Effects of wetted soil volume on young pear trees

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Abstract

Pear orchards in the Goulburn Valley, Australia, are being re-developed and expanded using better varieties and modern planting systems. Efficient irrigation systems, like drip, are an integral component of these new orchards. However, drip is rarely used in pear orchards in the region and many existing orchards use microjet irrigation systems. Soil wetting patterns from drip systems are much smaller than microjet systems and this may impact on the performance of young pear trees. A field experiment was established in 2012 to investigate the effects of wetted volume (imposed by the combination of irrigation system and irrigation frequency) on irrigation requirements, tree growth and water status. Drip and microjet irrigation at standard and pulse intervals were compared using a new red-blushed pear cultivar (*Pyrus communis* L. 'ANP-0118') grafted to BP-1 rootstock. No evidence was observed that a reduction in horizontal wetted volume (i.e., drip irrigation) impacted leader growth, pruning dry weight, radiation interception, and midday stem water potential and leaf conductance. However, a shallow broad wetted volume (microjet irrigation at frequent interval) made trees susceptible to water stress and trees exhibited a reduction in growth. Approximately 40% less irrigation was applied in the drip irrigation treatments resulting in a water saving of 2.1 ML ha^{-1} y^{-1}.

Keywords: stem water potential, leaf conductance, canopy radiation interception, pulse irrigation, wetting pattern

INTRODUCTION

Irrigation and water use efficiencies of drip irrigation systems are high compared to flood irrigation systems due to reduced understorey evapotranspiration and deep drainage losses, and improved ability to schedule irrigation events and run-times to match crop water requirement. Modernisation of pear orchard irrigation systems in the Goulburn Valley, Australia, historically involved converting flood to microjet irrigation systems. Few pear orchards use drip irrigation. In recent years, traditional pear orchards have been removed due to a decline in the processing industry. New fresh market pear varieties grown using modern high-density planting and training techniques will replace these traditional orchards. Efficient irrigation systems, like drip, are an integral component of these new orchards. However, many growers express concerns that smaller soil wetting patterns under drip irrigation compared with microjet systems could compromise tree development and productivity.

A large wetted root volume (e.g., microjet irrigation system) has been shown to increase tree vigour but this may be undesirable for precocity and water use efficiency. Studies in peach and grape showed that a small wetted root volume reduced vegetative vigour and drip irrigation was suggested as a tool to increase precocity (Boland et al., 1994, 2000; McClymont et al., 2006). Research is needed on the effects of wetted volume (imposed by the combination of irrigation system and irrigation frequency) in newly planted pear orchards on tree growth and precocity. The objectives of this study were to quantify the effects of wetted soil volumes, created by drip and microjet systems operated at 'standard' and 'pulse' intervals, on irrigation requirements, tree growth and water status of young pear trees.

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MATERIALS AND METHODS

Study area

The experiment was established using a new red-blushed pear variety (*Pyrus communis* L. 'ANP-0118', branded Lanya® grafted to BP-1 rootstock at the Department of Environment and Primary Industries' Tatura site (36.439° S, 145.266° E; 114 m a.s.l.) in the Goulburn Valley region of Victoria, Australia. The soil type was a Red Sodosol (Isbell, 2002), a duplex red-brown earth consisting of a 0.2 m deep sandy loam topsoil overlying a medium clay. The soil is known locally as Lemnos loam (Skene and Poutsma, 1962). The region has a temperate climate with average annual rainfall of approximately 480 mm. Annual average reference crop evapotranspiration (ET_o, Allen et al., 1998) is approximately 1190 mm (22-year mean, http://www.longpaddock.qld.gov.au/silo/).

Trees were planted in north-south oriented rows in winter 2012. Row and tree spacings were 4.5 and 1 m, respectively. Trees were trained with four leaders on an Open Tatura trellis where trees within a row were diagonally offset 0.25 m from the row centre (van den Ende, 2011).

Irrigation treatments

Two irrigation systems (drip and microjet) and two irrigation intervals (standard and pulse) were established in a randomised complete block design with four replicates. Irrigation treatments were imposed in the 2012/2013 (year 1, Y1) and 2013/2014 (year 2, Y2) growing seasons. Each plot consisted of three adjacent rows of 9 trees row^{-1}. The central five trees of each plot were used for measurements.

Drip irrigation treatments were applied by a single lateral located in the centre of the row with drip emitters (DripNet PC™ AS, Netafim, Melbourne, Australia) delivering 1.75 L h^{-1} and spaced at 0.5 m. Microjet irrigation treatments were applied by a single lateral located in the centre of the row with microjet emitters (SuperNet SRD, Netafim, Melbourne, Australia) delivering 32 L h^{-1}, spaced at 2 m midway between two trees and approximately 0.3 m above the soil surface. Each of the treatments were equipped with a solenoid valve connected to an auto controller (NMC-64, Netafim, Melbourne, Australia). Irrigation volumes applied to each treatment were monitored using electronic water meters (GSD8-R, B Meters, Gonars, Italy) and data loggers (Tinytag TGPR-1201, Gemini Data Loggers Ltd., Chichester, UK).

Irrigation run time (Table 1) aimed to wet the soil to a depth of 0.3 m in the standard treatments. The pulse treatments applied one-third of the standard treatments. Run time was calculated from the emitter rate, estimates of the wetting pattern and the water holding capacity of the soil. The drip and microjet treatments at standard interval applied approximately 21 and 56 L $tree^{-1}$, respectively, at every irrigation event.

Table 1. Irrigation run-time and average frequency for each treatment in year 1 and 2.

Treatment	Irrigation run-time	Irrigation frequency		
		Spring	Summer	Autumn
Drip-standard	6 h	3-6 days	2-3 days	3-5 days
Drip-pulse	2 h	1-2 days	Once-twice daily	1-2 days
Microjet-standard	3 h 30 min	5-8 days	3-4 days	5-8 days
Microjet-pulse	1 h 10 min	2-3 days	Daily	2-3 days

Irrigation frequency was determined from estimates of crop evapotranspiration (ET_c) according to Allen et al. (1998):

$$ET_c = K_{cb}\ K_e\ ET_o \qquad (1)$$

where K_{cb} was the basal crop coefficient, K_e was the soil evaporation coefficient and ET_o was reference crop evapotranspiration sourced from an automatic weather station approximately 50 m from the experimental site (http://weather.irrigateway.net/). K_{cb} was calculated from:

$$K_{cb} = 1.3 \text{ EAS} \quad (2)$$

where EAS was the effective area of shade (Goodwin et al., 2006) measured at regular intervals during the growing seasons. K_e was set to 0.15 and 0.35 for the drip and microjet treatments, respectively, based on wetting pattern size using the methods described in Allen et al. (1998).

Stem water potential and leaf conductance

Midday stem water potential (Ψ_{leaf}, MPa) was measured every 7-14 days between 1300 and 1500 h (AEST) on two fully expanded leaves per plot with a Scholander pressure chamber (Model 3000; Soil Moisture Equipment Co., Santa Barbara, CA, USA) from 144 to 226 days after bud burst (DABB) in Y1 and from 76 to 222 days after bud burst (DABB) in Y2. Leaves were covered with an aluminium foil bag for at least 2 h prior to excision.

Leaf conductance (g_{leaf}, mmol m^{-2} s^{-1}) was measured between 1200 and 1300 h (AEST) every 7-14 days on three or four fully expanded sunlit leaves per plot with a porometer (Model AP4; Delta-T Devices Ltd., Cambridge, UK) on clear sky days corresponding to measurements of Ψ_{leaf}.

Wetted soil volume

Soil samples were taken in mid-summer (DABB = 166-167) in Y2 for the determination of soil water content and estimates of wetted soil volume. A horizontal grid of samples at 0.1-0.25 m spacing between trees and rows were taken in 1 plot treatment^{-1} at depths of 0.1, 0.25, 0.4 and 0.55 m. Sampling perpendicular to the row stopped at 0.55 and 1.2 m from the emitters in the drip and the microjet treatments, respectively. Soil samples were immediately placed in sealed containers, weighed, oven dried and then reweighed to determine gravimetric soil water content. Volumetric soil water content (%) was estimated based on an A-horizon dry bulk density of 1.5 g cm^{-3} and a B-horizon dry bulk density of 1.7 g cm^{-3}. Wilting point was 13.2% at 0.1 and 0.25 m depth, and 25.0% at 0.4 and 0.55 m depths according to Cockroft (1964).

Canopy radiation interception

Photosynthetically active radiation (PAR) interception was measured using a handheld ceptometer (Sunfleck Ceptometer; Decagon, Pullman, USA). Measurements of transmitted PAR (PAR_t) were made over the planting square of the central trees in each plot three times daily; at solar noon and 3 h before and after solar noon on a clear sky day at 117, 203 and 236 DABB in Y2. The ceptometer was held horizontally below the canopy perpendicular to the row direction and then moved at a slow walking speed along the row. Approximately 7 measurements m^{-1} of row were taken by setting the ceptometer to continuous sampling at 4 Hz. Several passes were made to capture the entire area of shade. Unobstructed incoming PAR (PAR_i) was measured at 1.5 m above ground level in an open area prior to the measurement in each plot. Effective area of shade (EAS, %) was calculated as the mean value of intercepted PAR [$1-(PAR_t/PAR_i)$] at solar noon, solar noon -3 h and solar noon +3 h.

Tree growth

Annual leader extension growth was determined by measuring the length of the 2 northern leaders tree^{-1} at the end of each season. All vegetative material pruned during the growing season from the measurement trees in each plot was collected, oven dried at 65°C for 72 h and then weighed.

Statistical analysis

Data on each variable were analysed using RCBD-based analysis of variance (ANOVA) in GenStat 14.1 (VSN International Limited, Oxford, UK). Statistical significance of difference between any two treatments was assessed using Fisher's unrestricted least significant difference (LSD) at p=0.05.

RESULTS AND DISCUSSION

Approximately 290 and 500 mm irrigation were applied to the drip and microjet irrigation treatments, respectively, in Y1 (Figure 1). There was a particularly dry spring in Y1 such that newly planted trees relied almost entirely on water delivered by the irrigation system. Total ET_o and rain during the season in Y1 was 1089 and 170 mm, respectively. In Y2, slightly more irrigation was applied to all treatments as tree size increased, however, the amount applied to the drip treatments was still substantially less than the microjet treatments. Total ET_o and rain during the season in Y2 was 1026 and 250 mm, respectively.

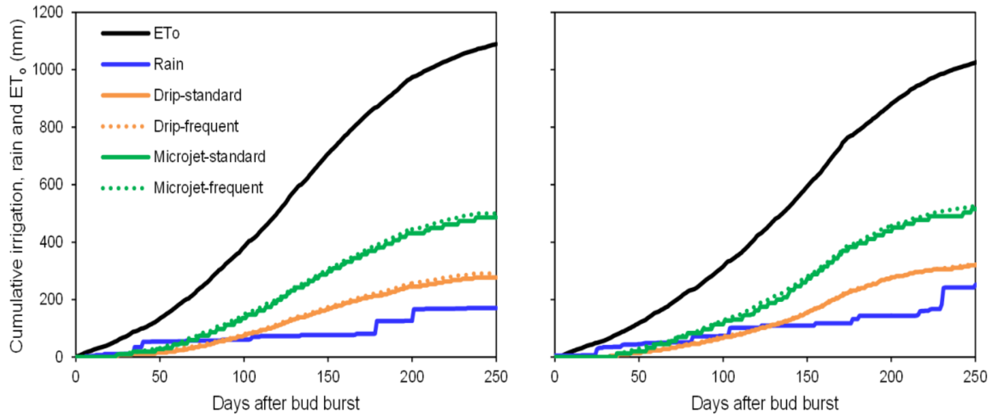

Figure 1. Cumulative reference crop evapotranspiration (ET_o), rain and applied irrigation from bud burst to leaf fall in year 1 (left) and year 2 (right).

Average irrigation frequency was similar in spring and autumn but increased in summer (Table 1). The drip-standard treatment was irrigated every 2-3 days in mid-summer whereas the drip-pulse treatment was irrigated once to twice daily. Microjet treatments were less frequent than drip treatments. Average irrigation frequency did not differ substantially between years due to the dominance of soil evaporation in the calculation of irrigation requirement (Equation 1).

There was no difference between treatments in season average Ψ_{leaf} (Table 2). Microjet-pulse tended to be lower in Y1 and was significantly lower on the first two measurement days (data not shown). Lower Ψ_{leaf} in the microjet-pulse treatment was attributed to greater soil evaporation and understorey transpiration from frequent wetting of the soil surface.

Table 2. The effects of irrigation system and frequency on average midday stem water potential (Ψ_{leaf}) and leaf conductance (g_{leaf}) in year 1 and 2.

Treatment	Ψ_{leaf} (MPa)		g_{leaf} (mmol m^{-2} s^{-1})	
	Year 1	Year 2	Year 1	Year 2
Drip-standard	-1.10	-0.90	578 a	317
Drip-pulse	-1.04	-0.89	399 b	343
Microjet-standard	-1.13	-0.91	432 b	339
Microjet-pulse	-1.18	-0.94	468 ab	339
F prob.	0.06	0.38	0.04	0.12

Values followed by the same letter or no letter are not significantly different (p=0.05).

There was a general trend for less tree growth in the microjet-pulse treatment most likely due to transient periods of water stress associated with a shallower wetting pattern (Table 3). Although not significant, leader growth was lowest in Y1 and pruning dry weight was lowest in Y1 and Y2 in the microjet-pulse treatment.

Table 3. The effects of irrigation system and frequency on leader extension growth and total pruning dry weight in year 1 and 2.

Treatment	Leader growth (cm)		Pruning dry weight (g)	
	Year 1	Year 2	Year 1	Year 2
Drip-standard	74.2	63.2 a	36	426
Drip-pulse	76.7	59.0 c	49	463
Microjet-standard	79.4	61.0 b	41	428
Microjet-pulse	67.9	59.4 c	34	334
F prob.	0.45	0.01	0.07	0.08

Values followed by the same letter or no letter are not significantly different (p=0.05).

Canopy radiation interception, as measured by EAS, increased to an average maximum of 17% by early autumn in Y2 (Table 4). There was no difference in EAS between irrigation treatments. Such values of EAS meant that the calculation of irrigation requirement (Equation 1) was dominated by soil evaporation and understorey transpiration particularly in the microjet irrigation treatments. This balance between K_e and K_{cb} will change as the tree canopy increases in subsequent years and intercepts more radiation.

Table 4. The effects of irrigation system and frequency on effective area of shade (EAS, %) measured 117, 203 and 236 days after bud burst in year 2.

Treatment	Days after bud burst		
	117	203	236
Drip-standard	9.2	17.0	17.3
Drip-pulse	13.3	21.3	19.2
Microjet-standard	10.1	17.4	17.1
Microjet-pulse	9.2	14.2	15.2
F prob.	NS	NS	NS

Soil water content was highest close to the emitter at 40 and 55 cm depth in the drip-standard treatment (Figure 2). Soil was consistently drier at 10 and 25 cm for all positions away from the emitter in the drip-standard treatment. In contrast, the soil water content in the microjet-standard treatment was similar at 10, 25, 40 and 55 cm depths and did not decrease until 70 cm from the emitter. These results show a distinct smaller wetted soil volume in the drip-standard treatment where the plant available water after an irrigation event was confined to approximately 40-50 cm in the horizontal plane towards the mid-row whereas plant available water in the microjet treatment extended beyond 100 cm.

CONCLUSIONS

This study established that a narrow wetting pattern under drip irrigation compared with a wider wetting pattern under microjet irrigation can be successfully used in young pear orchards planted in a duplex soil where the emitter lateral is offset 0.25 m from the tree base. No differences were observed in tree water status or growth in the first two years after planting despite minimal rainfall during the growing season. Substantially less water was applied to the drip irrigation treatments. Annual water saving was approximately 2.1 Ml ha^{-1} and this was attributed to reduced soil evaporation and understorey transpiration. The results also suggest that the microjet-pulse treatment was vulnerable to water stress and more frequent irrigation with the same amount of water may need to be applied to counter additional soil evaporation and understorey transpiration from shallow wetting of the soil surface.

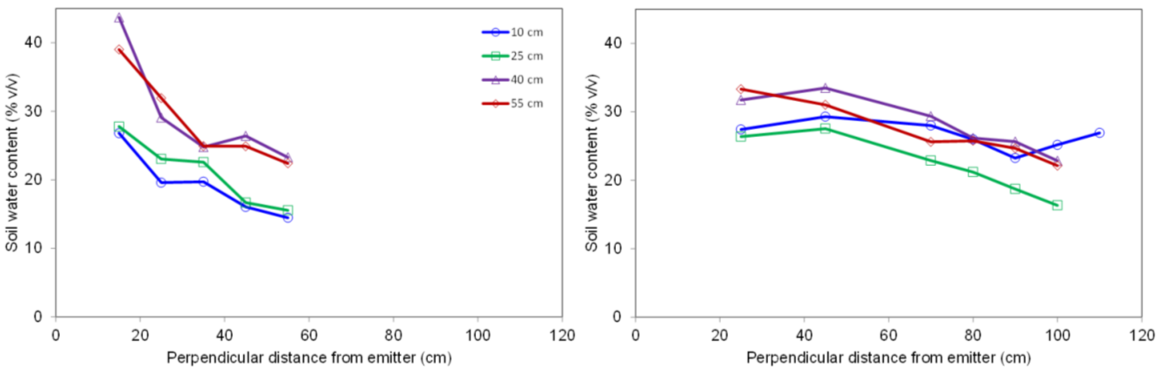

Figure 2. Soil water content to a depth of 0.55 m in the plane perpendicular to the tree row in the drip-standard (left) and microjet-standard treatments. Measurements were made in mid-summer Y2.

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