Health, Quality and Irrigation Indexing for Turf From Thermal and Visual Image Data Using a Hawk-Eye™ and/or an EYAS System

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Background:

Jackson et al. (1981)[1] determined that the canopy to air temperature difference ($T_{canopy} – T_{air}$) depends on vapor pressure deficit (VPD). Under non-limiting water conditions a healthy crop transpires at the potential rate (i.e. evapotranspiration is the maximum it can be, but maximum evapotranspiration increases with increasing VPD). Thus, for several crops, when crop health and water availability is not limiting and when measured under clear sky conditions, there is a linear relationship between $T_{canopy} – T_{air}$ and VPD. Jackson called this linear relationship the theoretical 'nonwater-stressed baseline' (nwsb). For a given crop, at a given VPD, this theoretical baseline provides the minimum possible value of ($T_{canopy} – T_{air}$)nwsb. The $T_{canopy} – T_{air}$ for a non-transpiring crop is insensitive to VPD and can be estimated if wind speed and net solar radiation are known. This sets the 'upper limit' (ul) to ($T_{canopy} – T_{air}$)ul. Jackson et al. used the idea of 'upper and lower' baselines, to create a crop water stress index (CWSI). The CWSI = ($T_{canopy} – T_{air}$) – ($T_{canopy} – T_{air}$)nwsb / ($T_{canopy} – T_{air}$)ul – ($T_{canopy} – T_{air}$)nwsb: where $T_{canopy} – T_{air}$ is the measured difference in temperature, ($T_{canopy} – T_{air}$)nwsb is the estimated difference at the same VPD under non-limiting water conditions (on-water stressed baseline), and ($T_{canopy} – T_{air}$)ul is the non-transpiring upper limit. This CWSI allows one to relate crop's temperature to the maximum and minimum values possible under similar environmental conditions. The higher the CWSI, the greater the crop stress is assumed to be. A disadvantage of the above form of CWSI is the need to determine the non-water stressed baseline by plotting $T_{canopy} – T_{air}$ against VPD. This requires substantial time to be spent determining the baseline for a well-watered crop, and the VPD needs to be known when measuring T_{canopy} of the crop of interest. Also, this index does not account for changes in T_{canopy} due to irradiance and wind speed, and the non-water-stressed baseline is not necessarily the same under different radiation conditions. Finally, the non-transpiring upper limit also varies, with a wide range of values (Ben-Gal et al., 2009). Establishing a Stress Index from empirical observations of the upper and lower limits is possible by understanding that transpiration is a key measurement and applying thermographic techniques to the image data.

Karcher and Richardson (2003)[2] and others, found that an analysis of a digital visual image (400 – 700 nanometers) pixel by pixel, provides a reliable method to measure the reflectance of color from vegetated surfaces. The color can be measured and expressed as the hue degree. Establishing an area of interest and then averaging the measured hue values of each pixel an average hue and the standard deviation of the hue in that area can be determined. The average hue and its standard deviation give a measure of the color and homogeneity of the turf. From the hue, chlorophyll content can be inferred and with the standard deviation of the hue, quality (color, uniformity, density) can be inferred.

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[1] Jackson, RD, Idso, SB, Reginato, RJ, Pinter, PJJ, Canopy temperature as a crop water stress indicator, Water Resources Research, Volume 17, Issue 4, 1981

[2] Karcher, Douglas E. and Richardson, Michael D., Dep. of Horticulture, Univ. of Arkansas, Quantifying Turfgrass Color Using Digital Image Analysis, Crop Science, 43:943–951, 2003

Persistent Measurements:

Because plants are continuously transpiring and respiring in a dynamic environment (air temperature, humidity, pressure, water availability, wind, solar intensity, and sky conditions), infrequent snapshots of the plant canopy don't reflect the plant's integrated health, stress, and water status. It is important to have an understanding of the thermal and visual character of the crop over a period of time. Settling on any one image as a starting point for scouting and or for indexing may lead one to a poor conclusion regarding actions needed. Long term observations and measurements in the image data make it possible to recognize persistent patterns and lead to a truer understanding of the condition of the turf. Especially in the thermal band, frequent persistent image data records are needed to understand the plant's health and water status. With respect to irrigation and understanding water status, persistent measurements are a must.

Discussion:

During the day evaporation of the transpired water vapor cools the leaf/canopy. At night one can see the heat from respiration, transpiration, and evaporation of the near surface moisture. There are two signals that can be obtained from thermal image data of the canopy. First, an examination of the homogeneity of a time series of images will highlight health and stress locations and also highlight (not measure) soil moisture. Secondly, persistent stress indexing will express the relative amount of stress. The Hawk-Eye™ and EYAS Systems use the canopy temperature normalized by the air temperature at every image data capture as an indicator of transpiration and respiration. This 'indexing' infers the plant health and plant stress. Thus, the turf's canopy temperature is the biotic integrator of the air temperature, humidity, pressure, water availability, wind, solar intensity, and sky conditions that contribute to the turf's health and water status. More than seven years of observations by Hawk-Eye™ Systems of turf has demonstrated that an equation of the form like one outlined by J. Miguel Costa[3] et al. (2013), addressing plant–environment interactions is a superb indicator of the health, stress, and water status of turf. Less frequent observations of other crops such as grapes and almonds strongly suggest that the stress equation applies to other crops.

The Hawk-Eye™ and EYAS Systems use this form of the Stress Index (SI); (SI) = $(Tm - TLL)/(TUL - TLL)$. The SI value is calculated over designated areas, every image pair (10 minute periodicity). It is known as the Image Stress Index. The Daily Stress Index is the average of the Image Stress Indexes from sunrise to sunset.

When paired with the Stress Indices over the period of several days the change of the hue and the standard deviation of the hue significantly contribute to the assessment of plant health. Thus a stable hue and a lower the standard deviation (high degree of uniformity) not only represents represent high quality but also confirm the stress assessments.

Indexing Stress:

Presently we calculate and use two versions of the Hawk-Eye™/EYAS Stress Indices.

a. Version 4 treats the SI equation as:

[3] J. Miguel Costa, Olga M. Grant, M. Manuela Chaves, 2013, Thermography to explore plant–environment interactions, equation (5) on page 3

Tm = canopy temperature minus air temperature measured at image data capture time
TLL {non-stressed condition} = early daylight canopy temperature minus air temperature (running average over six days)
TUL {stressed condition} = most stressed part of the day canopy temperature minus air temperature (running average over six days)

Version 4 has been shown to provide excellent results.

b. Version 3A treats the SI equation as:

Tm = canopy temperature minus air temperature measured at image data capture time
TLL {non-stressed condition} = early daylight canopy temperature minus air temperature (running average over two days)
TUL {stressed condition} = canopy temperature that cool season turf photorespiration is estimated to occurs at. Presently we are using 90 degrees fahrenheit.

Version 3A was established when we saw that method V4 did not follow very dynamic summer conditions. Weather hot and dry; then cool, moist, and overcast summer; then hot and dry over the period of a three days.

The Image Stress Index (reported with every index) looks like this:

[DATE/time: _____, zone01: Image Stress .92]

The Daily Stress Index (reported about 30 minutes prior to sunset) looks like this:

[DATE: _____, zone01: Daily Stress .31]

Indexing Quality:

Daily Visual Index is the average of the standard deviation of the hue, +/- one hour of solar noon (or for 2 hours of no shade during late morning thru early afternoon).

It looks like this:

[DATE/time: _____, zone01: color 97.33, uniformity 5.42]

Irrigation Guidance:

The Daily Irrigation Index threshold is the index value where the plant indicates it needs water. The Prescription is the amount of water the plant is given during the evening after it says it needs it. When the Daily Irrigation Index crosses the plant's threshold that day, irrigation is applied in a predetermined amount. The amount is a constant (i.e. the same amount all season) that is specific to the location and it is based on a typical amount of irrigation that might be applied. Daily Irrigation Index measurements continue every day and the next day the Irrigation Index crosses the threshold the water is applied again. The goal is to put just enough water into the root zone, then irrigate again when called for and not until then. There are periods where the Irrigation Index may call for the prescription two or three evenings in a row or it could go six or more days before water is called for by the plant.

The Daily Irrigation Index is checked by evaluating the Quality Index (QI) at noon and the Daily Stress Index (SI) at the end of the sunlight day. With respect to the signal to irrigate, the greatest weight is given to the Daily SI, but when the QI is seen to wander; i.e. the standard deviation is growing and/or the hue is decreasing, irrigation may not be needed. When there have been long periods of rain, cool air temperatures, and frequent cloudy sky conditions it is important to look closely for disease if the QI decreases rather than adding water if the stress measures high.

Using remote sensing for managing turf, or any crop, is complex and requires large amounts of image data measurements and calculations, 24/7/365. Hawk-Eye™ and EYAS Systems collect, measure, and calculate autonomously to make actionable alerts so that Users of the system can go about their business, to be alerted when there is something requiring attention.

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