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on new wood for production of fruit the following year. Conceivably, any water stress occurring during this peak in shoot production could limit production of new canes for next year’s crop.

Irrigation during Stage III is also critical and is perhaps the most sensitive period to water stress, as any water limitations at this point will reduce cell expansion and berry size and therefore have a large impact on yield. Mingea u et al. (2001) examined the effects of water deficits at various phenological stages in ‘Bluecrop’ blueberry and found that even moderate water stress (i.e., enough to reduce transpiration by 35%) during the final stage of fruit growth and ripening strongly influenced yield by reducing both mean fruit weight and fruit diameter. They also found that water stress after harvest reduced the number of flower buds. Flower bud induction occurs in mid- to late-summer in most cultivars and overlaps with late fruit development (Fig. 1). Thus, in addition to reducing yield of the current year’s crop, water stress during the final stage of berry development will also reduce the number of flowers and fruit produced the following year.

Nutrient requirements also vary over the growing season but do not necessarily correlate with water demands. This difference is an important consideration when using irrigation to fertigate (Bryla et al., 2010). Unlike water, the largest demands for many nutrients, including nitrogen (N), typically occur early in the season during canopy development and at the beginning of fruit production (Throop & Hanson, 1997).

3. Plant water relations and response of blueberry to drought

3.1 Fundamentals of plant water potential

The growth, function, productivity, and water use of a plant are intimately related to its water status. Various parameters are used as indicators of plant water status, the most common of which is tissue or organ water potential. Values are typically expressed in units of pressure such as megapascals (MPa), bars, or atmospheres or in units of height or hydraulic head. In plants, the principle components affecting water potential is solute concentrations in cell water and turgor pressure caused by rigidity of the cell wall. For practical purposes, the water potential of free water is considered zero. Therefore any movement of water from wet soil to the plant requires a negative potential. Water potential measured at any point in the soil, plant, and atmosphere, referred to as the soil-plant-atmosphere continuum, is a measure of the tendency of water to move away from that point. Water tends to move from places where its potential is high (e.g., moist soil) to places where its potential is lower (e.g., ambient air with relative humidity less than 99%). The difference between leaf water potential and soil water potential (the latter near zero for moist soils) is an estimate of the driving force for water movement from soil to the foliage. Water readily moves from foliage to the atmosphere (via stomatal openings on the leaf surface; see below) due to relatively higher vapor pressure deficits in the atmosphere.

Plant water potential is often measured using a pressure chamber, sometimes referred to as a “pressure bomb” or a “plant water status console”. To make a measurement, a severed part of a plant such as a leaf or branch is placed in an enclosed chamber with its freshly cut end protruding through a rubber seal. The air pressure in the chamber is then gradually increased until it just causes the exudation of xylem sap at the cut end (generally viewed with a magnifying glass). At this point, the resulting pressure of the sap is zero, so xylem pressure equals negative air pressure. If xylem osmotic potential can be
ignored (which is often the case as it’s usually near zero in most plants), xylem pressure is equal to xylem water potential, which can be the same as the water potential of the other tissues in the chamber (if water equilibration has been achieved) (for details, see Scholander et al., 1964).

Marked daily changes in the water potentials occur in the soil-plant-atmosphere continuum (Fig. 3). In most plants, leaf stomata close at night and as a result, transpiration essentially ceases, allowing root and leaf water to equilibrate with the soil water. The equilibration process may take hours to occur but generally happens before dawn. When the soil is wet and near field capacity, e.g., shortly after a rain or irrigation event, water potentials in the soil, root, and leaf approach zero at night. The stomata then open at dawn and transpiration begins, resulting in a decline in leaf water potential. Root and soil water potentials also decline shortly thereafter. If there is no additional rain or irrigation, leaf, root, and soil water potential becomes more and more negative. As the soil dries, the difference between root and soil water potential must become larger each day in order to sustain water movement from soil to the roots. In contrast, the difference between leaf and root water potential remains constant until the plant is no longer able to sustain a water potential gradient sufficient to absorb enough water to maintain leaf turgor, e.g., when leaf water potential reaches -1.5 MPa. The leaf thus wilts at this point but recovers at night. If drought persists, the leaf may wilt permanently and tissue damage will result.

![Figure 3. Daily changes in soil, root, and leaf water potential following irrigation or a rain event. The shaded regions on the x-axis represent night and the white regions represent daytime. The figure is adapted from Slayter (1967).](www.intechopen.com)
fall below reference values, irrigation is increased. Typically, irrigation is increased by 5-10% above the previous week’s rate when mean weekly stem water potentials are lower than reference values, and decreased by 5-10% when actual and reference values are equal for two consecutive weeks. To ensure plants are not over or under irrigated, soil water content should also be monitored at least monthly. Soil water content measurements may also provide information to help determine initial irrigation rates based on root-zone changes in the soil water profile during the first few weeks of the growing season.

5. Irrigation systems and considerations for water application

Most commercial blueberry fields in the U.S. are irrigated by overhead sprinklers or drip (Strik & Yarborough, 2005). Water is typically applied one to two times per week as needed with sprinklers and every one to three days with drip. Sprinkler systems are relatively simple to install and maintain, and when designed properly, obtain reasonable uniformity of water application. Some major advantages of sprinklers are that they can be used to maintain a cover crop, protect the crop from frost damage during subfreezing temperatures, cool the crop during hot conditions, and wash dust off the crop before harvest. Drip systems are somewhat more expensive to install and more difficult to maintain than sprinklers but offer superior water control and distribution uniformity, lower energy costs, improved application of fertilizer and other chemicals, improved cultural practices, including the ability to irrigate during harvest, fewer weed and disease problems, and reduced food safety risks when using surface water to irrigate (Kruse et al., 1990). A few growers are also using microsprays on blueberry. Microspray irrigation offers advantages similar to drip but applies the water to the soil surface by a small spray. Although not commonly used in blueberry, Holzapfel et al. (2004) found in Chile that production was higher with microsprays than with drip. Because microsprays wet more soil volume than drip, plants tend to produce a larger root system, which may be a considerable advantage in a shallow, densely-rooted crop like blueberry (Patten et al., 1988).

5.1 A comparison of irrigation methods

Bryla et al. (2011) compared the water requirements for growing blueberry with sprinklers, drip, and microsprays to determine which method produces the most growth after planting. Two cultivars, ‘Duke’ and ‘Elliott’, were evaluated. By the end of the second growing season, drip irrigation produced the largest ‘Elliott’ plants among the irrigation methods with 42% less water than microsprays and 56% less water than sprinklers. The benefit of drip in ‘Elliott’ was likely a result of superior plant water status due to higher soil water content in the vicinity of the roots. Drip also maintained higher plant water potentials than microsprays in other perennial fruit crops, including peach and almond (Bryla et al., 2005; Edstrom & Schwankl, 2004). Drip irrigation, however, was not beneficial in ‘Duke’ (Bryla & Linderman, 2007). In this case, plants irrigated by drip were only half the size of those irrigated by sprinklers or microsprays. Root sampling revealed that ‘Duke’ was infected by *Phytophthora cinnamomi*, the causal organism often associated with root rot in blueberry, and the wetter soil conditions with drip were more favorable to the disease. Therefore, in terms of early plant growth and water use efficiency, drip irrigation was the best method out of the three to establish healthy blueberry plants. However, sprinklers and microsprays may be better alternatives for cultivars such as ‘Duke’ that are highly susceptible to root rot, especially at sites with heavy soils or a history of the disease.


This book represents an overview of the direct measurement techniques of evapotranspiration with related applications to the water use optimization in the agricultural practice and to the ecosystems study. Different measuring techniques at leaf level (porometry), plant-level (sap-flow, lysimetry) and agro-ecosystem level (Surface Renewal, Eddy Covariance, Multi layer BREB), are presented with detailed explanations and examples. For the optimization of the water use in agriculture, detailed measurements on transpiration demands of crops and different cultivars, as well as results of different irrigation schemes and techniques (i.e. subsurface drip) in semi-arid areas for open-field, greenhouse and potted grown plants are presented. Aspects on ET of crops in saline environments, effects of ET on groundwater quality in xeric environments as well as the application of ET to climatic classification are also depicted. The book provides an excellent overview for both, researchers and students who intend to address these issues.

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