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Applying high resolution visible channels aerial scan of crop canopy to precision irrigation management

Assaf Chen*, Valerie Orlov-Levin and Moshe Meron

MIGAL Galilee Research Institute, Kiryat Shmona 11016, Israel www.migal.org.il

* Correspondence: assafc@migal.org.il; Tel.: +972-52-8616369

Abstract: Canopy cover (or vegetation cover) serves in irrigation management mainly to determine primary ET (evapotranspiration) coefficient, as radiation interception and evaporative surface area are directly related to canopy cover. Crop size and development with time depends on water supply, therefore crop canopy maps are tools for detection of irrigation systems spatial uniformity. Several aerial scan campaigns were deployed in the Upper Galilee of Israel in the 2017 growing season to follow up and evaluate irrigation uniformity and crop coefficients of peanuts and cotton by RGB scans of a Phantom 4 multirotor unmanned aerial vehicle (UAV). Foliage intensity and coverage were enhanced by a Green-Red Vegetation Index (GRVI), which is an NDVI like process where the green channel replaced the NIR. Results demonstrated that the GRVI is suitable for the purpose of determining vegetation cover. Furthermore, the GRVI yielded better results than the NDVI, in recognizing phenological crop changes (especially senescence). Therefore, this research proves the applicability of a low cost digital camera mounted on an easily accessible UAV for crop cover and actual, in-field, ET coefficients determination, and irrigation uniformity evaluation.

Keywords: canopy cover; vegetation fraction; green-red vegetation index (GRVI); precision irrigation; remote sensing; unmanned aerial vehicle (UAV).

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1. Introduction

A lot of work has been done investigating plants' spectral reflectance in the visible and near-infrared part of the electromagnetic spectrum at different phenological stages. Understanding the single leaf's spectral response and the processes that occur on this level allows to apply this knowledge to the canopy level [1]. Spectral indexes allow for better information extraction from remotely sensed data because they reduce effects of soil, view angle and topography, while enhancing the focus on the desired extracted feature (e.g. vegetation indexes enhance the visibility of vegetation) [2]. Multitude of vegetation indexes (VI) were introduced in order to evaluate plant's vigor and stress. While multiple VIs that use the ratio between the red and near-infrared (NIR) spectral wavebands (e.g. NDVI, RVI, SAVI) [3–6] are successful in reducing atmospheric radiance and transmittance [5,7], the red wavelengths are strongly absorbed by chlorophyll and therefore are less sensitive to changes in chlorophyll content [7–10]. As leaf area index (LAI) increases, canopy chlorophyll content also increases regardless of the single level leaf chlorophyll content, therefore these VIs are much more affected by LAI than by changes in chlorophyll at the canopy scale [7,11,12]. Since chlorophyll is vital for photosynthesis process, changes in chlorophyll levels can be linked to photosynthetic productivity, developmental (phenological) stages, and plant stress.

On the other hand, the green wavelengths are more sensitive to high chlorophyll levels, since it is less absorbed by chlorophyll a and b, unlike the blue, red and NIR wavelengths [7–10]. Therefore, VIs using the green wavelength are capable to detect changes in chlorophyll contents at the leaf and canopy scale, and are suitable to monitor plants' developmental stages and stress.

[13] found that the NIR reflectance band is less sensitive for determining vegetation cover (or vegetation fraction – VF), for VF >60%, and showed that a VI using the green-red-blue wavelengths have a linear relationship to VF, with an accuracy level of up to 90%. They showed that in Wheat, when VF is between 50-100%, the green wavelength is most sensitive to changes in vegetation cover (while the blue, red and NIR wavelengths were insensitive to changes in vegetation cover).

[14] found that the green to red (G/R) spectral wavelengths ratio index is sensitive to the amount of greenness of the plant: it is less than 1 in the beginning and at the end of the growing season, and above 1 at midseason [14,15]. [15] concluded that the G/R ratio may serve as a benchmark for crop growth, phenological stages and for indicating VF.

Another VI that is based on the G/R ratio is the Green-Red Vegetation Index (GRVI) that is defined according to **Eq. 1**:

$$GRVI = \left(\rho green - \rho red\right) / \left(\rho green + \rho red\right) \quad (1)$$

[16] evaluated the use of GRVI as a phenological indicator. They concluded that the GRVI index can differentiate between green vegetation (index above 0), water and snow (index around 0) and soils (index below 0). Furthermore they demonstrated that GRVI (unlike NDVI) is sensitive to leaf color change (leaf green-up and autumn coloring). They suggested using the threshold of GRVI=0 as a site specific threshold for monitoring phenological changes, and the GRVI index as an indicator for plant disturbances and comparing between different ecosystem types [16].

Current satellite-based remotely sensed products can cover large areas, but is limited both by its temporal (revisit time) and spatial (pixel size) resolutions, when compared to unmanned aerial vehicle (UAV). One of satellite imaging's challenges is dealing with pixels that have multiple objects with different spectral signatures (e.g. plants and soil). Such pixels are called mixed-pixels. UAV imaging high spatial resolution, produces mixed-free pixels, therefore making vegetation detection and differentiation an easier task. Similarly, high spatial resolution allows for precise estimation of vegetation cover fraction.

A basic method for irrigation scheduling is factoring the potential evapo-transpiration (PET), computed from measured radiation, wind speed, air temperature and relative humidity, with a crop specific coefficient (Kc), [17]. Crop coefficients are provided by diverse methods, such as empirical conclusions from field experiments, degree days based seasonal functions, experts' recommendations, and the FAO #56 publication Kc library; or by field specific measurements. Since the evapotranspiration (ET) driving energy received by the crop canopy is directly proportional to the light interception (LI) [18,19], and LI is directly proportional to crop cover, Kc can be fitted to field and plot specific dimension by measuring crop cover. Aerial surveys derived VF is directly proportional to cover, [20] thus aerial photography provides efficient method to Kc determination.

The main objective of this study was to test the ability of an inexpensive RGB camera mounted on an inexpensive unmanned aerial vehicle (UAV) to determine vegetation cover and vigor at the canopy scale in a large scale whole field resolution, and to investigate whether vegetation cover and vigor patterns can be utilized as indicators to irrigation water application uniformity. Another objective of this study was to compare the efficiency of an RGB based VI, with the well-known NDVI, both in UAV based high spatial resolution cameras and also via satellite imaging.

2. Materials and Methods

2.1 UAV imaging system

DJI Phantom 4 quadcopter UAV was used as the flying platform. The UAV is equipped with a built-in RGB camera with 4000x3000 pixel 4K resolution CMOS sensor, 20mm (35 mm eq.) lens with FOV of 94°, in a 3-axis stabilized gimbal. The UAV was flown using Pix4D Capture pre-programmed flightpath control. The Parrot Sequoia multispectral sensor was used in order to compare NDVI with GRVI. The Parrot Sequoia sensor consist of five downward looking image sensors: Visible 16 MPixel (RGB) with a definition of 4608x3456 pixels, and four 1.2 MPixel: Green (550 nm), Red (660 nm), Red

Edge (735 nm), and Near infrared (790 nm) bands, 1280x960 pixels. The sensor was mounted on a DJI Mavic-Pro small size foldable rotors quadcopter UAV.

2.2 *Flight campaigns*

Flight campaigns were conducted in two test sites: at the Gadot center pivot test site (33° 2'22.91"N , 35°38'0.43"E), and at the Havat Gadash field crops experimental farm (33°10'56.24"N , 35°35'5.78"E), both located in the Upper Galilee region in within the northern part of Israel. The area has a Mediterranean climate, characterized by wet, mild winters, and hot, dry summers. Annual winter rainfall in the range of 400-600 mm, while summer crops utilize 80-120 mm of winter soil water storage for initial growth periods. The field at the Gadot center pivot test site was cultivated with cotton crop, sown on April 4, 2017. The field was irrigated at 8 days intervals beginning from June 3. Two flight campaigns were conducted on July 5, and August 24, when the crop has already reached full cover. The flights were conducted at mid-day, at 50m altitude, and pixel spatial resolution of 0.02m. At the Havat Gadash Peanuts cv *Hanoch* were sown on May 1, 2017 and irrigated uniformly by an experimental lateral move, starting at May 8 (**Table 1**). PET was calculated according to the Penman-Montieth formula. Four differential irrigation treatments: 120%, 100%, 85% and 70% replacement of PET, starting on July 19. Prior to this date, uniform irrigation was applied to all treatments (**Table 1**). The Kc (70%) treatment yielded the highest, and was selected for ground truth validation. Experimental plots were 12x25m four plots side by side in 4 replicates. Seven flight campaigns were conducted at mid-day, at 10-50m altitude, and pixel spatial resolution of 0.006-0.02m. Crop cover didn't reach full cover during the first two campaigns (June 25, July 17).

Table 1: Cumulative ET, irrigation water applied, and Kc in the peanut irrigation experiment, Havat Gadash 2017.

	Date	**Cumulative ET (mm) ***	**Irrigation (mm)**	**Cumulative irrigation (mm) ***	**Kc ** **
Uniform irrigation	04/06/2017	170	40	40	0.23
	13/06/2017	230	40	80	0.35
	29/06/2017	342	45	125	0.37
	06/07/2017	389	45	170	0.44
	12/07/2017	432	45	215	0.50
0.7 Kc Irrigation	19/07/2017	43	37	37	0.86
	27/07/2017	96	37	74	0.77
	03/08/2017	143	37	111	0.78
	10/08/2017	186	37	148	0.80
	19/08/2017	240	37	185	0.77
	30/08/2017	308	37	222	0.72
	10/09/2017	369	37	259	0.70
	24/09/2017	434	40	299	0.69

* Cumulative amounts recalculated for the two experimental stages
** Kc calculated as cumulative irrigation divided by cumulative ET

Flight courses were created with the Pix4Dcapture software, which was also used to automatically pilot the DJI Phantom 4 UAV according to the flight path. Overlap percentage of 60% was chosen in order to ease the task of mosaicking.

In order to compare between NDVI and GRVI, a flight campaign using the DJI Mavic-Pro UAV was conducted in the peanut field at the Havat Gadash experimental farm, on October 10, twelve days before the end of the growing season. The Parrot Sequoia multispectral sensor was used to create the NDVI, while the RGB camera was used to create the GRVI.

2.3 *Data processing*

The images collected in each flight campaign were mosaicked and georeferenced using the Pix4Dmapper software. ArcGIS 10.5 geo-referencing tools were used for fine adjustments.

VF was calculated using ArcGIS 10.5, calculating the histogram of the GRVI products. Pixels with GRVI values greater than 0 were classified as vegetation. At the beginning of the growing season, negative values that were close to 0 were also classified as vegetation.

Sentinel-2 Level-2A atmospherically corrected images of the Gadot test site from August 29, 2017 were acquired curtsey of the Copernicus Open Access Hub. Several VI were created and compared to the UAV image from August 24, in order to check whether it is possible to use Sentinel-2 satellite imaging (with spatial resolution of 10m) to determine irrigation uniformity issues. The VI that were checked are: NDVI [5], GNDVI [9] and GRVI [5,16].

3. Results and discussion

3.1 Havat Gadash experimental farm campaign

The RGB images (**Fig. 1A,C**) have high spatial resolution from which crop can be differentiated from soil. The GRVI images reveal crop phenological stages: most of the vegetation pixels' GRVI values in the image taken 55 days from sowing are around zero, and even slightly below zero (**Fig. 1B**), G/R ratio is close to one and even less than 1 – indicative to the beginning of the growing season. On the other hand, most of the vegetation pixels' GRVI values in the later image from 77 days from sowing (**Fig. 1D**) are above zero, indicative to healthy and vital vegetation suitable to midseason phenological stage. Therefore, GRVI is also helpful in determining phenological stages. The VF determined according to the GRVI images histograms was 40% and 80% (**Fig. 1B,D** respectively). The calculated Kc for the campaign dates (**Table** 1) are in-par with the calculated VF, validating the VF calculations.

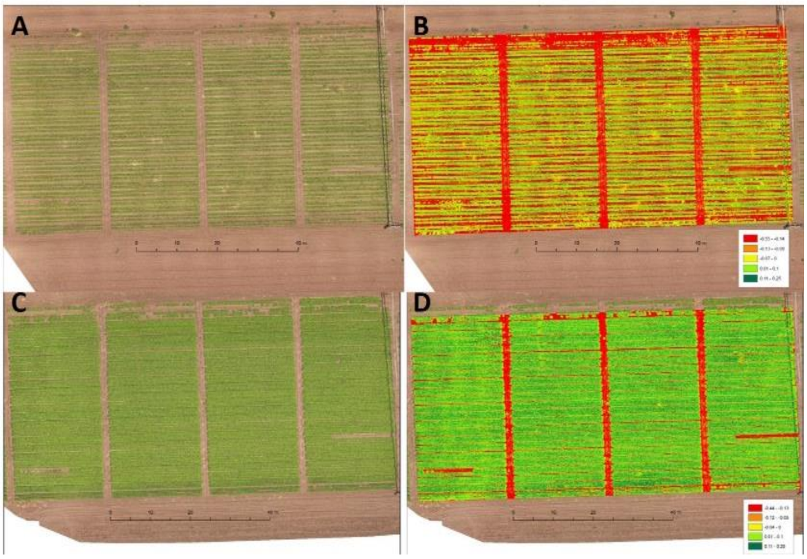

Figure 1: RGB (A+C) and GRVI (B+D) images of the peanut field in Havat Gadash experimental farm on 25/6 (A+B, 55 days from sowing), and on 17/7 (C+D, 77 days from sowing).

3.2 Comparison between NDVI and GRVI

Since there are 2 different sensors measuring the NDVI and the GRVI (**section 2.3**), the spatial resolution of the NDVI is lower (pixel size of 0.0373m) than that of the GRVI (0.0095m). thus enabling sharper GRVI imagery. The image was taken toward the end of the season, depicting plants in different stages of senescence. As can be seen in **Fig. 2**, GRVI captures plant senescence better than the NDVI: changes in plant color from green to yellow is depicted more accurately in the GRVI image, when compared to the NDVI image. Greener vegetation (depicted in the RGB image **Fig. 2A**) has higher GRVI values (**Fig. 2B**). On the other hand, the NDVI image (**Fig. 2C**) doesn't capture the differences between plants that are visible in the RGB image (**Fig. 2A**). NDVI values are very high for most pixels, indicating saturation of NDVI values, probably due to high LAI values [7,11,12]. It is probable that differences in pixel resolution are also responsible for the accuracy differences. Regardless, for the purpose of vegetation classification and vigor analysis, the use of RGB VI is better than the NDVI, thus making the Parrot-Sequoia NIR sensor superfluous.

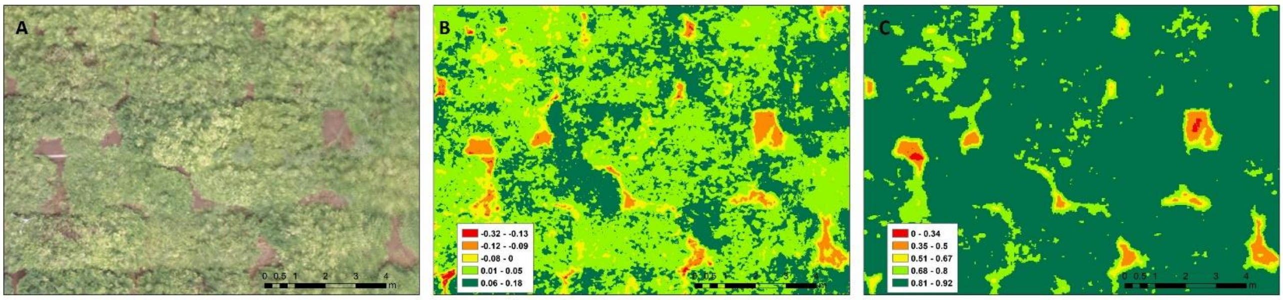

Figure 2: RGB (A), GRVI (B) and NDVI (C) zoom-in images of the peanut field at Havat Gadash experimental farm.

3.3 Gadot test site campaign

The images of the Gadot pivot irrigated cotton crop were taken after the crop has reached full canopy cover (**Fig. 3A,C**). A closer look at the GRVI images can reveal "sector" lines, indicating differences in plant vigor (**Fig. 3B,D**). The "sector" patterns are an indicative of ununiformed irrigation, due to intermittent pivot movement: the "greener" areas probably received more irrigation, due to lower pivot speed. This could be resulted from physical obstacles, uneven ground, malfunctioning pivot control, etc. Whereas these "sectors" are noticeably visible by the GRVI image, it's impossible to notice them from the RGB image. Therefore using the GRVI in this case is crucial in order to detect irrigation uniformity and irrigation malfunctions and other subtle disturbances.

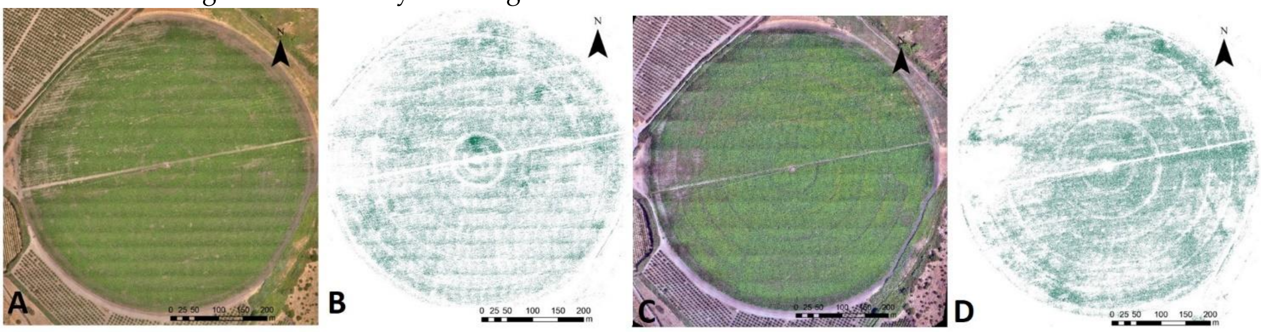

Figure 3: RGB (A+C) and GRVI (B+D) images of the cotton field in Gadot test site on 05/07 (A+B), and on 24/08 (C+D).

3.4 Sentinel-2 satellite VI of Gadot test site

The NDVI and GNDVI images are pretty similar, showing high values homogenously throughout the whole field, except the middle left corner (**Fig. 4A,B**). The GRVI image is more heterogeneous, showing patches of low values, that are correlated to the UAV high resolution GRVI image's patches (**Fig. 4C, Fig. 3D**), indicative of the field's heterogeneity of plant vigor and ununiformed irrigation. The GRVI is therefore better at presenting the real crop vigor situation. Whereas Saturation of red reflectance at intermediate to high Chlorophyll values is well known [10,15] and is indicative to NDVI, it is surprising to see that the GNDVI is also saturated and doesn't show the field's heterogeneity.

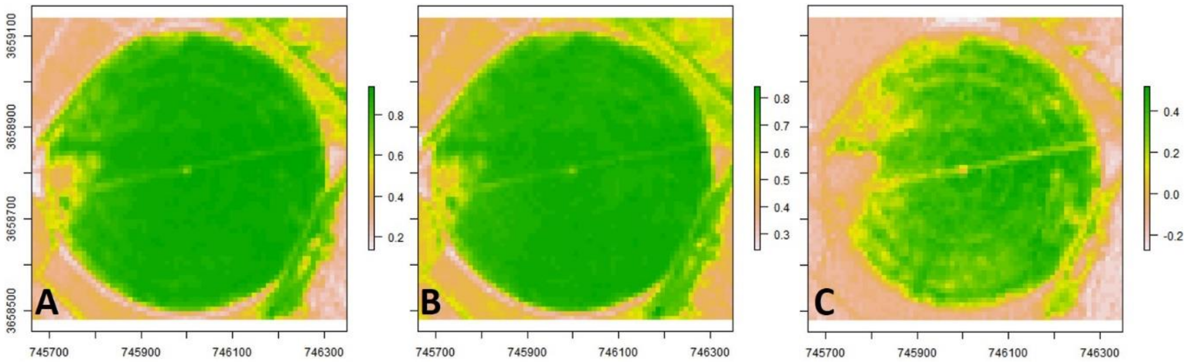

Figure 4: NDVI (A), GNDVI (B), and GRVI (C) vegetation indexes based on a Sentinel-2 imagery of the cotton field in Gadot test site from 29/08/2017

4. Conclusions

In this study the ability of a high resolution RGB imaging to determine vegetation cover and vigor at the canopy scale in a large scale whole field resolution was evaluated, using an RGB VI, the GRVI. It was concluded that the GRVI is suitable for determining vegetation cover, distinguishing between vegetation and other land covers (such as soil and dead vegetation, **Fig. 1**). VF can be accurately measured and be used by the farmer “on the spot” in order to directly define Kc. It was also shown that the GRVI can be used to distinguish plant’s phenological stages: detecting early season and senescence is easy with GRVI: when GRVI is lower than 0, that’s a sign for low plant’s vigor; when GRVI is greater than zero, this indicated strong plant vigor and is indicative to mid-season plant phenological stage (**Fig. 1-2**). It was also concluded that GRVI is better than NDVI and GNDVI in detecting subtle disturbances in mid-season period (**Fig. 4**). High resolution RGB imaging can be utilized to monitor irrigation water application uniformity, and to detect heterogeneity in field irrigation (**Fig. 3**). Since both the camera and the UAV used in this research are inexpensive and available, and with current auto-pilot UAV existing technologies easing the use of UAVs, the presented tools should be available for “on the spot” farming decision making processes involving precision irrigation and irrigation management.

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