AUTOMATED SOIL WATER TENSION-BASED DRIP IRRIGATION FOR PRECISE IRRIGATION SCHEDULING

IRRIGATION GOUTTE A GOUTTE AUTOMATISEE AU BASE DES MESURES DE L'EAU DE SOL

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ABSTRACT

It is widely known that careful irrigation scheduling is a key to high agricultural productivity, efficient water use, and reduction of off-site effects due to water movement. Several approaches are available for irrigation scheduling including calculations of the soil water balance (SWB) and irrigation scheduling based on soil moisture measurements. In 2014, common bean (*Phaseolus vulgaris* L.) was cultivated in Germany on a loamy sandy soil to estimate the crop irrigation water requirements. One sprinkler irrigated (irrigation schedule based on SWB calculations, treatment SWB), one rain-fed (treatment RF), and two a drip irrigated treatments (treatments $T_{-200hPa}$ and $T_{-350hPa}$) were conducted. The latter were automatically drip irrigated with 10 mm when a certain measured soil water potential threshold (-200 and -350 hPa) in 20 cm soil depth was measured by installed tensiometers. A comprehensive experimental data collection included measurements of leaf are index, plant height, biomass, yield, stomatal conductance and soil tension at three soil depths.

Irrigation increased fresh matter pod yield significantly. The drip irrigated treatment $T_{-200hPa}$ achieved the highest yield (29.1 t ha^{-1} with 170 mm). Treatments $T_{-350hPa}$, SWB and RF reached 96, 77 and 63% of the yield of treatment $T_{-200hPa}$ with 110 mm, 70 mm and no irrigation water applied. Moreover, above-ground biomass, leaf area index and plant heights were highest for the automatically drip irrigated treatments. The observed stomatal conductance let presume that no drought stress occurred in these treatments. Since the soil water tension can be closely related to stress experienced by plant tissues, soil water tension-based irrigation scheduling has a high potential to support precision irrigation. Advantageously, soil water tension-based irrigation is robust and cheap sensors are available. Difficulties arise from where exactly to probe and, in very heterogeneous soil, extensive measurement programs might be required.

RÉSUMÉ

La stratégie d'irrigation es essentielle pour une agriculture intense avec des rendements haute et un efficacité de usage de l'eau haut. Ce travail éprouve deux stratégie d'irrigation - une basée des calculs de bilan de l'eau et une au base des mesures de l'eau de sol avec irrigation goutteà goutte automatisée - dans une expérience dans le champs avec haricot commun (Phaseolus vulgaris L.). La stratégie d'irrigation goutte à goutte automatisée au base des mesures de l'eau de sol avais le rendement le mas haut. Le traitement $T_{-200hPa}$ (irrigation goutte à goutte de 10 mm à un tension de l'eau de sol de -200 hPa à 20 cm profondeur *de* sol) attendu 29.1 t ha^{-1} avec 170 mm de l'eau, et le traitement $T_{-350hPa}$ (irrigation goutte à goutte de 10 mm à un tension de l'eau de sol de -350 hPa à 20 cm profondeur *de* sol) *a* attendu 28.2 t ha^{-1} avec 110 mm de l'eau. Le traitement SWB (irrigation au base des calculs de bilan de l'eau) a attendu 25.2 t ha^{-1} avec 70 mm, et le non-irrigué 20.8 t ha^{-1}. En plus, l'indice de surface foliaire et la hauteur des plants irrigué automatiquement au base des mesures de l'eau avais augmenté.

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Keywords: Precision irrigation, sensor-based irrigation, tension-based irrigation, automated irrigation, common bean

1. Introduction

Drought stress is a severe environmental constraint to plant productivity (Farooq et al., 2009). It reduces plant growth and development, leaf size, stem extension and root proliferation leading to the production of smaller organs and hampered flower production, and disturbs plant water relations and decreases the water use efficiency (Farooq et al., 2009). A major effect of drought on plants is yield reduction (Cuellar-Ortiz et al., 2008; Porch et al. 2009; Rosales et al., 2012). The severity and duration of the stress and the timing (growth stage of the plant) are critical. The most sensitive stages of development to drought stress in legumes are generally the period just before flowering and during flowering (Prasad et al., 2008; Farooq et al., 2009). In common bean (*Phaseolus vulgaris* L.), a very important food legume, drought stress results in significant yield reduction (Porch et al., 2009; Reynolds et al., 2010). Beans, characterized by a rather limited and shallow root system, are particularly susceptible to drought stress during flowering (Graham and Ranalli, 1997).
Careful irrigation scheduling is a key to avoid drought in horticultural productivity to gain high yields and yield quality, but also for an efficient water use and the reduction of off-site effects due to water movement. Several irrigation scheduling approaches of different complexities and advantages are available. Traditionally, schedules are calculated based on soil water balance (SWB) calculations (Allen et al., 1998), an empiric approach which has its limitations in the achievable accuracy and transferability. The SWB calculation approach has generally been found to be sufficiently robust under a wide range of conditions (Jones, 2004). However, several inaccuracies are involved with this approach. The assumption in the approach that plant growth and development is dependent on calendar time alone ignores the influence of thermal time and water supply on crop development. This limits the ability to apply a particular Kc factor curve to different regions and even to different planting dates in the same region (Annandale et al., 2000). Moreover, errors accumulate over time which makes a data assimilation necessary. A similar approach named 'Geisenheim irrigation scheduling' provides development dependent Kc factors for many vegetables grown under German growing conditions (Paschold et al., 2010).
Alternatively, irrigation scheduling can be controlled by measurements of the soil water tension which closely relates to plant stress (Jones, 2004). Sensor-based irrigation scheduling – irrigation is triggered when a certain threshold value is reached – is technically complex but very precise, cheap sensors are available, and it is automatable (Jones, 2004, Shock and Wang, 2011). However, in heterogeneous soils and plantings and in large fields, difficulties arise from where to probe.

2. Material and Methods

2.1 Experimental site and design

In this study, a field irrigation experiment was conducted with common bean (cultivar Stanley) in Pillnitz, Germany (51°N, 13.9°E and 120 m altitude). The experimental site shows an average annual precipitation of about 650 mm and an average temperature of 10.4°C. The loess soil is a loamy sand with a deep groundwater table. The soil is composed of 35% sand, 39.5% silt, 25.5% clay (soil depth from 0-60 cm) with the sand content increasing in deeper soil depths.
Two randomized treatments, namely one sprinkler irrigated and one rain-fed treatment, were conducted. The crop rows were spaced 50 cm apart with a between-plant spacing of 6.1 cm. The plot size was 7.5 m^2. A linear move irrigation system (Gierhake, Germany) was used to sprinkler irrigate the plots. Irrigation scheduling was based on the soil water balance approach according to Paschold et al. (2010) (SWB treatment) with Kc values of 0.4 (until flowering), 1.1 until (full expansion of first pod), and 1.3 (until harvest). Moreover, a NMC-Pro drip irrigation system (Netafim, Israel) with a discharge rate of 1.6 l h^{-1} per emitter and a emitter spacing of 30 cm was installed in another field nearby. The drip lines were placed in a distance of 50 cm next to each crop row. Two treatments were drip irrigated automatically with 10 mm, when a certain measured soil water tension threshold (-200 and -350 hPa) in 20 cm soil depth was reached (treatments $T_{-200hPa}$ and $T_{-350hPa}$). Additionally, a rain-fed treatment (RF treatment) without irrigation was implemented.

2.2 Experimental data collection

The comprehensive plant data collection included continuous measurements of the leaf area index (LAI, measured with AccuPAR LP-80, Decagon Devices, Inc. USA), plant heights and stomatal conductance of the upper leave side (SC-1 steady state leaf porometer, Decagon Devices Inc., USA). Measurements of stomatal conductance were conducted on (almost) fully expanded leaves at the upper part of the canopy on midday. All measurements were replicated 10 times per treatment. Total above-ground fresh matter biomass at harvest was estimated for a 7.5 m^2 sub-plot. A sub-sample was collected by hand and dried until constant weight. In all measurements, only the center rows were considered. Moreover, the soil water tension was measured continuously in treatments SWB, $T_{-200hPa}$, and $T_{-350hPa}$ using tensiometers (T4e, UMS, Germany) in 20, 40 and 90 cm soil depths, respectively. Climatological data were collected at the research site.

3. Results and Discussion

Beans were sown on the 13th of May and harvested on the 29th of July 2014. The plants were fertilized once with about 50 kg N ha^{-1} according to soil sampling and quantification of mineral nitrate. Insect pests were controlled with pesticides according to standard grower practice. The growth period can be characterized as normally tempered with a rainfall of 204 mm during the growth period of 77 days, respectively.
Irrigation clearly influenced fresh matter yield and total above-ground biomass. With 29.1 ($T_{-200hPa}$) and 28.2 t ha^{-1} ($T_{-350hPa}$), the drip irrigated treatments achieved the highest fresh matter yield with 170 and 110 mm irrigation water applied (see Fig.1). The SWB treatment gained 25.2 t ha^{-1} with 70 mm, the rain-fed treatment 20.8 t ha^{-1}. Drought stress occurred in the rain-fed treatment especially around day after sowing (DAS) 52 (see g in Fig. 2). Dry matter yield differed less (up to 9%) and the rain-fed treatment achieved relatively high values due to a higher dry matter content.

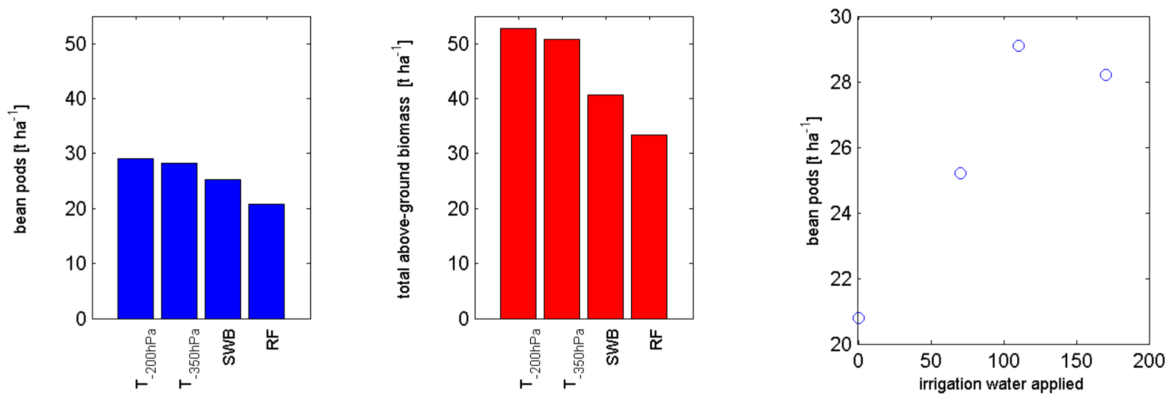

Figure 1.: Measured fresh matter bean yield (left), total above-ground biomass (middle) and fresh matter bean yield over irrigation water applied (right) of treatments $T_{-200hPa}$, $T_{-350hPa}$, SWB and RF.

The drip irrigated treatments achieved the highest plant heights and LAIs (see Fig. 2). During drought stress period around DAS 52, leaf stomatal conductance (g) decreased clearly in the rain-fed and moderately in the SWB treatment. In the drip irrigated treatments, very low dynamics of g were observed during the growing season due to the regular irrigation based on actual soil water tension measurements indicating no water limitations.

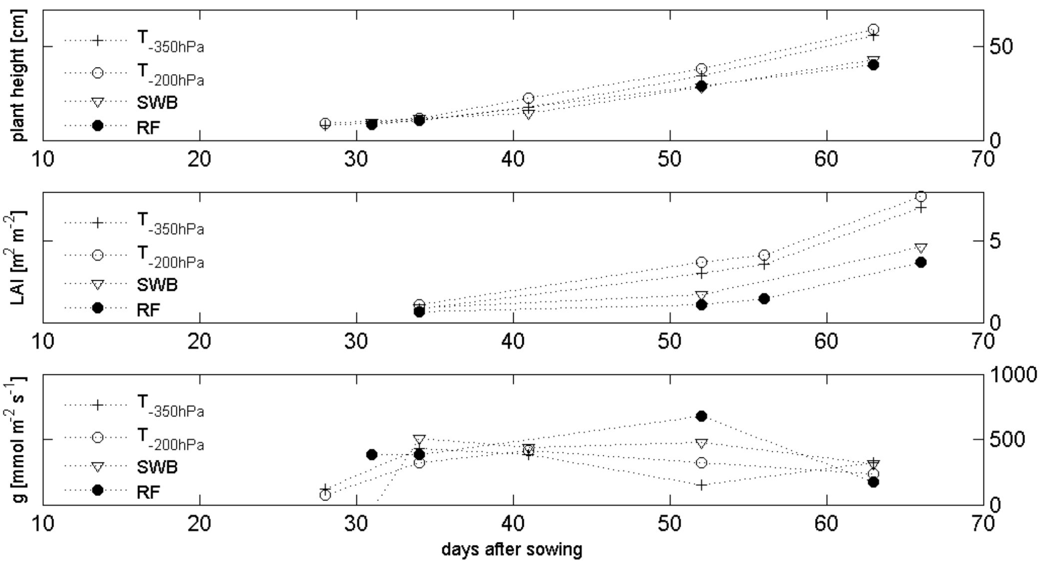

Figure 2.: Measured plant height, leaf area indices (LAI) and stomatal conductivity (g) of treatments $T_{-350hPa}$, $T_{-200hPa}$, SWB and RF.

In the drip irrigated treatments, the upper soil layer (20 cm) was kept moist according to the irrigation thresholds (-200 and -350 hPa), but also at 40 cm soil depth, soil tensions lower than about -200hPa were not observed (see Fig. 3). After about DAS 45, root water uptake was observed in 40 cm soil depth. In all treatments, the tensiometers at 90 cm soil depth (installed in a rather compact soil layer) showed almost no dynamics with values around -30 hPa.

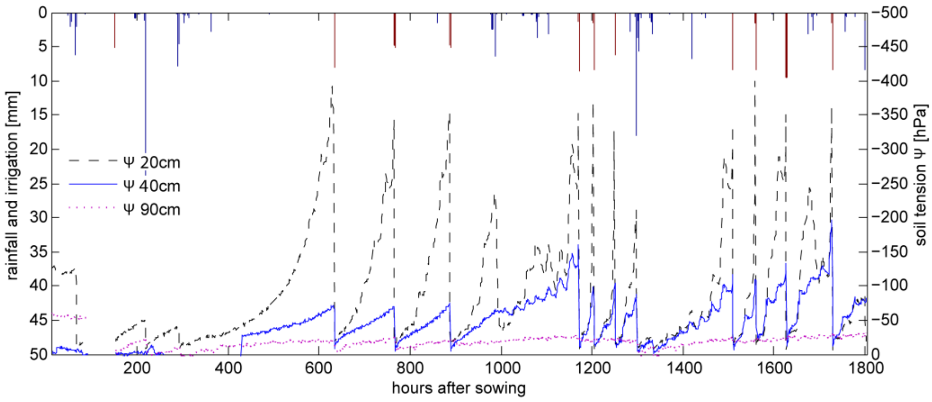

Figure 3.: Hourly rainfall (blue bars) and irrigation events (red bars) and hourly measured soil water tension in 20, 40 and 90 cm soil depths of treatment $T_{-350hPa}$ where irrigation is triggered automatically at a soil water tension of -350 hPa at 20 cm soil depth.

4. Summary and Conclusions

In this study, two different irrigation scheduling approaches - one based on soil water balance (SWB) calculations and one soil water tension-based - were evaluated in order to promote better agronomic practices in irrigated horticulture. Moreover, a rain-fed control treatment was installed. The field experiment was conducted with common bean on a loamy sand soil near Dresden, Germany. The results show that fresh matter yield, leaf area index and plant height increased significantly with increasing irrigation water input. Sensor-based drip irrigation of 10 mm at a soil water potential of -200 hPa measured at a soil depth of 20 cm achieved the highest yields with the highest irrigation water input (29.1 t ha^{-1} with 170 mm). The measurements of the stomatal conductance in the tension-based treatments showed very low dynamics indicating no water limitation. Irrigation scheduling based on SWB calculations led to under-irrigation due to underestimated crop coefficients, which highlight a better accuracy of their estimates**.** With an increasing demand for high yielding water-efficient horticultural production, common irrigation scheduling approaches should be evaluated properly and adapted if required, and new approaches have to be tested on different crops.

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