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Growing Direct-Seeded Watercress by Two Non-Circulating Hydroponic Methods

B.A. Kratky
Department of Tropical Plant and Soil Sciences

This publication describes two non-circulating hydroponic methods for growing watercress from seed (Figure 1). In each method, polyethylene-lined tanks (5.5 in or deeper) are filled nearly to the top with nutrient solution prior to seeding or transplanting watercress. An entire crop of watercress may be grown from seeding through harvest with only an initial application of water and nutrients, but more solution may be added if needed. Electricity and pumps are not needed, so the additional production costs and complexities associated with aeration and circulation in many conventional hydroponic systems are totally avoided by these methods.

In the first method, a cover with holes in it is placed over the tank and is supported by the outer frame of the tank. Individual net pots with growing medium are placed into the holes. The net pots may either be direct-seeded with 10 to 20 seeds or they may contain a similar number of 1- to 3-week-old watercress seedlings. The lower ½ in or more of each net pot is immersed in the nutrient solution. The entire growing medium in the containers moistens by capillary action, automatically providing the plants with water and nutrients. The nutrient solution level in the tank drops below the net pots within a few weeks, but by this time many roots have emerged from the net pots. The roots in the solution continue taking up water and nutrients, while roots between the net pot and surface of the solution become "oxygen roots" and take up air from the humid air layer between the tank cover and the nutrient solution. The crop is harvested before the nutrient solution is exhausted. Then, the tank is cleaned and refilled with fresh nutrient solution and the process is repeated.

Figure 1. Author and agricultural research technician Damian Arruda display extruded polystyrene tank cover with ready-to-harvest watercress.

The second method is similar except that an extruded polystyrene cover floats on the surface of the solution for the duration of the crop and there is no air space between the surface of the solution and the tank cover.

Experiments for this research project were conducted at the Mealani Agricultural Research Station and the Volcano Agricultural Research Station located on the Island of Hawai'i (Figures 2 and 3).

Watercress (*Nasturtium officinale* R. Br., also known as *Rorippa nasturtium-aquaticum* Schinz and Thell) is a semi-aquatic plant that has an edible aerial stem with an apex and leaves projecting above the water (Ryder 1979). Watercress is a perennial crop which flowers and produces seeds during each growing season. It may be grown as an annual or as a ratoon ("cut and come again") perennial crop.

Figure 2. Tanks of watercress in a plastic-covered rainshelter at the Mealani Agricultural Experiment Station.

Figure 3. Agricultural research technician Gaillane Maehira inspects ready-to-harvest watercress crop in a plastic-covered rainshelter at the Volcano Experiment Station.

Watercress is typically eaten raw as a leafy salad or cooked as greens (Neal 1965). It has been described as having a unique taste with a refreshing flavor (Shear 1968), peppery spiciness (Levenson 2011), or a biting peppery taste (Palaniswamy and McAvoy 2001). It contains phenethyl isothiocyanate (PEITC), which is a primary flavor component (Palaniswamy and McAvoy 2001, Freeman and Mossadeghi 1972). Supplemental light applied to watercress growing in an 8-hour photoperiod for 1 week before harvest increased PEITC levels (Palaniswamy et al. 1997), and it was suggested that plants harvested after 1 week of bright sunlight may be more flavorful (Palaniswamy and McAvoy 2001).

Watercress was reported to be a medicinal plant, a remedy for scurvy, by Dioscorides in about 77 A.D. (Ryder 1979), and it is in fact an excellent source of vitamin C, the lack of which causes scurvy. Other reported medicinal uses include as a diuretic, expectorant, purgative, stimulant, blood cleanser, and tonic. PEITC also inhibits various types of cancer (Stoner 1995).

In Hawai‘i, watercress has been traditionally grown in shallow ponds or beds fed by continuously flowing water from springs, where it is not unusual for 1 million gallons of water/acre/day to flow over the fields (McHugh et al. 1981, 1987). Upland watercress is produced on soils with adequate rainfall as well as on irrigated soils. Hydroponically grown watercress is produced in Hawai‘i by the nutrient film technique (NFT) where nutrient solution is kept continuously flowing. Watercress has also been grown in uncovered tanks (1 ft. deep) of non-circulating hydroponic nutrient solution, in which only about 0.1 percent of the water was required compared to the continuously flowing water method in field production (Kratky et al. 2002).

Field-grown watercress has been normally propagated in Hawai‘i from stem or terminal shoot cuttings (McHugh et al. 1981, 1987). However, propagation from seed greatly enhances the chance for virus-free production and has been preferred in other locations (Palaniswamy and McAvoy 2001, Ryder 1979, Tomlinson 1974). Ratoon harvests may be taken from original plantings.

A suspended-net-pot, non-circulating hydroponic method has been described for lettuce (Kratky 2009, 2010a). Watercress may be grown in a similar manner, but there are some deviations. This publication discusses the suspended-pot method and also a floating-tank-cover method for growing seed-propagated watercress.

Climate

Watercress prefers a moderately cool climate (Shear 1968), but air temperatures below 60^{o}F (15.5^{o}C) will cause slower growth (McHugh 1981). Optimum daytime air temperatures ranging from 70 to 85^{o}F (21 to 29^{o}C), such as occur during the “cool” winter season of November through April (McHugh et al. 1981, 1987), produced the best growth from low-elevation outdoor growing sites on the island of O‘ahu. Supplemental overhead sprinkling during the warm season (summer) at a near-sea level-elevation site reduced leaf temperature, increased yields, and improved quality (McHugh and Nishimoto 1980). When eight crops were grown in rainshelters over a one-year period, watercress produced 32 percent higher yields in 19 percent less time at the warmer Mealani Experiment Station (2,800 ft. elevation) than at the cooler Volcano Experiment Station (4,000 ft elevation) (Kratky 2010b). Yields per crop day at the warmer Mealani location were fairly uniform during March through October harvests, but they were about 15 percent lower from December and January harvests. However, at the cooler Volcano location, December and January harvests yielded 34 percent lower than March through July harvests, whereas August and September yields were 22 percent higher than March through July harvests.

Watercress generally prefers bright, sunny days with little or no cloud cover (McHugh et al. 1987). An optimum quantity of sunlight was required for a crop cycle to obtain maximum yield of 'Sylvasprings' watercress, and yield was correspondingly reduced when the total light deviated from this optimum point, but Kobayashi and McHugh (1987) suggested that this predictive model might only apply during the late spring and summer months. 'Stokes' watercress tolerated sunny to overcast conditions in rainshelters at Volcano and Mealani Experiment Stations. When the tanks were covered with 40-percent Aluminet® shade fabric, watercress yielded 15 percent less than when growing in uncovered tanks during 8 harvests throughout the year (Kratky 2010b). However, a 'Pepeekeo' watercress variety developed tipburn in full sunlight, which was significantly reduced when a shade screen provided 57 or 71 percent shade over the plots (Kratky et al. 2002). Thus, different watercress varieties have different sunlight and shade requirements.

Rainshelters

Rainshelters improve the predictability of watercress production by preventing the uncontrolled additions of water to the growing tanks and also by providing a framework to screen or fence out various insects and pests. Screened ends and sidewalls are recommended to protect against rainfall and large flying insects. A pertinent discussion of rainshelters appears in Kratky 2006, 2010a.

The nutrient solution is diluted when rainfall enters into growing tanks, and this may slow the growth rate and reduce yields. Rainfall also raises the level of nutrient solution in the tanks, but watercress growing by the suspended-pot or floating-top-cover methods discussed in this article can tolerate rainfall and other additions of water to the growing tanks without suffering the type of physiological damage that is experienced by lettuce growing with the suspended-pot method (Kratky 2010a). Thus, rainshelters are not mandatory for watercress production.

Suspended-Pot Method

Lettuce has been successfully grown with a suspended-pot method (Kratky 2009, 2010a). A similar system may be used to grow watercress. An entire crop of watercress may be grown with a single application of water and nutrients. Electricity and pumps are not needed. The additional production costs and complexities associated with aeration and circulation in many conventional hydroponic systems are avoided by this method.

Tanks with a minimum depth of 5½ in (deeper is better) are filled nearly to the top with nutrient solution (water plus fertilizer). Two-in net pots (tapered plastic containers with slits to allow root emergence) are filled with growing medium, seeded with 10–20 watercress seeds, and placed into a tank cover, which is supported by the tank frame such that the net pots are suspended above the tank of nutrient solution (Figure 4).

The lower ½ to 1 in of each net pot is immersed in nutrient solution. The entire growing medium in the containers moistens by capillary action, and this automatically provides the plants with water and nutrients. The nutrient solution level in the tanks drops below the net pots within a few weeks as the watercress grows. By this time, roots have emerged from the net pots and extended into the receding nutrient solution. The roots in the solution continue taking up water and nutrients, while roots in the increasing air space between the net pot and the surface of the solution become "oxygen roots" and take up air from the humid air layer between the tank cover and the nutrient solution (Imai 1987).

Watercress should be harvested before the nutrient solution is exhausted. Then the tank may be cleaned and refilled with fresh nutrient solution, and the process may be repeated. Alternatively, a ratoon crop may be taken. In this case, the nutrient solution level is maintained by periodic applications of 1 in or less of nutrient solution (water plus fertilizer). Watercress is more physiologically tolerant of nutrient solution additions to tanks than lettuce or tomatoes. After harvesting the ratoon crop, the tank

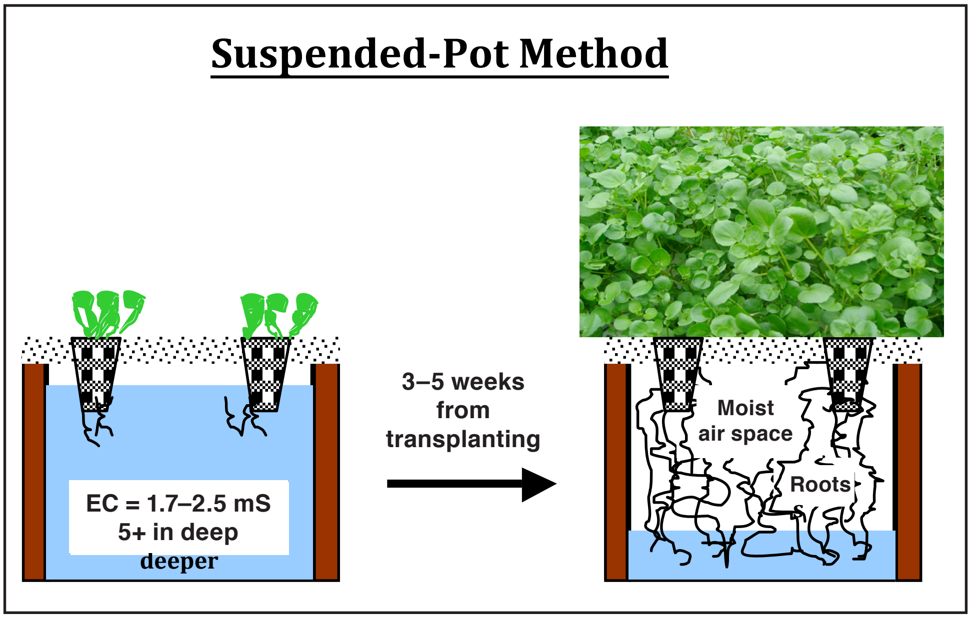

Figure 4. The suspended-pot method. The lower portion (½–1 in) of the net pots is initially immersed in nutrient solution. The entire growing medium in the net pot becomes moistened by capillary action, watering the seedlings. The nutrient solution drops below the bottom of the net pots as the plants grow, and the solution is depleted by transpiration and evaporation. This creates an expanding moist air space.

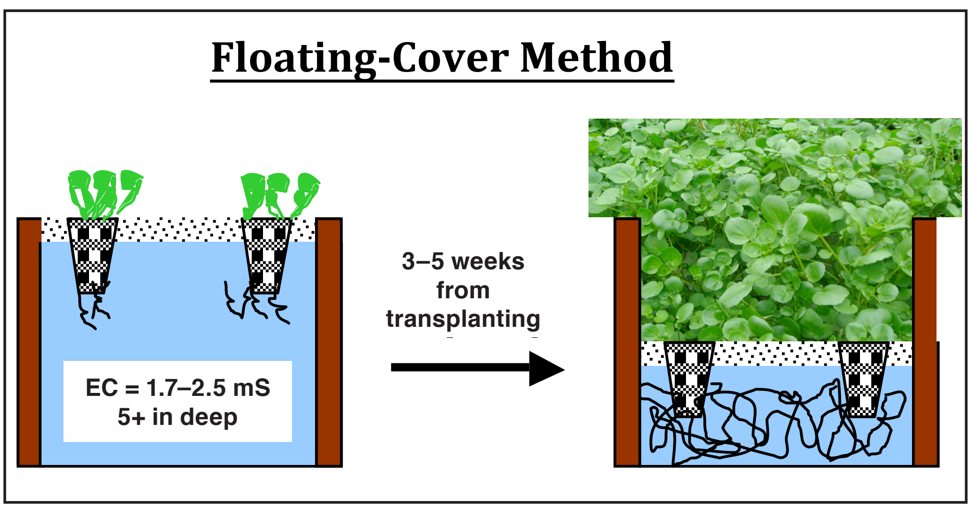

Figure 5. Floating-cover method. Extruded polystyrene tank cover floats on the nutrient solution at transplanting time and continues to float on the nutrient solution as the crop grows and nutrient solution level decreases. The tank may be partially refilled by periodic additions of nutrient solution.

is refilled with fresh nutrient solution and replanted with newly seeded or transplanted watercress.

The tank cover is placed on top of the tank and supported by the frame of the tank and is normally easily removable. Sheets of 1-in-thick expanded (white beadboard, 2 lb/cubic ft density) or ½-in or thicker extruded polystyrene (Styrofoam™) are preferred because they are lightweight, and it is easy to cut holes for the net pots. Individual sheets should be cut to a 2’ x 4’ dimension to facilitate handling. Larger-dimension sheets (4’ x 8’) are often broken while handling due to the fragility of the materials. Soft plastic pots may be placed on the floor of the tank to provide additional support to the middle of the sheets. This prevents bowing or sagging of the polystyrene. Coating the top surface of the polystyrene with white latex paint will prolong the life of the sheets.

Alternative options for tank cover materials include plywood and plastic. Thin plywood (0.25 in) with 1x2” lumber reinforcements is preferred over thicker plywood dimensions because it is easier to cut holes for the net pots in thinner plywood. Several growers have successfully constructed tank covers by covering lumber frames with plastic weed barrier fabric; holes for the net pots are burned in the fabric with a hot pipe. A coat of white latex paint is recommended for plastic and plywood covers. This is especially true for dark-colored covers, which heat up in direct sunlight.

Floating-Cover Method

Watercress may also be grown by a floating-cover method (Figure 5). Everything is similar to the suspended-pot method except the tank cover floats on the surface of the nutrient solution. Tank covers consist of extruded polystyrene sheets (½ to 1 in thick), which float on the liquid surface regardless of the liquid depth. Sheets of expanded polystyrene beadboard are not suitable for a float system, because they have occasional air pockets and may become waterlogged and covered with algae. Extruded polystyrene has a consistent structure without large air pockets and does not become waterlogged.

Tank cover dimensions should be about ½ to 1 in less than the inner tank dimensions so the edges do not become caught up on the sides of the tanks. Algae may grow in these uncovered perimeter areas, but a strip of dark plastic covering these areas will reduce algae growth (Figure 6).

Extruded polystyrene tank covers float on the surface of the nutrient solution regardless of the liquid depth. Depending upon the thickness of the cover, the lower 1 to 1½ in of the net pots is immersed in nutrient solution, and this automatically provides the plants with water and nutrients. The upper ½ to 1 in of the growing medium in the containers is moistened by capillary action. Since the top cover is floating, no air space develops below the top cover and nutrient solution as the liquid level recedes.

There should be at least 2 in of nutrient solution remaining in the tank at harvest time. After harvesting, the tank should be cleaned and refilled with fresh nutrient solution and a new crop can be grown. Alternatively, a ratoon crop may be taken. In this case, the nutrient solution level is maintained by periodic applications of any amount of nutrient solution. After harvesting the ratoon crop, the tank is refilled with fresh nutrient solution and replanted with newly seeded or transplanted watercress.

Comparisons Between the Two Methods

Watercress yields were higher for the floating-cover treatments than the suspended-cover treatments in 3 of 8 harvests in a trial at Mealani Experiment Station over a 1-year period. However, yields were similar for the remaining 5 harvests. Total yields for the floating treatments were 7 percent higher than the suspended treatments during the 1-year trial. In 2 other trials at Mealani Experiment Station, watercress yields were similar from both floating- and suspended-cover treatments.

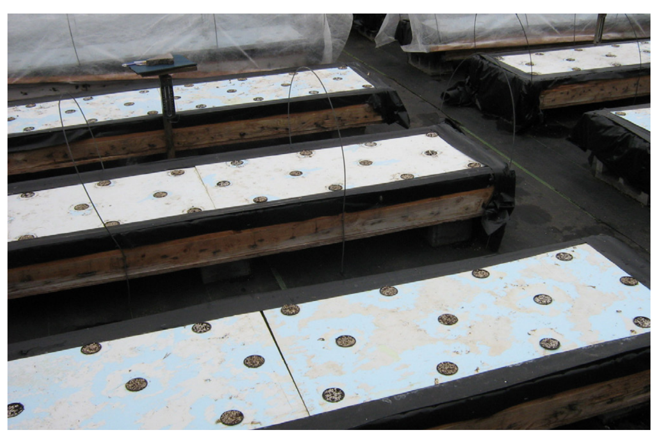

Figure 6. Reducing algae growth in the floating-cover method by covering the space between the edges of the tank cover and the tank frame with a black plastic strip. This excludes light from the nutrient solution.

Figure 7. Watercress growing by the suspended-pot method (left) has greater root growth than watercress growing by the floating-cover method (right).

In trials at the Volcano Experiment Station, total yields from 2 crops of direct-seeded floating- and suspended-cover treatments were similar. However, when 2- and 3-week-old seedlings were transplanted, total yields over a 12-week period were 17 and 22 percent higher, respectively, from suspended-tank-cover treatments than from floating-cover treatments. Also, there was more vigorous root growth in the suspended-cover treatments due to the moist air zone, which expands with crop growth and nutrient solution depletion (Figure 7).

Thus, it would be prudent to point out that watercress may be grown with either floating- or suspended-top covers (Figure 8), but individual growers would be advised to make this comparison at their farm location before committing to either method.

Figure 8. Growing watercress by a floating-cover method (left) and suspended-pot method (right) in the same tank at the Volcano Experiment Station.

Tanks

For the suspended-pot and floating-cover methods, watercress is grown in tanks filled with nutrient solution (water + a complete hydroponic fertilizer) instead of growing in flooded field soil, as is commonly practiced with conventional field production. The minimum recommended tank depth is 5.5 in. It would be prudent to employ deeper tanks rather than shallow tanks because a shallow body of nutrient solution is more likely to have greater temperature variations throughout the day and reach higher temperatures than a deeper body of solution. Solution temperatures exceeding 78°F are detrimental to watercress growth (McHugh et al. 1981). Tanks exceeding 10 in deep may not be economical to construct, plus they are heavier to move and waste more nutrient solution when emptied.

Common tank dimensions are 4 x 8 ft and 4 x 16 ft, but other dimensions may be used. Tanks should be level to within 0.75 in, but this becomes increasingly difficult to maintain as tank lengths increase, due to ground settling issues. The floating-cover method might be advantageous in situations where tanks are not level. If tanks are wider than 6 ft, it becomes difficult to reach the plants when harvesting.

A rectangular frame is constructed with 2x6”, 2x8”, or 2x10” lumber, and this is fastened with screws or nails to a 0.5-in or thicker plywood sheet which becomes the bottom of the tank. Lumber needed to build a 4 ft x 8 ft x 5.5 in-high tank includes 2x6” lumber (2 lengths of 8 ft and 2 lengths of 45 in) and a 4 ft x 8 ft sheet of plywood. Tanks should be installed at a convenient working height (30–36 in). A 4 ft x 8 ft tank that is 5.5 in deep weighs more than 800 lbs when it is filled with nutrient solution. Therefore, tanks should be supported at least every 4 ft. on stacked concrete blocks or have a well-braced lumber frame.

There are less expensive tank construction alternatives. A tank support structure from cross-braced, upright pallets may be constructed, with recycled metal roofing attached to this supportive framework to become a table top, but care must be taken to prevent sharp edges from cutting the plastic liner. Lumber frames without the bottom plywood sheet may rest directly on the metal table top without any attachment. Similarly, lumber frames without the bottom plywood sheets may rest directly on level ground that is covered by weed barrier fabric to cushion against rocks and prevent weeds from penetrating the plastic tank liner. Although ground-supported tanks are cheaper and easier to construct, they are not recommended because then stoop labor is required to plant and harvest the watercress.

Tanks are typically lined with 2 layers of 6-mil black polyethylene sheeting. Clear greenhouse-grade polyethylene is also acceptable, but clear construction-grade polyethylene should be avoided because the exposed plastic (any plastic not protected by the tank cover or sides) deteriorates from sunlight exposure. It is easier to lay and fit each layer of polyethylene sheeting individually rather than combining both layers. Polyethylene rolls are typically sold in 10 and 20 ft widths, but it is easier to work with the 10 ft width.

When cutting the polyethylene sheeting, allow several inches to overhang on the ends and sides. The polyethylene is loosely laid in the tank and then must be fitted snugly against the sides and bottom of the tank, because unsupported polyethylene sheeting is prone to leak. Air pockets may develop if the plastic is fastened before water is added, and this often causes leaks. Preliminary fitting is accomplished by using the side of one's hand—similar to a slow-motion judo chop. Then, about 2 in of water is added. The cool water causes the polyethylene to shrink and pull away from the sides of the tank, so it must be refitted to insure that it rests firmly against the lumber. Folding and trimming of the polyethylene are needed at the corners of the tank. Neat folds are an acquired skill. A staple gun is used to fasten the polyethylene to the outside frame rather than the top of the tank frame; stainless steel staples are preferred. After the polyethylene has been secured, the tanks should be filled with water and allowed to sit for at least a few hours. The tank should be drained with siphon tubing to remove contaminants that may have been on the plastic and have dissolved in the water. The tank may then be filled with nutrient solution and planted with watercress.

If a tank leaks while a crop is growing, vermiculite may be used to plug small holes and retard the leaks. The vermiculite is milled to very fine particles by rubbing between one's hands. A few handfuls of this very fine vermiculite are added to the leaking tank. Then, after the crop has been harvested, a new sheet of polyethylene may be installed over the 2 existing sheets.

Various types and sizes of plastic tanks are also commercially available, and growers may prefer these because they are more portable, and construction time and skill are not required.

Water

Good-quality water is required for hydroponic watercress production. Water should be clean and, ideally, pure enough to be used for drinking (Shear 1968). Clean rainwater should be used if the municipal water source has high salinity. A simple method for testing water quality is to compare the growth of watercress in 1-gallon bottles (Kratky 2002) filled with nutrient solution made with rainwater vs. municipal water.

Water with high salinity should be avoided, because plant growth may be adversely affected when unnecessary salts concentrate in the nutrient solution due to evaporation and transpiration. The osmotic effect increases as the total fertilizer salts in the nutrient solution increase, and this causes greater difficulty for the plants to take up water. This is commonly referred to as a condition of high salinity, which can also cause complex physiological interactions that affect nutrient uptake, internal nutrient requirements, plant metabolism, and susceptibility to injury (Grattan and Grieve 1998). Toxic concentrations of ions in plants and other metabolic disturbances may occur with high salinity.

Total fertilizer salts may be measured in millisiemens (mS) with an electrical conductivity (EC) meter (Figure 9). While the exact maximum optimum EC for watercress may fluctuate with cultivar, environmental conditions, and season, growers should be wary of EC values over 2.5 mS and avoid EC values in excess of 3.0 mS. An effective way to correct nutrient solution with high salinity is to dilute the nutrient solution with plain water.

Municipal water in the Hilo area is generally very good and has an EC of less than 0.1 mS, whereas some Kona municipal water supplies may have an EC of 0.3 to 0.5 mS. Salts in water with a high initial EC from salt contaminants will become more concentrated when the original nutrient solution has been lost by evaporation and transpiration. For example, if the initial EC of a 5-in depth of nutrient solution is 0.5 mS, these unnecessary salts alone will concentrate to 2.5 mS when the solution level drops to 1 in deep. The total EC will rise to an unfavorable level for watercress production when fertilizer salts are added to these unnecessary concentrated salt contaminants.

Non-circulating hydroponic systems are extremely efficient in terms of water use. It is common to grow a pound of watercress with less than 3 gallons of water. A water-use efficiency as low as 1.5 gallons of water per lb of watercress has been recorded in trials at the Mealani Experiment Station. In contrast, conventional production of watercress in shallow ponds with flowing water requires in the range of 3,800 to 6,900 gallons of water to produce a pound of watercress (McHugh et al. 1981, Kobayashi and McHugh 1987).

Water temperatures above 78°F cause slow or poor growth (McHugh et al. 1981, 1987). Thus, non-circulating hydroponic systems require an increased solution depth (5 in or more—deeper is better) coupled with an insulating extruded or expanded polystyrene tank cover to maintain solution temperatures below this temperature in low-elevation sites. Shorter day lengths, cooler air temperatures, and cooler solution temperatures contributed to 35 percent lower yields in the cool Volcano location during December and January, but it is unclear as to the relative contribution of any of the factors.

Planting Density

Two-in net pots are filled with a fine- to medium-grade peat–perlite or peat–perlite–vermiculite growing medium and seeded with 10–20 watercress seeds. The suggested density of the net pots is 1.5 plants per square ft or 48 net pots per 4 ft by 8 ft tank. The primary issue with net pot spacing is that watercress plants from one net pot tend to tangle with plants from adjacent net pots, and this makes harvesting difficult. Tangling is reduced by employing a wider spacing, but this reduces the yield potential per tank. Growers are advised to compare several planting densities for their growing situation on a small scale before committing to a particular spacing for commercial-scale production. Parameters to consider include quality, weight, size, and tangling.

An electric drill with a 2-in hole saw is used to cut openings in the cover sheets at the layout marks (Figure 10). Preferably, holes are cut about ¾ of the way from one side of the cover such that the drill bit emerges from

Figure 9. Different models of electrical conductivity (EC) meters to measure total fertilizer salts in milli-siemens (mS).

Figure 10. An electric drill with a 2-in hole saw is used to cut openings in the tank cover.

the other side; then, the operation is completed from the other side of the sheet. This gives a better cut and prevents the plugs from sticking in the hole saw.

Equidistant plant spacing is preferred, but this is not always possible. A suggested plant spacing for a density of 1.5 net pots per square ft on a 2 ft by 4 ft tank cover sheet is to first mark 3 rows along the 24-in side (located at 4, 12, and 20 in) and then place 4 net pots per row on the 48-in side (12 net pots per sheet.) The suggested spacing layout of the first and third rows will be at the 4-, 16-, 28-, and 40-in marks of the 48-in side. The layout of the middle row will be at the 8-, 20-, 32-, and 44-in marks. A uniform spacing arrangement can be achieved in a 4 ft wide tank by alternating cover sheets so the first sheet has the 4-in mark of the first and third rows from one side of the tank and the adjacent sheet is flipped end-to-end with the 8-in mark of the first and third rows on that same side of the tank.

Fertilizer

Growers may formulate their own fertilizer formulas, or they may use commercially available formulations prepared according to the manufacturer's instructions. We have successfully grown watercress with the following initial nutrient solution concentrations in ppm: nitrogen – 149, phosphorus – 42, potassium – 189, calcium – 127, magnesium – 38, boron - 1.3, copper – 0.3, iron – 2.5, manganese – 1.3, molybdenum - 0.06 and zinc – 0.3. Additional research is needed to optimize these nutrient concentrations.

For the sake of this discussion, Chem-Gro (Hydro-Gardens, Colorado Springs, CO) hydroponic lettuce formula fertilizer (8-15-36 + micronutrients) plus magnesium sulfate and solution-grade calcium nitrate will be used to prepare 2 stock solutions (concentrated fertilizer solutions) which are stored in plastic trash containers.

The Chem-Gro nutrient stock solutions (Figure 11) are prepared as follows:

Procure 2 good-quality plastic trash containers and place on a firm foundation such as a cement slab or plywood sheet. Make sure that there are no rocks under the trash cans, because they could crack the plastic and cause a leak. Label the first trash container "A" and the second "B."

Fill both trash containers with exactly 25 gallons of water and mark the water level. Then, remove about 5 gallons of water from each container before adding the fertilizer components.

To container A, add 25 lbs of Chem-Gro 8-15-36 (Hydro-Gardens, Colorado) plus 15 lbs of magnesium sulfate (Epsom salts). (To prepare smaller amounts of stock solution A, add 1.0 lb Chem-Gro 8-15-36 hydroponic fertilizer plus 0.6 lb (9.6 oz or 272 grams) of magnesium sulfate to each gallon of final solution.)

To container B, add 25 lbs of solution/soluble-grade calcium nitrate. (To prepare smaller amounts of stock

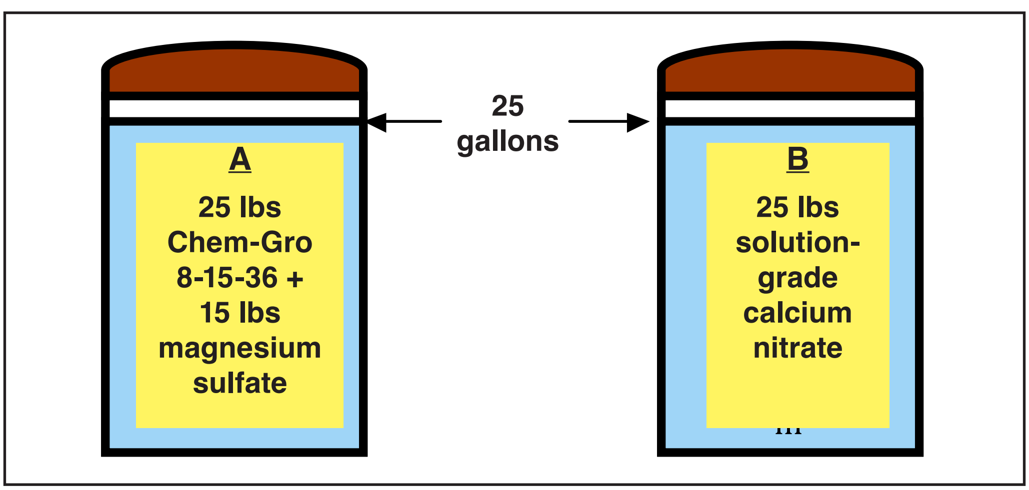

Figure 11. Nutrient stock solutions. Stock solution A consists of 1.0 lb/gal (25 lbs/25 gal) Chem-Gro 8-15-36 hydroponic fertilizer plus 0.6 lb/gal (15 lbs/25 gal) of magnesium sulfate. Stock solution B consists of 1.0 lb/gal (25 lbs/25 gal) of solution-grade calcium nitrate.

solution B, add 1.0 lb of solution/soluble-grade calcium nitrate to each gallon of final solution.) Do not use field-grade calcium nitrate.

Finally, top off with water to the 25-gallon mark. Both tanks now have exactly 25 gallons of stock solution. If the fertilizer components were added to 25 gal of water, that would result in a volume greater than 25 gallons, and the volume of tank A would be different than tank B, which would change the concentration of the nutrients.

Some growers choose to only add the Chem-Gro 8-15-36 fertilizer into tank A and to prepare a separate container C for magnesium sulfate. It is interesting to note that a white microorganism film has been observed to develop on Chem-Gro 8-15-36 stock solution that has been stored for a long time, but this doesn't occur with the Chem-Gro 8-15-36/magnesium sulfate combination.

Each stock solution should have its own measuring cup and stirring rod. Place a stirring rod into each stock solution container and stir well before using. Ideally, the stirring rods should be short enough to fit in the closed stock solution containers, because this will prevent contamination and interchanging of the stirring rods. Place one plastic measuring cup in each stock solution and label it so it does not become interchanged into another stock solution tank. Plastic measuring cups float, so they are easy to retrieve from the nutrient solution containers.

Concentrated stock solutions from the A and B containers chemically react to form precipitates (e.g. calcium sulfate and calcium phosphate) when combined in this concentrated state. This alters the soluble nutrient composition and causes fertilizer imbalances. However, these reactions do not occur when the stock solutions are mixed in the dilute growing solution. Therefore, growers are advised to carry the concentrated stock solutions separately to the growing tanks, where they should be added uniformly to the growing tanks and lightly stirred.

Stock solutions should be added in equal volumes (e.g., 1 measured quantity of A and 1 measured quantity of B) to prepare a nutrient solution with an electrical conductivity (EC) of 1.7 to 2.2 mS. However, the EC might be increased to as high as 2.5 mS in cool weather. Too much fertilizer causes salt injury, and too little fertilizer results in poor growth. Grower experience should be the final basis for determining the exact solution concentration.

If you do not have an electrical conductivity meter, then 0.75 ounce (or 1.5 tablespoons) of stock solution A and 0.75 ounce (or 1.5 tablespoons) of stock solution B should be added to each gallon of water in the growing tank.

To calculate the capacity of a rectangular tank, first calculate the area:

Length x width = area
The inside dimensions of a 4 ft. x 8 ft tank are 7.75 ft x 3.75 ft = 29.1 square ft.
One in. water depth on 1 square ft. = 0.625 gal of water.
One in. of water in a 4 ft x 8 ft tank = 18.2 gal.
Five in. of water in a 4 x 8 ft tank = 90.8 gal.

The 0.75 ounce/gallon rate of each stock solution would be 68 ounces of stock solution A and 68 ounces of stock solution B for 91 gallons of water. At this application rate, one batch (25 gallons) of the 2 stock solutions should contain enough fertilizer to grow more than 47 tanks (4 ft x 8 ft) of watercress. If the combined fertilizer materials cost $100, then the fertilizer cost would be $2.13 per tank or $0.044 to fertilize each net pot (assuming 48 net pots per tank).

The EC rises approximately 0.1 mS for each 1 ml of stock A plus 1 ml of stock B that is added to 1 gallon of water. Thus, adding 20 ml of each stock solution per gallon of water (1800 ml of stock A and 1800 ml of stock B to 90 gal of water) produces a nutrient solution with an approximate EC of 2.0 mS.

An EC meter measures electrical conductivity of all ions in solution but does not distinguish between individual ions. There can be a low level of an individual ion even if there is a high EC reading, and this can cause decreased yield or quality of watercress. Nevertheless, an EC meter is a very useful instrument when the grower applies a complete hydroponic fertilizer formulation. EC meters need periodic calibration.

Inaccurate readings may occur with poorly mixed solutions. Higher readings are often found at the bottom of the tank, especially if the solution wasn't mixed well.

EC meters give higher readings when the nutrient solution temperature increases. For example, an EC reading of 1.28mS at 68°F increases to 1.55mS at 86°F. Some growers have noticed that EC readings were higher several days after the nutrient solution was prepared. If cold water was added to the tanks, a lower EC reading is initially observed, but the reading increases as the solution temperature increases.

EC readings of the nutrient solution tend to rise during hot weather, because plants selectively take up more water to accommodate increased transpiration. This increases the concentration of total solutes and raises the EC of the nutrient solution. Conversely, during cool weather, plants selectively take up less water, and the EC tends to decrease. As a result, growers generally add nutrient solution with a lower EC (1.7 mS) in hot weather and a higher EC 2.0 to 2.5 mS) in cool weather.

Ideally, tanks should be drained and refilled after each crop. However, some growers just "top off" the remaining solution with new nutrient solution. As a general rule, tanks should be drained and refilled at least after every 2 crops.

Experiments were conducted with uncovered tanks of non-circulated nutrient solution at the Volcano Experiment Station with continuous ratoon crops of the 'Pepeekeo' cultivar where a harvest was taken every month. Total yields were 49 percent higher after 6 months when the nutrient solution was completely changed every 2 months as compared to only topping off the remaining solution with new nutrient solution (Kratky et al. 2002). In a subsequent trial (unpublished), 14 harvests were taken over a 13-month period. Total yields were 88 percent greater when the nutrient solution was completely changed every 2 months as compared to only topping off the remaining solution with fresh nutrient solution.

When nutrient solutions were topped off, nitrate-nitrogen levels were reduced from 121 ppm in the original nutrient solution to 65 and 7 ppm after 1 and 5 months, respectively (Kratky et al. 2002). Similarly, manganese levels were reduced from 0.72 ppm in the initial nutrient solution to 0.08 and 0.05 ppm after 1 and 5 months, respectively. In the 14-harvest trial, the initial nitrate and manganese levels of 76 ppm and 1.04 ppm, respectively, were reduced to 2 ppm and 0.04 ppm, respectively after 13 months. In this later trial, topping off with fresh nutrient solution plus adding 3.6 ounces (102 grams) of nitrogen (7 nitrate-nitrogen:1 ammonium nitrogen) + 0.032 ounce (0.93 gram) of manganese per 100 sq ft of tank after every harvest resulted in total yields over the 14-harvest period which were similar to changing the nutrient solution after every 2 harvests.

In the first trial, the pH of the nutrient solution increased from the initial 5.8 to 7.8 after 5 months. A rise in the magnesium level from 33 ppm in the initial nutrient solution to 60 ppm after 5 months contributed to this (Kratky et al. 2002). In the 14-harvest trial, the pH rose from 5.8 in the initial nutrient solution to 7.3 after 13 months, and this was accompanied by a rise in the magnesium level from the initial 36 ppm to 103 ppm after 13 months.

Although it is possible to grow successful crops of watercress by topping off with fresh nutrient solution plus adding individual elements that are deficient after each harvest, this would require periodic laboratory analyses of the nutrient solution, and that wouldn't be practical for many growers. Bearing in mind that these results occurred with a nutrient formulation designed for lettuce production, it would be worthwhile to research and design a nutrient formulation which is specific for watercress production.

Other Nutrients

Watercress grown at an N:S ratio of 10:6 produced 84 percent more PEITC than plants grown at an N:S ratio of 10:3. However, further increasing the N:S ratio to 10:9 resulted in only 61 percent higher PEITC levels than watercress grown at an N:S ratio of 10:3 (Palaniswamy et al. 1995, Palaniswamy and McAvoy 2001).

Supplemental iron is not normally added to the nutrient solution in non-circulating hydroponic culture. However, a brief discussion is warranted.

Iron is normally applied to growing solutions at recommended rates via commercial hydroponic fertilizer such as that in stock solution A. An iron concentration of 2 to 3 ppm should be maintained in the nutrient solution, but it can form complexes with other substances and become deficient (Jones 1997). Also, failure to properly mix the hydroponic fertilizer stock solution can result in an iron deficiency. Various iron chelates may be added to the nutrient solution (either to the calcium nitrate stock solution or directly to the growing solution), and only one ounce of the active ingredient (elemental iron) will supply slightly more than 1 ppm of iron to over 7,000 gallons of nutrient solution (28.35 g iron/26,495,000 g nutrient solution).

pH

The acidity or alkalinity of the nutrient solution is measured by pH units. If the nutrient solution is too acidic or alkaline, the crops will not grow well and may even die.

Physiological processes are affected by nutrient solution with an abnormal pH (below 4.0 or above 7.5. Nutrient availability and uptake are also affected by pH. Manganese (Mn), copper (Cu), zinc (Zn), and iron (Fe) availabilities are decreased at a high pH, whereas phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) availabilities are decreased at a low pH (Bugbee 2004).

The general recommended pH range for non-circulating hydroponic production is 5.5 to 6.5. Jones (1997) recommended a pH range of 6.0 to 6.5 and pointed out that plant growth may be affected below pH 5.0 or above pH 7.0 He also concluded that a pH range of 5.0 to 7.0 is less critical for flowing-solution culture than for static-solution culture. Bugbee (2004) recommended an optimum pH range of 5.5 to 5.8 and suggested that plants grow equally well between pH 4 and 7 if nutrients do not become limiting.

A pH meter is the most common way of measuring pH (Figure 12). All pH meters need periodic calibration, and pH electrodes tend to have a shorter lifetime than EC meters. An inaccurate reading from a malfunctioning pH meter can wrongly direct a grower to alter the pH of the growing solution with disastrous results. Inexpensive pH test kits with a pH range of 4.0 to 8.5 are also available and may be used alone or in addition to a pH meter. Several drops of indicator solution from the test kit are added to a test tube filled with nutrient solution, and the corresponding pH is read from a color chart. The indicator liquid has a precision of 0.5 pH unit, and this is good enough for most growers and hobbyists. Growers may also use pH paper strips to monitor nutrient solution pH. The pH paper strips shown in Figure 12 have a pH range of 0–13 and a precision of 1 pH unit.

Figure 12. Alternatives for measuring solution pH are a pH test kit, pH indicator paper, and a pH meter.

Field fertilizer formulations are not recommended for hydroponic applications because they typically have too high an ammonium nitrogen content. When nitrate:ammonium ratios exceed 9, the pH tends to increase, but ratios below 8 cause pH reduction in the nutrient solution (Jones 1997). Commercial hydroponic fertilizer formulas are usually blended to maintain pH values in the recommended pH range. However, nutrient solution pH may be affected by water quality, growing medium, the crop, and other factors. Acids and bases may be used to alter nutrient solution pH, but they are caustic. If the pH is too low, a simple method of raising pH is to place finely ground dolomite in fine netting such as a nylon stocking and immerse this in the tank until the pH adjusts upward, at which time the dolomite is removed. If the pH is too high, prepare a stock solution of 1 lb ammonium sulfate per 10 gallons of water and add ½ ounce of the stock solution per gallon of growing solution. The plant will utilize the ammonium nitrogen, and the solution pH will drop. Monitor the nutrient solution after several days and make necessary adjustments.

Propagating Watercress From Seed

Although watercress may be readily propagated from cuttings, direct seeding into net pots filled with growing medium is a better option for these two hydroponic methods.

Watercress seed is not commonly stocked by many seed companies. Potential growers may need to search international sources of watercress seed to amass a larger number of cultivars for testing. The availability of watercress cultivars from U.S. seed companies is fairly limited. For example, the Stokes Seed Co. listed only one unnamed watercress cultivar, which was used in the current studies and is referred to as the ‘Stokes’ cultivar.

Like other crops, individual watercress cultivars have unique characteristics. For example, the watercress cultivar from Stokes Seed Co. produced yields 17 and 37 percent higher than watercress cultivars from Johnny’s Seed Co. and Kitazawa Seed Co, respectively, in a non-circulating hydroponic trial at Volcano Experi-

Figure 13. Agricultural research technicians Roy Ishizu, Les Hasegawa, and Earl Arakawa fill net pots with growing medium. The net pots are tapped slightly to settle the medium, but they should not be packed so tightly as to restrict air space.

ment Station. The 'Kitazawa' watercress cultivar had the strongest flavor and the 'Stokes' watercress cultivar was the mildest.

A good seed source is important. If seed is ordered from a Mainland source, it should be sent by airmail or priority mail. Seeds should not be left in a hot vehicle, in the greenhouse, or outdoors. Each seed batch should be dated when it is received. Then place each batch in a sealable plastic container and store this in a refrigerator. These are the "mother batches," which remain in the refrigerator at all times except when filling zip-lock bags or similar small containers of "working batch" seeds which are transported from the refrigerator to the planting location and then back to the refrigerator. Eventually, seeds from the working batches lose viability and produce weak seedlings and/or poor germination. These seeds should be discarded and replaced with seed from the mother batches.

Eventually, the mother batches will also lose viability. Make a note of the germination percentage and days-to-emergence of new seed and compare this every year to the aged seed. Whenever either of these 2 factors significantly decreases, it is time to order new seed.

Alternatively, seeds may be collected from the pods of mature plants at the stage where the seeds shed from the pod when it is squeezed (Biddington and Ling 1983). Fresh seeds may fail to germinate, because they exhibit dormancy. This decreases as the seeds age, such that older seeds are less dormant than fresh seeds (Biddington and Ling 1983).

Watercress should be seeded into net pots containing moist and workable growing medium. Fine to medium grades of peat–perlite or peat–perlite–vermiculite media types are commonly used. A good growing medium has adequate capillary water movement, which wets the surface of the growing medium and allows the seeds to imbibe moisture to initiate the germination process. The net pots should be filled with growing medium (Figure 13) and tapped slightly to settle the medium, but they should not be packed so tightly as to restrict air space. Commercial seedling plugs may also be used, but they have less top surface area and don't allow for wide plant dispersion as compared to net pots filled with growing medium. Also, some seeds will roll off from the tops of plugs and become lost during planting.

Watercress seeds are very tiny (over 2 million seeds/lb) and are difficult to plant with most commercial seeders. A simple, but effective, shaker-type seeder may be fabricated from a test tube or small bottle with a plastic cap (Figure 14). One hole is drilled in the plastic cap with a 5/64-in drill bit. Seeds are placed in the tube and the grower shakes the seeds (usually with a flick of the wrist) onto the surface of each net pot.

The grower should "calibrate" the shaking motion intensity, so that each net pot receives 10–20 seeds. Calibration consists of shaking seeds onto a piece of clean white paper and counting them. When 10–20 seeds can be consistently discharged from the planting tube with one shaking motion, the grower is ready to plant the net pots filled with growing medium. A skilled worker can plant about 40 individual net pots per minute with this method. Growers may find it useful to lightly mist the seeded net pots with a spray bottle or hose mist nozzle.

The seeds germinate on the surface of the growing medium and should not be covered. Watercress seed germinates similarly in light or dark conditions within the range of 41 to 77°F, and the germination percentage was higher in light conditions at temperatures from 86 to 95°F (Biddington and Ling 1983). Thus, covering the seeds might reduce germination under warm conditions.

An experiment at the Mealani Agricultural Experiment Station compared one shaking motion delivering 10–20 seeds vs. two shaking motions of the same in-

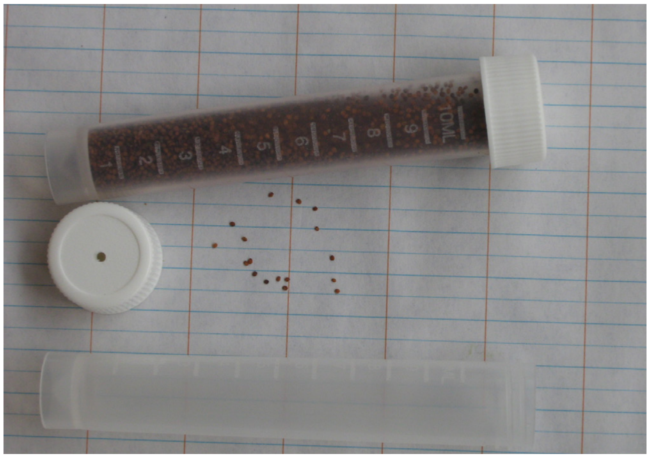

Figure 14. A shaker-type seeder may be fabricated from a test tube or small bottle with a $^{5}/_{64}$-in hole in the cap.

Figure 15. Agricultural research technician Les Hasegawa places seeded net pots into a floating extruded polystyrene tank cover.

tensity, delivering 20–40 seeds in total. Fresh weight yields were increased in the first cutting by 20 percent with 20 to 40 seeds per net pot, but there was no yield difference between one or two shaking motions in a ratoon cutting that was harvested 21 days later. Thus, the grower may find it beneficial to fine-tune the seeding rate.

Biddington and Ling (1983) demonstrated that 50 percent of 2-year-old watercress seeds germinated in 2 to 4 days in the temperature range of 68 to 95°F, but the germination time was extended to 10 days when the temperature dropped to 48°F. However, more than 50 percent of watercress seeds germinated in 3 days in February at the Volcano Experiment Station, where the temperature range was 48 to 76°F (G.T. Maehira, personal communication). Good-quality watercress seed usually germinates readily within 3 days in the warmer Hilo climate.

The seeded net pots may be placed directly into the growing tanks (Figure 15). However, a better option is to sub-irrigate the seeded net pots by placing them into nursery trays containing ½ in of water and allow the seeds to germinate before transplanting into the growing tanks (Figure 16). About 20 percent more net pots should be planted so the grower may select the best plants to transplant into the growing tanks. Transplanting reduces the time spent in the growing tanks, and this allows several extra crops of watercress to be harvested from each growing tank per year.

The seedling greenhouse should be maintained as a separate structure from the production greenhouse(s). When seedlings are grown in the same structure with the production tanks, there is increased likelihood of transferring diseases and insects to the young seedlings.

Seedlings less than 1 week old do not need supplemental fertilization, but fertilization is needed when older seedlings are produced. Seedlings may be fertilized by adding nutrient solution (at about ¼ the production rate or an EC of 0.5 mS) to the sub-irrigation nursery trays holding the net pots. Fertilizing seedlings via top-watering options include injecting ¼-strength nutrient solution into the irrigation mist used to water the seedlings or applying every 2 or 3 days with a sprayer or sprinkling can. Excessive fertilization will cause the plants to become too lush and weak.

A gel-seeding method (M.D. Orzolek, personal communication) was also tested where watercress seed was suspended in a gel and sown by extrusion of the gel. The seed–gel mixture consisted of 3 grams of watercress seed per 100 ml final volume of gel, resulting in approximately 139 seeds/ml of gel, and each net pot received 1 or 2 drops of the gel mixture. The gel consisted of 4 grams of Natrosol (hydroxyethyl cellulose) per 100 grams water. Watercress fresh weight yields were similar with both the gel and shaker methods over a total of 8 direct-seeded crops, each with one ratoon harvest, at 2 experimental locations. However, the gel-seeding method takes extra time to prepare and is messy

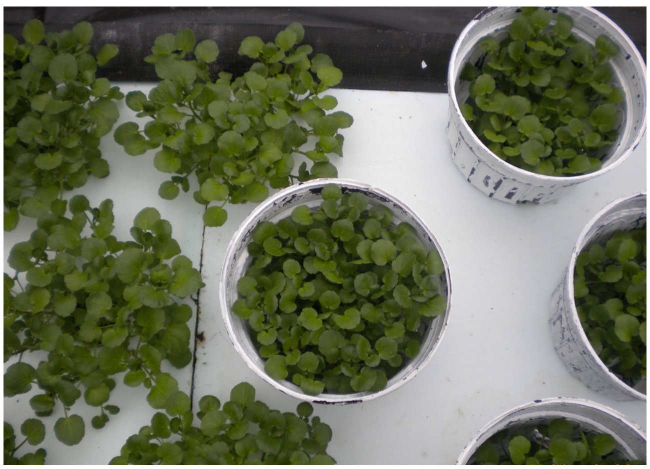

Figure 16 (top left). Seeded net pots are sub-irrigated with ½ in of ¼-strength nutrient solution and are ready to transplant into the growing tanks after 2 to 3 weeks. Figure 17 (bottom left and above). Containing watercress foliage in white pots reduced stem tangling but also reduced yields.

to clean up, and the remaining seed–gel mixture must be discarded. It was concluded that there was no advantage to employing the gel-seeding technique as compared to the shaker seeding method, which was simpler and more economical.

Harvesting

Watercress is normally harvested when the stems are 8 to 12 in long. When stems are allowed to grow longer than this, they grow into each other and become entangled, and this really slows down the harvesting procedure. Tangling of the stems may be reduced by widening the spacing between the net pots, but this reduces yield per area. An attempt was made to reduce stem tangling from adjacent plants by placing 5-in-high x 8-in-diameter white plastic pots over the net pots such that the stems were mostly contained in the pots (Figure 17). Tangling was definitely reduced, but yield was lowered by 36 percent.

A manual harvesting procedure involves grasping stems with one hand and cutting with a heavy-duty scissors, clipper, or knife (Figure 18). Stems may be trimmed as necessary. The watercress may be placed in a plastic produce bag (Figure 19), a hard plastic container, or a box if it is to be taken to a restaurant. Product labeling is usually suggested.

Misting with plain water either before or after harvesting is recommended because watercress is very perishable and wilts quickly if allowed to sit exposed to the sun. Watercress should be refrigerated as soon as possible after harvesting. Vacuum cooling of watercress has been practiced by growers of field-produced watercress

Figure 18. Agricultural field technician Eric Magno harvests watercress by grasping stems with one hand and clipping with the other hand.

Figure 19. Agricultural field technicians Les Hasegawa, Roy Ishizu, Lori Hasegawa, Earl Arakawa, and Damien Arruda place freshly harvested watercress into plastic bags.

to extend shelf life (McHugh et al. 1987). Early morning is best for harvesting, and midday harvesting should be avoided if possible.

Hands must be washed well before harvesting, especially after a toilet visit. Hydroponic watercress is a high-quality product which may be eaten raw, and the customer trusts that they are buying a clean and safe product. Best on-farm food safety practices should be followed (Hollyer et al. 2009b).

Yields

Four direct-seeded crops were each followed by one ratoon crop for a total growing time of 317 days over a 1-year time period (Oct. 21, 2008, to Sept. 24, 2009) at the Volcano Experiment Station. A cumulative yield from 8 harvests of 3.1 lbs of watercress was harvested per net pot area (96 sq in), which is equal to 4.7 lbs per sq ft. This can also be expressed as 1.48 lbs of watercress produced per tank occupancy day from 100 sq ft of tank area. Similarly, four direct-seeded crops, each followed by one ratoon crop, were harvested in a total of 256 days over a 1-year time period (Feb. 11, 2009, to Jan. 7, 2010) at the Mealani Experiment Station. Cumulative yields from the 8 harvests of 4.1 lbs were harvested per net pot area, which is equal to 6.2 lbs per sq ft. or 2.42 lbs per tank occupancy day from 100 sq ft of tank area.

Transplanting: 2- and 3-Week-Old Seedlings

A study was conducted at the Volcano Experiment Station over a 12-week-period (July 28 to Oct. 20, 2010) to compare watercress yields from crops that were direct-seeded or transplanted with 2- and 3-week-old seedlings. There were 2 harvests of the direct-seeded crops, 3 harvests of crops transplanted with 2-week-old seedlings, and 4 harvests of the crops transplanted with 3-week-old seedlings during the 12-week-period.

Total watercress yields during the 12-week-period were 2.42, 3.08, and 3.76 lbs/day per 100 sq ft of tank area from the direct-seeded, 2-week-old, and 3-week-old seedlings, respectively, for the floating-cover method. Similarly, total yields for the suspended-pot method during the 12-week period were 2.45, 3.74, and 4.80 lbs/day per 100 sq ft of tank area from the direct-seeded, 2-week-old, and 3-week-old seedlings, respectively. The latter yield was the highest yield recorded in our experiments, but it cannot be extrapolated to an annual yield due to seasonal yield differences.

Although yields were significantly higher from the suspended-pot method in this trial, other experiments conducted at the Mealani Experiment Station have not demonstrated yield differences between the suspended-pot method and the floating-cover method.

Transplanting 2- and 3-week-old seedlings clearly provided a yield advantage over direct seeding when measured as total yield per area per day in the growing tanks. Also, transplanting is preferred over direct seeding, because this enables the grower to select the best plants, which makes it possible to regularly achieve a 100-percent stand in the growing tanks. If 2 or 3 weeks of the normal growing time from seeding to harvest (5 to 7 weeks) are spent in a small seedling production area, then the time period in the growing tanks is significantly reduced, and this allows more crops to be harvested per year from the growing tanks. For example, if the growing time in the tanks can be reduced to 4 weeks, then 13 crops per year are possible from each growing tank.

Ratoon Crops

After harvesting, the grower may choose to add water and nutrients to the tank and proceed to grow a ratoon crop, which is a new crop of watercress that emerges from the root mass after harvesting the original seeded crop. Leaving a 1-in stem stubble after harvesting the initial crop is recommended if a ratoon crop is to be grown (Figure 20).

Ratoon crops generally may be harvested in less time than is required for the initial seeded crop. For example, 4 seeded crops, each followed by 1 ratoon crop, were grown throughout the year at the Mealani and Volcano Experiment Stations. The seeded crops were harvested at an average of 36 and 45 days after planting at each site, respectively, whereas the ratoon crops were harvested 28 and 35 days later at each site, respectively. The ratoon crops at Mealani Experiment Station yielded higher than the seeded crops (2.96 vs. 2.02 lbs/day per 100 sq ft of tank, respectively), but those at the Volcano Experiment Station yielded lower (1.40 vs. 1.56 lbs/day per 100 sq ft of tank, respectively). The yield comparisons between seeded and ratoon crops are somewhat arbitrary, because the yield is based upon a decision of when to harvest.

Additional ratoon crops beyond the first ratoon crop are generally not recommended because the risk of infestations with root aphids increases with time. Also nitrogen and manganese may become severely depleted from the remaining nutrient solution, which then varies greatly from the initial nutrient solution, because nutrient solutions are usually topped off rather than completely replaced when growing ratoon crops.

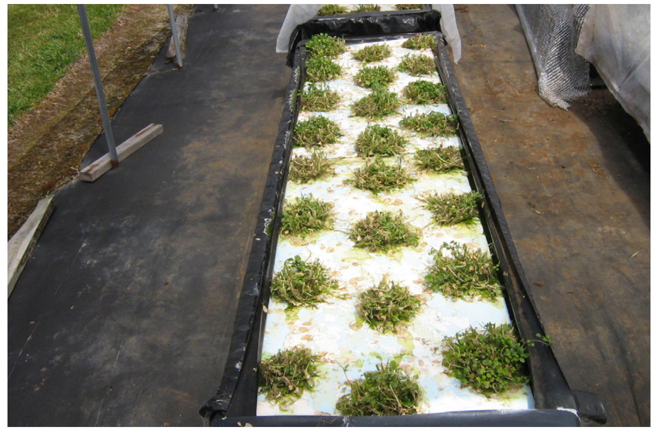

Figure 20. Leaving a 1-in stem stubble after harvesting the initial seeded crop encourages ratoon crop growth.

After Harvesting

After the original planting, if a ratoon crop will not be grown, the tank must be cleaned and prepared for the next crop. The net pots may be stored in covered plastic trash container for 1 to 2 weeks to allow decomposition of roots remaining in the net pots. This facilitates removal of the plant debris and growing medium from the net pots. After these are shaken free, net pots may be soaked in a 10-percent bleach solution, rinsed, and dried before reuse. The tank cover should be cleaned.

A complete nutrient solution change is preferred before replanting the tanks rather than just topping off the remaining solution with new solution. Ideally, the remaining nutrient solution should be siphoned from the tank and applied to another crop on the farm that is growing in soil, because there are nutrients remaining in the solution. Normally, the tank does not need to be rinsed with water. New nutrient solution is added to the tank, and the growing cycle is repeated.

Insects and Diseases

It is possible that a complete crop of watercress may be grown without the use of pesticides if the rainshelter is screened. However, it is not unusual to see various insects such as broad mites and aphids under a rainshelter. Also, some of the Mealani trials experienced root aphids in ratoon crops. The root aphid problem may usually be solved by only taking a single harvest from the seeded crop and then cleaning up the tank and starting over with a new seeded crop.

Little pest information is available specifically for hydroponic and greenhouse production of watercress in Hawai‘i. However, the most common diseases of watercress in Hawai‘i in field production are leaf spot (*Cercospera nasturti*) and watercress aster yellows (WAY – Phytoplasma). Likewise, the most common insect problems in field production are diamondback moth (*Plutella xylostella*); broad mite (*Polyphagotarsonemus latus*); watercress leafhopper (*Macrosteles* sp. nr. Severini); and various aphids (Figure 21), including green peach aphids (*Myzus persicae*), cotton aphids (*Aphis gossypii*), and root aphids (*Pemphigus populitransversus* Riley) (Brian Bushe 2014, personal communication). Other insect pests reported in Hawai‘i are cyclamen mites (*Steneotarsonemus pallidus*), turnip aphids (*Hyadaphis erysimi*), grass sharpshooters (*Draeculacephala minerva*), and southern green stinkbugs (*Nezara viridula*) (McHugh et al. 1987).

Growers often harvest and replant a tank within 24 hours so there is little downtime for the tanks. However, a short fallow period of about a week between harvesting and replanting can be an effective method to decrease insect and disease pressure, especially if the whole greenhouse is harvested and fallowed. For this reason, the optimum greenhouse size would be an area needed to produce one week's harvest. Smaller greenhouses or rainshelters are also preferred over larger structures because larger structures become hotter than smaller structures.

Figure 21. Aphid infestation on watercress.

Mosquitoes

Mosquitoes may breed in non-circulating nutrient solution and become both a health concern and a nuisance to workers. Possible control methods are discussed.

Sides of the greenhouse should be screened to prevent mosquitoes from entering. For the suspended-pot method, window screen may be draped in the tank such that the initial nutrient solution level is higher than the screen. Then, as the nutrient solution level drops below the screen as the crop grows, the newly hatched mosquitoes are trapped under the screen where they eventually die. Roots from the growing crop extend through the screen into the nutrient solution below.

Fish that eat mosquito larvae may be placed in hydroponic tanks. Tanks should be deeper than normal to insure there are at least several inches of nutrient solution in the tank at the end of the crop or else the fish will die. Testing the fish for salt tolerance is recommended because the salinity of the nutrient solution will kill many species of fish.

Pyronyl Crop Spray has been registered for use with hydroponically grown vegetables to control diptera larvae in the nutrient solution. (Growers should check the current registration status before using this insecticide, because registration specifications are continually changing.) Asian tiger mosquito larvae were killed within 36 hours by 1 ppm of the commercial formulation of Pyronyl (Furutani et al. 2005). To apply a 1 ppm Pyronyl solution for small tanks of nutrient solution, first prepare a 1-percent stock solution of Pyronyl (where each ml contains 0.01 ml Pyronyl) by adding 10 ml of Pyronyl to 990 ml of water. Then, add 38 ml of this stock solution to each 100 gal of nutrient solution in the growing tanks (0.38 g Pyronyl per 378,500 ml nutrient solution = 1 ppm). Pyronyl may also be sprayed under the elevated tanks to control adult mosquitoes, which frequently hide there.

Mosquito larvae in hydroponic tanks have also been controlled by *Bacillus thuringiensis israelensis* (*Bti*) toxins and methoprene (Furutani and Arita-Tsutsumi 2001a), but these materials caused reduced foliage weight and root growth when tested with lettuce. However, when a lower rate of *Bti* was applied as a split application 2 weeks apart, mosquito larvae and pupae were controlled and lettuce growth was not affected (Furutani and Arita-Tsutsumi 2001b). *Bti*'s effects on watercress were not tested, because there is no *Bti* material that is currently labeled for mosquito control in hydroponic watercress.

The rate of propagation of mosquitoes is greatly reduced or even eliminated at cooler, upper-elevation temperatures. Mosquitoes were not a problem at the 4,000 ft elevation Volcano Experiment Station. Since watercress grows well at cool, upper-elevation temperatures, the mosquito issue might be the determining factor for choosing a site to grow watercress by these non-circulating hydroponic methods.

Other Considerations

The quality of watercress produced by these hydroponic methods has been very good. However, there were many small white roots on the stems, especially on the lower portion of the stem (Figure 22), which detract from consumer appeal. More research is needed to correct this; hopefully, a cultivar will be found which solves this problem.

The rainshelter cover and screened sides should eliminate contamination of the crop by bird droppings. However, the presence of slugs and snails in the production area and of rats in the vicinity is of major concern because they may spread rat lungworm infection, which causes human eosinophilic meningitis. Recent incidents in Hawai‘i of people contracting this serious disease from eating contaminated fresh produce (Hollyer et al. 2010) should encourage growers to make every effort to ensure that slugs and snails cannot contact the watercress crop and that rodents are eliminated from the area (Hollyer et al. 2009a). Potential food safety issues can be greatly reduced by using domestic water for all production and harvest practices, raised tanks above a weed-control fabric ground cover, slug control, best on-farm food safety practices (Hollyer et al. 2009b), and careful inspection of the harvested watercress.

Figure 22. The ‘Stokes’ cultivar used in these trials had many small white roots on the stems, especially on the lower portion of the stem.

Growing a crop in a system utilizing plastic components raises questions related to migration of chemical contaminants from plastic tank liners, net pots, and tank covers into plants and whether this poses a potential food safety threat. Guidance on this issue recognizes that currently acceptable plastic materials are in widespread use for foods, beverages, and medicines, all of which are stored in plastic containers, and water, which is delivered by plastic irrigation and residential water pipes. The proposed hydroponic systems for watercress production employ polyethylene tank liners and polypropylene net pots. Material Safety Data Sheets (2012, 2014a) report that these plastics have very low toxicity to humans and animals and are not considered dangerous to humans. However, Yang et al. (2011) pointed out that polymerization is rarely complete in the manufacturing process and additives are not chemically part of the polymeric structures. Many monomers and additives used to make plastics exhibit some estrogenic activity and can be released from the plastic. Fortunately, Yang et al. (2011) have identified monomers and additives that do not have detectable estrogenic activity, and these can be utilized in manufacturing processes at minimal additional costs.

Recommended tank covers for these proposed growing systems include expanded and extruded polystyrene. Individual monomers of styrene can be released from polystyrene. Health hazard information from styrene is reported in a Material Safety Data Sheet (2014b) and an EPA report (2000). Currently, polystyrene cups are commonly used for drinking hot and cold beverages. Ahmad and Bajahlan (2007) could not detect styrene leaching into 122°F water from Styrofoam cups, but styrene was detected at higher temperatures. In addition, they pointed out that styrene and other aromatic compounds easily escaped by volatilization from the water surface due to high vapor pressure and low solubility in the water. Considering that the proposed growing systems utilize water temperatures that are typically below 77°F and that even with the floating method there is considerable exposed surface of the nutrient solution from which the compounds could escape, there appears to be limited risk of styrene migration into the watercress.

Although lettuce (Kratky 2009, 2010a) and other short-term leafy vegetables grow well with the suspended-net-pot, non-circulating hydroponic method, the diminished moist air zone in the floating-cover method would be expected to negatively impact plant growth of most short-term vegetables. Watercress ranks amongst a minority of crops that can tolerate the low oxygen conditions of the floating-cover method, and additional research is needed to determine if this method would also be suitable for other crops. Neither the suspended-pot method nor the floating-cover method is intended for production of long-term vegetables such as tomatoes and cucumbers, which require large quantities of water (Kratky 2003, 2004; Kratky et al. 2000, 2005).

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U.S. Patents 5,385,589 and 5,533,299 on the suspended-pot, non-circulating hydroponic method have expired and may be used freely by anyone for all legal purposes.

Keywords: *Nasturtium officinale* R. Br, electrical conductivity, expanded and extruded polystyrene, net pot, non-circulating hydroponics, nutrient solution, pH, rain-shelter, roots, tanks, water