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Nutrient Management for Growing Dandelion (Taraxacum officinale L.) in Nutrient Film and Deep Flow Hydroponics

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Nutrient Management for Growing Dandelion (*Taraxacum officinale* L.) in Nutrient Film and Deep Flow Hydroponics

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Horticulture

by

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Bachelor of Science in Agriculture, 2012

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This thesis is approved for recommendation to the Graduate Council

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Abstract

This research study was conducted to determine an optimal nutrient strategy for dandelion production in nutrient film technique (NFT) and deep flow technique (DFT) systems of hydroponics. It was achieved by growing dandelion at varying levels of nutrient solution concentration and pH in both NFT and DFT systems. Additionally, an optimal nutrient solution concentration and timing of application for dandelion seedling production was also determined.

Dedication

I dedicate this thesis to my family for their encouragement, inspiration and support throughout my life. I am thankful to my father Mr. Gurmeet S. Gill and mother Mrs. Ramanpreet K. Gill for believing in me and fulfilling my dream of studying in a prestigious institute such as University of Arkansas. I am fortunate to have Kanwal, Gagan, Karam and Rajan as my siblings who always provided me the emotional support. Lastly, I also owe a big thanks to my aunt Pardeep K. Gill, uncle Surjeet S. Gill and not to forget, my grandmother Satpal K. Gill for being with me and my family through thick and thin. I would not have been doing this without the support of all of you.

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Introduction

Controlled environment agriculture (CEA) includes modification of environmental parameters such as temperature, light, plant nutrition, humidity and carbon-dioxide to achieve optimal plant growth (Jensen, 2001). This is achieved by growing plants in enclosed structures such as greenhouses equipped with environmental control systems. The use of CEA has made possible the production of crops year-round, increased yield due to more control over diseases and pests and reduced use of agricultural chemicals (Goto et al, 1996). The use of CEA techniques in combination with hydroponics has further increased the efficiency of nutrient and water uptake and utilization for crop production (Jensen, 2001).

Hydroponics is a technique used to grow plants in a nutrient solution with or without using a substrate and can be classified as liquid hydroponics or substrate hydroponics (Jones, 2004). In liquid hydroponics, plant roots are directly suspended in a static or continuously flowing nutrient solution. In substrate hydroponics, plants are grown in an organic or inorganic substrate such as sphagnum peat moss, rockwool, perlite or wood chips (Olympios, 1992). Hydroponic systems can be further classified as: 1) recirculating systems, also known as closed systems, in which the nutrient solution is replenished, recirculated and reused in subsequent irrigation cycles and, 2) non-recirculating systems, also known as open or go-to-waste systems in which nutrient solution is used only once and allowed to drain or is discarded. The most widely used hydroponic systems (Jones, 2004) to grow leafy greens are nutrient film technique (NFT) and deep flow technique (DFT).

The NFT system consists of channels or gutters laid on a 2-3% slope in which nutrient solution is pumped from a supply tank through an inlet. The nutrient solution moves down the slope towards the outlet where it is collected in a manifold and is returned back into the supply tank (Winsor et al., 1979). The nutrient solution may pass through filters to remove debris before returning to the tank and treated with UV light or ozone to kill any pathogens (Graves, 1983). The channels have holes on the top in which young plants are placed so that their roots are continuously immersed in a few millimeters thin film of the nutrient solution, hence, called nutrient film technique (Burrage, 1997; Winsor et al., 1979). The nutrient solution concentration, expressed as electrical conductivity (EC) and pH in this system is monitored and adjusted manually or with an automated system. The EC of the nutrient solution can be increased or decreased by adding a desired volume of a standard nutrient formulation or water, respectively. The pH can be adjusted using an acid such as nitric acid, phosphoric acid or sulfuric acid or a base such as potassium hydroxide, sodium hydroxide or potassium bicarbonate.

Deep flow technique (DFT) was developed independently by Jensen in Arizona and Massantini in Italy in 1976 (Jensen, 2002). It consists of rectangular tanks referred to as runs, pools or raceways filled with nutrient solution to a few inches depth and covered with polystyrene or plastic rafts that float on the surface of the nutrient solution. The rafts have holes on the top in which plants are inserted so that the plant roots grow into a static or circulating nutrient solution. Since the nutrient solution is covered with rafts, oxygen exchange between the atmosphere and the nutrient solution can be impeded and thus, oxygen may become a limiting factor in a static DFT system (Goto et al., 1996). To overcome this, oxygenation of the nutrient solution is accomplished by using a pump and lines in the solution to bubble air in the solution. In circulating DFT, the nutrient solution may pass through filters before returning to the tanks, however, for static DFT system, the nutrient solution is cleaned before and after each crop cycle.

The nutrient solution is monitored and adjusted for EC and pH in a similar manner as described for NFT system.

Growing crops in hydroponic systems has multiple advantages over outdoor soil-based production methods such as the possibility of growing plants in areas with unsuitable soil. Soil management issues such as soil fertility, compaction and structure are eliminated in hydroponics. It is a soilless technique of crop production, therefore, it can be used to limit soil-borne diseases. There is also higher control of the root rhizosphere in hydroponics which increases water and fertilizer efficiency (Jones, 2004). When hydroponics is used in combination with CEA, higher yields can be achieved in a shorter period of time. Furthermore, increased biomass production with minimal contamination makes hydroponics suitable for the production of medicinal plants (Papadopoulos et al., 2000). Due to this, significant hydroponics research has been specifically focused on production of medicinal plants (Hayden, 2006). For instance, transgenic lettuce for vaccine production has been grown effectively in hydroponics (Ichikawa et al., 2010). Medicinal plants such as *Achillea millefolium, Artemisia vulgaris, Inula helenium, Stellaria media* and *Valeriana officinalis* are also reported as potential herbs for hydroponic production (Papadopoulos et al., 2000). Dandelion (*Taraxacum officinale* L.*)*, a member of the family Asteraceae is commonly considered as an undesired plant, however, its leaves have been used to add flavor to salads, sandwiches and teas. The plant has a mild laxative effect which complements its use as a food source and is recommended to be consumed in fresh salads (Escudero et al., 2008). Dandelion roots can be used in some coffee substitutes, the flowers can be used to make wines and the whole plant can be used for making beer (Buhner, 1998). Dandelion leaves are high in fiber, calcium, potassium, phosphorus, magnesium, iron, Vitamin A, Vitamin C and the B vitamins riboflavin and thiamine (Jackson, 1982; Schmidt, 1979).

Apart from culinary and nutritional properties, dandelion has also been used for medicinal properties. In traditional Chinese medicine, dandelion has been used to treat stomach problems, appendicitis and breast problems, such as inflammation or lack of milk flow (Sweeney et al, 2005). Dandelion has been claimed to cure ailments associated with the liver and gall bladder (Schütz et al., 2006). Its leaves have been reported to possess diuretic properties that help the body to get rid of excessive fluid, a condition known as fluid retention (Clare et al, 2009; Hook et al., 1993). The anti-inflammatory activity of dandelion has been reported by researchers in recent years (Ahmad et al., 2000; Kisiel and Barszcz, 2000; Jeon et al., 2008). The use of aqueous dandelion extract for the treatment of breast and prostate cancer has also been reported (Sigstedt et al., 2008). Dandelion roots, leaves and stems possess anti-inflammatory and anti-microbial properties. It is also reported to have immuno-stimulatory effects which have been attributed to the phenolic compounds such as chicoric acid and caffeic acid present in all parts of the plant. Flavonoids present in dandelion flower exhibit anti-oxidant properties (González-Castejón, 2012). The known medicinal effects of dandelion have been attributed to sesquiterpene lactone compounds (Ahmad et al., 2000; Jeon et al., 2008; Kisiel and Barszcz, 2000; Schutz et al., 2006). Medicinal effects of dandelion are well known since numerous herbal products are prepared from dandelion leaves and roots. Dandelion due to its culinary, nutritional and medicinal properties may have potential to be grown as a hydroponic crop.

Medicinal plants are typically grown hydroponically due to higher biomass production in hydroponics. Also, concentration of bioactive compounds has been reported to be higher in some medicinal plants when grown hydroponically. For instance, *Echinacea angustifolia* plants grown in deep flow hydroponics were shown to possess higher concentration of chicoric acid than the field grown plants (Zheng et al., 2006). Despite the advantages of hydroponics technique for production of medicinal plants, lack of information on dandelion production in hydroponics poses an issue for further research in this area. Therefore, specific management practices for dandelion production in hydroponics should be investigated. It is known that nutrient solution management is key for hydroponic production of crops. The growth of plants in hydroponic systems depend largely upon the nutrient solution properties, primary factors being fertilizer concentration as maintained by electrical conductivity (EC) and pH (DeRijck and Schrevens, 1995; Steiner, 1961). These properties affect the amount of nutrients available to the plants for growth and development (Sonneveld, 1989; Savvas and Adamidis, 1999) and should be maintained in an ideal range for optimal growth of dandelion in hydroponics. The overall objective of this research was to investigate the effect of nutrient solution properties specifically on growth and biomass accumulation of dandelion grown hydroponically.

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The effect of fertilizer solution electrical conductivity and pH on growth of dandelion in nutrient film and deep flow systems.

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Subject Category: Crop production: Herbs, Spices, Medicinal and Aromatic Plants

The effect of fertilizer solution electrical conductivity and pH on growth of dandelion in nutrient film and deep flow systems.

Additional index words. Taraxacum officinale L., medicinal herb, biomass accumulation, hydroponics.

Abstract. The leaf length and shoot and root dry weight of dandelion grown in a nutrient film technique (NFT) system increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to an EC of 1.2 dS/m and decreased as the EC was increased up to 1.4 dS/m or higher. Root length and number of leaves increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to an EC of 1.4 dS/m and decreased as EC was increased up to 1.6 dS/m or higher. The leaf length, shoot and root dry weight of dandelion grown in an NFT system were highest at an EC of 1.2 dS/m while root length and number of leaves were highest at an EC of 1.4 dS/m. Root to shoot ratio of dandelion grown in the NFT system decreased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to 1.8 dS/m and was highest at an EC of 1.0 dS/m. The leaf length of dandelion grown in a deep flow technique (DFT) system increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m to 1.2 dS/m, decreased as the EC was increased up to 1.6 dS/m and again increased at an EC of 1.8 dS/m. Shoot and root dry weight, root length and number of leaves increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to 1.4 dS/m, decreased at an EC of 1.6 dS/m and again increased at an EC of 1.8 dS/m. The leaf length of dandelion grown in a DFT was highest at an EC of 1.2 dS/m, shoot dry weight and number of leaves were highest at an EC of 1.4 dS/m while root dry weight and root length were highest at an EC of 1.8 dS/m. For the same fertilizer solution EC, the biomass accumulation of dandelion grown in the DFT was higher than that in NFT. Using varying pH levels in the NFT fertilizer solutions, the leaf length of dandelion decreased as the pH was increased from 5.2 to 5.5 and increased with increase in the pH up to 6.4. The shoot and root dry weight and root length of dandelion decreased as the pH was increased from 5.2 to 5.8 and increased with further increase in the pH up to 6.4. The leaf length, shoot dry weight and number of leaves of dandelion grown in an NFT were highest at a pH of 6.4 while root length and root dry weight were highest at a pH of 5.2. When grown in a DFT system, all the growth parameters of dandelion decreased as the fertilizer solution pH was increased from 5.2 to 5.5 and increased with further increase in the pH up to 6.4. Leaf length, root length, shoot and root dry weight of dandelion grown in a DFT system were highest when grown in a fertilizer solution at a pH of 6.4 while number of leaves was highest at pH 5.8. For same pH levels, the biomass accumulation of dandelion grown in the NFT was higher than that in the DFT.

Introduction

Dandelion (*Taraxacum officinale* L.) belongs to the family Asteraceae and is commonly considered an undesirable plant. However, it has been recognized by some groups for its culinary, nutritional and medicinal properties. Dandelion is used to add flavor to salads, sandwiches and teas. The plant has a mild laxative effect which complements its use as a food source being recommended to be consumed fresh (Escudero et al., 2003). Dandelion roots can be used in some coffee substitutes as it contains caffeic acid, the flowers can be used to make wine and the whole plant can be used for making beer (Buhner, 1998). The leaves are a rich source of fiber, calcium, potassium, phosphorus, magnesium, iron, Vitamin A, Vitamin C and the B vitamins riboflavin and thiamine (Jackson, 1982; Schmidt, 1979). The anti-inflammatory, anti-cancerous and anti-oxidative properties of dandelion have been reported by multiple researchers (Ahmad et al., 2000; Jeon et al., 2008; Kisiel and Barszcz, 2000; Schütz et al., 2006). Most notably, use of aqueous dandelion extract for the treatment of breast and prostate cancer has been reported (Sigstedt et al., 2008). Dandelion contains sesquiterpene lactone group of compounds which have been associated with the reported medicinal properties (Schütz et al., 2006). Despite the well-documented medicinal properties of dandelion, not much is known about dandelion production for medicinal purposes. Some researchers, however, have reported hydroponics as a suitable technique for medicinal herb production due to higher biomass production, minimal contamination and higher concentration of bioactive compounds (Hayden, 2006; Papadopoulos, 2000).

Hydroponics is a technique used to grow plants in a nutrient solution with or without substrate and can be classified as liquid hydroponics or substrate hydroponics (Jones, 1983). In liquid hydroponics, plant roots are directly suspended in a static or continuously flowing nutrient solution. In substrate hydroponics, plants are grown in an organic or inorganic substrate such as sphagnum peat moss, rockwool, perlite or wood chips (Olympios, 1992). Hydroponic systems can be further classified as: 1) recirculating systems, also known as closed systems, in which the nutrient solution is replenished, recirculated and reused in subsequent irrigation cycles and, 2) non-recirculating systems, also known as open or go-to-waste systems, in which nutrient solution is used only once and allowed to drain or is discarded.

Hydroponics has multiple advantages over outdoor soil-based production methods such as the possibility of growing plants in areas with unsuitable soil, higher water and fertilizer efficiency, elimination of soil-borne pathogens and increased yields (Goto et al., 1996). Also, due to improved product quality, higher biomass production and minimal contamination with weeds in hydroponics, it is a suitable technique for the production of medicinal plants (Papadopoulos et al., 2000). In fact, recent hydroponics research has been focused specifically on production of medicinal herbs. There are reports of hydroponic production of transgenic lettuce for vaccine purposes (Ichikawa et al., 2010). Medicinal herbs such as *Achillea millefolium, Artemisia vulgaris, Inula helenium, Stellaria media* and *Valeriana officinalis* have been reported to grow effectively in hydroponics (Papadopoulos et al., 2000).

The most widely used hydroponic systems (Jones, 2004) to grow herbs are the nutrient film technique (NFT) and deep flow technique (DFT). The NFT system consists of channels or gutters laid on 2-3% slope in which nutrient solution is pumped from a supply tank through an inlet. The nutrient solution moves down the slope towards the outlet where it is collected in a manifold and is returned back into the supply tank (Winsor et al., 1979). The nutrient solution may pass through filters to remove debris before returning to the tank and treated with UV light or ozone to kill any pathogens (Graves, 1983). The channels have holes on the top in which young plants are placed so that their roots are continuously immersed in a few millimeters thin film of the nutrient solution, hence, called nutrient film technique (Burrage, 1997; Winsor et al., 1979). The nutrient solution concentration, expressed as electrical conductivity (EC) and pH in this system is monitored and adjusted manually or with an automated system. The EC of the nutrient solution is increased or decreased by adding a desired volume of a standard nutrient formulation or water, respectively. The pH can be adjusted using an acid such as nitric acid, phosphoric acid or sulfuric acid or a base such as potassium hydroxide, sodium hydroxide or potassium bicarbonate.

Deep flow technique consists of rectangular tanks referred to as runs, pools or raceways filled with nutrient solution to a few inches in depth and covered with polystyrene or plastic rafts that float on the surface of the nutrient solution. The rafts have holes on the top in which plants are inserted so that the plant roots grow into a static or circulating nutrient solution. Since the nutrient solution is covered with rafts, oxygen exchange between the atmosphere and the nutrient solution can be impeded and thus, oxygen may become a limiting factor in a static DFT system (Goto et al., 1996). To overcome this, oxygenation of the nutrient solution is accomplished by using a pump and lines in the solution to bubble air in the solution. In circulating DFT, the nutrient solution may pass through filters before returning to the tanks, however, for static DFT system, the nutrient solution is cleaned before and after each crop cycle. The nutrient solution is monitored and adjusted for EC and pH in a similar manner as described for NFT system.

The growth of plants in hydroponics systems is affected by the nutrient solution properties, primary factors being EC and pH (DeRijck and Schrevens, 1995; Steiner 1961). The EC of a nutrient solution is used as an estimate of the total dissolved salts (Cooper, 1977) and in general, too high EC may lead to nutrient toxicity while too low EC may induce nutrient deficiency in plants (Sonneveld, 1989). The EC of a solution directly affects the quantity of essential nutrients available to the plant for growth. An EC of 1.5 dS/m has been recommended for production of leafy greens such as lettuce (Resh, 2012). Nutrient solution pH, an indicator of the amount of H^+

ions in the nutrient solution, also influences the availability of nutrients for plant growth (Islam et al., 1980; Savvas and Adamidis, 1999). A pH in the range of 5.8-6.5 has been recommended for crops grown hydroponically due to sufficient availability of all the nutrients in this range (Jones, 2004). At low pH, the macronutrients may become less available for the plant growth while at higher pH, the micronutrients may become a limiting factor (Bugbee, 2004). It is important to maintain the EC and pH in an ideal range at which there is sufficient availability of essential nutrients to carry out growth and development functions. Therefore, it is necessary to determine the optimal EC and pH requirement for dandelion production in hydroponics. The objective of this research was to test the effect of varying EC and pH levels on growth and biomass accumulation of dandelion when grown in NFT and DFT. This was achieved by growing dandelion in fertilizer solutions at different ECs and pH in both the systems and measuring various growth parameters to determine the difference in biomass accumulation due to EC, pH and systems.

Materials and methods

Experiment 1: The effect of fertilizer solution electrical conductivity on growth of dandelion in nutrient film and deep flow systems.

Phenolic-resin-foam sheets (162 Horticubes, Smithers Oasis, Kent, OH) were placed into plastic flats in a polycarbonate-glazed greenhouse with temperature set points of 16˚C and 20˚C for heating and cooling, respectively. The phenolic resin sheets were leached three times with clear water. Dandelion seed were obtained from Jelitto Seed Company (Pullman, Washington) and sown in phenolic sheets with a single seed per cell. Seeds were germinated and seedling grown under ambient light conditions without supplemental lighting. The seeds were sub-irrigated with clear water twice a day until the development of two true leaves after which they were fertilized with a dilute solution at an EC of 0.5 dS/m and a pH of 5.8 prepared using Arkansas standard greens formulation (Table 1). At a four-leaf stage, the seedlings were transplanted into the NFT and DFT systems. The NFT channels were laid on a 3% slope with plant spacing of 20 cm x 20 cm. The flow rate of the nutrient solution was maintained at 275 ml/min. The styrofoam rafts used for the DFT system had holes spaced at 20 cm x 20 cm spacing. Twelve seedlings were used for each EC treatment in both the systems. Seedlings in both systems were fertilized with a nutrient solution at an EC of either 1.0, 1.2, 1.4, 1.6 or 1.8 dS/m using the Arkansas standard greens formulation (Table 1). The final dilute nutrient solution prepared from 1:100 ratio of concentrated stocks and clear water resulted in an EC of 1.8 dS/m (Table 2). The fertilizer solution at an EC of less than 1.8 dS/m contained lesser amounts of essential nutrients. Equal volumes of stocks A and B were added to 50 gallon tanks filled with tap water to bring the nutrient solution to a desired EC level. All the treatments were maintained at a pH of 5.8 and were monitored twice a day for EC and pH using pH-EC meter (Hanna Instruments HI 98129 pH / EC / TDS / Conductivity Temperature Tester Meter state). The nutrient solution EC and pH were adjusted using citric acid (1 M) and potassium hydroxide (1 N). To adjust pH, small volume of citric acid was added followed by proper mixing of the nutrient solution was by stirring. The nutrient solution was allowed to settle for approximately ten minutes and pH was tested again. The addition of citric acid was continued until the nutrient solution was at the desired pH level.

The data collected were leaf length, root length, number of leaves per plant, shoot and root dry weight and root to shoot ratio four weeks after transplanting to determine biomass accumulation. The entire experiment was repeated three consecutive times. Analysis of variance (ANOVA) to determine significance differences on biomass accumulation of dandelion due to EC and production systems was carried out using statistical software SAS. Additionally, least significant difference (LSD) test was carried out to determine the significantly different EC treatments.

Experiment 2: The **effect of fertilizer solution pH on growth of dandelion in nutrient film and deep flow systems.**

Protocols, data collection and statistical analysis for this experiment were the same as Experiment 1 except where indicated. Based on the results from Experiment 1, the nutrient solutions were maintained at an optimal EC of 1.4 dS/m with five pH treatments 5.2, 5.5, 5.8, 6.1 and 6.4 for each system. Additionally, dissolved oxygen (DO) concentration was recorded at three different points in each nutrient solution tank for both the systems by using a DO meter (ExStik DO600, Nashua, NH) for ten consecutive days at the end of the study. The experiment was repeated three consecutive times.

Results

Experiment 1: The effect of fertilizer solution electrical conductivity on growth of dandelion in nutrient film and deep flow systems.

Fertilizer solution EC had significant effect on leaf length and shoot dry weight while production systems had a significant effect on all the growth parameters. There was no significant interaction between EC and system for any of the growth parameters (Table 3). The leaf length and shoot and root dry weight of dandelion grown in the NFT system increased as the fertilizer solution concentration was increased up to an EC of 1.2 dS/m but decreased at the EC of 1.4 dS/m or higher. The highest leaf length and shoot and root dry weight of dandelion grown in the NFT system were recorded at an EC of 1.2 dS/m. Root length and number of leaves increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to an EC of 1.4 dS/m and decreased as EC was increased up to 1.6 dS/m or higher. The highest root length and number of leaves for dandelion grown in the NFT system were recorded at an EC of 1.4 dS/m. Root to shoot ratio of dandelion grown in the NFT system decreased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to 1.8 dS/m and peaked at an EC of 1.0 dS/m.

For dandelion grown in the DFT system, the fertilizer solution EC had significant effect on the leaf length, shoot and root dry weight, root length and number of leaves (Table 4), however, there was no significant interaction between EC and system for these growth parameters. When grown in a DFT system, the leaf length of dandelion increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m to 1.2 dS/m, decreased as the EC was increased up to 1.6 dS/m and again increased at an EC of 1.8 dS/m. The highest leaf length for dandelion grown in the DFT system was recorded at an EC of 1.2 dS/m. The shoot dry weight of dandelion increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to 1.4 dS/m, decreased at an EC of 1.6 dS/m and again increased at an EC of 1.8 dS/m. The highest shoot dry weight of dandelion grown in the DFT system was recorded at an EC of 1.4 dS/m. Root dry weight and root length increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to 1.4 dS/m, decreased at an EC of 1.6 dS/m and again increased at an EC of 1.8 dS/m. The highest root dry weight and root length were recorded at an EC of 1.8 dS/m. The number of leaves increased as the fertilizer solution concentration was increased from an EC of 1.0 dS/m up to 1.4 dS/m, decreased at an EC of 1.6 dS/m and again increased at an EC of 1.8 dS/m. The highest number of leaves for dandelion grown in the DFT system were recorded at an EC of 1.4 dS/m. The fertilizer solution EC did not have significant effect on the root to shoot ratio of dandelion grown in the DFT system. The root to shoot ratio increased as the fertilizer solution concentration was increased from an EC of 1.0 to 1.2 dS/m, decreased at an EC of 1.4 dS/m and again increased when EC was increased up to 1.6 dS/m or higher. The highest root to shoot ratio was recorded at an EC of 1.6 dS/m. For dandelion grown at same fertilizer solution EC, all the growth parameters were higher when grown in the DFT system.

Experiment 2: The effect of fertilizer solution pH on growth of dandelion in nutrient film and deep flow systems.

Fertilizer solution pH and systems had significant effect on leaf length of dandelion. There was also significant interaction between pH and system for the leaf length of dandelion. The leaf length of dandelion grown in the NFT system decreased as the fertilizer solution pH was increased from 5.2 to 5.5 and increased with further increase in the pH up to 6.4. Fertilizer solution pH had significant effect on shoot dry weight of dandelion while systems did not have significant effect on shoot dry weight of dandelion. There was a significant interaction between pH and system for the shoot dry weight of dandelion. The shoot dry weight of dandelion grown in the NFT system decreased as the fertilizer solution pH was increased from 5.2 up to 5.8 and increased with further increase in the pH up to 6.4. The leaf length and shoot dry weight of dandelion grown in an NFT were highest at a pH of 6.4. Fertilizer solution pH had significant effect on root dry weight and root length of dandelion while systems did not have significant effect on root dry weight and root length of dandelion. There was a significant interaction between pH and system on the root dry weight and root length of dandelion. The root dry weight of dandelion grown in the NFT system decreased as the fertilizer solution pH was increased from 5.2 to 5.8 and increased with further increase in the pH up to 6.4. The root length of dandelion grown in the NFT system decreased as the fertilizer solution pH was increased from 5.2 to 5.8, increased at a pH of 6.1 and again decreased at a pH as high as 6.4. The highest root dry weight and root length of dandelion grown in an NFT were recorded at a pH of 5.2. The fertilizer solution pH had no significant on number of leaves and root to shoot ratio of dandelion while the systems had significant effect on the number of leaves and root to shoot ratio. There was significant interaction between systems and pH for these parameters. The number of leaves of dandelion grown in the NFT system decreased as the fertilizer solution pH was increased from 5.2 to 5.8 and increased with further increase in the pH up to 6.4. The root to shoot ratio of dandelion grown in the NFT system increased as the fertilizer solution pH was increased from 5.2 to 5.5 and decreased with further increase in the pH up to 6.4.

When grown in the DFT system, the fertilizer solution pH had significant effect on the leaf length, shoot and root dry weight, root length, number of leaves and root to shoot ratio of dandelion. There was also significant effect of interaction between pH and system on the leaf length, shoot and root dry weight, root length, number of leaves and root to shoot ratio of dandelion. All the growth parameters of dandelion grown in the DFT system decreased as the fertilizer solution pH was increased from 5.2 to 5.5 and increased with further increase in the pH up to 6.4. All the growth parameters except number of leaves for dandelion grown in the DFT were recorded highest at a pH of 6.4. The number of leaves of dandelion was highest at a pH of 5.8. All the growth parameters of dandelion except number of leaves were higher when grown in the NFT system. The average dissolved oxygen (DO) concentration was 3.9 and 4.0 mg/L for NFT and DFT, respectively.

Discussion

Experiment 1: The effect of fertilizer solution electrical conductivity on growth of dandelion in nutrient film and deep flow systems.

For dandelion grown in both the systems, the growth parameters were shown to increase with an increase in the fertilizer solution concentration up to an EC of either 1.2 or 1.4 dS/m after which the growth parameters decreased with further increase in the EC up to 1.6 dS/m. This can be explained by the insufficient availability of nutrients at EC as low as 1.0 dS/m. Sonneveld (1989) reported that the fertilizer solution at lower ECs have lesser nutrients which might induce nutrient deficiency in the plants. Although, nutrient deficiencies were not reported in this study, lesser availability of nutrients at an EC as low as 1.0 dS/m might have affected the plant growth and thus, resulted in lesser biomass production. The decrease in biomass accumulation at an EC higher than 1.4 dS/m can be attributed to the nutrient imbalance in the plant system. At higher concentrations, the availability of nutrients increases which may lead to more absorption of some ions present in higher quantities than others, thereby, creating a nutrient imbalance in the plant system (Bugbee, 2004; Schwarz, 1995). A higher solution concentration is also known to suppress the uptake of water and nutrients due to higher osmotic potential which can adversely affect the plant growth (Tesi et al., 2003). In a study conducted by Miceli et al. (2003), the plant fresh weight and leaf number of lettuce were shown to decrease as EC was increased from 1.6 to 4.6 dS/m in a coir dust culture. Similar trends in change in fresh weight of lettuce over an EC range of 1.5-3.5 dS/m were also reported (Serio et al., 2001). Samarakoon et al. (2006) reported that lettuce grown at an EC of 1.4 dS/m in a stationary culture resulted in higher number of leaves, fresh and dry weight as compared to ECs 2.0 and 4.0 dS/m. Therefore, the results from this study were in accordance with some of the previous findings. However, for dandelion grown in the DFT system, the plant growth parameters consistently decreased at an EC of 1.6 dS/m and again increased at an EC of 1.8 dS/m. This was contrary to the previously reported results and no definite explanation could be found for this. Therefore, this will be designated as a data artifact.

The higher root and shoot biomass accumulation for DFT than NFT can be explained by the design of the systems. In DFT system, roots have more vertical and lateral space for growth which ensures proper nutrient and oxygen supply to the roots. This resulted in higher root dry matter and subsequently higher shoot dry matter production in dandelion grown in the DFT system. The cause for lower biomass accumulation in NFT might be the occurrence of root lumping due to less space available for roots to spread and grow (Chun and Takakura, 1993).

Experiment 2: The effect of fertilizer solution pH on growth of dandelion grown in nutrient film and deep flow systems.

For dandelion grown in the NFT system, all the growth parameters decreased with increase in the fertilizer solution pH from 5.2 to either 5.5 or 5.8 and increased with further increase in the pH up to 6.4. The highest shoot biomass was recorded at pH 6.4 while the highest root biomass was recorded at pH 5.2. The results from this study were not consistent with the previous findings. In a study conducted by Yan et al. (1992) on corn (*Zea mays*) and broad beans (*Vicia faba*), poor root growth at a pH of 4.0 was reported. In general, at low pH, the macronutrients become less available for the plant growth which would result in lower biomass accumulation (Bugbee, 2004). For dandelion grown in DFT, both root and shoot biomass were highest when grown in a fertilizer solution at a pH of 6.4. However, the growth parameters were consistently low when grown in a fertilizer solution at a pH of 5.5. The occurrence of powdery mildew during this experiment suppressed the growth of dandelion plants which might have led to the inconsistent results from this study. This might also have led to lesser biomass production for dandelion grown in the DFT system than NFT. The average dissolved oxygen (DO) concentration in NFT and DFT was recorded as 3.9 mg/L and 4.0 mg/L, respectively. Previous studies suggest this amount to be sufficient for plant growth and reported 2.1 mg/L as the critical DO concentration for lettuce grown in deep flow hydroponics (Goto et al., 1996). Also, the difference in average DO concentration for NFT and DFT was not large enough to affect the plant growth in NFT. In a study conducted by Goto et al. (1996) on effect of different DO concentration on growth of lettuce, no significant differences in growth were found between DO concentrations of 2.1, 4.2, 8.4 and 16.8 mg/L. Therefore, the differences in the biomass accumulation of dandelion cannot be associated with DO concentration.

Conclusion

The ideal range of EC for dandelion production in both NFT and DFT systems is 1.2-1.4 dS/m. Dandelion grown in a fertilizer solution at an EC as high as 1.8 dS/m led to the decrease in biomass production due to less absorption of nutrients caused by the higher osmotic potential. On the other hand, dandelion grown in a fertilizer solution at an EC as low as 1.0 dS/m did not provide sufficient nutrients to the plant for growth and development. An ideal fertilizer solution pH for dandelion production in hydroponics is around 6.4, however, the results could have been affected due to the occurrence of powdery mildew. Therefore, further research should be conducted to determine an optimal pH for dandelion production in hydroponics. Among the two systems, the DFT system produced higher biomass for dandelion due to more space availability for root growth.

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Table 1. Composition of the concentrated stock solutions used for dandelion production[z].

Tank	Fertilizer source	Amount ($g.L^{-1}$)
A	Calcium nitrate	90.0
	Potassium nitrate	30.0
	Iron- DTPA[y]	4.1
B	Monopotassium phosphate	22.0
	Potassium sulfate	7.7
	Magnesium sulfate heptahydrate	43.0
	Manganese sulfate tetrahydrate	0.31
	Copper sulfate pentahydrate	0.04
	Zinc sulfate	0.02
	Boric acid	0.27
	Ammonium molybdate	0.11

[z] To prepare 1 liter of stock solution for 100x dilution.

[y] Iron chelate di-ethylene tri-amine penta-acetic acid.

Table 2. Composition of the final dilute fertilizer solution at an EC of 1.8 dS.m^{-1} and a pH of 6.1 used for dandelion production^{z}.

Nutrient	mg.L^{-1}
NO_3^-	169.0
NH_4^+	8.5
P	48.7
K	212.3
Ca	192.0
Mg	47.8
S	75.0
Fe	4.0
Cu	0.13
B	0.5
Zn	0.09
Mn	0.5
Mo	0.07

Table 3. Growth of dandelion in fertilizer solutions of varying electrical conductivity (EC) in nutrient film technique (NFT) and deep flow technique (DFT).

System	EC (dS·m^{-1})	Leaf length (cm)	Shoot dry weight (g)	Root dry weight (g)	Root length (cm)	Number of leaves	Root to shoot ratio
NFT	1.0	22.2	1.05	0.28	27.4	9.80	0.28
NFT	1.2	28.9	2.02	0.52	27.6	10.9	0.27
NFT	1.4	27.6	1.88	0.39	31.6	11.8	0.25
NFT	1.6	24.7	1.39	0.34	28.5	10.8	0.23
NFT	1.8	23.5	1.43	0.32	28.1	10.5	0.19
DFT	1.0	26.4	2.90	0.85	32.5	15.3	0.30
DFT	1.2	29.2	3.38	1.02	34.2	15.8	0.35
DFT	1.4	28.5	3.63	1.02	36.3	16.4	0.27
DFT	1.6	24.9	2.43	0.81	32.7	13.8	0.36
DFT	1.8	28.9	3.40	1.11	39.2	15.8	0.35

Table 3(Cont.). Growth of dandelion in fertilizer solutions of varying electrical conductivity (EC) in nutrient film technique (NFT) and deep flow technique (DFT).

Significance	Leaf length (cm)	Shoot dry weight (g)	Root dry weight (g)	Root length (cm)	Number of leaves	Root to shoot ratio
EC	*	*	NS	NS	NS	NS
System	*	*	*	*	*	*
EC x System	NS	NS	NS	NS	NS	NS
LSD (α = 0.05)	3.83	0.69	0.25	6.14	2.08	0.09

[NS,*] Nonsignificant or significant at P>F of 0.05, respectively.

Table 4. Growth of dandelion in fertilizer solutions of varying pH in nutrient film technique (NFT) and deep flow technique (DFT).

System	pH	Leaf length (cm)	Shoot dry weight (cm)	Root dry weight (g)	Root length (g)	Number of leaves	Root to shoot ratio
NFT	5.2	16.5	1.15	0.69	18.6	10.2	0.59
NFT	5.5	11.5	0.96	0.57	17.7	10.2	0.70
NFT	5.8	13.6	0.80	0.27	15.6	9.30	0.42
NFT	6.1	15.1	1.01	0.43	17.5	9.60	0.38
NFT	6.4	25.4	1.34	0.63	15.8	10.4	0.33
DFT	5.2	12.5	0.78	0.28	14.2	11.8	0.31
DFT	5.5	11.1	0.43	0.05	13.3	9.10	0.18
DFT	5.8	14.7	1.47	0.69	19.7	12.7	0.31
DFT	6.1	13.9	1.47	0.83	23.1	11.9	0.32
DFT	6.4	14.7	1.66	0.88	24.9	12.1	0.33

Table 4(Cont.). Growth of dandelion in fertilizer solutions of varying pH in nutrient film technique (NFT) and deep flow technique (DFT).

Significance	Leaf length (cm)	Shoot dry weight (cm)	Root dry weight (g)	Root length (g)	Number of leaves	Root to shoot ratio
pH	*	*	*	*	NS	NS
System	*	NS	NS	NS	*	*
pH x system	*	*	*	*	*	*
LSD (α = 0.05)	1.78	0.39	0.27	4.00	1.6	0.13

[NS,*] Nonsignificant or significant at P>F of 0.05, respectively.

The effect of fertilizer concentration and timing on the rate of development of dandelion seedlings.

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Subject Category: Crop production: Herbs, Spices, Medicinal and Aromatic Plants

The effect of fertilizer concentration and timing on the rate of development of dandelion seedlings.

Additional index words. Taraxacum officinale L., hydroponics, transplant production, biomass accumulation, fertigation.

Abstract. Dandelion seedlings grown at a fertilizer concentration of 1.0 dS/m required lesser number of days to reach one-, two- and four-leaf stage and also had higher leaf length, shoot fresh weight and number of leaves than the seedlings grown at a fertilizer solution concentration of 0.5 dS/m. Seedlings fertilized with solution at a concentration of 0.5 dS/m showed linear increase in growth as fertilization was delayed while the seedlings fertilized with solution at a concentration of 1.0 dS/m showed a non-linear growth pattern. The highest leaf length, shoot fresh weight and number of leaves was recorded when fertilization was initiated on day 0 for seedlings fertilized with solution at a concentration of 0.5 dS/m and day 6 for seedlings fertilized with solution at a concentration of 1.0 dS/m. The least number of days to reach a one-, two- and four-leaf stage was recorded when fertilization was initiated on day 0 for seedlings fertilized with solution at a concentration of 0.5 dS/m and day 6 for seedlings fertilized with solution at a concentration of 1.0 dS/m. No push-outs or stretched seedlings were observed for any of the treatments which is an indication that seedlings did not suffer from over-fertilization at a fertilizer concentration as high as 1.0 dS/m.

Introduction

Hydroponics has multiple advantages over outdoor soil-based production methods, such as the possibility of growing plants in areas with unsuitable soil, higher water and fertilizer efficiency, prevention of soil-borne pathogens and increased yields (Albright and Langhans, 1996). Also, hydroponics is increasingly being used for the production of medicinal plants due to the improved product quality, higher biomass production and minimal contamination. Dandelion (*Taraxacum officinale* L.), among other plants, has been identified for its medicinal and nutritional value (Schutz et al. 2006 and Sweeney et al. 2005). The anti-inflammatory, anti-cancerous and anti-oxidative properties of dandelion have been reported by multiple researchers (Ahmad et al., 2000; Jeon et al., 2008; Kisiel and Barszcz, 2000; Schütz et al., 2006). The use of aqueous dandelion extract for the treatment of breast and prostate cancer has also been reported (Sigstedt et al., 2008). The potential of dandelion as a medicinal herb in hydroponics has been supported by a few studies (Papadopoulos, 2001), however, detailed information on hydroponic dandelion production is lacking.

The first phase of hydroponic plant production is the propagation phase, in which the seedlings are raised in a nursery and then transplanted into the hydroponic systems at an appropriate age. Researchers have recommended different practices for raising seedlings for hydroponic production of leafy greens. For instance, Resh (2012) recommends using a nutrient solution of EC 1.5 dS/m for lettuce after the cotyledons have fully expanded. The lettuce seedlings raised using this method should reach the transplanting stage in 2-3 weeks. Morgan (2012), on the other hand, recommends watering the lettuce seeds until the development of two true leaves and later on, fertilizing the seedlings with a nutrient solution of EC 0.5-0.6 dS/m with a subsequent increase in EC to 1.0-1.2 dS/m after 4-5 days. This might take 3-4 weeks for the completion of the propagation phase. A short propagation phase is highly desirable for short duration crops such as leafy greens. However, in a previous study conducted on dandelion production in hydroponics, it was found that the propagation phase of dandelion may take up to five weeks, which is longer than that of other leafy greens. Therefore, an ideal strategy for raising dandelion seedlings in the shortest possible time is required. This can be achieved by manipulating the environmental factors that may affect the rate of development of the seedlings.

Among the multiple factors affecting seedling growth and development, nutrition provided in the nursery phase can be used to regulate the seedling growth (Dufault, 1998). The nutrition to the seedlings is commonly provided through a fertilizer solution known as fertigation. There are several standard nutrient formulations available to provide a balanced nutrition to the hydroponically produced plants (DeRijck and Schrevens, 1998). These formulations can be diluted in water to constitute a fertilizer solution of varying concentration. The fertilizer solution concentration, also expressed as electrical conductivity (EC), has been reported to have a significant effect on seedling growth (Sarooshi and Cresswell, 1994; Serio et al., 2000). In general, a fertilizer solution at a higher concentration provides more nutrients to the plants than that of the lower concentration (Sonneveld, 1989) while a fertilizer solution at concentration higher than the optimal may lead to adverse effects on seedling growth. For instance, development of seedlings with weak stems may result from excessive fertilization (Ciardi et al., 1998). The seedling growth and development can also be controlled by adjusting the timing of fertilization. In a study conducted by Ciardi et al. (1998), tomato seedlings that were pre-conditioned with an N-P-K based fertilizer 10 days before transplanting had higher dry mass and number of leaves, however, the plants also had weak stems and were difficult to transplant.

Similar results with no difficulty in transplanting were stated in a study conducted by Melton and Dufault (1991) on tomato seedlings.

Since fertilizer concentration and timing may have significant effect on the seedling growth, a nutritional regime can be developed for dandelion seedlings using these variables and the rate of development of dandelion seedlings can be determined at varying nutritional regimes. The objective of this research was to investigate the effect of fertilizer concentration and timing on the rate of development of dandelion seedlings.

Materials and methods

Phenolic-resin-foam sheets (162 Horticubes, Smithers Oasis, Kent, OH) were placed into plastic flats in a polycarbonate-glazed greenhouse with heating and cooling set points of 16°C and 20°C, respectively and were leached three times with clear water. Dandelion seed were obtained from Jelitto Seed Company (Pullman, Washington) and sown into the sheets with a single seed per cell and 45 seeds per sheet. Seed were germinated and grown under ambient light conditions without supplemental lighting. The seeds were sub-irrigated daily with a standard fertilizer formulation (Table 6) designed for use with greenhouse-grown leafy greens. Typically, a single irrigation was adequate to maintain a moist foam sheet, however, an additional sub-irrigation with clear tap water was conducted depending upon the environmental conditions. The fertilizer solution was applied at a concentration of 0.5 or 1.0 dS/m beginning on day 0, 3, 6, 9, 12 or 15 and continued for five weeks. For each seedling, the average number of days to reach one-leaf, two-leaf and four-leaf stage were recorded. After five weeks, the seedlings were harvested and the leaf length, shoot weight and number of leaves was recorded. Number of push-outs was also recorded for each treatment as an estimate of stretching due to over-fertilization. Push-outs are the seedlings whose radical undergoes excessive elongation such that the seedling is pushed out of the growing media. An analysis of variance was conducted to determine the differences in growth parameters due to fertilizer solution concentration and timing using statistical software SAS (SAS® 9.4). Additionally, regression analysis was done to predict the seedling growth trend at two ECs using software Prism (GraphPad Prism® 6).

Results

All the growth parameters were significantly affected by fertilizer concentration and timing. There was also significant interaction between fertilizer concentration and timing for all the growth parameters. For all fertilization initiation times, seedlings fertilized with a solution at a concentration of 1.0 dS/m had lesser number of days to reach the one-, two- and four-leaf stage (Figure 1, 2 and 3) as well as higher leaf length, shoot fresh weight and number of leaves than the seedlings fertilized with the 0.5 dS/m solution (Figure 4, 5 and 6). As fertilization with an EC of 0.5 dS/m solution was delayed, the time required for dandelion seedlings to develop to the one-, two- and four-true leaf stages increased linearly while leaf length, shoot fresh weight and number of leaves decreased linearly. For seedlings fertilized with a solution at an EC of 0.5 dS/m, the average number of days to reach one-, two- and four-leaf stage were least when fertilization was started on day 0 and increased with delay in the fertilization initiation up to day 15. The leaf length, shoot fresh weight and number of leaves were highest when fertilization was started on day 0 and decreased with delay in the fertilization initiation up to day 15. As fertilization with an EC of 1.0 dS/m solution was delayed, all the growth parameters altered non-linearly. The average number of days to reach one-, two- and four-leaf stage for the seedlings fertilized with a solution at an EC of 1.0 dS/m decreased with a delay in fertilization up to day 6 and increased when fertilization was further delayed to days 9, 12 and 15. The leaf length, shoot fresh weight and number of leaves increased with a delay in fertilization up to day 9 and decreased with further delay up to day 12 and 15. For seedlings fertilized with a solution at an EC of 1.0 dS/m, the leaf length and number of leaves were highest when fertilization was started on day 6 while shoot fresh weight was highest when fertilization was started on day 9. The average number of days to reach one-, two- and four- leaf stage were least when fertilization was started on day 6.

Discussion

Dandelion seedlings had higher leaf length, shoot fresh weight and number of leaves and required lesser number of days to reach a one-, two- and four- leaf stage when fertilized with a solution of higher concentration. At EC as low as 0.5 dS/m, the insufficient availability of essential nutrients might have caused the seedling growth to lag behind (Sonneveld, 1989). On the other hand, a nutrient solution at EC 1.0 dS/m provided more nutrients for the seedling growth, and thereby, allowed the seedlings to accumulate sufficient biomass and also increased the rate of development. In a previous study conducted by Morgan et al. (1980), an ideal fertilizer concentration range for lettuce transplant production was reported to be 0.6-1.1 dS/m. The dry biomass of seedlings was shown to reduce at EC as high as 2.0 dS/m.

The growth parameters of dandelion seedlings decreased linearly as fertilization with a solution at concentration of 0.5 dS/m was delayed. As fertilization with a solution at an EC of 0.5 dS/m was delayed, the effect of fertilization timing became more pronounced. However, when the seedlings were fertilized with a solution at an EC of 1.0 dS/m, the growth parameters increased linearly for the earlier fertilization timings of day 0, 3, 6 and 9 while decreased when fertilization was delayed up to day 12 and 15. Since there was little or no germination observed on days 0 and 3, the effect of fertilizer solution concentration was more pronounced on days 6 and 9 due to higher germination percentage on those days. The seedlings with fertilization initiated on days 12 and 15 treatments had lower biomass due to the delay in fertilization. Since no push-outs were observed in any of the treatments, it can be concluded that the seedlings did not suffer from over-fertilization at EC as high as 1.0 dS/m.

Conclusion

The fertilization initiated on the day of sowing with a nutrient solution at a concentration as low as 0.5 dS/m may increase the rate of development of dandelion seedlings while delay in fertilization would lead to decrease in the rate of development. The increase in fertilizer concentration up to 1.0 dS/m can further enhance the rate of development of dandelion seedlings, however, the fertilization can be delayed up to day 6 or 9 when a fertilizer solution is used at a higher concentration.

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Table 5. Composition of the stock solutions used for dandelion production[z].

Stock	Fertilizer	Amount (g)
A	Calcium nitrate	90.0
	Potassium nitrate	30.0
	Fe-DTPA	4.1
B	Monopotassium phosphate	22.0
	Potassium sulfate	7.7
	Magnesium sulfate	43.0
	Manganese sulfate	0.31
	Copper sulfate	0.04
	Zinc sulfate	0.02
	Boric acid	0.27
	Ammonium molybdate	0.11

[z] To prepare 1 liter of stock solution for 100x dilution.

Table 6. Composition of the final dilute fertilizer solution used for dandelion production at an electrical conductivity (EC) of 1.8 dS.m^{-1} and pH 6.1.

Nutrient	mg.L^{-1}
NO_3^-	169.0
NH_4^+	8.5
P	48.7
K	212.3
Ca	192.0
Mg	47.8
S	75.0
Fe	4.0
Cu	0.13
B	0.5
Zn	0.09
Mn	0.5
Mo	0.07

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Table 7. Effect of fertilizer solution electrical conductivity (EC) and timing (day) on growth of dandelion seedling.

	Number of days to reach			Leaf	Shoot	Number
Significance	1-leaf stage	2-leaf stage	4-leaf stage	length (cm)	fresh weight (g)	of leaves
EC	*	*	*	*	*	*
Day	*	*	*	*	*	*
EC x Day	*	*	*	*	*	*
Mean	19.7	23.9	31.0	3.71	0.24	4.3

^{NS,*}Nonsignificant or significant at P>F of 0.05, respectively.

List of Figures

Figure 1. Effect of fertilizer solution electrical conductivity (EC) and time of fertilization (d) on number of days to reach one-leaf stage for dandelion.

EC 0.5: $y = 0.2384x + 18.87$, $R^2 = 0.95$

EC 1.0: $y = 18.15 - 0.2169x + 0.03128x^2$, $R^2 = 0.94$

Figure 2. Effect of fertilizer solution electrical conductivity (EC) and time of fertilization (d) on number of days to reach two-leaf stage for dandelion.

EC 0.5: $y = 0.2895x + 22.63$, $R^2 = 0.95$

EC 1.0: $y = 22.09 - 0.1734x + 0.02917x^2$, $R^2 = 0.95$

Figure 3. Effect of fertilizer solution electrical conductivity (EC) and time of fertilization (d) on number of days to reach four-leaf stage for dandelion.

EC 0.5: $y = 0.2232x + 30.41$, $R^2 = 0.98$

EC 1.0: $y = 30.10 - 0.3019x + 0.03340x^2$, $R^2 = 0.93$

Figure 4. Effect of fertilizer solution electrical conductivity (EC) and time of fertilization (d) on dandelion leaf length after 5 weeks in propagation phase.

EC 0.5: $y = 3.785 – 0.07528x – 0.001521x^2$, $R^2 = 0.97$

EC 1.0: $y = 4.012 + 0.3442x – 0.03029x^2$, $R^2 = 0.82$

Figure 5. Effect of fertilizer solution electrical conductivity (EC) and time of fertilization (d) on dandelion shoot fresh weight after 5 weeks in propagation phase.

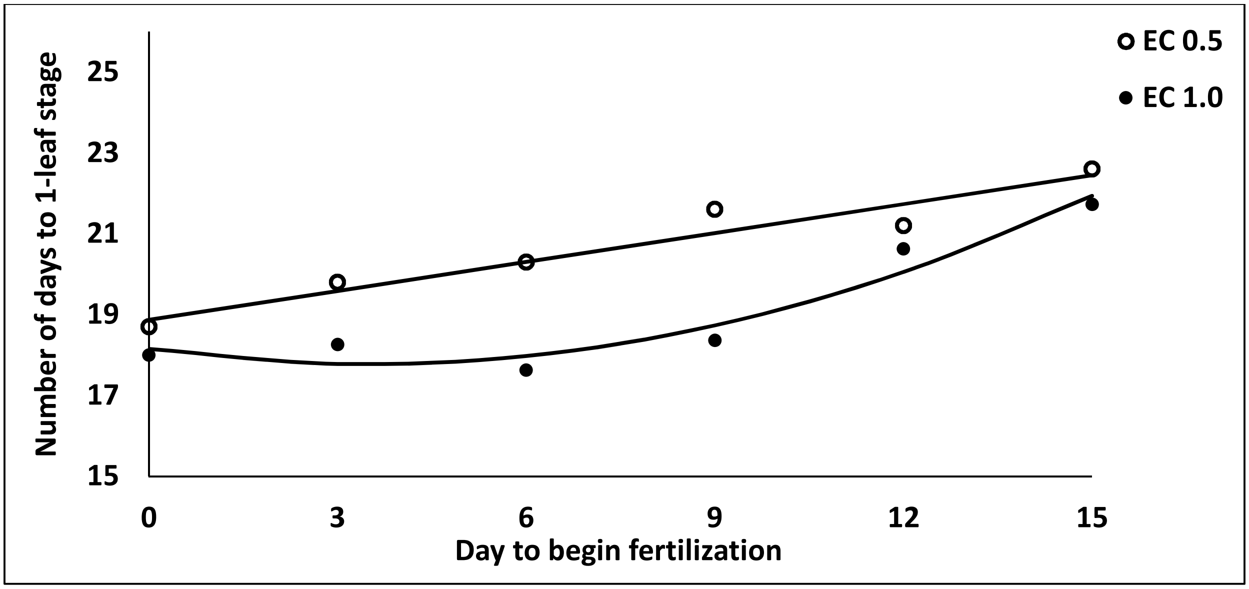
EC 0.5: $y = 0.2864 – 0.01740x + 0.0002249x^2$, $R^2 = 0.99$

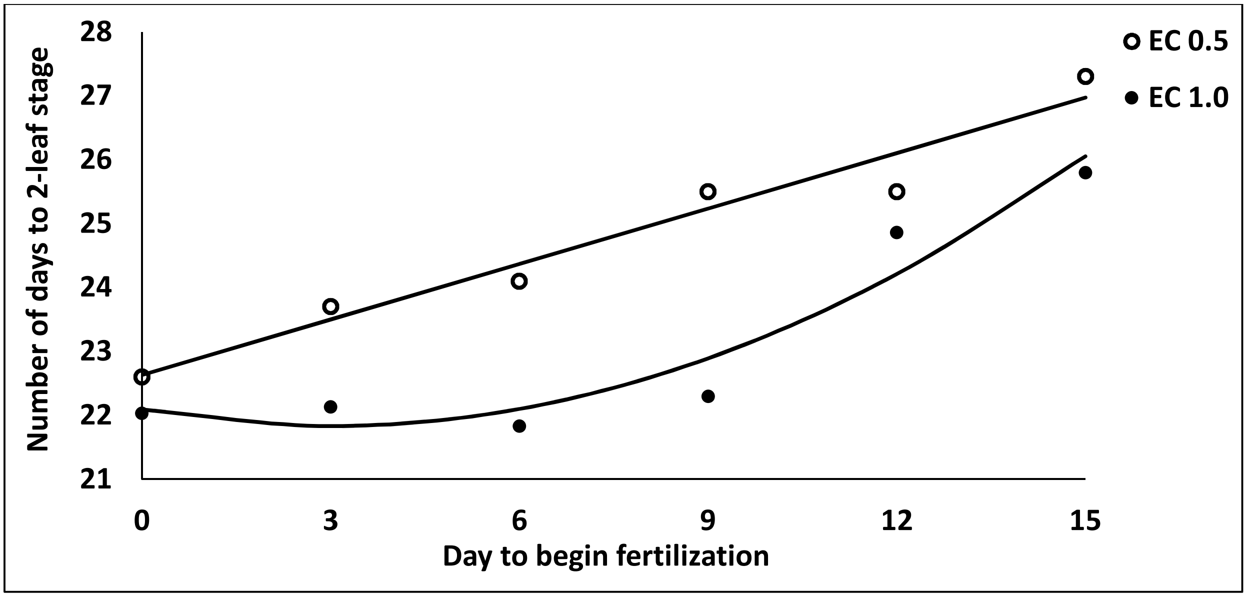
EC 1.0: $y = 0.2950 + 0.04023x – 0.003664x^2$, $R^2 = 0.91$

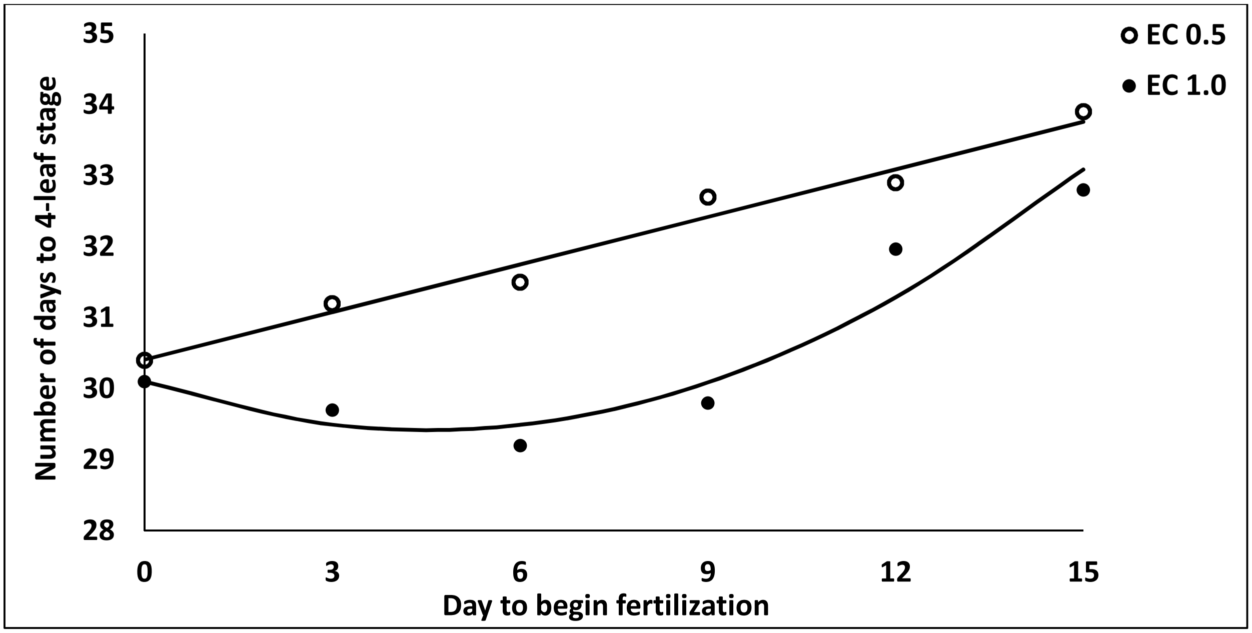
Figure 6. Effect of fertilizer solution electrical conductivity (EC) and time of fertilization (d) on number of leaves of dandelion seedling after 5 weeks in propagation phase.

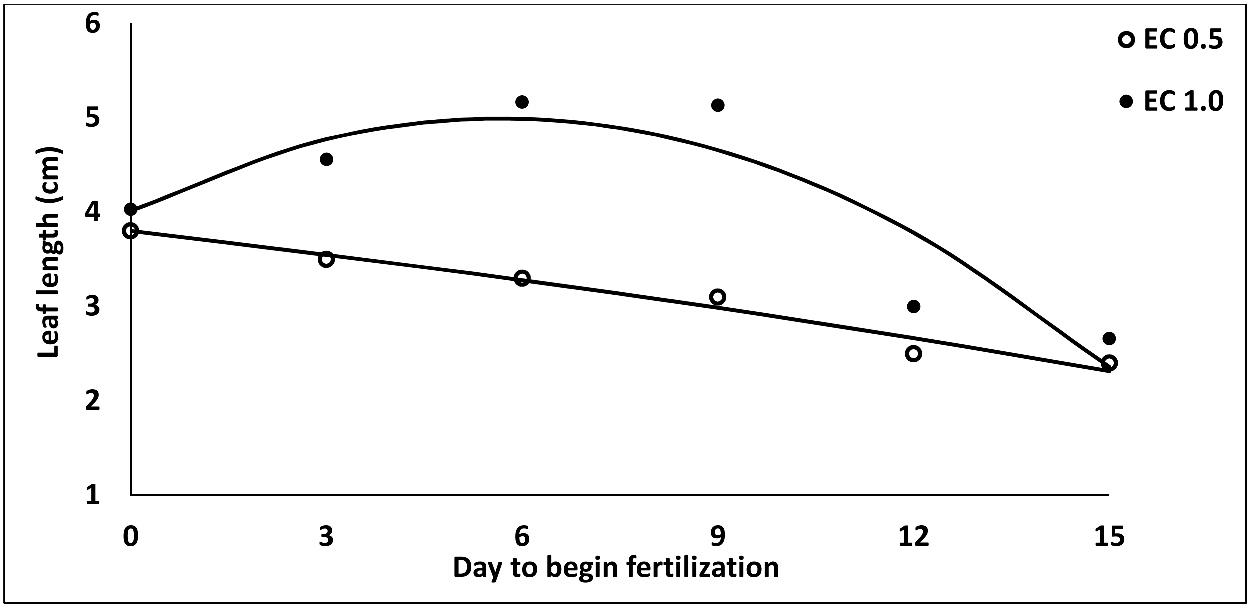
EC 0.5: $y = -0.03587x + 3.952$, $R^2 = 0.93$

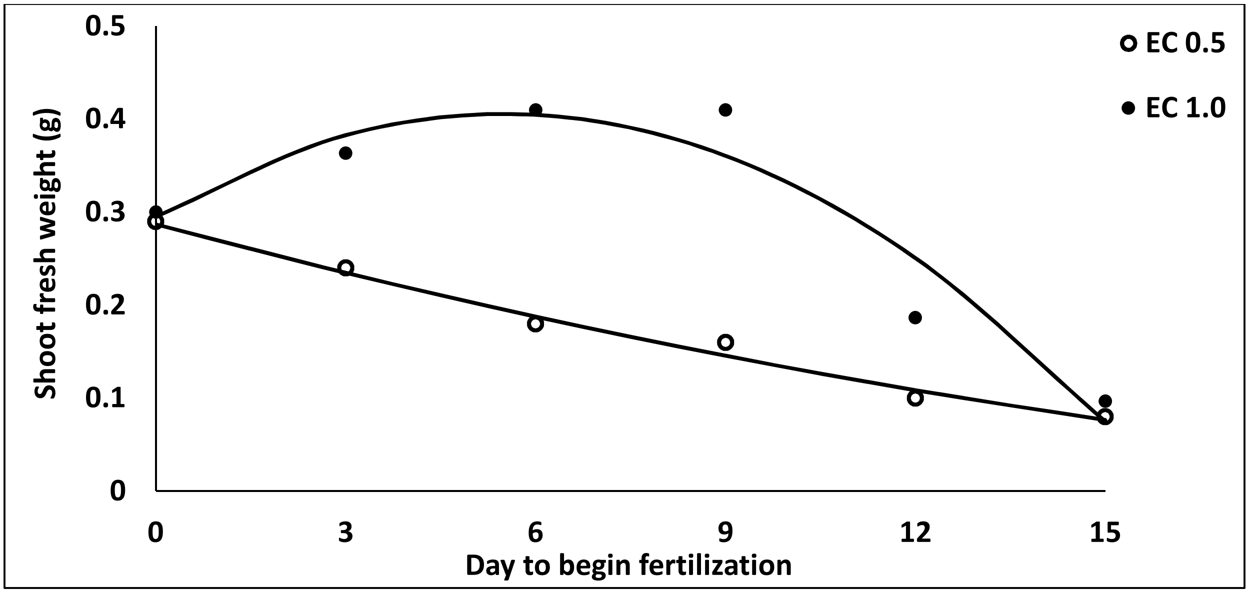
EC 1.0: $y = 4.218 + 0.2047x - 0.01634x^2$, $R^2 = 0.92$

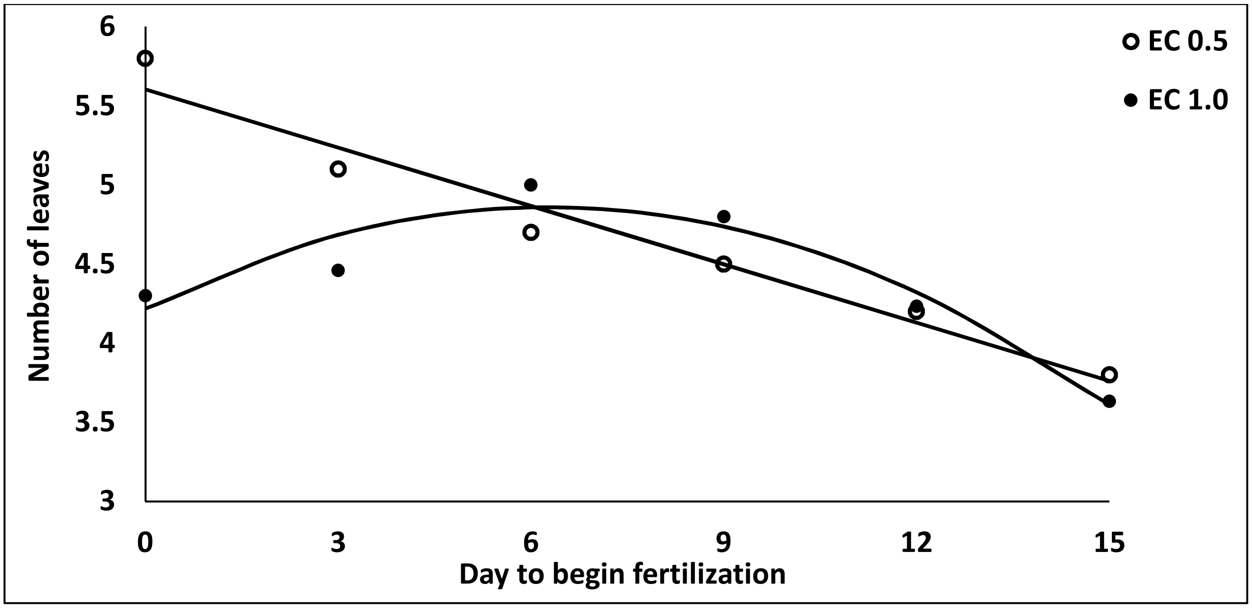

EC 0.5
EC 1.0
Number of days to 1-leaf stage
25
23
21
19
17
15
0
3
6
9
12
15
Day to begin fertilization


Number of days to 2-leaf stage
28
27
26
25
24
23
22
21
0
3
6
9
12
15
Day to begin fertilization
○ EC 0.5
● EC 1.0


35
34
33
32
31
30
29
28
Number of days to 4-leaf stage
0
3
6
9
12
15
Day to begin fertilization
○ EC 0.5
● EC 1.0


6
5
4
3
2
1
Leaf length (cm)
0
3
6
9
12
15
Day to begin fertilization
○ EC 0.5
● EC 1.0


Shoot fresh weight (g)
0.5
0.4
0.3
0.2
0.1
0
0
3
6
9
12
15
Day to begin fertilization
○ EC 0.5
● EC 1.0


Number of leaves
6
5.5
5
4.5
4
3.5
3
0
3
6
9
12
15
Day to begin fertilization
EC 0.5
EC 1.0

Conclusion

An optimal range of nutrient solution concentration for dandelion production in both NFT and DFT systems was 1.2-1.4 $dS.m^{-1}$. The amount of nutrients in this range are sufficient to allow the growth and development functions without causing any adverse effects on plant growth. The nutrient availability for plant growth was sufficient when the nutrient solution pH was maintained at 6.4. However, the occurrence of powdery mildew in this experiment was not taken into account. Therefore, further studies should be conducted to confirm the reliability of these results. The DFT is an optimal hydroponic system to grow dandelion for highest root and shoot yields. The rate of development of dandelion seedlings was highest when fertilization was initiated six days after sowing with a nutrient solution at an EC of 1.0 $dS.m^{-1}$. However, fertilization should be initiated earlier if a fertilizer solution of lesser concentration is to be used.