Utilizing Thermal and RGB Imaging for Nutrient Deficiency and Chlorophyll Status Evaluation in Plants

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Abstract.

As global population growth and climate change continue to challenge food security, addressing agricultural issues efficiently and cost-effectively is vital for enhancing productivity. Integrating technology into agriculture, particularly through timely interventions, offers promising solutions to mitigate challenges before they escalate. This study investigates the feasibility of using thermal and RGB imaging as efficient, non-destructive methods to assess nutrient deficiencies and chlorophyll status in white radish plants. Conducted under a soilless agriculture system, the experiment involved white radish plants subjected to five different nutrient concentrations, each replicated four times. Morphological characteristics such as leaf area, root diameter, root and shoot lengths, fresh weights, and shoot/root ratio were recorded. The plant image acquisition was conducted using thermal and RGB sensor cameras, and subsequent image processing was conducted using ArcGIS software. RGB images were analyzed to extract three bands (red-green-blue) and seven vegetation indices, while thermal images provided three bands for further analysis. Correlation analyses were performed to evaluate the relationship between various indices and nutrient levels, sulfur content, and chlorophyll concentrations. Significant associations were observed between specific indices and nitrogen levels, sulfur content, and chlorophyll concentrations. Specifically, band 3 in thermal images consistently exhibited high correlations with chlorophyll content measured by SPAD across multiple captures. At the same time, RGB indices demonstrated significant predictive capabilities for estimating nutrient and chlorophyll levels. The results showed that Woebbecke index, the excess blue index, the excess green index, the excess red index, the excess green-red index, and CIVE index significantly correlated with nitrogen (r=-0.9, 0.7, 0.7, -0.94, 0.91, and -0.83, respectively). This research highlights the effectiveness of thermal and RGB imaging as valuable tools for assessing nutrient status and chlorophyll levels in white radish plants. These findings offer valuable insights for advancing precision agriculture applications, enabling farmers and agricultural practitioners to make informed decisions regarding nutrient management and crop health monitoring. By leveraging innovative technologies such as thermal and RGB imaging, agriculture can move towards more sustainable and efficient practices, ultimately contributing to global food security in the face of evolving environmental and demographic challenges.

Keywords.
Thermal imaging, RGB imaging, nutrient deficiency, chlorophyll status, precision agriculture, image processing, ArcGIS

Introduction:

The productivity of most crops is significantly affected by climate change, posing a great challenge to agriculture. The use of thermal and RGB imaging technology offers time-saving, cost-effective, and non-destructive analysis methods (NDM) for plants (Manickavasagan et al., 2005). Thermal imaging is used to measure the temperature of objects, and these data can be utilized in both direct and indirect applications in agriculture (Manickavasagan et al., 2005). RGB (red-green-blue) imaging is used to determine the health and quality of plants (Gupta et al., 2014). Nutrient deficiencies in plants often go unnoticed until symptoms become visible. Therefore, thermal and RGB imaging can be employed to detect nutrient deficiencies before symptoms appear. This study was conducted to detect nutrient deficiencies in white radish plants grown in a sandy culture. The objectives of the present study were to: 1) study the effect of nitrogen and sulfur on chlorophyll content in the plant, and 2) investigate the relationship between chlorophyll concentration and the presence of certain nutrients using thermal and RGB images.

Materials and Methods:

The experiment was conducted at Damanhur University, Faculty of Agriculture, Elbeheira Governorate, Egypt, from 18th February 2019 to 4th April 2019, using white radish plants (Raphanus sativus L.) grown in a sandy culture. The sand was washed and sifted using a 10 and 270 mesh sieve. Five nutrient solutions were based on Hoagland and Arnon's solution (1940) (Benton, 2005), with different concentrations of nitrogen and sulfur (100%N+100%S, 50%N+100%S, 0%N+100%S, 100%N+50%S, and 100%N+0%S). Stock solutions were diluted to contain half-strength of the modified Hoagland and Arnon solution. White radish seeds were sown in plastic pots containing 1 kg of pre-washed sand. The pots were irrigated three times weekly with the different nutrient solutions. Thermal images were taken with a thermal imaging camera (HT-02D) which has 32*32 IR image pixels, a temperature measurement range of -20°C to +300°C, and a wavelength range of 8-14 µm, with adjustable emissivity from 0.1 to 1 (Rai et al., 2017). Images were taken after 43 days of planting from a height of approximately 55 cm. RGB images were captured with a 13-megapixel digital camera. Upon harvest, the whole plant was collected and separated into shoots and roots for measurement of various characteristics (Figure 1). All images were processed using ArcGIS software (Esri, 2017). Five points were randomly selected in each image to extract pixel values of the plant canopy. Three bands were obtained and seven vegetation indices were calculated for each RGB image using the raster calculator module in ArcGIS (Figure 2). Additionally, three bands were generated for each thermal image capture (Figure 3).

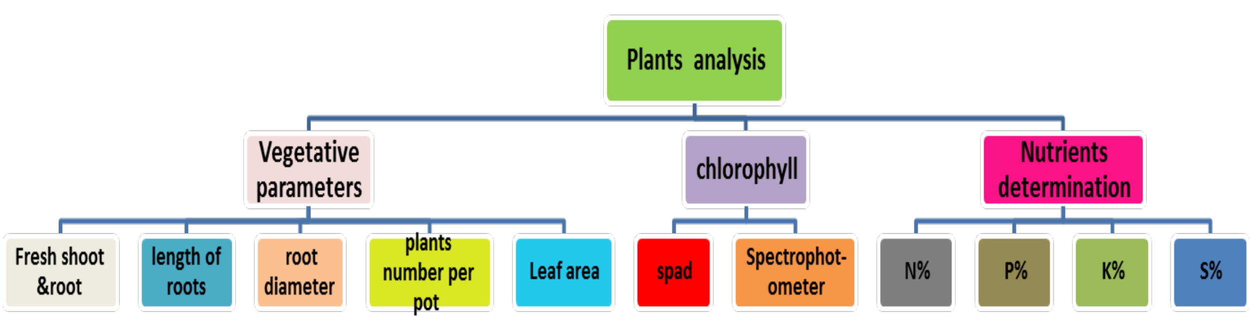

Figure 1: measured characteristics of white radish plants

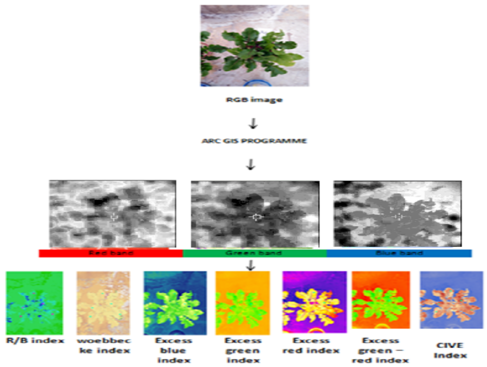

Figure 2: RGB Image Processing of White Radish.

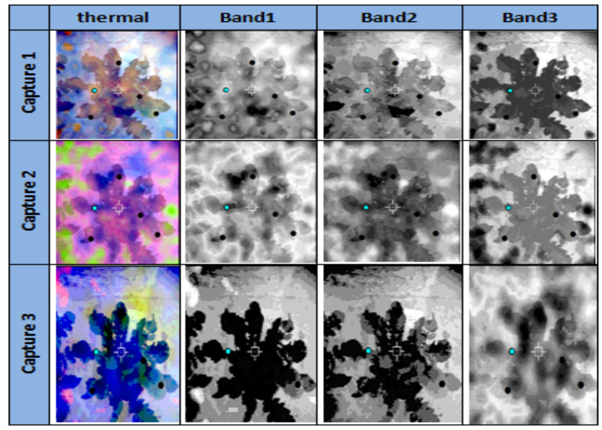

Figure 3: Thermal Image Processing of White Radish.

The experiment was designed as a completely randomized design (CRD), and the results were analyzed using the SAS program (SAS, 1996). Averages were compared according to Steel and Torrie (1980) at a 0.05 level of significance.

Results and Discussions:

Nutrient Performance Assessment:

The blue band showed a non-significant correlation with nitrogen, while the red and green bands showed a high negative correlation with sulfur and nitrogen. The relationship between nitrogen and sulfur content and the bands of RGB images in white radish is shown in Table 1. In corn leaves, nitrogen had a high significant negative correlation with the EXR index and CIVE index, a high correlation with the EXG index and EXGR index, and a non-significant correlation with the Woebbecke index (Junior et al., 2021), which is compatible with the current study. Table 2 shows the correlation coefficient between nitrogen and sulfur content and the bands of thermal images of white radish.

Table 1: Correlation Coefficient between nitrogen and sulfur Content and indices of RGB Images in White Radish.

	R/B index	Woebbecke index	Excess blue index	Ecess green index	Excess red index	Excess green-red index	CIVE index
N	-0.794***	-0.906***	0.776 ***	0.737 ***	-0.953 ***	0.920 ***	-0.885 ***
S	-0.421 ns	-0.694***	0.3268ns	0.463*	-0.665**	0.570**	-0.559*

Table 2: Correlation Coefficient between Nitrogen and Sulfur content and the Bands of Thermal Images of White Radish Plant.

	Capture 1			Capture 2			Capture 3		
	Band1	Band2	Band3	Band1	Band2	Band3	Band1	Band2	Band3
N	0.883***	0.409ns	0.843***	0.039ns	0.879***	0.972***	0.932***	0.629**	0.649**
S	0.679***	0.110ns	0.686***	0.334ns	0.791***	0.717***	0.731***	0.227ns	0.299ns

Chlorophyll Performance Assessment:

Chlorophyll a, chlorophyll b, total chlorophyll, and chlorophyll measured by SPAD had a high negative correlation with the red band but a non-significant correlation with the green and blue bands. Table 3 shows the correlation coefficient between chlorophyll and vegetation indices of RGB images. Table 4 shows the correlation coefficient between chlorophyll content and the bands of thermal images of white radish plants in three captures.

Table 3: Correlation coefficient between chlorophyll and vegetation indices of RGB images in white radish.

	R/B index	Woebbecke index	Excess blue index	Excess green index	Excess red index	Excess green-red index	Cive index
Chl a	-0.88***	-0.47*	0.86***	0.91***	-0.73***	0.82***	-0.69***
Chl b	-0.69***	-0.69***	0.76***	0.51*	-0.67**	0.70***	-0.73***
Total chl	-0.80***	-0.67**	0.73***	0.75***	-0.76***	0.84***	-0.81***
SPAD	-0.88***	-0.80***	0.85***	0.89***	-0.93***	0.95***	-0.88***

Table 4: Correlation Coefficient between Chlorophyll and Bands of Thermal Images in White Radish.

	Capture 1			Capture 2			Capture 3		
	Band1	Band2	Band3	Band1	Band2	Band3	Band1	Band2	Band3
Chl a	-0.52*	0.32ns	0.78**	0.30ns	-0.50*	0.60**	-0.71**	0.69**	0.58**
Chl b	-0.70**	0.43 ns	0.41 ns	0.20ns	-0.42ns	0.72**	-0.51*	0.73**	0.62**
Total chl	-0.67**	0.36ns	0.65**	0.05ns	-0.62**	0.72**	-0.74**	0.64**	0.61**
SPAD	-0.79**	0.39 ns	0.91**	0.12 ns	-0.80**	0.87**	-0.92**	0.71**	0.70**

Conclusions:

This study demonstrates the potential of using thermal and RGB imaging technologies as effective, non-destructive methods to assess nutrient deficiencies and chlorophyll status in white radish plants. The correlation analyses revealed significant associations between specific thermal and RGB indices and nutrient levels, sulfur content, and chlorophyll concentrations. Notably, thermal imaging, particularly band 3, showed consistent high correlations with chlorophyll content across multiple captures. Additionally, several RGB indices exhibited substantial predictive capabilities for estimating nutrient and chlorophyll levels. These findings highlight the practicality and reliability of integrating thermal and RGB imaging into precision agriculture practices. By enabling timely and accurate monitoring of plant health and nutrient status, these technologies can aid in optimizing nutrient management strategies, thereby enhancing crop productivity and sustainability. The use of such advanced imaging techniques can help farmers make informed decisions, reducing the reliance on traditional, labor-intensive methods of plant assessment. Future research should focus on expanding the application of these imaging technologies to a wider variety of crops and environmental conditions to validate their effectiveness and accuracy further. Additionally, developing more sophisticated algorithms and improving sensor capabilities will enhance the precision and usability of thermal and RGB imaging in agricultural practices. Ultimately, leveraging these innovative technologies will contribute to addressing the global challenges of food security and sustainable agricultural practices in the face of climate change and population growth.

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