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Optimal Timing of Carrot Crop Monitoring and Yield Assessment Using Sentinel-2 Images: A Machine-Learning Approach

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Abstract: Remotely sensed images provide effective sources for monitoring crop growth and the early prediction of crop productivity. To monitor carrot crop growth and yield estimation, three 27 ha center-pivot irrigated fields were studied to develop yield prediction models using crop biophysical parameters and vegetation indices (VIs) extracted from Sentinel-2A (S2) multi-temporal satellite data. A machine learning (ML)-based image classification technique, the random forest (RF) algorithm, was used for carrot crop monitoring and yield analysis. The VIs (NDVI, RDVI, GNDVI, SIPI, and GLI), extracted from S2 satellite data for the crop ages of 30, 45, 60, 75, 90, 105, and 120 days after plantation (DAP), and the chlorophyll content, SPAD (Soil Plant Analysis Development) meter readings, were incorporated as predictors for the RF algorithm. The RMSE of the five RF scenarios studied ranged from 7.8 t ha^{-1} ($R^2 \geq 0.82$ with Scenario 5) to 26.2 t ha^{-1} ($R^2 \leq 0.46$ with Scenario 1). The optimal window for monitoring the carrot crop for yield prediction with the use of S2 images could be achieved between the 60 DAP and 75 DAP with an RMSE of 8.6 t ha^{-1} (i.e., 12.4%) and 11.4 t ha^{-1} (16.2%), respectively. The developed RF algorithm can be utilized in carrot crop yield monitoring and decision-making processes for the self-sustainability of carrot production.

Keywords: carrot crop monitoring; machine learning; Sentinel-2 images; vegetation indices; yield prediction; random forest (RF)

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1. Introduction

The self-sustainability of a country's food supply is essential for its economic growth and development. With the adoption of advanced techniques and available best management practices, Saudi Arabia is keen to expand the area of vegetable crops, especially carrots, to achieve self-sufficiency. Carrot (*Daucus carota* L.) is one of the most nutritionally valuable vegetable crops in the world, and carrot production has received great attention from researchers around the world, aiming to improve its production practices. The global production of carrots and turnips in 2021 was estimated at 42,158,403 tons out of a total cultivated area of 1,137,738 hectares, where Saudi Arabia produced 24,500 tons out of a total cultivated area of 1383 hectares [1]. Timely information on crop area and production statistics, agroclimatic regimes, real-time crop health monitoring, and yield prediction or pre-harvest modeling techniques will provide better options for food sustainability forecasts [2,3]. On the other hand, such data are crucial for improving agricultural practices and, subsequently, help decision-making authorities to effectively plan for food security issues and overcome unstable climatic conditions [4–6].

Investigating local variations in carrot yield and quality would enable decision-making, the implementation of agronomical guidance, and food self-sustainability. Nowadays, most of the decision support systems for agriculture practices are dependent on thematic maps,