Understanding drought stress in winter wheat (*Triticum aestivum L.*) using UAV thermal and multispectral data

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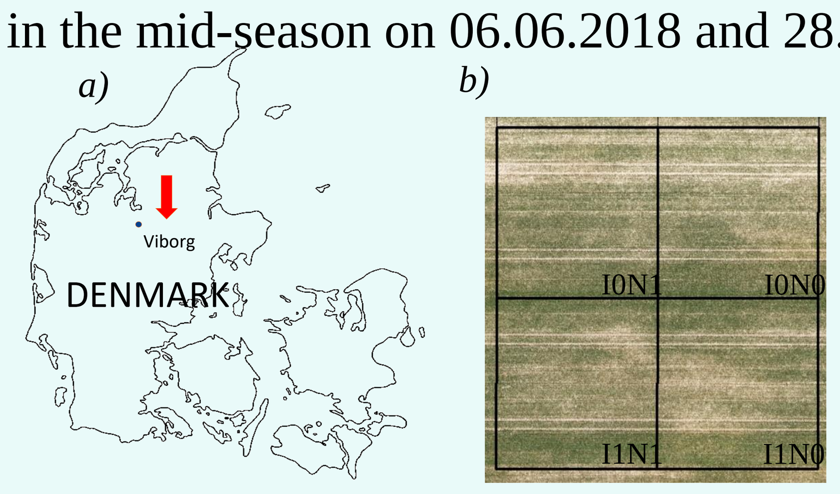
Introduction

Drought is the most significant stress that reduces crop yield, and irrigation is a common practice to ameliorate its impact. Water often is a limited resource, hence there is everlasting need to improve irrigation applications to increase water use efficiency and save water. In order to get advanced information regarding if the plants are suffering from stress before the appearance of visible stress symptoms, multispectral reflectance as well as temperature information from Unmanned Aerial Vehicle (UAV) data can be used to quantify crop drought stress through the use of different temperature and vegetation indices. The objective of this study is to develop crop drought stress maps using vegetation indices derived from UAV multispectral and thermal imagery in order to explore seasonal and diurnal winter wheat behavior under drought conditions.

Study Area

The field experiment was performed on 24 winter wheat plots (30m x 30m each) under three different irrigation regimes and two nitrogen fertilization levels in 2018 and 2019 in central Denmark. Quadrotor DJI Matrice 100 equipped with multispectral and thermal sensors (RedEdge (1.2 Mpix MS – 5 bands) and DRONExpert Thermal (640x480 pix) respectively) was used to perform several flights in seasons 2018 and 2019. Out of 24 plots, 4 plots were chosen to perform diurnal flights with thermal sensor in the mid-season on 06.06.2018 and 28.06.2019 (Fig. 1b).



I0N0 – low irrigation, low fertilization
I0N1 – low irrigation, high fertilization
I1N0 – high irrigation, low fertilization
I1N1 - high irrigation, high fertilization

Fig. 1. *Location and field design of the experiment in Denmark:*
a) location of Havrisvej fields in Denmark; b) plot chosen for diurnal flights

Years 2018 and 2019 were dramatically different regarding weather conditions as 2018 was unusually hot and dry compared to the average Danish climate (Fig. 2).

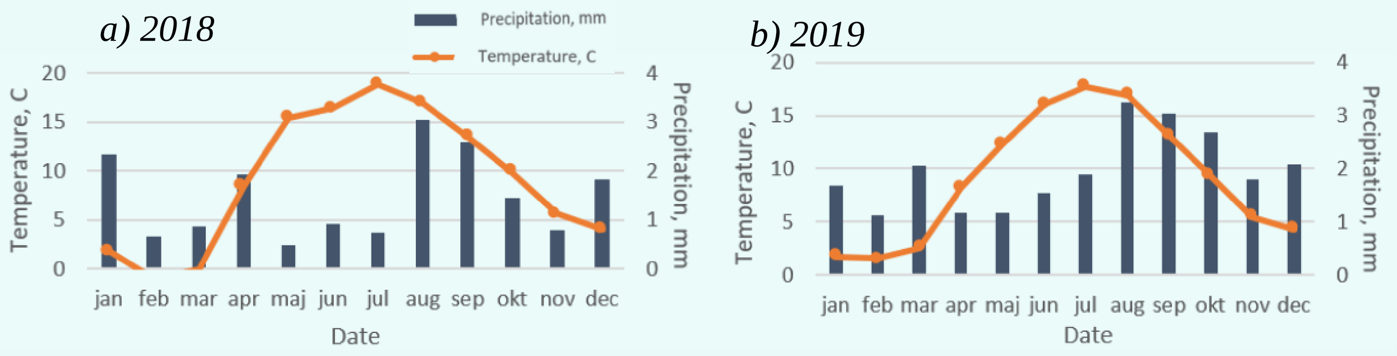


Fig. 2. *Average monthly temperatures (ºC) and average monthly precipitations (mm) in experimental fields: a) 2018; b) 2019*

As a result of a severe drought stress, yields in 2018 were distinctively lower, almost half compared to 2019 even in plots with higher irrigation rates (Fig. 3)

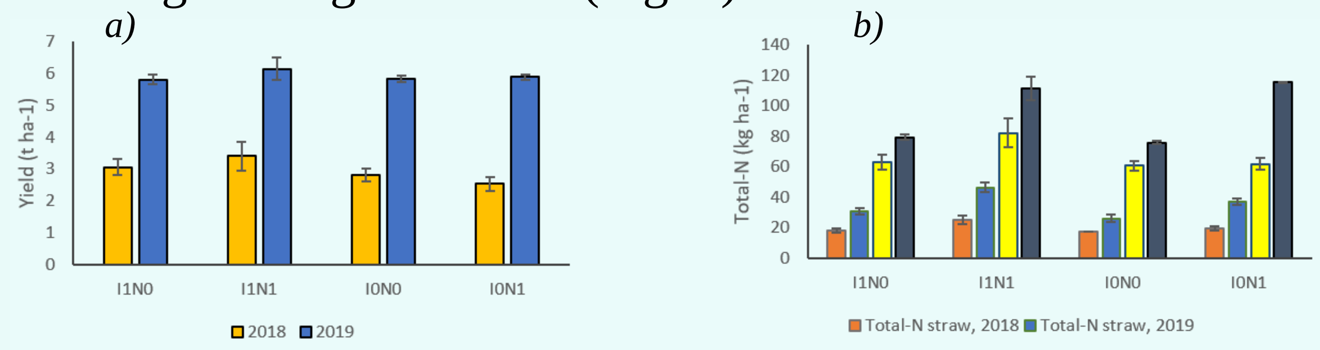


Fig. 3. *Average yield data by plots:*
a) Final grain harvest; b) Total N content in yield, grain and straw

Results

Normalized Difference Vegetation Index (NDVI) is frequently applied to evaluate plants "greenness", due to the high reflectance in the IR region , which is related to plant structural traits and low reflectance in the red band due to chlorophylls.
NDVI = (NIR-R)/(NIR+R) where NIR is infrared - the reflectance in the near-infrared band (800 nm) R is the red band (680 nm). Fig.4 shows how green biomass was lower in 2018 compared to 2019 and that winter wheat has ripened earlier.

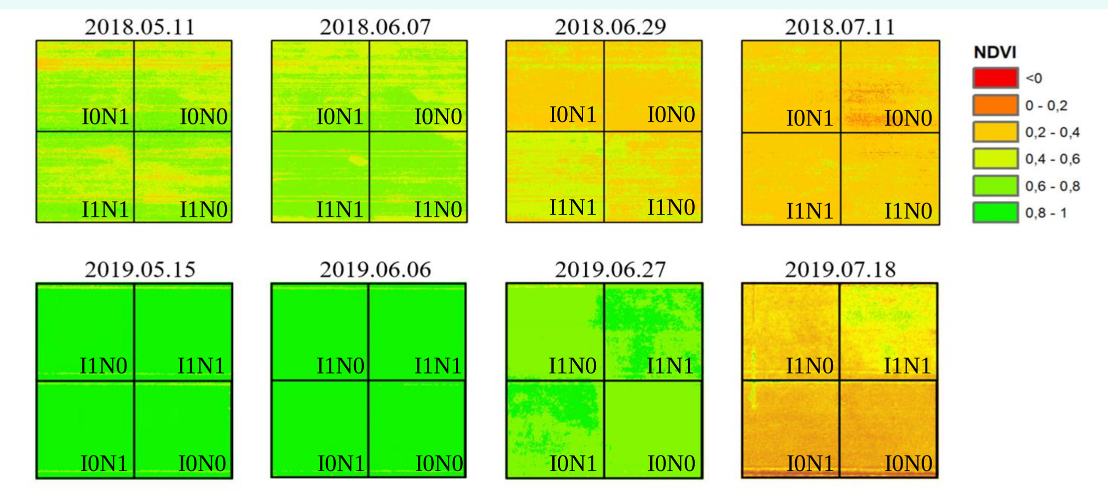


Fig. 4. *NDVI over the season in 2018 (plot size 30*30 m) and 2019 (plot size 15*15 m)*

To evaluate UAV multispectral images, 3-channel radiometer (RapidScan) was used to measure crop reflectance in Red, RedEdge and NIR regions weekly and Ratio Vegetation Index (RVI= NIR/Red) was calculated (Fig. 5). There is a big difference between years in RVI values as well as treatment dynamics, specifically in 2018 higher RVI values are corresponding to higher irrigation while in 2019 higher RVI corresponds to plots with higher nitrogen level.

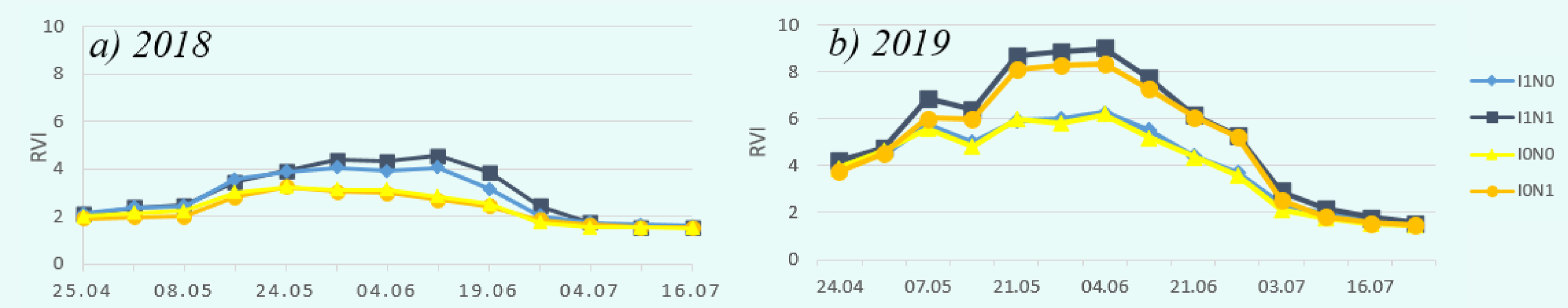


Fig. 5. *RVI over the season in 2018 (a) and 2019 (b). Data points are average values for each treatment*

Thermal images acquired by UAVs have higher potential to detect early drought stress than multispectral, since stomatal closure of the plant while reducing transpiration leads to an increase in leaf temperature. One of the most widely used thermal indices Crop Water Stress Index (CWSI, Idso, 1982) is calculated as:
CWSI=(Tl−Twet)/(Tdry−Twet); where Tl is a temperature of the plant; Twet is the temperature of the fully transpiring plant and Tdry is the temperature of non-transpiring (fully stressed) plant. CWSI (Fig. 6) highlights high spatial variability within each of the treatment in all plots, and also changes during the day following the heat stress.
Twet and Tdry baseline were derived from the images with statistical method described by Cohen, 2017

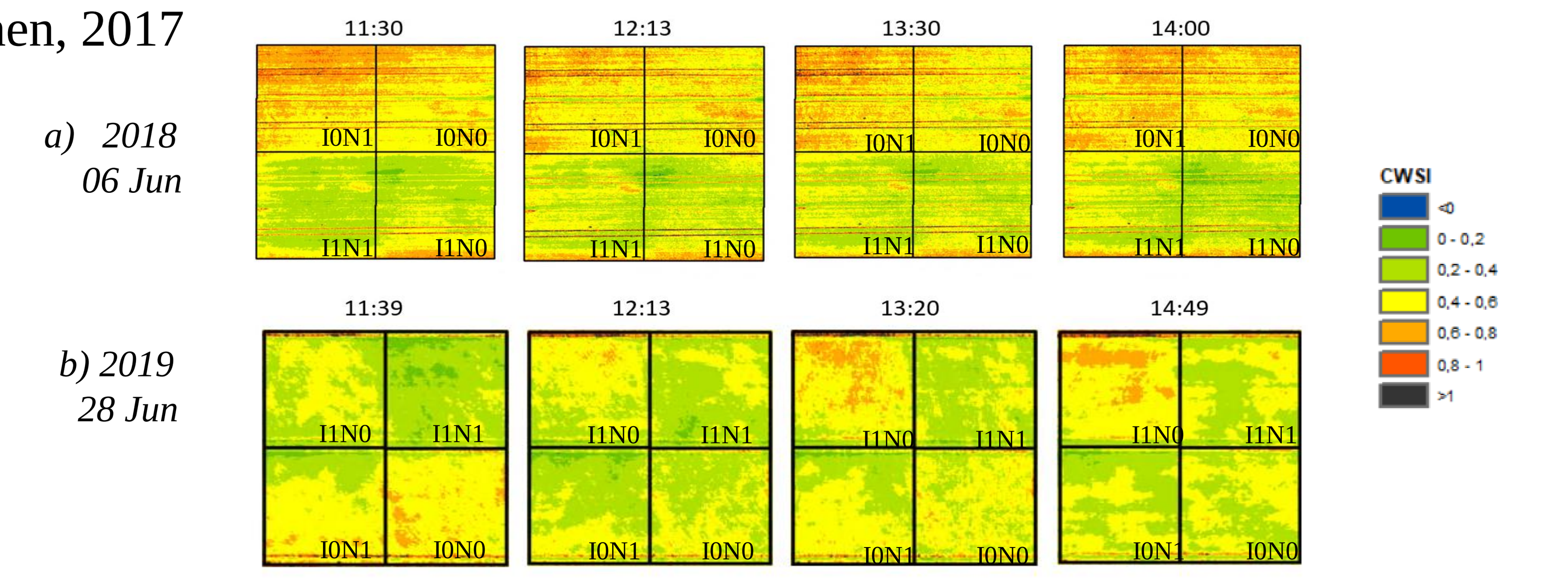


Fig. 6. *Diurnal change in CWSI in a) 2018 (plot size 30*30 m) and b) 2019 (plot size 15*15 m)*

Small difference between treatments can be explained with the low difference in soil water content between treatments in both years (Fig. 7).

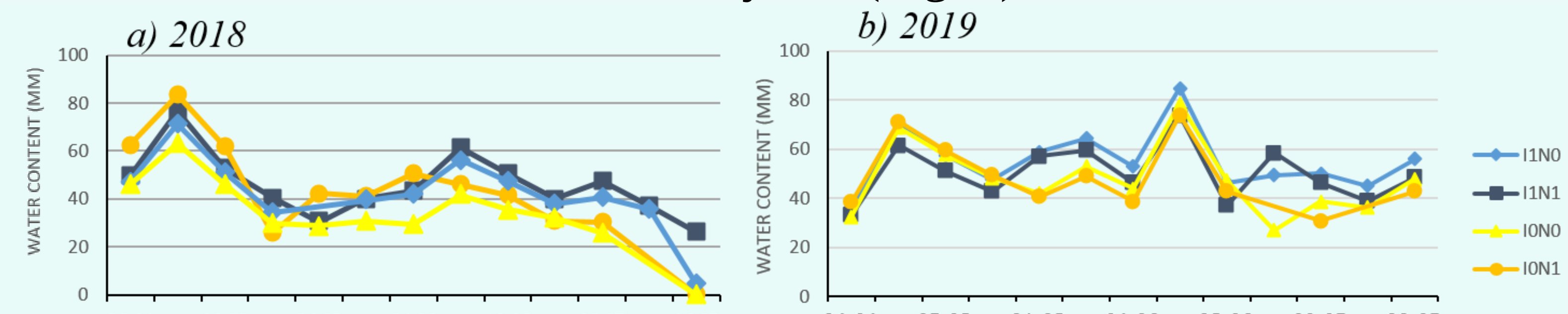


Fig. 7. *Seasonal change in soil water content at 50 cm depth in 2018 (a) and 2019 (b)*

Discussion and Conclusions

Understanding seasonal changes in crop behavior, as well as diurnal changes in crop temperature is an important step in achieving practical use of thermal and multispectral UAV data. While vegetation indices, such as NDVI and CWSI, can show us real-time picture of crop biomass, it is necessary to take into account abiotic stresses caused by environmental conditions, seasonal weather behavior, soil status and crop growth stage.
As an example here, due to extremely dry conditions in 2018, yield was exceptionally low even in plots with a high irrigation amount (Fig. 3) while in 2019 the difference between treatments is caused mostly by the different nitrogen inputs. For all treatments in 2018 and 2019 canopy temperature displays high spatial variability in all plots that is reflected in CWSI (Fig. 7), showing stressed parts in well-watered plots and less stressed within non-irrigated plots. Such differences may be used to design more site-specific irrigation if it will be possible to find the exact amount of plant water deficit in these areas. This may be achieved by correlating and validating thermal crop indices to plant parameters, but is also challenging due to the high sensitivity of thermal data.

Future Work

Future studies involve further analysis of CWSI and methods of its derivation, examining other thermal indices such as Water Deficit Index (WDI) and Temperature–Vegetation Dryness Index (TVDI). These should be calculated by taking into account weather conditions; distinguishing the effect of irrigation from spatial variability of a soil; examining the effect of fertilization and comparing calculated indices to resulting yield. Thereby taking another step in designing decision support systems for precision irrigation.

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References

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