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Evaluation of the Interactive effect of Carbon Dioxide and Temperature on Plant Growth using Hyperspectral Remote Sensing Technology

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Remote sensing is a powerful tool for monitoring spatiotemporal variations of crop health status in terms of morpho- physiology status helping for precision farming. In comparison with multispectral, hyperspectral imaging with narrow bands are capable of acquiring a subtle variation in spectral response of target crop like garlic under high CO_2 and temperature conditions. The present results indicate the potential of spectral information for evaluating various stress conditions as well as status of crop conditions through the use of band rationing technique, mainly NDVI in comparison to the use of individual spectral bands. The present investigation revealed that plant grown under CTGT II (550 ppm CO_2 + 4°C elevation of temperature) shows significantly good health in all garlic varieties with high LAD and NDVI. On the other hand, the higher temperature stress treatment brought about significant reduction in the LAD and NDVI. This adverse effect was lesser under CTGT II than CTGT III which indicated that all varieties, Ekfutia Assam in particular, exhibited certain degree of tolerance against high temperature stress. Hyperspectral remote sensing technique acts as an important tool in real time monitoring, early warning and quick damage assessment due to various abiotic stresses.

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1. INTRODUCTION

Remote sensing techniques provide a suitable alternative for crop health assessment as it gives a timely, precise, synoptic and estimation of various crop parameters [1]. The role of RS and GIS has already been established as a scientific and cost- time effective means in the field of resource mapping. The spectral reflectance of a plant is determined by the characteristics of its leaves. The spectral reflectance of an individual leaf is controlled by a number of factors, the most important of which is absorption by photosynthetic pigments and water. Hyperspectral sensing is a sensor with hundreds of narrow and contiguous bands in the portion of the light spectrum. Various mathematical combinations of the spectral bands have been found to be sensitive indicators of green vegetation´s health. These mathematical quantities are called indices. There are many proven Hyperspectral (narrow band) indices developed worldwide for continuous monitoring of vegetation conditions like the Normalized Difference Vegetation Index (NDVI), which have been shown to be crucial for monitoring crop conditions and quantifying biophysical and biochemical parameters of agricultural crops [2]. In the present study, an attempt has been made to use leaf optical properties to evaluate the interactive effect of elevated CO_2 and high temperature stress. Elevated CO_2 can partially ameliorate some of the adverse effects of environmental stress, including high temperature on crops. Even though elevated CO_2 can mitigate the detrimental effects of the above optional temperatures on crop growth and yield, certainly temperature near the upper limit for crop will negatively affect yield, regardless of CO_2 concentration [3].The atmospheric CO_2 concentration has increased from 280 ppm before the industrial revolution to the present 390 ppm. The rate of increase is currently1.5-1.9 ppm year^{-1} and CO_2 concentration is estimated to rise up to 750 ppm by 2050 [4]. The Intergovernmental Panel on Climate Change (IPCC) also reports an approximate temperature increase ranging from 1.1-6.4^{o} C by the end of this century. In the North Eastern + Region region (NER) of India also Carbon dioxide content in the atmosphere is increasing at a rate of 1.5 ppm year^{-1}. Long-term rainfall records suggest that the average annual rainfall is receding alarmingly *i.e.* @ 200 mm of annual average rainfall. The minimum temperature on average has risen at many places from 1^{o}C to 1.5^{o}C in the last over 90 years. Therefore, the changing climate triggered by warming is adding a new and very serious dimension to the already observed phenomenon in NER [5]. Our crop cultivars were selected for the current CO_2 concentration and their response to the doubling CO_2 needs to be characterized to develop the plant type for future. Being an important and unique crop, garlic (*Allium sativum* L.) has been selected for the present study to generate some database under the changed climatic condition. The hyperspectral remote sensing may whether help to identify the genotype to the response of the future climatic conditions by measuring some bio-physical data and its correlation to each other. This hypothesis was tested under automatic controlled simulated condition. The results of the study will contribute towards determining vegetation indices under elevated CO_2 and temperature conditions and how to effectively utilize them [6].

2. MATERIALS AND METHODOLOGY

The present investigation was carried out in a controlled environment under carbon-dioxide temperature gradient tunnel (CTGT),established in the Department of Crop Physiology, Assam Agricultural University, Jorhat to understand the differential response of four germplasms of *Allium sativum* L., commonly cultivated in Assam *viz*.,: Ekfutia Assam, Assam Local and two national varieties *i.e.* Bhima Omkar, Bhima Purple which were grown under elevated CO_2 and temperature giving the following treatments (T): T_1: Ambient temperature, T_2: CTGT I (400 ppm CO_2 + 2^{o}C higher than ambient temperature), T_3: CTGT II (550 ppm CO_2 + 4^{o}C higher than ambient temperature), T_4: CTGT III (750 ppm CO_2 + 6^{o}C higher than ambient temperature).

Data were recorded from 10 numbers of randomly selected plants per plot. Various bio-physical properties such as plant height, Leaf Area Duration (LAD) *etc*. have been measured under different treatments using various field instruments. LAD at 90 days after planting (DAP) was recorded using Laser Area Meter (model CI 203) [7]. The LAD from LAI was calculated by the following formula and expressed in days.

$$\text{LAD} = \frac{\text{Leaf Area}}{\text{Ground Area}}\text{x}100$$

The spectral measurement has been collected for each crop at different phenological stages in order to evaluate the interactive effect of CO_2 and temperature on biophysical parameters of plant using a portable Spectro radiometer (SVC HR-1024). Band rationing has been worked out to find the correlation with the bio-physical parameters like plant height and LAD.

3. RESULTS AND DISCUSSION

Plant spectral properties describe the growth and vigour of plants. The spectral profile of all four varieties has been shown in Fig. 1. It has been observed that Ekfutia Assam has shown very good growth and health over the other three varieties *viz*., Assam Local, Bhima Omkar and Bhima Purple. Vegetation Indices like Normalized Differential Vegetation Index gives the amount of vegetation and its condition per pixel basis. The healthy and dense vegetation shows a large NDVI. Thus, those features yield negative index values or sometimes low positive values in the hyper spectral region ($NDVI_h$) t treatment levels.

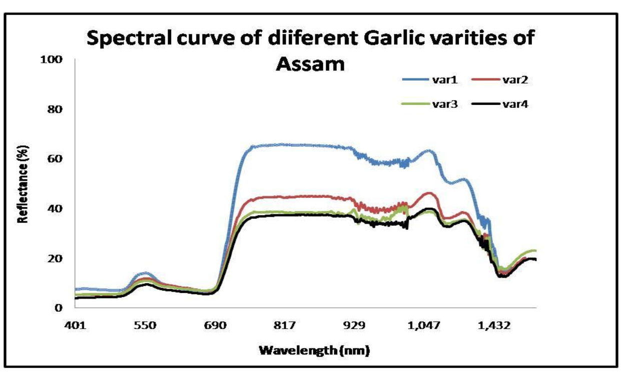
$$NDVI_h = \frac{R_{800} - R_{680}}{R_{800} - R_{680}}$$

Where, R_{800}, R_{680} gives reflectance at NIR and Red region of 800 nm and 680 nm wavelength respectively.

Ekfutia Assam genotype showed the highest NDVI followed by Assam Local, Bhima Omkar, and Bhima Purple (Fig. 2). It was observed that CTGT II showed the highest NDVI value which shows good health condition of all varieties under CTGT II. Similarly, a significant difference in LAD and plant height was also noted among the cultivars. Ekfutia Assam showed the highest LAD and plant height as compared to all other three varieties. It has been observed that elevated CO_2 and temperature brought about a significantly higher increase in LAD and plant height as compared to ambient condition as shown in Fig. 3 and Fig. 4.

A similar interaction effect has been observed where a significant difference in LAD was noted in all the four environment namely ambient condition, CTGT I, CTGT II and CTGT III. The increase in LAD in CTGT II was observed for all four varieties. Measured LAD and spectrally derived NDVI has shown a very high positive correlation (R^2= 0.50) as shown in Fig. 5. R^2 value (0.50) shows that model explains about 50% of variation leaving only 50% of variation due to other factors. Similarly, in case of plant height and NDVI, both show a positive correlation with R^2 value 0.804 (Fig. 6).

The positive effects of elevated CO_2 on plant growth under non-stressful temperatures have been well documented [8,9]. Various reports indicated that growing plants at elevated CO_2 concentration leads to increased leaf area, leaf area duration (LAD) and leaf thickness (SLW) [10,11,12] and which ultimately helps to increase the photosynthesis and yield in crop like *Brassica* [12]. According to him some elevated CO_2 had also some amelioration effect on moisture stress condition. The present investigation revealed that plant grown under CTGT II (550 ppm CO_2 + 4°C elevation of temperature) shows significantly good health in all garlic varieties with high LAD and NDVI. On the other hand, the higher temperature stress treatment brought about significant reduction in the LAD and NDVI. This adverse effect was lesser under CTGT II than CTGT III where temperature was high.



V1- Ekfutia Assam V2- Assam Local, V3- Bhima Omkar V4- Bhima Purple

Fig. 1. Spectral profile of garlic varieties of Assam

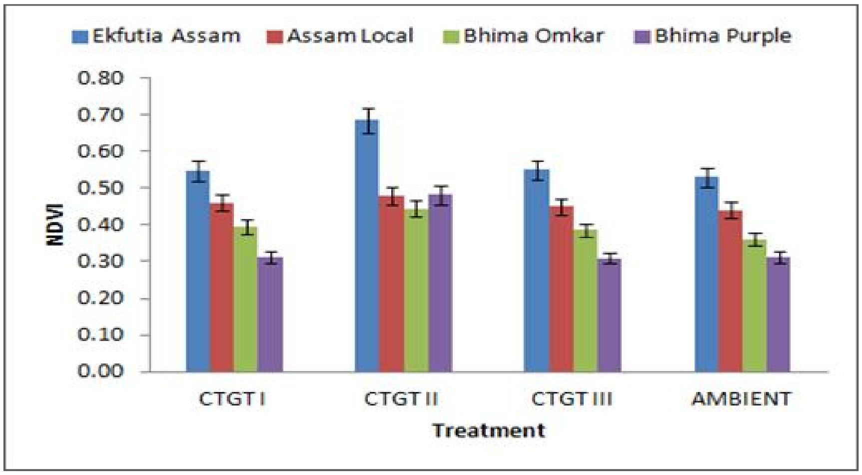


Fig. 2. NDVI variation within varieties under different CTGT

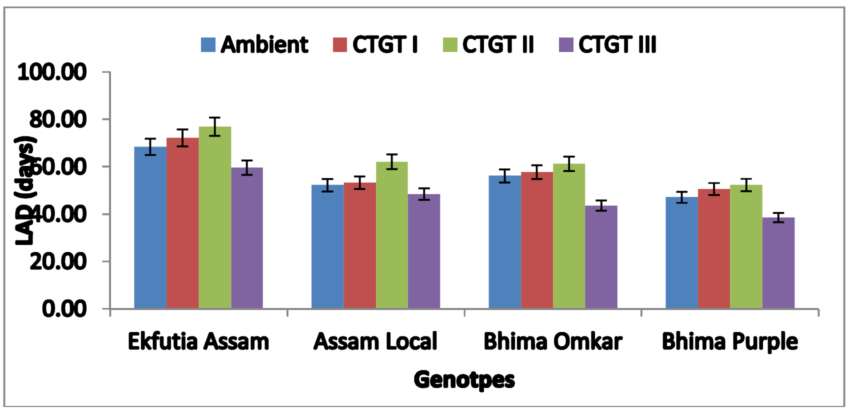


Fig. 3. Graph showing interactive effect of LAD

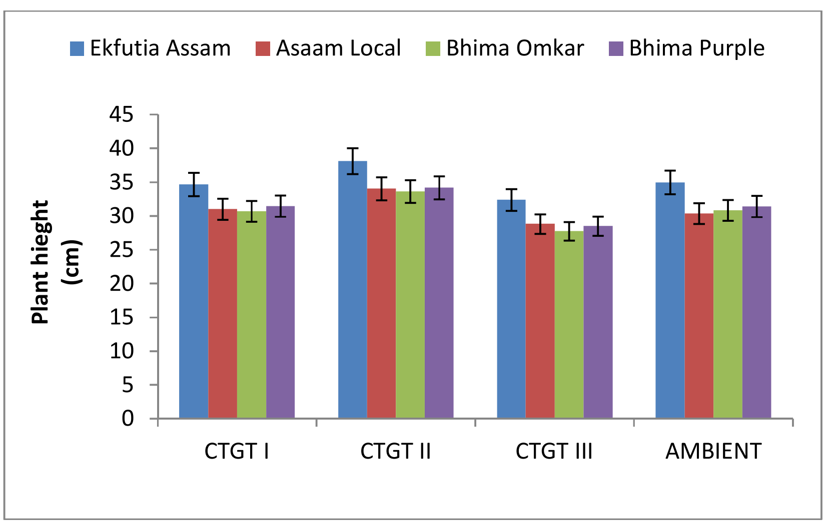


Fig. 4. Graph showing interactive effect of plant height (cm)

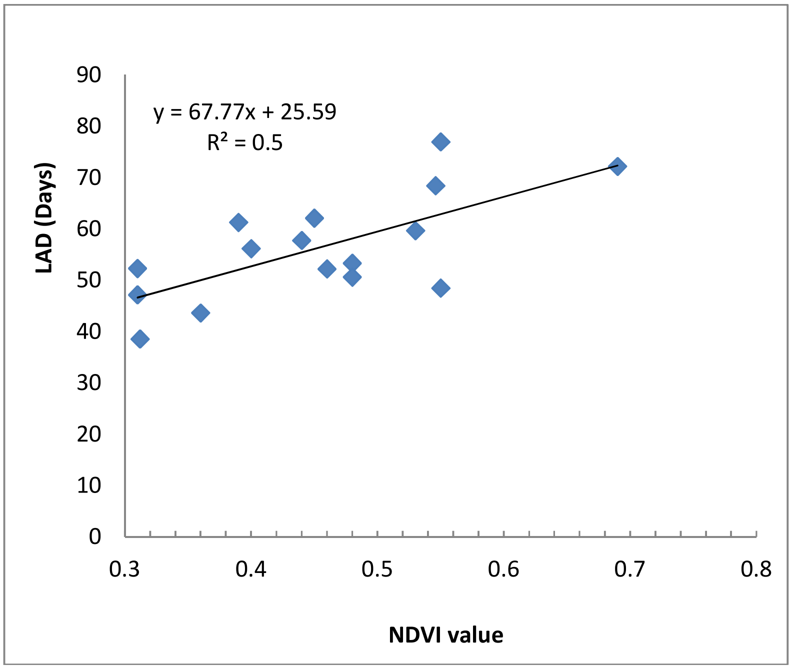


Fig. 5. Relationship between in-situ measured LAD and spectrally derived NDVI using hyperspectral measurement

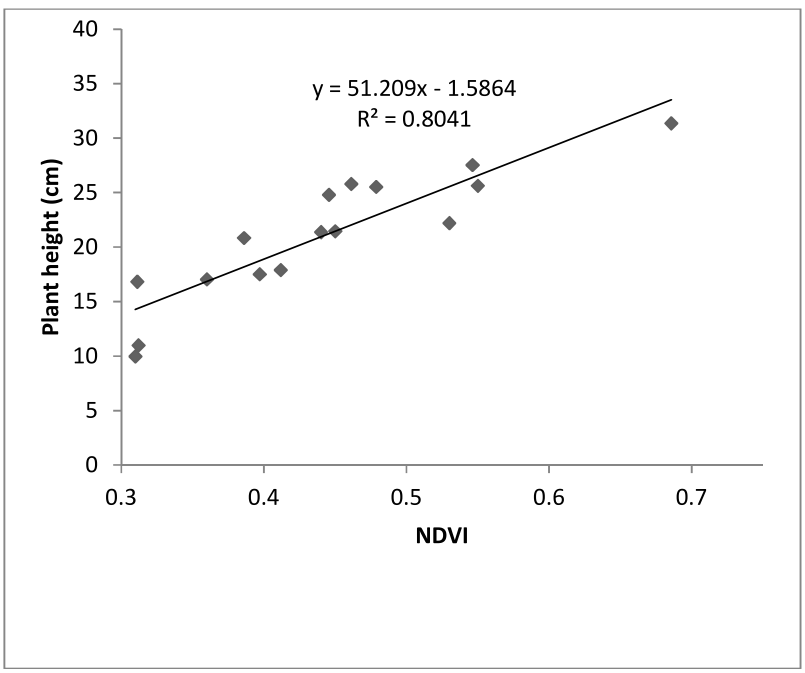


Fig. 6. Relationship between in-situ measured plant height (cm) and spectrally derived NDVI using hyperspectral measurement

4. CONCLUSION

The present investigation shows the potential of using spectral information for evaluating various stress conditions as well as biophysical parameter retrieval. Crop health statuses are often better characterized through the use of band rationing technique, mainly NDVI in comparison to the use of individual spectral bands. Advancements in the hyperspectral remote sensing technique will help in real time monitoring of crop health, quick detection of damages due to various abiotic and biotic stresses and varietal screening towards precision agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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