Combined Proceedings IPPS 74:300-303. 2024.

Water Use Efficiency and Water Footprint in Ornamental Crops

Raul I. Cabrera

Department of Plant Biology, Rutgers University and Rutgers Agricultural Research & Extension Center, Bridgeton, New Jersey 08302 USA.

cabrera@njaes.rutgers.edu

Keywords: irrigation management, conservation, efficiency, nursery production

Summary

Water is crucial for plants, constituting up to 95% of their fresh weight, and is essential for growth and nutrient transport. However, only a small portion of water absorbed by plants is retained, with most lost through transpiration, which also helps cool leaves and allows nutrient uptake. Water-use efficiency (WUE) is the ratio of plant biomass to water used, and it varies across crops. For instance, roses grown hydroponically have a WUE of 2.3-3.0 g/L. The concept of effective WUE considers water lost to drainage. The water footprint (WF) expands on WUE by including water sources and pollution, divided into blue (irrigation), green (rainwater), and gray (pollution). Greenhouse crops like roses have a WF of 8-26 liters per stem. Reducing water use and recycling effluents can improve WUE and lower WF, supporting sustainability and market preferences for eco-labels.

INTRODUCTION

Water is essential to life, and in the case of plants, it constitutes 70 to 95% of their herbaceous (non-woody) fresh weight. In addition to its contribution to these herbaceous tissues, water transports minerals and metabolites through cells and tissues, and provides the positive pressure, or turgor, against cell walls, which is the main driver of plant growth through cell expansion. Interestingly, only a small fraction (as low as 1%) of the total water absorbed by a plant through its entire life is retained in this biomass, and the rest is 'lost' through transpiration. This apparent inefficiency in the use of water by plants is a consequence of the leaves opening their stomata to capture CO_2 to photosynthesize. This stomatal opening leads to loss of water (i.e., transpiration), which facilitates uptake and transport of nutrients from the soil, and helps control the plant's temperature by cooling its leaves through transpiration.

Water-use efficiency. The trade-off of CO_2 capture and water loss from the leaves of plants and crops has been defined since the early 1900s by the concept known as "transpiration ratio" or water-use efficiency (WUE). Transpiration ratio or biomass WUE refers to the unit of plant biomass (grams or pounds of fresh or dry weight) produced per unit of water used or evapotranspired by the crop (like liters or gallons). For example, greenhouse roses growing in recirculating hydroponic and open (free drainage) soilless substrate growing systems were reported to have average biomass WUE of 2.3 to 3.0 g of harvested flower dry weight (DW) per liter of water evapotranspired. The woody ornamental, Texas privet (*Ligustrum texanum*), grown in 1-gallon containers in southern California was reported to have biomass WUE of 0.7 to 2.2 g/L, whereas Japanese privet (*Ligustrum japonicum*) growing in northern Florida showed values of 2.8 to 3.6 g/L. In comparison, intensively managed greenhouse-grown vegetable crops have been reported to have maximum biomass WUE of 3 to 6 g of DW per liter of water evapotranspired.

Considering the rather large inputs and large drainage and runoff losses of water to intensively managed greenhouse and nursery crops, some researchers prefer to use the concept of effective WUE, which relates the yield dry weight biomass produced in relation to the total volume of *applied water* from irrigation and precipitation. This concept effectively accounts for the volume of water that is lost to drainage and runoff, in addition to what was actually used by the crop (evapotranspiration). Considering again the example of greenhouse-grown rose crops, the effective WUE reported for these crops range from 0.7 to 2.3 and 2.3 to 2.8 g of harvested DW yields per liter of water applied, respectively, for soilless substrate and recirculating hydroponic growing systems. Compare these values to the range of 0.8 to 2.2 g/L reported for other irrigated agronomic and vegetable crops.

Water footprint. Serious issues with the availability and pollution of water resources suitable for irrigation and pressing competition from urban and industrial uses led to the development of the water footprint (WF) concept. From a sustainability viewpoint, WF is more comprehensive than WUE, as it specifies the volumes of water applied, consumed, and polluted by source to produce a unit of agricultural product. The overall value of WF includes a "blue" component which is the irrigation volumes applied to (including evaporation and other losses) and consumed (or incorporated) by the crop. It also includes a "green" component, which denotes the consumption of the volume of rainwater stored in the soil. Lastly, it's also comprised of a "gray" component, effectively a pollution factor, which is defined as the volume of freshwater that would be required to dilute (or assimilate) the load of agricultural pollutants from the production cycle (in drainage and runoff water) to existing water quality standards. In a nutshell, this "gray" component of WF is what effectively distinguishes this concept from WUE.

The WF of an agricultural product is expressed as the total liters of water (including the green, blue and gray components) used and polluted to produce one unit (one piece) or one unit (gram) of fresh or dry weight of product. According to a WF global database, for example, one average-sized unit of tomato, apple and banana will have a WF of 50, 125 and 160 liters of water, respectively. Expressed in units of fresh weight, the global WF averages estimated for vegetables, fruits, species and nuts are 0.35, 1.0, 7.0 and 9.0 liters per gram, respectively.

Information on the WF of ornamental greenhouse and nursery crops is extremely limited in the literature, and mostly based on modelling exercises. For example, the WF of export cut flower crops grown in Kenya have been modeled to range from 0.3 to 0.4 liters per gram of fresh weight. In the specific case of cut rose flowers, the modeling exercise suggested a WF range of 7 to 13 liters of water per single rose stem, with one-third of it associated to the gray (pollution) component. Using data from a scientific study on the annual water and nitrogen balance of California-grown rose crops, we were able to calculate their actual WF. Across the various irrigation and nitrogen fertilization treatments, the WF values ranged from 8 to 26 liters per stem, or 0.3 to 0.7 liters per gram of fresh weight. These range of experimental values validated, to a large degree, the values previously modelled for the export roses growing in Kenya. Using data from another water and nitrogen balance study in the woody ornamental *Lagerstroemia* x *fauriei*, plants growing in 1-gallon containers and receiving a nutrient solution of 60 mg of nitrogen per liter had a WF value of 47 liters per plant or 0.3 liters per gram of fresh weight. Fertigating this crop with higher nitrogen concentrations produced much higher WF, as the polluting "gray" component of the total WF rose to significantly higher values, thus requiring higher volumes of water to dilute the excessive nitrogen applications.

Any greenhouse and nursery production system that captures drainage and runoff effluents and recycles them back into production will lead to significant increases in water-use efficiency and reductions in their overall water footprint. In addition to meeting environmental pressures and mandates, a reduced use of water and fertilizers, and containment of agricultural tailwaters (runoff volumes rich in fertilizers and other agrichemicals), effectively a reduced total WF, are among the cultural practices that could lead to eco-labels and "green" certifications, which are beginning to be expected or preferred by some consumers and markets.

LITERATURE CITED

Cabrera, R.I. (2021). Irrigation and nutrition management, p. 224-257. *In*: J. Faust and J. Dole (eds.) Cut Flowers and Foliages, CABI, Wallingford, UK.

Cabrera, R.I. (2003). Nitrogen balance for two container-grown woody ornamental plants. Scientia Horticulturae *97*:297-308

Jarrell, W.M., Whaley, S.J. and Miraftabi, B.. (1983). Slow-release fertilizer and water management with container-grown *Ligustrum texanum*. Scientia Horticulturae *19*:177-190.

Jones, H.G. (2004). What is water use efficiency? p. 27-41. *In*: M.A. Bacon (ed.) Water Use Efficiency in Plant Biology, Blackwell Publishing, Oxford, UK.

Mekonnen, M.M., Hoekstra, A.Y. and Becht, R. (2012). Mitigating the water footprint of export cut flowers from the Lake Naivasha, Kenya. Water Resource Management *26*:3725-3742.

Miller, M.N., Gunter, D.L., Melton, B.E., Johnson, C.R. and Midcap, J.T. (1980). Selecting economically optimal levels of fertilization and irrigation for container production of woody ornamentals. Journal of the American Society for Horticultural Sciences *105*:766-768.

Raviv, M. and Blom, T. (2001). The effect of water availability and quality on photosynthesis and productivity of soilless-grown cut roses. Scientia Horticulturae *88*:257–276.