UTILIZING SENTINEL – 2 SATELLITE IMAGERY FOR PRECISION AGRICULTURE OVER POTATO FIELDS IN LEBANON

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ABSTRACT

Lebanon has traditionally been a major potato producer with 451,860 tons produced in 2014. Generally, potatoes make up 30% of the total Lebanese agricultural exports where approximately 60% of the potato production is exported to the Arab region, the UK and Brazil. The purpose of this study is to promote precision agriculture techniques in Lebanon that will help local farmers in the central Bekaa Valley with land management decisions. The European Space Agency's satellite missions Sentinel-2A, launched June 23rd 2015, and the Sentinel-2B, recently launched on March 7th 2017, are multispectral high resolution imaging systems that provide global coverage every 5 days. The Sentinel program is a land monitoring program that includes an aim to improve agricultural practices. The imagery is 13 band data in the visible, near infrared and short wave infrared parts of the electromagnetic spectrum and ranges from 10-20 m including three 60 m bands pixel resolution. Sentinel is freely available data that has the potential to empower farmers with information to respond quickly to maximize crop health. Due to the political and security conflicts in the region, utilizing satellite imagery for Lebanon is more reasonable and realistic than operating Unmanned Aircraft Systems (UAS) for high resolution remote sensing. During the 2017 growing season, local farmers provided detailed information in designated fields on their farming practices, crop health, and pest threats. In parallel, Sentinel-2 imagery was processed to study crop health using the following vegetation indices: Normalized Difference Vegetation Index, Green Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index and Modified Soil Adjusted Vegetation Index 2. Most Lebanese farmers inherit their land from their parents over generations, and as a result most still use traditional farming techniques for irrigation, where decisions are based on prior generations' practices. However, with the changes in climate conditions within the region, these practices are no longer as efficient as they used to be. Normalized Difference Water Indices are calculated from satellite bands in the near-infrared and short-wave infrared to provide a better understanding about the water stress status of crops within the field. Preliminary results demonstrate that Sentinel-2 data can provide detailed and timely data for farmers to effectively manage fields. Despite the fact that most Lebanese farmers rely on traditional farming methods, providing them with crop health information on their mobile phones and allowing them to test its efficiency has the potential to be a catalyst to help them improve their farming practices.

KEYWORDS: crop health, field management, potatoes, remote sensing, Sentinel-2

INTRODUCTION

Lebanon relies heavily on its agricultural sector with an agricultural area of approximately 2,730 km^2 out of a total 10,452 km^2 (El Gazzar 2015). The agricultural sector contributes 7% to the Gross Domestic Product (GDP) while providing work to 15% of the Lebanese population (FITA 2008). Potato crops account for 56% of vegetable production in the country, mainly in the Bekaa Valley and North Lebanon states (Hatoum 2005). Hence, it is important to ensure the health of potato crops to improve production in order to revive the local market as growers are having a hard time selling their produce (شهيب نقل إلى سلام معاناة المزارعين درباس: نمر في أخطر المراحل 2015) and expanding the Lebanese economy by increasing potato exports. The Bekaa Valley located in the center of Lebanon is one of the largest agricultural regions in the country and potatoes are the main crop. Potatoes are an important irrigated crop that is vulnerable to water stress, pests, disease and other crop threats. Precision agriculture has the potential to help minimize such issues and improve crop yield through empowering farmers with timely scientific knowledge on crop condition. Precision agriculture offers a solution; however, in a country such as Lebanon, precision agriculture is still in its early stages of adoption. Lebanon recently teamed up with the Food and Agriculture Organization of the United Nations on May 16, 2016, to launch the Country Programming Framework from 2016 to 2019 (United Nations Food and Agriculture Organization 2016) in order to develop more sustainable practices to improve the agricultural sector and may include the concept of precision agriculture. Hence, this project is aimed at showing the potential of precision agriculture through open-access satellite imagery and the potential it has to help farmers with decision making. The main goal is to submit this work to the Lebanese Ministry of Agriculture to demonstrate how satellite image analysis can assist farmers to respond to crop health issues.

To identify potato viruses in Lebanon, Abou-Jawdeh et al. (2001) sampled potatoes from major agricultural regions in the country detecting various potato viruses and found that potato virus Y (PVY) *(Potyvirus)* to be the most dominant one among all samples. PVY represents a big threat to potato crops worldwide as it is considered the most harmful on potato fields (Steinger, Gilliand, and Hebeisen 2014) and in some places like Turkey they are recording the highest percentages of infections among other potato viruses (Yardımcı, Kılıç, and Demir 2015). Another threat to potato production in Lebanon is Potato Cyst Nematodes (PCN) *(Globodera)* which is the major potato pest in the country (Ibrahim, Abi Saad, and Moussa 2004). PCN are the most severe potato pest where losses could reach up to 80% within a growing area (Hassan et al. 2013). The biggest challenge in detecting PCN is that it needs skilled and experienced workers to visually identify infected plants and soil in the field or by using, real-time Polymerase Chain Reaction in the labs, which saves time but is very costly (Hassan et al. 2013).

Satellite imagery technology improved steadily since the early 1970's, as reflected by increased sensor resolution and expanding applications of satellite imagery to cover precision agriculture applications (Mulla 2013). Not only has satellite imagery improved in quality, but they have also become more accessible to the public (Turner et al. 2015) through constantly updated datasets such as the Sentinel-2 mission by the European Space Agency (ESA). Sentinel-2A, launched in June 2015, and more recently, Sentinel-2B launched in March 2017, are two new multispectral imagers covering 13 spectral bands (443 nm – 2190 nm) at resolutions of 10 – 20 and 60 m. The Sentinel-2 program is filling a void for low-cost, medium resolution imaging with 5 day revisit times depending upon latitude, cloud cover and other factors, to assess plant health and vigor during growing seasons (Dash and Ogutu 2016). In addition, there is the RapidEye satellite constellation operated by Planet Labs that is freely available for university researchers. It was launched on August 29 of 2008 with 5 spectral bands (440 nm – 850 nm) at a resolution of 5 m. Both the Sentinel-2 mission and RapidEye data are partially aimed for agricultural uses making them an ideal source for researching precision agriculture.

Irrigation plays a major role in the health status of potato crops, and as the world's climate is constantly changing, it is important to analyze water stress and content in crops to manage water resources more efficiently and to assess what irrigation techniques are the most efficient. According to research performed in Egypt, (Nahry, Ali, and Baroudy 2011), using satellite imagery proved to be very effective in increasing economic profitability and environmental sustainability respectively by 29.89% and by limiting fertilizers and irrigation to where it is needed only. Using multispectral satellite imagery such as Sentinel data, Normalized Difference Water Index (NDWI) could be easily calculated to provide a better assessment of water stress in agricultural fields (Gao 1996).

The main vegetation indices used for monitoring crop health status are Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Soil Adjusted Vegetation Index (SAVI) and Modified Soil Adjusted Vegetation Index 2 (MSAVI2). Both NDVI and GNDVI have similar purposes in which they reflect how dense the vegetation in a specific area is. The main difference is that NDVI reduces noise and provides an approach for comparing change over periods of time (A. Huete et al. 2002) while GNDVI is more aimed towards the greenness of the plant due to its sensitivity to the chlorophyll content and is related to the Leaf Area Index (Candiago et al. 2015). Similarly, SAVI and MSAVI2 are vegetation indices less sensitive to bare soil in the pixel. While SAVI does a great job with minimizing the effect of soil in vegetation, MSAVI2 gives a more accurate estimation of wide range vegetation cover (Liu et al. 2007).

This study focused on demonstrating the potential of Sentinel-2 imagery for monitoring crop health of potato fields in Lebanon and whether or not vegetation indices relate to potato crop yield. It is hypothesized that a low vegetation index during critical times over the growing season indicate problems in the field and will correspond to lower yield numbers than areas where vegetation indices values are higher. This preliminary work shows that Sentinel imagery provides an accessible and low-cost alternative for Lebanese farmers to use in combination with open source software such as QGIS for low-cost data processing.

METHODS

Study Area

The study area is located in *Tal Znoub* in the southwestern part of the *Bekaa Valley* in Lebanon. It lies north of *Quaroun Lake* and is along the path of the *Litani River.* It is located at around 33.66 N latitude and 35.78 E longitude with an altitude of 872 m (5861 ft.) above mean sea level. *Tal Znoub* is located at 4 km north northeast of the city of *Jeb Jannine*, the capital of the *West Bekaa*. The overall area of the site is 462,600 m^2 and is divided into sub fields as shown in Figure 1 and Table 1. Just like Lebanon overall, the study area has a moderate climate with the hottest months of the year between June through September, while the rainy season is between January and February as well as November and December. The area is known for growing mainly potatoes, vegetables, grapevines, and various grains including wheat. The Bekaa Valley is uniform when it comes to soil types mainly being *Lithic Leptosols* as the soil type comprising this study area in *Tal Znoub*.

Figure 1. Study Area, Tal Znoub, Bekaa, Lebanon - Basemap source: Planet Team (2017). Planet Application Program Interface: In Space for Life on Earth. San Francisco, CA. https://api.planet.com

Table 1. Field Areas

Field_ID	Area (m^2)
1	6000
2	11900
3	19200
4	14000
5	24400
6	38200
7	65700
8	28800
9	32000
10	35400
11	30400
27	38300
28	31500
29	17200
30	18800
33	50800
Total	462600

Data Resources

The satellite imagery dataset for this work was downloaded through the USGS Earth Explorer interface for the Sentinel-2A imagery and through the ESA Copernicus interface for the Sentinel-2B imagery (Table 2). In addition, Rapid Eye imagery was acquired through the Planet application interface. Rapid Eye imagery is the base for digitizing the field boundaries within the study area location due to the high resolution of the imagery at 5m.

Table 2. Satellite Imagery Sources

Data Type	Data Source	Data Link
Sentinel-2A	USGS Earth Explorer	https://earthexplorer.usgs.gov/
Sentinel-2B	ESA Copernicus	https://scihub.copernicus.eu/s2b/#/home
Rapid Eye	Planet Application Program Interface	www.planet.com/explorer

Data Pre–Processing

The Sentinel–2A and Sentinel–2B imagery are processed using the open source software QGIS for atmospheric correction via the Semi-Automatic Classification Plugin. The software takes level – 1C Sentinel imagery metadata and individual bands and converts the imagery from "Digital Count" to "Reflectance Values" from Top of Atmosphere (TOA) to Bottom of Atmosphere (BOA) in order to run indices and perform image analyses (L. Congedo 2016).

Data Processing

Indices used for analyzing crop health status are outlined in Table 3 and include: NDVI and SAVI. NDVI is a normalized ratio of near-infrared and red bands that ranges between -1 and 1 where areas with green plants have values above 0 and the higher the value the more photosynthetic activity there is due to the energy absorption of plant canopies. SAVI has a range between -1 and 1 where values between -1 and 0.1 are most likely not vegetation. This index has the variable L in its equation which is related to the density of vegetation and is used as a canopy background adjustment factor based on soil brightness (Candiago et al. 2015). For this research, the estimated value of L was 0.5.

After the scenes are corrected in QGIS, the needed bands (Near Infrared: Band 8, Red: Band 4 and Green: Band3) were imported into Esri's ArcMap 10.5.1 for processing vegetation indices (Table 3). In order to increase efficiency, using raster calculator, the various indices' formulas were built into a tool using model builder in ArcMap and the output raster datasets were saved into a specific geodatabase for data management purposes.

Based on the processed data and the vegetation indices values, a qualitative analysis was performed to verify that the different indices are consistent with one another. The collaborating farmer in Lebanon provided information regarding the field conditions, fertilizer applications, crop threats and the final yield to assist in interpreting our results.

Table 3. Indices

Vegetation Index	Formula	Reference
Normalized Difference Vegetation Index	$\frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$	(Rouse et al. 1973)
Soil Adjusted Vegetation Index	$\frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red} + L}$ + (1+L)	(A. R. Huete 1988)
Normalized Difference Water Index	$\frac{\rho_{Green} - \rho_{NIR}}{\rho_{Green} + \rho_{NIR}}$	(S.K. 1996)

Data Post–Processing

After the processing of all indices on the fields, "Zonal Statistics as Table" tool in ArcMap was used to summarize the values obtained. Using the specific output raster of each individual index as the input raster and using the fields as the zone, descriptive statistics were calculated and exported as an excel sheet. These summary statistics for each index in every field included: minimum value, maximum value, mean and standard deviation.

Information from Grower

The Lebanese farmer supported the data analysis by providing information for the fields and the growing practices throughout the season (Table 4). The harvesting process involves manually extraction by digging up of potato tubers while the crop canopy is still green. The green plant matter is removed and tossed into the field.

Table 4. 2017 Growing Season Information

Planting Date	February 20^{th}
Harvesting Date	Approximately June 25^{th}
Potato Variety	Agria
Fertilizer/Pesticide Application Date	April 20^{th}
Fertilizer/Pesticide Re-application	Every 20 days
Fertilizer Type	Organic; 15/15/15 & 20/20/20
Pesticides Targeted	Aphids, Worms & Fungus
Overall Crop Yield	Good – average

RESULTS

Figure 2 shows the progress of NDVI over the growing season between early April and late June, 2017. The values start at around 0.2 for all the fields and then increase to peak at 0.9 towards end of May till early June then gradually decrease to a range between 0.6 and 0.8. Figure 3 displays the plots for the mean NDVI values for each field throughout the season and demonstartes the trends of the fields for the processed dates.

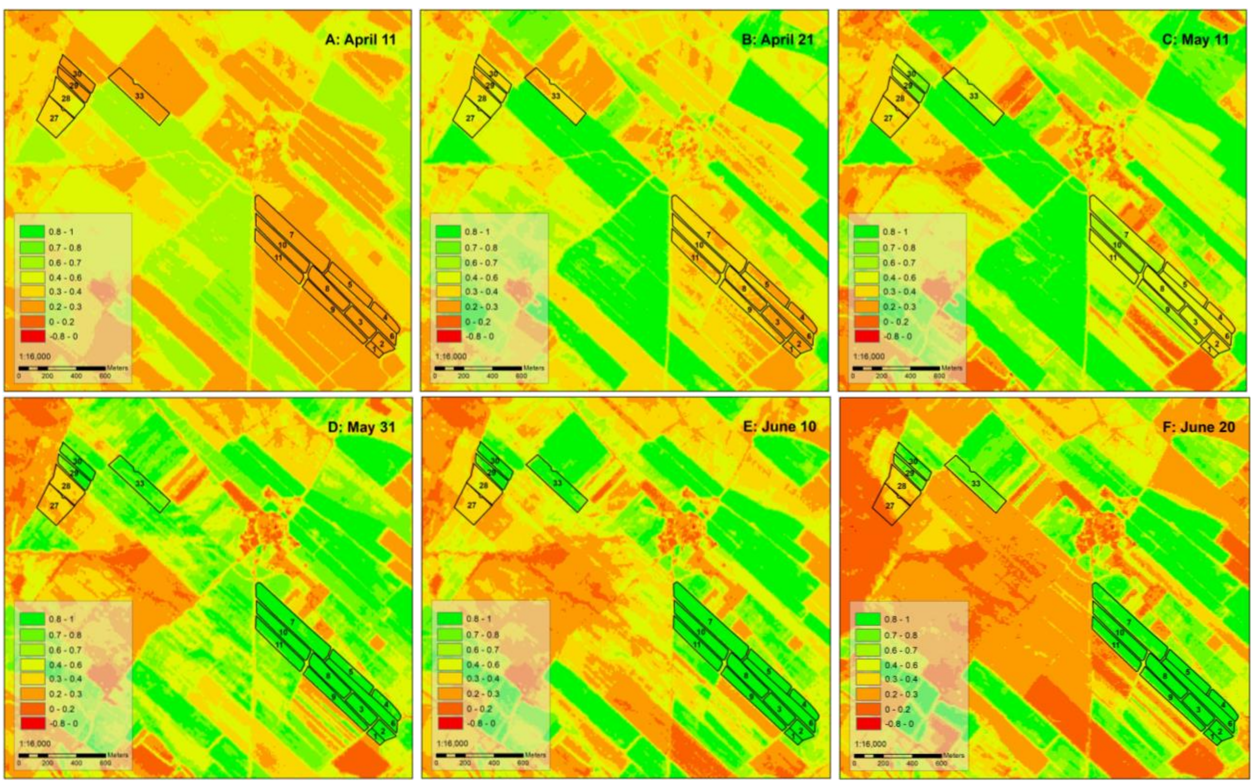

Figure 2. Normalized Difference Vegetation Index

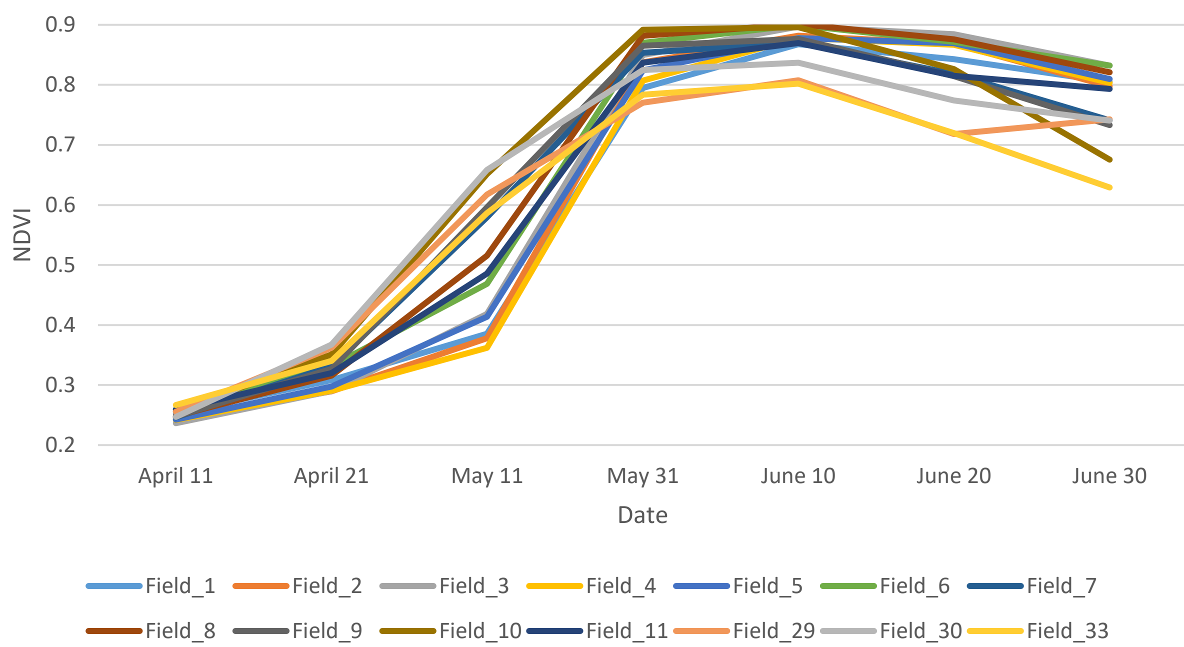

Figure 3. Normalized Difference Vegetation Index – Mean Values

Figure 4 shows the progress of SAVI over the growing season between early April and late June, 2017. The values start at around 0.1 and then increase to peak at approximately 0.7 towards end of May till early June then gradually decrease to a range between 0.4 and 0.6. Figure 5 displays the plots for the mean SAVI values for each field throughout the season and demonstartes the trends of the fields for the processed dates.

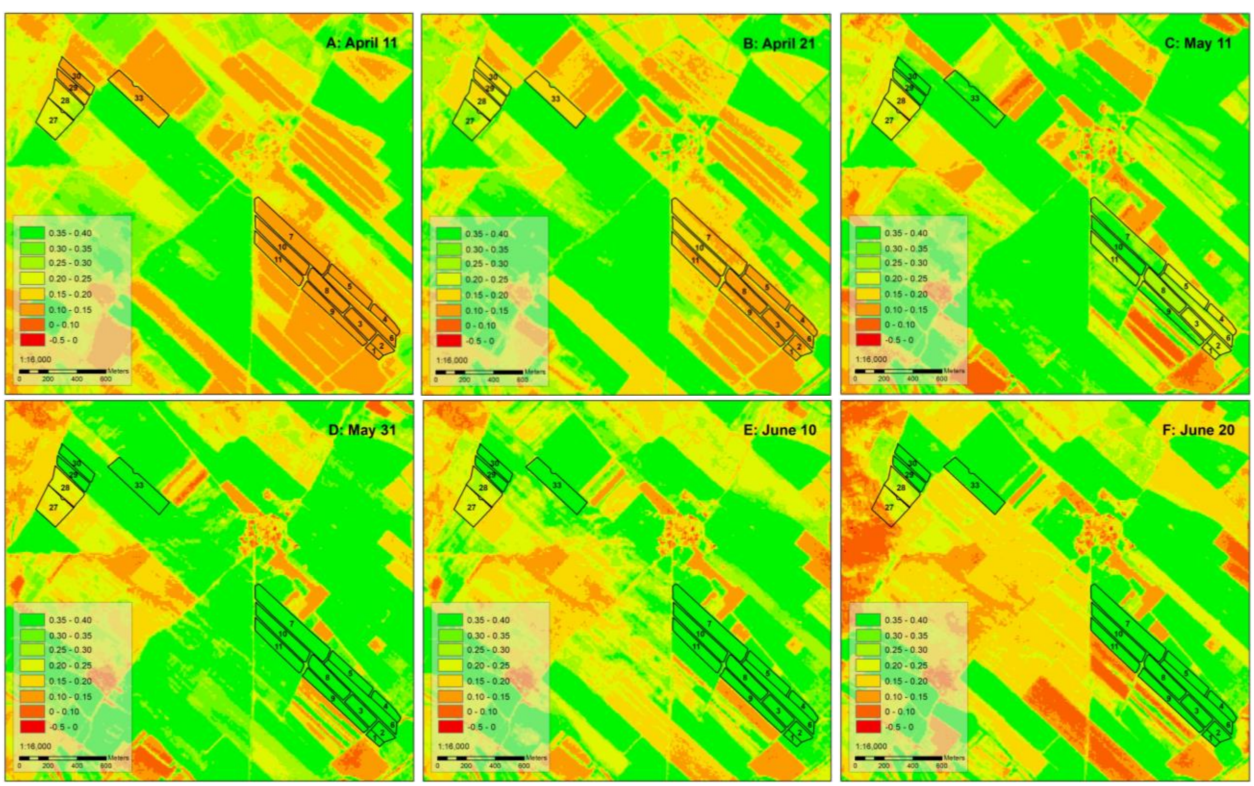

Figure 4. Soil Adjusted Vegetation Index

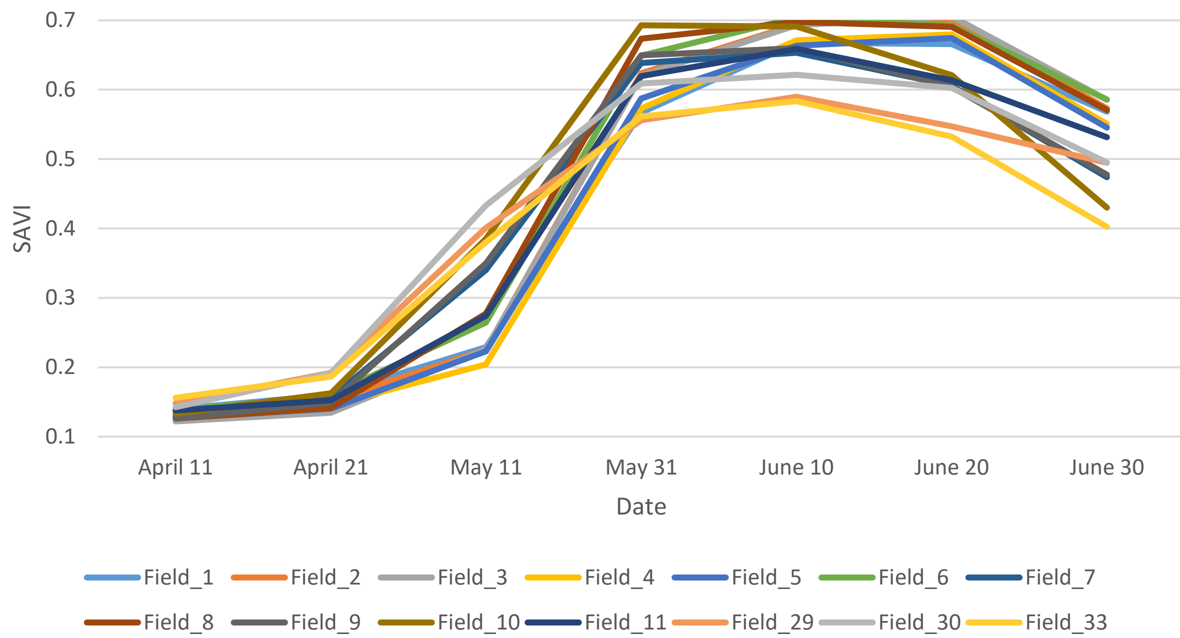

Figure 5. Soil Adjusted Vegetation Index – Mean Values

NDWI is highlighted in figure 6 over the growing season between early April and late June, 2017. The values start at around -0.45 and then decrease to minimum at -0.9 towards end of May till early June then gradually increase to a range between -0.8 and -0.7. Figure 7 displays the plots for the mean NDWI values for each field throughout the season and demonstartes the trends of the fields for the processed dates.

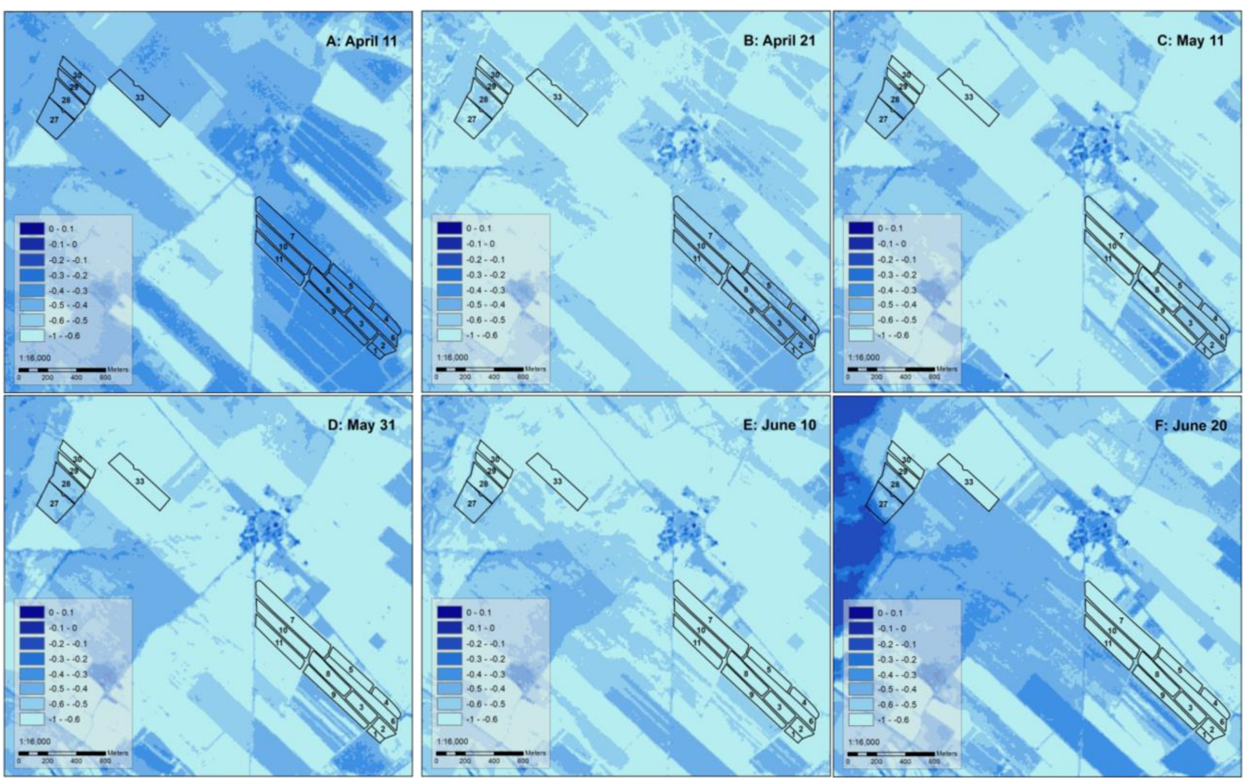

Figure 6. Normalized Difference Water Index

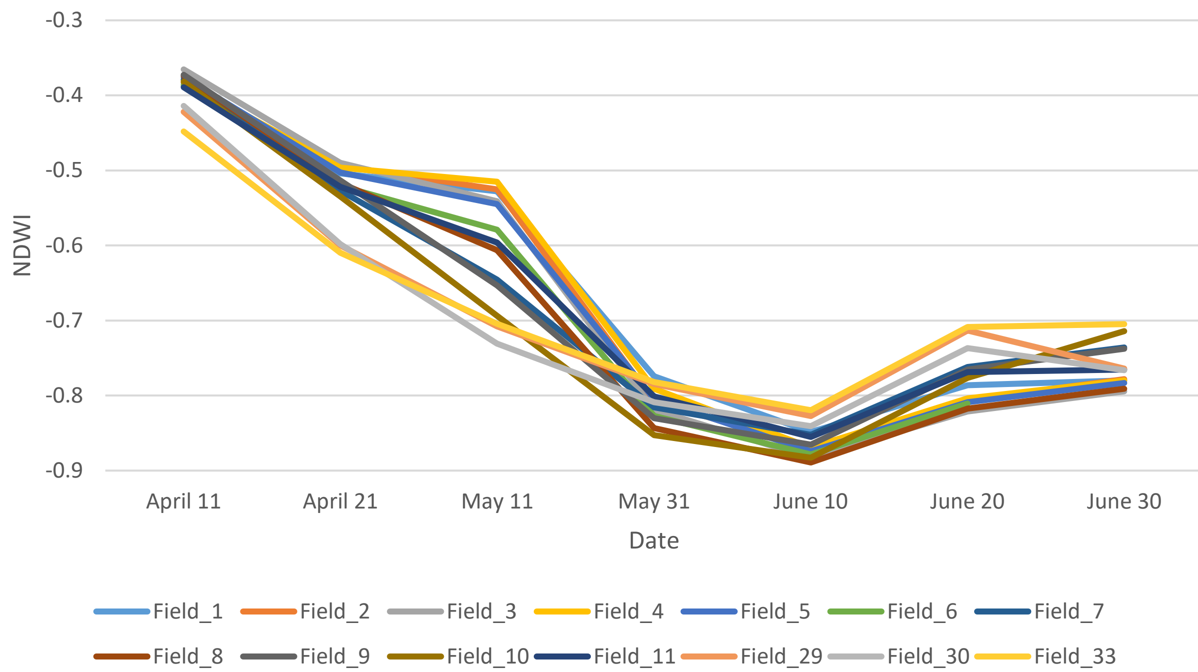

Figure 7. Normalized Difference Water Index – Mean Values

DISCUSSION/CONCLUSION

Based on a visual interpretation, it is apparent that the fields can be subdivided into clusters with similar responses to the vegetation and water indices. Fields 1 through 5 showed consistency with each other, recording the highest NDVI and SAVI values and lowest water stress values. This could be due to the geographic location of these fields as they are the closest to the Litani River, which could explain the higher performance of these fields. On the other hand, fields 29, 30 and 33 have similar trends, where the vegetation indices started with some of the highest indices values rate than the rest of the fields. Those fields are clustered geographically and may have had a different planting date than the other fields that would explain the difference in rate compared to the other fields. Field 10 showed odd patterns with the indices throughout the season that could indicate a problem within the field. This might be due to topographic variations that would have affected irrigation and crop performance.

Through the various indices processed for Sentinel-2 data, satellite imagery proved that it is a reliable source for analysis and for precision agriculture applications. All the indices showed compatibility with one another. The peak productivity of the season based on the image analysis was between May 31st and June 20th.

Future work for this research will involve processing Planet RapidEye and 4Band data along with Sentinel-2B to help explain the variations of vegetation indices for the fields. In addition, Planet data provides a higher resolution and having more data will allow the option to run regression models on the data which was not feasible with this limited dataset. Moreover, working more directly with the Lebanese farmer and obtaining more detailed information about the specific planting and harvesting dates will confirm the hypothesized interpretation about the varying responses of the fields. Also, studying the topography will help explain what the indices are showing since the fields are influenced by topographic variations that impacts the amount of sun energy received and absorbed by the plants as well as the influence of irrigation which all lead to different responses.

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