in green colour).

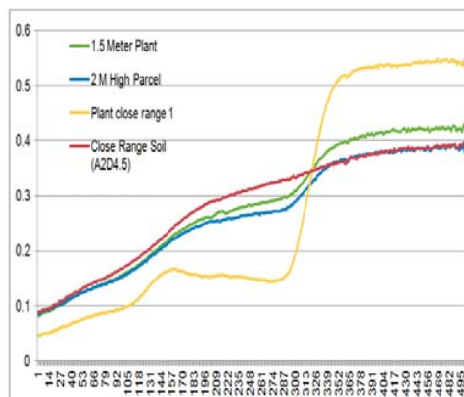


Figure 8. Example of spectral mixture of soil, amendments and vegetation.

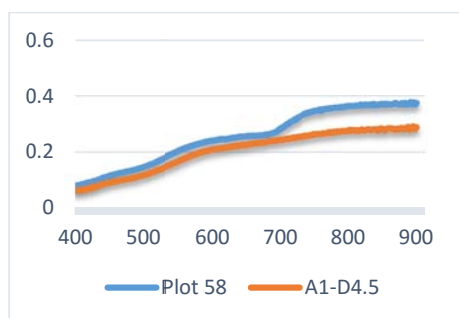


Figure 9. Mixed soil, amendment and vegetation spectral signature aside reference Soil and Amendment spectral signature.

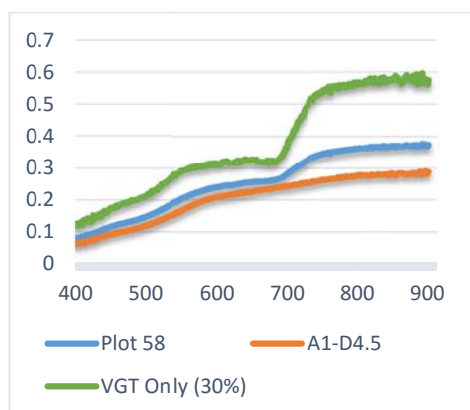


Figure 10. Vegetation spectral signature retrieved using the LMM from the mixed signature (blue) and the reference one (orange).

The same approach is applied to all plots for March and May 2015 (ICBA-UAE) field spectral signatures to retrieve only the vegetation one, see figure 11 (a and b)

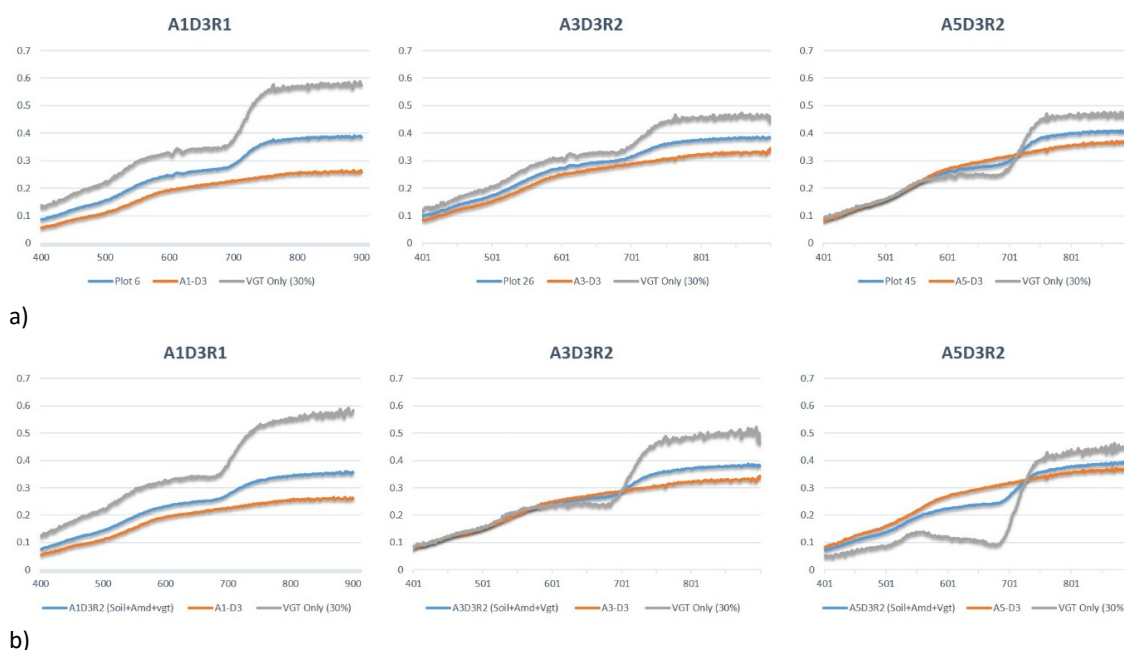


Figure 11. Unmixing of Vegetation spectral signatures from field collected spectra in (a) March 2015 and (b) May 2015 at ICBA-UAE.

Tables 4 and 5 presents the three vegetation indices (NDVI, TDVI and SAVI) calculated for the crop only during March and May 2015. These values are obtained from crop spectral signature extracted using the LMM as presented in figure 11.

Table 4. Crop only Vegetation indices values during March 2015.

	680nm	850 nm	NDVI	TDVI	SAVI
Control	0.25	0.37	0.19	0.19	0.15
A1 Replica 1	0.30	0.36	0.10	0.11	0.09
A1 Replica 2	0.27	0.38	0.17	0.19	0.15
A1 Replica 3	0.29	0.38	0.13	0.14	0.11
A3 Replica 1	0.31	0.39	0.12	0.13	0.10
A3 Replica 2	0.30	0.38	0.12	0.13	0.10
A3 Replica 3	0.31	0.39	0.11	0.13	0.10
A4 Replica 1	0.28	0.41	0.18	0.20	0.15
A4 Replica 2	0.28	0.42	0.20	0.23	0.18
A4 Replica 3	0.29	0.41	0.16	0.18	0.14

Table 5. Crop only Vegetation indices values during May 2015.

	680nm	850 nm	NDVI	TDVI	SAVI
A1 Replica 1	0.26	0.36	0.17	0.17	0.14
A1 Replica 2	0.53	0.75	0.17	0.28	0.19
A1 Replica 3	0.26	0.35	0.16	0.16	0.13
A3 Replica 1	0.24	0.35	0.20	0.20	0.16
A3 Replica 2	0.24	0.37	0.21	0.22	0.18
A3 Replica 3	0.27	0.38	0.17	0.18	0.14
A4 Replica 1	0.26	0.37	0.18	0.19	0.15
A4 Replica 2	0.22	0.36	0.23	0.23	0.19
A4 Replica 3	0.24	0.39	0.23	0.24	0.19
A1 Replica 1	0.25	0.38	0.21	0.22	0.18

4. Conclusion

It was possible in this study to unmix plot collected spectral signatures using a simple LMM to obtain Okra (*Abelmoschus esculentus*) spectral information in the range of 400-500nm. For this purpose, separate spectral signature of soil, amendments and soil mixed with amendments at a rate of 3kg/m² were used as reference. The fraction of vegetation if a mixed FOV was obtained by simple thresholding classification of field photos using Geomatica 2015. The key outcome of this analysis was the considerable bias was induced when using a mixed F.O.V. In fact, the compost as an organic soil amendments containing dead vegetation affect similarly the sensitivity of the three Vegetation indices in the vegetative stage of Okra compared to Austrahort and Zeoplant pellet amended plots. However, the TDVI is very sensitive to vegetation presence even with unmixed crop spectra. Austrahort amendment led to better status of Okra both in March and May with values of 0.19 and 0.28 respectively. Bias induced by some soil amendments can be misleading when upscaling spectral information to satellite imagery with low spectral and spatial resolutions. The results obtained are encouraging for further use of spectral information for crop monitoring in soil containing amendments. The next step to this study is to collect the spectral signatures on pure vegetation samples to try to correlate the spectral vegetation indices with the crop characteristics. Hence, if achieved successfully, spectral crop model(s) will be generated to quantify spectrally, using close range remote sensing data, crop characteristics such as chlorophyll content/absorption which is linked in its turn to the status of the crop.

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Acknowledgment

This study is made possible by the support of the Arabian Gulf University (kingdom of Bahrain) and the International Center for Biosaline Agriculture (Dubai, UAE). It is also made possible by the support of the American People through the United States Agency for International Development (USAID.). It is a part of the joint research project “Improving Agricultural Soil Properties Using Soil Amendments to Enhance Water and Nutrient Use Efficiency for Crop Production in Dry Lands and Assessing These Efficiencies Via Remote Sensing Techniques” between AGU and the International Center for Biosaline Agriculture (ICBA) under the Further Advancing the Blue Revolution Initiative (FABRI), USAID-DAI Contract No. AID-EPP-00-04-00023. The contribution of PCI Geomatica for providing image processing capabilities via its Educational Alliance with AGU is also acknowledged.