POTENTIAL FOR GREENHOUSE AEROPONIC CULTIVATION OF MEDICINAL ROOT CROPS

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ABSTRACT: The therapeutic use of medicinal plants such as Echinacea, ginseng and St. John's wort has gained widespread acceptance in North America in the last two decades. Aeroponic cultivation of medicinal plants have shown great potential for producing root yields that are cleaner, more uniform and faster maturing than can be obtained using conventional soil-based methods. Two pilot-scale commercial A-frame aeroponic systems were constructed at the Controlled Environment Agriculture Center (CEAC) using PVC plastic pipe and PVC-coated hex wire to support the plants. The entire surface of the A-frame structure was covered with a white-on-black co-extruded polyethylene film to contain the nutrient solution while preventing light from reaching the root zone. The bottom of the frame was lined with heavy plastic to collect the nutrient solution and return it to an external reservoir for reuse.

Observation studies incorporating 96 Echinacea (*Echinacea purpurea*) and 30 burdock (*Arctium lappa*) plants were conducted beginning in December of 2000. The burdock demonstrated tremendous foliar and root production during their six months of growth. The harvested roots had desirable coloration with thick taproots and mature root bark. The Echinacea initially grew slowly, but exhibited accelerated growth by early March and were in full bloom by May. The fibrous roots of the Echinacea plants were harvested nine months after seeding, showing excellent coloration and growth. Considerable variation in size and yield was observed among plants, particularly in the Echinacea, which was likely due to significant genetic variation of the seed.

Keywords: aeroponics, medicinal crops, roots, *Echinacea purpurea*, *Arctium lappa*

INTRODUCTION

For the past two decades, a growing number of Americans have been turning to alternative forms of medicine in response to disillusionment with the modern medical system and the rising cost of prescription drugs. Many over-the-counter botanical products such as Echinacea, ginseng, gingko, and burdock have gained popularity for the treatment of ailments and diseases such as the common cold & flu, hypertension, depression, insomnia, and even cancer. In 1994, Americans spent approximately $1.6 billion on botanical products (Brevoort, 1998). By 1997, the botanical market had risen to an estimated $5.1 billion (Eisenberg, et al., 1998). This explosive growth in demand has fueled rapid expansion of medicinal plant cultivation both here and abroad.

Many of the most popular and highly valued botanical products, such as Echinacea and ginseng, are root crops. Cultivation often requires 3-6 years before roots reach maturity. Harvest requires labor and energy intensive extraction of the roots from the soil. Even with modern farming techniques such as trenching or building raised beds of loose soil, most of the fragile secondary roots are lost in the harvest process, representing a significant loss of potential yield. Additionally, commercial products derived from roots cultivated in soil risk adulteration with soil and soil-borne organisms, as well as roots of weed species. Consumer demand for greater quality control and standardization of botanical products has proven to be a difficult and expensive challenge. Many growers are looking for alternative methods of cultivation that reduce contamination risks and improve the quality and consistency of the raw material.

Aeroponics is a form of hydroponic plant cultivation in which plant roots are suspended in a closed chamber and misted with a complete nutrient solution. Aeroponics requires no solid or aggregate growing medium and allows for easy access to roots. The chamber and misting system provide complete control of the root zone environment, including temperature, nutrient level, pH, humidity, misting frequency and duration, and oxygen availability. Plants often exhibit accelerated growth and maturation in aeroponic systems (Mirza, et al., 1998). These qualities have made aeroponics a popular research tool for scientists studying root growth and plant nutrient uptake (Barak, et al., 1998). These qualities may also permit aeroponics to become a viable method for commercial cultivation of high value medicinal root crops, circumventing many of the difficulties associated with soil cultivation. Table 1 summarizes the many advantages associated with aeroponic culture compared to conventional soil cultivation.

The advantages offered by aeroponic technology for root growth suggest that this culturing technique could be a powerful tool for the botanical products industry. The objective of the present observation study was to assess the feasibility of medicinal root crop cultivation in an aeroponic system. Three main questions guided the study, including:

1. Do aeroponically cultivated medicinal root crops demonstrate normal growth and maturation?
2. Is yield comparable in quantity and quality to conventional field-grown crops?
3. What areas need additional research before recommending commercial scale aeroponic cultivation of medicinal root crops?

Table 1: Advantages of aeroponic vs. soil-based cultivation of botanical root crops.

1) Clean root material free of soil, soil-borne organisms, or adulteration from foreign plant species contaminants.
2) Accelerated cultivation cycles due to increased rate of growth and maturation.
3) Potential for improved root yield and phytochemical consistency due to uniform nutrient and water availability, and reduced risk of diseases.
4) Higher planting density potential through elimination of water and nutrient competition and the use of an A-frame structure design.
5) Minimized use of nutrients and water due to recycling capability.
6) Independence from local land and climate conditions when grown in the controlled environment of a greenhouse.
7) Precise control of root zone through manipulation of nutrient solution composition, temperature, and application.
8) Possible multiple root harvests of a single perennial crop.

MATERIALS AND METHODS

The observational study was performed in a 48’ x 20’ double-walled acrylic research greenhouse located at the University of Arizona Controlled Environment Agriculture Center in Tucson, Arizona. Two aeroponic units were built using 3.2 cm (1.25 in) diameter PVC plastic pipe constructed in an “A-frame” configuration (see Fig. 1 & 3). The base, 2.4 m (8 ft) long by 1.7 m (5.5 ft) wide, supported an A-frame that reached 1.5 m at the peak. Each of the two inclined growing surfaces were approximately 3m^2 (32 ft^2) in area but required only 2m^2 (22ft^2) of greenhouse floor space (4m^2 or 44ft^2 total). The units were covered with 2.5 cm PVC coated hex wire (“chicken wire”) to support the plants. The base of the unit was lined with heavy black plastic to collect and channel nutrient solution to an outside storage reservoir for re-use during the next spray cycle. The novel plastic construction scheme eliminated the need for metal supports that can react with and contaminate the nutrient solution (Hayden, 2001). The inclined growing surfaces were hinged at the peak to allow easy access to the roots. The entire unit was covered with 2 mil white-on-black co-extruded polyethylene mulch film to protect the root zone from light infiltration and to prevent loss of nutrient solution.

An external one-half horsepower centrifugal pump drew nutrient solution from the storage reservoir, pumping it through nine spray nozzles arranged uniformly below the growing surface. A mechanical timer was used to control spraying frequency and duration. Cycles averaged 30 seconds ON and 60 seconds OFF, but were adjusted slightly over the course of the study to offset heat and growth conditions. Both units were irrigated with the same complete hydroponic nutrient solution (Resh, 1997) with pH maintained between 5.5-6.5 and electrical conductivity (EC) between 2.0-2.6 mS cm^{-1}. Recycled nutrient solution lost to transpiration or evaporation was replenished daily, and the nutrient solution was replaced once a week. Greenhouse temperatures were maintained between 75-78°F (day) and 68-74°F (night) during the entire trial period.

Figure 1: Echinacea purpurea in full bloom in aeroponic A-frame unit.

Figure 2: Echinacea fibrous root systems just before harvest.

Figure 3: Mature burdock (A. lappa) in aeroponic A-frame unit.

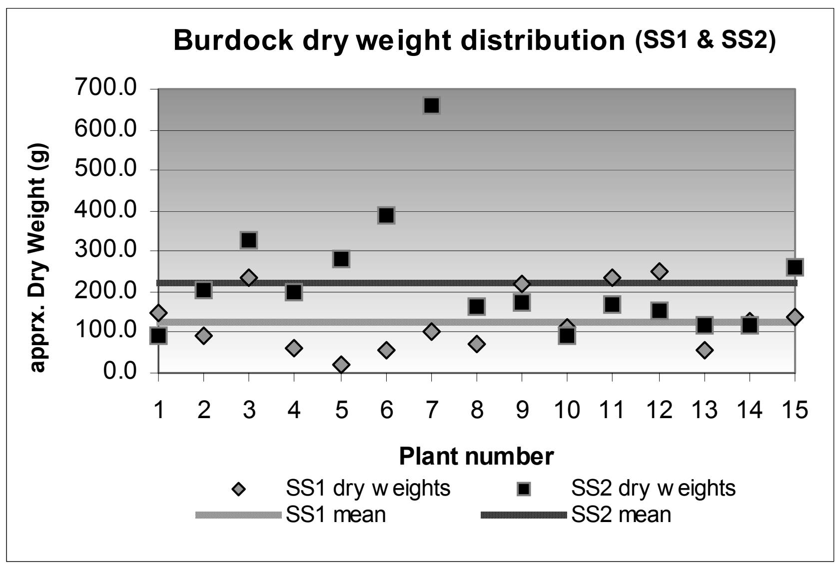
Figure 4: Authors holding well developed burdock tap root systems approximately six months old.

Plant material: Two species from the Asteraceae family, *Echinacea purpurea* (purple coneflower) and *Arctium lappa* (burdock), were chosen for the study for their commercial significance, ease of cultivation, growth characteristics, and relatively short maturation periods (usually 1-3 years under conventional field conditions). The *E. purpurea* and half the *A. lappa* seeds were purchased from a commercial seed source (SS1), additional *A. lappa* seeds were purchased from a second seed source (SS2). Seeds were germinated in Rockwool™ cubes and transplanted approximately five weeks after seeding. Burdock plants were arranged 40 cm (16”) on center (15 plants per A-frame side, or 30 plants per aeroponic unit), equating to 7.5 plants/m^2 of floor space, or approximately 30% of the recommended field production spacing of 20-25 cm (8-10”) on center or 20-30 plants/m^2 (New Zealand Institute for Crop & Food Research Ltd., 1996). The Echinacea planting density of 48 plants per side equated to 24 plants/m^2 of floor space, or 120% of the recommended field density of 20 plants/m^2 (Parmenter & Littlejohn, 1997).

RESULTS AND DISCUSSION

Arctium lappa: The fifteen SS1 plants were transplanted into the aeroponic unit in late December 2000 and showed aggressive growth until harvest six months later. Fifteen SS2 plants were transplanted two weeks later and lagged in growth for the entire duration of the study. Growth of the SS2 plants continued to appear substantially smaller and less dense than the SS1 group, suggesting that it may have been a different variety or even a different species, despite seed labeling. Burdock species are known to hybridize across species, creating a wide range of variation (Gross, et al., 1980). Both treatments, however, produced large, long, thick tap root systems with excellent coloring and mature root bark (see Fig. 4). Root lengths ranged from approximately 80-140cm (30”-55”) in length. Mean dry weights of SS1 roots were 227g (□147g) per plant (Fig. 5). SS2 dry weights averaged 128g (□74g) per plant (Fig. 5). Fifteen individual plants were harvested from each seed source (n=15).

Figures 5: *Burdock biomass yield data (approximated dry mass)*

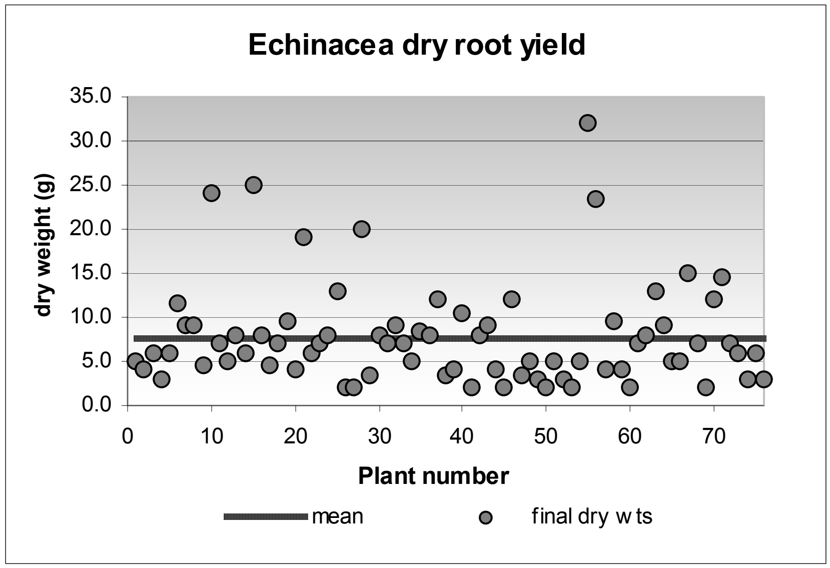


Commercial burdock fields in the United States produce roughly 10 tons of dry root biomass per hectare, or approximately 910g/m^2, assuming a planting density of 25 plants/m^2 (New Zealand Institute for Crop & Food Research Ltd., 1996). The SS1 plants yielded 1703g/m^2 root dry weight at a planting density of 7.5 plants/m^2 of greenhouse floor space (only 30% that of recommended planting density for field crops). These results suggest that aeroponic production could dramatically outperform field production, since it appeared that the planting density in the aeroponic units could be substantially increased. These results do not take into consideration the possibility of multiple crops during the year. The easily accessible aeroponic roots might be trimmed and allowed to re-grow in this biennial plant, yielding additional biomass with subsequent harvests.

Echinacea purpurea: Five week old Echinacea seedlings were transplanted into an aeroponic unit in early January, 2001. Very little growth was observed until late April. By the second week of May, however, plants expressed accelerated growth and were in full bloom by the end of the month. The environmental conditions and nutrient solution did not vary substantially throughout the trial, suggesting that photoperiod may have played a role in the delayed growth surge.

In the last three months of the study, the Echinacea crop experienced significant infestation of greenhouse white fly (*Trialeurodes vaporariorum*) and a fungal/algal infection of the crown of several plants. This led to the loss of 20 plants and possible stunting of growth during the last two months before harvest. Despite this setback, the majority of remaining plants had healthy, white fibrous root systems (Fig. 2). Seventy-six plants were harvested on September 8, 2001 (n=76). The average dry root weight was 7.8g/plant (□5.8g) or 187g/m^2 at a planting density of 24 plants/m^2 floor space in less than 10 months of growth (Fig. 6). Commercial *Echinacea purpurea* fields in New Zealand have produced maximum yields of 260 g/m^2 or 13g/plant dry weight assuming a two year growing season and a planting density of 20 plants/m^2, (Parmenter & Littlejohn, 1997). Visual estimates suggest that planting density in the aeroponic units could be increased without substantial reduction of root yields, generating a projected yield of greater than 280g/m^2 in 10 months, assuming a planting density of 36 plants/m^2. If pest problems were better controlled, and higher yielding individuals selected and cloned, yields may be improved even more. This does not take into account the possibility for multiple root harvests, possibly three to four, within the traditional two year field season.

Figures 6: *Echinacea biomass yield data (dry mass)*



CONCLUSION

The results of both the burdock and Echinacea trials suggest that aeroponic cultivation is capable of equivalent or superior yields compared to conventional field production (Table 2). Higher planting densities, improved plant varieties, and multiple harvests may increase yields significantly over those of field production. Dried root samples of each crop have been sent to analytical labs for marker compound content analysis, allowing phytochemical quality

Table 2: *Root yield comparisons (aeroponic vs. published field data)*

Maximum reported average yield – field grown plants	910 g/m^2 at 25 plants/m^2 over 12 months	260 g/m^2 at 20 plants/m^2 over 24 months
Maximum average yield – aeroponic systems	1703 g/m^2 at 7.5 plants/m^2 over 6 months	187 g/m^2 at 24 plants/m^2 over 10 months
Aeroponic vs. conventional field grown yields (corrected for density and time)	> 1000 %	140 %

comparisons to be made. Rate of growth and development in aeroponics systems appear to be far superior in the burdock crop, and significantly accelerated in the Echinacea crop. Visual quality of all root product was excellent, with minimal risk of contamination and no loss of root during harvesting. The main concerns for full commercial scale aeroponic production of medicinal roots include: (1) better crop management practices, including pruning and pest management; (2) reducing costs and improving reliability of the aeroponic units; (3) improving access to certified seed that will reduce variation between individual plants; (4) establishing crop physiological requirements, such as photoperiod; and (5) determining optimal root zone environmental and nutrient conditions for maximizing secondary metabolite concentrations.

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