Evaluating Different Vegetation Indices for Assessing Crop Growth Condition Derived from UAV Images

F. Feizolahpour [a, *], M. H. Afshar [b], E. Duzenli [b], S. Besharat [a], M. T. Yilmaz [b]

[a] Department of Water Engineering, Urmia University, Oroumieh, Iran - f_feizolahpour@yahoo.com, s.besharat@urmia.ac.ir
[b] Department of Civil Engineering, Orta Doğu Teknik Üniversitesi, Ankara (afshar.mahdi, eren.duzenli, tuyilmaz)@metu.edu.tr

KEY WORDS: UAV, Vegetation Index, crop yield productivity, multispectral images

ABSTRACT:

Crop health monitoring is one of the important issue of successful farming. Traditionally, crop health assessment is a very time consuming and labor intensive process to carry out. Unmanned aerial vehicles (UAVs) present an exciting opportunity to monitor crop fields with high spatial and temporal resolution. In this study, we have used a drone with sequoia sensor to assess crop condition during the growing season. This sensor captures the light reflected by plants in four separate bands (green, red, red-edge, and near-infrared bands based indices). Different multispectral vegetation indices such as the Normalized Difference Vegetation Index (NDVI), the Green Normalized Difference Vegetation Index (GNDVI), the Soil Adjusted Vegetation Index (SAVI), and the Normalized Difference Red Edge (NDRE), were analyzed to assess crop yield productivity and evaluate the effect of different stresses on crop yield. Three different Irrigation level (100%-80%-60% of water requirement) and Three N fertilizer level (100%-80%-60% of fertilizer requirement) were applied to maize experimental plots. Experiments were carried out in a randomized complete block design (RCBD) with factorial arrangement in 6 replications. Vegetation indices were computed from the derived orthoimage for different treatments and compared with ground samples. Based on the results, the minimum values for NDVI, GNDVI, SAVI and NDRE indices were obtained respectively 0.75, 0.65, 0.62, 0.37 and their maximum values respectively 0.79, 0.70, 0.78 and 0.46. Also, SAVI and NDRE indices could indicate better plant conditions. This research indicated that high-resolution UAV data have great potential in collect multispectral images for precision farming applications and farmers no longer need to spend hours or days surveying on foot. Instead they can collect data, run analyses, and act on problems all in the same day.

1. INTRODUCTION

Crop health management is one of the cornerstones of a successful farming season. Traditionally, crop health assessment was a very time consuming and labor intensive process to carry out. With the help of remote sensing technology and advanced sensors like the Sequoia multispectral sensor, farmers no longer need to spend hours or days surveying on foot. Instead they can collect data, run analyses, and do an action about their problems all in the same day.

In recent years, the use of remote sensing technology has been developed for modelling of crop yield and monitoring agriculture drought because of high temporal and spatial resolution in acquiring water, soil, plant data and the ability of evaluating different crop stresses. In general, there are two categories of methods to estimate crop yield by use of remote sensing. a) Empirical models, which fit a regression equation to predict crop yield based on vegetation indexes (VIs) such as NDVI, NDWI, EVI, RVI, MSAVI and etc. b) Semi-empirical methods, which the most important of them is Monteith (1972) equation as:

$$Bio_{act}^{tot} = \varepsilon \sum (APAR(t)(t)(Kgm^{-2}) \qquad (1)$$

Where (kg/m2) is the accumulated biomass in period t, ε (g M/J) the light use efficiency and t describes the period over which accumulation takes place. According to the above, each method has some advantages and disadvantages explained below.

Empirical models are easy to utilize but they don't consider all factors and are valid for the studied region. In other hand, semi empirical models are general and they can be used in other places by calibration in that region, while they have more parameters and also don't consider all parameters like fertilizer and pests' stresses.

Kroos et al. (2015) by using RapidEye satellite vegetation indices provided a set of relationships for estimating leaf area index and biomass of both maize and soybeans. They used seven vegetation indices based on the combination of green, red, red-edge and near infrared gangways for 2011-2013. Kogan et al. (2012) by examining NDVI and LST indices on plants such as wheat, sorghum and corn, concluded that NDVI is a cumulative index and is suitable for evaluating plant growth. Johnson (2014) investigated the correlation between NDVI data, daily and nightly LST of MODIS sensor and precipitation with the yield of corn and soybean plants. According to their results, daily NDVI and LST data correlate well with plant yield. Stanton et al. (2017) used a drone to examine plant conditions under pest stress. During a test in different plots, they created different pest stress levels and measured their reflection with the drone and examined the NDVI index and plant height. Anderson et al. (2016) conducted a study on the correlation of plant yield with the index of evapotranspiration (ESI), surface temperature (LST) and leaf area index (LAI) over the period 2003-2013 for dominant products in Brazil.

In the current study, we are trying to analyse the potential utility of different multispectral vegetation indices to monitor crop condition. The study involved the use of a standard UAV service for acquiring multispectral images and explores the

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

possibilities of using this type of service in commercial farms on a day-to-day basis.

2. MATERIALS AND METHODS

2.1 Study area and Field Experiments

Field experiments were carried out in a farm with different irrigation and Fertilization managements at the Urmia University, IRAN. The farm had a steady topography with gentle slope and deep underground water level. The characteristics of the farm are presented in the table 1.

Farms	1
Area	0.4 ha
Crop	Corn
Irrigation level (I)	3 (100%-80%-60%)
Nitrate fertilizer level (F)	3 (100%-80%-60%)
Repeats	6

Table 1. The characteristics of the farm

Experiments were carried out in a randomized complete block design (RCBD) with factorial arrangement in 6 replications. Analysis of variance of all product performance data was done with SPSS software. The mean of data was analysed based on LSD test at 5% level (Figure 1).

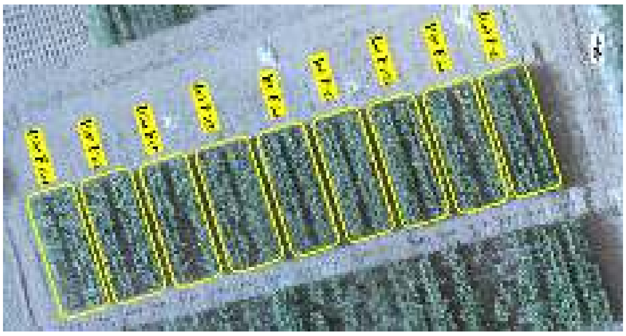

Figure 1. Study area and location of the treatments

2.2 Remote sensing of plant physiology by UAV

In this study we have used an ebee+ sensefly drone with sequoia sensor to assess crop condition. This sensor captures the light reflected by plants in four separate bands: green, red, red-edge, and near-infrared (Figure 2).

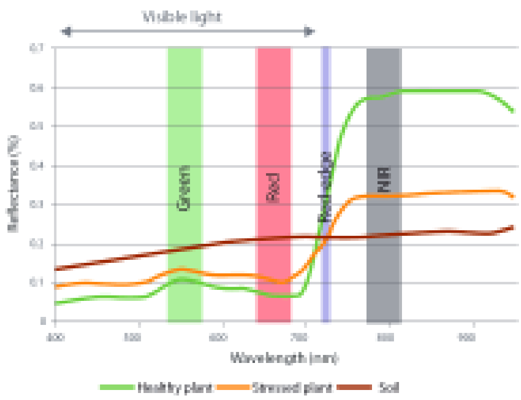

Figure 2. Sequoia bands with their spectral range and the spectral signature of vegetation

2.3 Vegetation Indices from drone Imagery

Vegetation Indices (VIs) are combinations of surface reflectance at two or more wavelengths designed to vegetation's vigor and vegetation properties (e.g. chlorophylls and xanthophyll), which can indeed reflect plants' physiological status (Jones and Vaughan, 2010; Table 2). Between different VIs, the most employed indices are: Normalized Difference Vegetation Index (NDVI) (Rouse et al. 1973), Green Normalized Difference Vegetation Index (GNDVI) (Gitelson et al. 1996), Soil Adjusted Vegetation Index (SAVI) (Huete ,1988) and Normalized Difference Red Edge Index (NDRE).

Index	Formula
NDVI	$\frac{\rho NIR-\rho R}{\rho NIR+\rho R}$
GNDVI	$\frac{\rho NIR-\rho G}{\rho NIR+\rho G}$
SAVI	$\frac{\rho NIR-\rho R}{\rho NIR+\rho R+Lc}(1+Lc)$
NDRE	$\frac{\rho NIR-\rho RedEdge}{\rho NIR+\rho RedEdge}$

Table 2. The considered vegetation indices where ρNIR, ρL, ρG and ρRedEdge represent the reflectance in the specific bands; L is a constant empirical value related to the vegetation density on the ground.

3. RESULTS AND DISCUSSION

The images taken using the UAV were processed in the pix4d software environment, and after the creation of the orthodontic maps, calculations were carried out on the determination of vegetation indices within the desired area. The NDVI, GNDVI, SAVI and NDRE indices maps are shown in Figure 3.

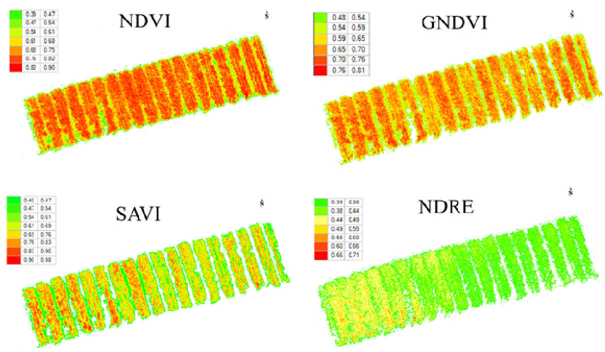

Figure 3. The NDVI, GNDVI, SAVI and NDRE maps for the study area.

Also, crop yield was measured for different treatments and its results are presented in Fig 4. Accordingly, by reducing the amount of water and fertilizer, the yield of the crop has also decreased. The highest crop yield for I100F100 and I80F100 treatments were 92.87 and 92.67 kg / ha, respectively and the lowest yield was related to I60F60 treatment with 60% water and fertilizer requirement.

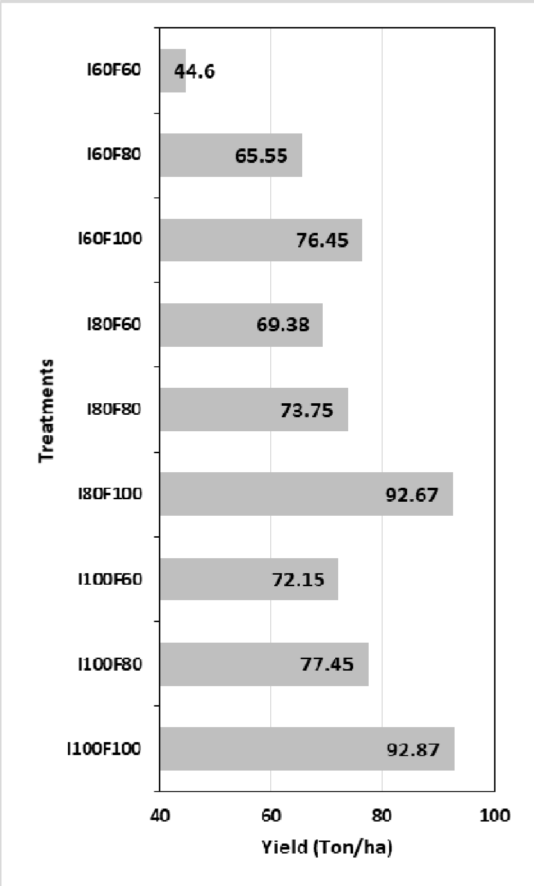

Figure 4. Sequoia bands with their spectral range and the spectral signature of vegetation

Table 3 and Figure 5 represent the overall results of corn yields. Based on the results of analysis of variance of data (Table 3), crop yield was affected by irrigation levels, fertilizer and their interaction at 5% level.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
C Model	10096.86[a]	8	1262.108	232.24	0
Intercept	294694.02	1	294694.02	54228.68	0
Irr	3723.17	2	1861.587	342.56	0
Fer	5826.15	2	2913.080	536.05	0
Irr*Fer	547.53	4	136.883	25.19	0
Error	244.54	45	5.434		
Total	305035.43	54			
C Total	10341.40	53			

Table 3. Analysis variance of crop yield under the influence of irrigation levels, fertilizer and their interaction (Irr is abbreviation of Irrigation, Fer is abbreviation of Fertigation, and C is abbreviation of Corrected)

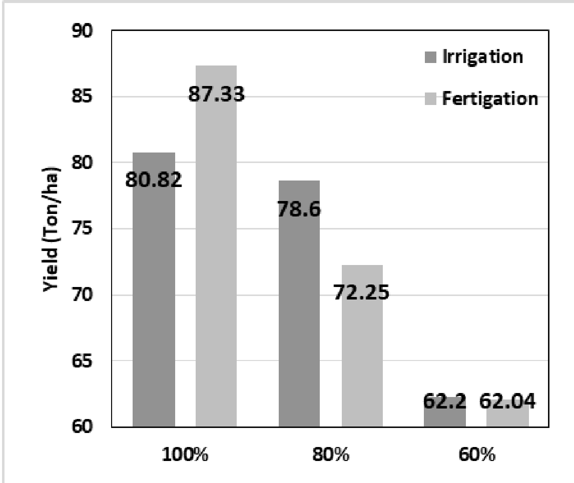

Figure 5. Comparison the effect of irrigation and fertilizer levels on crop yield

According to the Figure 5, by reducing the amount of fertilizer and water application, the yield of the crop significantly decreased. Accordingly, the yield of corn in treatments with irrigation and fertilization levels of 100% was 80.82 and 87.33 kg / ha respectively, which by reducing 40% of irrigation and fertilizer, yield of corn decreased to 62.2 and 62.04 kg / ha respectively.

The results of variance analysis of NDVI amounts indicated that the effect of irrigation and fertilizer levels has not affected on NDVI statistically during different treatments. Based on the results (table 3), the values of NDVI for different treatments ranged from 0.75 to 0.79, and between different levels of irrigation and fertilization, there was no significant difference between index values.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
C Model	.004[a]	8	.000	1.86	0
Intercept	31.970	1	31.970	132190.08	0
Irr	.000	2	.000	.64	.530
Fer	.001	2	.000	1.93	.157
Irr*Fer	.002	4	.001	2.43	.061
Error	.011	45	.000		
Total	31.985	54			
C Total	.014	53			

Table 4. Analysis variance of NDVI under the influence of irrigation levels, fertilizer and their interaction (Irr is abbreviation of Irrigation, Fer is abbreviation of Fertigation, and C is abbreviation of Corrected)

The results of analysis of variance of data (Table 5) indicated that just the effect of irrigation levels on GNDVI index was significant. So, the effect of fertilizer levels and its interaction with irrigation at 5% level was not significant on GNDVI values and there was no statistically difference between the GNDVI in these treatments. Moreover, the average values of GNDVI for treatments with 100 percent irrigation levels were 0.694, which was statistically more than 60 and 80 percent levels (Figure 6).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
C Model	.006ª	8	.001	2.726	.015
Intercept	25.242	1	25.242	91359.678	.000
Irr	.003	2	.002	5.818	.006
Fer	.001	2	.000	1.334	.274
Irr*Fer	.002	4	.001	1.877	.131
Error	.012	45	.000		
Total	25.261	54			
C Total	.018	53			

Table 5. Analysis variance of GNDVI under the influence of irrigation levels, fertilizer and their interaction (Irr is abbreviation of Irrigation, Fer is abbreviation of Fertigation, and C is abbreviation of Corrected)

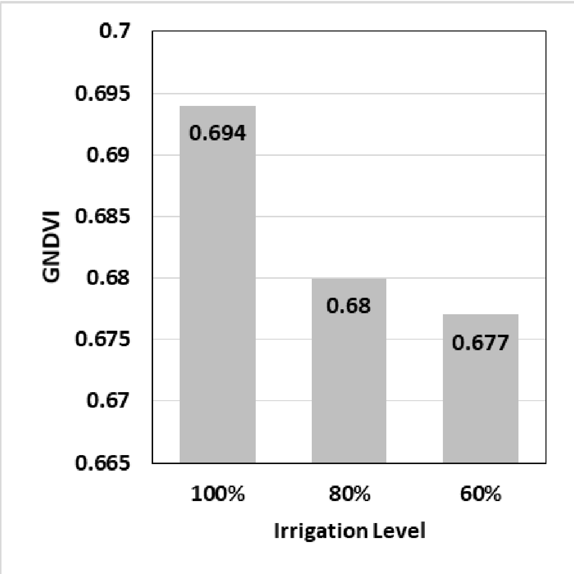

Figure 6. Comparison the effect of irrigation levels on GNDVI

Concerning the SAVI index, the results of statistical analysis indicated that the effect of irrigation levels, fertilization and their interaction on this index was significant. Thus, the average values of SAVI for irrigation level of 100 percent were equal to 761 and more than 60 and 80 percent levels, and there was no significant difference between levels 60 and 80.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
C Model	.102ª	8	.013	9.706	.000
Intercept	27.292	1	27.292	20681.899	.000
Irr	.076	2	.038	28.949	.000
Fer	.008	2	.004	3.176	.050
Irr*Fer	.018	4	.004	3.350	.017
Error	.059	45	.001		
Total	27.454	54			
C Total	.162	53			

Table 6. Analysis variance of SAVI under the influence of irrigation levels, fertilizer and their interaction (Irr is abbreviation of Irrigation, Fer is abbreviation of Fertigation, and C is abbreviation of Corrected)

Moreover, according to Figure 7, the mean values of SAVI for treatments with fertilization levels of 100 and 80 were not statistically significant, but more than those for treatments with fertilization levels of 60 percent. While investigating NDRE values showed that similar to SAVI index, effect of irrigation levels, fertilizer and interaction of water and fertilizer were significant on NDRE values (Table 7).

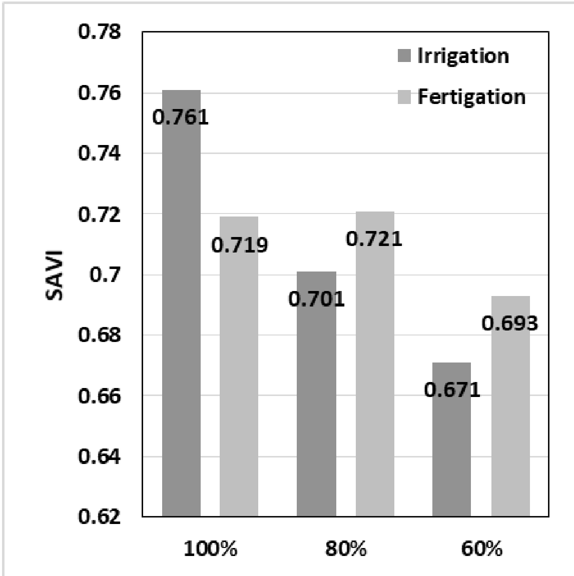

Figure 7. Comparison the effect of irrigation and fertilizer levels on SAVI

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
C Model	.068ª	8	.008	33.548	.000
Intercept	9.392	1	9.392	37290.471	.000
Irr	.062	2	.031	123.713	.000
Fer	.002	2	.001	3.228	.049
Irr*Fer	.004	4	.001	3.625	.012
Error	.011	45	.000		
Total	9.471	54			
C Total	.079	53			

Table 7. Analysis variance of crop yield under the influence of irrigation levels, fertilizer and their interaction (Irr is abbreviation of Irrigation, Fer is abbreviation of Fertigation, and C is abbreviation of Corrected)

As shown in Figure 8, the average values of NDRE for treatments with irrigation levels of 100, 80 and 60 percent were respectively 0.463, 0.450, and 0.383 and the difference between them statistically were significant at 5%. Also, the effect of fertilizer levels was significant on NDRE and its value for treatments with 100% fertilizer application was higher than 60% treatments.

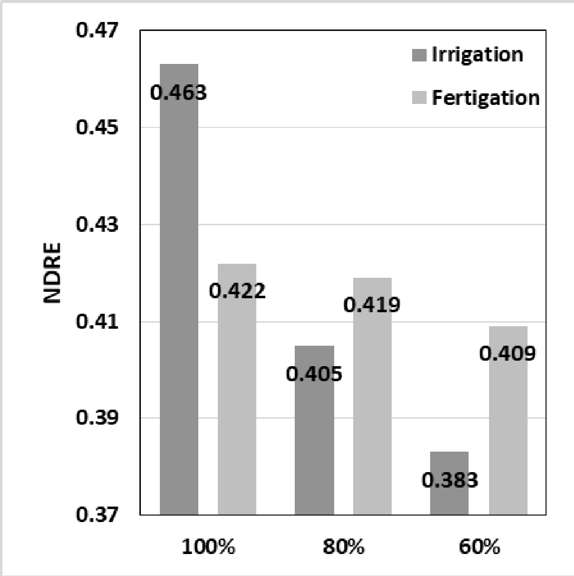

Figure 8. Comparison the effect of irrigation and fertilizer levels on NDRE

4. CONCLUSIONS

In recent years, the use of UAVs has been improved to monitor crop status due to high spatial and spectral resolution and ease of their use. In this study, a field experiment was carried out with corn cultivation under different levels of irrigation and fertilization and the ability of different vegetation indices was studied based on statistical analysis. At the end of the growing season, crop yield was measured based on plant sampling and vegetation indices were calculated using UAV images. Based on the results, the level of crop yield decreased significantly with decreasing water and fertilizer rates. Investigating the effect of different levels of water and fertilizer on vegetation indices showed that NDVI index had no significant effect on water and fertilizer levels. GNDVI index changes were significant in irrigation levels. In contrast, the values of SAVI and NDRE indices were significant compared to irrigation levels, fertilizer and their interaction. This research indicated that high-resolution UAV data have great potential in collect multispectral images for precision farming applications and farmers no longer need to spend hours or days surveying on foot. Instead they can collect data, run analyses, and act on problems all in the same day.

REFERENCES

Anderson, M. C., Zolin, C. A., Sentelhas, P. C., Hain, C. R., Semmens, K., Yilmaz, M. T., ... & Tetrault, R (2016). The Evaporative Stress Index as an indicator of agricultural drought in Brazil: An assessment based on crop yield impacts. Remote Sensing of Environment, 174, 82-99.

Gitelson, A. A., Kaufman, Y. J., & Merzlyak, M. N. (1996). Use of a green channel in remote sensing of global vegetation from EOS-MODIS. Remote sensing of Environment, 58(3), 289-298.

Huete, A. R. (1988). A soil-adjusted vegetation index (SAVI). Remote sensing of environment, 25(3), 295-309.

Johnson, D. M (2014). An assessment of pre-and within-season remotely sensed variables for forecasting corn and soybean yields in the United States. Remote Sensing of Environment, 141, 116-128.

Jones, H. G., & Vaughan, R. A. (2010). Remote sensing of vegetation: principles, techniques, and applications. Oxford university press.

Kogan, F., Salazar, L., & Roytman, L (2012). Forecasting crop production using satellite-based vegetation health indices in Kansas, USA. International Journal of Remote Sensing, 33(9), 2798-2814.

Kross, A., McNairn, H., Lapen, D., Sunohara, M., & Champagne, C (2015). Assessment of RapidEye vegetation indices for estimation of leaf area index and biomass in corn and soybean crops. International Journal of Applied Earth Observation and Geoinformation, 34, 235-248.

Monteith J (1972). Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology, 9: 747–766.

Rouse Jr, J., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS.

Stanton, C., Starek, M. J., Elliott, N., Brewer, M., Maeda, M. M., & Chu, T (2017). Unmanned aircraft system-derived crop height and normalized difference vegetation index metr ics for sorghum yield and aphid stress assessment. Journal of Applied Remote Sensing, 11(2), 026035.