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COMPARASION OF CROP WATER STRESS INDEX (CWSI) AND WATER DEFICIT INDEX (WDI) BY USING REMOTE SENSING (RS)

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Abstract

Drought, water scarcity and climate changes are very important threats for agriculture on a global basis. Remote sensing (RS) is accepted as a technique to collect data and determine water stress indices. Water Stress Indices (WSI) are useful tools to prevent drought and determine irrigation scheduling. The water stress indices are primarily identified as the Crop Water Stress Index (CWSI) and the Water Deficit Index (WDI). The effect of soil background is major problem to establish CWSI especially during early growth stage measurements of canopy temperature (Ts). Hence, WDI is a better index when it comprised with CWSI because of Ts. CWSI and WDI can be determined by two different techniques. These are determined by using measured by using traditional components to collect data and estimated methods by applying RS components to collect necessary data. Estimated method has many advantages when this method compared with measured method. However, estimated method needs some RS components which are infrared gun (IR), sling psychrometer, Spectro radiometer. With the help of these tools, the necessary data are obtained and WDI is determined. By using Spectro radiometer vegetation indices are defined. Among the many vegetation indices, the Normalized Difference Vegetation Index (NDVI) is mostly used one. By using NDVI determination of vegetation cover is easy and accurate technique to establish WDI. Establishing these both stress indices with less fieldwork and by saving money, time and labor conveys the necessary information for agriculturists using remotely sensed data especially for large agricultural fields.

Key Words: Water Stress Index, Crop Water Stress Index, Water Deficit Index, Remote Sensing

INTRODUCTION

Drought is a main reason of limited agricultural productivity and of plant yield uncertainty throughout the world (Martinez-Fernandez et al., 2016). For this reason, agricultural drought is a very big threat that can be defined by shortage of water supply (Al-Solaimani et al., 2017). Water is one of the fundamental elements required to keep important functions of all living things in the past and coming years (Akay and Önder, 2016). The total water supply of the world is 1410 million km^3 and unfortunately only 1.3% of it is fresh-water (USGS, 2006a). Rapidly growing population is causing the consumption of clean water resources to a certain extent (El-Shirbeny et al., 2015). Irrigation is the dominant user of fresh-water on a global basis (USGS, 2006b). Droughts and water scarcity are already a serious problem in many European countries (Giannerini and Genovesi, 2015). Moreover, growing global fear regarding water scarcity means that efficient water use is important (Gal et al., 2003) by improving water management and focusing plant stress in agricultural management as well (Xu et al., 2015). All the current trends show that water scarcity threaten humanity globally due to available freshwater amount and quality have significantly decreased in the last few decades (Silber et. al., 2015); therefore, water management is very important issue (Tanriverdi, 2005). Not only water scarcity and drought but also climate change is very important topic for agriculture productivity (Liu et al., 2017). Climate warming and changes in the extremes have eventually influenced vegetation dynamics in northern terrestrial ecosystems based on the modeling and observational studies (Piao et al., 2014). Determining exactly how climate change effects vegetation changes has received common attention in the past several decades (Yang et al., 2012). Vegetation growing is limited by water scarcity (Zhang et al., 2010). It is necessary to figure out the vegetation dynamic changes and responses to climate change to estimate the quality of ecosystem and maintain optimal ecosystem functioning (Mu et al., 2013). Monitoring climate changes is possible by using new technologies which are remote sensing (RS) and Normalized Difference Vegetation Index (NDVI) (Tucker, 1979; Nash et al., 2017).

Effective monitoring of water status by utilizing indices is required to efficiently maximize yield and quality of crop under today's competitive conditions of reduced water resources (Rud et al., 2014). Thus, water stress indices (WSI) are important to prevent drought and determine irrigation scheduling (Qui et al., 2000; Kacar, 2007; Sharda et al., 2013). Consequently, water stress indices may be decided to have a better water management. The water stress indices are primarily identified as the Crop Water Stress Index (CWSI) and the Water Deficit Index (WDI).

The objectives of this study were to explain importance of the water stress indices and determine them to have a better irrigation management with indicate the benefits of using RS. Withal compare these indices (CWSI and WDI) to result which one is better index to use in irrigation management.

REMOTE SENSING (RS)

Recent developments of Remote Sensing (RS) components have extended the practice of remote sensing in agriculture (Turner et al., 2011; Hoffmann et al., 2016a; Liu et al., 2017). The ability to automate data collection, and to process and perform such data has been significantly increased by RS. The detection and recording components to this order are known as remote sensors. These sensors are like photographic cameras, mechanical scanners and radar systems (Diker, 1998).

RS may have utilized to estimate the evapotranspiration (ET) (Jimenez et al., 2011) especially for large areas (Tanriverdi, 2003; Yang et al., 2017); by known estimation ET, RS supplies analysis of irrigation system performance, high productivity and it is significant guidance to managers and system designers as well (Mulla and Schepers, 1997). RS is verified to be useful in agriculture for stress classification, irrigation scheduling through canopy temperature monitoring, and yield prediction. Progress in thermal RS of ET were extremely summarized, including major reviews by Carlson (1986); Moran and Jackson (1991); Kustas and Anderson (2009). Petropoulos et al. (2009) provided a comprehensive and systematic review of the surface temperature-vegetation index (T_s-VI) space method. Presently, Wang and Dickinson (2012) served a comprehensive review of ET observation, modeling and climatic variability. Rud et al. (2014) stated that RS methods utilizing the thermal part of the spectrum can provide an indication of crop water status.

CROP WATER STRESS INDEX (CWSI)

With increasing water scarcity and drought impacts, water saving irrigation techniques are commonly used in agricultural fields to determine better water management (Belder et al., 2004; Uphoff et al., 2010; Zia et al., 2012; Li et al., 2014). Crop water deficit definition or water status monitoring is the base to proper irrigation scheduling (Xu et al., 2015). Therefore, crop water deficit definition techniques based on soil water condition, crop water potential, and leaf physiological parameters are of great worry (Yatapanage and So, 2001; Silva et al., 2007). The crop water stress index (CWSI) outputs are quite stable, proposing the feasibility of implementing this method for irrigation management (Rud et al., 2014; Bai et al., 2017). CWSI is able to notice stress 24-48 hrs. prior to the stress detection by visual observation (Kacira et al., 2002). CWSI is a technique that utilizes vapor pressure deficit (VPD) and measurements of the crop surface temperature (T_s) mostly by an infrared thermometer (IR) to establish the crop water status (Idso et al., 1977; Jackson et al., 1981; Peng et al., 2011). CWSI based on canopy temperature and meteorological terms following Idso et al. (1981) was used (Rud et al., 2014). After Idso et al. (1981) CWSI has been successfully applied in many different plants, such as wheat (Yuan et al., 2004), cotton (O'shaughnessy et al., 2011), maize (Romano et al., 2011), potato (Ramirez et al., 2016), bean (Erdem et al., 2006), and some vegetables (Cremona et al., 2004; Rud et al., 2014) or fruits (Paltineanu et al., 2009).

Air temperature (T_a), T_s and VPD are necessary data to establish CWSI. The dry and wet bulb temperatures measure with an aspirated psychrometer at the level of 2 meters in the open field part. The mean T_a is determined from average of these measurements (Erdem et al., 2005). While other factors should be considered in order to attain accurate measurements of stress levels, T_s is the most important (Jackson et al., 1981). A crop's T_s can be measured remotely through the use of infrared thermometers (IR) or thermal scanners (Jackson, 1982). The mean VPD is computed as the average of calculated instant VPD utilizing the corresponding instant wet and dry bulb temperatures and the pyschrometer equation (Allen et al., 1998). Numerous early researches focused on T_s and T_a differences to determine the transpiration. The relationship between T_s and water stress is based on the statement that as a crop transpires, the evaporated water-cools the leaves lower the T_a. Jackson et al. (1981) confirmed that when a plant is transpiring fully, the T_s is 1 to 4 degrees cooler than the T_a and the CWSI comes 0. T_s will increase, as the crop becomes water stressed, the stomata close and transpiration decreases (Rud et al., 2014). As transpiration decreases, the T_s increases and can be 4 to 6 degrees warmer than the T_a (Jackson et al., 1981). Thus, an estimate measurement of water stress in crops is based on the inverse correlation between T_s and stomal opening (Fuchs, 1990). Garcia et al. (2000) declared that in the stressed plot, the average of T_s was 5 or 4 ^{o}C higher than the unstressed plot. When the plant is not transpiring anymore, the CWSI is 1 (El-Shirbeny et al., 2015). A primary impediment to the routine operation of IR in assessing crop water stress status and irrigation scheduling was overcome when Idso et al. (1981) developed an innovative CWSI that normalizes the stress-degree-day parameter (Idso et al., 1977; Jackson et al., 1977) for environmental variability. Under natural terms of evaporation, the condition of a given mass of air can be described by its temperature and vapor pressure (VP). The CWSI is an indicator of the relation transpiration rate occurring from a crop at the time of measurement using a measure of T_s and the VPD, which is a measurement of air dryness. A sample of VPD baselines is given in Figure 1. The atmospheric VPD (kPa) (Banerjee et al., 2012) was calculated with the relative humidity (RH, %) and temperature (T, °C) measured by the automatic weather station meanwhile of the image capturing.

$$VPD=0.6108e^{(17.27T/T+237.3)}(1-RH)$$

Thus, VPD (the vapor pressure deficit of air at T_a (kPa)) is an essential calculation to determine VPD upper (maximum stress) and lower (minimum stress) baselines. Besides, it was used to calculate the lower limit of $T_s - T_a$ (dT_{ll}).

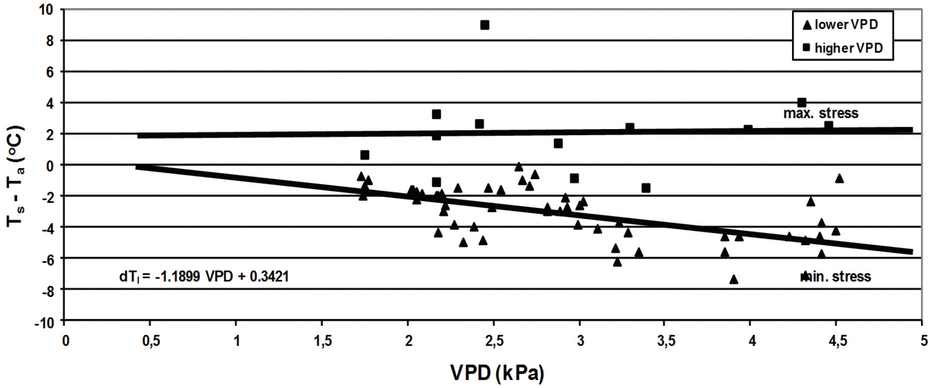


Figure 1. VPD upper and lower baselines for corn (Tanriverdi, 2003).

dT_{ll} = Slope (VPD) + Intercept,
dT_{ul} = Intercept + Slope ($VP_{sat}\{T_a\} - VP_{sat}\{T_a$ + Intercept$\}$)

These calculated parameters (dT_l and dT_u) and the current difference in $T_s - T_a$ (dT) are utilized in the CWSI formula (Idso et al., 1981).

$$CWSI = (dT - dT_{ll}) / (dT_{ul} - dT_{ll})$$

where:
dT; the current difference between canopy and air temperature °C. ($T_s - T_a$)
dT_{ll}; the baseline difference between canopy and air temperature of a well-watered, transpiring plant, °C. $(T_s - T_a)_{ll}$
dT_{ul}; the baseline difference between canopy and air temperature of a fully stressed, non-transpiring plant, °C. $(T_s - T_a)_{ul}$

WATER DEFICIT INDEX (WDI)

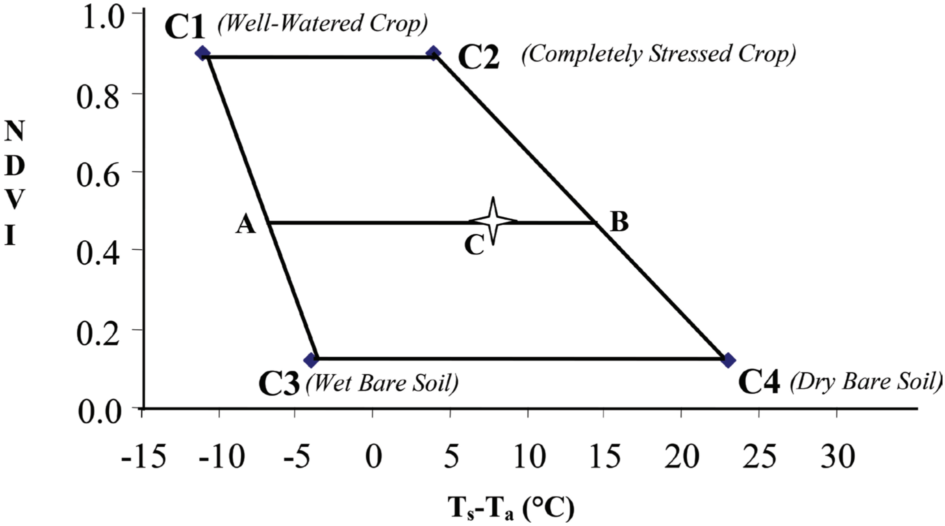
Water deficit index (WDI) is another WSI and it works the same way as CWSI. That is, 0 indicates no water stress and 1 indicates that water stress is at the maximum point (El-Shirbeny et al., 2015). The CWSI is functional technique in only full vegetation cover (Wang and Takahashi, 1999). Thus, the WDI used by Moran et al. (1994) addressed this limitation by proposing the WDI to explain a soil canopy water deficit status, was derived from the theory of CWSI presented by Jackson et al. (1981) (Colaizzi et al., 2003). WDI is noted a composite of both vegetation cover and soil background to measure T_s (Hoffmann et. al., 2016b).

Determining the vegetation cover is the most important part of preparing the WDI. Both estimated by using remotely sensed data and measured by using Light Bar (LB) vegetation cover (fraction, f) techniques can be utilized for determination of vegetation cover in agricultural fields. There are numerous techniques for estimating vegetation cover generally by utilizing Spectro radiometer, such as Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Modified Soil Adjusted Vegetation Index (MSAVI), Visible Atmospherically Resistant Indices ($VARI_{green}$) and Vegetation Index (VI_{green}) (Tanriverdi, 2003). NDVI, as an effective indicator to monitor vegetation and natural environment at regional and global scales, has been commonly utilized (Colaizzi et al., 2000; Beck et al., 2006; Fensholt et al., 2010; Fensholt and Proud, 2012; Gao et al., 2015; Tong et al., 2017), to search the effect of climate change on the vegetation growth and ecosystem structure and functions (Zhang et al., 2005; Park and Sohn, 2010). There is no doubt that vegetation growth depends upon a suitable hydro-thermal condition (Xu et al., 2011). Relations between NDVI and T_s are generally utilized to investigate the hydro-thermal limit on vegetation growth (Zhou et al., 2015). The vegetation cover is plotted versus the difference between measured T_s and T_a ($T_s – T_a$) (^oC) to determine WDI. There are three key techniques for determining the vegetation cover which are estimate by using RS components, measure by using light bar and theoretical. Figure 2 shows the VIT trapezoid by estimating vegetation cover by using NDVI.

The NDVI proposed by Rouse et al. (1973) for monitor vegetation is one of most widely used indices. NDVI is defined as the difference between the NearInfrared (NIR) and Visible (VIS, generally red) bands divided by their sum (Tucker, 1979; Liu et al., 2017). There has been substantial evidence that NDVI formulation can reduce atmospheric, Bidirectional Reflectance Distribution Function (BRDF) and other effects (van Leeuwen et al., 2006).

$$NDVI = (NIR – RED) / (NIR + RED)$$

As shown in figure 2, the VIT trapezoid offers lines that attach the four corners (C1, C2, C3, C4), in which the left line contains point A and describes the range of ($T_s – T_a$) possible for full vegetation cover where water is not limiting. In like way, the right line includes point B and describes the possible range of ($T_s – T_a$) for status of no available water. The range of ($T_s – T_a$) possible for full vegetation cover is characterized by the top line between C1 and C2, which is also the range of ($T_s – T_a$) possible for the CWSI. In figure 2, A, B, and C are formed on the plot of the WDI for a given amount of vegetation cover.



Source: Colaizzi *et al.* (2000)

Figure 2. VIT trapezoid for cotton in Arizona

Point A presents a non-limiting condition for ET; point B is the upper limit at which no water is available, and point C presents the actual measurement. The WDI is defined as the proportion of the distances of AC to AB. Using the VIT trapezoid, WDI is calculated,

$$WDI = \overline{AC} \,/\, \overline{AB}$$

Moran et al. (1994) introduce the origin and underlying assumptions of the equations on a theoretical basis, as well as the assumptions underlying the VIT trapezoid. The necessary meteorological data include T_a, VPD, R_s, and u (wind speed (m s^{-1})) measured at height z, all of which are accessible from the weather station. With the measurement of actual ($T_s – T_a$) and vegetation cover (Point C, figure 2), ($T_s – T_a$) at the four corners of the VIT trapezoid have to also be identified.

CONCLUSION

Agricultural drought monitoring is of rising interest and more accurate and efficient calculation and assessment techniques, as well as early warning systems, are needed (Martinez-Fernandez et al., 2016). For this purpose, stress indices are important subject because index can warn to irrigators before 24-48 hours for irrigation need (Kacira et al., 2002). Moreover, rapid increase of global population, pollution of natural resources, global warming and climate change nowadays increases the pressure on limited water resources (Colak et al., 2014). Therefore, one of the primary important entries for agricultural sector is irrigation as accepted by many researchers. If accurately managed, obviously irrigation management plays a critical role in increasing crop output. Al-Solaimani et al. (2017) found that increased yield could be achieved with limited water if WDI was used. Moreover, Garen and Moore (2005) mentioned, known traditional methods were not easy techniques before RS was widely available to collect extensive spatial data sets on field, soils and vegetation. Also, RS has an advantage to collect data from large field if it is compare with traditional methods (Tanriverdi, 2003; Hoffmann et al., 2016b). Especially, RS technology allows capability for large scale field level or regional evaluation and monitoring of crop field cover, crops growing and status by remotely sensed data (Yang et al., 2017).

Many scientists using CWSI to quantify water stress and schedule irrigations should use early studies to determine a suitable non-water stressed baseline equation (Nielsen, 1990; Çolak et al., 2014). However, CWSI has some difficulties to measure crop surface temperature (T_s). WDI is accepted both soil and crop canopy temperatures as a surface temperature (T_s) (El-Shirbey et al., 2015). Contrarily, collected surface temperature data T_s had to symbolize the plant surface temperature to establish the CWSI. In this way, some of the data are not useful to determine the baselines of CWSI for early growing season because of partial vegetation cover. The CWSI is merely applicable to cases of full vegetation coverage, however Moran et al. (1994) developed WDI that allowed the index to be estimated for partial vegetation coverage as well. Under these circumstances, WDI was found to be a better index when compared with CWSI since T_s measurements were more reliable in determining the four corners of VIT.

As mentioned before, there are two different techniques (measured and estimated) to determine the vegetation cover values for WDI. A LB can be used to calculate the fraction (f) which is called as a measured vegetation cover technique to establish WDI. Calculated f can be plotted versus $T_s – T_a$ (°C) to determine the WDI like estimated technique. Clearly, f needs more fieldwork to represent vegetation cover when it comprised with estimated vegetation cover. Tanriverdi (2003) mentioned that statistically, vegetation indices have a reliable relationship with measured vegetation cover (f). Thus, the review evidences the importance of utilizing vegetation indices, which are quick and easy to calculate. Contrarily, for measured vegetation cover, it is hard to complete the data set with the limited time (during noon under clear sky conditions) available (Payero et al., 2005). When estimated vegetation cover calculations are compared with measured vegetation cover calculation clearly estimated vegetation cover (vegetation indices) methods have many advantages especially in large agricultural fields (Rud et al., 2014). Among the many vegetation indices, NDVI is the most popular one to establish WDI. Many scientists are identified NDVI which has reliable and accurate outputs to represent vegetation cover from agricultural fields.

Daily data would also have ensured a better comprehension of VWC in the soil profile and would therefore be a better tool for improving irrigation management. Utilizing RS daily essential data can be collected even for large fields, but it should be very hard by using measured technique. Finally, this review stated that;

- Drought, water scarcity and climate changes are vital topics for agriculture.
- WDI is better water stress index when it compared with CWSI because of T_s measurements.
- RS conveys the necessary information to the irrigator with less fieldwork, and is useful in saving money, time and labor
- Among the many vegetation indices, NDVI is the best one to determine vegetation cover to established WDI.
- Estimated vegetation cover technique is useful if it is compare with measured technique.

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