Nursery Techniques Influence the Growth of Hazelnuts

by
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ABSTRACT

NURSERY TECHNIQUES INFLUENCE THE GROWTH OF HAZELNUTS

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Dr. Adam Dale

Since Ferrero SpA established a manufacturing plant in Brantford, Ontario, there has been considerable interest in developing a hazelnut industry locally. One of the issues that needs to be overcome is to supply large numbers of suitable plants rapidly. They can be micropropagated, and then grown in the nursery. Usually, it takes two years to grow suitably sized plants in the nursery. This thesis investigated methods to grow suitably sized plants in one year and evaluated the nursery systems from financial aspect. Hazelnut seedlings were planted in ellepots and plastic pots, and then subjected to three treatments: grown in a retractable roof greenhouse, treated with root pruning technology or grown in outdoor environment. Also, two transplant timings were tested: the fall of 2011 and the spring of 2012. The results showed that pot type did not influence the growth of hazelnut seedlings. The retractable roof greenhouse increased growth and the root pruning technology changed the seedlings root structure but not their growth. Transplant timing did not affect the seedlings growth in the first year in the field. The retractable roof greenhouse has the potential to produce two crops of seedlings in one growing season compared to one crop in the outdoor nursery. The estimated cost per seedling under retractable roof greenhouse was $9.31, which was $1.95 cheaper than outdoor.
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Chapter 1  Literature Review

1.1 Hazelnut industry

The number of hazelnut producing countries has increased from 24 in 1998 to 30 in 2007. Turkey is the largest hazelnut producing country with 68% of the world’s production, followed by Italy (14%), United States (3.8%), Azerbaijan (3.3%) and Spain (2.6%) (Fideghelli and De Salvador, 2009). The world hazelnut production has increased by 19.2% (Table 1.1) from 697,681 tons (mean production in 1996-1998) to 831,653 tons (mean production in 2005-2007) during the past decade (Fideghelli and De Salvador, 2009). Increases were observed in all the main producing countries and varied from 4% (Italy) to 194% (Azerbaijan) (Fideghelli and De Salvador, 2009).

The world acreage of hazelnut steadily rose by 14% from 1997 to 2007 (Fideghelli and De Salvador, 2009), to 567,000 hectares in 2007 (Table 1.1). From 1998 to 2007, Iran, Turkey, China and Azerbaijan increased their acreage by 96%, 20%, 5.9% and 1% respectively, whereas Spain, United States, Georgia and Italy had reduced their acreage by 30%, 5%, 4% and 1% respectively (Table 1.1) (Fideghelli and De Salvador, 2009).

Although Turkey is the largest producing country, its unit production (1.32t/ha) was below the world average level (1.48t/ha) during 2004 to 2006. Italy and United States, the second and third producing country, had higher unit production than the world mean. United States had almost double the world average which reached 2.93t/ha (Fig 1.1) (Fideghelli and De Salvador, 2009).
The nut market can be segmented into two categories: in-shell nuts and kernels (shelled nut). The in-shell nuts, which share a relatively small market, are prepared mainly for the fresh market. The most common use of hazelnuts is processing without the shell. The kernels are extracted from the shells, then blanched, diced, coated, roasted or grinded to meet product formulation needs or add customer value (Demir et al., 2003).

The total value of exports worldwide in 2003 was $571 million shelled and $41 million in-shell. Turkey had the largest production and stock; it is the key driver in market supply and price (USDA, 2005). Turkey exports 72% of the world’s shelled hazelnut, with an export revenue of $410 million. Those hazelnuts are exported in a raw or semi-processed stage. The primary market for Turkey has traditionally been the European Union, but it is expanding into the Far East, the former Soviet Union and the United States. Meanwhile, Turkey exports an estimated $3.6 million of in-shelled hazelnuts, accounting for 9% of the total in-shelled hazelnut market. The in-shell hazelnuts are mainly exported to Hong Kong and Germany (USDA, 2005).

Although Italy is the second largest producer of hazelnuts, it is a net importer. It exported $93 million hazelnuts while it imported $119 million in 2003 (USDA, 2005). The domestic consumers were mainly the confectionary and bakery companies. Approximately 90% of the Italian harvest went to the processing companies, while the fresh market only represented 10%. Italy mainly imported hazelnuts from Turkey, Azerbaijan and Georgia and exported hazelnuts to Germany, France, and Switzerland (USDA, 2012).

Like Italy, Spain is also a net importer. It exported $13 million worth of hazelnuts but imported $18 million in 2003. Almost 74% of imports were from Turkey. Spain exports most
of its hazelnuts to other EU counties, and the main receiver is Germany, which imports 48% of the Spanish exports (USDA, 2005).

The United States is the dominant exporter of in-shell hazelnuts; it generally exports 80% of hazelnuts in-shell. In 2003, the value of in-shell hazelnuts was $24 million, compared to $8.5 million for shelled hazelnuts (USDA, 2005). The main export market for the United States in-shell hazelnuts is Hong Kong, representing 54% of the total in-shell market. Those in-shell hazelnuts were re-exported to China and other markets (USDA, 2005).

In-shell hazelnuts have a higher quality and longer shelf life than shelled hazelnuts. They are used mainly for the high value snack market, which has the highest value. Also, in-shell nuts are sold to processors who store the nuts to maintain supplies during the off-cycle years. The domestic in-shell hazelnut market brings the United States growers the highest price, since the quantity of in-shell hazelnuts imported is limited, which prevents oversupply. Also, the Oregon industry created the Hazelnut Marketing Board to control the volume and quantity of in-shell hazelnuts, and help maintain grower price (Perez and Pollack, 2007).

From the 1970s through the mid-2000s, the average hazelnut price in the United States has steadily increased at 4% annually and reached $2.30/kg in 2005. The price of hazelnuts fluctuates as the volume of nuts in storage and the current year’s production. Lower supplies lead higher prices (Perez and Pollack, 2007).

Ontario has a small local market for fresh in-shell hazelnuts. It also has some commercial interest in processed hazelnuts, such as dairy, baked food, brewery and distillery products (T. Leuty pers. comm., 2012). However, in 2006, Ferrero SpA, the manufacturer of Nutella and Ferrero Rocher chocolates, established a processing facility in Brantford, Ontario. Initially it
consumed 6000 tonnes of shelled hazelnuts annually. In 2008, Ontario imported 7,000 tonnes in-shell and shelled hazelnuts, with an average price of $ 3.28/kg for in-shell nuts and $7.93/kg for shelled nuts. The amount of hazelnuts imported from overseas implied an estimated demand of 4,800 to 6,100 hectares of trees. However, Ontario currently has only 41 hectares of hazelnut orchards. In 2011, the prices of hazelnut at farm gate or local outlets were approximately $10/kg for in-shell nut and $18/kg for shelled nut (T. Leuty pers. comm., 2012).

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1 Belarus, Bulgaria, Cameroon, Croatia, Cyprus, Cyprus, Denmark, France, Greece, Hungary, Kyrgyzstan, Moldova, Mongolia, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Tajikistan, Tunisia, Ukraine.
Other minor producing countries not recorded by FAO: Albania, Australia, Canada, Chile, Estonia, India, Serbia, Syria, UK.
Source: Fideghelli and De Salvador, 2009, compiled data from FAO
1.2 Hazelnut botany

1.2.1 Species

The term ‘hazelnut’ is used for all species of the genus Corylus (Fideghelli and De Salvador, 2009), which belongs to the Betulaceae. There are nine widely recognized species: five of those are shrubs: C. avellana L., C. americana Marshall, C. cornuta Marshall, C. heterophylla Fischer, and C. sieboldiana Blune, and four are trees: C. columa L., C. Jacquemontii Decaisne, C. chinensis Franchet, and C. ferox Wallich (Thompson et al., 1996).

Of the nine species, two are native to North America, C. americana and C. cornuta, and a third, C. avellana, has been introduced. Corylus americana is a medium-small shrub that is sucker-free. It grows from Saskatchewan to Maine, southward to Missouri and Oklahoma. This species has been used in breeding programs for its good productivity, cold hardiness, and resistance to eastern filbert blight. Corlyus cornuta overlaps the distribution of C. americana
and extends further north and west to British Columbia (Thompson et al., 1996). It has undesirable traits: long husk, small and thick-shelled nuts, but it still has breeding value for its extreme cold hardiness and reputed resistance to eastern filbert blight. European hazels, *Corylus avellana*, are large plants, with 3-10 m tall (Dale et al., 2012). The nuts of *C. avellana* are large with superior quality; this species is less hardy and used in breeding programs either exclusively or combination with other species (Thompson et al., 1996).

In North America, hazelnuts are commercially grown on the west coast from Oregon northward to British Columbia (SONG, 2003). The main production area is in Oregon, where approximate 12,900 hectares of bearing hazelnut trees are grown. Among these bearing trees, 67% are ‘Barcelona’ and 6% ‘Lewis’ (Oregon Agric. Statistics Service, 2005). The total number of trees has dropped by 8% since 2000, as Barcelona trees are removed as they die from eastern filbert blight (McCluskey et al., 2009). Other common varieties include ‘Delta’, ‘Gamma’, ‘Gem’, ‘Jefferson’, ‘Lewis’, ‘Tonda di Giffoni’, ‘Santiam’, ‘Clark’, and ‘Yamhill’ (Lawrence Fruit Tree Project, 2012). In recent years, eastern North America shows a great potential with eastern filbert blight resistant varieties in zone 6 regions of Ontario. Varieties ‘Geneva’, ‘Slate’, ‘Grimo 208D’, ‘Grimo 186M’, ‘Skinner’ and ‘Grand Traverse’ have been selected (SONG, 2003).

### 1.2.2 Hazelnut tree characteristics

Hazelnuts are monoecious. Their leaves are flat, elliptical in shape with hairs on both surfaces and a doubly serrated margin (Snare, 2008). The female inflorescences, known as burrs, are borne in tight clusters (Dale et al, 2012). While the male inflorescences, known as catkins, have 130 to 290 flowers (Pisani et al, 1968; Barbeau, 1972; Kelley, 1980). The nuts
are round or oval, (Thompson et al., 1996). Hazelnut trees begin to bear from the third year of planting, and reach moderate production in five or six years. Full production is obtained in eight to ten years (Dale et al., 2012).

Hazelnuts have a shallow root system without a significant tap root (French and French, 2009). They extend their roots just below the soil surface. A ten-year hybrid hazelnut can extend its roots 4-5 m from the crown of the plant (Fig. 1.2). The roots near the ground surface are very dense and fine (Rutter, 2004).

![Root structure of a 10-year old hybrid hazelnut.](image)

**Figure 1.2** Root structure of a 10-year old hybrid hazelnut. The picture was drawn in 2004 by Phil Rutter from University of Minnesota (Rutter, 2004)

1.2.3 Plant annual cycle

Hazelnut trees are planted either in early winter to encourage more roots before leaf development in next spring (Pollack, 1998), or in early spring while the trees are still dormant to settle the roots in the soil and be ready to grow when buds break (Leuty et al., 2012). The trees start to develop roots as long as the soil is above 4°C; the earlier the trees are planted in the
winter, the more roots will grow in next spring. Young trees with well-developed root systems grow more vigorously than those with small root systems; strong root systems ensure a better tolerance to environmental stresses during their first years (Pollack, 1998). Hazelnut trees have poor tolerance to wind, heat and water stress. The trees achieve optimum photosynthesis at 25°C to 28°C (Schulze and Küppers, 1979). Temperatures above 30°C-35°C combined with persistently low humidity may cause heat stress (Kerslake, 2012).

As a deciduous plant, hazelnuts undergo a period of dormancy during the winter. Dormancy allows hazelnuts to make physiological and morphological changes to be ready for next year’s growth. During this period, the terminal shoots stop growing, the leaves fall, the buds develop protective waxy foliar structures, and then the trees start their true winter rest (French and French, 2009). Leaf fall indicates the onset of dormancy. In North America, hazelnut leaf fall ranges over a period of eight weeks; from the last week of October to the third week of December (Thompson et al., 1996). Some varieties can tolerate as cold as –40°C when dormant (Leuty et al., 2012).

To break dormancy, a period of chilling between 0°C to 7°C is required. Chilling requirements vary depending on the cultivar and the kind of tissue (Fidghelli and Salvador, 2009). Generally, catkins need 100-990 hours, female flowers need 290-1,645 hours, and vegetative buds need 365-1,550 hours (Dale et al., 2012).

Hazelnuts produce both male and female flowers on the same plant. However, the flowers are self-incompatible, which means that the pollen from a variety is not able to fertilize the female flowers of the same variety. Therefore, compatible pollinating trees must be planted in an orchard to assure good nut set (Pollack, 1998). Hazelnuts flower from the third to fifth years
onwards (Thompson et al., 1996); In Ontario, female flowers open in early March, while male flowers open approximately 10 days later (Dale et al., 2012). A breeze during blooming is the best condition for good pollination (Fidghelli and Salvador, 2009). Pollination starts at 4°C to 5°C (Łukasiewicz, 1994). Temperatures below –8°C or above 20°C can damage pollen and stigmas at the time of pollination (Baldwin, 2004). The ovary fails to develop if it is not pollinated (Germain, 1994). The nuts reach full size in July and generally fall for several weeks from early September to the end of October (Dale et al., 2012).

1.3 Hazelnut propagation

Hazelnuts are usually propagated vegetatively. The asexual propagation gives rise to a group of genetically identical plants. Also, vegetative propagation allows the plants to be produced more rapidly than by sexual means (Hubert, 1977).

1.3.1 Layering

Layering is one of the most successful methods of hazelnut propagation (Baron and Stebbins, 1969; Howes, 1948). It produces large, well rooted trees (Hubert, 1977). Simple layering and mound layering are commonly used in hazelnut propagation. In simple layering, hazelnut stems are bent down into a 20 to 25 cm deep trench and covered with soil while they are dormant. Two to three buds on the tips of the stems remain above the soil surface (Roots of Peace, 2007). Usually, 26,000 to 29,600 layers are obtained per hectare (Achim et al., 2001).

Mound layering: originally, growers mounded the soil surrounding the base of an established tree and allowed the suckers to root (Fuller, 1910). Commercial layering beds are specially prepared in old orchards by coppicing the trees at ground level in winter, and allowing
new shoots to grow in next spring (Hubert, 1977). The new shoots are usually girdled at the base in early summer, and rooting hormones applied in a one inch wide band immediately above the girdle. One hundred to two hundred liters of sawdust are mounded up over the rooting area to hold the moisture. New rooted plants are ready to transplant in the following spring after dormancy (Braun, 2010).

Layering allows trees to be propagated while they remain connected to the mother plants. This allows the new plants to get water and nutrients from the mother plants until their root system is established. This method is effective and produces a high survival rate (Hubert, 1977). However, the plants are expensive to produce. Layering consumes a lot of hand labour, and needs a large propagation area with a relatively low plant yield. One has to maintain suitable mother plants (Hartmann and Kester, 1968), even though there may be no market available for young trees. Also, the new plants from simple layering have suckering growth habit (Hubert, 1977), which increases the cost of sucker control.

1.3.2 Root cuttings

Propagation from cuttings is a simple, rapid and inexpensive method (Hartmann and Kester, 1968). However, it is influenced by environmental conditions (Bush, 1953; Shreve, 1972), chemical treatments (Barry and Sachs, 1968; Doran, 1957; Kawase, 1965), and physiological age of the cuttings (Perry and Vines, 1972; Rhodes, 1968). The various influencing factors make propagation difficult to control, although many studies have been done to make this more consistent.

Generally, one uses two types of cuttings for hazelnut propagation: softwood and hardwood. Softwood cuttings are first year shoots taken in June and treated with 1000-3000 ppm IBA
11

(Kantaric and Ayfer, 1994), then in mid July treated with 1000 ppm IBA (Solar et al., 1994). Hardwood cuttings are taken at the end of winter and treated with 3-5000 ppm IBA (Kantaric and Ayfer, 1994). Highly aerated soil media (Lagerstedt, 1968), ample light, and low foliar temperature are beneficial for rooting (Gonderman, 1971; Hess, 1965).

1.3.3 Grafting

   Grafting is commonly used for plant propagation in commercial nurseries (Roots of Peace, 2007), but is less used on hazelnut than the previous methods (Fideghelli and Salvador, 2009). This method allows desirable varieties to be grafted onto non-suckering rootstocks (Pollack, 1998) to eliminate the cost of sucker control. Corylus colurna and Corylus chinensis are common rootstocks (Korac et al., 1997), the former one has been found to improve drought and frost resistance (Nimic-Todorovic et al., 2008) and increase the nut and kernel size (Miletic et al., 2008). However, to ensure successful grafts, the scion wood should be healthy, fully dormant, and collected in January and stored moist at -1°C, and then be grafted when it still dormant. Machine grafting has been tried, but was found less successful than grafting by hand (Hubert, 1977).

1.3.4 Micropropagation

   Micropropagation is an advanced propagation method that allows one to rapidly generate a large number of genetically identical plants. It is an alternative to traditional propagation. A successful micropropagation proceeds through a series of stages: initiation of aseptic cultures, shoot multiplication, rooting of microshoots and hardening and field transfer of micropropagated plants. Explants are sterilized and maintained in aseptic conditions throughout the procedure. Artificial growth media are used to provide explants with carbohydrate, macro-nutrients and
micronutrients. Plant growth regulators are used to stimulate shoot and root growth; 6 benzylaminopurine (BAP) and gibberellic acid (GA₃) are commonly used for bud proliferation and embryo germination, and indole butyric acid (IBA), naphthalene acetic acid (NAA) are commonly used to induce and elongate roots (Payghamzadeh and Kazemitabar, 2011).

Micropropagation has been widely used in some woody species for a commercial scale (Damiano et al., 2005). Like other woody species, mature hazelnut tissues are the most desired for micropropagation, since many tree features change during maturation, which are not possible to select during the juvenile phase (Nas and Read, 2001). The success of micropropagation of hazelnuts depends on the physiological phase of the primary explants; the nodal shoot collected in spring or the cold-treated single buds derived from dormant plants are most suitable for commercial-scale propagation (Bacchetta, 2008). Also, the culture medium (Nas and Read, 2004) and hormone concentration determine the success of hazelnut culture (Bacchetta, 2008). It was found that hazelnut microshoots treated with 1000 ppm IBA solution for 10 seconds and transplanted in peat pellets had the highest survival rate of 97% after three months’ culture (Nas and Read, 2004).

1.4 Main hazelnut cultivation problems in North America

There were two major limits to growing hazelnuts in North America. One is eastern filbert blight and the second is lack of cold hardness in eastern United States and Canada.

1.4.1 Eastern filbert blight

Eastern filbert blight is a fungal disease caused by Anisogramma anomala (Peck) E. Müller (Thompson et al, 1996; Farris, 2000). It invades the twigs and eventually kills the plants. The
disease is endemic to eastern North America, from Maine to Saskatchewan, south to Georgia and Louisiana, and west to Oklahoma (Gleason and Cronquist, 1998). *C. americana* is the host for the fungus, while *C. avellana* is very susceptible to the disease.

Many breeding studies have been done to combine the higher quality, larger nut size, thinner shells, and free-falling traits of *C. avellana* with the disease resistance and cold hardiness of *C. americana*. Also, ‘Gasaway’, the first blight-resistant *C. avellana* cultivar was crossed with several susceptible cultivars (Thompson et al., 1996). In the past thirteen years, Oregon State University released four disease resistant kernel varieties: ‘Clark’, ‘Sacajawea’, ‘Santiam’, and ‘Yamhill’ in 1999, 2005, 2006 and 2008 respectively (Azarenko et al., 1999; Mehlenbacher et al., 2006; McCluskey et al., 2009), and four disease resistant pollenizers: ‘Gamma’, ‘Delta’, ‘Epsilon’ and ‘Zeta’ in 2002 (Mehlenbacher and Smith, 2004).

1.4.2 Lack of cold hardiness

Hazelnuts have wide range of adaption to cold weather. *C. heterophylla* stem sections can survive at as low as -70°C (Sakai, 1978), and the vegetative buds of several *C. avellana* cultivars can adapt to -40°C (Hummer, 1986). However, for most commercial cultivars, a cold winter is a challenge. After a winter with -35°C in New York, the stems of ‘Barcelona’ and ‘Montebello’ were severely injured, and up to 20% of ‘Daviana’ and ‘Gasaway’ were damaged. Also, 50%-90% of catkins of ‘Barcelona’, ‘Montebello’ and ‘Daviana’ were injured (Slate, 1933). The killing point for most unopened buds was -12°C; -3°C when the first leaf appeared; -1°C when the second or third leaf extended (Tombesi and Cartichini, 1974). Generally, pistillate flowers were less hardy than staminate flowers in October; the situation is opposite in January (Hummer, 1986).
1.5 Nursery techniques

There are several nursery techniques which can help plants acclimate to the environment and make plants grow faster. These evolved nursery methods may change plant physical structures or modify plant growing environment to promote growth.

1.5.1 Air root pruning technology

Air root pruning is a technique that kills the tips of the roots by exposing them to the air. This technique stimulates the plants to constantly produce new and healthy branched roots. Unpruned roots may grow around container in a constricted pattern; the roots may spiral, twist, kink or become strangled (Walker, 2005). Marler and Willis (1996) found that *Averrhoa carambola*, *Dimocarpus Longan* and *Mangifera indica* seedlings had increased the proportion of roots in the upper half of the rootball when they were grown in air-root-pruning containers. Also, air pruned plants of *Elaeagnus x ebbingei* produced roots earlier and were able to be transplanted three months earlier compared with regular liner production (Maguire and Harun, 2007).

The ellepot is a new type of plant pot made of degradable paper which allows air pruning when the roots pierce the wall. This stimulates plants to produce many fibrous roots and avoid root deformation. The degradable walls also make transplanting easier and avoid damage to the roots (A.M.A, 2012).

Root production method (RPM™) is an innovative technique developed by a forest nursery in the US (Forrest Keeling Nursery, Elsberry, MO). This technique combines bottomless containerization on raised open benches, seed selection, seed handling and air root pruning to

1.5.2 Culture environments

Outdoor and greenhouses are the two most commonly used environments; both have advantages and disadvantages. Recently, an advanced cultural greenhouse named the retractable roof greenhouse was introduced to the market to avoid the disadvantages of other environments.

Outdoor production provides plants with natural conditions. Compared to a greenhouse, plants get direct sunlight and excellent air flow, which improves transpiration and consequently facilitate water and nutrient uptake. However, as the weather changes daily and seasonally, production conditions are inconstant; plants also sometimes suffer from extreme environmental conditions, such as high sunlight radiations, extreme air temperature, humidity and rainfall. These factors often cause plant water stress. Outdoor container productions even have more problems. The soil temperature in a container that is exposed to sunlight can fluctuate up to 30°C and sometimes reaches as high as 50°C, which can damage plant roots and cause water stress or even kill the plants. Water stress will trigger more root growth, which may lead to lost production. Also, plants under water stress are more susceptible to disease (Vollebregt, 2004).

Greenhouse systems improve growing conditions for crops. They protect plants from adverse weather conditions and attacks from animals (Vox et al., 2010). The modified environment allows one to obtain fresh crops throughout the year (Loredana and Mircea, 2011) and usually allows higher yield (Vox et al., 2010). However, the greenhouse covering
structures also block air flow, lead to CO$_2$ deficiency, high air temperature and high humidity. Also, the greenhouse cover filters sunlight and can cause poor light quality and quantity. These can reduce plant transpiration and cause localized nutritional deficiencies. The low transpiration and evaporation may keep the soil media wet and essentially increase the supply of available water, which leads plants to produce succulent leaves with thinner cuticles and encourages a smaller root/shoot ratio. Greenhouse grown plants are more susceptible to insects, disease and environmental stress during shipping and after transplanting (Vollebregt, 2004). To operate a conventional greenhouse requires a large amount of energy; air and root zone heating systems, ventilation systems, cooling systems (Loredana and Mircea, 2011) and artificial lights are usually employed in conventional greenhouses (Vox et al., 2010).

The retractable roof greenhouse is a computer controlled system with several sensors outside and inside the greenhouse. The roof and walls of the greenhouse can be opened to various degrees depending on the weather conditions to keep the crops in optimum growing conditions as long as possible (Cravo Equipment Ltd., 2012). The retractable roof greenhouse can provide plants with optimal sunlight conditions without the risk of high soil temperature. In the cool days, the roof and walls are opened to provide the plants with direct sunlight, because direct sunlight contains most photosynthetically active radiation (Both, 2001).

Like the retractable roof greenhouses, hinged roof greenhouses can also adjust their roof’s position. However, plants under hinged roof greenhouses sometimes may not get desired sunlight, because the folded roofs can block the sunlight especially in the early morning and late afternoon; the amount of sunlight enter the hinge roof greenhouse are affected by the angle of incidence of the sunlight (Fig 1.3). Retractable roof greenhouses roll the polyfilms with tubes to control the position of the roof, which allows sunlight to enter the greenhouse from any angle,
so that plants can obtain full sunlight at any time of a day (Fig 1.4) (Vollebregt, 2004).

However, in the hot summer days, the direct sunlight brings too much radiant energy, which may lead to excessive soil temperature and cause root damage. Therefore, the roof of retractable roof greenhouse will be closed to certain degrees for shading (Mathers, 2003). Soil temperature was lower under clear and white poly roof than that under 63% black shade cloth (Vollebregt, 2004). According to its photosynthetic rate, diffuse light is more efficient than direct light in hot summer days, because the cool soil protects the root system and consequently improves the photosynthetic capacity of the plants (Mathers, 2003).

Figure 1.3 Demonstration of the angles of the sunlight incidence from morning to evening in a hinge roof greenhouse (Vollebrege, 2004).
Figure 1.4 Completely retracted roof of retractable roof greenhouse. Sunlight can enter the greenhouse from any angle (Vollebrege, 2004).

On the other hand, in the winter, the roof and walls of the retractable roof greenhouse will be closed during the day to increase the temperature inside the greenhouse, and at night to help maintain the heat captured during the day (Mathers, 2003). Therefore, the temperature inside the retractable roof greenhouse is more stable than that outside the greenhouse throughout the year, which is beneficial for nutrient uptake. The stable temperature allows the fertilizer to be released steadily, because the mineralization of composted container substrate is affected by temperature (Kraus et al., 2000). Hence, the plants have an ideal temperature range to optimally absorb mineral nutrients (Pisek et al., 1973). For example, Antirrhinum majus cv. Peoria had best uptake of NO$^3$-, NH$^{4+}$, P, K, Ca, Mg, B, Fe, Mn and Zn at root-zone temperature ranged from 15 to 29°C, but had poorer nutrient uptake at 8°C and 36°C (Hood and Mills, 1994).

The retractable roof greenhouse extends the growing season by modifying the microclimate; it raises the minimum soil and air temperatures in the cool months (Schuch et al., 2008) by
making full use of sunlight. It also maximizes ventilation, modifies extreme light levels in summer, protect crops from frost, storms and summer monsoons (Nelkin and Schuch, 2004). Many studies have showed that crops had better growth under retractable roof greenhouse. For example, Basil (Ocimum basilicum) and lemon grass (Cymbopogon citrates) had superior biomass and quality compared to those grown in the field in semi-arid climate (Nelkin and Schuch, 2004). Rose cultivar ‘Mr. Lincoln’ and ‘Oregold’ were taller with greater diameter and earlier leaf emergence, and produced more flowers than those forced in full sun (Schuch et al., 2008). Containerized tree liners had lower mortality and faster growth when out-planted into fields than those from conventional bareroot production (Mathers et al., 2009).

1.6 Objectives and hypotheses

Ellepots, retractable roof greenhouse and root pruning technology were found to be beneficial for the growth of some species. Also, the transplant timings influenced the growth of many species in the field. However, there has been little previous research into the effects of these nursery techniques upon the growth of hazelnuts in Ontario.

The objectives of my study were to determine an appropriate culture technique to grow suitably sized hazelnut plants in one year, and compare its cost with a more standard cultural method.

My hypotheses are: 1. Hazelnut plantlets grown in ellepots would grow faster than those grown in plastic pot, as ellepot can stimulate plants to produce more branching roots. 2. The retractable roof greenhouse and root pruning technology would improve the growth of hazelnut seedlings compared to outdoor nursery, because they can optimize the microclimate and change
plant root structure respectively.  3. Fall transplanting might encourage hazelnut roots to development before dormancy and enable the trees to grow more rapidly in the following season.
Chapter 2  The Effect of Nursery Techniques on the Growth of Hazelnut

2.1 Introduction

As Ferrero SpA opened their North America manufacturing plant in Brantford Ontario in 2006, Ontario potentially has a demand for 4,800 to 6,100 hectares of hazelnut trees. However, only 41 hectares of hazelnut orchard have been planted, and very little research has been done in Ontario on hazelnut nursery production.

To develop a hazelnut industry in Ontario, one of the issues that needs to be overcome is to supply many trees of suitable cultivars rapidly. Usually, it takes two years to grow suitably sized plants in the nursery (Stahl, 2007).

Micropropagation is a rapid and disease-free propagation method. It allows one to obtain clonally uniform plants. This technique is widely used in woody species for commercial propagation (Damiano et al., 2005), such as woody bamboo, chestnut and azalea (Gielis and Oprins, 2012; De Paoli et al., 2012; Rose et al., 2002).

There are also several nursery techniques which can make plants grow faster. One such technique is the ellepot; a new type of plant pot made of degradable paper which allows air pruning when the roots pierce the wall. This stimulates plants to produce many fibrous roots and avoid root deformity. The degradable walls also make transplanting easier and avoid damaging the roots (A.M.A, 2012).

A retractable roof greenhouse is a greenhouse system which can optimize the plant’s growth environment by adjusting the microclimate. The greenhouse is computer controlled with several sensors that can response to rain, wind, light and temperature. It is used to culture
basil, lemon grass, roses and containerized trees (Nelkin and Schuch, 2004; Schuch et al., 2008; Mathers et al., 2009).

Root pruning technology combines efficient growth and rapid root branching by root air-pruning to produce an extensive fibrous root system (Earthgen Ltd., 2012), and consequently improve plants’ uptake of water and nutrients.

Transplant timing from nursery to field is another factor which needs to be considered when hazelnut orchards are established rapidly. One can transplant hazelnut trees from a nursery pot to the ground either in early winter (Pollack, 1998), or in early spring to settle the roots in the soil and ready to grow when the buds break (Leuty et al., 2012). A study on *C. colurna* indicated that hazelnuts transplanted in fall started to grow roots 1-2 weeks before bud break, while those transplanted in spring began to develop roots 3 weeks after bud break (Harris et al., 2001).

2.2 Experiment 1-Culture of seed-propagated hazelnuts in May

2.2.1 Materials and methods

Two hundred and seventy two hazelnut seeds of a European x American hybrid selection were obtained from a local grower Martin Hodgson in Courtland, Ontario.

The seeds were soaked in water for 24 h on March 3, 2011 to soften the shell. The seeds were then cracked with forceps and soaked in 75 ppm GA$_3$ (Sigma-Aldrich Canada Ltd., Oakville, ON, Canada) for another 24 hours at room temperature for stratification (Jarvis, 1975). The stratified seeds were planted in 24-cell plastic trays (JVK, St Catharines, ON, Canada) (5*5*6 cm) with Sunshine® Mix 4 soil media (Sun Gro Horticulture Canada Ltd, Vancouver,
BC, Canada) and placed in the mist at University of Guelph, Ontario, in 12 weeks until they were 10-15 cm tall. Fifty one seedlings out of 272 seeds were obtained, and 48 relatively uniform seedlings were selected for the experiment.

The effects of two pot types (ellepot and plastic pot), three culture techniques (Outdoor, retractable roof greenhouse and root pruning technology) and two transplant timings (fall 2011 and spring 2012) on hazelnut growth were tested.

The seedlings were moved to Vineland Research and Innovation Centre, Vineland Station, Ontario on May 27, 2011. They were divided into two groups as follows: the seedlings were ranked from short to tall and paired together in order. Then one plant of each pair was randomly selected to become the first group and the remainder became the second group. This grouping method was used in all experiments.

Ellepots and plastic pots were tested. The plants were planted AMA grow mix (A.M.A. Plastics Ltd, Kingsville, ON, Canada) one group in 130mm*130 mm* 70 mm (1200 cu cm) plastic pot (Kord Product Inc., Brampton, ON, Canada) and the other in 120mm*120mm* 90mm (1357 cu cm ) Ellepot (A.M.A. Plastics Ltd, Kingsville, ON, Canada).

The seedlings were tied to bamboo stakes. One tablespoon (18g) 19-04-10 Polyon® nursery+ Minors slow release fertilizer (Agrium Advanced Technologies®, Brantford, ON, Canada) was applied to each pot. All pots were placed on the bench in a greenhouse at 25 °C for 4 weeks. A sachet of Amblyseius Swirkii (Biobest®N.V., Westerlo, Belgium) was placed among every 4 pots for pest control.
After 4 weeks, on Jun 26, 2011, the seedling height from the soil surface to the tip of the tallest leaf, and the trunk diameter at 6 cm from the soil surface and were measured, the number of nodes counted, and the length and width of every fifth leaf from the base of the stem were measured.

The seedlings from each of the two pot treatments were sub-divided into three groups; six replications per group. Each group was placed in one of three environments: either outdoors, or in a retractable roof greenhouse (Cravo equipment Ltd., Branford, ON, Canada) at Vineland Research and Innovation Center, or treated with root pruning technology by Earthgen International Ltd. (Mississauga, ON, Canada) at Dunnville, Ontario from Jun 27, 2011 to Oct 3, 2011.

The seedlings at Vineland were transplanted into 11-liter plastic containers (27*27*23 cm) (JVK, St. Catharines, ON, Canada) that filled with Fafard soil media (Conrad Fafard Inc., Agawam, MA, USA). Three tablespoons (54 g) of 19-04-10 Polyon® nursery+Minors slow release fertilizer were applied to the seedlings under outdoor environment and retractable roof greenhouse. The automatic irrigation system was set at 50 ml/minute for 3-6 minutes, 4 times a day for a total of approximately 600-1200 ml of water per day per pot; the amount of water depended on the weather. The trunks were tied to bamboo stakes, and suckers were removed by hand every week.

The retractable roof greenhouse oriented N-S with flat-roof and roll-up side that are made of clear woven-polyethylene. The roof was set to close above 26.6°C or below 10°C. The side wall was set to open when outdoor temperature exceeded 21°C.
The same variables that were used in the pot experiment were measured every two weeks from Jun 21, 2011 to October 3, 2011. The trunk diameter was measured at 15 cm from soil surface.

The seedlings from each of treatment of part two were sub-divided into two groups to be transplanted to field either in late fall, on Nov 4, 2011 or in spring, on April 11, 2012.

The seedlings were planted in one row oriented N-S at Butternut Farm, Courtland, ON, Canada, with four blocks. Trees were planted 3 m apart in the row. The root balls were cut perpendicularly from the base of the seedlings in order to disperse the roots, and dripped in water before planting. Thirty-centimeter round coconut fiber mats were used to mulch the trees. The trees were tied to bamboo stakes and protected by plastic tree wraps. Field soil nutrients were adjusted to the recommend standard using 15-15-15 slow release fertilizer (Cargill, Courtland, ON, Canada). Soil pH was raised to over 6 with C.I.L. dolomite lime (Premier Tech, Quebec, ON, Canada).

The number of seedlings which died back, (dried from the tips but still survived), was counted. Also, the number of seedlings which survived was recorded. The height, trunk diameter at 15 cm from soil surface, leaf number and the length and width of the leaf were measured every 20 days from March 17, 2012. The leaf area of a seedling was calculated with the following formula:

\[ \text{Estimated leaf area} = \text{leaf area per leaf} \times \text{node number} \]

\[ \text{Leaf area per leaf} = \frac{\sum \pi \times (\text{length}/2) \times (\text{width}/2)}{\text{the number of measured leaves}} \]
2.2.2 Statistical analysis

The experiment was arranged as a split-split plot design, with the pot type as the main plot, culture technique as the subplot and transplant timing as the sub-sub plot. Analysis of variance was performed on plant height, stem diameter, leaf area, node number and leaf number using PROC GLM in SAS 9.2 (SAS Institute, Cary, NC) and the regression analysis done for the three culture techniques with date as the independent variable. Replication was a random effect and pot type, culture technique and transplant timing combinations were fix effects. Tukey test was used to generate the mean growth rate of each combination treatment.

The correlations between the four variables were calculated. Then they were analyzed by Principal Components Analysis (PROC PRINCOMP in SAS 9.2, SAS Institute, Cary, NC). The vectors whose eigenvalue was over 1 were used for further analysis (Conway and Huffcutt, 2003). The scores from these vectors were analyzed in the same way as the original data.

2.2.3 Results

Seedlings grown in ellepots and plastic pots did not differ significantly for height ($P=0.22$), node number ($P=0.96$), truck diameter ($P=0.27$) and leaf area ($P=0.58$). Seedlings cultured in ellepots were 44.7 cm tall with 16 nodes, 923 cm$^2$ leaf area and 3.86 mm trunk diameter on average. While seedlings from plastic pots had an average height of 46.8 cm with 16 nodes, 871 cm$^2$ leaf area and 3.99 mm trunk diameter after four weeks’ culture.

All the variables measured varied significantly for the three culture techniques, but they did not differ significantly for pot types and pot type*culture technique interactions (Table 2.1). Seedlings under retractable roof greenhouse grew tallest and had the greatest trunk diameter, most nodes and the largest leaf area, while those treated with root pruning technology grew
least had the smallest trunk diameter and fewest nodes and smallest leaf area (Table 2.2). A heavy hail storm occurred at Dunnville on September 2, 2011 and damaged the seedlings treated with root pruning technology. Over the growing season, all variables in the root pruning technology increased slowly from late June to early August and hardly grew from late August. Seedlings under the outdoor environment had moderate growth rates, height, node number and leaf area stopped increasing at the end of August, but trunk diameter kept increasing for another two weeks. However, seedlings under retractable roof greenhouse had relatively constant high increase rates on all variables during the whole growing season (Fig. 2.1-2.4).

All the variables were highly positively correlated (Table 2.3) in the principle component analysis: the first principle component, described as plant vigor, accounted for 89% of variance, explained how the seedlings developed; all variables increased simultaneously as seedlings grew (Table 2.4). Generally, hazelnut seedlings under retraceable roof greenhouse had a longer growing season; seedlings kept a high growth rate from late June to October. However, the growing season under the other two treatments almost ended in early September (Fig. 2.5).

All the variables in the field differed significantly for the culture techniques and their interactions with transplant timing. Trunk diameter differed significantly for the interactions with pot types and culture techniques. The leaf number differed significantly for all the factors except block and pot type interaction, and pot types and transplant timing interaction (Table 2.5).

Seedlings previously grown in the outdoor environment grew fastest in height, leaf number and leaf area, while seedlings grown in the retractable roof greenhouse increased most in trunk
diameter. Seedlings pre-treated with root pruning technology grew least. Seedlings transplanted in the spring developed more leaves than those transplanted in the fall. Ellepot combined with outdoor treatment increased in height fastest, but when combined with retractable roof greenhouse increased most in trunk diameter. The plastic pot combined with the outdoor treatment developed the most leaves and the largest leaf area. The interaction of the outdoor environment with the spring transplant timing made the fastest growth in height, leaf number and leaf area, while the trees treated with the root pruning technology and transplanted in fall 2011 grew slowest. The retractable roof greenhouse combined with fall transplant timing increased most in trunk diameter (Table 2.6).

For the field results, all the variables except for trunk diameter were highly correlated (Table 2.7). The first principle component, accounted for 58.5% of variance (Table 2.8), described the vigour of the seedlings. All the variables increased as the seedlings grew. Seedlings grown outdoors in the nursery had the best vigour (Table 2.9). The second principle component, accounted for 25.2% of variance (Table 2.8), explained the plants’ response to high temperature and high wind. The growth rate of leaves declined to reduce transpiration and evaporation. But the growth rate of trunk diameter increased to anchor the seedlings in the wind. Seedling grown using root pruning technology and transplanted in the spring expressed this principle component most strongly, while seedlings grown outdoors in the nursery and transplanted in the spring expressed this component least (Table 2.9).

Some hazelnut seedlings died back during the season; the plants were dried from the tip downwards, and some seedlings died completely. There was no significant difference on dieback rate (40%) and survival rate (94%) either among the three technique treatments, or
between the two transplant timing treatments. By August 13, 2012, several trees produced catkin. However, only the trees pre-grown under retractable roof greenhouse had catkin.

Table 2.1 Variance analysis of the effects of two pot types (ellepot and plastic pot) and three culture techniques (outdoor, retractable roof greenhouse and root pruning technology) on the seed-propagated hazelnuts’ height, node number, trunk diameter and leaf area. The data was collected on Oct 3, 2012. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario.

<table>
<thead>
<tr>
<th>Source</th>
<th>Height</th>
<th>Diameter</th>
<th>Node number</th>
<th>Leaf area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot type</td>
<td>0.83</td>
<td>0.81</td>
<td>0.57</td>
<td>0.83</td>
</tr>
<tr>
<td>Culture technique</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Pot type *culture technique</td>
<td>0.86</td>
<td>0.85</td>
<td>0.69</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Table 2.2 Mean height, node number, trunk diameter and leaf area of seed-propagated hazelnut seedlings from June 27 to October 3, 2011 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario (n=48).

<table>
<thead>
<tr>
<th>Technique</th>
<th>Height (cm)</th>
<th>Node number</th>
<th>Diameter (mm)</th>
<th>Leaf area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retractable roof greenhouse</td>
<td>108.4 a</td>
<td>27.3 a</td>
<td>6.9 a</td>
<td>2639 a</td>
</tr>
<tr>
<td>Outdoor</td>
<td>76.8 b</td>
<td>22.5 b</td>
<td>6.1 b</td>
<td>1528 b</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>66.9 c</td>
<td>20.3 c</td>
<td>5.6 c</td>
<td>1272 c</td>
</tr>
</tbody>
</table>

*Values in the same column with different letters differ significantly under Tukey test (P ≤ 0.05).
Table 2.3 The correlation matrix of height, node number, trunk diameter and leaf area of seed-propagated hazelnut seedlings from June 27 to October 3, 2011 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario (n=48).

<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>Node</th>
<th>Diameter</th>
<th>Leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.94***</td>
<td>0.90***</td>
<td>0.84***</td>
<td></td>
</tr>
<tr>
<td>Node</td>
<td></td>
<td>0.88***</td>
<td>0.80***</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
<td>0.75***</td>
<td></td>
</tr>
<tr>
<td>Leaf area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** P=0.01

Table 2.4 Three major principle component analysis vectors of seed-propagated hazelnut seedlings’ height, node number, trunk diameter and leaf area from June 27 to October 3, 2011 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario.

<table>
<thead>
<tr>
<th></th>
<th>Prin 1</th>
<th>Prin 2</th>
<th>Prin 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.52</td>
<td>-0.10</td>
<td>-0.28</td>
</tr>
<tr>
<td>Node</td>
<td>0.51</td>
<td>-0.22</td>
<td>-0.60</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.50</td>
<td>-0.48</td>
<td>0.71</td>
</tr>
<tr>
<td>Leaf area</td>
<td>0.47</td>
<td>0.84</td>
<td>0.21</td>
</tr>
<tr>
<td>% variance accounted</td>
<td>89.0%</td>
<td>6.8%</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

*Prin 4 was omitted, because it only took 1% of variance.
Table 2.5 Variance analysis of the effect of two pot types (ellepot and plastic pot), three culture techniques (outdoor, retractable roof greenhouse and root pruning technology) and two transplant timings (fall 2011 and spring 2012) on the amount of increased height, truck diameter, leaf number and leaf area of seed-propagated hazelnuts in the field. The data was collected from March 17 to August 13, 2012. The trees were planted in Butternut Farm, Courtland, Ontario.

<table>
<thead>
<tr>
<th>Source</th>
<th>Height</th>
<th>Diameter</th>
<th>Leaf number</th>
<th>Leaf area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>0.49</td>
<td>0.33</td>
<td>0.82</td>
<td>0.57</td>
</tr>
<tr>
<td>Pot type</td>
<td>0.076</td>
<td>0.9</td>
<td>0.21</td>
<td><strong>0.041</strong></td>
</tr>
<tr>
<td>Block*pot type</td>
<td>0.20</td>
<td>0.61</td>
<td>0.30</td>
<td>0.32</td>
</tr>
<tr>
<td>Culture technique</td>
<td>0.012</td>
<td>0.0041</td>
<td>0.024</td>
<td><strong>0.0028</strong></td>
</tr>
<tr>
<td>Pot type*culture technique</td>
<td>0.17</td>
<td><strong>0.0049</strong></td>
<td>0.11</td>
<td><strong>0.015</strong></td>
</tr>
<tr>
<td>Block<em>pot type</em>culture technique</td>
<td>0.64</td>
<td>0.52</td>
<td>0.071</td>
<td><strong>0.035</strong></td>
</tr>
<tr>
<td>Transplant timing</td>
<td>0.084</td>
<td>0.55</td>
<td>0.38</td>
<td><strong>0.027</strong></td>
</tr>
<tr>
<td>Pot type* transplant timing</td>
<td>0.54</td>
<td>0.57</td>
<td>0.86</td>
<td>0.82</td>
</tr>
<tr>
<td>Culture technique* transplant timing</td>
<td><strong>0.023</strong></td>
<td>&lt;.0001</td>
<td><strong>0.072</strong></td>
<td><strong>0.0038</strong></td>
</tr>
<tr>
<td>Pot type<em>culture technique</em>transplant timing</td>
<td>0.093</td>
<td>0.014</td>
<td>0.23</td>
<td><strong>0.018</strong></td>
</tr>
</tbody>
</table>
Table 2.6 Increased height, trunk diameter, leaf number and leaf area of seed-propagated hazelnut seedlings transplanted in the fall 2011 or spring 2012, after being grown initially in two pot types and grown during 2011 in three culture techniques during May 17 and August 13, 2012. The seedlings were planted in Butternut Farm, Courtland, Ontario.

<table>
<thead>
<tr>
<th>Treatments and treatment combinations</th>
<th>Height (cm)</th>
<th>Diameter (mm)</th>
<th>Leaf Number</th>
<th>Leaf area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor</td>
<td>21.7 a</td>
<td>1.0 b</td>
<td>88.7 a</td>
<td>4056 a</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>13.1 b</td>
<td>1.7 a</td>
<td>54.6 b</td>
<td>2805 ab</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>14.4 b</td>
<td>1.4 ab</td>
<td>32.6 b</td>
<td>1494 b</td>
</tr>
<tr>
<td>Fall, 2011</td>
<td>14.4 a</td>
<td>1.3 a</td>
<td>46.2 b</td>
<td>2522 a</td>
</tr>
<tr>
<td>Spring, 2012</td>
<td>18.4 a</td>
<td>1.4 a</td>
<td>71.1 a</td>
<td>3049 a</td>
</tr>
<tr>
<td>Ellepot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>22.7 a</td>
<td>0.7 b</td>
<td>54.1 b</td>
<td>721 ab</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>13.0 ab</td>
<td>2.0 a</td>
<td>59.3 b</td>
<td>667 ab</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>20.2 ab</td>
<td>1.3 ab</td>
<td>32.0 b</td>
<td>770 b</td>
</tr>
<tr>
<td>Plastic pot</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>20.7 ab</td>
<td>1.3 ab</td>
<td>123.2 a</td>
<td>770 a</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>13.1 ab</td>
<td>1.3 ab</td>
<td>49.9 b</td>
<td>721 ab</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>8.6 b</td>
<td>1.5 ab</td>
<td>33.3 b</td>
<td>943 b</td>
</tr>
<tr>
<td>Fall, 2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>19.0 ab</td>
<td>0.8 c</td>
<td>46.8 b</td>
<td>2881 ab</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>15.6 ab</td>
<td>2.3 a</td>
<td>63.1 b</td>
<td>3507 ab</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>8.6 b</td>
<td>0.9 c</td>
<td>28.8 b</td>
<td>1177 b</td>
</tr>
<tr>
<td>Spring, 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>24.3 a</td>
<td>1.2 bc</td>
<td>130.5 a</td>
<td>5232 a</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>10.5 b</td>
<td>1.1 c</td>
<td>46.2 b</td>
<td>2103 ab</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>20.2 ab</td>
<td>2.0 ab</td>
<td>36.5 b</td>
<td>1812 ab</td>
</tr>
</tbody>
</table>

*Values in the same column with different letters differ significantly under Tukey test ($P≤0.05$)
Table 2.7 The correlation matrix of increased height, trunk diameter, leaf number and leaf area of seed-propagated hazelnut seedlings from May 17 to August 13, 2012. The seedlings were planted in Butternut Farm, Courtland, Ontario.

<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>Diameter</th>
<th>Leaf Number</th>
<th>Leaf area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.26^{NS}</td>
<td>0.39^{**}</td>
<td>0.52^{***}</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>0.08^{NS}</td>
<td>0.19^{NS}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf Number</td>
<td></td>
<td></td>
<td>0.95^{***}</td>
<td></td>
</tr>
<tr>
<td>Leaf area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** P=0.05, *** P=0.01, NS=not significant

Table 2.8 Three major principle component analysis of seed-propagated hazelnut seedlings’ increased height, node number, trunk diameter and leaf area from May 17 to August 13, 2012. The seedlings were planted in Butternut Farm, Courtland, Ontario.

<table>
<thead>
<tr>
<th></th>
<th>Prin 1</th>
<th>Prin 2</th>
<th>Prin 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.46</td>
<td>0.28</td>
<td>-0.84</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.22</td>
<td>0.88</td>
<td>0.41</td>
</tr>
<tr>
<td>Leaf Number</td>
<td>0.59</td>
<td>-0.33</td>
<td>0.30</td>
</tr>
<tr>
<td>Leaf area</td>
<td>0.63</td>
<td>-0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>% variance accounted</td>
<td>58.5%</td>
<td>25.2%</td>
<td>15.4%</td>
</tr>
</tbody>
</table>

*Prin 4 was omitted, because it only took 0.8% of variance

Table 2.9 Means of the scores of vector 1 and vector 2 of six treatment combinations during May 17 to August 13, 2012. The seedlings were planted in Butternut Farm, Courtland, Ontario.

<table>
<thead>
<tr>
<th></th>
<th>Prin 1</th>
<th>Prin 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall,2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>0.15 ab</td>
<td>-0.32 c</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>0.21 ab</td>
<td>0.25 ab</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>-1.15 b</td>
<td>-0.42 bc</td>
</tr>
<tr>
<td>Spring,2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>2.18 a</td>
<td>-0.98 c</td>
</tr>
<tr>
<td>Retractable roof greenhouse</td>
<td>-0.92 b</td>
<td>-0.31 abc</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>-0.11 ab</td>
<td>0.71 a</td>
</tr>
</tbody>
</table>

*Values in the same column with different letters differ significantly under Tukey test (P≤0.05)
Figure 2.1 Regression of the growth of height of seed-propagated hazelnut seedlings during from June 27 to October 3, 2011 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario where heavy hail on September 2, 2011 damaged the plants. The regressions between height and each treatment were height=$36.9618+0.5083\text{day}-0.0068\text{day}^2$, height=$40.6836+1.2183\text{day}-0.0068\text{day}^2$ and height=$45.9225+0.8758\text{day}-0.0068\text{day}^2$ for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.

Figure 2.2 Regression of the growth of node number of seed-propagated hazelnut seedlings from June 27 to October 3, 2011, under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario where heavy hail on September 2, 2011 damaged the plants. The regressions between node number and each treatment were node number=$13.3601+0.4141\text{day}-0.0019\text{day}^2$, node number=$13.3804+0.3177\text{day}-0.0019\text{day}^2$ and node number=$14.0998+0.2538\text{day}-0.0019\text{day}^2$ for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.
Figure 2.3 Regression of the growth of trunk diameter of seed-propagated hazelnut seedlings from June 27 to October 3, 2011, under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario where heavy hail on September 2, 2011 damaged the plants. The regressions between trunk diameter and each treatment were \( \text{diameter} = 2.9886 + 0.1113 \text{day} - 0.0004 \text{day}^2 \), \( \text{diameter} = 3.2286 + 0.0894 \text{day} - 0.0004 \text{day}^2 \) and \( \text{diameter} = 3.4316 + 0.0743 \text{day} - 0.0004 \text{day}^2 \) for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.

Figure 2.4 Regression of the growth of leaf area of seed-propagated hazelnut seedlings from June 27 to October 3, 2011 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario where heavy hail on September 2, 2011 damaged the plants. The regressions between leaf area and each treatment were \( \text{leaf area} = 975.2072 + 43.2315 \text{day} - 0.1347 \text{day}^2 \), \( \text{leaf area} = 650.1628 + 27.4250 \text{day} - 0.1347 \text{day}^2 \) and \( \text{leaf area} = 703.6439 + 20.7072 \text{day} - 0.1347 \text{day}^2 \) for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.
Figure 2.5 Regression of Prin 1 score from July to October, 2011 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario where heavy hail on September 2, 2011 damaged the plants. The regressions between score and each treatment were score=\(-2.5462+0.1019\text{day}-0.0004\text{day}^2\), score=\(-2.6569+0.0724\text{day}-0.0004\text{day}^2\) and score=\(-2.4206+0.0624\text{day}-0.0004\text{day}^2\) for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.
2.3 Experiment 2-Culture of seed-propagated hazelnut in June

2.3.1 Materials and methods

One hundred and sixty seeds of a European x American hybrid selection were obtained from a local grower Martin Hodgson in Courtland, Ontario.

The seeds were stratified on May 10, 2011, using the same method that used in the first experiment. Then they were placed in the mist at Vineland Research and Innovation Centre, Ontario, for 4 weeks until they were 5-10 cm tall. Forty one seedlings out of 160 seeds were obtained, and 36 relatively uniform seedlings were selected for the experiment on Jun 10.

The effects of two pot types (ellepot and plastic pot), three culture techniques (Outdoor, retractable roof greenhouse and root pruning technology) on growth were tested.

The seedlings were divided into two groups on Jun 10, 2011; ellepots and plastic pots were tested. The plants were planted AMA grow mix (A.M.A. Plastics Ltd, Kingsville, ON, Canada) one group in 130mm*130 mm*70mm (1200 cu cm) plastic pot (Kord Product Inc., Brampton, ON, Canada) and the other in 120mm*120mm*90mm (1357 cu cm ) Ellepot (A.M.A. Plastics Ltd, Kingsville, ON, Canada). The same nursery management were used.

The same variables as in the first experiment were measured after 4 weeks on July 10, 2011.

The seedlings from each of the two pot treatments were sub-divided into three groups. Each group was placed in one of three environments: either outdoors, or in a retractable roof
greenhouse (Cravo equipment Ltd., Branford, ON, Canada) at Vineland Research and Innovation Center, or treated with root pruning technology (Earthgen International Ltd. Mississauga, ON, Canada) at Dunnville, Ontario on July 10, 2011.

The pots, soil media and nursery management were the same as in the first experiment. Also, the same variables as in the first experiment were measured every other week from July 10, 2011.

2.3.2 Statistical analysis

The experiment was arranged as a split plot design, with the pot type as the main plot and culture technique as the subplot. Replication was a random effect and pot type and culture technique combinations were fix effects. The same SAS program that used in the first experiment was employed to determine significant growth rate differences among the treatments.

2.3.3 Results

All the variables measured did not differ significantly for pot type (height, \(P=0.08\); node number, \(P=0.41\); trunk diameter, \(P=0.19\); leaf area, \(P=0.18\)). The seedlings grown in ellepots were 40.3 cm tall with 16 nodes, 814 cm\(^2\) leaf area and 3.20 mm trunk diameter on average. While seedlings planted in plastic pots had an average height of 44.2 cm with 17 nodes, 954 cm\(^2\) leaf area and 3.40 mm trunk diameter after 4 weeks.

After 4 days’ culture in the three culture techniques, disease exploded in outdoor nursery and retractable roof greenhouse. Seedlings started to wilt and the roots and crowns rotted.
*Fusarium* sp. was found in plant samples. Seventy-five percent of the seedlings died after 2 weeks.

The seedlings treated with root pruning technology grew normally. They were 70 cm tall with 24 nodes, 2110 cm² leaf area and 5.74 mm trunk diameter on September 10, 2011.

2.4 Experiment 3—Culture of micropropagated hazelnuts

2.4.1 Materials and methods

Seventy-two rooted micropropagated hazelnut cultivar ‘Geneva’ plantlets with 3-5 cm height were obtained from the Plant Cell Technology laboratory at University of Guelph, Ontario.

The effects of two pot types (ellepot and plastic pot) and three culture techniques (Outdoor, retractable roof greenhouse and root pruning technology) on hazelnut growth were tested.

The healthy rooted plantlets in GA-7 culture vessels (Magenta corporation, Chicago, IL, USA) were moved from the Plant Cell Technology laboratory, University of Guelph to Vineland Research and Innovation Centre on March 3, 2012. The rooted plantlets were moved out from the artificial agar medium, and their roots were gently cleaned in water on March 4, 2012. Half of the plantlets were transplanted into 65mm*70mm ellepots (232 cu cm) (A.M.A. Plastics Ltd, Kingsville, ON, Canada), and the other half were transplanted into 70mm*70mm plastic pots (270 cu cm) (Kord Product Inc., Brampton, ON, Canada). The plantlets were placed on a mist bench in #12 greenhouse with a three-second water spray every
12 minutes at 22 °C for hardening. Forty plantlets were selected on March 24, 2012 from those that survived; twenty plantlets for each pot treatment.

The soil media and nursery management were the same as in the first experiment. Also, the same variables as in the first experiment were measured after 4 weeks, on April 24, 2012.

The seedlings from the two pot types were sub-divided into three groups. One group was sent to Earthgen International Ltd at Dunnville, Ontario on May 1, 2012 for root pruning technology treatment. The other two groups were transplanted into 130mm*130 mm*70mm (1200 cu cm) plastic pots (Kord Product Inc., Brampton, ON, Canada), and stayed in a greenhouse in Vineland Station until May 23, 2012. The two groups of plantlets were then transplanted into 11-liter containers (27*27*23 cm) (JVK, St. Catharines, ON, Canada) filled with Sunshine® Mix 4 soil media (Sun Gro Horticulture Canada Ltd, Vancouver, BC, Canada) and placed either outdoors or in the retractable roof greenhouse at Vineland Research and Innovation Centre on May 24, 2012.

The nursery management was the same as in the first experiment, except water was applied by hand. Also, the same variables as in the first experiment were measured every two weeks from May 24, 2012 to August 13, 2012.

The air temperatures inside and outside the retractable roof greenhouse were recorded from May 24 to September 5, 2012 using Priva temperature sensors (Priva North America, Ontario, Canada).

The roots from the three treatments were examined on August 21, 2012. Six root samples of each treatment were gently washed by hand. Fine roots (less than 1mm) and thick roots of
each seedling were separated. The fresh weight and dry weight of each root sample were recorded, and fine root to thick root ratio was calculated.

2.4.2 Statistical analysis

The experiment was arranged as a split plot design, with pot type as the main plot and culture technique as the subplot. Replication was a random effect and pot type and culture technique combinations were fix effects. The same SAS program that used in last experiment was employed to determine significant growth rate differences among the treatments and generate the mean growth rate of each combination treatment.

2.4.3 Results

Plantlets grown in ellepots and plastic pots did not differ significantly for height ($P=0.06$), node number ($P=0.11$), trunk diameter ($P=0.06$) and leaf area ($P=0.52$); they were 11.8 cm tall with 5.4 nodes, 175 cm$^2$ leaf area and 2.10 mm trunk diameter on average. While seedlings from plastic pots had an average height of 10.7 cm with 5.0 nodes, 166 cm$^2$ leaf area and 1.92 mm trunk diameter.

For the growth in the culture techniques, the variables varied significantly for the culture techniques, but did not vary significantly for pot type and pot type*culture technique interactions (Table 2.10). The plantlets grew fastest for all variables under retractable roof greenhouse, and those grown using the root pruning technology grew extremely slowly (Table 2.11, Fig. 2.6-2.10). The growth rates of the four variables were highest under retractable roof greenhouse and lowest under root pruning technology.
All the variables were highly positively correlated (Table 2.12). The first principle component, accounting for 92.7% of variance, explained how the plants developed; all variables increased simultaneously as plants grew (Table 2.13). The overall growth was fastest under retractable roof greenhouse and slowest under root pruning technology (Fig. 2.11).

Plants grown under the retractable roof greenhouse had the heaviest root mass, but those treated with the root pruning technology had the lightest root mass (Fig. 2.12). There was no significantly difference on root dry weight between the retractable roof greenhouse and the outdoor treatments. However, the root pruning technology produced the highest fine/thick root ratio on dry weight (Table 2.14, Fig. 2.13).

The average temperature of Vineland Station, Ontario during May 24 to August 27, 2012 was 22.2°C. During this growing season, the air temperature reached the highest at 36.4 °C and lowest at 10.6 °C. The air temperature inside and outside the retractable roof greenhouse was similar (Fig. 2.14).

Table 2.10 Variance analysis of the effects of two pot types (ellepot and plastic pot) and three culture techniques (outdoor, retractable roof greenhouse and root pruning technology) on the micropropagated hazelnuts' height, node number, trunk diameter and leaf area. The data was collected on August 13, 2012. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario.

<table>
<thead>
<tr>
<th>Source</th>
<th>Height</th>
<th>Diameter</th>
<th>Leaf number</th>
<th>Leaf area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot type</td>
<td>0.040</td>
<td>0.094</td>
<td>0.57</td>
<td>0.25</td>
</tr>
<tr>
<td>Culture technique</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Pot type *culture technique</td>
<td>0.19</td>
<td>0.19</td>
<td>0.69</td>
<td>0.58</td>
</tr>
</tbody>
</table>
Table 2.11 Mean height, node number, trunk diameter and leaf area of micropropagated hazelnut seedlings from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario.

<table>
<thead>
<tr>
<th>Technique and treatment combinations</th>
<th>Height (cm)</th>
<th>Node number</th>
<th>Diameter (mm)</th>
<th>Leaf area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retractable roof greenhouse</td>
<td>39.7 a</td>
<td>18.9 a</td>
<td>3.5 a</td>
<td>1369 a</td>
</tr>
<tr>
<td>Outdoor</td>
<td>32.4 b</td>
<td>17.5 b</td>
<td>3.0 b</td>
<td>972 b</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>10.9 c</td>
<td>8.5 c</td>
<td>0.5 c</td>
<td>49 c</td>
</tr>
</tbody>
</table>

*Values in the same column with different letters differ significantly under Tukey test (P≤0.05).

Table 2.12 The correlation matrix of height, node number, trunk diameter and leaf area of micropropagated hazelnut seedlings from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario.

<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>Node</th>
<th>Diameter</th>
<th>Leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.92***</td>
<td>0.94***</td>
<td>0.93***</td>
<td></td>
</tr>
<tr>
<td>Node</td>
<td></td>
<td>0.91***</td>
<td>0.85***</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
<td></td>
<td>0.85***</td>
<td></td>
</tr>
<tr>
<td>Leaf</td>
<td></td>
<td></td>
<td></td>
<td>0.85***</td>
</tr>
</tbody>
</table>

*** P=0.01
Table 2.13 Three major principle component analysis vectors of micropropagated hazelnut seedlings’ height, node number, trunk diameter and leaf area from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario.

<table>
<thead>
<tr>
<th></th>
<th>Prin 1</th>
<th>Prin 2</th>
<th>Prin 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.51</td>
<td>0.10</td>
<td>-0.14</td>
</tr>
<tr>
<td>Node</td>
<td>0.50</td>
<td>-0.42</td>
<td>0.75</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.50</td>
<td>-0.45</td>
<td>-0.65</td>
</tr>
<tr>
<td>Leaf</td>
<td>0.49</td>
<td>0.78</td>
<td>0.05</td>
</tr>
<tr>
<td>% variance accounted</td>
<td>92.7%</td>
<td>4.1%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

*Prin 4 was omitted, because it took less than 1% of variance

Table 2.14 Mean weight of micropropagated hazelnut roots under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario. The data was recorded on August 21, 2012.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Fine root (fresh)</th>
<th>Fine root (dry)</th>
<th>Thick root (fresh)</th>
<th>Thick root (dry)</th>
<th>Fine/thick (fresh)</th>
<th>Fine/thick (dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retractable roof greenhouse</td>
<td>4.4 a</td>
<td>2.3 a</td>
<td>5.3 a</td>
<td>3.3 a</td>
<td>0.86</td>
<td>0.65 b</td>
</tr>
<tr>
<td>Outdoor</td>
<td>2.6 b</td>
<td>1.6 b</td>
<td>4.6 a</td>
<td>2.8 a</td>
<td>0.55</td>
<td>0.60 b</td>
</tr>
<tr>
<td>Root pruning technology</td>
<td>0.8 c</td>
<td>0.7 c</td>
<td>0.9 b</td>
<td>0.6 b</td>
<td>0.92</td>
<td>1.30 a</td>
</tr>
</tbody>
</table>

*Values in the same column with different letters differ significantly under Tukey test (P≤0.05).
Figure 2.6 micropropagated hazelnut seedlings produced by three nursery techniques after 12 weeks. The photo was taken on August 16, 2012.
Figure 2.7 Regression of the growth of height of hazelnut seedlings from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario. The regressions between height and each treatment were sqrt(height)=4.1907+0.0054day+0.0003day^2, sqrt(height)=4.1407+0.0157day+0.0003day^2 and sqrt(height)=2.8907+0.0088day for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.

Figure 2.8 Regression of the growth of node number of hazelnut seedlings from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario. The regressions between node number and each treatment were node=10.0134+0.1533day+0.0006day^2, node=10.1670+0.1098day+0.0006day^2 and node=6.1921-0.0738day+0.0019day^2 for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.
Figure 2.9 Regression of the growth of trunk diameter of hazelnut seedlings from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario. The regressions between trunk diameter and each treatment were diameter=1.2893+0.045day, diameter=1.3361+0.0334day and diameter=0.1224+0.0073day for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.

Figure 2.10 Regression of the growth of leaf area of hazelnut seedlings from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario. The regressions between leaf area and each treatment were sqrt (leaf area)=20.1409+0.2714day-0.0033day², sqrt (leaf area)=19.3341+0.3675day-0.0049day² and sqrt (leaf area)=6.0202+0.1639day-0.0092day²+0.0001day³ for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.
Figure 2.11 Regression of Prin 1 score from May 24 to August 13, 2012 under three nursery techniques. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario. Root pruning technology was applied in Dunnville, Ontario. The regressions between score and each treatment were score\(=\-1.0158+0.0383\text{day}+0.0003\text{day}^2\), score\(=\-0.7860+0.0144\text{day}+0.0003\text{day}^2\) and score\(=\-1.8320-0.0132\text{day}+0.0003\text{day}^2\) for retractable roof greenhouse, outdoor nursery and root pruning technology respectively.
Figure 2.12 Root systems of micropropagated hazelnut seedlings produced by three nursery techniques after 12 weeks. The photo was taken on August 19, 2012.
Figure 2.13 Root structures of micropropagated hazelnut seedlings produced by three nursery techniques after 12 weeks. The photo was taken on August 19, 2012.
2.5 Discussion

2.5.1 Pot type

The growth of seed-propagated hazelnut seedlings and micropropagated plantlets in the two types of pot were similar. This was inconsistent with that of Maguire and Harun (2007), who reported that *Elaeagnus x ebbingei* cuttings in ellepots reached suitable size three months earlier than those grown in regular pots. This result may be due to hazelnut’s fibrous root system. The hazelnut plantlets in plastic pots naturally did not produce a significant tap root; they can generate many fibrous roots without air-root pruning.

2.5.2 Culture technique

The retractable roof greenhouse accelerated the growth of both seed-propagated and micropropagated hazelnuts. This confirmed with other species. Under a retractable roof greenhouse, roses were taller with a greater diameter than in full sun (Schuch et al., 2008), basil and lemon grass had greater biomass and optimal quality, compared to those grown in the field (Nelkin and Schuch, 2004), and containerized tree liners reached saleable size two years sooner than the field bareroot liners (Mathers et al., 2009).

Root pruning technology produced more fine roots than other treatments, which was also found with *Pyracantha* hybrid (Whitcomb, 1981). Also, Dey et al. (2003) and Lovelace (1998) indicated that with the root production method (RPM™) oak seedlings grew faster. However, this was not found with hazelnuts in their first growing season. This may be because the plants need more energy to produce the fine fibrous root system. Also, the
micropropagated plantlets grew extremely slowly under the root pruning technology. The reason was unclear, but it could because of insect attack or the extremely warm summer (A. Koziol pers. comm., 2012).

Hazelnut trees achieve optimum photosynthesis at 25°C to 28°C (Schulze and Küppers, 1979). However, the air temperature in this experiment did not seem to be the key factor which influenced hazelnuts’ growth, because the air temperature inside and outside the retractable roof greenhouse was similar. This is possible because the greenhouse walls opened most of the time in the summer, which allowed good air flow between the greenhouse and the outdoor environment. Possibly, the better growth under the retractable roof greenhouse was because the greenhouse cover blocked infrared radiation and cooled down the soil and plant surfaces. Vollebregt (2004) indicated that a clear polyethylene roof covering prevented overheating of the soil more effectively than a 63% black shade cloth, as it block up to half of the infrared radiation (Both, 2001). The factors which improved the growth of the hazelnuts need to be further investigated in future studies.

In the second experiment, most of the hazelnuts died because they were infected with *Fusarium*. This fungus was first found in other plants in the retractable roof greenhouse. Consequently, this was probably the disease source for the hazelnut seedlings. The fungi might spread in recirculating systems via the irrigation lines or spread by the contaminated pruning instruments (Cerkauskas, 2001). Heat stress might have made the young hazelnut seedlings susceptible to *Fusarium* sp. Hazelnuts are stressed when the temperature exceeds 30 to 35°C (Kerslake, 2012), and the average maximum temperature during July 10 to July 20 was 33.3°C. *Solanum lycopersicum* showed disease symptoms earlier in high water stress
than in low water stress when they were attacked by *Fusarium oxysporum* f. sp. *Lycoperseci (Fol)* (Ghaemi et al., 2010). Young plants, especially during the first 4 weeks, were particularly susceptible to *Fusarium* sp. (Cerkauskas, 2001). In commercial production, crops share one irrigation system and are planted in high density, which increases the risk of infection of *Fusarium* sp.

### 2.5.3 Transplanting

Transplant timing did not affect hazelnut growth. This has also been shown with Turkish hazelnut *Corylus colurna*, when they were fall- and spring- transplanted (Harris et al., 2001). The reason might be that Turkish hazelnut failed to regenerate roots until spring (Harris and Bassuk, 1995).

However, many studies have indicated that transplanting in the fall may encourage plants to produce new roots before they became dormant and allow them to be ready to grow next spring. *Picea engelmannii, Pinus lambertiana* and *Pseudotsuga menziesii* transplanted in early fall developed greater roots and shoots than those transplanted early the following spring. The plants grew their roots in October and November, when the temperature was 8°C-11°C (Steinfeld et al., 2000). *Chionanthus virginicus* transplanted in early fall when the temperature was 10 °C had more root dry mass, leaf area and greater canopy width than plants transplanted three weeks later when the temperature was 5°C (Harris et al., 1996). This is possible because the root extension of many temperate zone trees is limited below 10°C (Harris et al., 1995; Headley and Bassuk, 1991; Lyr and Hoffmann, 1967). Here, the hazelnut seedlings were transplanted in late fall, when the temperature was approximately 7°C.
Further studies on transplanting date are needed to understand the hazelnut’s root
development after transplanting.

The nursery culture techniques significantly influenced the hazelnuts’ growth in the field. This was consistent with Mathers et al. (2009), who showed that *Acer x freemanii*, *Malus* ‘Prairifire’, *Vercis Canadensis* and *Quercus rubra* liners pre-grown under a retractable roof greenhouse had a greater calliper than bare-root liners. Only seedlings grown under retractable roof greenhouse produced catkins in the field. No reports could be found to confirm this. The effects of root pruning technology on plant field performance were inconsistent in previous studies. Tolliver et al. (1980) indicated that root pruning technology did not promote the survival or growth of *Quercus nigra*, *Quercus phellos* and *Carya illinoensis* in the field. Similar a result was found with *Magnolia grandiflora* (Gilman, 1992). However, after two years growing in the field, taller plants with a greater shoot dry weight were found with *Picea smithiana* plants that have been treated with root pruning than those that have not (Singh et al., 1984). Hazelnut seedling’s field growth in the first year was not increased by root pruning technology, but this may change in the future growth.
Figure 2.14 Daily average, maximum and minimum temperature inside and outside the retractable roof greenhouse from May 24 to September 5, 2012. The retractable roof greenhouse was conducted in Vineland, Ontario.
Chapter 3  Finance of Nursery Cultivation

3.1 Introduction

In Ontario, there is potentially the demand for hazelnuts from 4,800 to 6,100 hectares of hazelnut trees. The first step is to propagate the trees, which can be done locally. However, there has been no previous study on the finances of hazelnut nursery production. In this study, two production systems were compared: outdoor and retractable roof greenhouse. Estimated costs of the two production systems were provided based on our production model. Growers are encouraged to substitute their own data to get an accurate accounting of their costs.

A retractable roof greenhouse can extend the crop growing season (Mathers et al., 2009) compared to field production by adjusting the microclimate. Also, the retractable roof greenhouse can provide a better growing environment, so the crops can reach a desirable size in a relatively short period (Nelkin and Schuch, 2004; Schuch et al., 2008; Mathers et al., 2009). Therefore, retractable roof greenhouses can produce more than one crop in a growing season. Hence, each individual plant may consume less labour, water, electricity and other costs.

The costs were analysed in two groups: variable costs and fixed costs. The former varied directly or proportionally with changes in production capacity, but it does not vary per unit product. The latter are costs that would not change, in a relevant range, with changes in production capacity or output. The trend to use more automation and less labour leads to more fixed costs and less variable costs (Weygendt et al., 2010).
3.2 Methods

The information for this report was collected from 2011 to 2012. Outdoor and retractable roof greenhouse production at the Vineland Research and Innovation Centre, Vineland Station, Ontario were used as the analysis models (Table 3.1). Land and office building rates were obtained from comFree (2012). The costs of retractable roof greenhouse and irrigation system were quoted by the staff of Cravo Equipment Ltd. and Zwart Systems respectively. The costs of labour and management were obtained from Vineland Research and Innovation Centre. The rates for the nursery supplies were obtained from the suppliers around the Niagara region, Canada.

3.3 Analysis Model

The production started with 3-5 cm tall micropropagated hazelnut plantlets and ended when they reached transplantable size. The seedlings were grown in 11-liter containers, placed in rows and passageways were left every four rows.

Niagara region has an average low temperature below 0°C from December to March (Fig 3.1). Outdoor container production usually starts in late May, and only one culture can be obtained in a growing season of approximate 16 weeks. Retractable roof greenhouses can extend the growing season, as productions can start in mid-April and end in late October. Plants also grow faster in retractable roof greenhouse. Therefore, two cultures of production are highly obtainable in a retractable roof greenhouse; 12 weeks for one culture. With a
shorter production time, each individual plant grown in the retractable roof greenhouse will consume less electricity, water, labour and a lower overhead cost.

Table 3.1 The analysis models of outdoor nursery and retractable roof greenhouse.

<table>
<thead>
<tr>
<th></th>
<th>Outdoor</th>
<th>Greenhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area (ft²)</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Land rate ($/ft²)</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Nursery area (ft²)</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>Area per tree (ft²/tree)</td>
<td>1.58</td>
<td>1.58</td>
</tr>
<tr>
<td>Capacity</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td>Land trial period (year)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Office building ($)</td>
<td>80,000</td>
<td>80,000</td>
</tr>
<tr>
<td>Office building lifespan (year)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Office building depreciation rate</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Greenhouse lifespan (year)</td>
<td>N/A</td>
<td>50</td>
</tr>
<tr>
<td>Greenhouse depreciation rate</td>
<td>N/A</td>
<td>2%</td>
</tr>
<tr>
<td>Irrigation system lifespan (year)</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Number of cultures per year</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Growing period per culture (week)</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Water needed per plant per week (L/week)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Labour (hour/week)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 3.1 The average high temperature and low temperature of Niagara on the lake, Ontario for each month of the year. The sampling period covered recent 30 years. Source: The Weather Network, 2012.
3.4 Cost analysis

Table 3.2 showed the detailed cost of the two culture systems. A hazelnut seedling grown under the outdoor production system is $1.95 more expensive than that under the retractable roof greenhouse.

3.4.1 Variable costs

Plant materials

Hazelnut plant materials were micropropagated plantlets that obtained from the University of Guelph. The plantlets were 3-5 cm tall, and needed to be hardened before transplanting into the two production systems.

Plant hardening

Plantlets were kept in a mist room to remain moist until they reached 10 cm tall. Then they were transplanted to the outdoor environment or the retractable roof greenhouse. The plant density in the mist room was approximate 240 plants/m². The labour and greenhouse rental costs were included. A nine-square meter greenhouse space was needed for 2000 plantlets. One or two hours of labour work per day were required to water and monitor the plantlets for three weeks. The survival rate ranged from 50% to 100%.

Labour

An average of 20 hours of labour work per week was required in both outdoor and retractable roof greenhouse systems. The work was mostly concentrated on setting up the
nursery, which includes transplanting plantlets into 11-liter containers, tying them to bamboo stakes, lining up the plants with steel wire, and fertilizing. Once the nursery was set up, little labour was required. One only needed to prune suckers, tie the newly grown stems to bamboo stakes, flush the irrigation lines and check the fertility once a week. Chemical spray would be applied when needed.

Fertilizer

19-04-10 slow release fertilizer was used in production. This fertilizer should be effective for 8 to 9 months to allow for a one-time fertilization during the growing season and to eliminate additional labour (verbal price from suppliers).

Tools

Tools refer to those reusable implements, including tapeners, pruners, groves, and bamboo stakes and so on. It was assumed that their lifespan are 3 years in this project.

Electricity and water

The retractable roof greenhouse requires electric power to adjust the position of its roof and walls, but it doesn’t need light and heat except in winter. Therefore, the electricity expense was primarily used to support the office building. An average of one litre of water per day was required during the whole growing season. The water rate in this report referred to the City of St. Catharines (2012).
3.5 Fixed cost

Land, retractable roof greenhouse and office building

The main fixed cost of building a nursery is the land, the greenhouse and the office building. Referring to comFree (2012), we assumed the rate of land in Niagara region was $27/m². The cost of the greenhouse varies, as there are several types of retractable roof greenhouse available in the market. The selection of the type of greenhouse depends on the local weather, geographic environment and the type of the crop grown. In the case of hazelnuts, a flat roof greenhouse was used, because the production only lasts from spring to late summer. We used an average cost of $47/m² for analysis; construction cost was included (B. Martin pers. comm., 2012). The greenhouse structure should last for 50 years, but the greenhouse cover needs to be replaced every 11 to 13 years. Cost of replacement is estimated to be $7/m² plus labour (B. Martin pers. comm., 2012).

Property depreciation

We calculated the property depreciation of greenhouse and office building using the straight line method with a depreciation rate of 2%. By this method, the depreciation is constant every year, which is 2% of the initial cost. The straight line depreciation rate was obtained by the formula (Mueller, 2009): Straight line depreciation rate=

(Purchase price of asset - approximate salvage value) / estimated useful life of asset
Property taxes

The property taxes are obtained by the formula:

Tax amount = property’s assessed value * tax rate

The property tax was estimated by online property tax calculator (City of Niagara Falls, 2012).

Irrigation system

An automated drip irrigation system was employed delivering approximate one litre of water per day during two 30-minute irrigation events. This method saved the cost of labour, and facilitated management. One only needed to flush the water pipe once a week to remove the dirt build up, and the pipe was cleaned once a year by running pH 3.5 water for 20 minutes (A. Van Geest pers. comm., 2012).

Management

The nursery systems were highly computerized and automated, which minimized the cost of management. The managerial work focused on purchasing, hiring, controlling the computer systems, monitoring diseases or other damages, and dealing with urgent matters as they arise.

3.6 Sensitivity Analysis

The costs of the variables were estimated based on the most probable forecasts, but some major quantifiable variables likely vary with each individual grower and can significantly influence the final cost (Table 3.2).
The costs for labour and management were based on the assumption of 10 hours labour work and 10 hours managerial work per week in the two production systems. The working time and hourly pay may differ with different nursery operations.

The commercial price on the micropropagated plantlets ranges from $1.65 to $2.45 per plantlet, according to the cultivar, plantlet size and order quantity (North American Plants Inc., 2012). The cost of plantlets also relates with mortality rate. The mortality rates may sometimes reach as high as 50% (Nas and Read, 2004; Nas et al., 2003). Twenty-five percent of mortality was used for cost estimation in this program, which raises the cost of plant material to $2.2 to $3.27 per plantlet. We took the average number $2.7 in this analysis (Table 3.2).

The cost of plant hardening varies with the hardening methods. One can either cover the plantlets with polythene bags or use a mist room to keep moisture. The former consumes more labour, because one has to cover every individual plant by hand. But the cost of the polythene bags is very little ($0.02 per bag). The mist room requires an automatic sprinkler system, which is much more expensive than the polythene bags. However, once the sprinkler system is built up, little labour is needed. The same as the plant material, the cost of plant hardening is also influenced by the survival rate.

The greenhouse operations can make differences in the fixed cost. Growing two cultures in a season will keep the cost lower than outdoor production. Growing some valuable crops in the retractable roof greenhouse in idle time can also compensate the cost of building the
greenhouse and maintenance. The office building and greenhouse depreciations are relative to the property value and property lifespan, which vary with each individual operation.

When the both factors are taken into consideration, the estimated cost per seedling in outdoor nursery was $9.34 in the best conditions and $14.19 in the worst conditions. Meanwhile, the estimated cost for a plantlet in retractable roof greenhouse was $7.98 and $14.21 in the best and worst conditions respectively.
Table 3.2 Cost analysis of outdoor and retractable roof greenhouse production. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario.

<table>
<thead>
<tr>
<th>Number of plants</th>
<th>Cost per unit</th>
<th>Cost per plant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outdoor</td>
<td>Greenhouse</td>
<td>Unit</td>
</tr>
<tr>
<td><strong>Variable costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>15</td>
<td>15</td>
<td>($)/hour</td>
</tr>
<tr>
<td>Plant material</td>
<td>2.7</td>
<td>2.7</td>
<td>($)/plant</td>
</tr>
<tr>
<td>Plant hardening in mist</td>
<td>0.50</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Fertilizer</td>
<td>56</td>
<td>56</td>
<td>($)/20kg</td>
</tr>
<tr>
<td>Spray</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Potting soil</td>
<td>95</td>
<td>95</td>
<td>($)/m³</td>
</tr>
<tr>
<td>Pot</td>
<td>0.50</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Tools</td>
<td>420</td>
<td>420</td>
<td>($)/3 year</td>
</tr>
<tr>
<td>Electricity</td>
<td>15</td>
<td>17</td>
<td>($)/week</td>
</tr>
<tr>
<td>Water</td>
<td>0.0012</td>
<td>0.0012</td>
<td>($)L</td>
</tr>
<tr>
<td>Telephone</td>
<td>8</td>
<td>8</td>
<td>($)/week</td>
</tr>
<tr>
<td>Shipping</td>
<td>15</td>
<td>15</td>
<td>($)/week</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>7.23</td>
<td>6.50</td>
<td></td>
</tr>
<tr>
<td><strong>Fixed costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation system</td>
<td>1.5</td>
<td>1.5</td>
<td>($)/ft²</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>0</td>
<td>264</td>
<td>($)/year</td>
</tr>
<tr>
<td>Office building depreciation</td>
<td>1600</td>
<td>1600</td>
<td>($)/year</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>0</td>
<td>2.25</td>
<td>($)/ft²</td>
</tr>
<tr>
<td>Land</td>
<td>12,500</td>
<td>12,500</td>
<td>($)</td>
</tr>
<tr>
<td>Property taxes</td>
<td>1282</td>
<td>1465</td>
<td>($)/year</td>
</tr>
<tr>
<td>Management</td>
<td>3000</td>
<td>4500</td>
<td>($)/year</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>63</td>
<td>63</td>
<td>($)/week</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>4.03</td>
<td>2.81</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>11.26</td>
<td>9.31</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.3 Sensitivity analysis of outdoor and retractable roof greenhouse production. Outdoor production and retractable roof greenhouse production were conducted in Vineland, Ontario.

<table>
<thead>
<tr>
<th>Sensitive impacts</th>
<th>Description</th>
<th>Cost per plant ($)</th>
<th>Outdoor</th>
<th>Greenhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>The hourly pay may fluctuate ±20%</td>
<td>2.02-3.03</td>
<td>1.52-2.27</td>
<td></td>
</tr>
<tr>
<td>Plant material</td>
<td>The cost per plantlet depends on the survival rate, which ranges from 50%-100%</td>
<td>2.05-4.1</td>
<td>2.05-4.1</td>
<td></td>
</tr>
<tr>
<td>Plant hardening in mist</td>
<td>The cost for hardening varies from the hardening methods and survival rate</td>
<td>0.2-0.75</td>
<td>0.2-0.75</td>
<td></td>
</tr>
<tr>
<td>Number of crops in one growing season</td>
<td>Growing only one crop in a growing season in a retractable roof greenhouse will raise the fixed cost per seedling in the greenhouse</td>
<td>4.03</td>
<td>2.81-5.22</td>
<td></td>
</tr>
<tr>
<td>Office building depreciation and property tax</td>
<td>The office building depreciation and property tax are determined by property salvage value and assessed value. The fluctuations are set as ±20% in the analysis</td>
<td>1.04-1.98</td>
<td>0.65-0.97</td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td>9.34-14.19</td>
<td>7.98-14.21</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 4 General Discussion

Investment in the hazelnut industry in Ontario has a great economic potential. The United States, our neighboring country, produced 4% of the world production with an export income of $24 million for in-shell hazelnuts and $9 million for shelled hazelnuts in 2003 (USDA, 2005). The average price of hazelnuts in the United States has steadily increased at 4% annually (Perez and Pollack, 2007). Like the United States, the price of hazelnuts in Canada has kept growing in recent years. In 2011, the in-shell hazelnuts that sold at the farm gate were approximately $10/kg, while the kernel price in supermarket reached $18/kg (T. Leuty pers. comm., 2012). Ferrero SpA opened their manufacturing plant in Ontario in 2006. This facility annually uses 6000 metric tonnes of shelled hazelnuts for confectionary (T. Leuty pers. comm., 2012). With an average unit production of 1.48 t/ha (Fideghelli and De Salvador, 2009), 4,800 to 6,100 hectares of hazelnut orchard would be required to supply Ontario’s market (T. Leuty pers. comm., 2012). More and more investors and growers have realized the promising future of the hazelnut industry and become interested in developing local hazelnut orchards.

Micropropagation of hazelnuts is becoming an alternative propagation method for commercial propagation because it is faster and more economical. The traditional propagation methods, layering, root cuttings and grafting, are effective. However, they are either expensive or requiring strict environmental conditions (Hubert, 1977; Bush, 1953; Shreve, 1972). Micropropagation has recently become popular in woody plants for commercial production (Damiano et al., 2005). The cost for a micropropagated hazelnut plantlet ranges from $1.65 to $2.45 per plantlet, according to the cultivar, plantlet size and...
order quantity (North American Plants Inc., 2012). However, the acclimation of hazelnut plantlets when they are transplanted from laboratory to nursery production systems is a challenge, because plantlets are quite susceptible to water stress in this period. Approximate 25% mortality rate was found in research experiments (Nas and Read, 2004; Nas et al., 2003), which raises the cost to $2.2 to $3.27 per plantlet.

The retractable roof greenhouse increased the growth of hazelnuts in nursery. It also produced hazelnut seedlings with a lower cost than outdoor production. Hazelnuts achieve optimum photosynthesis at 25°C to 28°C (Schulze and Küppers, 1979). They have poor tolerance to wind, heat and water stress (Kerslake, 2012). The retractable roof greenhouse adjusts the microclimate by changing the position of its roof and walls, and extends the growing season by exposing the plants to optimal growth conditions for as long as possible.

The Niagara region has an average low temperature below 0°C from December to March. Container production in outdoor environment usually starts in late May; only one culture of hazelnut seedlings can be obtained annually. The retractable roof greenhouse allows the production to start earlier and end later, so that two crops of hazelnut plants can be grown annually. This makes the cost per plant $9.31, which is $1.95 lower than that for outdoor production.

The root pruning technology has been promoted, because it can stimulate nursery trees to grow more rapidly. However, the effects of roof pruning are inconsistent. Here, the hazelnut plantlets produced more fine roots, but it did not increase their growth in both nursery and field in the first year. Similar results have been shown for Quercus nigra, Q. phellos, Carya illinoensis (Tolliver et al., 1980), but better growth has been found with Picea smithiana
(Singh et al., 1984), and *Quercus bicolor* seedlings (Grossman et al., 2003). Also, the *Q. bicolor* seedlings produced acorns in the first three years; in contrast to the bare root plants. Possibly reasons for this inconsistency is that root pruning can induce water stress and reduce plant growth in the short term, but plant growth would be unaffected or increased in the long term (Watson and Sydnor, 1987). Also, the studies here indicated that there could be environmental issues, such as hail storms and heat stress.

The time that the hazelnut seedlings were planted in the field did not affect their subsequent growth, which was inconsistent with reports from many other species, e.g. *Picea engelmannii*, *Pinus lambertiana* and *Pseudotsuga menziesii* (Steinfeld et al., 2000). This was possibly because the hazelnut seedlings were transplanted too late in the fall when the temperature had dropped below 10°C. This temperature has been shown to be the threshold below which root extension is limited in many temperate zone trees (Harris et al., 1995; Headley and Bassuk, 1991; Lyr and Hoffmann, 1967). A result which has been confirmed with *Chionanthus virginicus* (Harris et al., 1996). Spring transplanting may raise the production cost for winter stock, because plants in containers have to be moved indoor over winter to avoid cold injury.

Disease is a risk for nursery production. This pathogen was first found in other plants in the retractable roof greenhouse. It might be spread by the irrigation lines or by the contaminated pruning instruments (Cerkauskas, 2001). Also, the heat stress probably made the young hazelnut seedlings susceptible to disease (Ghaemi et al., 2010). This risk exists in both outdoor and retractable roof greenhouse systems.
The cost of hazelnut seedlings would be reduced if plant mortality and diseases were reduced. One way is to acclimate the micropropagated plantlets. Rooting the IBA treated microshoot *ex vitro* in peat plugs increased the survival rate to 97%-98% (Nas and Read, 2004; Nas et al., 2003). This technology enabled 38-50 cm plants to be grown in only three months in a greenhouse, and was recommended for commercial hazelnut propagation. Also diseases need to be prevented. Micropropagated plantlets can be provided disease-free and eliminate the risk of seed infection. Workers have to monitor the plants continually, especially in the first four weeks, so that any infected plants can be removed at the first sign of symptoms. The pruning tools and irrigation system should be sanitized periodically (Cerkauskas, 2001). These activities may increase the labour cost, but can effectively prevent diseases and so avoid heavy economic losses.

The way the nursery is operated also influences the cost. The retractable roof greenhouse can produce transplantable plants in a shorter time, which make each individual plant consume less electricity, water, labour and overhead cost. Growing two cultures in retractable roof greenhouse in one growing season would keep the cost of greenhouse plants lower than outdoor production. Also, other valuable crops can be grown in the other times of the year to reduce the cost of building the greenhouse and maintenance.

To better understand and evaluate the effects of culture techniques on the growth of hazelnuts, further studies are needed. Hazelnut production in the retractable roof greenhouse can be started earlier, in early or mid-April, to confirm whether two crops of hazelnut plants can be obtained in one growing season. The reasons that led to better growth of hazelnuts in the retractable roof greenhouse were unclear. Air temperature was not the key factor. Plant
surface temperature, soil temperature and infrared radiation are likely to be the impact factors and should be studied. Another factor could be wind. Further observations of hazelnut field performance are underway; the vegetative growth, reproductive development and nut yield among the treatments will be compared. The results will come over the next seven years. Also, different transplanting dates need to be tested. Transplanting hazelnuts in September when the temperature is above 10°C is expected to be beneficial for next year’s growth, and this method will also save the cost of winter stock.

Summary

As the demand and price of hazelnuts increase, the hazelnut industry in Ontario keeps growing. Advanced culture techniques are being tested in this industry to optimize all the steps along the value chain. Micropropagation is an alternative for traditional propagation. It is more economical and can produce uniform and disease free hazelnut plantlets in a short time. A retractable roof greenhouse can extend the growing season by adjusting microclimate. Hazelnut plantlets grew faster in the retractable roof greenhouse than in outdoor environment. Possibly two crops can be obtained during one growing season using a retractable roof greenhouse. The combination of the two techniques made the cost of a transplantable hazelnut trees from the nursery below ten dollars. The root pruning technology changed the hazelnuts’ root structure and will potentially have a long term benefit on its growth in the field. Further studies on plantlet acclimation and transplanting dates will make the hazelnut production more integrated and further reduce the cost of nursery plants.
References


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