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MONITORING WATER AND HEAT STRESS OF LETTUCE CROP BY USING INFRARED THERMOGRAPHY TECHNIQUE

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Abstract

The objective of this study was the possibility of using infrared thermography IR to detect and continuously monitor for lettuce plants growing conditions. Also, discernment plants stresses under the shortage of nitrogen and irrigation water. The results showed for Lettuce plants, At the level of fertilization (0%), the maximum values of lettuce the lowest values for MTD maximum temperature difference, and normalized relative canopy temperature NRCT were 0.673 and 0.1 °C at irrigation systems ETC 100% and ETC 50% and nitrogen fertilization systems at 0% level.. And ETC 50% and systems and nitrogen fertilization level 100%. In the fourth level of fertilization (150%), the maximum value of leaf temperature was 24, 23, 22.5, and 23 °C and NRCT was 5.5 and 3.5 °C, and the lowest values for MTD and NRCT were 0.82, 0.28 °C, and 0.018 °C at 0.018 °C. Irrigation ETC 100% and ETC 50% and systems and nitrogen fertilization standard 150%. Also crop water stress index increased from 0.18. at the initial stage to 0.4. and at rapid stage, mid-season stage, and late season stage increased from 0.28 to 0.45, from 0.3 to 0.5, and from 0.31 to 0.59 respectively at constant irrigation level (0%) and the fertilization level from 0 % to 100%, also the index of stomatal conductance with the same trend the crop water stress index increased from 0.51. at the initial stage to 1.26. and at rapid stage, mid-season stage, and late season stage increased from 0.36 to 2.14, from 0.93 to 3.52, and from 0.95 to 5.52 respectively at constant irrigation level (0%) and the fertilization level from 0 % to 50%

Key words*: *Lettuce, temperature , thermography, monitoring, heat, water, stress

INTRODUCTION

Lettuce (*Lactucasativa* L.) is a green leafy vegetable belonging to the Asteraceae family. It is a cool-season vegetable which thrives in temperatures ranging from 7 to 24 ◦C and is commonly consumed in salad mixes. Among different vegetables grown in the United States, lettuce surpasses all others except potato in terms of land devoted to production and crop value. Lettuce is very nutritious and a rich source of vitamin C, minerals and fiber. Lettuce has been used as a medicine for different ailments including stomach problems, inflammation, pain and urinary tract infections from ancient times due to the presence of secondary metabolites such as terpenoids, flavonoids and phenols. Nowadays, consumption of organic vegetables, including lettuce, is surging because of the fast-growing human population, rapid urbanization and increased health concerns. However, one significant factor that limits vegetable cultivation is inadequate land space [24].

In Libya, food demand is expected to increase significantly in the upcoming decades due to rapid population growth, expected to be nearly 1% annually. Libya imports approximately 80% of its total food [5].

The water released from the leaf stomata (transpiration) consumes energy and reduces the leaf temperature. Sunlit leaves receive more direct radiation than shaded leaves of the canopy, and sunlit leaves are therefore assumed to have higher temperature than that of shaded leaves. When non transpiration occurred (no transpiration cooling effect), the temperature difference between sunlit and shaded leaves is maximum. When water is available for the plant to transpire, the transpiration rate in sunlit portions of the canopy would be higher than the transpiration rate in shaded portions [11].

Leaf lettuce belongs to Lactucacompositae and originated on the Mediterranean coast. Leaf lettuce is one kind of high nutrition vegetable, which contains vitamins (A, B1, B2), calcium, iron and other nutrients [23].

lettuce plants were divided into below- and aboveground parts. The belowground part consisted of the roots, and the aboveground part included the stems, leaves and heads. The biomass per fraction, distribution ratio and total biomass under different water and fertilizer coupling treatments are presented in previous studies. Different treatments had significant effects on the head biomass; specifically, the head biomass of spring Lettuce in HWLF was significantly higher than that in MWMF and LWHF, and the head biomasses of autumn Lettuce in HWLF and MWMF were significantly higher than that in LWHF [4].

Vegetable planting area accounts for approximately 13% of the grain crop planting area, but vegetable water consumption accounts for approximately 20% of the grain crop water consumption. At present, the greenhouse vegetable planting area accounts for 58.7% of the vegetable planting area in the Beijing–Tianjin–Hebei region, and the planting area of greenhouse vegetables, water consumption and fertilization amount are increasing annually. It has been reported that the amount of nitrogen (N) fertilizer used in greenhouse vegetable production in this area is 1.3–5.8 times higher than the recommended value, and the nitrate content in groundwater of vegetable fields in some areas exceeds 37.5%–44.8% [28].

Both irrigation and fertilization had significant effects on the root, leaf and total biomass of Chinese Lettuce, but the effects of the different water and fertilizer treatments on root, leaf and total biomass were not significant. The irrigation and fertilization had no significant effect on the head biomass of broccoli but had a significant effect on the biomass of leave [9].

Among many factors affecting crop growth, water and fertilizer are key factors that can be adjusted and controlled. In actual agricultural production, to obtain higher yields, excessive water use and fertilization have become standard practices, and these practices not only leach nutrients from surface soil to deep soil, reducing water and nutrient use efficiency [15].

Compost as an organic source of fertilizers is a valuable product that manipulates soil properties, via improving organic matter content, nutrient availability, aeration and water holding capacity and reducing soil bulk density. Moreover, the use of biochar for soil restoration and bio fertilization has increasingly received interest as low-cost and eco-friendly amendment. Biochar caused a positive impact on soil stability by altering the size of aggregates and regulating soil water, actions that may promote plant growth. In addition, vermicompost as an organic fertilizer plays a role in enhancing soil fertility, increasing soil–water holding capacity and soil aggregates [16].

Since plants cannot move, they face many environmental stresses. Plants have to deal with changes in light, humidity, drought, or cold. And if that was not enough, they still have to fight against all kinds of pathogens. The stress in plants can be categorized as abiotic (originated by drought, cold, high light) and biotic (originated by the attack of bacteria, fungi, herbivores). For those reasons, plants have developed an arsenal of enzymes, metabolites, and signaling pathways to face all kinds of environmental stresses. But even though a lot of research has been done in this sense, there are still some important gaps in understanding how plants interact and defend themselves [26].

Plants have had to develop different mechanisms to face those stresses. The stress not only affects the plant's productivity but also their survival. Depending on the type of stress, plants can dry out, freeze, burn or even die. Plant stress obviously matters to the plants, but also to all of humanity because plants are the primary source of food for human consumption. The findings conclude that plants have many strategies: such as protein and metabolite production, activation of the gene expression, and signaling cascades (or transduction pathways) to face abiotic and biotic stress. Also, plants use similar strategies to respond to different types of stresses [29].

When crops are experiencing water shortage, transpiration from the leaves decreases that is expected to reduce both stomata conductance and water potential of leaves. A decrease in transpiration can also cause insufficient cooling of leaf surface which will ultimately lead to an increase in leaf temperature. Although there are a number of factors which affect actual level of water stress in a plant, leaf temperature is considered as one of the most important factors [12].

Water use is also important to the irrigator from the point of view of gaining maximum return from a limited resource. Irrigation scheduling is a farmer level decision process which includes when to irrigate and how much water to apply to a crop field. suggested that greater precision in the application of irrigation can potentially be obtained by the using ‘plant stress sensing’. The most established method for detecting crop water stress remotely is through the measurement of a crop’s surface temperature [13].

Water stress is one of the most critical abiotic stressors limiting crop development. The main imaging and non-imaging remote sensing based techniques for the detection of plant stress (water stress and other types of stress) are thermography, visible (VIS), near- and shortwave infrared (NIR/SWIR) reflectance, and fluorescence. Just very recently, in addition to broadband thermography, narrowband (hyperspectral) thermal imaging has become available, which even facilitates the retrieval of spectral emissivity as an additional measure of plant stress. It is, however, still unclear at what stage plant stress is detectable with the various techniques [10].

The levels of water stress are not harmful to the development of the crop and affect its productivity, its detection and monitoring are necessary, and it can occur in different ways. One of them is through the Crop Water Stress Index (CWSI). This index quantifies water stress through the normalization of leaf temperature between the maximum and minimum plant temperatures as a function of evaporation conditions. The responses of a low-cost infrared (IR) sensor were crossed with image processing through segmentation by the Excess Green model to develop a water stress detection system using CWSI. A soil/plant temperature map was generated through a point-to-point scan of the IR sensor. And when it overlaid with a segmented image of the experimental area, only points identified as plants had their temperature values maintained. The Non-Water-Stressed Baseline (NWSB) equation was parameterized for the same conditions of the experiment and external environmental. The experimental area was divided into three different treatments, maintained under stable water conditions throughout the experiment and the system was able to identify stably different stress values between treatments. Although the relationship between crop and environment affected the results, this work showed that using an irrigation system based on CWSI is possible [3].

To satisfy crop needs, farmers combine several irrigation water sources, such as brackish groundwater, desalinated water, reclaimed water, and desalinated water. Good agricultural and irrigation practices are essential for preventing soil salinization and production losses, and remote sensing might be used to evaluate these practices. The thermal camera did not operate well within the greenhouse, but it performed in the commercial plot, where the canopy temperature was linearly correlated, with an R2 value of 0.50. The second analyzed vegetative metric, the Normalized Difference Plants Index (NDVI), was exclusively applied to the vegetation and showed minimal relationships with the soil salinity [17].

Plant growth monitoring is an important aspect of precision agriculture implementation. The monitoring can be performed by estimating the volume by the result of Three-dimensional (3D) reconstruction by using Close-range Photogrammetry. However, to present the functionality of the system for plant growth behavior, it is necessary to evaluate its accuracy and performance. The objective of this study was to apply a 3D reconstruction system using the CRP method for validating volume variation and estimate the rate of growth of Chinese Lettuce. This system consists of Canon 700D's DSLR camera and camera stabilizer. The stage of image processing using 3DF's Zephyr Pro photogrammetric software for generating 3D models. For the validation purposes and its functionality for modelling and estimating volumetric objects[19].

Many technological advances assist plant stress science in overcoming such limitations, which results in extensive datasets originating from the multiple layers of the plant defensive response. For that reason, artificial intelligence tools, particularly Machine Learning (ML) and Deep Learning (DL), have become crucial for processing and interpreting data to accurately model plant stress responses such as genomic variation, gene and protein expression, and metabolite biosynthesis. In this review, we discuss the most recent ML and DL applications in plant stress science, focusing on their potential for improving the development of hormesis management protocols [21].

Studied water and nitrogen productivity for lettuce under the shortage of nitrogen and irrigation water during growing lettuce (Babura) plants. Mass production, nitrogen productivity, water productivity, chlorophyll A, chlorophyll B and total chlorophyll, respectively were test under using four levels of nitrogen fertilization (0, 50, 100 and 150% of Nitrogen recommended) and also four levels of water regime (50%, 75%, 100% and 125% of ETc) in Libya conditions. The optimum conditions in drip irrigation greenhouse for crops grow were provided to give us high yield, quality production for lettuce crops. The highest value of chlorophyll A, chlorophyll B and total chlorophyll obtained with 100%N and 100% ETc applied water for lettuce were (0.382, 0.299 and 0.681 mg/100 gm), respectively [8].

Infrared thermal imaging is a non-destructive testing technology that can be used to determine the superficial temperature of objects. This technology has an increasing use in detecting diseases and distress in animal husbandry within the poultry, pig and dairy production. The process can identify changes in peripheral blood flow from the resulting changes in heat loss and; therefore, have been a useful tool for evaluating the presence of disease, edema, and stress in animals. also detect plants heat stress. [22].

The results confirmed the possibility of pre-symptomatic detection of P. carotovorum subsp. carotovorum in lettuce at the canopy level. With respect to identifying healthy and infected lettuce plants by supervised classification, the best results were obtained at 4 and 8 DAI, especially when using the subsets derived from the Mapir Survey3W camera (RGN sensor), for both classifiers. The subsets obtained with the conventional visible sensor (RGB sensor) produced the best results at 20 and 24 days [2].

Pinter. et.al., (2003) stated that green plant leaves typically display very low reflectance and transmittance in visible regions of the spectrum (0.4 to 0.7 μm) due to strong absorbance by photosynthetic and accessory plant pigments since controlling factors for this region are leaves pigments (Chlorophyll and anthocyanins) [18].

Infrared radiation is energy emitted by the mobility of atoms and molecules on the surface of an object at temperatures greater than absolute zero. The strength of the emittance varies with the material's temperature. In other words, the higher the temperature, the more intense the infrared energy released. Materials not only emit infrared radiation, but they also reflect it, absorb it, and, in certain situations, transfer it. When the material's temperature equals the temperature of its surroundings, the amount of thermal radiation absorbed by the item equals the amount emitted by the object [27].

Thermal image allows the visualization of differences in surface temperature by detecting emitted infrared radiation [long-wave infrared (8–14 μm)]. Computer software transforms these radiation data into thermal images in which temperature levels are indicated by a false-colour gradient. Infrared thermography can give frequency distributions of leaf temperature over the target area. A one-shot thermograph has more than 70,000 pixels, each pixel with visual temperature information of sensitivity < 0.1°C. The canopy temperature difference of approximately 8°C in this study is large enough to visually detect transpiration changes in foliage of the genotypes and instantly monitor the soil water stress of plant growth. The frequency distributions ranged from 18°C to 26°C which were clearly different with some genotypes under salinity to have a greater variance of temperature. Thus, infrared thermography has great potential as a tool to instantly monitor water stress in fields [14].

The main objectives of this research were the possibility of using infrared thermography for detailed and continuous monitoring of plant. Display the temperature difference, crop water stress and stomatal conductance index changes under greenhouse condition

MATERIALS AND METHODS

The experimental design was set up as a spilt, spilt plot design with three replicates. The treatments were applied under the shortage of nitrogen and irrigation water, using four levels of nitrogen fertilization (0, 50, 100 and 150% of Nitrogen recommended) and four levels of water regime (50%, 75%, 100% and 125% of ETc). The leaf-to-air temperature difference (ΔT), The relationship between the temperature of the canopy (Tc) and temperature of soil (Ts), pair is best suited to find the plant under plant stresses. Also determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), water stress index (CWSI) and stomatal conductance index (Ig) using various reference and non-reference thresholding techniques were estimations. Mass production, nitrogen productivity, water productivity, chlorophyll A, chlorophyll B and total chlorophyll, respectively were tested at the season is separated into initial, rapid, midseason, and late season growth periods.

Experiment statements

Different agricultural practices were performed such as the greenhouse preparing, **Lettuce** planting, watering fertilizer and plants protection during plants growth using an application of thermal imaging to detect plants stresses.

The greenhouse preparing

The field work began on Saturday 10/10/2021 for cleaning operations, removing all existing obstacles, and preparing the greenhouse land from the inside on which the experiment is based .Greenhouse preparation stages. The soil of the experimental study wasn't planted five years ago so the land was reclamation to preparing it for planting and then put drip irrigation system. The soil samples were collected from the study area and chosen randomly from surface at 10 cm. Ten soil samples were collected covering most of the study area a soil sample was Collected and put in a sealed plastic bag to determine the soil chemical analysis was done in the lab to determine some soil chemical properties.

Lettuce planting

Lettuce crop were planted in plant nursery. 6 week-old seedlings were transplanted in the greenhouse in 4 November 2021. The distance between rows and plants on the same furrow was 100 and 30 cm respectively. A two-meter distance was left between different treatments to avoid overlapping between different treatments.

Lettuce watering

As for the first irrigation after transplanted, the amount of water added was 3.5 m^3 every four days from 4/11 to 28/11/2021. Most of the irrigations were in the morning with a network pressure of 1.45 bar. The field experiment was divided into sixteen combinations treatments. Four irrigation schedules (50%, 75%, 100% and 125% ETc). Water was added about 24 twenty-four times during four stage, I from 29/11, 3/12,7/12, 11/12 and15/12/2021, stage, II from 19/12/2021 to 8/1/2022, stage, III from

13/1/2022 to 3/2/2022 and stage, IIII from 8/2/2022 to 28/2/2022, the amount of water added after seeding was 4.2 $m^3.h^{-1}$. The irrigation treatments were according to the program prepared for irrigation. The amount of water distributed with the initial stage (Init. (Lini), rapid stage (Dev. (Ldev), mid-season stage (Mid (Lmid)), and late season stage (Late (Llate) growth periods as shown in Table 1.

Table 1. Lettuce growth periods with crop coefficient

Crops	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})
Lettuce	40	60	50	15
Lettuce Kc	Kc_{ini}=0.7	Kc_{mid}=1.05		Kc_{end}=0.95

Source: Authors' determination.

Lettuce fertilizer

Phosphorous and potassium fertilizers were applied in liquid form during irrigation. Phosphate and potassium fertilizer were added in the form of Phosphoric Acid H3PO4 85%(w/v) and JOSPA K50. Nitrogen fertilizer was added in the form of nitrate (3.88 kg) and applied in four equal doses: The first one at 20 days after planting on 29/11/2021 after planting and the other on 29/12/2021 and the other on 9/1/2022.while the last dose from potassium only on 4/2/2022. Four nitrogen nutrient levels distributed with (0, 50, 100 and 150%N).Irrigation and fertilization scheduling in one program to distribute of irrigation and fertilization prepared the replicates of the experiment**.**

The IR soft steps

Interface have three items ribbon, work space and status bar to detect thermal image.The ribbon helps you to carry out modifications and settings and to find the relevant functions and commands quickly. The functions are divided into different groups on four tabs: Analysis, Report, Imager and Settings. The functions/commands vary depending on the tab selected, the sequence of digital and thermal image analysis processes as showed inFigure 1.

Experimental measurements

Many measurements were taken to include meteorological and microclimatic measurements of temperature and humidity, water measurements, vegetative measurements of lettuce and Lettuce, thermal measurements, and measurement indicators of plant stress.

Meteorological and microclimatic

The meteorological data comes from a meteorological station in, Agricultural Research center, Tripoli, Libya (latitude of 32°12`25`` and longitude of 13°62`16``) during the winter season of 2021-2022. Lettuceand lettuce plants were planted in November 2021. Agriculture greenhouse microclimatic measurements It comes with a small and portable weather station.

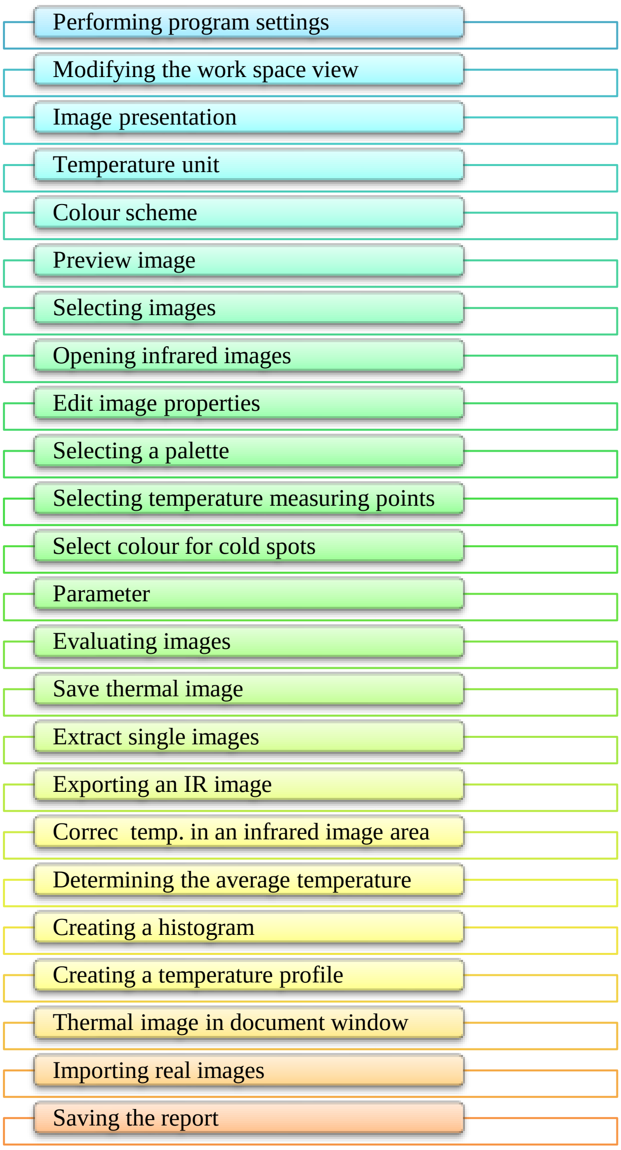

Fig. 1. The sequence of digital and thermal image analysis processes
Source: Authors' determination.

Irrigation water requirements

Irrigation water requirements for the drip irrigation system was calculated based on the meteorological data collected from Tripoli weather station which is next to the experiment. Irrigation water requirements were based on the calculation of potential evapotranspiration using CUP plus model application.

Reference Crop Evapotranspiration

Because of the extra high aerodynamic resistance induced by low wind velocity (0.01–0.3 m s^{-1}), ETo will be underestimated in greenhouse under low wind velocity situations [6]. Therefore, the ETo inside greenhouse, referred to $ETo_{,GH}$, was computed using a modified Penman–Monteith method established in greenhouse [9], where a constant aerodynamic resistance of 295 s m^{-1} was utilized to counterbalance the effect of the low wind speed on ETo.

$$ETO_{GH} = \frac{0.408\Delta(R-G)+Y(\frac{628}{(T+273)})VPD}{\Delta+1.24Y} \quad ..(1)$$

where:

$ETo_{,GH}$ is the reference evapotranspiration (mm d^{-1}); Rn is the net radiation (MJ m^{-2} d^{-1}); G is the soil heat flux density (MJ m^{-2} d^{-1}); T is the mean air temperature (◦C);

Δ is the saturation slope of the saturation vapor pressure curve at T (kPa $◦C^{-1}$); γ is the psychometric constant (kPa $◦C^{-1}$); and VPD is the vapor pressure deficit (kPa).

Lettuce and lettuce Crop Coefficient

The Lettuce and lettuce crop coefficient (K_{cb}) was defined as the ratio of crop transpiration (T_r) to reference crop evapotranspiration ETo when the average soil water content of the root zone was adequate to sustain full plant transpiration [1]. In this study, the soil surface was covered by a plastic sheet, and the total water use was from crop transpiration. At the daily base, the crop transpiration amount can be regarded as the daily sap flow when the water storage in plant tissue is negligible. Then, K_{cb} is calculated as the ratio of plant sap flow (SF) to $ETo_{,GH}$:

$$K_{cb} = SF/ETo_{,GH} \quad ....(2)$$

where:

K_{cb} is the Lettuce and lettuce crop coefficient; SF is the daily sap flow amount (mm d^{-1}); and $ETo_{,GH}$ is the daily reference evapotranspiration (mm d^{-1}) in greenhouse.

Crop Water Stress Index (CWSI)

The measurement of canopy temperature as an indicator of stress was put on a sound footing by [20] who defined a 'Crop Water Stress Index' (CWSI).Natural references were actual vine leaves (either detached in their natural position within the canopy, or detached and hung on a frame) The index IG was proportional to the leaf conductance to water vapor transfer which was calculated from leaf temperatures as follows:

$$IG = (T_{dry}-T_{leaf})/\ (T_{leaf}-T_{wet}) \quad ....(3)$$

This index is theoretically proportional to stomatal conductance (gs) . An index analogous to [18] crop water stress index (CWSI) was also calculated, where in this case:

$$CWSI= (T_{dry}-T_{leaf})/\ (T_{dry}-T_{wet}) \quad ....(4)$$

Heat Indices Basics IR

To consistently compare plant temperature across the plant age, we calculated the deviation of Tp from ambient temperature (dTp=Tp - Ta), a measure often used in field phenotyping studies of heat tolerance.

Canopy Temperature CT

[25]affirmed that canopy temperature measured with the infra-red can be utilized successfully to indicate water stress in grapevines by comparing them to well-irrigated reference vines.

ΔT normalized canopy or leaf temperature=

T_{canopy}-T_{air}orT_{leaf} - T_{air}.............................(5)

MTD, maximum temperature difference= T_{leaf_max}-$T_{leaf-min}$.....................................(6)

NRCT, normalized relative canopy temperature=

$$\frac{(T\ leaf-Tminimum)}{(Tmaximum-Tminimum)} \quad ....(7)$$

C++ plus model

The C++ programming language was used to build a set of algorithms to determine and predict the colorimetric and thermal indicators and to study the effect of thermal, water and fertilization stress. The simulation and predicting programs model written by C++

Program mode Crop Stress Index (CWSI)

To estimate the Color Vegetation indices (CVI) program model I, and Crop Stress Index (CWSI) program mode for plant greenhouses as presented in Figure 2.

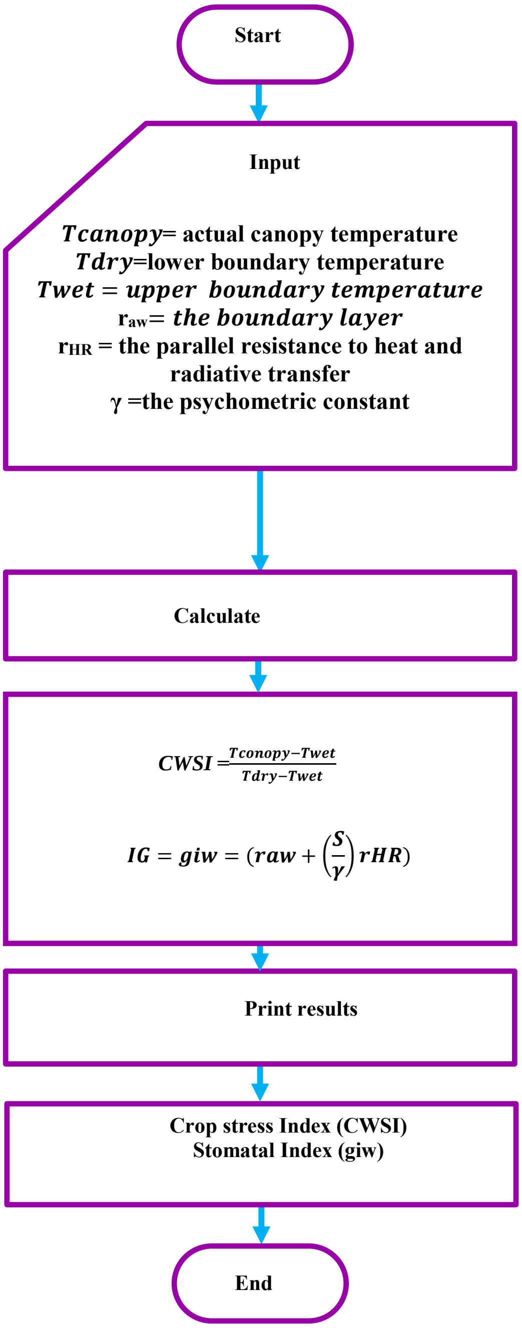

Fig. 2. Flowchart of Crop Stress Index (CWSI) program mode
Source: Authors' drawing.

RESULTS AND DISCUSSIONS

The temperature of air, soil, canopy, and leaf were measured by IR image affected by different irrigation and fertilization levels of lettuce crops at different fertilization levels.The interaction between the water regime and nitrogen fertilization levels has an effect on Lettuce temperature indices. The results were discussed during irrigation levels 50% ETC, 75% ETC, 100% ETC and 125% ETC. Also at different levels of nitrogen fertilization 0, 50, 100 and 150% at average temperature for growth periods are shown in Figures3 and 4 .

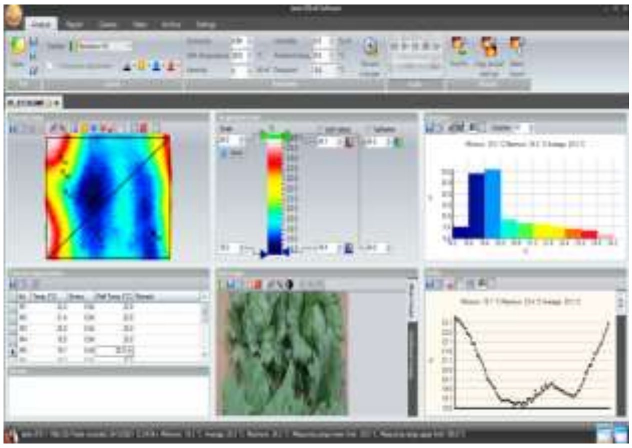

Fig. 3. IR soft interface, ribbon, work space and status bar for Lettuce Crop
Source: Authors' determination

Monitoring temperature of lettuce crop under different fertilization and irrigation levels

With the control level of fertilization (0%), Figure (5)showed the maximum value of lettuce temperature of air, soil, canopy, and leaf were 27, 25, 27, and 24 °C, recorded with 100 % ETC also showed the minimum value for the same indices were 23, 23, 22and 21 °C at 50%ETC. With the control level of irrigation (100%ETC), Figure (6)showed the maximum value of lettuce temperature of air, soil, canopy, and leaf were 24, 22.5, 18.5, and 17.3 °C, recorded with 125 % fertilization, also showed the minimum value for the same indices were 19, 18.3, 16.2 and 15.3 °C recorded with 0 % fertilization level.

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With the levels of fertilization, Figure (7)showed the maximum value of maximum temperature difference, andnormalized relative canopy temperature were 6.24. and 0.56 °C, alsoFigure (8) showed the minimum value for the same indices were 4.44 and 0.33 °C. Linear regression analysis was performed to predict the MTD and NRCT at different irrigation and fertilization levels. The following equation represents the relationship. MTD:

$y = 0.6091x + 3.9119 \quad R^2 = 0.9804$

$y = 0.5535x + 3.9729 \quad R^2 = 0.943$

NRCT:

$y = o.0779x + 0.2444 \quad R^2 = 0.9861$

$y = 0.1004x + 0.1155 \quad R^2 = 0.9351$

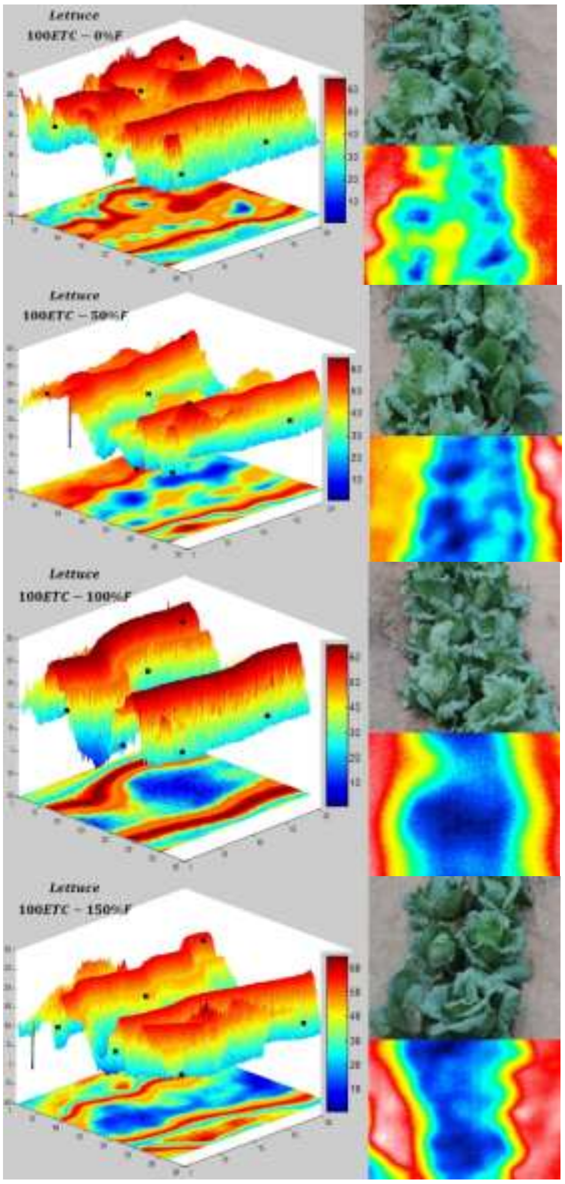

Fig. 4. Lettuce temperature recorded under different fertilization at 100% ETC irrigation levels
Source: Authors' determination.

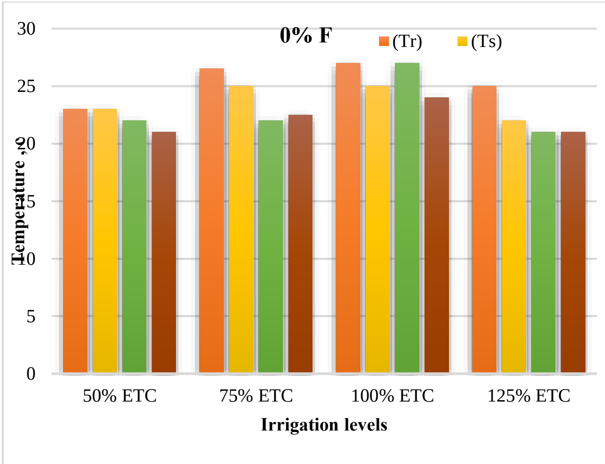

Fig. 5. Relationship between heat stress indicators and irrigation levels of lettuce crop
Source: Authors' determination.

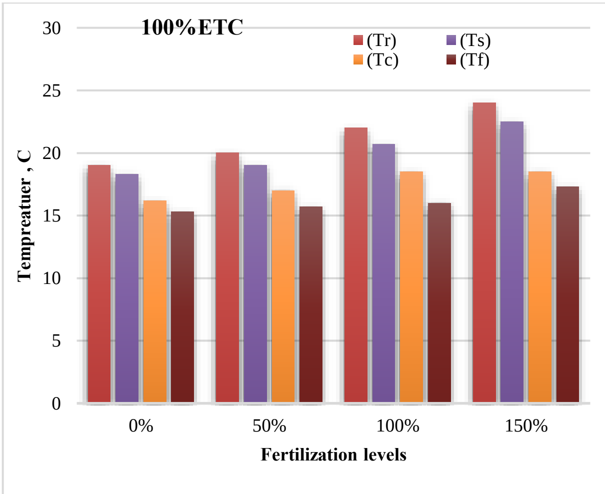

Fig. 6. Relationship between heat stress indicators and fertilization levels of lettuce crop
Source: Authors' determination.

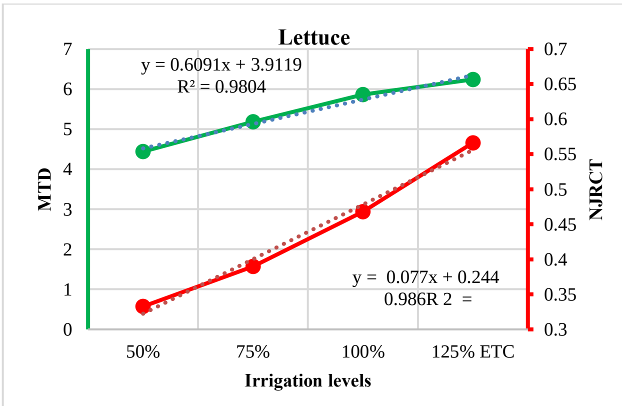

Fig. 7. Maximum temperature difference and normalized relative canopy temperature with irrigation levels of lettuce crop
Source: Authors' determination.

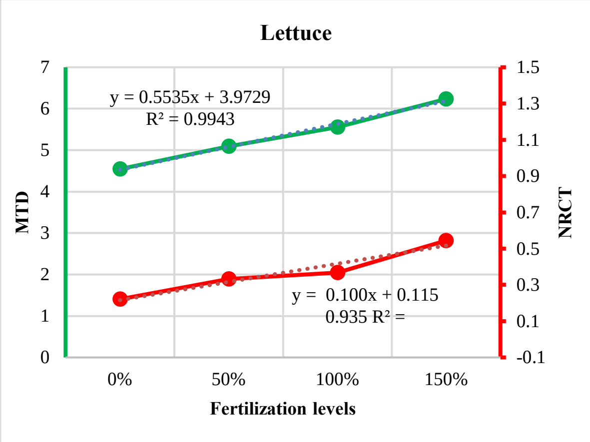

Fig. 8. Maximum temperature difference and normalized relative canopy temperature with fertilization levels of lettuce crop
Source: Authors' determination.

CONCLUSIONS

In greenhouse production systems often crop growth monitoring involving accurate quantification of plant physiological properties. plant becomes stressed when any biological or environmental factor inhibit growth and development. Stressed plants express their symptoms in many ways. It is difficult to detect and rapid accurate quantification of early symptoms with conventional measurement methods. For Lettuce plants, the results showed: At the level of fertilization (0%), the maximum values of lettuce the lowest values for MTD and NRCT were 0.673 and 0.1 °C at irrigation systems ETC 100% and ETC 50% and nitrogen fertilization systems at 0% level.. And ETC 50% and systems and nitrogen fertilization level 100%. In the fourth level of fertilization (150%), the maximum value of leaf temperature was 24, 23, 22.5, and 23 °C and NRCT was 5.5 and 3.5 °C, and the lowest values for MTD and NRCT were 0.82, 0.28 °C, and 0.018 °C at 0.018 °C. Irrigation ETC 100% and ETC 50% and systems and nitrogen fertilization standard 150%.

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