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Classification of hybrid maize seeds (Zea mays) with object-based machine learning algorithms using multispectral UAV imagery

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Abstract

In recent years, detailed monitoring of different vegetation classes by using modern remote sensing technologies has become one of the essential issues for smart agriculture activities. In this study, using three advanced machine learning algorithms, namely canonical correlation forest (CCF), rotation forest (RotFor) and support vector machines (SVM), and object-based image classification techniques on multispectral (MS) unmanned aerial vehicle (UAV) orthomosaics, the separability of 12 maize species were investigated. The investigations were performed in Sakarya Maize Research Institute application area located in Arifiye district of Sakarya province, Turkey. In maize monitoring, besides the five spectral bands (R, G, B, red edge, NIR) of the MS UAV, the Normalized Digital Surface Model (NDSM) describing the height of maize species was generated and included as an additional band to improve classification performance, evaluated with F-score, overall accuracy (OA) and Kappa metrics. The results demonstrated that CCF and RotFor algorithms provide similar OA as 76.61% and 76.75%, respectively and the SVM algorithm has 74.18%. In parallel, the Kappa values of CCF and RotFor are 0.75 and the SVM is 0.72. In terms of class-based F-scores, by all algorithms, C. Sweet and C. Arifiye were identified with over 97% and 94% accuracies, respectively, that prove the successful determination of their boundaries using object-based classification.

1. Introduction

Cereals are grown in large quantities around the world for their edible parts and provide billions of people with more food energy than all other crops combined (Bigini et al. 2021). The maize plant, included in the cereal group, is a plant of high economic value, adaptability, and the highest productivity (Slavin 2004). The plant can be cultivated at altitudes up to thousands of meters in almost every region of the earth's surface, except in the polar regions where cold climatic conditions prevail (Kırtok 1998). Approximately 20% of the maize produced worldwide is used in human nutrition, 65-70% is used as animal feed and the remaining 10-15% is used in industry (Bilgic et al. 2012). Due to the increasing population in Türkiye, the need for maize plants is increasing day by day, and imports have been undertaken to maintain the balance between production and consumption (Akkurt and Demirbas 2021). Accordingly, the detailed monitoring of maize and increase its production have a vital importance.

Traditionally, plant monitoring studies are carried out by onerous, low-accuracy and costly terrestrial methods in under-developed or developing Countries. In contrast, modern remote sensing technologies provide easily achievable, highly accurate, low-cost data. In recent years, especially the Unmanned Aerial Vehicles (UAV) has become indispensable for large-scale mapping, smart agriculture and forest activities and image classification by means of high-resolution, high-frequency and low-cost multispectral data (Sefercik et al. 2021).

In the literature, several studies exist about plant monitoring by modern remote sensing technologies. In Yilmaz (2018), multi-temporal Sentinel-2 satellite images and object-based classification approach were used to generate crop maps of 9 different plant species growing including maize plant. In the study carried out by Öztürk (2021), multi-temporal PlanetScope satellite images were used together with texture features to map the vineyard plant. Object and pixel-based classification methods were applied with machine learning algorithms, and the highest overall accuracy (91%) was obtained in

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object-based classification method using Random Forest algorithm. In the study conducted by Guo et al. (2022), plant heights were measured using RGB and Multispectral (MS) UAV images in three years. Using the generated digital elevation model (DEM) and vegetation and texture indices as the basic data set, the combination of DEM-RGB VI was found to adequately (90%) predict the heights of maize plants.

In this study, on generated MS UAV orthomosaic, the separability of 12 different maize species was examined by using advanced machine learning algorithms and object-based image classification method during the period of the tassel showing a strong relationship with yield. The performance of maize classification was improved with the contribution of generated Normalized Digital Surface Model (NDSM), produced with RGB UAV data.

2. Study Area and Dataset

The study area is located in the Arifiye district of Sakarya province, Türkiye. In the area, 12 agricultural parcels in rectangular shape each has 500 m² (20 m × 25 m) are designed and has been planted with a different type of maize species. For easier separation of parcels from each other and delineation of each parcel clearer, 2.5 m width roads were left between them. Figure 1 shows the study area and maize species.

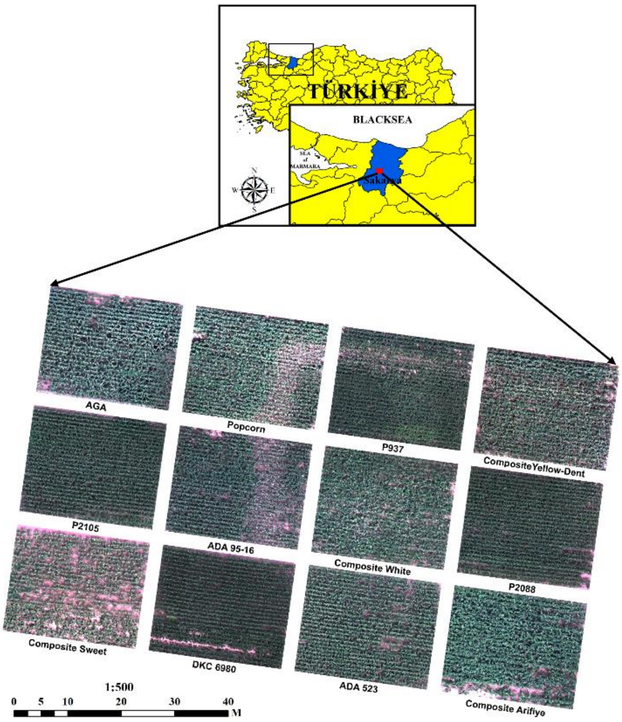

Figure 1. Study area and maize species

3. Methodology

3.1. UAV data acquisition

The flights were planned with two different UAVs as DJI Phantom 4 MS RTK and DJI Phantom 4 Pro V2.0 RGB with different imaging capabilities. While, five band (R, G, B, red edge, NIR) multispectral aerial photos were collected with 2.08 MP spatial resolution by MS UAV to create qualified orthomosaic for classification processes, 20 MP aerial photos were provided by RGB UAV to generate high resolution NDSM. The flights were implemented as polygonal and bundle grid from 50 m altitude applying 80% and 60% front and side overlap, respectively. In bundle-grid flights, 70° camera viewing angle (off-nadir 20°) was preferred while nadir view is applied in polygonal flights. The aerial photos were achieved with ground sampling distances (GSD) of 1.44 cm and 2.61 cm for RGB and MS UAV flights.

For geometric calibration of the RGB UAV aerial photos, mobile polycarbonate ground control points (GCPs) were established and measured by CHC-i80 GNSS receiver before the flights. GCPs were not required for MS UAV due to availability of RTK GNSS equipment. For radiometric calibration of MS UAV aerial photos, MAPIR V2 calibration target was observed by the UAV at the beginning of the flights.

3.2 Generation of UAV orthomosaic and NDSM

UAV orthomosaics were produced applying photogrammetric processing steps for orthomosaic generation in SfM-based Agisoft Metashape Professional Software (Sefercik et al. 2022). With the advantage of SfM approach, reconstruction of the 3D geometry in high resolution from a series of overlapping 2D sequential photos is possible (Westoby et al., 2012). In photogrammetric processing, first the UAV aerial photos were oriented in two steps as generation of the sparse point cloud by initial alignment and absolute orientation utilizing GCPs. The sparse point cloud is a low-resolution 3D vector representation of the study area and generated to increase geometric orientation accuracy however it is insufficient for further process. That's why, dense point clouds, which provide more realistic and complex characterization of the study area for producing high-quality orthomosaic, were generated utilizing depth maps. Using dense point cloud, a 10 cm grid digital surface model (DSM), the 3D digital cartographic representation of earth surface including all natural and human-made objects, was generated applying vector-raster transformation. As a last step for photogrammetric processing, orthomosaic was produced with 2.6 cm GSD.

NDSM is the differential 3D model of the DSM and the digital terrain model (DTM) which is the 3D digital representation of bare earth surface. By subtracting the bare earth surface from the crown surface of the maize using RGB UAV DSM and DTM, the exact heights were calculated by utilizing LISA software. NDSM of the maize species are shown in Figure 2.

3.3 Object-based classification

This study investigated the separability of maize species through object-based image classification. To achieve this purpose, three process steps, including i) image segmentation, ii) determination of class labels of segments via machine learning algorithm, and iii) accuracy assessment, were performed.

Due to its more effective and accurate performance in classifying high-resolution images compared to the pixel-based technique, object-based classification has been widely utilized in many research (Whiteside et al. 2011; Georganos et al. 2018; Chen et al. 2018). Unlike traditional pixel-based mapping, the pixels are combined into meaningful objects or segments based on their spectral, spatial, and contextual specifications in the object-based classification, and this process is known as image segmentation. The multi-resolution segmentation (MRS) presented by Baatz and Schape (2000), a robust and effective algorithm, was applied to the UAV dataset to perform image segmentation. The segmentation process is controlled by three main parameters (i.e., scale, shape, and compactness) by MRS. Since the definition of scale parameter value determining the segment sizes is one of the most significant factors affecting the qualitative and quantitative results of thematic mapping, several algorithms were developed to estimate the optimal value of this parameter. In this paper, the Estimation of Scale Parameter-2 (ESP-2) algorithm developed by (Drăguţ et al. 2014) was employed to select scale parameter.

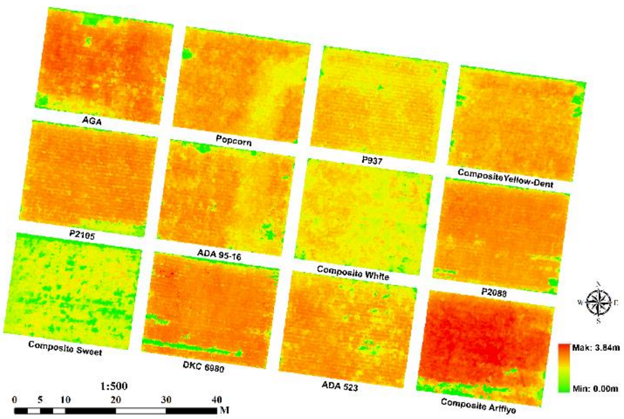

Figure 2. NDSM of maize species

3.4 Classification algorithms

Within the scope of this study, three robust machine learning algorithms, namely canonical correlation forest (CCF), rotation forest (RotFor) and support vector machine (SVM), were employed for estimating the class labels of each segment.

RotFor, presented by Rodriguez et al. (2006), is one of the most effective tree-based machine learning algorithms. RotFor, which has a similar structure to the random forest, first randomly splits the input variables into K subsets, unlike this algorithm. Then, principal component analysis is applied to each subset before constructing individual decision trees. The unknown class labels of each sample are determined by majority voting (Colkesen and Ozturk 2022).

CCF was introduced by Rainforth and Wood (2015), mainly based on applying canonical correlation analyses (CCA) to ensure maximum correlation between features and class labels before the construction of the classification model (Colkesen and Ertekin 2020). With canonical correlation, not only the relationship between features but also the relationship between features and class labels are considered.

SVM is one of the most widely used machine learning algorithms in the literature due to its robustness and success in solving complex classification and regression problems. The basic principle of the algorithm is to map the nonlinear input data (e.g., UAV imagery) into a higher-dimensional feature space through kernel functions and determine an optimum hyperplane separating two classes in the feature space (Kavzoglu and Colkesen 2009).

4. Results

In this research, the MRS algorithm was applied to UAV dataset with five spectral bands and NDSM to obtain homogeneous image objects. The shape and compactness values of the MRS algorithm were set as 0.5 and 0.9 by considering the trial-and-error strategy, while the scale parameter value was determined using an automated estimation algorithm, ESP-2, based on these parameter values. According to the ESP-2 result, the optimal scale value was estimated as 52, and input image was divided into 100,311 segments (Figure 3). A total of 68 spectral, spatial and textural features, including maximum, minimum, mean, standard deviation, mode, ratio, brightness, area of the pixel, GLCM entropy, GLCM contrast, GLCM homogeneous, GLCM mean and GLCM standard deviation values were calculated and utilized in the object-based mapping.

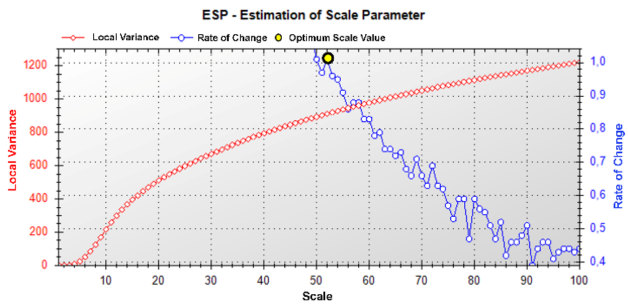

Figure 3. LV-RoC graphs produced by ESP-2.

In the prediction of class labels of each segment by CCF, RotF, and SVM algorithms, a total of 3,035 and 913 segments were utilized to construct classification models and hyperparameter optimizations, respectively. CCF and RotF algorithms were implemented in MATLAB software, while the SVM thematic mapping process was conducted in R software. In addition, 3,000 samples for each class (a total of 42,000) were selected on the UAV data to evaluate thematic maps produced by machine learning algorithms statistically. Confusion matrix-based metrics, overall accuracy (OA), Kappa coefficient, and F-Score, were calculated to assess accuracy. Estimated class-level accuracies (i.e., F-score) of hybrid maize species and map-level accuracies (i.e., OA and Kappa coefficient) were given in Table 1. As can be seen from the table, the map level accuracies of CCF and RotFor are approximately 77%, while the accuracy achieved with the SVM algorithm is 74.18%.

When class-level accuracies of each crop were analyzed, all algorithms estimated that C. Arifiye and C. Sweet maize crops with over 94% accuracy. In addition, individual class accuracies of C. White and DKC 6980 crops were about 81% and 89%. On the other hand, algorithms showed inferior performance in the determination of ADA 95-16 and ADA 523 classes, producing the lowest F-Score values. Furthermore, the boundaries of popcorn, AGA, and P2105 maize crops were separated from other crop types with a better class-based accuracy using CCF and RotF algorithms. On the other hand, SVM outperformed the other algorithms for classifying P937 maize class with approximately 4% higher accuracy.

Table 1. Object-based classification results.

Maize Crop	F-Score (%)		
	CCF	RotF	SVM
C. Yellow-Dent	64.29	62.80	56.34
P937	74.46	75.06	79.92
Popcorn	62.70	60.71	52.57
AGA	76.98	79.19	71.31
P2105	64.45	63.94	60.05
ADA 95-16	50.37	54.14	48.57
C. White	80.04	81.44	80.47
P2088	67.92	69.99	68.04
C. Arifiye	94.38	95.20	94.86
ADA 523	50.86	46.67	48.03
DKC 6980	89.01	87.67	90.11
C. Sweet	99.52	97.69	97.48
Shadow	94.73	94.40	92.40
Soil	99.92	99.98	97.30
OA (%)	76.61	76.75	74.18
Kappa	0.75	0.75	0.72

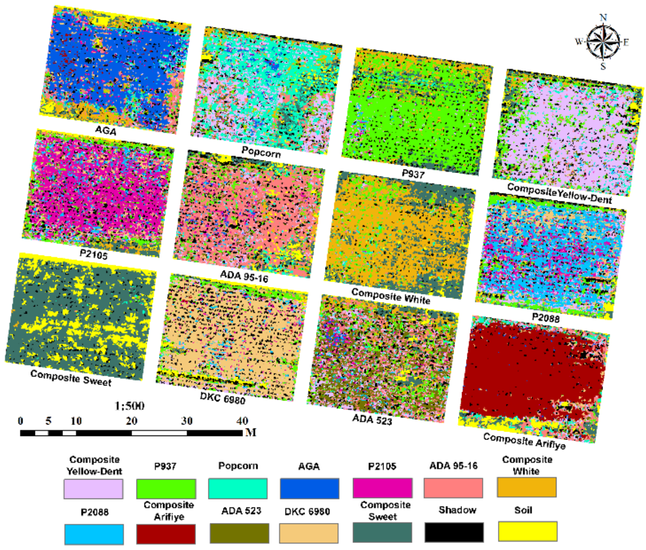

Figure 4. Thematic map of RotFor algorithm

As an example of the crop maps, a thematic map produced by of RotFor algorithm with the highest OA value was presented in Figure 4 to perform qualitative evaluations. When the figure was analyzed, it was observed that the boundaries of C. Arifiye, DKC 6980, and C. Sweet were successfully identified using object-based image classification. On the other hand, in the area where ADA 523 is cultivated, it is observed that the misclassifications are relatively high, and it cannot be distinguished due to its spectral similarity to other species. In addition, misclassification errors were also observed in the P2105 and P208 cultivated fields.

5. Conclusion

This study investigated the separability of 12 maize crop types through object-based image classification. Several important conclusions can be drawn as follow. First, object-based mapping of the C. Arifiye and C. Sweet maize crops was conducted with over 94% class-based accuracy. In addition, it was observed that the boundaries of these crop types were successfully determined by object-based mapping. The most important reason for this result is the heights of the two corn types mentioned. This finding verified that utilizing NDSM as an auxiliary dataset positively contributed to determining and identifying maize species. Secondly, all machine learning algorithms showed inadequate classification performance for ADA 523. As a result, it can be stated that ensemble-learning algorithms make statistically more accurate predictions than the SVM algorithm in the classification of maize species considered in this study. To increase the accuracy of the results obtained, there is a need for further studies to examine the spectral structure and height changes of these maize species in different phenological stages.

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