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Wheat and Barley Cultivated Area Determination Using NDVI Threshold Values and Google Earth Engine

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Abstract: This study aims to determine the optimal imaging time for detecting wheat and barley (W-B) cultivated areas using Sentinel-2 images and NDVI-based threshold values (December 2018-June 2019) via Google Earth Engine (GEE). The study was conducted in Mahmudiye village, situated to Çanakkale province, Türkiye. Randomly selected parcels (RSP) were determined through ground surveys were used to obtain monthly minimum and maximum NDVI thresholds ($NDVI_{min}$ and $NDVI_{max}$). Monthly NDVI threshold-based W-B maps were produced. In addition to the month-based maps, the areas that meet all the threshold conditions for all months at once were also mapped. The predicted and actual inventory of W-B areas were compared for identification of the most appropriate imaging time within the growing season. Findings have shown that using the image acquired in April gave the most satisfactory W-B area prediction with an overestimation of only 53 pixels. Use of $NDVI_{min}$ and $NDVI_{max}$ thresholds for prediction of W-B cultivated areas and yield predictions considering imageries acquired in April strongly suggested for more precise estimations under similar climate conditions, whereby the method provides more time and labor-effective investigations in comparison with land use land cover classification methods.

Keywords: GEE, imaging time, NDVI threshold values, Sentinel-2, Wheat-Barley

NDVI Eşik Değerleri ve Google Eart Engine Kullanılarak Buğday ve Arpa Yetiştirilen Alanların Belirlenmesi

Makale Geçmişi
Geliş: 14/02/2025
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Öz: Bu çalışma, Sentinel-2 uydu görüntüleri ve NDVI tabanlı eşik değerler kullanılarak (Aralık 2018-Haziran 2019) buğday ve arpa (B-A) ekim alanlarının tespiti için en uygun görüntüleme zamanını belirlemeyi amaçlamaktadır. Çalışma, Türkiye'nin Çanakkale iline bağlı Mahmudiye köyünde gerçekleştirilmiştir. Rastgele seçilen parseller (RSP), arazi çalışmaları ile belirlenmiş ve aylık en düşük ve en yüksek NDVI eşik değerleri ($NDVI_{en\ düşük}$ ve $NDVI_{en\ yüksek}$) elde edilmiştir. Bu eşik değerler kullanılarak her ay için B-A alanı tahmin haritaları üretilmiştir. Ayrıca, tüm aylara ait eşik koşullarını aynı anda sağlayan alanlar da haritalandırılmıştır. Tahmin edilen ve gerçek B-A alan envanter değerleri karşılaştırılarak yetiştirme sezonu içinde en uygun görüntüleme zamanı belirlenmiştir. Bulgular, Nisan ayında elde edilen görüntünün kullanımının, sadece 53 piksel fazla tahmin ile en tatmin edici B-A alanı tahminini verdiğini göstermiştir. Benzer iklim koşulları altında, arazi kullanım ve arazi örtüsü sınıflama metotlarına göre daha zaman- ve emek efektif incelemeler sağlayan $NDVI_{en\ düşük}$ ve $NDVI_{en\ yüksek}$ eşikleri metodu göz önüne alınarak B-A yetiştirilen alan ve verim tahminlemelerinde, daha hassas tahmin eldesi için Nisan ayında alınan görüntülerin kullanımı önerilmektedir.

Anahtar Kelimeler: Buğday-Arpa, GEE, görüntüleme zamanı, NDVI eşik değer, Sentinel-2

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Introduction

Agricultural activities play a key role in Türkiye's socio-economic status since the suitability of climate, soil and topographic conditions enable the growth of various agricultural products. Identifying cultivation areas for specific products is important for future planning and management strategies, such as crop rotation decisions, yield and production estimates. There is a great variety of products, whereas wheat and barley (W-B) production constitute a considerable part of the cultivation areas. According to Turkish Statistical Institute (TSI) data, the total agricultural areas cover approximately 240 million hectares, whereby 42.37% of the areas consisted of W-B cultivated areas (TSI, 2023). On the other hand, Food and Agriculture Organization (FAO) reported that national and global events together with the impacts of changing climate, led to a reduction in W-B production in Turkey in 2022 and 2023, as well as in many other countries (FAO, 2024). However, W-B products still known to have a key role in nutrition; thus, production and demands should be well-evaluated to ensure balance. Hence, identification of production areas and spatio-temporal changes presents a priority for forecasting yield (Campos et al., 2019; Ayub et al., 2022), import and export amounts in specified regions (Balambar et al., 2021).

Remote sensing imageries with different spatial, spectral and temporal resolutions have long been used for identification of W-B production areas (Gumma et al., 2022). The use of different techniques, algorithms, and indices are well documented in the literature (Meraj et al., 2022; Wang et al., 2022). Recent improvements in cloud-based applications for image processing, namely Google Earth Engine (GEE) have accelerated the number of studies due to the advantages of time-effective processing and reduced requirements of data storage (Tian et al., 2019; Cheng et al., 2022). Plant indices are important parameters in crop monitoring and agricultural practices (Qiao et al., 2024). Moreover, among the various indices for investigating specific characteristics of plants, Normalized Difference Vegetation Index (NDVI) is known to be one of the most widely used vegetation indices (Rouse et al., 1973). The sensitivity of shortwave and near-infrared bands for identification of vegetation has yielded successful results for determining wheat yield over large areas (Wu et al., 2020; Zhang et al., 2023). Qi et al. (2022) achieved a high accuracy (92%) in classification model for detecting wheat areas in the Shandong region of China. Shin et al. (2022) developed crop (W-B) classification models based on Sentinel-2 data in the southern part of the Republic of Korea using Deep Neural Networks (DNN), Machine Learning (ML) regression approaches, and five different indices, including the NDVI index, and achieved an accuracy of 89% for barley, and 45% for wheat. However, more time- and labour-effective methods are required since the classification procedures are laborious and time consuming. A simple and easy-to-understand model using minimum and maximum NDVI threshold ($NDVI_{min}$ and $NDVI_{max}$) values were used in different studies. For instance, Toscano et al. (2019) and Bouras et al. (2023) used NDVI values collected from reference parcels considering W-B phenological stages in the southern region of South Korea to identify the optimum time for W-B monitoring and yield estimation.

This study aims to determine the appropriate image timing for identifying W-B cultivation areas based on $NDVI_{min}$ and $NDVI_{max}$ threshold values collected from randomly selected parcels (RSP), which were sampled during ground surveys, using GEE. The study was conducted within the boundaries of Mahmudiye village, Çanakkale province, Türkiye. Data were collected using Sentinel-2 images from the RSP. The NDVI maps for each month were produced, monthly $NDVI_{min}$ and $NDVI_{max}$ threshold-based W-B prediction maps were obtained, and consistency between actual and predicted values were evaluated to highlight the optimum imaging time for W-B prediction under similar conditions.

Materials and Methods

Materials

Study Area

The study was conducted in Mahmudiye village, located in Ezine District of Çanakkale province (39° 51′ 52.92″ N - 26° 14′ 39.66″ E) (Figure 1). The survey area covers approximately 3200 hectares. The study area is under the impact of typical Mediterranean climate whereby the average temperature and precipitation range between 15-16°C and 500-700 mm, respectively, enabling the growth of several agricultural products. A major part of the study area is covered by agricultural lands, whereby the most widely cultivated agricultural products are wheat, barley, tomatoes, and paddy rice.

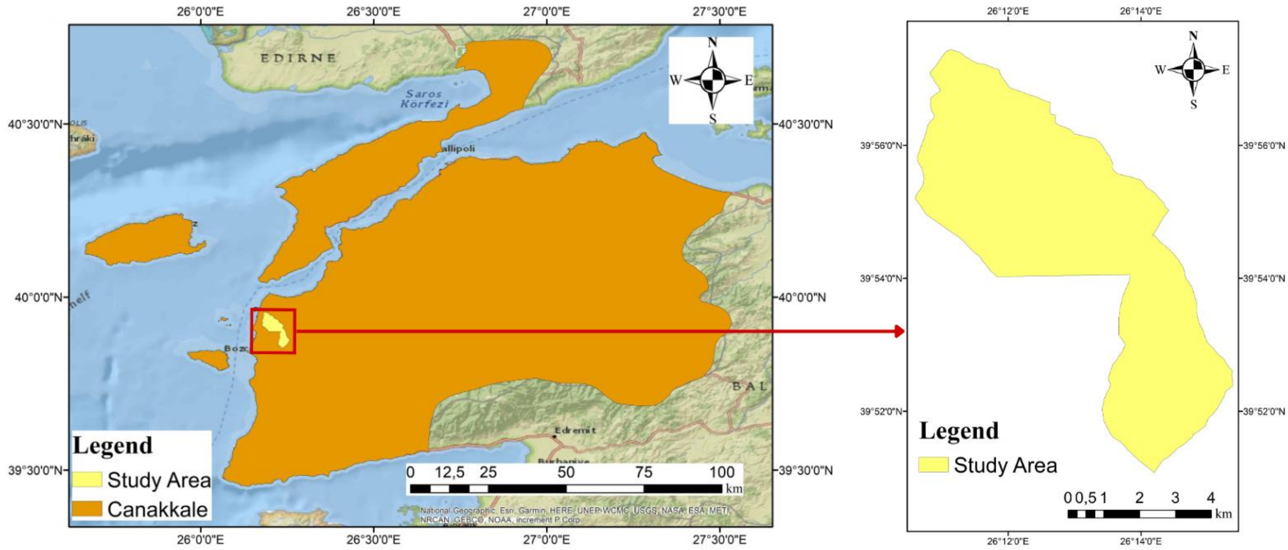


Figure 1. Location of the study area.

Data Processing

Sentinel-2 satellite collect data with an optical sensor via 13 spectral bands, with spatial resolution ranging between 10 and 60 m (Zhang et al., 2023). In present study, red (band 4) and near-infrared (band 8) bands with 10 m spatial resolution were used for NDVI calculation. The acquisition dates of imageries were selected depending on cloud cover threshold (under 10%) and growth stages of the W-B. Depending on the criteria, the images of December 17, 2018; January 06, 2019; February 05, 2019; March 17, 2019; April 26, 2019, May 28, 2019, 2019, and June 07, 2019 were used to achieve the aims.

The Sentinel-2 data were processed using the GEE open-source cloud-based platform, which provides computation and analyzing geospatial data easily, without requiring user preprocessing (Aghlmand et al., 2021). The GEE platform enables rapid computation of various processes, thus, commonly preferred to be used for environmental monitoring and modelling through remote sensing data.

Methods

The study was completed in three stages (Figure 2), and the methods are detailed below. In the first stage, NDVI of each pixel were calculated, and the NDVI maps were generated. The second stage involved the determination of monthly NDVI maximum and minimum thresholds, and the creation of monthly W-B maps depending on determined NDVI thresholds. Finally, the third stage included validation and the identification of the best image timing.

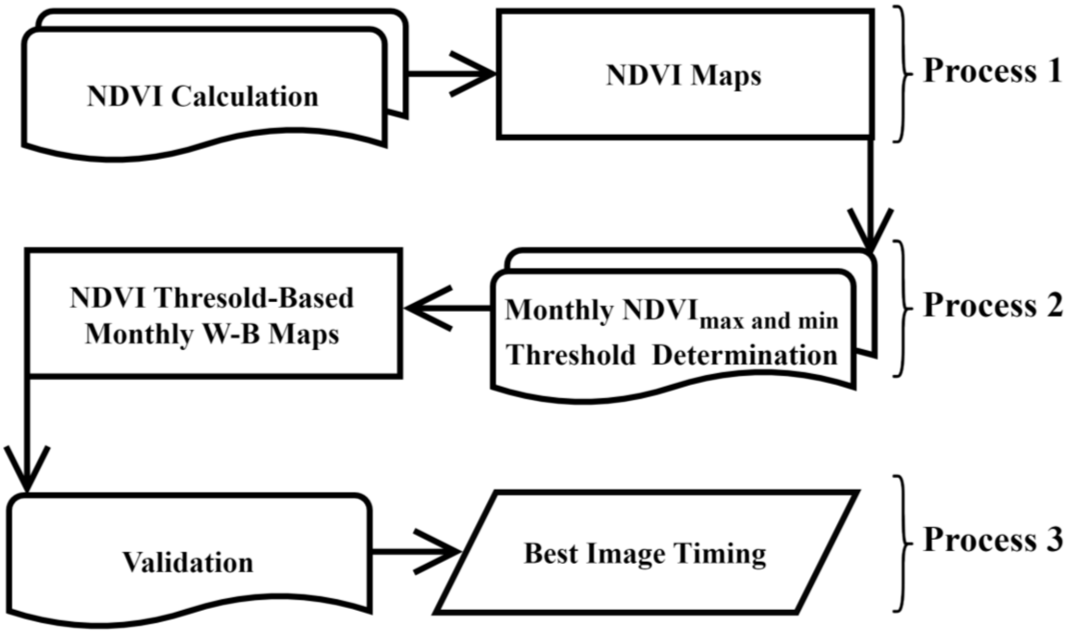


Figure 2. Flow chart of the study.

Generation of NDVI Maps

The NDVI maps of the study area were composed using red and near-infrared bands of each date through the following equation (Eq. 1). The NDVI values range between -1 and 1 whereby higher values represent dense vegetative cover.

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

Producing NDVI Threshold-Based W-B Prediction Maps

Among the cultivated parcels, 20 parcels were randomly selected and digitized into a vector layer using ArcGIS (10.7). After the digitizing process, the vector layer overlapped with NDVI maps and randomized training polygons, which consisted of at least 9 pixels, were collected from each parcel vector. The average NDVI values of training polygons were calculated to ensure capture of the variability. Finally, the maximum and minimum thresholds from NDVI values of training polygons were identified ($NDVI_{min}$ and $NDVI_{max}$) for each month. The threshold values of $NDVI_{min}$ and $NDVI_{max}$ were used to obtain prediction maps for W-B cultivated areas for each month depending on the formula. Accordingly, if a pixel (*p*) has a value ranging between $NDVI_{min}$ and $NDVI_{max}$, the pixel (*p*) acknowledged as W-B, otherwise, other land use or land cover type (*O*). In addition to monthly maps, pixels that meet the threshold requirements in all months were presented within an individual map (Eq. 2).

$$f(NDVI) = \begin{cases} W, & NDVI_{max} \geq p \geq NDVI_{min} \\ O, & otherwise \end{cases} \quad (2)$$

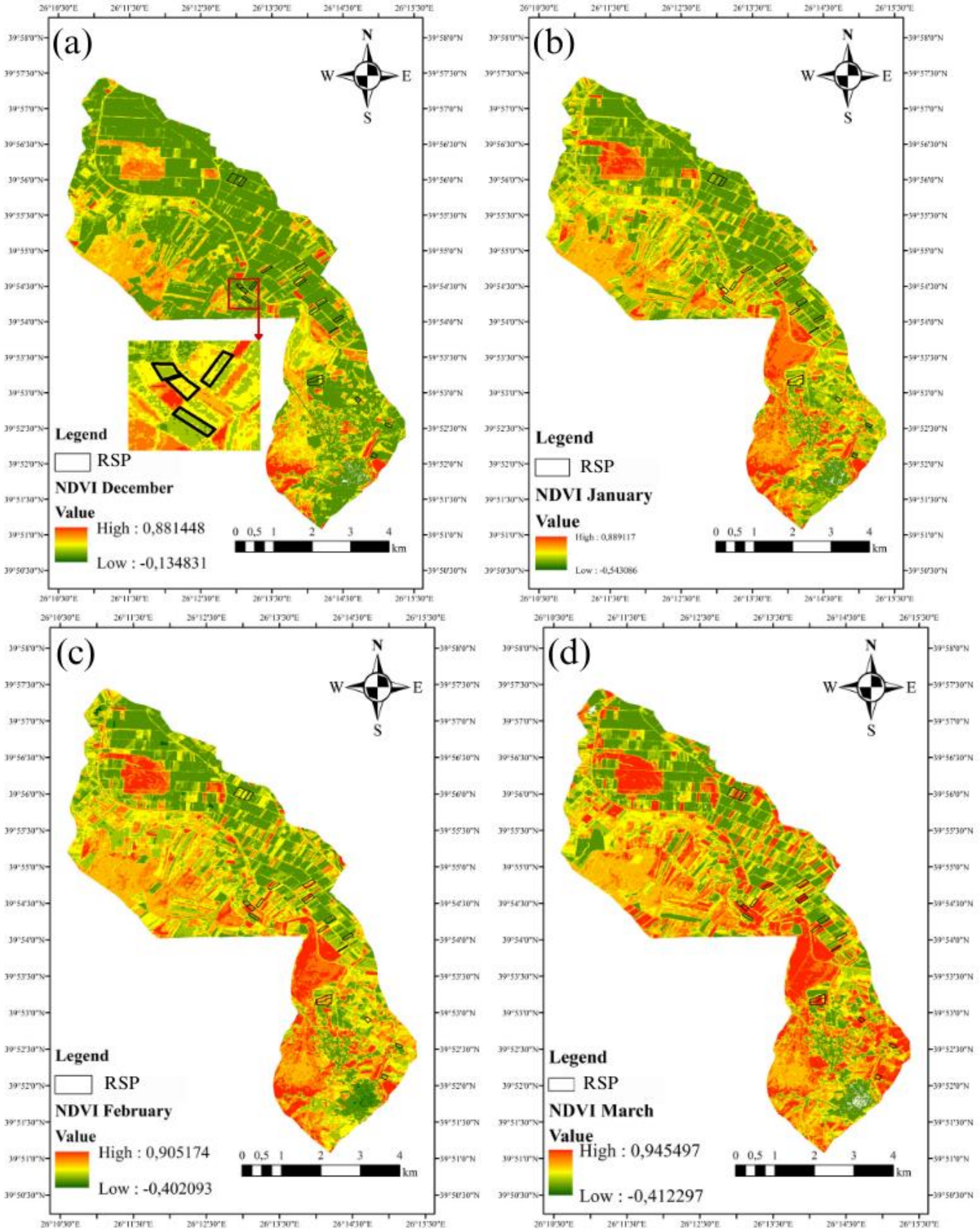
Reliability of Prediction Maps

The reliability of threshold-based prediction maps was assessed depending on the coherencies between actual inventory records of 2019 and predicted W-B areas. Village-level inventories were obtained from the Çanakkale Provincial Directorate of Türkiye Ministry of Agriculture and Forestry (ÇPDAF, 2019).

Results and Discussion

The NDVI maps of each month are given below, whereby black squares represent RSP depending on ground surveys for collecting NDVI threshold values (Figure 3 a-g). As it can be seen, $NDVI_{min}$ and $NDVI_{max}$

values in the study area range between 0.12 and 0.36 in December (2018), 0.15 and 0.39 in January (2019), 0.20 and 0.74 in February (2019), 0.52 and 0.85 in March (2019), 0.52 and 0.85 in April (2019), 0.16 and 0.77 in May (2019), and 0.20 and 0.59 in June (2019), respectively. Previous studies have shown that, phenological stages of W-B can be determined using NDVI with higher accuracy in comparison with other vegetation indices (Yang et al., 2019). Therefore, monthly monitoring of NDVI values provides valuable information on the maturity level of plants and became an important indicator.



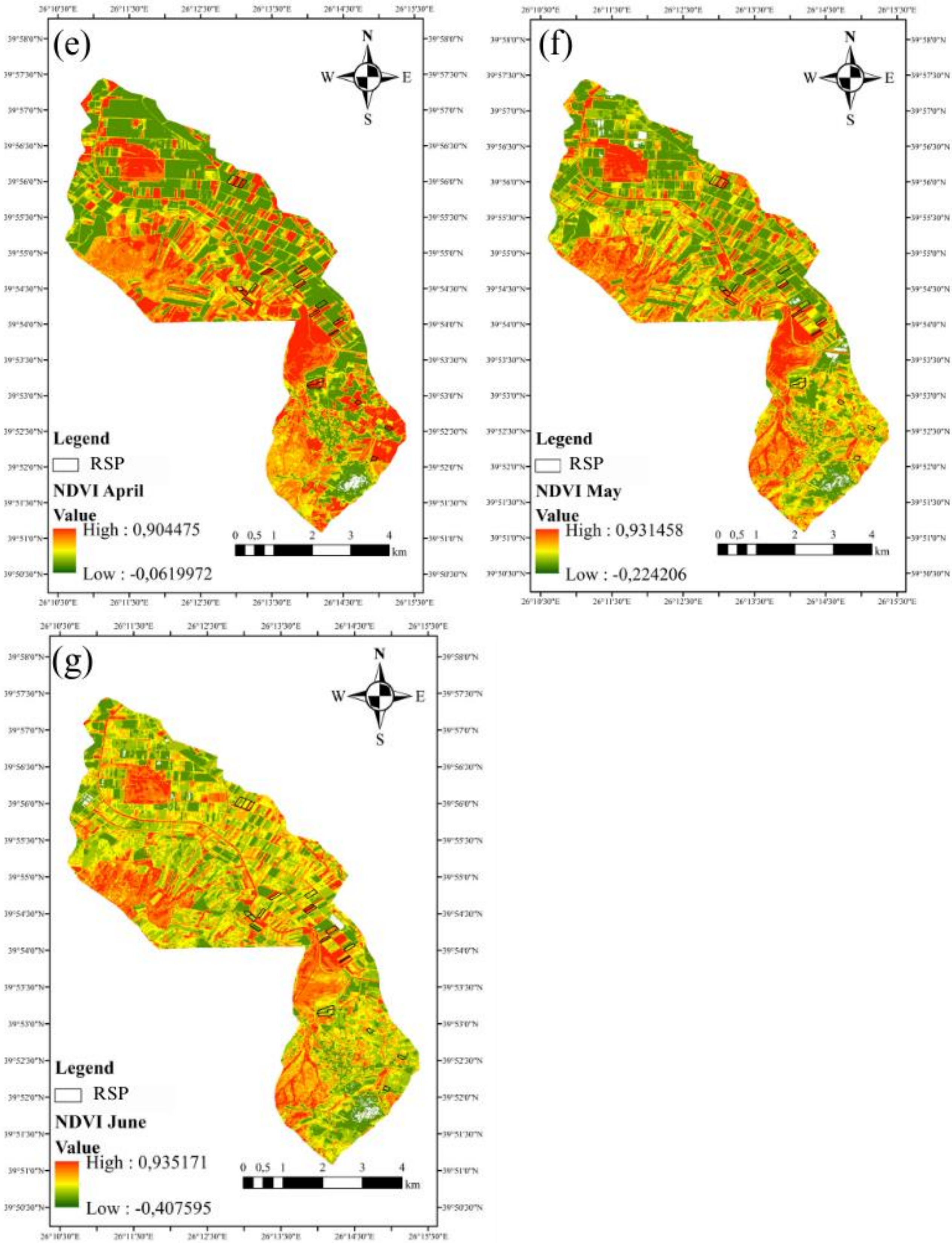


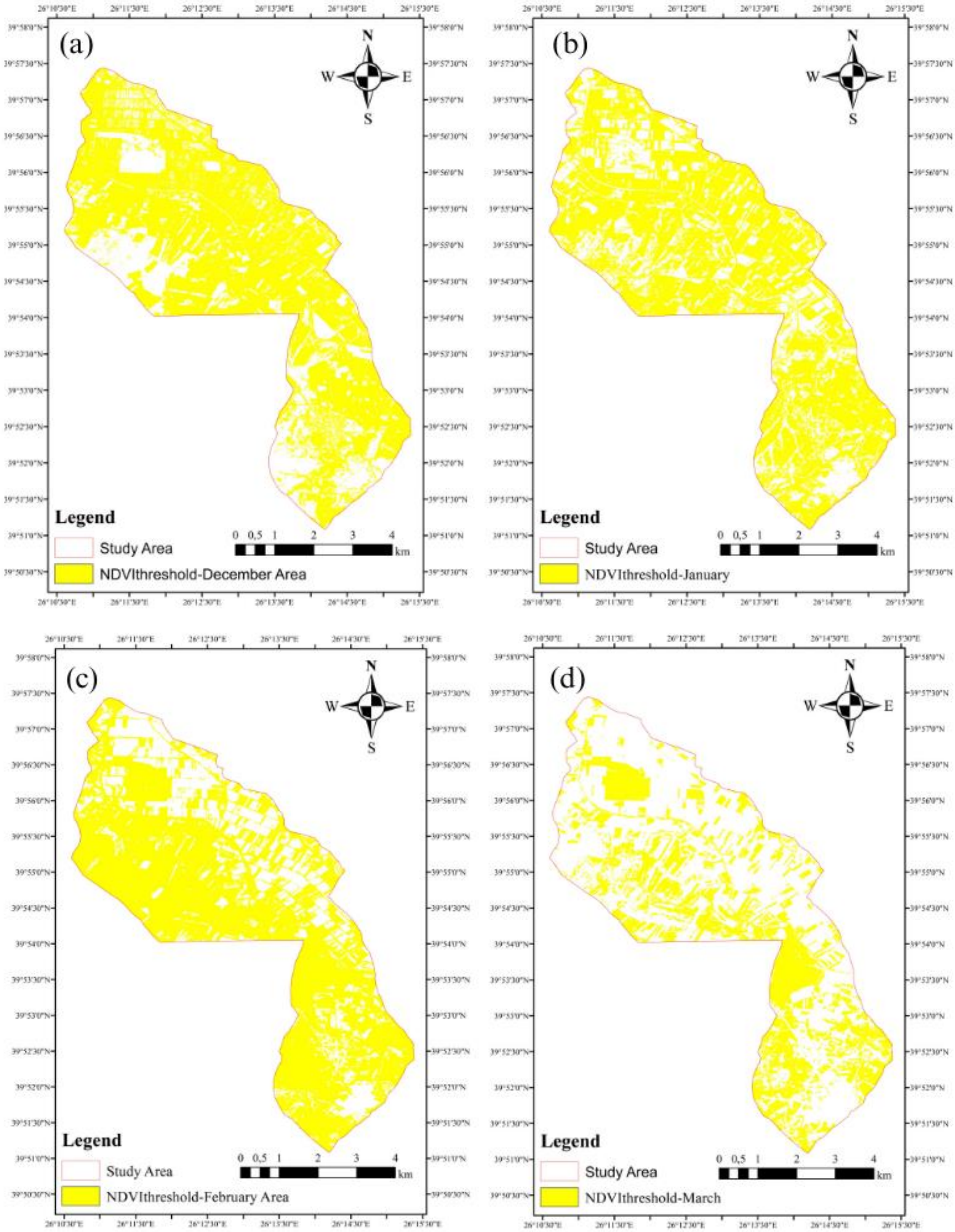
Figure 3. Randomly Selected Parcel (RSP), Normalized Difference Vegetation Index (NDVI), (a) $NDVI_{min}$ and $NDVI_{max}$ values in December, (b) $NDVI_{min}$ and $NDVI_{max}$ January, (c) $NDVI_{min}$ and $NDVI_{max}$ February, (d) $NDVI_{min}$ and $NDVI_{max}$ March, (e) $NDVI_{min}$ and $NDVI_{max}$ April, (f) $NDVI_{min}$ and $NDVI_{max}$ May and (g) $NDVI_{min}$ and $NDVI_{max}$ June.

Threshold methods are commonly used for determination of specific crops in many areas of the world, and the main issue is known to be the determination of the accurate thresholds. The parameters are usually manually prepared depending on the phenological stages of the considered plant (Wang et al., 2015; Wang et al., 2019; Li et al., 2021). There are different methods for identifying the more appropriate threshold values. In the present study, $NDVI_{min}$ and $NDVI_{max}$ reference threshold values were collected from overlay analysis using NDVI maps and RSPs that were defined during ground surveys (Table 1). Accordingly, $NDVI_{min}$ values ranged between 0.12 (December 2018) and 0.73 (May 2019), while $NDVI_{max}$ values seemed to change from 0.36 (December 2018) to 0.88 (May). Similar results were found for winter wheat in the Thessaly plain, central Greece, between 2018 and 2019 growing season, whereas the highest NDVI values were obtained from the image acquired in April (Cavalaris et al., 2021). Moreover, the findings of the study were also coherent with the NDVI values mentioned by Yang et al. (2019); the minimum and maximum NDVI values of different months were ranged between approximately 0.18 and 0.80, respectively.

Table 1. Monthly $NDVI_{min}$ and $NDVI_{max}$ threshold values.

Years	Months	$NDVI_{min}$ Threshold Value	$NDVI_{max}$ Threshold Value
2018	December	0.12	0.36
2019	January	0.15	0.39
	February	0.20	0.74
	March	0.52	0.85
	April	0.73	0.88
	May	0.16	0.77
	June	0.20	0.59

Considering these predetermined thresholds from the individual images, W-B and barley parcels were predicted and mapped, namely $NDVI_{threshold-December}$ (Figure 4 a), $NDVI_{threshold-January}$ (Figure 4 b), $NDVI_{threshold-February}$ (Figure 4 c), $NDVI_{threshold-March}$ (Figure 4 d), $NDVI_{threshold-April}$ (Figure 4 e), $NDVI_{threshold-May}$ (Figure 4 f) and $NDVI_{threshold-June}$, (Figure 4 g). Furthermore, a single map has been created that separately satisfies the $NDVI_{min}$ and $NDVI_{max}$ threshold conditions for each month at once ($NDVI_{threshold-combined}$) (Figure 4 h).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NDVIthreshold-February Area
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NDVIthreshold-March
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km

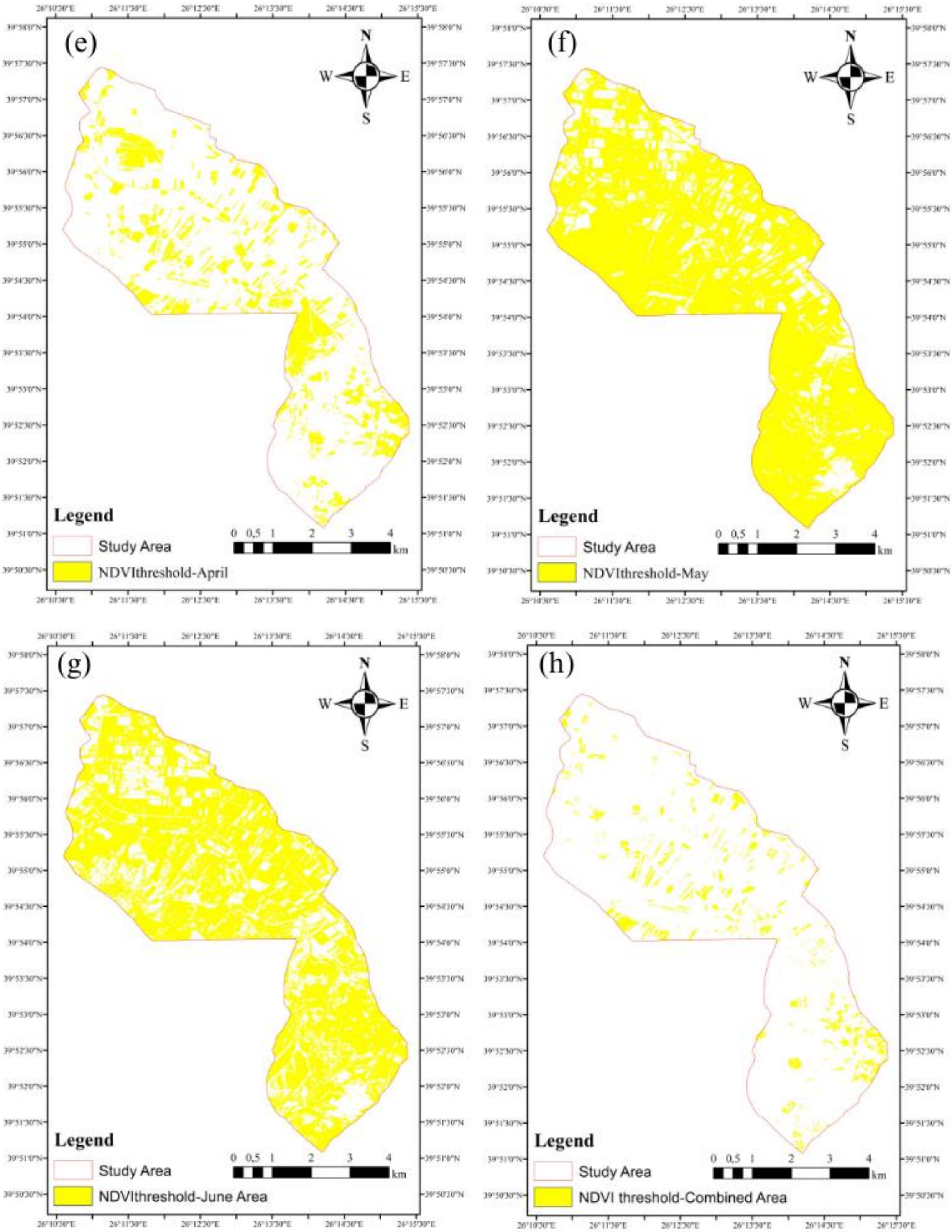

Figure 4. W-B areas determined according to $NDVI_{min}$ and $NDVI_{max}$ threshold values. (a) $NDVI_{threshold\text{-}December}$, (b) $NDVI_{threshold\text{-}January}$ (b), (c) $NDVI_{threshold\text{-}February}$, (d) $NDVI_{threshold\text{-}March,}$ (e) $NDVI_{threshold}$, (f) $NDVI_{threshold\text{-}May}$ and (g) $NDVI_{threshold\text{-}June}$, (h) $NDVI_{threshold\text{-}Combined}$.

Depending on the monthly and combined prediction maps, W-B cultivated areas were calculated (da), and compared with actual inventory data of ÇPDAF to evaluate coherency between actual and predicted values (Tablo 2). Inventory data has shown that W-B cultivated parcels cover 5510 da area. Examination of NDVI threshold-based maps has shown that W-B cultivation areas were predicted as 21964 da depending on the December (2018) image, 18350 da depending on the January (2019) image, 22749 da depending on the February (2019) image, 11668 da depending on the March (2019) image, 6041 da depending on the April (2019) image, 25328 da depending on the May (2019) image, and 21593 da depending on the June (2019) image. Briefly, use of month-based NDVI thresholds lead mostly to exceed overestimation of W-B areas, except $NDVI_{threshold\text{-}April}$. Moreover, use of $NDVI_{threshold\text{-}combined}$ values resulted in underestimation of W-B areas (2363 da).

Table 2. $NDVI_{min}$ and $NDVI_{max}$ based W-B areas (da).

	NDVI Threshold							
W-B Area (da)	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**Combined**
	21.964	18.350	22.749	11.668	6.041	25.328	21.593	2.363

The cultivation area of a specific product that is calculated through remotely sensed data usually differs from official inventories at national- or regional-level (Li et al., 2021), due to cumulative effects of spatial resolution-related issues. Therefore, the study focused on a small-scale evaluation of the method. The method provided reliable results at village-level coherency between Sentinel-2 derived NDVI threshold-based cultivated area and the local inventory records in April, answering the research question on selection of the optimum imaging time for W-B area determination within a growing season.

Conclusion

The optimal imaging time for identifying W-B areas in a growing season was investigated through $NDVI_{min}$ and $NDVI_{max}$ threshold values. For this purpose, monthly NDVI thresholds were obtained from selected W-B parcels identified during ground surveys in 2019. NDVI threshold-based monthly prediction maps, as well as the combined NDVI thresholds map that meets all months NDVI threshold requirements at one query, were generated in GEE. The predictions for W-B cultivated areas were compared to actual W-B cultivation areas using inventory records to identify more appropriate acquisition time for Sentinel-2 images to perform more realistic W-B predictions. Findings of the study revealed that the use of NDVI thresholds mostly resulted in extremely overestimated W-B areas. Depending on these findings, it can be clearly seen that the image acquired in April gave the most coherent value with actual W-B cultivation areas with a difference of approximately 53 pixels. Moreover, the study provided a simpler identification of W-B areas in comparison with land use land cover classification, which is a more time consuming and laborious method. Therefore, the study is believed to serve as a baseline for future research, which may be conducted under similar climate conditions and growth periods.

Additional Information and Declarations

Authors' Contributions: N.C. collected the data, conducted the analysis, performed the calculations, and developed the model, while writing the manuscript with support from M.I. and L.G.
M.I. contributed to the data analysis, assisted in the development of the model, and wrote the main manuscript with support from N.C. and L.G
L.G. designed the proposed idea, developed the theory, contributed to the creation of the model, contributed to the data analysis, and wrote the main manuscript with support from N.C. and M.I.
Conflict of Interests: The authors declare that there are no conflicts of interest among them.

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