Spatial Variation in Soil Humidity – Implications for Yield and Irrigation Management of 'Conference' Pear

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Keywords: *Pyrus communis*, stem water potential (Ψ_{stem}), drip irrigation, irrigation scheduling, remote sensing

Abstract

Drip irrigation is a technique frequently used to prevent water stress and to achieve a maximal fruit yield and fruit quality in pear orchards cultivar 'Conference' in Belgium and the Netherlands. The irrigation scheme in an orchard is often based on measurements performed at only a few trees per orchard disregarding the spatial variance in soil moisture throughout the orchard, which occurs due to slopes, differentiation in soil profiles and differentiation in planting regime. To evaluate the importance of this spatial variation in soil moisture an intensive survey was set up in a Belgian fruit orchard in 2010 and 2011. Soil water content (θ_v) and stem water potential (Ψ_{stem}) were monitored weekly at different positions alongside a slope in the fruit orchard. The variation in topography caused variation in soil moisture which lead to variations in fruit yield in the high fruit size classes. This yield variation was successful related to Ψ_{stem} illustrating its value for revealing water stress. A model was suggested to predict Ψ_{stem} based on θ_v and ETo when no direct observations of Ψ_{stem} are available.

INTRODUCTION

Pear fruit (*Pyrus communis* 'Conference') has become an important part of fruit growing in Belgium and the Netherlands. The financial return of fruits having a diameter bigger than 60 mm is twice the return of smaller sized fruits (diameter ≤55 mm). An accurate fill in of daily water demand of the trees is necessary for an optimal fruit size and production. Several authors observed yield decline and decline of fruit size in relation to water stress (Naor, 2001; Marsal et al., 2002; O'Connel and Goodwin, 2007). In Belgium, pear trees are mainly grown on loam and sandy loam soils with high water storage capacity. Sensitivity of fruit size to water stress under these conditions was shown by Janssens et al. (2011b).

The majority of the fruit orchards is situated in the central eastern part of Belgium. The region is characterized by variation in topography which has implications for the course of soil moisture evolution. Janssens et al. (2011b) demonstrated the variation in soil water tension alongside a slope in a 'Conference' pear orchard. Soil water tension during the growing season varied between -100 kPa on the lower part of the slope and -200 kPa on top of the slope. Also Aggelopoulou et al. (2010) and Fountas et al. (2011) discussed the importance of spatial variation due to topography in respectively an apple and olive orchard. Since the drip irrigated orchards in Belgium often are equipped with an automatic steering unit, fruit growers could respond to the variation in the orchard by supplying more water in dryer parts of the orchard.

In this study the main objective was to quantify the importance of the variation in soil moisture due to topography in relation to pear fruit yield. This information supports the development of upcoming remote sensing techniques (Dzikiti et al., 2010; Suarez et al., 2010) where information on spatial variation in the orchard can be acquired.

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MATERIAL AND METHODS

The experiment was conducted in 2010 and 2011 in an orchard situated in Bierbeek (50.826621°N, 4.794847°E), Belgium. The influence of topography on soil moisture and fruit yield was studied on a slope with a length of 93 m and an elevation difference of 13 m. Alongside the slope four plots were monitored (Fig. 1a, b). Each plot consisted of four consecutive trees.

In the upper soil layer (0-30 cm) the soil texture was loamy whereas in the deeper soil layer (30-60 cm) it was a sandy loam. The orchard was planted in 2000 with pear cv. 'Conference' on quince C, with a planting distance of 3,3 x 1 m. The trees are trained in an intensive V-system with four fruiting branches per tree on one central stem.

Two irrigation regimes were maintained during the experiment. One treatment received full irrigation (FI) throughout the growing season and in the other treatment a deficit irrigation regime was applied (DI). In the DI treatment the irrigation amount was lowered during the shoot growth period which for Belgium takes place in the months June and July. The irrigation amount in the two treatments is indicated in Table 1. In 2011 irrigation was withheld in the DI treatment to maximize the moisture gradient between FI and DI. In 2010 the experiment was set up in one row per treatment, in 2011 the set up was extended to two rows per treatment (Fig. 1a, b). Rainfall was recorded on site with rain gauges. Reference evapotranspiration (ET_0) was calculated using the Penman-Monteith equation (Allen et al., 1998) based on data recorded at the weather station at Beauvechain, 10 km from the experimental plot.

In each plot volumetric soil water content (θ_v) and stem water potential (Ψ_{stem}) were monitored weekly. To calculate θ_v gravimetric soil samples were taken with a gauge auger of 30 cm in the soil layers 0-30 cm and 30-60 cm. One sample consisted of minimal 8 subsamples taken randomly in the weed free strip beneath the canopy. Gravimetric water content was measured by drying the soil samples at 105°C for 24 h. Volumetric soil water content was calculated trough bulk density obtained on undisturbed soil samples (Kopecki cylinders).

Stem water potential (Ψ_{stem}) was measured on sunny days without rainfall between 1:00 and 3:00 pm. For each measurement three leaves were selected from the inner part of the canopy. Leaves were enclosed in a plastic bag covered with aluminium foil. After one hour, the leaves were detached and put immediately in a pressure chamber to determine Ψ_{stem} (Scholander et al., 1965).

Fruit yield was determined by harvesting 4 trees of each plot. From each plot the total fruit yield was obtained and distinction was made between the high fruit size classes (larger than 60 mm and larger than 65 mm).

RESULTS

In the DI treatment the average volumetric water content (θ_v) was in 2010 and 2011 lowest at the top of the slope (Plot 1) (Fig. 2a, b). The distinction between Plot 1 and the other plots was more pronounced in the DI treatment but in 2010 even in the FI treatment θ_v was lowest at the top of the slope. In 2011 there was no distinction in θ_v between the plots in the FI treatment probably due to over irrigation, indicated in Table 1. In general there is a clear separation in θ_v between the DI treatment and the FI treatment.

The results of the average Ψ_{stem} correspond with the observations on θ_v (Fig. 3a, b). In both years in the DI treatment the lowest Ψ_{stem} was measured on the trees in Plot 1, at the top of the slope. The Ψ_{stem} of the trees at the other plots on the slope differed less. In 2010 Ψ_{stem} was lower in the DI treatment with a low average Ψ_{stem} under -1,4 MPa. In 2011 the differences in Ψ_{stem} between FI and DI were smaller, probably due to more rain events in 2011 (Table 1).

The lower θ_v and Ψ_{stem} for Plot 1 is reflected in a lower fruit yield in the size class larger than 65 mm, especially in the DI treatment but also in the FI treatment in 2010 (Table 2). This is in accordance with the observations of θ_v and Ψ_{stem} in 2010 in the DI treatment (Figs. 2a and 3a). The effect of low θ_v and Ψ_{stem} observations is less reflected in the total yield. However, in 2011 total yield and yield in the size class larger than 60 mm was significantly ($p<0.05$) lower in the DI treatment according to the Mann-Withney U test. In general total fruit yield was in 2011 3,2 kg/tree lower in the DI treatment and 1,5 kg/tree for the size class larger than 60 mm. In 2010 there were no significant yield differences between the DI and the FI treatment due to the high variation in fruit yield between the plots in the DI treatment.

The sensitivity of the pear yield in the high fruit size classes is reflected in a significant correlation between yield and Ψ_{stem} for 2010 (Fig. 4a) and 2011 (Fig. 4b). Between θ_v and fruit yield there was no correlation (data not shown) but θ_v could be related to Ψ_{stem} involving ETo and the number of days after bloom in a multiple regression (Fig. 5a, b). These relationships show again the dependency of fruit yield on soil moisture evolution in the soil.

DISCUSSION

The objective of the study was to examine and quantify the influence of spatial variation in soil humidity on yield due to topography. On top of a slope in an orchard in Bierbeek fruit yield was up to 5 kg/tree lower in the highest fruit size class (larger than 65 mm) which was related to lower values of θ_v and Ψ_{stem}. Water runoff and rapid drainage are probable explanations for the faster water depletion on top of the slope.

Yield in high fruit size classes has previously been described to be highly dependent on water stress (Naor, 2001; Janssens et al., 2011b). The yield decline on top of the slope was the most pronounced in trees suffering from a water deficit. It suggests that the trees on top of the slope would benefit from a site specific irrigation regime which is feasible because the orchard is drip irrigated and equipped with an automatic steering unit. However, in a commercial orchard it is not possible to establish a dense network of soil moisture measurements. Therefore the implementation of remote sensing techniques which reveal the spatial variation in the orchard (Dzikiti et al., 2010; Suarez et al., 2010) is recommended. These expensive data sources with high spatial but low temporal resolution can be combined with less expensive soil moisture sensors or a soil water balance (e.g., Janssens et al., 2011a) which have a lower cost and a high temporal resolution.

In this study Ψ_{stem} proved again to be a valuable robust indicator for water stress in accordance with Intrigliolo and Castel (2006) and Naor et al. (2006). Therefore Ψ_{stem} seems a good indicator for comparison with remote sensing data to reveal spatial patterns of water stress. Therefore the described relationship between θ_v, day after bloom and ETo can have several applications. Ψ_{stem} can be predicted when no measurements of Ψ_{stem} are available at the time of the remote sensing data acquisition. Secondly the relationship can be used to estimate Ψ_{stem} on other places in the orchard where only θ_v observations are available to enlarge the Ψ_{stem} dataset for comparison with remote sensing data. Third the estimation of Ψ_{stem} can be used to estimate production differences due to spatial variation in moisture content since variations in Ψ_{stem} were closely related to variations in fruit yield in the high size classes.

To conclude, this study showed that variations in topography can lead to yield differences due to variations in soil moisture. Furthermore Ψ_{stem} was related to yield and to soil moisture. It seems a valuable indicator for comparison with remote sensing data to reveal water stress and to estimate yield losses.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Institute for the Promotion of Innovation by Science and Technology in Flanders.

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Tables

Table 1. ETo, Rain and Irrigation in 2010 and 2011 (FI: Full Irrigation, DI: Deficit Irrigation).

	June 2010	July 2010	Aug. 2010	June 2011	July 2011	Aug. 2011
ETo (mm)	114	134	91	102	82	84
Rain (mm)	9	69	138	70	61	119
Irrigation DI (mm)	34	41	25	0	0	0
Irrigation FI (mm)	41	71	25	53	82	77

Table 2. Fruit yield in 2010 and 2011 (FI: Full Irrigation, DI: Deficit Irrigation).

	Fruit yield (kg/tree) FI			Fruit yield (kg/tree) DI		
	Total	> 60 mm	> 65 mm	Total	> 60 mm	> 65 mm
2010						
Plot 1	31,5	11,0	3,2	25,8	6,7	1,1
Plot 2	21,7	13,5	6,8	24,7	14,0	7,0
Plot 3	26,2	15,1	6,8	24,7	5,0	0,6
Plot 4	23,2	12,9	4,4	26,7	6,3	1,7
2011						
Plot 1	29,3	20,4	12,5	27,7	19,1	9,7
Plot 2	28,7	22,3	14,3	23,2	20,1	15,2
Plot 3	30,8	22,9	13,7	28,0	22,2	14,5
Plot 4	30,9	22,6	12,7	28,1	20,6	10,8

Figures

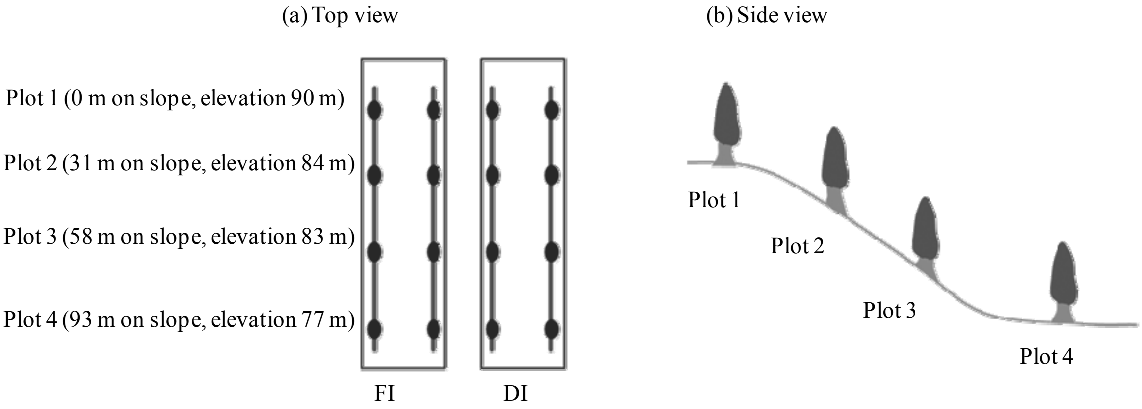

Fig. 1. Schematic of the experiment (FI: Full Irrigated, DI: Deficit Irrigated) (a) Top view (b) Side view.

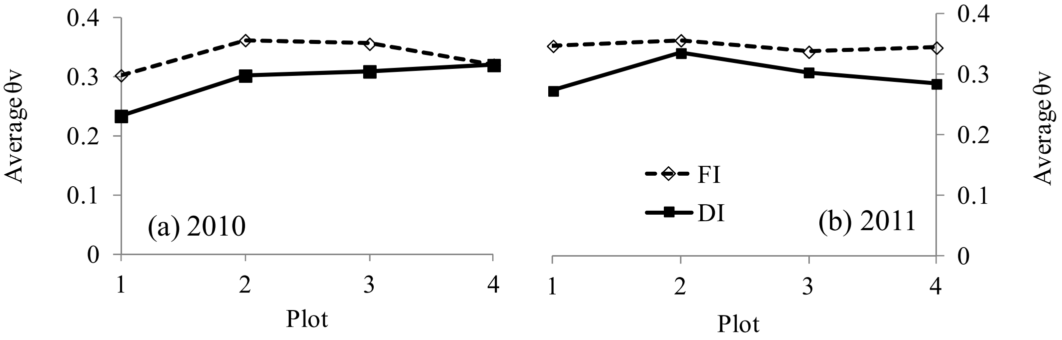

Fig. 2. Average volumetric water content (θ_v) during the growing season in relation to location on the slope for the Full Irrigation (FI) treatment and the Deficit Irrigation (DI) treatment in 2010 (a) and 2011 (b).

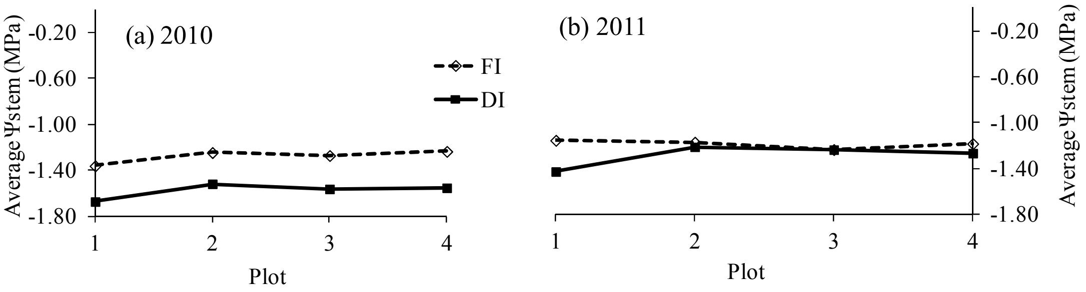

Fig. 3. Stem water potential (Ψ_{stem}) during the growing season in relation to location on the slope for the Full Irrigation (FI) treatment and the Deficit Irrigation (DI) treatment in 2010 (a) and 2011 (b).

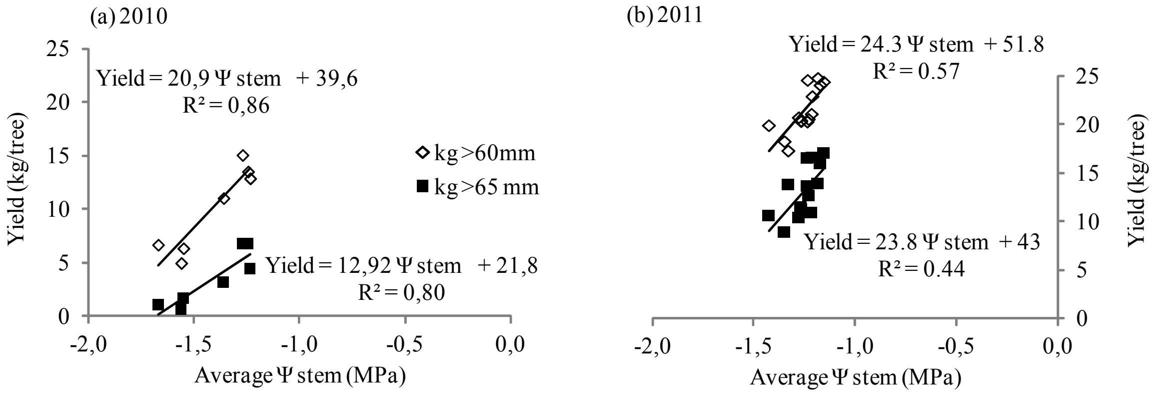

Fig. 4. Average Ψ_{stem} related to fruit yield in size class >60 mm and >65 mm for 2010 (a) and 2011 (b).

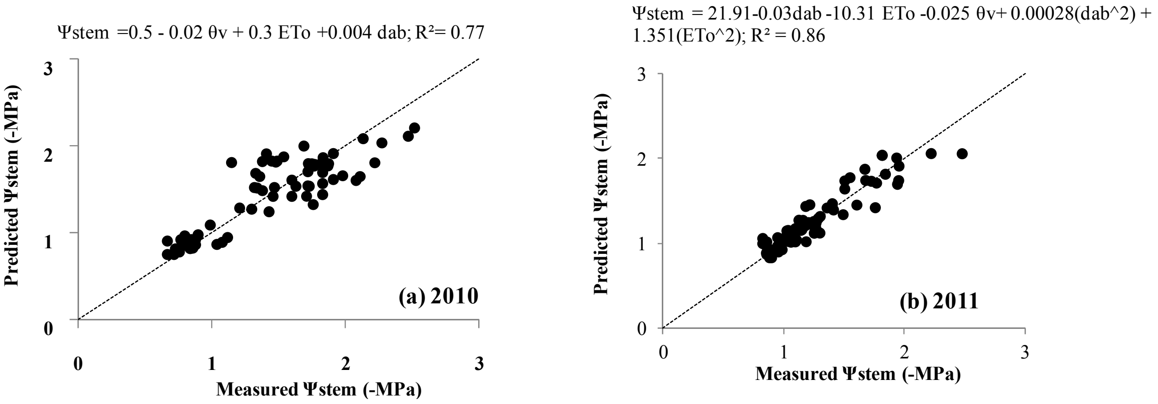

Fig. 5. Relation between Ψ_{stem} and dab (days after bloom), θ_v and ETo for 2010 (a) and 2011 (b).