林木容器苗
培育技术研究进展

Research Advances in Technique of Containerized Tree Seedling Production

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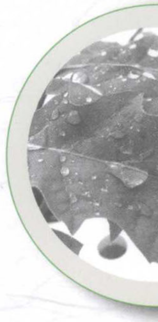

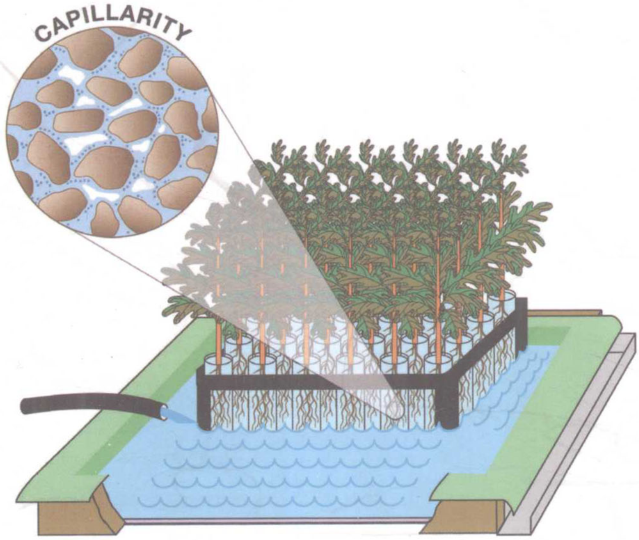

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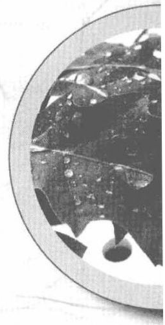

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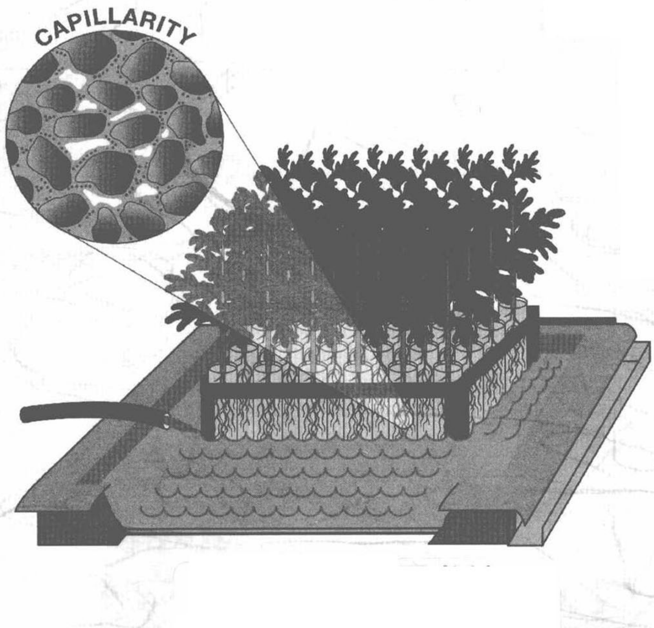

中国林业出版社

图书在版编目(CIP)数据

林木容器苗培育技术研究进展/刘勇，卢宝明主编. —北京：中国林业出版社，2014.9
ISBN 978－7－5038－7629－5

Ⅰ. ①林… Ⅱ. ①刘… ②卢… Ⅲ. ①苗木－容器育苗 Ⅳ. ①S723.1

中国版本图书馆 CIP 数据核字(2014)第 197388 号

中国林业出版社·生态保护出版中心
责任编辑：刘家玲　肖　静

出版发行：中国林业出版社(100009　北京市西城区德内大街刘海胡同 7 号)
网　址：http://lycb.forestry.gov.cn　　电话：(010)83225836　83280498
印　刷：北京卡乐富印刷有限公司
版　次：2014 年 9 月第 1 版
印　次：2014 年 9 月第 1 次印刷
开　本：787mm×1092mm　1/16
印　张：10.25
字　数：320 千字
定　价：48.00 元

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PREFACE

前　言

容器苗是在装有基质的容器内培育的一种苗木类型。与裸根苗比较，容器苗具有育苗周期短、造林季节不受限制、造林时苗木根系完整、造林后没有缓苗期、成活率高、初期生长速度快等优点，尤其在困难立地造林优势明显。第八次全国森林资源清查结果显示，我国营造森林难度越来越大，现有宜林地质量好的仅占10%，质量差的高达54%，造林重点已向质量差的立地转移。因此，如何提升容器苗培育技术，提高苗木质量，对于促进我国造林效果的提高，尤其是困难立地的造林效果有重要意义。

为了加强我国林木容器苗培育技术从业者间的交流，及时跟踪国际研究前沿，我们引进美国在林木容器苗水、肥、基质、容器等方面的最新关键技术，并于2014年9月22~23日在北京圆山大酒店举办林木容器苗培育技术培训会，邀请美国林务局苗木培育专家 Kasten Dumroese 博士和 Jeremiah Pinto 博士，就美国容器苗培育底部渗灌条件下的水、肥管理技术进行了讲解，国内学者也介绍了我国造林树种容器苗底部渗灌技术、精准施肥技术及苗木育苗其他相关技术的最新研究成果。本书就是这次会议演讲内容的汇集，希望对提高我国容器苗培育技术有一定促进作用。

由于我们水平有限，在本书编写过程中必定存在不少错误，敬请批评指正。

本书的出版得到了国家“948”计划项目(2012－4－66)和北京市科学技术委员会重大科技项目“北京林木种苗产业提升及‘圃林一体化’科技示范项目”(D14110500400000)的联合资助。会议的成功举办得到了北京林业大学科技处、国际合作处、林学院等相关职能部门以及北京市林业种子苗木管理总站、国家林业局国有林场和林木种苗工作总站、中国林学会造林分会等单位的鼎力协助，在此一并致以衷心感谢！

编者

2014年9月

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Subirrigation for Production of Native Plants in Nurseries—Concepts, Current Knowledge, and Implementation [①]

Justin L Schmal[1], R Kasten Dumroese[2], Anthony S Davis[3], Jeremiah R Pinto[2], and Douglass F Jacobs[1]

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Abstract: Subirrigation, a method whereby water is allowed to move upward into the growing medium by capillary action, has been the focus of recent research in forest and conservation nurseries where a wide variety of native plants grow. Subirrigation reduced the amount of water needed for producing high quality plants, discharged wastewater, and leaching of nutrients compared with traditional overhead irrigation systems. Recent research has shown additional benefits of subirrigation, such as enhanced crop uniformity and improved outplanting performance. With these advantages and successful operational use in some locales, it seems likely that subirrigation would be of use to a greater number of native plant nurseries. In this paper, we provided an overview of ebb-and-flow subirrigation technologies including potential benefits, summarized the current state of research knowledge for native plant production, presented special considerations for these systems, and offered a basic framework on how growers could implement such a system.

Key words: controlled-release fertilization, electrical conductivity, fertilizer-use efficiency, irrigation, nitrogen-use efficiency, water-use efficiency

Nomenclature

Plants: USDA NRCS (2011)

Insects: ITIS (2011)

Fungi: IFP (2011)

Nursery managers, striving to produce quality seedlings, face government regulations on water use (Oka, 1993) and waste water discharge (Grey, 1991), and mounting public concern about environmental contamination (Neal, 1989). One area where managers can simultaneously address all these concerns is through irrigation water management. Specifically, growers can reduce the quantity of water used during crop production, the amount of water discharged from irrigation, and the fertilizers and chemicals present in discharged water. Use of subirrigation has shown promise in overcoming these challenges without compromising crop quality and may concurrently provide other benefits (for example, Dumroese *et al.*, 2006; 2007; 2011; Landis *et*

① Published in Native Plants, 12(2): 81 - 93, 2011.

al., 2006; Bumgarner *et al.*, 2008; Davis *et al.*, 2008; Pinto *et al.*, 2008).

Overhead irrigation systems can cover large areas, prevent fertilizer salt accumulation in medium (Argo and Biernbaum, 1995), and are relatively inexpensive to install (Landis and Wilkinson, 2004). From a water and nutrient management perspective, however, these systems can be inefficient, may result in significant fertilizer leaching, and are difficult to use on small areas containing diverse species and (or) stocktypes. For example, Dumroese *et al.* (1995) found between 49% and 72% of water and 32% and 60% of nitrogen (N) applied using an overhead irrigation system was discharged from a container nursery. Additionally, a study examining nutrient uptake efficiency and leaching fractions in western white pine (*Pinus monticola* Douglas ex D. Don [Pinaceae]) culture found that irrigation water was leached at a rate of 1.3 L/m^2 per day with N losses of 8 mg/m^2 per day from leachate (Dumroese *et al.*, 2005). In another conifer seedling container study, Juntunen *et al.* (2002) recovered 11% to 19% of applied N and 16% to 64% of P in collected leachate. These examples of discharged nutrients within wasted water demonstrated the impacts to the environment and the nursery budget. Culturally, overhead irrigation also resulted in water interception and deflection (that is, "umbrella effect") by the leaves of broad-leaved plants (Fig. 1). This effect may lead to uneven water distribution (Landis and Wilkinson, 2004), crop variability, mortality in dry cavities (Dumroese *et al.*, 2006), and reduced irrigation application efficiencies (Beeson and Knox, 1991). Yet despite these potential disadvantages, overhead irrigation systems are still standard practice in forest and conservation nurseries (Landis *et al.*, 1989a; Leskovar, 1998).

The proven benefits of subirrigation have been demonstrated for a variety of species and nursery systems (Dumroese *et al.*, 2006; 2007; 2011; Landis *et al.*, 2006; Bumgarner *et al.*, 2008; Davis *et al.* 2008; Pinto *et al.*, 2008). Recent work with northern red oak (*Quercus rubra* L. [Fagaceae]), koa (*Acacia koa* A. Gray [Fagaceae]), pale purple coneflower (*Echinacea*

Fig. 1 Northern red oak, with its large leaves that form an umbrella preventing efficient overhead irrigation, can be readily grown with subirrigation (photo by Anthony S Davis; reprinted from Dumroese *et al.*, 2007)

pallida (Nutt.) Nutt. [Asteraceae]), 'ōhi'a (*Metrosideros polymorpha* Gaudich. [Myrtaceae]), and blue spruce (*Picea pungens* Engelm. [Pinaceae]) demonstrated the benefits and versatility of subirrigation and increased interest in this system (Dumroese *et al.*, 2007). Benefits may include less water use, reduced labor inputs, improved fertilizer efficiency, decreased liverwort and moss growth, plant quality improvements, and more uniform crop growth. Incorporating subirrigation systems into nurseries can be easy and low cost. Either commercially available equipment can be purchased to fit onto existing nursery benches, or custom, low-tech equipment can be constructed in-house to accommodate a multitude of specialized needs (for example, Schmal *et al.*, 2007). Although several types of subirrigation systems are available (for example, wick, trough, flooded floor, *etc.*), we will focus our discussion on ebb-and-flow subirrigation.

While subirrigation systems are often used by the horticultural industry, this system and its application in native plant nursery production is relatively new. Our intent is to present an overview of the benefits of ebb-and-flow subirrigation as reported by recent research, examine special considerations with these systems, and provide practical information about commercial and custom systems.

1 The Subirrigation System

In subirrigation, a water-containing structure is flooded (Fig. 2) until the water level contacts the medium (Fig. 3). Once contact is made, capillary action (the attraction of water molecules for each other and other surfaces) moves water up through the medium and throughout the container (Fig. 4A) (Landis and Wilkinson, 2004). Growing medium pore space and medium type (for example, sphagnum peat) are the primary factors dictating saturation height and speed (Fig. 4B) (Landis and Wilkinson, 2004). For a very well-drained medium, it may be that capillary action alone is insufficient to maintain moisture levels at the medium surface during germination; therefore, subirrigation may need to be supplemented with overhead irrigation to keep seeds and medium adequately moist (Dumroese *et al.*, 2007). As with any new irrigation system, it is essential to test and trouble-shoot a subirrigation system before going into full-operation because of variability in media, equipment, container types, and the moisture demands of different species.

Several types of subirrigation systems are available on the market (Landis and Wilkinson, 2004); one of the most promising systems for forest and conservation nurseries is a closed system (Dumroese *et al.*, 2007). In a closed system, water is pumped from a reservoir tank into a subirrigation tray (Fig. 2); when the irrigation cycle is completed, the water returns to the reservoir tank (Fig. 3). Typically, water is held in the tray until the medium is brought to field capacity; however, a range (that is, low to high cost) of equipment is available to obtain and fine-tune this process. Many growers use automated pumps with programmed flood-cycles where the pump fills the tray, turns off for several minutes, allows the tray to completely drain, and repeats the process until the medium is brought to field capacity. Alternatively, systems utilizing

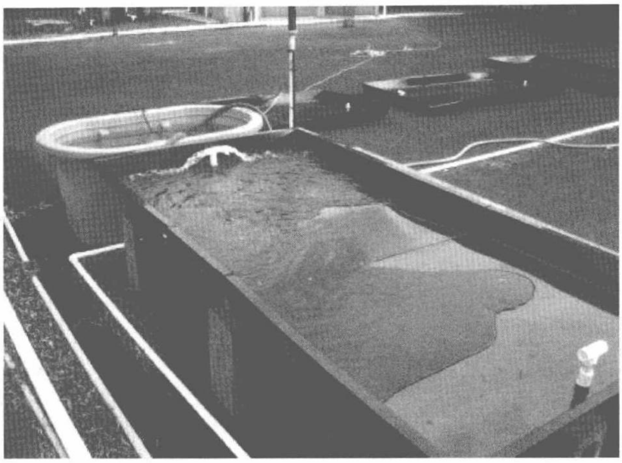


Fig. 2 Flooding of subirrigation trays at Hawai'i Division of Forestry and Wildlife Kamuela (Waimea) State Tree Nursery, on the Island of Hawai'i (photo by Douglass F Jacobs)

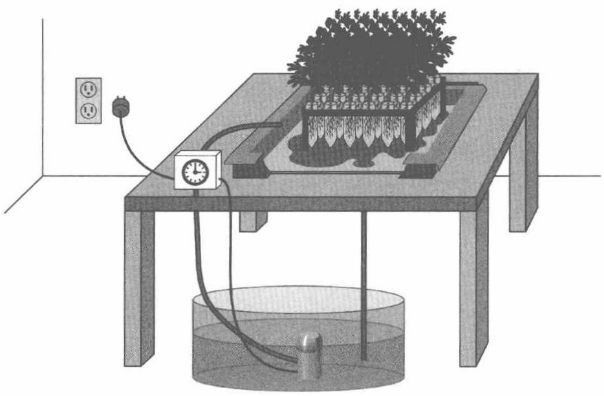
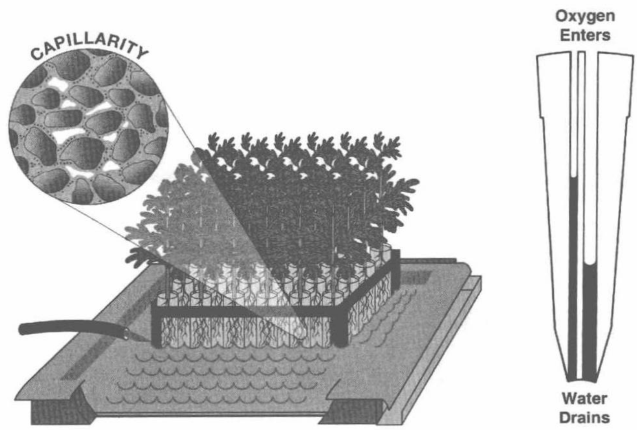


Fig. 3 Schematic of a typical subirrigation system. An electronic timer activates a submersible pump that pushes water up into the subirrigation tray. When the tray is full, the timer deactivates the pump and the water drains back into the reservoir tank (illustration by Jim Marin Graphics; reprinted from Dumroese *et al.*, 2007)

solenoid valves, which close the irrigation line for a specified duration, can have a separate drain component where water is released after a certain amount of time. The USDA, Forest Service, Missoula Technology and Development Center has demonstrated the effective use of remote soil moisture probes for determining when to water bareroot nursery beds (Davies and Etter, 2009). Integrating this technology into subirrigation systems would further decrease water usage, labor inputs, and prevent crop overwatering. Minimal maintenance is needed throughout the growing season to keep a subirrigation system work properly; however, water losses through evaporation and crop transpiration require periodic refilling of reservoir tanks.



(A) (B)

Fig. 4 Subirrigation works because water is drawn upward into the containers by capillary action of water (A). The amount and speed of water uptake will depend on the porosity of the growing medium, the smaller the pores, the more that will be absorbed (B) (illustration by Jim Marin Graphics; reprinted from Landis and Wilkinson, 2004)

2 Seedling Quality and Morphology

Subirrigated plants are morphologically similar or superior to those receiving overhead irrigation (Fig. 5) (Coggeshall and Van Sambeek, 2002; Dumroese *et al.* 2006; 2007; 2011; Landis *et al.*, 2006; Bumgarner *et al.*, 2008; Davis *et al.*, 2008). Pinto *et al.* (2008) used subirrigation to propagate pale purple coneflower seedlings that had better nutrition (that is, 11% greater N content per seedling), 13% greater nitrogen use efficiency (NUE), less mortality, and greater growth (that is, 15% taller and 14% more total dry weight) than overhead irrigated seedlings receiving the same nutrient rates (Fig. 6). Compared with overhead irrigated seedlings, subirrigated northern red oak seedlings had increased aboveground biomass production and greater root and shoot N contents during nursery culture (Fig. 7) (Bumgarner *et al.*, 2008).

Greater crop uniformity and outplanting performance have also been noted with subirrigated seedlings. Bumgarner *et al.*, (2008) showed that subirrigated northern red oak seedlings had greater stem diameter growth following outplanting compared to overhead irrigated seedlings. Increased stem diameter and improved survival was also noted in an outplanting trial of koa seedlings (Davis *et al.*, 2011). Although not quantified, Landis *et al.* (2006) noted that stem heights and diameters were very uniform in seedlings propagated using subirrigation. Crop uniformity is easily attainable with subirrigation systems because the "umbrella effect" is eliminated and an equal amount of water and nutrients are supplied to each container. These results affirm that a correctly used subirrigation system yields similar or better seedling morphology, quality, and outplanting success than seedlings grown with overhead irrigation.

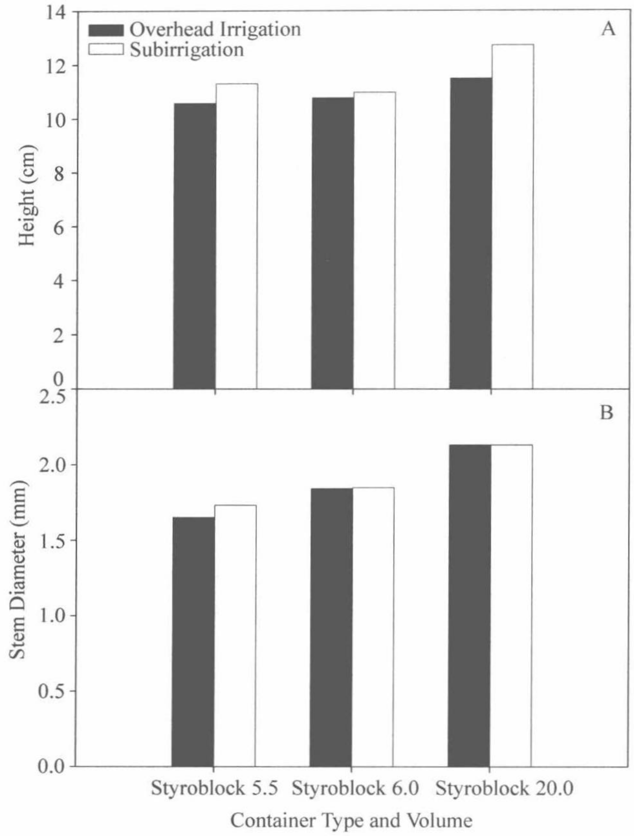


Fig. 5　Blue spruce seedlings were slightly larger with subirrigation compared to sprinkler irrigation in all three container types in height (A) and diameter (B) (reprinted from Landis *et al.*, 2006)

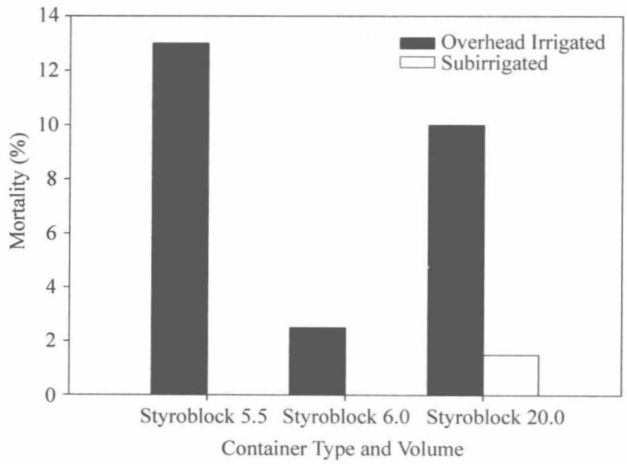


Fig. 6　Mortality of pale purple coneflower seedlings grown with subirrigation and fixed overhead irrigation (reprinted from Dumroese *et al.*, 2007)

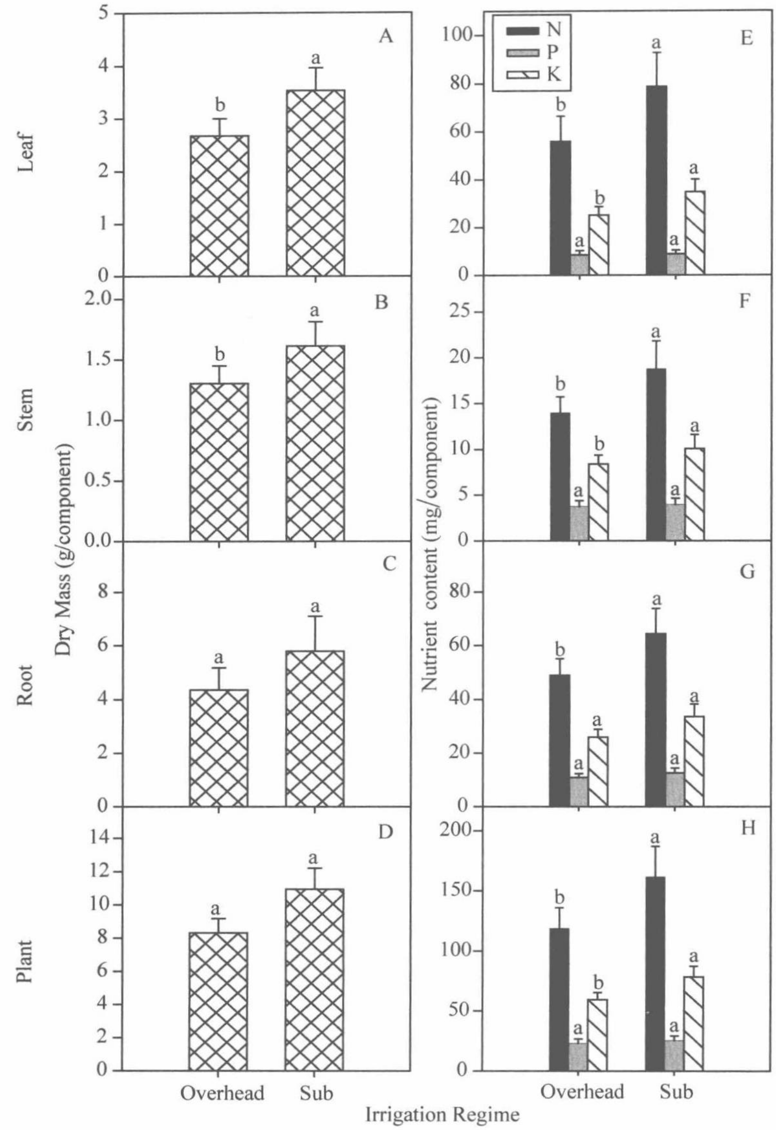


Fig. 7 Effects of irrigation method on northern red oak component dry weight (A – D) and nutrient content (E – H) sampled 4 mo after sowing under controlled greenhouse environments (reprinted from Bumgarner *et al.*, 2008). Treatments marked with different letters are statistically different according to Tukey's honestly significant difference test at $\alpha = 0.05$.

3 Reduced Water Use

Closed subirrigation systems allow for increased water use efficiency because the only losses from the system are through transpiration and evaporation. A study in Hawai'i with 'ōhi' a reported a 56% reduction in irrigation water using a subirrigation system; application values per container were 36 mL of water per day using fixed overhead irrigation and 16 mL/d with subirrigation (Dumroese *et al.*, 2006). The same study illustrated the inefficiency of overhead systems because only 17% of the applied water from the fixed overhead system was "used" by the crop, as nearly 70% was errant spray and 13% of the applied water leached from the pots. Moreover, this study was conducted at a remote site with very limited management; subirrigated seedlings were probably watered more than necessary, indicating that additional water savings could have been made. Similarly, the Tamarac Nursery in Ontario, Canada experienced a 70% savings in water and fertilizer use (Landis and Wilkinson, 2004). These reductions in water use are attributable to the absence of lost leachate in closed subirrigation systems, the lack of errant spray, and the elimination of the "umbrella effect" and its subsequent need for extended irrigation periods to make up for non-uniform irrigation coverage.

4 Improved Fertilizer Use Efficiency

Most research with subirrigation in forest and conservation nurseries has used controlled release fertilizer (CRF). Incorporating CRF into the medium of nursery crops has many benefits including improved fertilizer use efficiency, less fertilizer pollution in discharged water, and the elimination of a need to rinse foliage (Landis and Dumroese, 2009). Combining the use of CRF with a subirrigation system further enhances these benefits. To illustrate, the aforementioned study with 'ōhi'a (Dumroese *et al.*, 2006) used CRF in both overhead irrigated and subirrigated treatments. The average concentration of N in leachate from overhead irrigation was 43 ppm[①] [24 g (0.85 oz[②]) N per replicate; equivalent to 5 g (0.18 oz) N leached per square meter], representing a 3% loss of the total applied. A 3% loss is very low compared with 32% to 60% losses with standard fertigation systems (Dumroese *et al.*, 1992; 1995). In spite of this, the average N concentration in subirrigation reservoir tanks was even lower at 5 ppm [0.7 g (0.025 oz) N per replicate tank] (Dumroese *et al.*, 2006). Thus, a subirrigation system allows nursery growers to save money by using less fertilizer.

Another added benefit of subirrigation is the persistence of residual fertilizer salts in the medium and holding tanks (Dumroese *et al.*, 2006; 2011). For example, after 9 mo of irrigation using a 6-mo release CRF, electrical conductivity (EC) in the medium of subirrigated seedlings was higher than that of overhead irrigated plants (Dumroese *et al.*, 2006). These residual fertilizer salts improved plant nutrient availability and fertilizer use efficiency, while also serving as a source of nutrient reserves during field establishment (Dumroese *et al.*, 2006; 2011). The capture of leachate in closed subirrigation systems allowed for recycling of nutrients that would otherwise be lost with overhead systems, leading to subsequent improvements in nutrient use efficiency and seedling nutrient content (Fig. 7E – H and Fig. 8) (Bumgarner *et al.*, 2008; Pinto *et al.*, 2008; Dumroese *et al.*, 2011).

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① 1 ppm = 1 mg/kg.

② 1 oz = 31.1035 g.

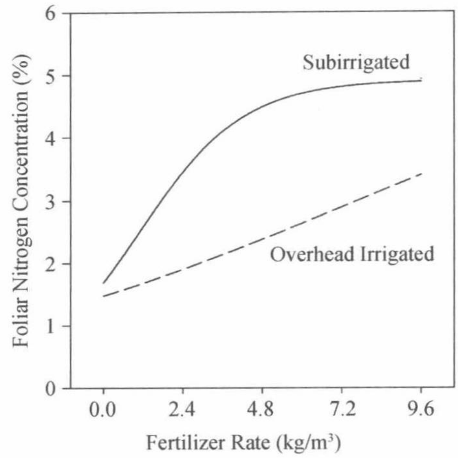

Fig. 8 Foliar N concentrations in subirrigated koa seedlings were higher than overhead irrigated seedling and increased with increasing rates of fertilization (reprinted from Dumroese *et al.* , 2011)

5 Decreased Presence of Damaging Agents

Given the constant recycling of irrigation water in subirrigation systems, the potential proliferation of disease is of concern and has prevented some growers from experimenting with and (or) using subirrigation systems. This concern is justified, as water mold fungi, such as Phytophthora and Pythium, have been shown to spread in various subirrigation systems, including ebb-and-flow ones, used in floriculture and ornamental horticulture (Sanogo and Moorman, 1993; van der Gaag *et al.* , 2001; Oha and Son, 2008), especially when surface water sources are used (Hong and Moorman, 2005). Whether or not disease ensues depends on the plant and pathogen (van der Gaag *et al.* , 2001), and in several experiments, placement of diseased plants within subirrigation areas spread less disease than that when inocula were added directly to the subirrigation reservoir (Sanogo and Moorman, 1993; van der Gaag *et al.* , 2001).

We have yet to observe any water-borne disease issues with subirrigation systems, probably because the media is allowed to dry between irrigations; in conifer nurseries in the Pacific Northwest, *Phytophthora* and *Pythium* are generally only a problem when soil or media are persistently excessively wet (Dumroese and James, 2003). Moreover, the absence of disease in subirrigated seedlings may reflect seedlings that are healthier than those propagated via overhead irrigation. In cases where disease problems do arise, the cause(s) will likely result from a failure to use clean propagules, disease-free medium, and (or) disease-free water, not from the subirrigation system itself. Recent reviews discuss a myriad of cultural, physical, and chemical methods that can be used in subirrigation systems to control water-borne diseases (Newman, 2004; Stewart-Wade, 2011); control may be as simple as adding a surfactant to the water (Stanghellini *et al.* , 2000).

Subirrigation may actually reduce some nursery pests. In a ' ōhi ' a crop, subirrigation decreased moss and liverwort cover on the medium to one-third of that observed with overhead irrigation (Dumroese *et al.*, 2006) (Table 1; Fig. 9). Additionally, the moss growing in the fixed overhead containers was more mature (that is, had roughly four times more sporangium) than the moss in the subirrigation containers (Dumroese *et al.*, 2006) (Table 1; Fig. 9). Because moss and liverworts compete with the crop for fertilizer and light, they can easily choke out small seedlings, reduce seedling growth, or foster other pests, such as fungus gnats (*Bradysia* species [Diptera: Sciaridae]).

Table 1 Average coverage of moss in each container with either fixed overhead or subirrigation and percentage of those containers with sporangium present (Dumroese *et al.*, 2006)

Irrigation	Moss Coverage (%)	Sporangium (%)
Fixed Overhead Irrigation	50	86
Subirrigation	15	23

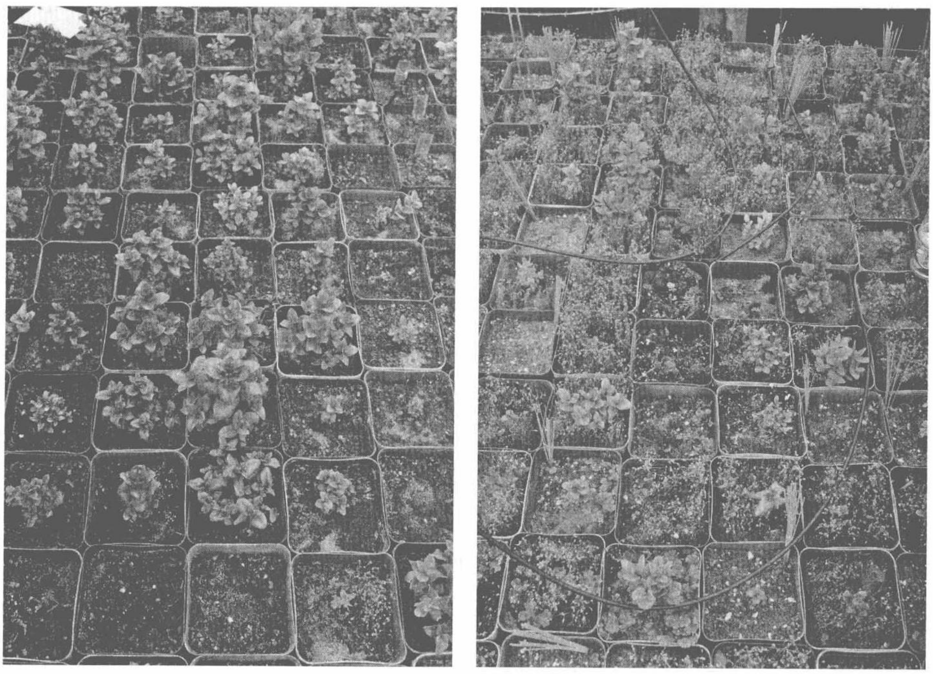

Fig. 9 General lack of moss and liverwort growing on the surface of the medium of 6-mo-old subirrigated plants (A) versus that growing with fixed overhead irrigation (B) (photos by R Kasten Dumroese; reprinted from Dumroese *et al.*, 2007)

The moistening of root crowns and foliage by overhead irrigation can encourage foliar diseases such as grey mold (*Botrytis cinerea* Pers. [Sclerotiniaceae]) (Landis *et al.*, 1989b). Because subirrigation keeps foliage dry, it lessens the potential for foliar diseases. Dumroese *et al.* (2006) did observe that subirrigating too frequently (that is, overwatering) could lead to the proliferation of fungus gnat populations. Therefore, as previously mentioned, it is important to test, monitor,