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Short Communication

Evaluation of wheat canopy cover using NDVI in large areas of Iran

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ABSTRACT-To studies a suggested method for estimating fractional green canopy cover (FGCC or CC) from normalized difference vegetation index (NDVI) in Iran, a research project was carried out on four wheat farms in the large-scale region, in Fars and Khuzestan provinces during four growing seasons from 2015 to 2019. Two different image classification methods were used to provide the CCs of farms. In both methods, R^2s were greater than 0.95 and NRMSEs were less than 0.15. A simple regression equation was constructed between CC and NDVI of 64 Landsat 8-Oli images with high accuracy from 2015 to 2018. The R^2s of CC-NDVI equations were 0.84, 0.85, 0.88, 0.80 and 0.76 in Dezful, Omidieh, Darab, Zarghan and all sites together. The simple regression equation was used to simulate CC in 2018-2019 for validating the equation and had a good agreement with the measurements, especially in using the general equation of all sites. The p-values of the four equations were less than 0.03. As a suggested method, the CC-NDVI equation can be used to predict CC from NDVI as a low-cost and less time-consuming method in the study area to use in crop growth studies, crop growth models and crop growth management.

Estimation of crop growth factors is essential in crop growth monitoring, especially in crop models to achieve optimum yield. One of the widely used factors of crop growth studies is fractional green canopy cover (FGCC or CC). There is a relationship between CC and satellite indices, especially normalized difference vegetation index (NDVI).

Crop growth monitoring throughout the growing season has an important role to achieve maximum yield. There is interest in methods of estimating grain yield at earlier growth stages. The traditional methods such as ground measurements are costly and time-consuming. One of the most widely used indicators of crop growth is fractional green canopy cover (FGCC or CC), defined as the portion of the ground covered by green vegetation (Goodwin et al., 218). CC estimation has been also used in determining crop irrigation requirements and crop growth models such as AquaCrop (Allen and Pereira, 2009; Steduto et al., 2009). The most common nondestructive method of identifying CC at the field scale is by taking several photos at different locations using digital cameras and performing image analysis to separate green pixels (representing vegetation) in the photos (Calera et al., 2001). The accuracy of this method depends on the photo quality and the type and complexity of the image analysis technique implemented (White et al. 2000; Patrignani and Ochsner 2015).

Despite several benefits of ground-based digital photography, it is time-consuming and would not be feasible in studying large agricultural areas with a large number of heterogeneous farms. Space-borne remote sensing can be implemented to decrease the cost and time associated with mapping CC at regional scales (Larson 2007; Trout et al., 2008; Johnson and Trout 2012; Chianucci et al., 2018).

In particular, satellite-derived vegetation indices (VIs) such as NDVI, SAVI and VARI can be used to monitor CC variations in the farms. Previous studies have shown that NDVI is highly correlated with crop growth assessment rates (Huete et al., 2002; Taghvaeian et al., 2013).

The relationship between CC and NDVI has been studied in different researches. Gutman and Ignatov (1998) used CC and NDVI map from NOAA -GVI data in weather prediction models on the global scale. Zhang et al. (2013) developed a simple equation to evaluate CC from NDVI in China. It has been reported that the canopy cover of barley was related to NDVI by separating bare soil and shadows from the canopy (Calera et al., 2001).

In a study in California, it was found that NDVI extracted from TM Landsat imagery can be used as an effective parameter for monitoring CC (Trout et al., 2008). Canopy cover was evaluated for 11 horticultural crops using a digital camera by using a simple regression equation between CC and NDVI. (Trout et al., 2008). Johnson and Trout (2012) developed a simple model between CC and NDVI (CC=1.26×NDVI+0.18; R^2=0.96; NRMSE=0.062) for a large number of fields in California under row crops, orchards, and vineyards. Abdolalizadeh et al (2020) estimated rangeland canopy cover by using Landsat OLI data and vegetation indices correlation equation (R^2=0.7) in Sabalan rangelands, Iran.

Casa et al. (2018) developed a non-linear model to estimate soybean CC from Landsat NDVI in 16 sampling areas. Used photographs and Landsat images to estimate CC, had good agreement with R^2=0.956 and R^2=0.939, respectively.

Tenreiro et al. (2021) conducted a meta-analysis of the NDVI-CC relationships with data collected from 19 different studies for 13 different agricultural crops. Correlations were adequate for the majority of crops as R^2 values were above 75% and Root Mean Square Error RMSE around 6–18% for most cases.

Field management varies in distinct soil, crop and water management. Also, spectral reflectance is influenced by agro-climatological conditions such as crop varieties and soil characteristics. Due to these differences, the CC and NDVI relationship change from farm to farm. Applying the CC-NDVI relationships in large areas should be considered spatial differences in soil, crop and water. According to the literature review, the CC correlation equation has not been investigated for southwest and south-central Iran. The importance of this study was to evaluate the CC estimation methods and base the CC-NDVI relationship on irrigated wheat in a wide region. Wheat is the main agricultural product in Iran and the prediction of wheat growth parameters is essential to making national management decisions, especially in the crop model using (Ahmadi et al., 2017). The more specific research objectives of this study included: i) to compare the results of two image processing methods in estimating wheat CC from digital photography; ii) to develop a correlation equation to estimate CC from space-borne NDVI in a large area.

The studied sites were located in Khuzestan and Fars provinces (28°47′-32°16′N, 48°25′-54°17′E) in the southwest (SW) and south-central (SC) Iran, respectively. These provinces hold the top two places in wheat production in Iran (Ahmadi et al., 2017). The four studied sites are classified as semi-arid regions with an annual rainfall of less than 350 mm. Two irrigated wheat fields were selected in Dezful (SW1) and Omidieh (SW2) in Khuzestan Province; and two irrigated wheat fields in Darab (SC1) and Zarghan (SC2) in Fars Province (Fig. 1). The general characteristics of the studied sites are shown in Table 1. Meteorological data were obtained from the nearest station and soil data by sampling in four sites (Table 1). This study was accomplished in the 2015-2016 to 2017-2018 growing seasons to develop a simple model and in the 2018-2019 growing season to validate the models. Wheat planting dates in the study period were from 16 November to 16 December in the four studied sites.

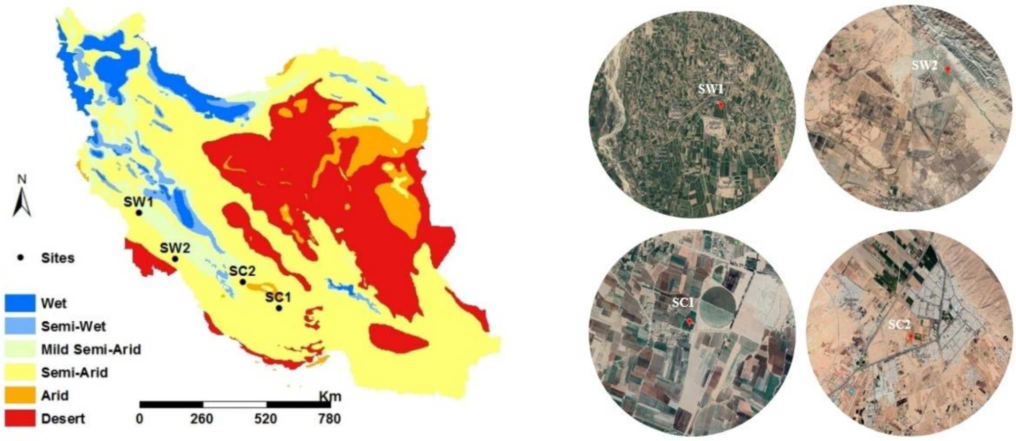

Fig. 1 The location of four studied areas in the southwest (SW1 and SW2) and south-central (SC1 and SC2) of Iran

Table 1. The general characteristics of the studied sites

Properties	SW1	SW2	SC1	SC2
Area ha	8.2	7.4	6.2	5.6
Elevation m	143	35	1098	1604
Soil texture	Silty Clay Loam	Silty Loam	Clay Loam	Silty Clay Loam
Soil pH	7.5	7.5	8	7.5
Wheat variety	Chamran	Mehregan	Sirvan	Sirvan
T_{max} ºC	32	32	27	24
T_{min} ºC	16	18	13	8
RH_{mean} %	56	51	49	52
Annual rainfall mm	295	292	263	316

Canopy cover photos were acquired by a digital camera (model: SX700HS, Canon Inc., Japan) at a 2.0 m vertical distance above the soil surface at an average of three locations within each site. The taking photos times were around solar noon as recommended by Trout et al. (2008). So, in the current study photos were taken around solar noon on 16, 12, 19 and 17 satellite overpass dates in 2015-2016, 2016-2017, 2017-2018 and 2018-2019 wheat growing seasons, respectively as shown in Table 2. The values of the day after planting (DAP) in Table 2 were the dates of the selected satellite overpass.

In this study, CC was estimated from the acquired digital photos using two methods. The first method was based on the supervised classification of photos using ENVI (V5.1, Exelis Visual Information Solutions, Inc.). The second method relied on the Canopeo, a web-based application for CC estimation developed at Oklahoma State University. It has been reported that Canopeo employs an unsupervised approach for detecting green canopy cover (Patrignani and Ochsner 2015). The supervised classification in ENVI is more time-consuming than that of the fully-automated unsupervised classification of Canopeo. However, ENVI allows users to select different classes to achieve higher accuracy. The CC values obtained from each method were compared against each other to determine their differences.

NDVI (Huete et al. 2002) is defined as:

$$\text{NDVI} = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}} \quad \text{Eq. (1)}$$

where NIR and RED stand for the surface reflectance in the near-infrared and red bands, respectively. In this study, NDVI was estimated using the at-surface reflectance maps developed by the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) based on Landsat 8 (OLI) imagery (Masek et al., 2012). LEDAPS employs the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer models to minimize the radiometric errors in developed reflectance maps. The images Path/Row were 166-38, 164-39, 161-40 and 163-39 in SW1, SW2, SC1 and SC2, respectively (Table 2). The spatial resolution of NDVI maps was 30×30 m, which is equal to approximately 11 pixels per hectare. The relationship between CC and NDVI was developed using a linear regression model as Eq. (2):

$$CC=a.NDVI+b \quad \text{Eq. (2)}$$

where a and b are coefficients that should be evaluated in each site. The flow chart describing the proposed methodology and data needs are shown in Fig. 2.

Table 2 Landsat 8 (OLI) path/row and number of NDVI images used in the study area in the growing seasons

	Path/row		Growing season 2015-2016	2016-2017	2017-2018	2018-2019
Dezful	166-38	Planting Date	2015-12-9	2016-12-7	2017-12-7	2018-12-16
		DAP*	24, 90, 120, 150	34, 125, 152	26, 91, 123, 135, 157	35, 98, 115, 131, 150
Omidieh	164-39	Planting Date	2015-11-15	2016-11-25	2017-11-16	2018-11-22
		DAP*	17, 34, 95, 130	39, 104, 136	16, 32, 97, 123	20, 39, 123
Darab	161-40	Planting Date	2015-11-22	2016-12-7	2017-11-23	2018-12-7
		DAP*	22, 70, 110, 140	22, 103, 135	60, 108, 124, 146, 163	35, 98, 115, 131
Zarghan	163-39	Planting Date	2015-11-9	2016-11-15	2017-11-11	2018-11-24
		DAP*	10, 45, 130, 150	45, 145, 172	10, 74, 133, 155, 175	20, 60, 95, 115, 140

* Day after planting (DAP) simultaneously with satellite image picking

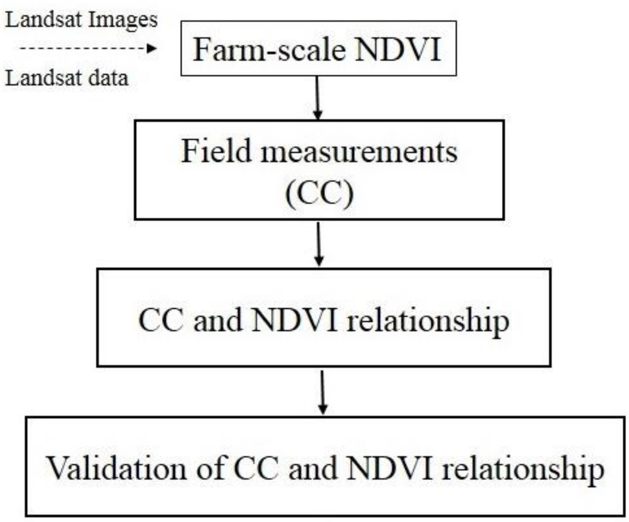

Fig. 2 The flow chart describing the proposed methodology and data needs

Canopy cover based on ENVI analysis ranged from 0.11 to 0.85 in the growing seasons. Fig. 3 demonstrates the digital photo captured on 12 January 2017 at SW1 and the corresponding CC images derived from ENVI and Canopeo methods.

The similarities in the supervised ENVI and unsupervised Canopeo estimates of CC are also evident in Fig. 4, especially for CC ratios between 0.30 and 0.70. The reason for the more agreements in the middle stages is due to the high contrast of the green vegetation and a more appropriate distinction between colors in both methods. The distinction between wheat canopy, bare soil, shadows, and senesced vegetation is more difficult in the early and late periods of the growing season. ENVI and Canopeo showed similar results in CC evaluation in each site (R^2s were greater than 0.95 and NRMSEs were less than 0.15) and in all sites together (p-value = 0.87, R^2=0.96, NRMSE=0.05).

The NDVI change rates were similar to those of CC at all studied sites. Plotting CC against NDVI (Fig. 5) revealed a simple regression model as Eq. 2. In the form of Eq. 2, the values of a, b and R^2 were obtained as 1.06, -0.08 and 0.84 in Dezful; 1.18, -0.04 and 0.85 in Omidieh; 1.15, -0.12 and 0.87 in Darab; and 1.07, -0.01 and 0.81 in Zarghan, respectively. By using the general relationship between CC and NDVI of all sites together, a, b and R^2 were obtained as 1.05 and -0.03 and 0.76, respectively.

In the study areas, better CC measurement conditions were usually provided in the early and late stages of growth. The measurements were often in the coverage of below 0.3 and above 0.8 which can be seen in Fig. 5.

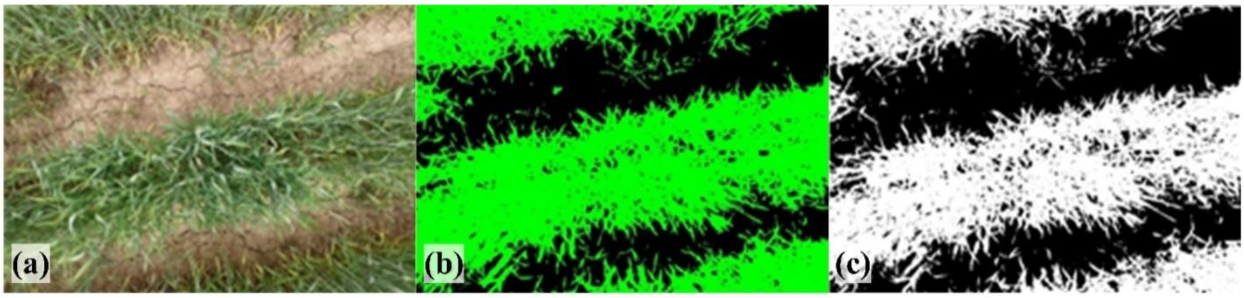

Fig. 3 Digital photo of wheat canopy cover taken on 12 Jan. 2017 at SW1 (**a**) along with CC images derived by ENVI (**b**) and Canopeo (**c**)

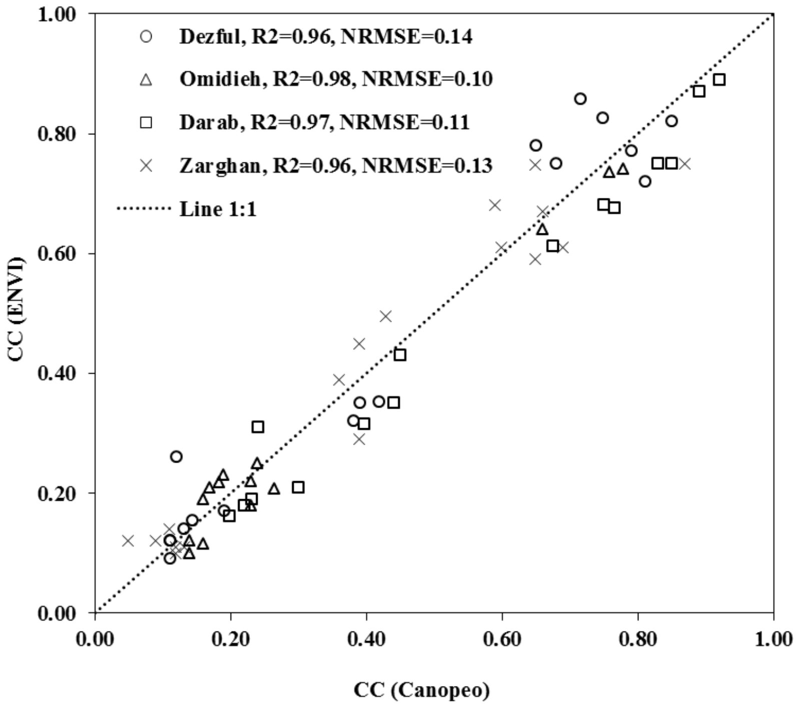

Fig. 4 Comparison between CC values evaluated by ENVI and Canopeo methods along the 1:1 line in the study area

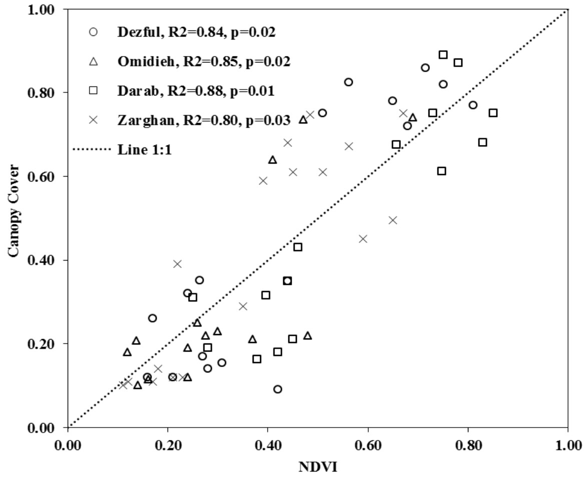

Fig. 5 Relationship between ground-based CC and space-borne NDVI for irrigated wheat in 2015 to 2017 growing seasons in the study area.

The NDVI values in the 2018-2019 growing season were used in simple relationships to simulate CC and validate site models (Fig. 6). The R^2 values were obtained greater than 0.93 which indicated the accuracy of simple models to simulate CC by using CC-NDVI relationships. The NRMSEs between measured and simulated CCs were obtained as 0.28, 0.47, 0.15 and 0.32 in Dezful, Omidieh, Darab and Zarghan, respectively. Using the general CC-NDVI regression model (a=1.05 and b=-0.02) instead site regression models changed the NRMSs between measured and simulated CC to 0.22, 0.33, 0.14 and 0.25 in Dezful, Omidieh, Darab and Zarghan, respectively. The R^2 values of using the general model were close to those in each site model used. It was shown that using a general equation in each site had a more accurate CC prediction compared to using each site equation. It is supported by the use of the obtained general equation to predict canopy cover from NDVI in large areas.

NDVI can be used as a reliable indicator of CC. The coefficients of Eq. 2 in the studied region were in agreement with simple regressions developed in prior studies in different sites. The results of previous studies along with the present study are shown in Table 3 indicating the values of R^2s in the present study were in the range of previous studies.

Ground-based digital photography was used to evaluate canopy cover (CC) of irrigated wheat in four study sites in semi-arid regions of Iran during four growing seasons. Two methods were used in estimating CC from digital photos including i) supervised classification in an image processing environment; and, ii) unsupervised classification conducted by a web-based application (Canopeo). Both methods revealed close results.

Simple regression models were constructed between CC and NDVI in each site and all sites together. Canopy covers were simulated with simple models and showed high similarity with measurements especially by using the general modal. The superiority of the general model to simulate CC supported the unsupervised use of the method in other regions. Furthermore, the developed relationship was similar to those developed for other crops and in other parts of the world (Table 3). Using this approach provides the ability to develop CC maps of wheat farms in the region. The web-based application is recommended for CC estimation due to its fully automated approach and less time-consuming.

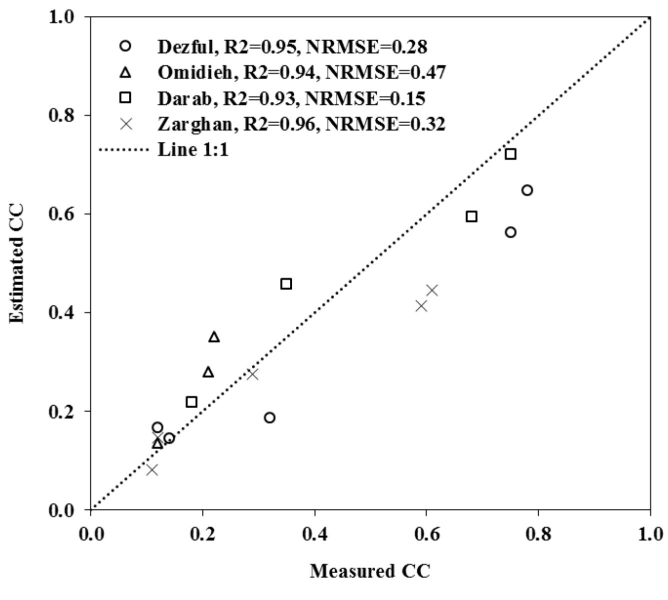

Fig. 6 Measured and simulated canopy cover in the 2018-2019 growing season using CC-NDVI equation in the study area

Table 3 Coefficients of CC-NDVI relationships in different studies

a*	b*	R^2	Crop	Site (Ref.)
1.06	-0.08	0.84	Wheat	Iran, Dezful (This study)
1.18	-0.04	0.85	Wheat	Iran, Omidieh (This study)
1.15	-0.12	0.87	Wheat	Iran, Darab (This study)
1.07	-0.01	0.80	Wheat	Iran, Zarghan (This study)
1.05	-0.03	0.76	Wheat	Iran, south areas (This study)
1.09	-0.07	0.94	Cotton	U.S. (Barnes et al., 2000)
0.99	-0.11	0.96	Barley	Spain (Calera et al., 2001)
1.18	-0.14	0.89	Wheat	Morocco (Er-Raki et al., 2007)
1.11	-0.11	0.96	Wheat	Spain (López-Urrea et al., 2009)
1.26	-0.18	0.96	18 crops	U.S. (Johnson and Trout, 2012)
-	-	0.93	6 crops	U.S.(Prabhakara et al., 2015)
1.21	-0.04	0.94	Soybean	Argentina (Casa et al., 2018)
1.05	-0.06	0.71	1397 crops	(Tenreiro et al., 2021)

*a and b are the slope and intercept in CC=a×NDVI+b

Remote sensing estimates can be obtained under a variety of physical and agricultural practices in a large area. With the availability of satellite images, the suggested method can be extended to other regions. This methodology is an efficient and low-cost approach to replace the use of ground measurements for evaluating canopy cover as a widely used parameter in crop studies.

This study was done only in four regions and four years. Other different tools and methods should also be studied for measuring canopy cover . A limitation of this method is the need for high accuracy in determining the NDVI at the same point of CC measurement. A large amount of data is needed to achieve more accurate results in the CC-NDVI equation. NIR and R are severely influenced by irrigation, plant daily age, atmospheric interference and irradiance. These parameters should be considered in further studies.

Future research should focus on the use of more accurate satellite images along with a good understanding of the uncertainty of the optimal size of a region for the application of the NDVI model.

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مقاله کوتاه علمی

تخمین پوشش تاجی گندم با کاربرد NDVI در مناطق وسیع ایران

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پوشش تاجی

شاخص NDVI

رشد گیاه

لندست ۸

چکیده – به منظور مطالعه یک روش پیشنهادی برای تخمین پوشش تاجی از NDVI ، یک طرح تحقیقاتی در چهار مزرعه بزرگ مقیاس در جنوب ایران، در استان های فارس و خوزستان در چهار فصل زراعی از سال ۱۳۹۵ تا سال ۱۳۹۸ انجام شد. دو روش طبقه بندی تصاویر برای تحلیل تصاویر جهت برآورد پوشش تاجی بکار رفت. در هر دو روش، مقادیر R^2 بزرگتر از ۰/۹۵ و مقادیر NRMSE کوچکتر از ۰/۱۵بود. یک مدل ساده همبستگی خطی بین CC و NDVI حاصل از ۶۴ تصویر لندست ۸، از سال ۱۳۹۵ تا ۱۳۹۸ بنا شد که دقت قابل قبولی داشت (مقادیر R^2 در سایت های دزفول، امیدیه، داراب، زرقان و کل مناطق با هم به ترتیب برابر ۰/۸۴، ۰/۸۵، ۰/۸۸، ۰/۸۰ و ۰/۷۶ بود). با کاربرد این مدل ساده، مقادیر CC در سال زراعی ۱۳۹۹-۱۳۹۸ برآورد شد که خصوصا در کاربرد معادله کل مناطق، به مقادیر اندازه گیری شده نزدیک بود. مقدار p آماری در معادله های چهار مزرعه، کمتر از ۰/۰۳ بود. نکته کلیدی، کاربرد مدل عمومی در مناطق وسیع بود. به عنوان یک روش پیشنهادی، معادله بین پوشش تاجی و NDVI می تواند به عنوان یک روش کم هزینه با صرف زمان کم، برای مطالعات رشد گیاهی، مدل های رشد گیاهی و مدیریت رشد گیاه، در مناطق مورد مطالعه بکار رود.