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Evaluation of Irrigation Methods for Highbush Blueberry—I. Growth and Water Requirements of Young Plants

David R. Bryla[1]
U.S. Department of Agriculture, Agricultural Research Service, Horticultural Crops Research Unit, 3420 NW Orchard Avenue, Corvallis, OR 97330

Jim L. Gartung
U.S. Department of Agriculture, Agricultural Research Service, Water Management Research Laboratory, 9611 S. Riverbend Avenue, Parlier, CA 93648

Bernadine C. Strik
Department of Horticulture, OR State University, 4017 ALS, Corvallis, OR 97331

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***Abstract.* A study was conducted in a new field of northern highbush blueberry (*Vaccinium corymbosum* L. 'Elliott') to determine the effects of different irrigation methods on growth and water requirements of uncropped plants during the first 2 years after planting. The plants were grown on mulched, raised beds and irrigated by sprinklers, microsprays, or drip at a rate of 50%, 100%, and 150% of the estimated crop evapotranspiration (ET_c) requirement. After 2 years, drip irrigation at 100% ET_c produced the most growth among the irrigation methods with at least 42% less water than needed for maximum growth with microsprays and 56% less water than needed with sprinklers. Drip irrigation also maintained higher soil water content in the vicinity of the roots than the other methods but reduced growth when plants were over-irrigated at 150% ET_c. Only 570 mm of irrigation water, or the equivalent of 1320 L per plant, was required over two seasons to reach maximum total plant dry weight with drip, whereas 980 mm or more water was needed with sprinklers and microsprays. Consequently, irrigation water use efficiency (defined as the difference in plant biomass produced under irrigated and rain-fed conditions divided by the total amount of irrigation water applied) was significantly higher with drip than with the other irrigation methods, averaging 0.41 g of total dry weight per liter of drip irrigation. In terms of both growth and water use, drip irrigation was the best and most efficient method to establish the plants.**

Highbush blueberry (*Vaccinium corymbosum* L.) is a shallow-rooted crop that is very susceptible to water stress (Bryla and Strik, 2007; Mingeau et al., 2001). The plants usually require irrigation for commercial production, even in wet climates (e.g., Byers and Moore, 1987; Haman et al., 1997). Within the United States, overhead sprinklers are typically used to irrigate blueberry in Florida, Michigan, New Jersey, North Carolina, and Oregon, whereas drip irrigation is usually preferred in Arkansas, California, Indiana, Minnesota, Mississippi, New York, and Washington (Strik and Yarborough, 2005). Each system has its advantages and disadvantages, making selection of the proper system sometimes difficult. Sprinkler systems, for example, are easier to install and maintain than drip, require little to no filtration, and enable frost and heat protection when necessary. However, overhead systems also require more water and energy, have higher installation costs, limit access to the field during and after irrigation, pose potential food safety risks when using surface water to irrigate, and occasionally lead to problems with fruit rot and other fungal diseases on leaves and canes. Drip irrigation, on the other hand, applies water directly to the roots and enables more frequent and uniform water applications, thereby increasing water use efficiency (i.e., growth and yield per unit of water applied) and potentially reducing plant water stress, but drip emitters plug readily when water infiltration is inadequate and/or the system is improperly maintained, the small wetted area produced by drip reduces root development, and by sustaining high soil moisture levels, drip may increase susceptibility to root rot disease (Bryla and Linderman, 2007). Water is usually applied one or two times per week, as needed, with sprinklers and every 1 to 3 d by drip.

Some growers are also testing low-volume microsprays (also known as microjets or microsprinklers) on blueberry. Although microsprays are not commonly used in blueberry, Holzapfel et al. (2004) found in a 7-year study in Chile that production and water use efficiency were higher with microsprays than with drip. Microspray irrigation offers advantages similar to drip irrigation but applies the water to the soil surface by a small spray. Because microsprays wet more soil volume than drip, plants tend to produce a larger root system, which may provide an advantage in a shallow, densely rooted crop such as blueberry (Patten et al., 1988, 1989). However, one major problem with microsprays is difficulties with plant interference during water applications. Once plants mature, much of the water from microspray emitters is intercepted by canes, thus reducing the uniformity of water application. This could be particularly problematic in blueberry because evidence from pot studies suggests that the plants are unable to translocate water and nutrients laterally (Abbott and Gough, 1986; Gough, 1984).

Ideally, irrigation is scheduled to replace any water lost by ET_c unless compensated by rain. Weekly estimates of ET_c are often accessible on the Internet from weather-based web sites such as AgriMet (Pacific Northwest Cooperative Agricultural Weather Network) and California Irrigation Management Information System. These sites obtain data from a satellite-based network of automated agricultural weather stations located throughout a region of interest. Weather data are used to estimate ET of a reference surface such as grass (ET_o) or alfalfa (ET_r), which is then converted to ET_c using the appropriate crop coefficient for blueberry (see Allen et al., 1998 for details). Adjustments to these values are needed when plants are young or stressed (e.g., nutrient deficient). Under these circumstances, irrigators should pay close attention to soil moisture conditions to avoid under- or over-irrigating their crop.

The objective of the present study was to determine the effects of sprinklers, microsprays, and drip on vegetative growth in blueberry. Data were collected during the first 2 years after planting and focused on identifying irrigation systems that improved growth of the crop during establishment. Irrigation was also applied at different levels to identify the optimum irrigation rate and to investigate the consequences of over- and under-irrigation with each system. Irrigation requirements are usually much less during establishment than at maturity but are often considered very important at this stage because even small amounts of water stress (drought or flooding) in young plants may substantially increase the time for the plants to reach their full production potential.

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[1] To whom reprint requests should be addressed; e-mail david.bryla@ars.usda.gov.

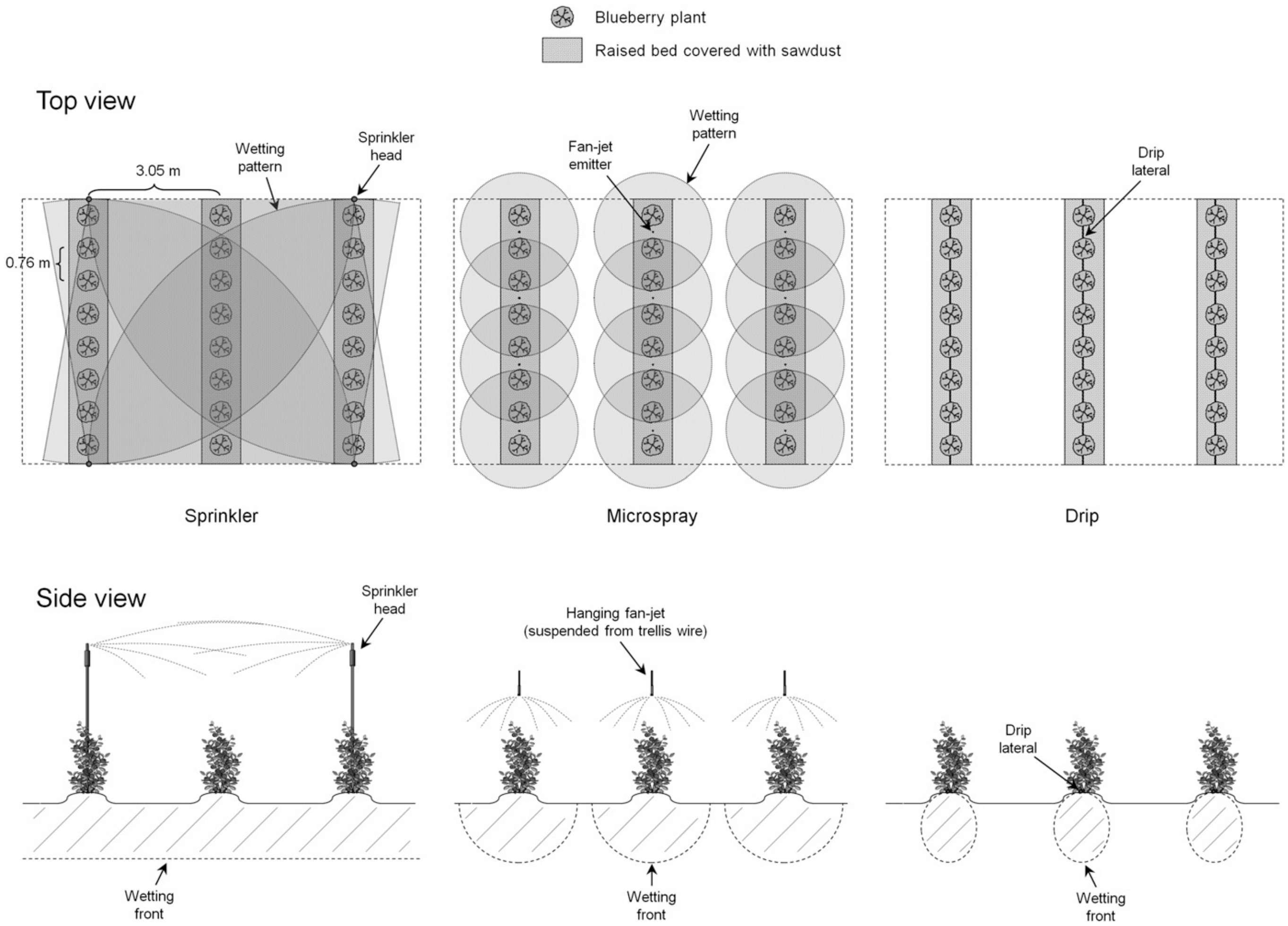

Fig. 1. Illustration of irrigation treatments applied to ‘Elliott’ blueberry. Plants were irrigated by sprinkler, microspray, or drip at 50%, 100%, and 150% of estimated crop evapotranspiration (ET_c). Each treatment plot consisted of three rows of eight plants (top view); only the center six plants of each plot were used for measurements. Soil water distribution varied from full coverage of the plot with sprinklers to only the beds irrigated by drip (side view).

Materials and Methods

The research was conducted on ‘Elliott’ northern highbush blueberry planted in Apr. 2004 at the Oregon State University Lewis–Brown Horticultural Research Farm in Corvallis, OR. Plants were obtained from a commercial nursery as 2-year-old container stock and spaced 0.76 × 3.05 m apart on raised beds (0.4 m high and 0.9 m wide). Soil was a Malabon silty clay loam (fine, mixed, superactive, mesic Pachic Ultic Argixerolls) adjusted to pH 5.5 with two applications of 670 $kg \cdot ha^{-1}$ of elemental sulfur incorporated 6 and 10 months before planting. Approximately 9 cm of douglas fir (*Pseudotsuga menziesii* Franco) sawdust plus 100 $kg \cdot ha^{-1}$ of nitrogen (N) as ammonium sulfate fertilizer were also incorporated within the plant row before planting, and 5 cm of the sawdust was applied on top of the beds immediately after planting. Grass alleyways, 1.1 m wide, were planted and maintained between the bed rows. Ammonium sulfate fertilizer was applied in three equal applications (once in April, May, and June) around the base of the plants at a rate of 67 $kg \cdot ha^{-1}$ of N during the first year after planting and banded beneath the canopy on each side of the row at a rate of 90 $kg \cdot ha^{-1}$ of N the second year. To dissolve and wash the fertilizer into the soil, the fertilizer was always applied just before a major rain event (greater than 10 mm). Plants were established with hand-move sprinklers (six water applications of ≈8 mm each) before irrigation treatments were initiated on 9 July 2004.

Table 1. Total irrigation water applied to ‘Elliott’ blueberry during the first (2004) and second (2005) year after planting in Corvallis, OR.

	Irrigation (mm)[z]					
	2004			2005		
Irrigation level	Sprinkler	Microspray	Drip	Sprinkler	Microspray	Drip
50% ET_c	184	115	103	450	212	178
100% ET_c	365	228	203	927	436	370
150% ET_c	547	339	295	1397	642	534

[z] Irrigation was applied 9 July to 10 Sept. 2004 and 23 May to 22 Sept. 2005. Values do not include precipitation (which from April to September contributed an additional 216 mm of water to each treatment in 2004 and 244 mm in 2005) or the six hand-set sprinkler applications (≈8 mm each) applied before 9 July 2004 (see Fig. 2). Each millimeter of water was equivalent to 2.32 L/plant.

ET_c = estimated crop evapotranspiration.

Irrigation treatments were arranged in a split-split-plot design and included two cultivars, Duke and Elliott, as main plots; three irrigation systems, sprinklers, microsprays, and drip, as subplots; and three irrigation rates, 50%, 100%, and 150% of the estimated ET_c requirements as sub-subplots; however, ‘Duke’ developed problems with root rot and therefore was not included in the present study (see Bryla and Linderman, 2007). There was no evidence of root rot in ‘Elliott’, and root samples collected from one plant per plot tested negative for *Phytophthora* sp. Each treatment plot consisted of three rows of eight plants each and was replicated five times (Fig. 1).

Sprinkler treatments were irrigated by a 5.7 $L \cdot min^{-1}$ rotor sprinkler (Model 32SA; Rain Bird Corp., Glendora, CA) located on each corner of the sub-subplots. The sprinklers were set to rotate in a 100° wetting pattern and covered a radius of ≈6 m at operating pressures of 170 to 210 kPa. Microspray treatments were irrigated with 22.7 $L \cdot h^{-1}$ hanging fan-jet microsprays (DC Series; Bowsmith, Exeter, CA) located between every other plant. Microsprays were suspended on a trellis wire ≈1.2 m above the plants (rather than on the soil surface as usual) to reduce problems with plant interference during water applications, and the system was designed to accommodate future machine harvest. The fan-jet emitters had a 2.7- to 3.0-m diameter, circular wetting pattern at operating pressures of 100 to 140 kPa. Drip treatments were irrigated using a single lateral of drip tubing (GeoFlow, Charlotte, NC) located on top of the planting bed near the base of the plants. The tubing had 1.9 $L \cdot h^{-1}$ pressure-compensating, inline emitters spaced every 0.30 m. Irrigation in each treatment was scheduled weekly using an automatic irrigation timer and electric solenoid valves. Sprinklers and microsprays were always set to run between 0000 HR and 0600 HR to minimize problems with wind drift between adjacent plots. There was no evidence of water ponding or runoff after irrigation by any treatment method.

Precipitation, air temperature, and ET_c were obtained at least weekly from a Pacific Northwest Cooperative Agricultural Weather Network AgriMet weather station (http://usbr.gov/pn/agrimet/). The station was located less than 0.25 km from the field site. Evapotranspiration estimates were adjusted for plant size and irrigation system efficiency (defined as the ratio of the volume of irrigation water beneficially used by a crop in a specified area to the volume of irrigation water delivered to this area) in each treatment following procedures outlined in Holzapfel et al. (2004). Water applications were measured using turbine water meters (Sensus Metering Systems, Uniontown, PA) installed at the inflow of each irrigation system.

Soil water content was measured on 16 Aug. 2004 and 7 Sept. 2005 using a Trase I time domain reflectometry system (Soilmoisture Equipment Corp., Santa Barbara, CA). The system was equipped with a pair of 0.3-m stainless steel waveguides and a waveguide connector. The waveguides were installed vertically at two locations in the middle of the center row of each plot ≈0.15 m from two representative plants. Measurements were taken 1 d after irrigation was applied and at least 1.5 months after hand-set sprinkler applications or any major (greater than 5 mm) rain events.

Leaf N concentration was determined in mid-August of each year. Fifty recent fully expanded leaves (Hart et al., 2006) were randomly sampled per sub-subplot and then immediately oven-dried at 70 °C, weighed, ground (40-mesh), and analyzed for percent N using a combustion analyzer (Model CNS-2000; LECO Corporation, St. Joseph, MI). Accuracy of the N analysis was verified by running an EDTA reference standard with every 10 leaf samples.

New canes produced at the base of each plant were counted at the end of each season. Total buds and fruit buds were also counted

Table 2. Monthly weather conditions during the first (2004) and second (2005) year after planting in Corvallis, OR.

	Air temp. (°C)[z]		Precipitation (mm)		Solar radiation. ($W \cdot m^{-2}$)[y]		Relative humidity (%)[z]	
Month	2004	2005	2004	2005	2004	2005	2004	2005
January	4.4	5.4	211	60	45	55	92	89
February	6.5	5.3	129	11	85	100	86	82
March	9.5	9.0	39	113	165	141	80	82
April	11.3	10.1	62	71	223	196	75	83
May	13.5	14.0	30	105	236	218	78	81
June	17.0	15.0	37	50	279	256	71	78
July	20.2	20.2	1	2	318	314	66	65
August	20.3	20.0	45	4	255	299	70	63
September	15.5	15.2	62	37	169	211	80	71
October	12.1	12.0	100	101	110	97	87	89
November	6.3	5.1	61	152	53	48	93	93
December	5.9	3.7	112	295	35	39	91	86
Avg./total	11.9	11.3	890	1001	164	165	81	80

[z] Mean daily average.

[y] Mean daily total.

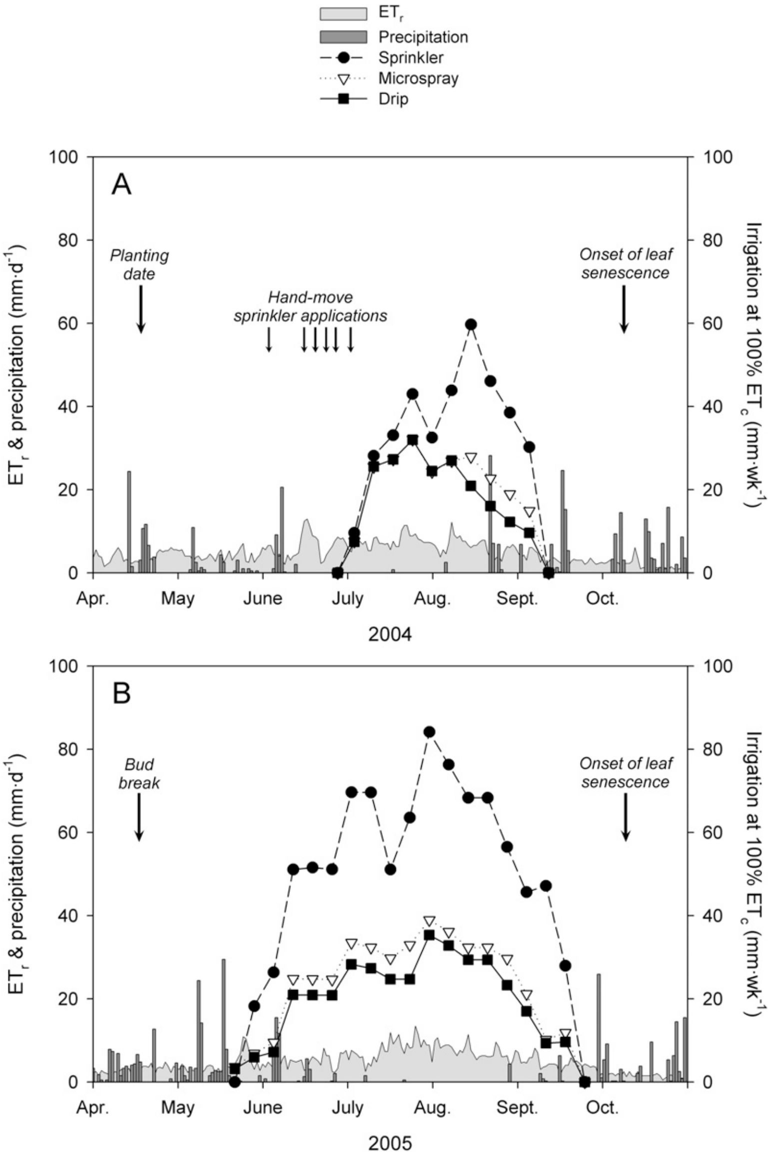

Fig. 2. Reference evapotranspiration (ET_r), precipitation, and irrigation water required to replace 100% of estimated crop evapotranspiration (ET_c) in young 'Elliott' blueberry plants irrigated by sprinkler, microspray, or drip in 2004 (**A**) and 2005 (**B**). Crop evapotranspiration was calculated weekly and used to schedule irrigation twice a week as needed by sprinklers and three times per week by microspray and drip.

on two representative plants per plot to calculate percent fruit bud set. Fresh dormant pruning weights were measured after hand pruning in January. To maximize vegetative growth during establishment, all fruit buds were removed from the plants in the first 2 years after planting (Strik and Buller, 2005).

One representative plant per plot was destructively harvested in Oct. 2005 at the end of the second season. The plants were selected from a border row of each plot. To harvest the plants, soil was first cut around them using a flat shovel. Cuts were made on each side of the plant, both parallel and perpendicular to the row at ≈0.4 m from the crown, and below the plants at ≈0.3 m below the soil surface. Few roots were found deeper than 0.3 m, which is typical for blueberry (Bryla and Strik, 2007). Plants were divided into shoots (canes only; many leaves had already senesced) and roots and washed. Canes and roots were oven-dried at 70 °C and weighed. Total dry weight was also measured at planting and averaged 30 g per plant ($n = 5$).

Data were analyzed by split-plot analysis of variance using SAS Version 9.1 (SAS Institute, Cary, NC) with irrigation system treated as the main plot effect and irrigation level treated as the subplot effect. Comparisons among means were performed at the 0.05 level using Fisher's protected least significance difference test. Response to irrigation levels and system × level interactions were determined using trend analysis and orthogonal polynomial contrasts.

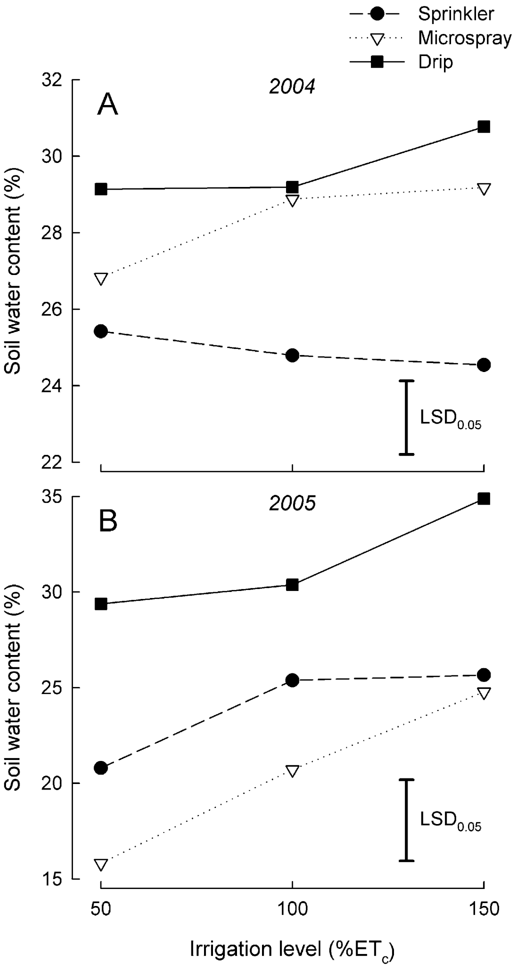

Fig. 3. Volumetric soil water content at 0- to 0.3-m depth in young 'Elliott' blueberry plots irrigated by sprinkler, microspray, or drip at 50%, 100%, and 150% of estimated crop evapotranspiration (ET_c). Plots were measured 1 d after irrigation was applied on 16 Aug. 2004 (**A**) and 7 Sept. 2005 (**B**). Each symbol represents the mean of five replicates, and error bars represent the least significant difference between two irrigation methods within the same irrigation level at the 5% level of significance ($LSD_{0.05}$). Soil water content was significantly affected by irrigation system ($P < 0.001$) and the system × level interaction ($P < 0.05$) in 2004 and by irrigation system ($P < 0.001$), irrigation level ($P < 0.001$), and the system × level interaction ($P < 0.05$) in 2005.

Results

Irrigation and soil water availability. The total amount of irrigation water applied to each treatment in 2004 (Year 1) and 2005 (Year 2) is shown in Table 1. To adjust for differences in plant size and irrigation system efficiency at each level of irrigation, an average of 13% and 82% more water was applied by microsprays and sprinklers, respectively, than by drip the first year, and an average of 19% and 156% more water was applied by the two methods the second year. Budbreak began in mid-April each year, and plant growth continued until the onset of leaf senescence in October. Late June to early September was the warmest and driest period during the growing season (Table 2) with only 9 to 15 mm of total precipitation each year and therefore was when most irrigation was required (Fig. 2).

Despite using the least amount of water, drip irrigation maintained higher soil water content near the plants than sprinklers in both years and microsprays in the second year (Fig. 3). When plants were irrigated by drip, soil water content was the same both years whether water was applied at 50% or 100% ET_c, but increased from 31% in 2004% to 35% in 2005 when water was applied at 150% ET_c. Soil water content with sprinklers, in contrast, remained ≈25% each year when irrigated at 100% to 150% ET_c but decreased from 25% in 2004 to 21% in 2005 when irrigated at 50% ET_c. With microsprays, soil water content declined between years at all three levels of irrigation, including at 150% ET_c, indicating that the levels of irrigation used with this method were underestimated the second year.

Plant growth. Plant growth was similar among treatments the first year after planting. Each treatment that year produced an average of 2.2 new canes per plant and 43 g per plant of fresh pruning weight (data not shown). By Year 2, drip irrigation produced the largest plants among the irrigation methods and had the highest number of new canes and cane dry weight when plants were irrigated at 100% ET_c (Fig. 4A–B). Cane dry weight was also high when plants were irrigated at 150% ET_c by microspray (Fig. 4B). Clearly, plants irrigated by microsprays benefited from the additional water; however, no benefit occurred when plants were irrigated at 150% ET_c by sprinklers and drip. In fact, cane dry weight was significantly less at 150% ET_c than at 100% ET_c with drip, which, when combined with the oversaturated soil conditions in this treatment, suggests that these plants were over-irrigated. Dormant pruning weight averaged 94 g per plant in Year 2, but like the previous year, it was similar among treatments (data not shown).

Root dry weight also differed among irrigation methods ($P < 0.05$) and averaged 0.20, 0.21, and 0.23 kg per plant with sprinklers, microsprays, and drip, respectively (data not shown). Root dry weight was unaffected by irrigation level or its interaction with method, although plants irrigated by microsprays allocated relatively less biomass belowground to root and crown tissue as more irrigation water was applied (Fig. 4C).

Fruit bud set averaged 44% in January 2006 but was similar among each method and level of irrigation and therefore had no significant influence on treatment differences in fruit production the next season (D. Bryla, unpublished data).

Leaf nitrogen. Leaf N concentration was lower in Year 1 than in Year 2 ($P < 0.05$), averaging 17.2 $g\cdot kg^{-1}$ dry weight in 2004 and

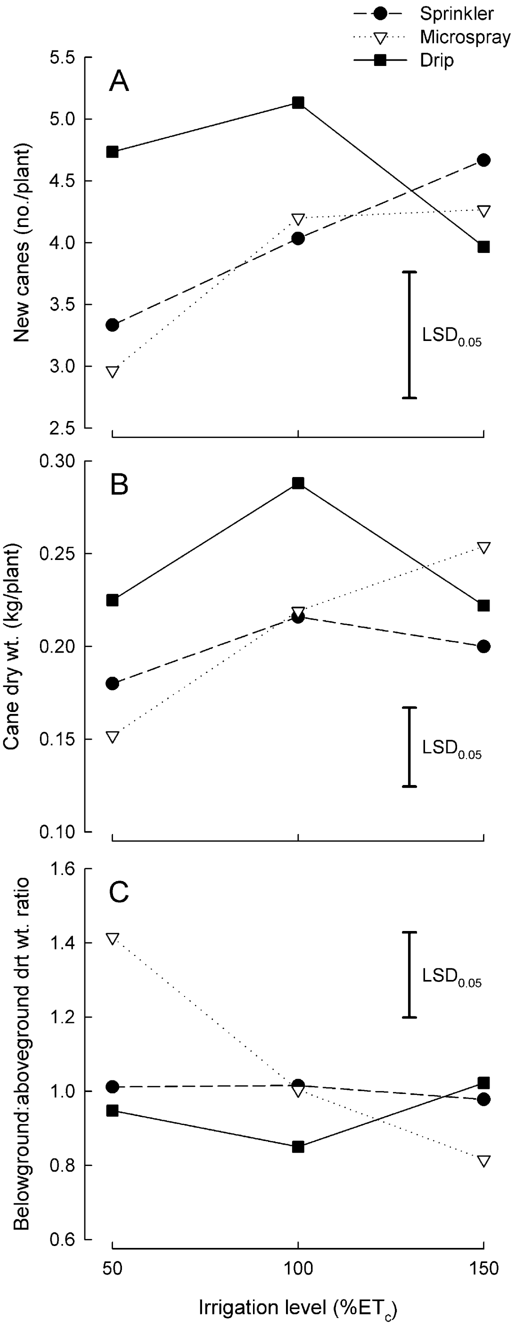

Fig. 4. Number of new canes (**A**), cane dry weight (**B**), and belowground (roots and crown) to aboveground (canes) dry weight ratio (**C**) in 'Elliott' blueberry irrigated by sprinkler, microspray, or drip at 50%, 100%, and 150% of estimated crop evapotranspiration (ET_c). New cane number and plant dry weight were determined in late Oct. 2005 after the second growing season. Each symbol represents the mean of five replicates, and error bars represent the least significant difference between two irrigation methods within the same irrigation level at the 5% level of significance ($LSD_{0.05}$). Cane number was significantly affected by irrigation level ($P < 0.05$) and the system × level interaction ($P < 0.01$); cane dry weight was significantly affected by irrigation method ($P < 0.05$), irrigation level ($P < 0.001$), and the system × level interaction ($P < 0.01$); and belowground:aboveground dry wt. ratio was significantly affected by irrigation level ($P < 0.01$) and the system × level interaction ($P < 0.01$).

19.3 $g \cdot kg^{-1}$ dry weight in 2005. However, leaf N was unaffected by irrigation method or method × level interactions in either year and was only affected by irrigation level in Year 2 ($P < 0.01$), in which N concentrations that year increased from 18.4 $g \cdot kg^{-1}$ dry weight at 50% ET_c to 19.6 to 19.7 $g \cdot kg^{-1}$ dry weight at 100% to 150% ET_c.

Soil pH. Soil pH ranged from 4.7 to 5.2 and averaged 5.0 ± 0.1 SE at 0- to 0.2-m depth on 15 June 2005. The pH was unaffected by irrigation method, irrigation level, or the interaction between the two.

Irrigation requirements. Only 570 mm of irrigation water was required over two seasons to reach maximum total plant dry weight with drip (Table 1; Fig. 5A). In comparison, 980 mm or more water was needed with sprinklers and microsprays. As a result, irrigation water use efficiency, defined as the difference in plant biomass produced under irrigated and rain-fed conditions (presumed to be zero in this case) divided by the total amount of irrigation water applied (Howell, 2000), was significantly higher with drip than with the other irrigation methods, averaging 0.41 g of total dry weight per liter of drip irrigation (Fig. 5B). Irrigation water use efficiency declined with each system as more water was applied, but according to orthogonal contrasts, it decreased significantly faster with drip than with sprinklers or microsprays ($F_{1,24} = 21.02$, $P < 0.01$).

Discussion

Drip irrigation produced the largest plants among the irrigation methods, requiring at least 42% less water than needed to reach maximum dry weight with microsprays and 56% less water than needed with sprinklers. The primary benefit of drip was likely the result of higher soil water content in this treatment in the vicinity of the roots. We previously found that because 'Elliott' blueberry produces a dense canopy, less water reaches the roots during sprinkler irrigation (or rain) and thus exposes the plants to more water stress (Bryla and Strik, 2007). Because soil water content was lower with sprinklers and microsprays than with drip, it is likely that a similar situation occurred in the present study. However, drip irrigation was not beneficial at the site in 'Duke' (Bryla and Linderman, 2007). In this case, plants irrigated by drip were only approximately half the size as those irrigated by sprinklers or microsprays. Root sampling revealed that 'Duke' was infected by *Phytophthora cinnamomi*, the causal organism primarily associated with root rot in blueberry, and drip maintained conditions more favorable to the disease. In a survey of commercial fields in Oregon, *P. cinnamomi* was observed more frequently in 'Duke' than many other cultivars, including 'Elliott' in which it was never found, suggesting 'Duke' is highly susceptible to root rot (Bryla et al., 2008). Thus, in terms of plant growth and water use efficiency, drip irrigation was the best method to establish healthy blueberry plants in the present study. However, as we noted previously, sprinklers and microsprays may be better alternatives for susceptible cultivars grown at sites prone to problems with root rot (e.g., heavy soil and poor drainage).

The total amount of irrigation water required for optimum growth with drip (i.e., 100% ET_c) was ≈200 mm the first season after planting and 370 mm the second season. At a planting density of 4305 plants per hectare, this amount was equivalent to 1320 L of water per plant over the two growing seasons and averaged ≈48% of total reference ET. The maximum amount of water was required in late July to early August each year and averaged 9 L per plant per day during this period. In comparison, water use during this same period averaged 15 L per plant per day at the best irrigation rate with microsprays (150% ET_c) and 18 L per plant per day at the

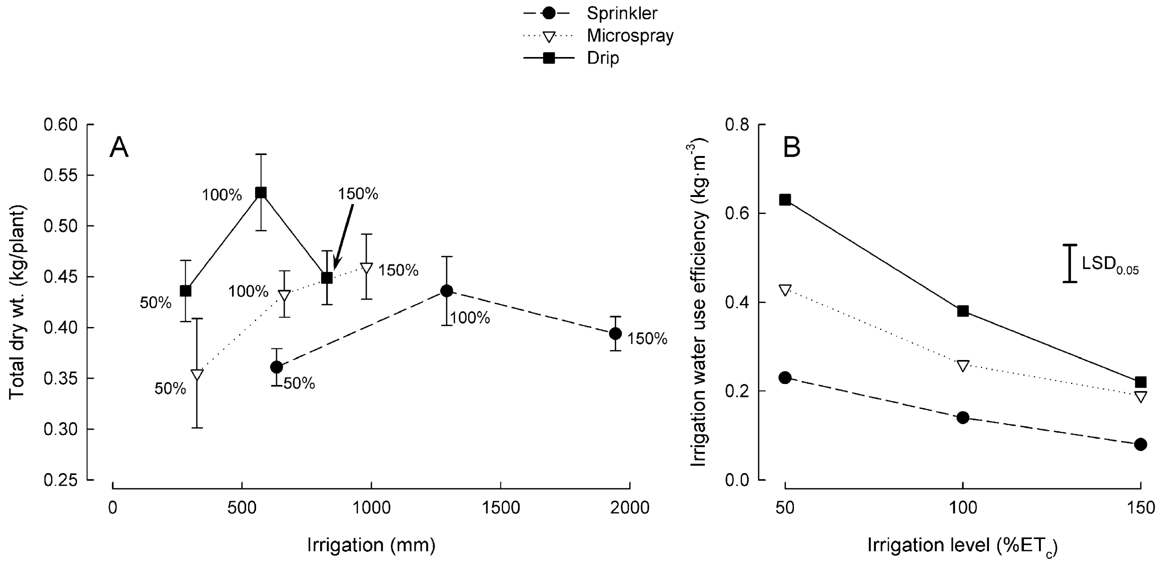

Fig. 5. Total dry weight (**A**) and irrigation water use efficiency (**B**) of young 'Elliott' blueberry plants irrigated by sprinkler, microspray, or drip at 50%, 100%, and 150% of estimated crop evapotranspiration (ET$_c$). Each symbol represents the mean of five replicates, and error bars represent ± 1 SE for total dry weight and the least significant difference between two irrigation methods within the same irrigation level at the 5% level of significance (LSD$_{0.05}$) for water use efficiency. Irrigation water use efficiency was significantly affected by irrigation method ($P < 0.001$), irrigation level ($P < 0.001$), and the system × level interaction ($P < 0.01$).

optimum rate with sprinklers (100% ET$_c$). Haman et al. (2005) estimated that highbush blueberry in Florida requires ≈102 mm or 410 L/plant at a density of 2471 plants per hectare the first year after planting and 175 mm or 710 L per plant the second year. In Arkansas, Byers and Moore (1987) estimated 'Bluecrop' blueberry required only 150 to 225 L per plant, equal to 50% to 75% of Class A pan evaporation, from April to September the second year. In New Jersey, Storlie and Eck (1996) found that 5- and 6-year-old 'Bluecrop' plants used 3.5 to 4.5 L·d^{-1} on sunny days in June, July, and August. Blueberry water use was thus lower in these earlier studies, partly because ET demands are much higher during the summer months in Oregon and partly because 'Elliott' is more vigorous than many other highbush cultivars, including Bluecrop. The plants in these other studies were also grown in containers (to determine ET$_c$). More water is needed in the field to adjust for irrigation system efficiency, deep percolation, and runoff.

Irrigation water use efficiency was higher with drip than with the other irrigation methods as expected and decreased with each system as more irrigation water was added. Spiers (1996) also found that water use by rabbiteye blueberry irrigated by drip was more efficient at lower rates of water application (3.3 L/plant per week) and became progressively less efficient as more irrigation water was applied (6.6 to 26.5 L/plant per week). Drip irrigation usually requires less irrigation water than sprinkler systems because water applications are more uniform and applied entirely to the crop (as opposed to between rows) and less water is lost to evaporation (see Fig. 1). As a result of higher uniformity and efficiency, plants irrigated using well-maintained drip systems generally require 40% less water than those irrigated by sprinklers (although actual plant water use is theoretically identical) (Burt et al., 1997). Blueberry irrigation was also more efficient with microsprays than with sprinklers in this study.

Drip irrigation was applied three times per week during the first 2 years after planting. More frequent water applications by drip may reduce irrigation requirements by limiting water loss by deep percolation. However, Haman et al. (1997) found that if irrigation was applied every time soil matric potential in the root zone reached 10 kPa (high frequency), blueberry plants required 1.6 to 2.5 times more water than those irrigated every 15 kPa (medium frequency) and up to four times the water as those irrigated every 20 kPa (low frequency). Frequent water applications are especially important when using drip systems, which tend to restrict soil wetting and thus promote smaller root systems (Patten et al., 1988). When done properly, frequent irrigations are beneficial and often increase growth in many horticultural crops. For example, in young peach trees, frequent irrigation by drip increased growth and early yield compared with other irrigation methods, primarily by maintaining a higher tree water status (Bryla et al., 2003).

High-frequency irrigation may be especially beneficial and perhaps even required when organic matter is incorporated into the planting bed. In the present study, under-irrigated beds, which had sawdust incorporated before planting, tended to remain drier than well-watered beds even after 50 mm of rainfall and did not become fully saturated until the following spring (Bryla, personal observations). Organic matter often reduces water-holding capacity of the soil and can lead to problems with hydrophobicity. Soil hydrophobicity is the lack of affinity of soil to water and is thought to be caused by a coating of long-chained hydrophobic organic molecules on individual soil particles such as those released from decaying organic matter (DeBano, 2000). Hydrophobic soils often become very difficult to rewet once they dry out. White (2006) found that even with drip, sawdust incorporated into raised planting beds made it difficult to retain adequate moisture in the upper portions of the soil profile where many of the roots were located. To compensate, much longer and more frequent irrigation was required in the beds with incorporated sawdust than in those without it.

More frequent applications are also possible with microsprays but are usually impractical with solid-set sprinklers. However, less frequent irrigation with either sprinklers or the other systems may encourage more root development, which is often desirable in a young planting. For example, in peach, drip laterals located 1.2 m away from the trees reduced growth the first year after planting compared with laterals placed near the base of the trees, but they also encouraged more root development, which the next year resulted in more shoot growth and larger trees by the end of the second year (D. Bryla, unpublished data). In blueberry, Patten et al. (1988) found that microsprays located on each side of the plants encouraged more lateral root development than one or two drip emitters per plant.

It is important to note that plant growth was reduced in the study when water was over-applied by drip. Over-irrigation depletes the root zone of much needed oxygen, thus reducing both root growth and nutrient uptake and leading to a host of potential root disease problems (Bryla and Linderman, 2007; Davies and Wilcox, 1984). Davies and Flore (1986) observed in both highbush and rabbiteye blueberry that stomatal conductance declined within 5 d and photosynthesis declined within 9 d when plants were grown in flooded soil, and

18 d or more were required for both processes to recover to pre-flood conditions. However, it is unclear why over-irrigation reduced plant growth with sprinklers. Soil water content was similar between sprinkler plots irrigated at 100% and 150% ET_c and in both cases was less than field capacity. Because plants were grown on mulched raised beds, perhaps most of the additional water ran off the bed once a particular wetness was reached. Further investigation of water movement with different irrigation methods in mulched soil is warranted.

Although variations in irrigation method and quantity of water application are known to affect availability and uptake of soil N in perennial fruit crops (e.g., Nielsen et al., 1995), both appeared to have little influence on N nutrition in the young blueberries. Leaf N concentrations were unaffected by irrigation method in the study and only differed with irrigation level the second year after planting, in which plants irrigated at 50% ET_c had lower N concentrations than those irrigated at 100% and 150% ET_c. Regardless of the amount of water applied, leaf N was only slightly below the range recommended for blueberry [i.e., 17.6 to 20.0 $g \cdot kg^{-1}$ dry wt. (Hart et al., 2006)] in Year 1 and was within this range in Year 2. To compensate for low leaf N in Year 1, N fertilizer application was increased by 33% the next spring.

The present study demonstrates that drip irrigation may not only increase water use efficiency in blueberry compared with other irrigation methods, but it also may improve plant establishment. Generally, plants that establish more quickly have higher production once fruiting begins (Strik and Buller, 2005). Next, we will examine the effects of the different irrigation methods and rates of water application on fruit production during transition of the planting to full maturity.

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