Use of Field Spectroscopy for the Determination of the Water Status in Crop Canopies

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Introduction

Water is, in addition to nitrogen, the most important yield-determining factor for crops. A determination of the water content of crops for site-specific crop management which does not require direct physical contact, could improve existing fertilizing and irrigation systems. The results of this study may contribute to the development of a non-contacting online water-status sensor.

Comparing two experiments, we want to show what impact water supply and nitrogen fertilization have on spectral index as well as the reflectance when using short-wave infrared (SWIR).

Various authors have pointed out that some wavelengths in the SWIR may correlate well with the water status of plants (Bowman 1989, Carter 1991, Kleman and E. Fagerlund 1987). This raises to the question whether we may differentiate between drought and N-stress in field experiments.

Material & Methods

All canopy reflectances were measured with a GER 3700 hyper-spectral spectroradiometer (Geophysical & Environmental Research Corp., Millbrook, NY, USA) ranging from 330 to 2500 n.m. Fiber optic was used for all measurements. The reference measurements were done using a spectralon white standard.

In two experiments one in the laboratory, one in the field, drought was established by withholding watering, and compared with a control treatment that was optimally watered. The spectral signature and the water status (water potential) of wheat were measured parallel.

For the first experiment (pot experiment), corn (5 plants per pot) and wheat plants (10 plants per pot) were cultivated in the greenhouse. Water potentials, osmotic potentials, turgor pressures and relative water contents were measured. Immediately afterwards, the plants were spectrally recorded in a photo room, using the light of a 1,000-watt halogen headlamp with day-light characteristics (experiment planning and taking: U. Schmidhalter, R. Gutser, A. Zintel, T. Schneider, K. Günther and U. Beisl).

The experiment contained five stress treatments (S1, S2, S3, S4, S5) and one control treatment (C) with four replications. Pot measurements and leaf measurements were carried out with both corn and wheat. Measurements were conducted at tillering (leaf stage 6 to 7).

Leaf measurements: Three corn and two wheat leaves were chosen per pot (one pot corresponds to one replication), and three (corn) and two (wheat) measurements were taken per leaf side. In order to prevent multiple reflection a black slit shade was made use of.

Pot measurements: eight differing measurement positions were taken per pot (45° turn of the pot respectively, 8 x 45°=360°). In order to do the analysis, The mean was taken of all measurements of both up and down side at leaf level, and all measurements of differing viewing angles at canopy level.

For the second experiment (field experiment), wheat with differing water supply was cultivated on a field in Thalhausen (Bavaria/Germany) in plots of app. six m² (experiment planning: D. Geesing).

The control plots (C) were exposed to „normal" weather conditions. Some of the plots received additional water during times of little rain (B), and others were covered with a roof at the end of tillering (U) to generate drought.
The spectral measurements were carried out when the sky was almost free of clouds. The measurements were taken from a device fixed to a tractor, from about 5 m above the plants. Water potentials, IR temperature, and SPAD values were also parallely determined with a Minolta Spad meter. Measurements were performed at ear emergence (EC 52).

Results & Discussion

Table 1: Measured values of the pot experiment with wheat plants.

Treatment	WP (bar)	Turgor (bar)	RWC (%)	Osm. Pot. (bar)
C	-15.3	-14.6	87.9	-14.6
S1	-22.3	-17.5	65.7	-17.5
S2	-25.0	-18.7	60.4	-18.7
S3	-27.7	-20.2	60.5	-20.2
S4	-28.7	-20.8	58.5	-20.8
S5	-38.6	-25.7	54.8	-25.7

Table 2: Measured values of the field experiment with wheat plants.

Location	U3 Nh	U4 Nn	B1 Nh	B2 Nn	C2 Nh	C1 Nn	Replications
Treatment	Covered by roof	Covered by roof	Watered	Watered	Control Check	Control Check	X
N fertilizers (kg/ha)	150	120	150	120	150	120	X
Water potential (bar)	24.6	24.5	18.1	19.7	20.1	19.6	5
IR-temperature (°C)	23.4	23.1	20.9	21.2	20.5	19.6	10
Temp.difference w/air	-1.0	-1.1	-2.1	-2.4	-2.4	-2.7	10
Spad values	33.7	32.3	45.3	40.2	38.4	37.5	30
REIP (Guyot and Baret)	719.6	720.0	725.5	724.3	723.5	722.2	3

Greatly varying wavelengths, indices and their combinations were correlated with the water potential. Wave lengths mainly were tested in the local curve maxima, minima, ascending and descending areas of water-absorption bands and combinations thereof, and additionally water indices known from the literature, as well as NDVI, SAVI, IR/R, REIP, 740/720, and other indices of biomass - alone and in combination.Penuelas showed that the correlation of the WI (water index, R970/R900) to relativ water content could be improved by including a NDVI (Penuelas et al. 1997).
Thus, theoretically locations of differing biomass with the same water status and locations with the same biomass, but differing water status, may be differentiated spectrally. This also means that we might be able to determine the difference between two similar locations with respect to the biomass influenced by differing limiting factors (drought or nitrogen deficiency). This difference might be useful for improving current practices of fertilizing and irrigation.

Special attention was paid to the use of simple wavelengths and indices to make them practically applicable. The results clearly show the impact of nitrogen fertilization on the development of the spectral signature and the possibility of differentiating between nitrogen stress and drought stress.
In the laboratory experiment, drought was linearly correlated to NDVI reduction (Fig. 1, pot experiment, WP/NDVI).

In the field experiment, the linearity was offset by a cross combination of several fertilizer applications and water supply levels. Both high and low fertilizer treatments were applied in both stressed and watered as well as in control plots. Thus, no significant correlation between water status and biomass or NDVI was apparent. When the NDVI and a wavelength which correlates with water potential was taken into account, the coefficient of correlation increase markeblyin the field experiment. This is not only valid for the wavelength 2020 nm, but also for a great number of other wavelengths and indices. When combining the data from the field and the laboratory experiment (without NDVI), the reflectance with the wavelength of 2020 nm showed the best correlation to the water potential (sq.R. adj. = 0.87). Good correlations were also found with 1450 (sq.R. adj. = 0.77), 1979 (sq.R. adj. = 0.83), 2000 (sq.R. adj. = 0.85), 2010 (sq.R. adj. = 0.81), 1439/1668 (sq.R. adj. = 0.78) and 1670/1450 (sq.R. adj. = 0.78). In all cases, sq.R. adj. was improved by including the NDVI (with a minimum of 0.02). This was caused by the improvement of the field data (Fig. 2). The laboratory data were not significantly improved including the NDVI (Fig. 1). The correlations in the laboratory experiment were in general significantly better due to the controlled conditions. Other biomass indices (e.g. SAVI, REIP, etc.) resulted in a smaller improvement of the correlation of the wavelengths to water potential in the field experiment than the NDVI.

When both experiments are looked at separately, both of them showed further correlating wavelengths and indices. The factors correlating in the combination of both experiments seem especially inert against the differing test conditions (slightly different development stages, different measurement surfaces, different light compositions). This might make them especially interesting for the use in practice.

The relatively small data set represents a weakness of this experiment. The indices found have to further evaluated in other experiments. It is not known yet to what level the indices found can distinguish differences between water potentials. I.e. the index 2,020/NDVI correlated significantly and strongly for a relatively narrow range of water potentials (-18.1 to -24.6 bar, Table 2). But the correlation only refers to five values. Each Measurements were taken at great expenditure. Apart from the averaging inherent in the equipment itself (four times), the average was taken from three measurements taken one after the other with an individual reference for each of the three. Wavelengths of around 2000 are located in a region of strong atmospheric steam absorption. This could cause a problem especially in the morning and in the evening when a thicker atmospheric layer has to be penetrated by the radiation. We have not yet mentioned a number of other problems that made it impossible to take into account one further set of data. Serious problems are caused by changing light conditions and by heterogeneous locations. Other kinds of plants lead to completely different values for the indices found. When comparing the laboratory experiments with wheat and corn, correlations could be found at similar wavelengths, however the relations were completely different.

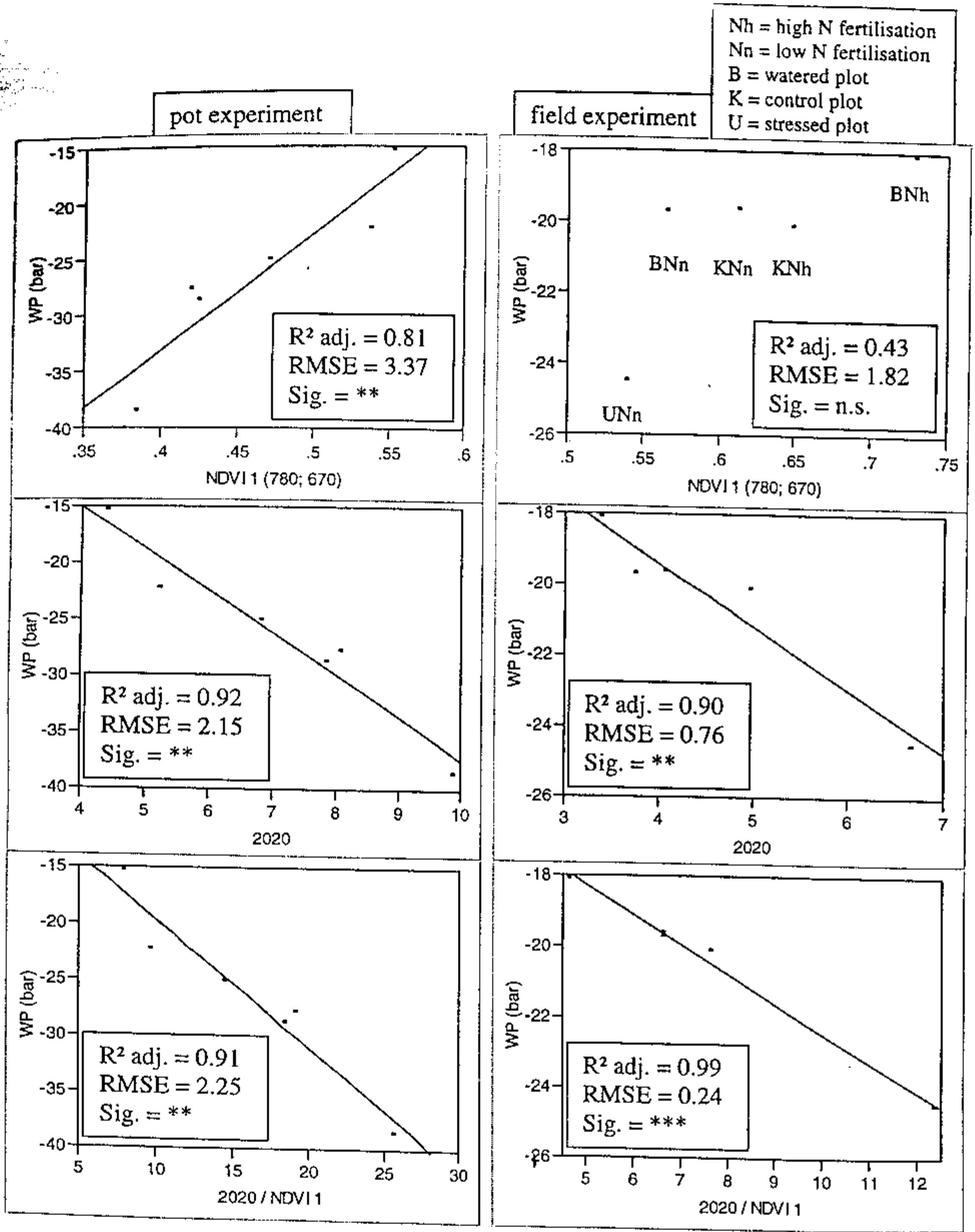

Figure 1: Linear fits of water potential (WP) with reflectance and reflectance indices (RMSE = Root Mean Square Error; Sig. = Significance, 0.001<0.001<0.05, ***<**<*)

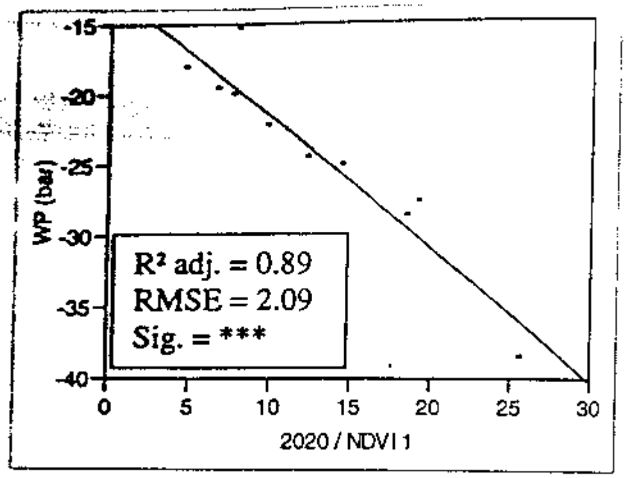

Figure 2: Linear fit of water potentials (WP) with reflectance index R2020/NDVI; field and pot experiments combined

Reference List

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