J. Amer. Soc. Hort. Sci. 111(5):858–861. 1986.

# The Use of Initial Withholding of Irrigation and Tree Spacing to Enhance the Effect of Regulated Deficit Irrigation on Pear Trees

**P.D. Mitchell, D.J. Chalmers, P.H. Jerie, and G. Burge**[1]

*Institute for Irrigation and Salinity Research, Department of Agriculture, Tatura, Victoria, Australia, 3616*

*Additional index words.* *Pyrus communis*

***Abstract.*** **Withholding irrigation (WI), followed by regulated deficit irrigation (RDI) at 2 levels, were compared with conventionally scheduled irrigation during rapid vegetative growth on 'Bartlett' pear (*Pyrus communis* L.) trees. All trees were irrigated at an increased common level during subsequent rapid fruit growth, by which time most vegetative growth had ceased. Irrigation effects were studied at 3 tree spacings (4 × 1 m, 4 × 0.75 m, and 4 × 0.5 m). Shoot and frame growth was related directly to early irrigation treatment before summer pruning. However, significant shoot growth that was reinitiated following summer pruning during one year increased on RDI treatments. The improved tree water status gained by changing from RDI to full irrigation in both years and from WI to RDI in the first year stimulated the growth rate of the total crop on the RDI treatments. Gross yield was increased significantly by WI and RDI in both years. Blossom density also was increased. Preliminary WI increased the control of vegetative growth by RDI when the soil was wet at flowering.**

Conventional irrigation of 'Barlett' pears in the Goulburn Valley of Victoria, Australia, results in excessive vegetative vigor and many associated problems. Regulated deficit irrigation (RDI) has been shown to reduce vegetative growth successfully while increasing flowering and yield (1–3, 6, 7). On the other hand, winter precipitation is characteristic of the environment of many semi-arid irrigation areas (including the Goulburn Valley), and winter precipitation usually results in a fully wetted root zone in the spring. Vegetative growth is rapid during the period a tree is drying the root zone. It therefore seems illogical to apply water to an RDI treatment until available soil water has been depleted to the degree that one intends to obtain with RDI.

This investigation was initiated to compare WI followed by RDI at 2 rates of replacement with conventional management of trickle irrigation.

## Materials and Methods

The experiment was conducted during 2 successive growing seasons (1982–83 and 1983–84). The experimental procedure was essentially the same as previously reported (7). Briefly, the block layout (9) consisted of 3 rows of 'Bartlett' pear trees on *Pyrus calleryana* D6 spaced 4 m apart on Tatura trellis. In each row, the tree spacing was arranged in 3 blocks of 0.5, 0.75, and 1.0 m. Each row was used as a replicate, and 3 irrigation treatments were randomized within rows and tree spacing. A polyethylene barrier between rows (1.2 m deep) avoided influence from irrigation treatments between neighboring rows. Irrigation was withheld (WI) altogether from RDI treatments until 22 Nov. and 19 Nov. in years 1 and 2, respectively, to dry winter rainfall from the root zone. Irrigation during the RDI period was related to the evaporation from a nearby U.S. Class A pan. Each tree was trickle-irrigated, with a percentage of the water evaporated during the preceding 1 or 2 days from a free water surface equivalent to the area of the tree planting square (Eps). Although the percentage of replacement of Eps and RDI treatments varied slightly between years, the ratio between the volume of water applied in each treatment was 4:2:1 in both seasons. The 3 irrigation treatments are described by the replacement factors of the first season. Irrigation commenced on the 92% Eps treatment on 13 and 15 Oct. in the first and 2nd year, respectively (about 14 days from full bloom). RDI was discontinued and full irrigation (120% Eps) commenced on all treatments on 13 Dec. and 10 Dec. in years 1 and 2, respectively, and continued until harvest. Periods of irrigation treatment are illustrated schematically in Fig. 1.

*Measurements.* Eight shoots and fruits per plot were measured weekly. The crop growth rate was calculated from weekly increases in fruit diameter by means of the equation: fruit weight $= 0.851 \text{ diam}^{2.831}$ (5) and expressed as kilograms per meter of row per day.

Trunk cross sectional area (TCA) increase was estimated from trunk diameter measured at the same position before the commencement of irrigation, at the end of RDI, and at harvest. The trees were summer-pruned in mid-December by removing strong, upright growing laterals from the inside of the trellis V. Prunings were then weighed. All fruit were harvested from treated sections of the trellis in late January and yield and fruit number expressed per meter of row.

In year 1, at the end of RDI, soil from the 23% and 92% Eps treatment from the 0.5- and 1.0-m tree spacing were sampled and soil moisture was determined gravimetrically. Samples were taken under the dripper and at 30-cm intervals across the tree rows from the dripper. In the winter of year 1, prunings were weighed and the soil sampled for fiber root under the 23 and 92 Eps treatment. Root samples were collected using a 6-cm sampler from the 0.5- and 1.0-m tree spacings to a depth of 45 cm. Samples were taken 0, 25, 50, and 100 cm from the tree line. The dry weight of the fiber root was determined and root density expressed as kilograms per kilogram of oven dry weight of the soil sampled.

## Results

The effect of irrigation treatments on vegetative and fruit growth was highly significant in both seasons.

*Fruit yield.* The average fruit number over all irrigation treat-

Received for publication 15 July 1985. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Present address: Levin Horticultural Research Centre, Ministry of Agriculture and Fisheries, Private Bag, Levin, New Zealand.

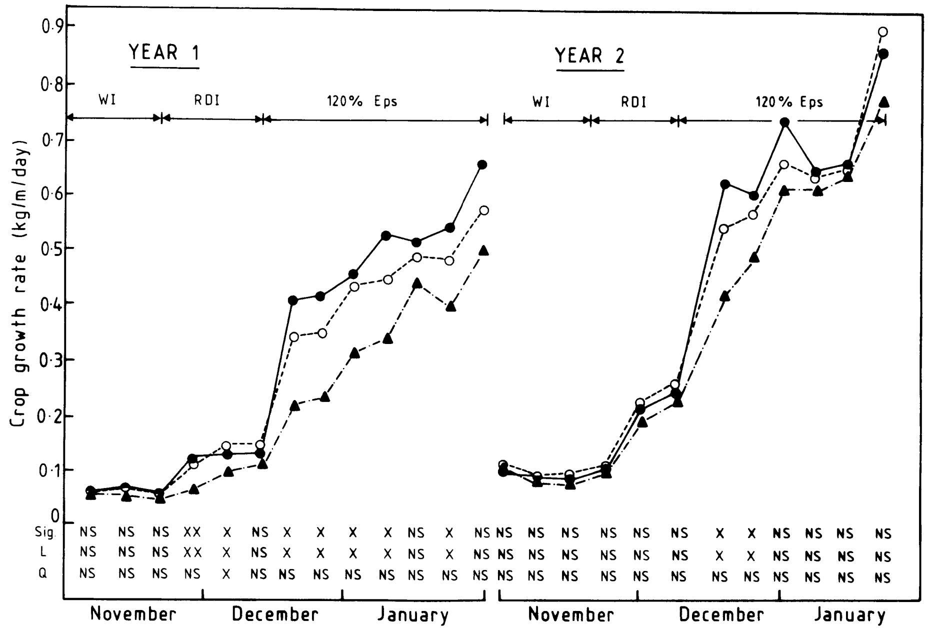


Fig. 1. Influence of irrigation treatment on rate of crop growth of 'Bartlett' pear trees. ● 0.23 Eps, ○ 0.046 Eps, and ▲ 0.92 Eps.

ments and tree densities was 152 and 241 fruit per meter of row length in the first and 2nd years, respectively (Table 1). This difference was due to a continuing biennial bearing pattern that became established before RDI experiments were begun. Although the difference in crop load modified the growth response of individual fruit to RDI in each year, the 23% Eps treatment yielded a 20% greater weight of fruit than the 92% Eps treatment in both years (Table 1). In year 1, RDI treatments increased gross yield by increasing fruit set and fruit size. In contrast, high fruit numbers in year 2 resulted in smaller average fruit size on RDI treatments. Nevertheless, because gross yield was substantially increased, RDI treatments still carried a slightly higher canning yield than the 92% Eps control.

*Fruit growth.* Because fruit load was not uniform across all treatments, growth measurements of individual fruit distorted the real effect of RDI on fruitfulness of the treatments. However, crop growth, expressed as fruit weight increase per meter of row length per day (Fig. 1), shows that at no time during either season did RDI inhibit fruit growth aggregated for the treatment plot. In both years, RDI followed a preliminary WI period to dry out the root zone prior to RDI. Withholding irrigation prior to RDI did not reduce crop growth compared to the 92% Eps control, nor was crop growth rate inhibited by RDI. On the contrary, crop growth rate was significantly stimulated by RDI during year 1 and following RDI (during irrigation with 120% Eps) on RDI trees in both years (Fig. 1). These effects of RDI on fruit growth have been a characteristic of RDI throughout our studies on peaches and pears (2, 6, 7) and have

Table 1. Influence of irrigation and tree spacing on fruit number, size, and yield of 'Bartlett' pear.

| | Year 1 | | | | Year 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Yield | | Fruit | | Yield | | Fruit | |
| | Total ($kg\cdot m^{-1}$) | Canning[z] ($kg\cdot m^{-1}$) | No. per meter | Mean fresh wt (g) | Total ($kg\cdot m^{-1}$) | Canning ($kg\cdot m^{-1}$) | No. per meter | Mean fresh wt (g) |
| Spacing (m) | | | | | | | | |
| 1.0 | 33.3 | 32.3 | 164 | 219 | 43.7 | 37.5 | 252 | 174 |
| 0.75 | 26.8 | 26.1 | 138 | 193 | 40.0 | 34.5 | 232 | 176 |
| 0.50 | 27.7 | 26.5 | 154 | 176 | 38.3 | 31.4 | 238 | 161 |
| Significance | ** | ** | * | * | NS | * | NS | NS |
| Linear | ** | ** | NS | * | NS | * | NS | NS |
| Quadratic | * | * | * | NS | NS | NS | NS | NS |
| Irrigation (% Eps) | | | | | | | | |
| 92 | 25.2 | 24.0 | 140 | 181 | 36.2 | 32.2 | 202 | 181 |
| 46 | 30.3 | 29.4 | 154 | 202 | 41.2 | 35.5 | 244 | 169 |
| 23 | 32.3 | 31.4 | 163 | 206 | 44.5 | 35.8 | 277 | 161 |
| Significance | ** | ** | NS | NS | * | NS | * | * |
| Linear | ** | ** | NS | * | * | NS | ** | ** |
| Quadratic | NS | NS | NS | NS | NS | NS | NS | NS |

[z]Diameter >57 mm.

*,**Significantly different at the 5% and 1% levels, respectively.

increased yield up to 30%. The physiological mechanism underlying these fruit growth effects is the subject of an accompanying paper (1).

*Flowering*. Blossom density in this experiment was 3.34, 1.87, and 1.73 blossoms/cm$^2$ TCA ($P < 0.01$, LSD = 0.60) for the 23%, 46%, and 92% Eps irrigation treatments, respectively. This increase in flowering was induced in the heavy crop year, but RDI also increased blossom density in the preceding light crop season by a similar proportion (7).

*Shoot growth*. In both years, the rate of shoot growth reached a maximum in late October and declined to little or no growth by mid-December (Fig. 2). Withholding irrigation and RDI advanced this decline. The growth rate of shoots, however, did not decline significantly on the WI/RDI trees until 15 Nov. and 19 Nov. in year 1 and 2, respectively. A considerable proportion of the annual shoot extension on a mature cropping tree has taken place by that time. Winter and spring in both years were relatively wet, and this result indicates that considerable growth occurs before evapotranspiration is sufficient to dry the root zone sufficiently to inhibit growth. The 0.5- and 0.75-m tree spacing appeared to exacerbate the effect of WI on soil drying as significant effects on growth were measured several days earlier on those spacings than at the 1.0-m spacing.

Following summer pruning, shoots began to regrow in early January. In year 1, shoots grew rapidly in early January but had almost stopped growing by the start of February. The growth rate was influenced by the previous level of RDI and tree spacing, with increased shoot growth following the 23% Eps treatment at the 1.0 m spacing (Table 2). In year 2, January regrowth

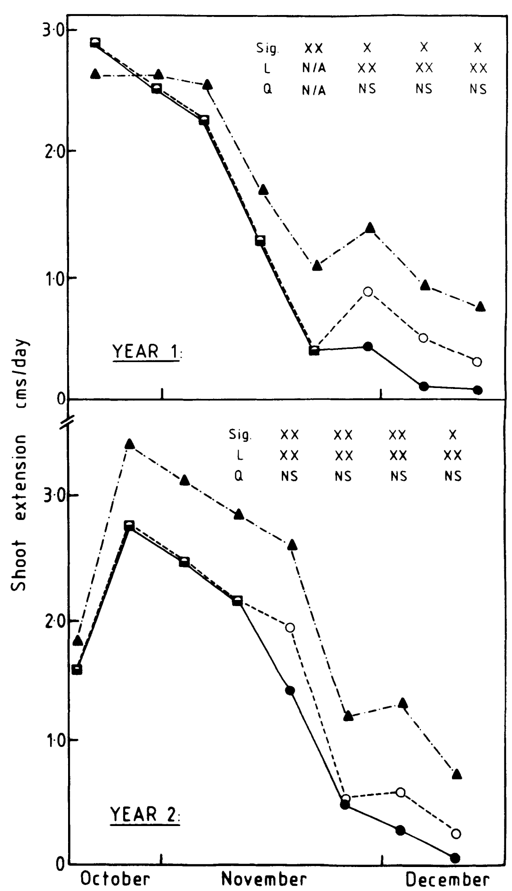


Fig. 2. Influence of irrigation treatment on shoot growth of 'Bartlett' pear trees. ● 0.23 Eps, ○ 0.46 Eps, and ▲ 0.92 Eps.

was very weak due to the heavy crop load and soon terminated. Growth was not measured. Clearly, this growth is not desirable, and perhaps a lower rate of Eps replacement may be needed during full irrigation following RDI on light crops.

*TCA increase*. TCA increase was significant and linearly related to RDI irrigation levels (Table 2). This relationship was positive until the end of RDI in year 2, with a similar trend after RDI and before the end of RDI in year 1. The relationship, however, was negative after RDI in year 1, which was consistent with the effect of RDI on shoot growth in year 1 and confirms the need to reconsider rates of Eps replacement during full irrigation in the presence of a light crop.

*Pruning weights*. The weight of shoots pruned from the RDI treatments in summer during both years was related directly to the irrigation water applied during the RDI period (Table 2). There were no differences in the weight of winter prunings. Total shoot growth was reduced by 52% with WI/RDI.

*Soil moisture*. At the end of the RDI period, soil in the 92% Eps treatment was significantly wetter under the 1-m than the 0.5-m tree spacing (16.6% and 14.2% moisture, respectively). Furthermore, differences in soil moisture between irrigation treatments were significant only at the 1-m spacing, where moisture was 16.6% and 12.7% under the 92% and 23% Eps treatment, respectively.

*Distribution of fiber roots*. The results of sampling were variable and no differences were measured between irrigation treatments; however, roots had spread further across the tree rows under the 1-m tree spacing than under the 0.5-m planting. The mean root density at 0, 25, 50 and 100 cm from the tree line, respectively, was 240, 195, 219 and 44 g dry weight per kilogram of oven dry soil under 1-m planting compared to 358, 137, 44 and 25 g·kg$^{-1}$ under the 0.5-m planting ($P < 0.05$, LSD = 32). Measurements of root size and particularly root growth (where one attempts to measure a small increment of root growth to a large root system) in situ are extremely difficult to make. These data should not be interpreted as definitive evidence that RDI did not alter root growth patterns.

## Discussion

The design and results of these RDI experiments were different from our previous work (2, 6, 7) in several important respects. First, the effects of the WI period introduced to dry out the root zone before RDI treatments have shown that preliminary WI is an important extension of the RDI concept. Low evaporation, zero water use, and often higher winter rainfall (e.g., in mediterranean climates) will make water available for growth at the start of a growing season for a deciduous fruit crop. Furthermore, leaf area and transpiration potential develop slowly while other components of vegetative growth with potential to compete with fruit growth (e.g., cambial growth) develop rapidly. Lack of early irrigation dried out the root zone as rapidly as possible and did not affect fruit growth. Inhibition of shoot growth (Table 2) and soil drying also accelerated at close plant spacing (where roots were confined more to the tree line), indicating the need for further study of the period of WI and interacting factors. Nevertheless, RDI will be most effective at high tree density where the need to control tree vigor is greatest.

While the effects of RDI in successive years were qualitatively similar, there were quantitative differences between years. For example, although shoot growth was reinitiated after 120% Eps irrigation was begun on all treatments, considerably more growth occurred in year 1 than year 2. Also, during year 1,

Table 2. Influence of irrigation and spacing on weight of prunings, trunk cross sectional area increase, and shoot growth of 'Bartlett' pear.

| | Year 1 | | | | | Year 2 | | |
|---|---|---|---|---|---|---|---|---|
| | Pruning wt | | Shoot extension | TCA increase | | Wt of summer pruning | TCA increase | |
| | Summer ($kg \cdot m^{-1}$) | Winter ($kg \cdot m^{-1}$) | 13:1 to 2:2 (mm) | 5:10 to 9:12 | 9:12 to 2:2 ($cm^2$) | ($kg \cdot m^{-1}$) | 15:10 to 10:12 ($cm^2$) | 10:12 to 31:1 ($cm^2$) |
| Spacing (m) | | | | | | | | |
| 1.0 | 3.08 | 2.88 | 30.1 | 3.41 | 2.16 | 3.25 | 2.46 | 2.65 |
| 75 | 3.09 | 2.73 | 24.0 | 3.91 | 2.41 | 3.48 | 2.49 | 2.34 |
| 50 | 3.25 | 2.73 | 15.3 | 3.92 | 2.66 | 3.46 | 1.86 | 2.35 |
| Significance | NS | NS | * | NS | NS | NS | NS | NS |
| Linear | NS | NS | ** | NS | NS | NS | NS | NS |
| Quadratic | NS | NS | NS | NS | NS | NS | NS | NS |
| Irrigation (% Eps) | | | | | | | | |
| 92 | 4.34 | 2.63 | 14.0 | 4.15 | 1.88 | 4.44 | 3.21 | 2.71 |
| 46 | 2.72 | 3.04 | 20.3 | 3.72 | 2.79 | 3.41 | 2.26 | 2.47 |
| 23 | 2.36 | 2.67 | 35.2 | 3.37 | 2.57 | 2.34 | 1.35 | 2.15 |
| Significance | ** | NS | ** | NS | * | ** | ** | NS |
| Linear | ** | NS | ** | NS | * | ** | ** | NS |
| Quadratic | NS | NS | NS | NS | NS | NS | NS | NS |

*,**Significantly different at the 5% and 1% levels, respectively.

fruit growth was stimulated by RDI, whereas it was only stimulated after 120% Eps begun in year 2. The heavy crop load in year 2 we feel, was mainly responsible for these differences, although close tree spacing was a contributing factor. Water is transpired by fruit trees in relation to crop load and trees with heavy crops experience increased water deficits whether fully irrigated (4) or under drying conditions (8). On the other hand, an encouraging conclusion to be reached from these data is that the increased yields of RDI do not suppress subsequent flowering or fruit set or reduce productive potential. On the contrary, flowering was increased by 50% before the "on" (1) as well as the "off" (7) year, and although RDI has not eliminated the biennial bearing trend of these trees, it has raised the "off" year yield to a satisfactory level (see below).

Clearly, the proportion of Eps replacement during full irrigation and perhaps also during RDI needs to be adjusted for crop load and tree spacing, although fruit growth was not inhibited by RDI in either year. During full irrigation, however, especially at the wide tree spacing (Table 2), vegetative growth was reinitiated with 120% Eps in year 1. It appears that the trees received more water during 120% Eps irrigation than necessary, since fruit growth was stimulated at the same time. The results of this experiment nevertheless confirm our earlier results with peaches and pears (2, 6, 7). Significantly, the 2 crops from the 92% Eps treatment at the 1-m spacing reported in this paper yielded 73.5 and 105.0 $t \cdot ha^{-1}$ in years 1 and 2, respectively. RDI increased these very high yields to 91.0 and 121.2 $t \cdot ha^{-1}$ in years 1 and 2, respectively. Yield increase has been a consistent feature of RDI even though yields from the control treatments have always been heavy.

## Literature Cited


1. Chalmers, D.J., G. Burge, P.H. Jerie, and P.D. Mitchell. 1986. The mechanism of regulation of 'Bartlett' pear fruit and vegetative growth by irrigation withholding and regulated deficit irrigation. J. Amer. Soc. Hort. Sci. 111:904–907.
2. Chalmers, D.J., P.D. Mitchell, and L.A.G. van Heek. 1981. Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning. J. Amer. Soc. Hort. Sci. 106:307–312.
3. Chalmers, D.J., P.D. Mitchell, and P.H. Jerie. 1984. The physiology of growth control of peach and pear trees using reduced irrigation. Acta Horticulturae 146:143–149.
4. Chalmers, D.J. and I.B. Wilson. 1978. Productivity of peach trees: Tree growth and water stress in relation to fruit growth and assimilate demand. Ann. Bot. 42:285–294.
5. Mitchell, P.D. 1986. Pear fruit growth and the use of diameter to estimate fruit volume and weight. Hortscience 21:1004–1006.
6. Mitchell, P.D. and D.J. Chalmers. 1982. The effect of reduced water supply on peach tree growth and yield. J. Amer. Soc. Hort. Soc. 107:853–85.
7. Mitchell, P.D., P.H. Jerie, and D.J. Chalmers. 1984. The effects of regulated water deficits on pear tree growth, flowering, fruit growth and yield. J. Amer. Soc. Hort. Sci. 109:604–606.
8. Proebsting, E.L. and J.E. Middleton. 1980. The behavior of peach and pear trees under extreme drought stress. J. Amer. Soc. Hort. Sci. 105:380–385.
9. van den Ende, B., and D.J. Chalmers. 1983. The Tatura trellis as a high-density system for pear trees. Hortscience 18:946–947.