ABSTRACT

Poor rooting percentage is a common problem of many dwarfing apple rootstock genotypes when propagated by layering. Four field experiments were performed in 2008 and 2009 to improve rooting of dwarfing rootstocks. Locations included Ephrata, Washington; Angers, France; and Canby, Oregon. The experiments consisted of three approaches to increase rooting: plant growth regulator treatment, dark preconditioning and planting angle and planting density. The first set of experiments compared the application of various plant growth regulators at various times of the year on B.9, M.9 T337, M.9 EMLA and G.41 rootstock stool beds. The chemicals used were: Apogee (250 ppm or 1000 ppm), IBA (1000 ppm or 10000 ppm) and NAA (50 ppm or 200 ppm). IBA sprayed early in the season before mounding with sawdust consistently increased the rooting percentage. Foliar applications of Apogee in the summer also increased the rooting with variations in response due to location and timing. NAA applied foliarly in the summer did not increase rooting percentage. The second set of experiments evaluated the effects of dark preconditioning on B.9 and M.9 T 337 stool beds. The two treatments included early sawdust mounding (two weeks early) or a period of light exclusion (shading). Shading increased the rooting percentage consistently compared to the control. Early sawdust mounding did not significantly increase rooting. Another experiment combined the effects of chemical treatments and dark preconditioning on G.41 stool beds. This treatment did not improve rooting compared to the control. The final experiment examined the effects of planting style (upright vs. angled) and planting density on rooting of B.9, M.9 T337 and G.935. The upright planting style had the greatest rooting and was the most productive. Increasing planting density also improved production and rooting.

BIOGRAPHICAL SKETCH

Richard was born in central Washington in the heart of apple country. His grandfather, Paul, started an apple nursery in 1964 which is now run by Richard's father and two uncles. Richard began working on the family farm at age 12 where he learned the important skill of budding. It was there that he developed a love for apple rootstocks. After he graduated from high school, Richard went to Brigham Young University to study agri-business management. He took a two year break to serve a mission for the Church of Jesus Christ of Latter-day Saints in Peru. Living among the Andean people only increased his love for agriculture. After completing two years of service, he resumed his studies at BYU and received his bachelor's of science degree. Richard continued working for his family nursery while he began studying at Cornell University. He was lucky enough to perform most of his master's thesis at his family nursery in Washington. Driving across the country with his wife and daughter twice a year from New York to Washington soon became a tradition and a welcomed adventure. After completion of his M.S. degree, Richard will return to the family nursery.

To Leisha, my loving wife, you kept me going for over five years of schooling. To my children, I hope this will be an example to you to work hard and never give up on your dreams. To my parents who encouraged me to seek out higher learning. “Education is the great equalizer.” – Roger Adams

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CHAPTER 1 – APPLE ROOTSTOCK OVERVIEW

1.1 Introduction

Like most fruit crops, apples are very heterogeneous and do not reproduce true to type from seed. In other words, the seeds from any given apple tree will result in a tree that is completely different from the parent. This can be very problematic when desired characteristics are found in a fruit tree. Luckily, growers in ancient times realized that buds or shoots of desirable trees could be grafted onto new trees, thus preserving the original cultivar with its desirable characteristics such as fruit color, size and yield. To facilitate the preservation of desirable varieties through grafting, seedlings were grown to serve as the new trees or rootstocks that receive the desired cultivar as a graft. A rootstock is the root system and small portion of the lower trunk of a grafted tree. This method of propagation is quite efficient. Most apple varieties do not propagate easily by rooting a cutting, thus it became much easier to propagate by seed and graft the desired variety to the seedling rootstock (Webster, 1995). However, growers noticed that the rootstocks also contributed to the characteristics of the grafted tree. Some rootstocks affected the size of the tree, while others affected the yield. With this realization, it became important to preserve desirable rootstocks by propagating them in such a way that the desired traits of the rootstock would be maintained.

Apple rootstocks have become important because of their desirable characteristics and their ability to be propagated vegetatively. This allows the grower to effectively clone a rootstock with desirable characteristics. Some major characteristics include: growth vigor (dwarfing), growth habit, precocity of fruit bearing, production level, fruit size, cold tolerance and pest resistance (Wertheim, 1998). There are many varieties of rootstocks available and they can be matched with a desired scion variety to create the ideal tree for any given environment. For example, a grower may choose a more vigorous rootstock to be paired with a less vigorous scion variety. Another grower may choose a rootstock that is more cold tolerant than other rootstocks. The trees can be designed for any given location. Most growers tend to use more dwarfing rootstock cultivars because they are more efficient, have higher yield per acre, and reduce the amount of spray needed to treat the trees for pests, thinning or other chemical practices.

Rootstock History

The use of rootstocks for apples goes back about 2000 years (Webster and Wertheim, 2003; Webster, 1997). However, the rootstocks used for most of the 2000 years were seedlings of unspecified origin. More recently, in the 1600's to 1800's, Europeans began selecting mother trees for their ability to produce seedlings with improved rootstock uniformity or performance (Janson, 1996). It is believed that apples and their rootstocks have their origins in Central Asia (Forsline and Hummer, 2007), with *Malus sieversii* being recognized as the major progenitor of the domesticated apple (Fazio et al. 2009). It is believed that seedlings were initially selected on the silk route and then carried to Europe and North America where most breeding and selection has taken place (Hancock et al. 2008). Most of the early clonal rootstocks were derived from seedlings of unspecified origin used by fruit growers in Europe. These were often mixed with other varieties or not uniformly named. In the early 1900's a selection and characterization program was developed by the East Malling Research Station in England to sort out the mixtures and characterize the clones and their properties (Hatton, 1917). By the 1920's individual clones were identified, described by main properties according to dwarfing capability and precocity, and named sequentially, creating the Malling (M) series rootstocks of M.1 to M.16 (Hatton. 1919). Breeding and collaboration occurred in the next few decades with the John Innes Institute at Merton. The focus was on breeding wooly apple aphid resistance rootstocks to be used in the countries of the British Empire in the Southern

Hemisphere. The ‘M’ series rootstocks were bred with ‘Northern Spy’ to create the ‘MM’ (Malling-Merton) series in the 1950’s (Ferree and Carlson, 1987; Wertheim, 1998). Following World War II, several researchers in Holland, Germany and England began to develop high density production systems using dwarfing rootstocks (Wertheim, 1998) In the US, the development of dwarfing rootstocks was aided by the organization in 1958 of the International Dwarf Fruit Tree Association (IDFTA, later shortened to IFTA) which was formed in the US with the purpose "to promote an understanding of the nature and use of dwarf fruit trees through research, education and dissemination of information”. In the 1960’s researchers identified and began removing viruses from the ‘M’ series rootstocks. The work was principally done at East Malling and Long Ashton research stations in the UK. The result was the ‘EMLA’ series of rootstocks. Meanwhile, other countries began breeding apple rootstocks. Specific traits like cold tolerance in Russia and Poland were selected after tree loses of ‘M’ series resulted from severe winters. In the late 1960’s and the 1970’s breeding programs were started in Canada, Germany, US, Japan, and Czechoslovakia (Cummins and Aldwinckle, 1974; Fischer and Fischer, 2004; Webster and Wertheim, 2003; Wertheim, 1998). Because of the long term investments and intensive resource needs required to breed apple rootstocks, several of those breeding programs have now ceased activity. Only a few programs have remained active in the world and are incorporating molecular marker technology or genetic engineering to improve the efficiency of breeding (Fazio and Mazzola, 2004; Malnoy et al. 2007)

Rootstock Cultivars

Rootstock varieties are primarily categorized by their size controlling ability to a given scion. When East Malling researchers first sorted and named the rootstock clones that became the ‘M’ series they organized them by size induction (Hatton, 1917). These became the standard sizes that are used to compare and measure modern rootstocks (Figure 1.1). The names of most apple rootstocks follow a convention where the first letters of the name are the initials of the breeding program(s) followed by a dot, the number in the series and the name of the clone selection or sport mutation (e.g. Malling 9 Pajam 2 = M.9 Pajam 2; Geneva 16 = G.16)

Currently, the most commonly used dwarfing rootstock is Malling 9 (M.9). M.9 originally selected in France and known as Jaune de Metz, was one of the first group of rootstocks collected and identified at East Malling (Webster, 2001). It produces a tree that is roughly 30% the size of a seedling. It is somewhat difficult to propagate in stoolbeds and is very susceptible to fire blight and replant disease (Leinfelder and Merwin, 2006; Webster, 1997). However, in ideal conditions, a tree grafted on M.9 can have extremely high yield. In the process of propagation of the M.9 rootstock many sport mutations have been selected, characterized and developed into rootstocks with unique propagation or dwarfing properties (van Oosten, 1986). The M.9 EMLA clone for example, was developed when latent or non symptom producing viruses were removed by heat treatment of the original M.9. In the process of removing the latent viruses, M.9 EMLA was re-juvinated and thus was slightly less dwarfing than the original M.9. In the Netherlands, M.9 was also heat treated to remove viruses. The resulting rootstock was the M.9 NAKB T337, or M.9 T337 for short. The NAKB referred to the Netherlands inspection service and the T referred to 'top-graft', or the method used to graft a small M.9 bud onto a seedling for heat treatment to remove viruses. French selection programs developed two virus free sub-clones of M.9 that are called Pajam 1 and 2. The most commonly used today is Pajam 2, a clonal mutation characterized by a more juvenile appearance and performance than the original M.9. Because of the unique properties of dwarfing, induction of precocity and increased flower density in the scion, most apple rootstock breeding programs have used M.9 and other Malling material as parental material for rootstocks

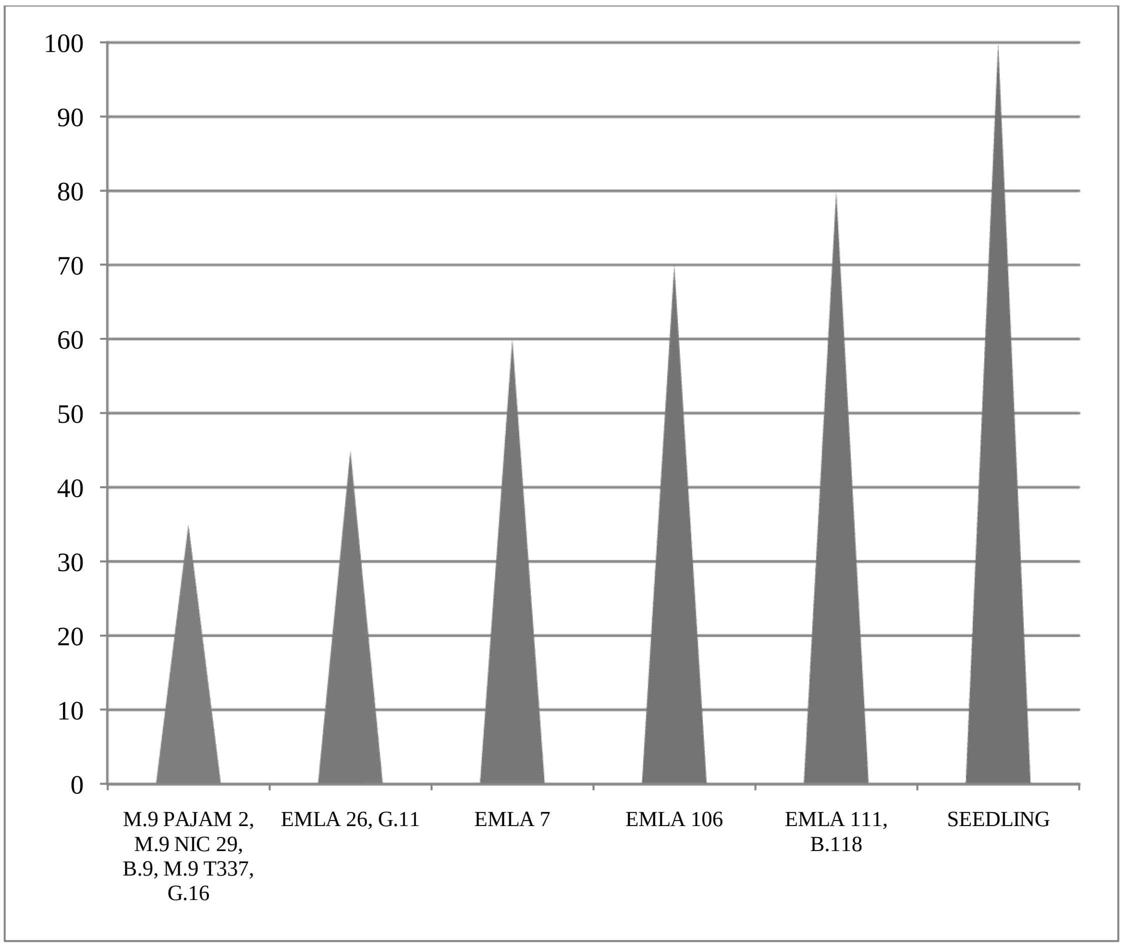

Figure 1.1 Rootstock size comparison chart.

such as the Ottawa 3 (O.3). O.3 is an M.9 open pollinated selection prized for its cold tolerance. It was developed at the Ottawa breeding program in Canada (Wertheim, 1998).

Another important series of apple rootstocks is derived from Budagovsky's breeding program in Michurinsk, Russia. The most common of the series is the Budagovsky 9 (B.9) rootstock. It is derived from a cross of M.8 and Red Flag, which give the leaves their red color. It generates a tree similar in size to M.9 and needs support like other M.9 size rootstocks (Wertheim, 1998). Unlike M.9, B.9 has shown good resistance to fire blight in the orchard, is cold tolerant, but unfortunately very susceptible to replant disease (Russo et al., 2008).

New Rootstocks

Some of the most important recent developments in apple rootstocks have come out of Cornell University (Johnson et al. 2001). In 1968, James Cummins and Herb Aldwinckle began breeding and selecting rootstocks for disease resistance, giving priority to resistance to fire blight and root rot. Selections from the program were tested as Cornell-Geneva (CG) code numbers. Elite rootstocks become the Geneva® (G.) series when released for commercial use. The most common currently in commercial production are G.11, G.16 and G.30. G.11 is an M.9 to M.26 size rootstock with moderate fire blight resistance. G.11 is an excellent rootstock in stoolbeds and roots much more easily than several other G series rootstocks. However, G.11 does have a tendency to form root suckers in the orchard. G.30 is resistant to fire blight, has yield efficiency similar to M.9 and is semi-dwarfing (similar to M.7). G.16 is another rootstock that produces a tree similar in size to M.9. It propagates well and produces a highly feathered nursery tree; however, it is extremely sensitive to latent viruses (Robinson et al., 2007). Recently, the program has released G.41, G.935 and G.202. These are very promising rootstocks that are being evaluated and used at the commercial level. Commercial production of G.41 is the most highly anticipated due to its dwarfing capabilities (similar to M.9) and high yield efficiency. It also has the combination of high resistance to fire blight and wooly apple aphid and tolerance to the replant disease complex (Fazio et al. 2005). However, G.41 has proved rather difficult to propagate in stoolbeds. G.935 generates a tree that is slightly larger than M.9 (about 30-35% of seedling), highly efficient, fire blight resistant, tolerant to replant disease but susceptible to wooly apple aphids (Fazio et al. 2005). G.202 is similar in size to M.26 (about 35-40% of seedling), resistant to fire blight and wooly apple aphids and has moderate propagation ability in stoolbeds (Robinson et al., 2004; Wertheim, 1998). Many breeding programs now focus on resistance to pests like wooly apple aphid and diseases such as fire blight, *Phytophthora* crown rot and root rot and replant disease.

1.2 Important Apple Rootstock Diseases

Most rootstocks are susceptible to the same diseases as apple scion cultivars. Three of the most devastating diseases of apple rootstocks are fire blight, crown rot and replant disease.

Fire Blight

Fire blight is a bacterial disease caused by *Erwinia amylovora*. Fire blight infects the floral, fruit, vegetative and woody parts of the trees, moving as quickly as 15-30 cm in just a few days (Van der Zwet, 1979). The first noticeable sign of fire blight on young woody material is found at the tips of the shoots. Wilting occurs forming the “shepherds crook” on the tip of the infected branches. This is followed by a clear to orange to red bacterial ooze. The shoots then become blackened and appear fire scorched, thus giving the disease its name (Grove et al. 2003). Shoot infections usually occur on tissues injured due to hail, wind whipping, and insects. Fire blight forms cankers in the bark as the infection slows down. These cankers cause cracks in the limbs and have a dark, water-soaked appearance. Cankers can also cause girdling which kills shoots, branches or scaffold limbs, rootstock suckers and the rootstock crown itself. Many times affected areas seem streaked, an appearance which is caused by amber colored ooze that runs down the branches (Van der Zwet, 1979). The bacterium can be transported asymptomatically within the tree beyond the point of diseased tissue. *E. amylovora* has been reported two weeks after shoot-tip inoculation at a distance of around 70 cm from the point of inoculation (Thomson, 2000), proving to be a fast moving bacterium within the internal structure of the tree. Rootstock blight can be due to collar or root crown infections and is the most destructive forms of fire blight, in most cases causing the eventual death of the tree (Aldwinckle et al. 2004). Collar and root crown blight often occur in highly susceptible rootstocks, such as M.9 and its clones, and M.26. The bacteria can only survive in the soil on infected tissue, and even the only until the lesion dries out. In stoolbeds there may be a danger of infection of healthy shoots by contact with infected tissue lying above the soil line. Fire blight can also be caused by bacteria that are surviving within the internal tissue of the tree (Grove et al., 2003).

***Phytophthora* Crown and Root Rot (PCRR)**

This disease is caused by various species of *Phytophthora* most notably, *P. cactorum*. PCRR affects the crown and fine root systems, above and below the ground of apple rootstocks. Tree symptoms are those typical of root damage and include premature discoloration of leaves, reduced productivity, wilt and collapse. PCRR lesion are characterized by reddish-brown inner bark and an alcoholic odor. Lesions usually originate where the main roots meet the trunk, and may spread up the rootstock shank and down toward the fine roots. Although it may not completely kill the tree as fast as other pathogens, such as fire blight, the reduced productivity results in a serious economic loss. The pathogen thrives in wet soils as a result of poor drainage or low spots in the field (Wertheim, 1998).

Phytophthora cactorum is a great survivalist. The oomycete can survive in the soil as a thick walled spore called an oospore. When the soil becomes moist, the oospores begin to germinate forming sporangia. Repeated drying and wetting of the soil, causes increasing numbers of oospores to germinate. The sporangia are filled with zoospores, which are released into the soil water. The zoospores then swim actively toward nearby host tissue, and can also be carried passively in irrigation or flood water to other infection sites (Wertheim, 1998). *P. cactorum* has been found in irrigation water that was spread across entire crops of apple rootstocks (Tidball, 1990). Most infections occur in very wet soils. The rootstock's ability to resist *Phytophthora* spp. can depend on the amount of oxygen available to the roots. When the soil is saturated with water, the roots do not have as much oxygen and become more susceptible to disease. As the disease colonizes the roots, more zoospores are released and more infection occurs (Wilcox, 1997). Infected rootstocks in the orchard can result in the decline and death of mature trees. Rootstocks of nursery trees can be infected with *P. cactorum* but show no symptoms, which can be a hazard for newly planted orchards (Tidball, 1990). Resistance to PCRR has been observed in domesticated and wild apple and appears to be the best method for controlling the effects of the disease (Aldwinckle et al. 1974).

Replant Disease

Replant disease is caused by a variable combination of pathogens, including oomycetes, fungi, bacteria and nematodes that cause poor growth in newly planted trees (Costante et al., 1991). The composition of the pathogens appears to vary from site to site. Growth of newly planted trees has been improved in problem areas by fumigation (Mazzola and Mullinix, 2005). There are typically two types of replant problems. The first problem is caused by the root-lesion nematode *Pratylenchus penetrans*. The nematode is typically a problem in light soils. *Pratylenchus penetrans* is a migratory endoparasite, meaning it feeds inside the roots and can leave the root and migrate to another feeding site as necessary. All stages of the nematode are injurious; however, the 4th and adult stages move further into the roots than other stages. The females lay 1-2 eggs per day singly or in clusters in the roots and in the soil surrounding rootstocks (Berry and Coop, 2000). The nematodes also help cause damage to roots, making the rootstock more vulnerable to other pathogens. The second problem is a complex of fungi and oomycetes found in heavier soils. The fungi and oomycetes typically found in problem areas are from the genera *Cylindrocarpon*, *Phytophthora, Pythium* and *Rhizoctonia* (Mazzola and Mullinix, 2005). Apple replant disease causes poor growth or even death. Some major symptoms are stunting, shortened internodes, rosetted leaves, small root systems, decayed or discolored roots, reduced productivity.

Most rootstock breeding programs now focus on these three major diseases. Disease resistance has become so important in the orchard setting that some of the traits that previously had higher priority in breeding programs, such as propagation ability, have been superseded by the need for the trees to survive these devastating diseases.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

Apple rootstocks can be propagated by two methods: sexual or asexual (clonal) propagation. Sexual methods consist of propagation by seed. Asexual methods consist of cuttings, micropropagation and layering. Each method has its own advantages and disadvantages.

2.2 Sexual Propagation

Rootstock production by seed is still a common method of propagation because it allows the nursery to produce a large number of rootstocks easily and at low cost. Because in apple no viruses are known to be transmitted by seed, seed propagation allows nurseries to grow virus free rootstocks. This method of propagation also avoids of root-borne diseases often transmitted in stoolbeds. When planting trees on seedling rootstocks, the fruit grower is generally at a disadvantage because most seedling rootstocks have inferior performance in the orchard when compared to clonal rootstocks. One distinct problem is increased vigor of the seedling rootstocks which results in a very large tree that takes several years to flower and reach full production potential. Another problem is the genetic variation among seedlings. This results in an orchard with very little uniformity. Uniformity can be increased by careful seed selection. The use of self-fertile cultivars such as ‘Golden Delicious’ or apple cultivars that produce apomictic seeds are the best ways to increase uniformity (Webster, 1995). Apomictic seeds are produced when asexual reproduction takes the place of sexual reproduction that normally leads to embryo formation. A cell fails to undergo meiosis but forms a zygote that is genetically similar to the seed-bearing plant (Howard, 1987). Unfortunately, many apple apomicts produce both zygotic and apomictic seeds requiring a difficult culling process. The apomictic seedlings are also typically susceptible to subsequent virus infections (Webster, 1995).

Propagation starts with seed selection, extraction and storage. Effort should be made to acquire seed that is as uniform as possible. Apple seeds are readily available from processing facilities and can be selected by cultivar (Howard, 1987). Seeds may also be collected from apple orchards grown specifically for seed. Seed apples are collected from the seed orchards by various methods (hand picking, beating limbs, shaking trunk, etc.), and then taken to extraction facilities. The extraction process is fairly simple. The apples are cut into pieces and then macerated with a fruit press or something as simple as a rolling pin (McDonald, 1986). Typically the seeds are removed easily with ripe or overripe fruit. Following extraction, the seeds are washed and dried. Seed grading may also be necessary to ensure the best and largest seeds are selected because they result in the best plants (Wertheim and Webster). Drying temperatures should be around 32°C (90°F) and no more than 43°C (110°F). Rapid drying can cause cracking and hard seed coats (Hartmann et al., 1997). Typical moisture content at the end of the dehydration process is about 10-12 % at which point the seeds are moved to burlap sacks and kept in cold storage around 3°C (37°F) (McDonald, 1986). Harvested seed are dormant and therefore cannot be germinated until dormancy is broken. Low temperature, light and moisture control are a few factors that help break dormancy (Dennis, 1994). The process used to break dormancy is called stratification. Stratification breaks physiological dormancy by after-ripening the embryo through a period of chilling. Temperatures should range from 0-5°C (32-41°F) for 60-90 days (Hartmann, 1997). The seeds can be mixed with a stratification medium to help retain moisture or they can remain 'naked' (McDonald, 1986).

The next step is seed planting and germination. Before planting, a site should be selected that is fertile and has well drained soil. Efforts should be made to use best management practices in crop rotation and nutrient management during the year prior to seed planting. Fumigation may be necessary to remove soil-borne diseases and nematodes. Herbicides can also be used to control weeds in the seed bed site (Hartmann, 1997). Chemical treatments might also be used to help promote germination. Seeds may be soaked in various plant growth regulators such as gibberellic acid, benzyl-adenine or ethephon to increase germination (Webster, 1995). Seeds should be planted into closely spaced rows with a seed planter. Individual seed spacing should be close enough to maximize field acreage but without overcrowding. Overcrowding can result in damping-off and reduced vigor and size of the seedlings (Hartmann, 1997). Typical densities could reach up to 150 to 200 seeds per square meter (McDonald, 1986). Seeds are planted in the spring from late April to early May in colder climates like Washington and New York to avoid low temperature injury. Planting depth is determined by the size of the seed. As a general rule, planting depth should be equivalent to three to four times the diameter of the seed, roughly two cm deep (Wertheim and Webster, 2003). The seeds should then be covered by soil or mulch. After planting, seedlings should be irrigated to supply continuous moisture. Cultivation of weeds may also be necessary. Fertilization with nitrogen is also highly recommended (Hartmann, 1997).

After seedlings have been in the ground for one season (April to November), they can be harvested as liners for budding and grafting. Harvesting methods may differ depending on available equipment. Most harvesting is done by mechanically undercutting the seedlings (Hartmann, 1997). Some harvesting equipment can even lift the seedlings out of the ground and pull them along a conveyor to storage bins pulled behind a tractor (Figure 2.1). The seedlings are then put in cold storage until the next spring when they will be planted as liners.

Figure 2.1 Seedling harvest with digger and conveyor at Willow Drive Nursery, Ephrata, WA.

2.3 Asexual Propagation

The main purpose of asexual propagation is to produce plants that are genetically identical to the original plant. This is often known as vegetative propagation. Vegetative propagation of apple rootstocks can be broken into three categories: cuttings, micropropagation and layering.

Cuttings

One of the main advantages of cuttings is their ability to produce clones of the mother plant. Cuttings can be used to propagate the scion cultivar directly or can be used to create rootstocks for later grafting or budding. Cuttings also allow nurseries to start many new plants in a limited space and with few stock plants. Compared to other asexual propagation techniques, scion plants made directly from cuttings are relatively inexpensive and can in many cases remove the costly step of grafting or budding. However, propagation by cuttings is not without disadvantages. Plants produced from cuttings are generally more expensive than seedlings. Many cutting operations are done in greenhouses that must be maintained, require expensive mist or fog systems and typically need heating. More importantly, in the case of fruit trees, specialized rootstocks can give the tree desired traits that are not inherent in the scion cultivar alone (Hartmann, 1997). Self-rooted apple trees tend to be more vigorous than is desired for modern management; they can also lack tolerance of soil diseases or unfavorable soil conditions (Webster, 2001).

Three things are necessary in order for successful propagation by cuttings, regardless of cutting technique. First, the cutting must be healthy and in the correct physiological condition. Second, the cutting may need additional treatment, either physical or chemical, to induce rooting. Finally, the cutting must kept in an environment that will ensure survival and root development (Webster, 1995). Cutting types can be broken down into hardwood or softwood cuttings.

Hardwood Cuttings. Hardwood cuttings are made from dormant firm wood after leaves have fallen. For this reason they are also known as leafless winter cuttings. This technique has the advantage of allowing nurseries to take cuttings from stock plants according to demand. However, they usually require a year of growth before they are suitable for budding (Wertheim and Webster, 2003).

Successful hardwood cuttings depend first on the stock plants from which they are taken. Stock plant material can come from many sources. Hard pruned trees and stoolbeds are excellent sources when they are readily available. However, it may be necessary to plant stock plants specially. It is recommended to plant stock plants at two foot spacing with rows six feet apart. This allows tractor access as well as adequate light and good branching (Sabin, 1983). After cuttings are taken, the hedges are pruned severely to stimulate shoot growth the following season. This can also influence rooting in the subsequent years (Howard, 1987; Wertheim and Webster, 2003).

Cuttings should be made in the winter months from stock plants that are at least two years old. If necessary, cuttings can be taken from one year old trees but the success rate is reduced by 50%. Cutting survival from tips of newly budded trees or the tops of stoolbeds can be as low as 10-20%. Thus, it is always recommended to use older stock plants (Sabin, 1983). Stock plants can also be manipulated to increase rooting. In certain environment conditions, girdling of the shoots 15 weeks before cutting may increase rooting. Growing stock plants in polyethylene tunnels can also enhance rooting (Webster, 1995). Cuttings should be about 20-25 cm. (8-10 in.) long (Knight et al., 1927) but can range from 10-75 cm. (4-30 in.) (Hartmann, 1997). Rooting potential is highest in the basal section of the cutting and decreases in the second or third cutting of the same branch (Howard, 1987; Sabin, 1983). Longer cuttings allow insertion of a bud directly into the original cutting instead of a new side shoot (Hartmann, 1997). After the cuttings are made, trimmed and cleaned, they are wrapped in bundles of 50-100. They can then be dipped in a hormone treatment of Indole-3-butyric acid (IBA) at 2500 ppm for no more than five seconds (Wertheim and Webster, 2003; Howard, 1987). Within an hour the cuttings should be stored upright in a wooden apple bin. The bundles can be wrapped with polyethylene while the basal section is imbedded in about 5 cm. (2 in.) of peat moss or sawdust which will help maintain moisture and humidity. The bins are then moved to a temperature controlled room at 18-20°C (64-68°F). This process helps ensure callusing on the basal portion of the cutting and can stimulate rooting. After 30 days, the cuttings can be moved to cold storage until planting (Sabin, 1983).

Cuttings should be planted in the spring when the ground temperature is at least 13°C (55°F) (Sabin, 1983). Planting style varies depending on future uses. For stoolbed production, cuttings should be planted according to standard practices (see section on stooling and layering). Cuttings can also be planted directly to the nursery to be budded later in the season.

Softwood Cuttings. Softwood cuttings are taken from soft, succulent growth. This usually takes place in the summer, giving these cuttings the term leafy summer cuttings. Unfortunately, softwood cuttings are typically small and therefore not suited to apple rootstock production. It usually takes too long for the softwood cuttings to be large enough for sale as rootstocks. However, softwood cuttings can be very useful in rapid multiplication of new rootstocks (Howard, 1987).

Softwood cuttings also rely on healthy stock plants to ensure successful propagation. Cuttings can come from a variety of sources. Some growers might utilize the tips of stool shoots after seasonal topping, while others might grow plants specifically to be used as stock material. Shoots from stoolbeds tend to root better than those from one-meter tall hedges. Rooting potential increases with the severity of pruning. Rooting also increases as the distance between the position of the cut and the stock plant's root system decreases (Wertheim and Webster, 2003). Stock plant manipulation is an important factor in root initiation of cuttings. Etiolation and blanching have long been known to increase rooting potential in vegetative propagation (Ryan, 1969). Etiolation is the development of plants or plant parts in the absence of light (Hartmann, 1997). This can be done in many ways and has many names: banding, blanching and shading are all techniques to cause etiolation. Etiolation helps keep the stem tissue of the stock plants tender, in which condition they root better than those with mature or hardened stem tissue (Gardner, 1936; Delargy and Wright, 1979). Etiolation may be performed by different methods depending on the number of cuttings to be taken. For a large operation, the entire stock plant can be covered with black polyethylene or shade cloth. Shade boxes can be constructed to house stock plants and regulate the light exclusion, ideally around 99% exclusion (Maynard and Bassuk, 1987). Shade boxes can increase rooting of cuttings from 11% to 78% (McDonald, 1986). Etiolation effects can persist for up to four months after etiolation ends (Maynard and Bassuk, 1992). For smaller operations, blanching or banding techniques can be used. Originally, black insulation tape was used to blanch shoots for etiolation (Gardner, 1936). More recently, Velcro strips have been used. Velcro strips have been found to increase rooting as well as stimulate lateral budbreak in cuttings (Sun and Bassuk, 1991). Two-centimeter wide strips of Velcro are wrapped around the base of the shoots for cuttings. IBA can also be applied on either side of the Velcro to increase rooting even further (Maynard and Bassuk, 1987). Stem banding with Velcro for 10-20 days before cuttings are collected is highly recommended. In many cases, rooting is increased and basal rotting of cuttings decreases as Velcro banding time increases (Sun and Bassuk, 1991).

Cuttings can be taken as soon as they become available. This allows the stock plants to produce more shoots for cuttings later in the year. Cuttings from earlier in the growing season have an increased rooting percentage and number of roots compared to cuttings from later in the season (Wertheim and Webster, 2003). Cuttings should be taken in the morning when the leaves and stems are turgid and then promptly moved to the rooting environment. This step is crucial because softwood cuttings desiccate quickly. Most cuttings are about 5-20 cm in length and should receive a quick dip in IBA to aid rooting (Webster, 1995). The cuttings are then placed in rooting medium consisting of peat, sand and grit. Bottom heating may be necessary to increase rooting but it is not required. High humidity must be maintained to avoid water loss and desiccation. For many years misting was the only way to maintain the high humidity necessary for rooting. However, fogging systems are becoming more common because they provide much finer droplets of water that minimize water loss and can increase the number of rooted cuttings (Harrison-Murray et al., 1988). The rooting process can take up to several months. The cuttings should be acclimated to a non humid environment (hardened off) after adequate rooting. This is done by diminishing the relative humidity. The new plants can then be planted in the nursery in the spring if they are large enough. It may be necessary to continue growth in the greenhouse until they are large enough to be planted (Wertheim and Webster, 2003).

Micropropagation

Micropropagation, tissue culture or in vitro culture, has become more important in recent years. Micropropagation can be quite useful to build up large populations of a new rootstock in a short time. Plants in tissue culture can be easily moved across national borders as they more easily satisfy plant importation and phytosanitary regulations (Webster, 1995). Tissue culture derived plants can also be advantageous when used to establish stoolbeds because of the increased vigor, which is typical of newly acclimated plants that portray juvenile characteristics. However, in some cases the opposite can be said about use of tissue culture plants when used to produce orchard trees directly. For example, plants of G.16 derived directly from tissue culture were found to be more vigorous and slightly less efficient than traditionally propagated rootstock liners (Robinson et al., 2007). Direct tissue culturing of apple cultivars with no grafting onto dwarfing rootstocks can also result in unwanted problems. Most tissue culture derived apple trees are vigorous with little to no size control (Larson and Higgins, 1993). In vitro trees produced on their own roots tend to be more vigorous than trees on dwarfing rootstocks, require more time to fruit, and have lower yield efficiencies (McMeans et al. 1998). They also tend to produce more root suckers and burr-knots (Wertheim and Webster, 2003). Despite these drawbacks, micropropagation is a very efficient technique to develop many plants in a short period. One single microshoot can produce many plantlets. Since the process takes place in a controlled environment, the propagation is not bound by growing seasons and can therefore be done multiple times in one year. Hypothetically, one mother plant may produce 6 shoots. Each of the 6 shoots will have many axillary buds which can be used as explants. If only half of the explants actually form plantlets you would still have many more plants than through other traditional asexual propagation methods.

Micropropagation is a very specialized technique. Procedures can differ between cultivars. Slight improvements in propagation protocols are constantly being developed to improve results. Techniques have been developed for a number of apple rootstocks. Regardless of the rootstock, there are four stages:

1. Establishment
2. Multiplication
3. Root formation

4. Acclimatization

The key to micropropagation is totipotency defined as the ability of each living cell to reproduce the entire organism since it possesses all the necessary genetic information (Hartmann, 1997). The establishment stage is based on utilizing totipotency to isolate an explant (portion of a plant) in an environment suitable for shoot production and induce it to grow on an artificial media. Explants can be derived from many different materials such as leaf pieces, roots, and even anthers. The most common explants are axillary buds which help minimize somaclonal variation. It is important to keep the explants clean and free of pathogens. Explant disinfestation is done by chemical treatments of calcium hypochlorite or sodium hypochlorite. After the explants are surface sterilized, they are placed in a culture medium. The medium is made of four types of components: inorganic salts, organic compounds, complex natural ingredients and inert support ingredients. Inorganic salts consist of nitrogen, phosphorus, potassium, calcium, magnesium, boron, cobalt, copper, manganese, iodine, iron and zinc. Organic compounds consist of carbohydrates, vitamins, hormones and growth regulators. In many instances, stock solutions can be purchased that contain most of the necessary ingredients. There is no uniform formula for tissue culture media which can present a problem to commercial operations. The media formulations also change according to the stage of development and according to the cultivar being cultured. Typically in the establishment phase a moderate level of cytokinin is used, roughly 0.5-1 mg/l (Hartmann, 1997). After 4-6 weeks, the plantlets are moved to stage two.

The multiplication stage is very similar to the establishment stage. The cytokinin levels are increased which stimulates the initial explant to produce more microshoots. The explant is then divided, or subcultured every 4-8 weeks. This allows for rapid multiplication of microshoots. The multiplication stage can go on for years until a determined number of microshoots is reached at which point the shoots move to stage three (Wertheim and Webster, 2003).

Stage three, or root formation stage, is possibly the most difficult stage to complete (Modgil et al., 1999). The microshoots are transferred to a cytokinin-free medium. IBA is typically added to aid in root formation (Alvarez et al., 1989). Rooting can also be increased by low light treatment (Welander, 1983) and increased temperature (Zimmerman, 1984). Root formation can also be achieved by direct rooting in a potting mix. With this method, the microshoots are directly placed in a mix of peat and sand, after a treatment with rooting hormone, and treated as softwood cuttings. This eliminates the need for in vitro rooting (Simmonds, 1983).

Stage four is the acclimatization stage. Plantlets are moved from agar media to pots in the greenhouse. Poor survival is often a problem in the acclimatization stage due to desiccation of the transplanted shoots. A mist or fogging system similar to those used in softwood cutting operations is critical in maintaining moisture and humidity. There are also problems with variability among acclimatized rootstocks which may require grading to produce uniform liners (Webster, 1995).

At the present time propagating apples by plant tissue culture can be very challenging but is commonly used with other fruit crops such as for cherry rootstocks which do not propagate well in stoolbeds. With apple rootstock production, micropropagation is too expensive for common use. At the moment tissue culture rootstock plants cost about $1.00 per plantlet while a plant from a typical rootstock plant propagated by layering in a traditional stoolbed would cost only $0.64 (Jay Adams, Personal Communication).

If apple rootstocks could be eliminated, micropropagation could offer the potential to propagate apple trees directly, at substantially lower tree costs. However; with apple, in vitro trees have occasionally shown reduced size control resulting in slightly more vigorous trees. Modern apple production depends on smaller trees and high density orchards with higher yield efficiencies. Micropropagated trees may have a difficult time meeting the requirements of size control, yield efficiency and early fruit bearing. However, tissue culture is used extensively in the dissemination of material and to rapidly bulk up material for stoolbed establishment.

Stooling and Layering

Stooling and layering are the most common forms of apple rootstock propagation. They involve the induction of adventitious rooting on shoots that are still attached to a mother. Mother plants are planted in the spring in an upright position (stooling) or angled (layering). In the case of layering, the mother plants are pinned or tied down horizontally at the end of the first year. In both stooling and layering the mother plants are mounded with soil or sawdust during the growing season as new shoots grow from the mother plant to induce rooting on the new shoots. The shoots are harvested in the fall as rooted shoots (liners) leaving the mother plant in the ground. The original plants are referred to as mother plants because they remain in the ground for many years and produce new shoots each year that will be induced to root and then harvested as rootstocks liners. These rootstock production fields are termed stoolbeds or layer beds.

As with all vegetative propagation techniques, layering or stooling produces new plants which are clones of the mother plant. Layering techniques were first used as an alternative propagation method for fruit crops which were hard-to-root by cuttings (Knight et al., 1927). Layering is also used because of its adaptability to mechanization, high quality of the produced rooted liner, relative low cost and ease of maintenance (Anderson and Elliott, 1983). Stoolbeds have the added benefit of being a reliable and constant production system. A typical stoolbed can be used for up to 10-20 years before productivity declines and it must be replaced. However, the consistency of a stoolbed can also be a problem when demand is low. Propagation systems that use either soft or hardwood cutting can simply omit to take cuttings in a year of low rootstock demand, while stoolbeds must be maintained continually regardless of marketability (Howard, 1987). Disease can also be a major concern in layering operations as many soil-borne pests can infect the new shoots each year (Webster, 1995). Other concerns are land requirements, high labor costs and mechanical damage or dislodging of shoots (McDonald, 1986).

Site selection is very important for layer beds. The planting site should be as flat as possible and rock free in order to minimize damage to harvest equipment. Fumigation may be necessary to eliminate soil borne pests and diseases.

There are several common planting schemes for mother beds. One common method utilizes trenches about a foot deep into which the mother plants are planted (Figure 2.2). The mother plants can be planted in single or double rows with spacing from 10-50 cm between plants. With double rows and planting the mother plants upright (stooling), typical plant spacing is 10-20 cm between each double row and between each plant (Figure 2.3). The close spacing ensures that there are plenty of mother plants if one were to die. When mother plants are planted at 30-40 degree angles (layering, Figure 2.4), larger spacing of 30-50 cm are used since the plant will later be laid horizontal which can also give good shoot density (Anderson and Elliott, 1983). Stooling requires many more plants per hectare to establish a healthy stoolbed than through layering. However, layering requires higher quality mother plants to avoid large gaps in the established stoolbed. Regardless of the planting style, the first year is usually required to establish the mother plants and to fill the space between

Figure 2.2 Stoolbed trench for new plantings at Willow Drive Nursery, Ephrata, WA.

Figure 2.3 Upright (stooling) planting at Willow Drive Nursery, Ephrata, WA.

Figure 2.4 Top view of angled (layering) plantings at Willow Drive Nursery, Ephrata, WA.

plants. Stoolbed trenches can be filled in immediately after planting, while layerbeds are filled after sufficient growth is obtained from the mother shoots. Some growers mound the newly planted stoolbed mother plants to induce rooting. Although the rooting percentage is typically very low in the year they are planted, the harvested shoots can be used to start new stool and layer beds (Jay Adams, Personal Communication). If stoolbeds plants are not mounded the first year, the new shoots of a stoolbed mother plant are severely pruned, leaving stubs about two inches (Knight et al. 1927). With layer bed mother plants, the shoots are tied down late in the season or in the spring before growth starts. In some stressful climates the layerbed plants are pinned down after shoots have grown 5-10 cm long to protect the mother plant from sunburn.

With stoolbed plants, each pruned stub will produce about 3-5 new shoots. The shoots are allowed to grow during the first four to eight weeks of the growing season without much maintenance (Figure 2.5). The beds should be watered and fertilized as needed. Weed competition is a major concern for growth of young shoots and should be controlled as soon as weeds begin to emerge. As the shoots grow, soil or sawdust is mounded around the shoots to create a favorable rooting environment. If sawdust is used, it can be laid between the rows in preparation for mounding (Figure 2.6; Figure 2.7). Sawdust should come from trees that contain no chemicals, natural or induced, that may inhibit rooting (Webster, 1995). Beginning in mid June, sawdust or soil is mounded or “pushed” around the new shoots up to about 12 inches high (Figure 2.8). Many European countries do not use sawdust and mound soil at a lower height of about 6 inches (Knight et al., 1927). The main principle however remains the same; light exclusion similar to etiolation techniques used with cuttings and a moist environment which promotes rooting (Webster, 1995). Many techniques are used in the mounding process. Nurseries that use sawdust typically do the mounding in stages,

Figure 2.5 New shoots in May at Willow Drive Nursery, Ephrata, WA.

Figure 2.6 Tractor drawn sawdust wagon, used to apply sawdust between stoolbed rows at Willow Drive Nursery, Ephrata, WA.

Figure 2.7 “Blade” used to mechanically push sawdust against stoolbed shoots at Willow Drive Nursery, Ephrata, WA.

Figure 2.8 Stoolbeds mounded up about 12 inches at Willow Drive Nursery, Ephrata, WA.

with the initial application by hand with large crews (Jay Adams, Personal Communication). Soil mounding nurseries, like those in France and the United Kingdom use a combination of plows and rubber tipped cultivators (Joris Nicolleau, Personal Communication; Howard, 1987). The important point is that adequate coverage of the shoots with the mounding material is achieved. It is extremely important that the inner sections of the stoolbed are also surrounded by the mounding material. The sawdust also forms a base which helps keep the new shoots straight. After mounding, heavy irrigation is recommended to maintain moisture levels necessary for rooting (Anderson and Elliott, 1983). Further mounding may be necessary about a month after the first application due to continued growth. This second mounding can be done mechanically with rolling tined cultivators commonly known as “rakes” (Figure 2.9). Insect and disease control is crucial during the summer months. Insect pests can damage the terminal bud and force unwanted lateral branching. Diseases are easily transmitted by hand labor, mechanical means or by irrigation water. Depending on the climate, most of the rooting actually takes place in August and September (Anderson and Elliott, 1983). Harvest can start as early as November (Knight et al., 1927) in some areas such as Washington and as late as March in other areas like Oregon (Anderson and Elliott, 1983). Traditionally the shoots were harvested by hand but cutting machines have been developed which substantially reduce the costs of this labor intensive operation. Stoolbed growers experimented with all manner of mechanical trimmers, cutters and even adapted hay mowers. Most sawdust mounding operations now use sickle type harvesters with moving teeth that undercut the shoots just above the mother plant (Jay Adams, Personal Communication). Soil mounding operations use a rear-mounted unit with a saw-blade that cuts the shoots (McDonald, 1986). Most harvest equipment is built on the farm to fit the grower’s needs. Some of the more efficient models undercut the

Figure 2.9 “Rake” used to mound stoolbeds and straighten shoots after mounding by hand at Willow Drive Nursery, Ephrata, WA.

Figure 2.10 Stoolbed harvester with conveyor at Willow Drive Nursery, Ephrata, WA.

Figure 2.11 Stoolbeds covered by sawdust ready for wintering at Willow Drive Nursery, Ephrata, WA.

Figure 2.12 “Sweeper” used to sweep the sawdust from the stoolbeds in the spring to induce shoot production at Willow Drive Nursery, Ephrata, WA.

Figure 2.13 Harvested rootstocks ready for cold storage at Willow Drive Nursery, Ephrata, WA.

Figure 2.14 Grading of rootstock liners at Willow Drive Nursery, Ephrata, WA.

Figure 2.15 Harvested rootstocks are stored in moist sawdust at Willow Drive Nursery, Ephrata, WA.

Figure 2.16 Storage of harvested rootstocks at Willow Drive Nursery, Ephrata, WA.

Figure 2.17 Rootstocks liners planted in the spring at Willow Drive Nursery, Ephrata, WA.

stocks and lift the rooted liners up a conveyor to workers who gather the rootstocks and place them in bins for storage (Figure 2.10). After harvest, a tractor pulls a roller over the beds to gently cover the cut stumps with sawdust which acts as insulation during the winter (Figure 2.11). In the early spring the sawdust which covers the mother plants is swept to allow shoot initiation and bud break (Figure 2.12). Harvested rooted liners are placed in cold storage until they can be graded by caliper and level of rooting (Figure 2.13, Figure 2.14, Figure 2.15 and Figure 2.16). Culling of harvested liners also takes place at this time to remove any defective shoots. Graded rootstock liners can be grafted in the later winter with a scion variety before planting the following spring in a nursery or they can be planted the following spring in a nursery for later budding (Figure 2.17).

CHAPTER 3 – PROBLEM STATEMENT AND OBJECTIVES

3.1 Problem Statement

Apple rootstocks are an essential component of most fruit tree production systems including apple. They are critical for reducing tree size and increasing yield efficiency. They also impart many important characteristics to the tree such as cold tolerance and disease resistance. Apple rootstocks can be propagated by seed, cuttings, tissue culture and most importantly by layering. Propagation by cuttings, tissue culture and layering produces clones of desirable rootstock cultivars. Due to efficiency and cost, the most common method of apple rootstock propagation is by layering.

Breeders primarily have focus on dwarfing, precocity, yield efficiency, diseases resistance, reduced number of spines, cold tolerance, fruit quality, anchorage, and suckering (Cummins and Aldwinckle, 1983). A major selection trait that characterizes newer rootstocks, such as G.41 and G.935, is the absence of burrknots and low suckering. Both these traits are excellent in the orchard, but are contrary to current propagation methods. Many rootstocks, from the original dwarfing rootstocks like M.9, to the newest rootstocks like G.41, suffer from poor shoot production and root formation in stoolbeds. The need to have rootstocks with dwarfing, precocity, yield efficiency, disease resistance and other traits is increasingly important since orchards suffer under the constant threat of fire blight, crown and root rot, wooly apple aphid and many other pests. Highly productive high density orchards with dwarf trees are an economic necessity now with increased labor costs. Unfortunately the rootstocks that are easy to propagate do not have the dwarfing, yield efficiency or disease resistance that modern orchards require. Thus improved propagation methods for the dwarfing rootstocks are very much needed. Little has been done to improve the propagation methods involved in layering since they were described over 80 years ago. Work that has been done with plant growth regulators has proven to be inconclusive or genotype dependent (Webster, 1995).

3.2 Objectives

The goal of this research was to improve the propagation of highly desirable dwarfing apple rootstocks but which have poor propagation characteristics. Our goal was described perfectly in 1927 by Knight et al., (1927) : “It is much easier to improve the propagation of a variety of good performance, than to improve the performance of a less desirable variety, which happens to be easily propagated”. Specifically, the focus of this research was to:

1. Increase rooting in dwarfing apple rootstock stoolbeds by etiolation techniques commonly used in softwood and hardwood cuttings, such as shading and blanching.
2. Increase rooting in dwarfing apple rootstock stoolbeds by chemical application of root inducing auxins or vegetative growth inhibitors.
3. Assess the relationship between planting style/density and shoot production and rooting in apple rootstock stoolbeds.

CHAPTER 4 – MATERIALS AND METHODS

4.1 Plant Growth Regulator Experiments

In 2008 and 2009 experiments on the effect of plant growth regulators on rooting efficiency were conducted at Willow Drive Nursery in Ephrata, Washington, DL Nursery in Anger France and in 2009 at Willamette Nursery in Canby Oregon.

At Willow Drive Nursery previously established stool beds of B.9 and M.9 T337, at were selected for plant growth regulator treatments. The selected beds of B.9 and M.9 337 ran parallel to each other and were planted in 2001 on Timmerman coarse sandy loam (Soil Survey Staff). A randomized complete block design with a split-plot treatment design and 4 replications was used. The main plot was rootstock genotype and the subplot was plant growth regulator treatment. Each subplot consists of a 3m long section of stoolbed. The treatments were:

1. Apogee 250 ppm
2. NAA 50 ppm
3. IBA 1000 ppm
4. Untreated control
5. Apogee 1000 ppm
6. NAA 200 ppm
7. IBA 10000 ppm

The IBA sprays were applied on June 9, 2008 to the young stoolbed shoots before mounding with sawdust. Sprays were applied with a pressurized sprayer with a wand. Shoots were sprayed to drip. The stoolbed plots were then mounded a few days later. The Apogee and NAA sprays were applied on August 25, 2008 long after mounding had already occurred. Control plots received no chemical treatments. All treatments received typical management through the season including irrigation, pest control, and cultural practices.

At DL Nursery in Angers, France previously established stoolbeds of G.41 and M.9 EMLA stoolbeds planted in 2005 were used. The stoolbed rows of each rootstock ran parallel in the field. A randomized complete block design with a split-plot treatment design and 4 replications was used. The main plot was rootstock genotype and the subplot was plant growth regulator treatment. Each subplot consists of a 3m long section of stoolbed. The main plot was rootstock genotype and the subplot was plant growth regulator treatment. Sprays were applied with a pressurized sprayer with a wand. Shoots were sprayed to drip. The treatments were:

1. Regalis (Apogee) 250 ppm
2. ANA (NAA) 50 ppm
3. Untreated control
4. Regalis (Apogee) 1000 ppm

Both of the chemicals were sprayed on the stoolbed shoots on August 11, 2008 after they had been previously mounded with soil in June (At DL Nursery they do not use sawdust for mounding).

In the second year (2009) after preliminary data analysis of the data from year one, changes were made in the timing of chemical applications. At Willow Drive Nursery in Washington the 2009 treatments and their corresponding dates on both B.9 and M.9 T337 were:

1. IBA 1000 ppm on June 17, 2009 for B.9 and June 24, 2009 for M.9 T337 (just before mounding)
2. IBA 10000 ppm on June 17, 2009 for B.9 and June 24, 2009 for M.9 T337 (just before mounding)
3. Apogee 1000 ppm on June 25, 2009
4. Apogee 1000 ppm on July 23, 2009
5. Apogee 1000 ppm on June 25 and July 23, 2009
6. Apogee 250 ppm on August 3, 2009
7. Apogee 1000 ppm on August 3, 2009
8. NAA 50 ppm on August 3, 2009
9. NAA 200 ppm on August 3, 2009
10. Apogee 1000 ppm on August 24, 2009
11. Untreated control

At DL Nursery in Angers, France treatments in 2009 were changed to focus on timing of application. Plot length was also increased to three meters. Treatments in 2009 were:

1. Regalis (Apogee) 1000 ppm on June 29, 2009
2. Regalis (Apogee)1000 ppm on July 29, 2009
3. Regalis (Apogee)1000 ppm on June 29 and July 29, 2009
4. Untreated control

At Willamette Nursery in Canby, Oregon a previously established stoolbed of G.41 planted on Latourell loam (Soil Survey Staff) was treated with the same treatments as in France. A randomized complete block design with 4 replications was used. Each plot consists of a 3m long section of stoolbed. Sprays were applied with a pressurized sprayer with a wand. Shoots were sprayed to drip. The treatments and their corresponding dates were:

1. Apogee 1000 ppm on June 29, 2009
2. Apogee 1000 ppm on July 29, 2009
3. Apogee 1000 ppm on June 29 and July 29, 2009
4. Untreated control

4.2 Dark Preconditioning Experiment

In 2008 and 2009, previously established stool beds of Budagovsky 9 (B.9) and Malling 9 NAKT337 (M.9 T337) rootstocks at Willow Drive Nursery in Ephrata, Washington were treated with dark preconditioning treatments. The selected beds of B.9 and M.9 T337 ran parallel to each other and were planted in 2001 on Timmerman coarse sandy loam (Soil Survey Staff). A randomized complete block design with a split-plot treatment design and 4 replications was used. The main plot was rootstock genotype and the subplot was dark preconditioning treatment. Treatments were:

1. Shading
2. Early sawdust mounding
3. Untreated control

Shading consisted of a “box” made of pvc pipe and covered with shade cloth. The boxes were 3m long, 30cm wide and 30cm tall (Figure 4.1). Three layers of shade cloth were attached to the pvc frame (Figure 4.2). The top layer excluded 90% of the light, while the two inner layers excluded 50% of the light. The combined effects of the 3 layers of cloth excluded up to 97.5% of the light. Boxes were placed over stoolbeds about two weeks after bud break on May 19, 2008 (Figure 4.3). The new shoots were approximately 3-15cm tall for M.9 T337 plants and 3-20cm inches tall for B.9 plants. The top layer of shade cloth (90%) was removed two weeks later on June 2, 2008. The second layer (50%) was removed two days later on June 4, 2008. The final layer (50%) was removed 5 days later on June 9, 2008 (Figure 4.4). The beds were mounded with fresh sawdust one week later on June 16, 2008.

Early sawdust treatment consisted of mounding sawdust in the normal manner two weeks before conventional mounding. Conventional mounding usually occurs in mid June in Washington State. Sections of stoolbed for this treatment were mounded on June 2, 2008. The sections were mounded a second time on June 16, 2008.

Control plots were mounded conventionally on June 16, 2008. All treatments received typical management through the season including; irrigation, pest control, and cultural practices.

There were a few changes in methodology in year two of the trial. B.9 was treated earlier than M.9 T337 in year two to fit more accurately the growth of the new shoots. B.9 typically grows faster than M.9 T337. Shade boxes were put over B.9 plots on May 20, 2009. The first layer of shade cloth was removed on June 3, 2009. The second layer was removed a week later on June 10, 2009 and the final layer was removed June 17, 2009. The bed was mounded immediately. Shade boxes were put on M.9 T337 on May 27, 2009. The first layer of shade cloth was removed on June 10, 2009. The second layer was removed on June 17, 2009 and the final layer was

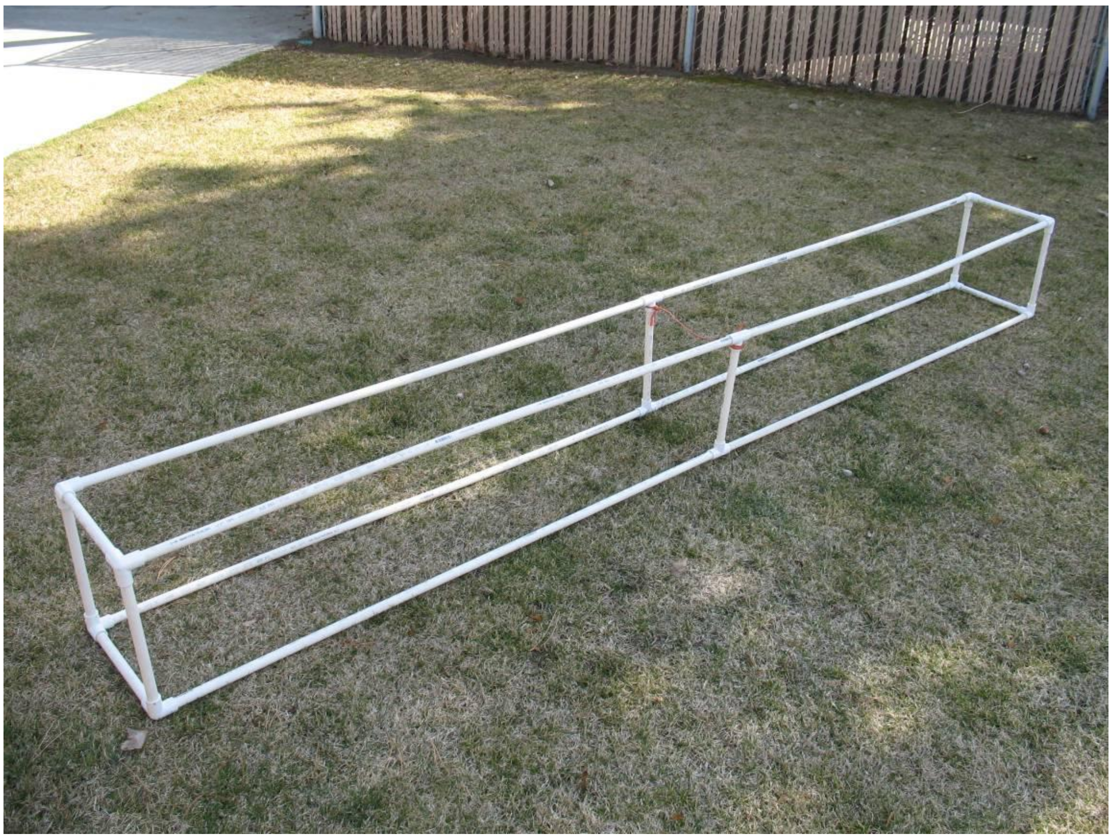

Figure 4.1 Shade box constructed of pvc.

Figure 4.2 Shade box with shade cloth.

Figure 4.3 Shade boxes on B.9 and M.9 T337.

Figure 4.4 M.9 T337 rootstock under 50% shade.

removed on June 24, 2009 with mounding done immediately. Early sawdust mounding for B.9 was performed on June 3, 2009 while early mounding for M.9 T337 was on June 10, 2009.

4.3 G.41 Experiment

Due to limited numbers of G.41 rootstocks, an experiment was done in 2008 and 2009 to combine the effects of shade boxes and chemical application. G.41 rootstocks planted on Timmerman coarse sandy loam (Soil Survey Staff) were used in the experiment. A randomized complete block design with 4 replications was used. Each plot consists of a 3m long section of stoolbed. The two treatments were:

1. Untreated control
2. Shade plus IBA treatment

Treated sections of the stoolbed were covered with shade boxes of identical construction as those used in the dark preconditioning experiment on May 21, 2008 when the new shoots were 3-15cm tall. The first layer of shade cloth was removed on June 2, 2008 and the second layer was removed on June 4, 2008. The final layer was removed on June 9, 2008 at which point the plot received an application of IBA at 2000 ppm and was then mounded. The control plots were mounded at the same time on June 9, 2008.

After analysis of the results from 2008, slight changes were made to the treatment for year two (2009) to correspond with the growth of the shoots. In year two the treatment consisted of early sawdust mounding plus IBA chemical application. On June 10, 2009 IBA was sprayed at 2000 ppm, mounding followed immediately. Control plots were mounded two weeks later on June 24, 2009.

4.4 Planting Style Experiment

A new stoolbed was planted in the spring of 2008 at Willow Drive Nursery in Ephrata, Washington on Timmerman coarse sandy loam (Soil Survey Staff) to test the effect of planting style and planting density on shoot production and rooting. A randomized complete block design with a factorial treatment design and 3 replications was used. The main plot was rootstock genotype and the subplot was a 2x2 factorial of style and density. Four planting styles were used:

1. Upright plants at high planting density (18-20 plants/m)
2. Upright plants at low planting density (6-8 plants/m)
3. Angled plants at high planting density (18-20 plants/m)
4. Angled plants at low planting density (6-8 plants/m)

Three rootstock clones were used in this experiment: B.9, M.9 T337 and G.935. Liners harvested from other stoolbeds of each rootstock were planted in a 25-30cm deep trench with two rows about four inches apart in each trench. The rootstocks were planted either upright or at a 45 degree angle and at a spacing of 10cm apart (high density) or 40cm apart (low density). The rootstocks were planted in a randomized complete block design with each experimental unit consisting of a 3m long section of stoolbed.

4.5 Harvest and Data Collection

At the end of the season the stoolbed in each experiment were harvested by a mechanical harvester that cut the shoots from the mother plants below the sawdust line just above the soil line. Plots were harvested the second week of November in Washington, the end of November in France, and early January in Oregon. Rootstock shoots were taken immediately to cold storage after harvest. The rootstocks were graded in December and January. Rootstock liners from the plots were separated into "grades" by visual inspection according to typical nursery standards. The four grades were:

A – ≥16 roots
B – 9-15 roots
C – 1-8 roots
D – no roots

Figure 4.5 Example of “A” grade rootstock.

Figure 4.6 Example of “B” grade rootstock.

Figure 4.7 Example of “C” grade rootstock.

Figure 4.8 Standard nursery caliper gauge.

Total number of liners of each grade from each plot was recorded (Figure 4.5, Figure 4.6, Figure 4.7). A sub-sample of 5 liners was taken at random from each grade for additional data collection. Caliper, total height, number of spines and branches, straightness of the shoot, number of roots, number of root nodes, and number of rooted nodes were recorded from each sample. Caliper measurements were taken with a standard nursery gauge in inches (Figure 3.8). Caliper is measured about six inches above the root zone. Standard nursery calipers are; 2/16 (0.318cm), 3/16 (0.476cm), 1/4 (0.635cm), 3/8 (0.953cm) and 7/16 (1.111cm) inches. Total height was measured from the bottom of the root zone to the top of the rootstock. Spines branches, roots and rooted nodes were counted and straightness of the shoot was rated using standard nursery practices. A rootstock is considered bent if the rootstock bends in at least one inch (2.5cm).

4.6 Data Analysis

Data for each experiment were analyzed by analysis of variance using SAS (SAS Institute, Cary, NC) general linear model procedure. Whe the ANOVA was significant, mean seperation was determined by Duncan's multiple range test with $P \leq 0.05$.

CHAPTER 5 – RESULTS

5.1 Plant Growth Regulator Experiments

Washington 2008

In Washington in 2008 there was no significant difference in the percentage of A or B grade liners, while the percentages of C and D grade were significantly different. Treatment with IBA at 1000 ppm significantly increased the combined percent of A and B grade by 11% over the control. Other treatments such as Apogee at 1000 ppm and IBA at 10000 ppm also increased the combined percent of A and B grade but were not significantly different from the control (Table 5.1). There were significant differences in liner gradeout between B.9 and M.9 T337 rootstocks. B.9 had a higher percentage of A grade and a smaller percentage of C and D grade than M.9 T337. 88.2% of B.9 shoots were categorized as A and B grade rootstock liners compared to only 41.8% of M.9 T337 shoots. There was no significant interaction between PGR treatment and rootstock on liner gradeout (Table 5.1)

The proportion of nodes with roots was greatest with the A grade and decreased with the lower grades. Along each liner, most roots formed on the more basal nodes (Figure 5.1).

Chemical treatment did not significantly affect caliper or proportion of straight shoots. IBA at 10000 ppm significantly reduced the height of the rootstock liners by 3.5cm compared to the control. IBA at the high concentration caused more lateral growth increasing the number of spines and branches per liner by more than two compared to the control. IBA at both the low and the high concentrations increased the number of total roots compared to the control. Chemical treatment did not have any effect on the number of nodes below the sawdust line. IBA at 10000 also increase the number of rooted nodes and percent of rooted nodes compared to the control (Table 5.2). Caliper was not significantly different between rootstocks; however, B.9

Table 5.1 Effect of plant growth regulator sprays on rootstock liner grade of B.9 and M.9 T337 in Washington in 2008.

		Percentage of stoolbed shoots in grades A-D[z]					
Treatment	Rootstock	%A	%B	%C	%D	%AB	%CD
Apogee 1000 ppm		40.8 a[y]	26.1 a	16.3 c	16.7 a	67.0 ab	33.0 ab
Apogee 250 ppm		37.7 a	22.6 a	24.5 ab	15.2 ab	60.3 b	39.7 a
Control		35.6 a	27.2 a	26.1 a	11.2 bc	62.7 b	37.3 a
IBA 10000 ppm		44.3 a	22.8 a	20.7 abc	12.2 abc	67.1 ab	32.9 a
IBA 1000 ppm		43.5 a	30.3 a	18.2 bc	8.0 c	73.8 a	26.2 b
NAA 200 ppm		36.4 a	25.2 a	24.5 ab	13.9 ab	61.6 b	38.4 a
NAA 50 ppm		34.8 a	27.7 a	25.5 a	12.0 abc	62.5 b	37.5 a
PGR Treatment Significance		NS	NS	*	*	*	*
	B.9	58.9 a	29.3 a	8.9 b	2.9 b	88.2 a	11.8 b
	M.9 T337	19.1 b	22.7 a	35.6 a	22.6 a	41.8 b	58.2 a
Rootstock Significance		**	NS	**	**	**	**
Significance of Interaction of PGR Treatment and Rootstock		NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=8 for PGR treatment means, n=28 for rootstock means and n=4 for Interaction means.

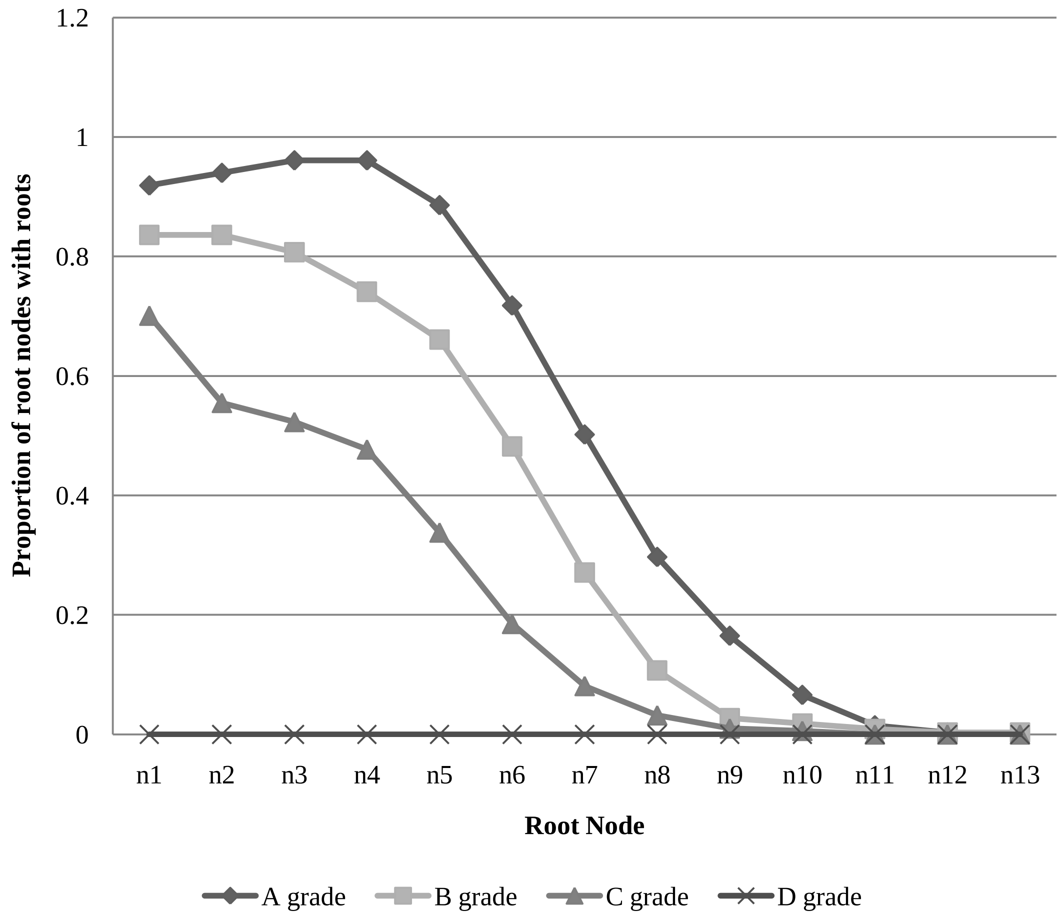

Figure 5.1 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 rootstocks and the 7 chemical treatments in Washington in 2008 n=40.

Table 5.2 Effect of plant growth regulator sprays on rootstock liner characteristics of B.9 and M.9 T337 in Washington in 2008.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Apogee 1000 ppm		0.63 a[z]	84.3 ab	1.4 b	0.862 a	10.2 bc	7.6 a	4.0 a	52.0 a
Apogee 250 ppm		0.64 a	81.5 ab	0.8 bc	0.831 a	9.6 c	7.3 a	3.6 a	48.8 a
Control		0.65 a	81.5 ab	0.4 c	0.799 a	9.4 c	7.6 a	3.7 a	48.5 a
IBA 10000 ppm		0.65 a	78.0 c	2.7 a	0.728 a	12.3 a	7.7 a	4.2 a	54.8 a
IBA 1000 ppm		0.64 a	81.0 bc	1.3 b	0.828 a	11.2 ab	7.6 a	3.8 a	49.7 a
NAA 200 ppm		0.64 a	82.8 ab	0.8 bc	0.847 a	9.3 c	7.4 a	3.6 a	47.9 a
NAA 50 ppm		0.64 a	84.6 a	0.7 bc	0.831 a	10.1 bc	7.3 a	4.0 a	52.5 a
PGR Treatment Significance		NS	**	**	NS	*	NS	NS	NS
	B.9	0.64 a	85.6 a	0.2 b	0.71 b	10.8 a	7.5 a	4.1 a	53.9 a
	M.9 T337	0.64 a	79.0 b	1.9 a	0.91 a	9.8 a	7.5 a	3.6 a	47.8 a
Rootstock Significance		NS	**	**	**	NS	NS	NS	NS
Significance of Interaction of PGR Treatment and Rootstock		NS	NS	*	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=175 for PGR treatment means, n=612 for rootstock means and n=87 for Interaction means.

rootstocks were taller, had fewer spines and had a higher proportion of bent shoots than M.9 T337 rootstocks. The number of roots, nodes below the sawdust line and rooted nodes was not significantly different between rootstocks while B.9 had six percent more rooted nodes than M.9 T337. There was a significant difference in the interaction of PGR treatment and rootstock on the number of spines per liner (Table 5.2).

Washington 2009

Apogee at 1000 ppm sprayed on August 24, Apogee at 1000 ppm sprayed on August 3 and IBA at 1000 ppm sprayed on June 17 had a significantly higher percentage of A grade liners than the control. Apogee at 1000 ppm sprayed on August 24 and IBA at 1000 ppm sprayed on June 17 had a significantly lower percent B grade liners than the control. The combined percentage of A and B grade liners did not differ significantly from the control (Table 5.3). The differences in rootstocks followed the same trend in 2009 as in 2008. B.9 had a higher percentage of A grade liners and lower percentage of B, C and D grade than M.9 T337. With B.9, the combined percentage of A and B grade liners was 98.8% while with M.9 T337 it was only 77.9%. There was a significant difference in the interaction of PGR treatment and rootstock on the percentage of B grade liners (Table 5.3).

The proportion of root nodes with roots and the total number of roots per liner were greatest for the A grade liners and least for the D grade liners (Figure 5.2).

Liner caliper, number of spines, proportion of straight shoots and number of nodes below the sawdust line did not vary significantly among treatments. However, Apogee at 1000 ppm sprayed on August 24, Apogee at 1000 ppm sprayed on August 3, Apogee at 250 ppm sprayed on August 3 and Apogee at 1000 ppm sprayed on July 23 resulted in liners which were significantly shorter than the control. Apogee at 1000 ppm sprayed on August 24 resulted in significantly more roots per liner than the

Table 5.3 Effect of plant growth regulator sprays on rootstock liner grade of B.9 and M.9 T337 in Washington in 2009.

Treatment	Rootstock	Percentage of stoolbed shoots in grades A-D[z]					
		%A	%B	%C	%D	%AB	%CD
Apogee 1000 ppm Aug 24		66.6 a[y]	24.2 b	8.8 a	0.4 a	90.8 a	9.2 a
Apogee 1000 ppm Aug 3		64.6 ab	26.6 ab	8.6 a	0.2 a	91.2 a	8.8 a
Apogee 1000 ppm July 23		60.4 abc	30.9 a	8.6 a	0.1 a	91.3 a	8.7 a
Apogee 1000 ppm June 25		60.0 abcd	27.4 ab	11.1 a	1.5 a	87.4 a	12.6 a
Apogee 1000 ppm June 25 and July 23		60.8 abc	28.7 ab	9.8 a	0.6 a	89.6 a	10.4 a
Apogee 250 ppm Aug 3		55.5 bcd	31.1 a	12.4 a	1.0 a	86.6 a	13.4 a
Control		55.3 cd	30.4 a	13.5 a	0.7 a	85.7 a	14.3 a
IBA 10000 ppm June 17		63.6 abc	26.1 ab	8.7 a	1.7 a	89.7 a	10.3 a
IBA 1000 ppm June 17		65.3 a	23.9 b	9.8 a	1.0 a	89.2 a	10.8 a
NAA 200 ppm Aug 3		51.4 d	31.7 a	15.6 a	1.3 a	83.1 a	16.9 a
NAA 50 ppm Aug 3		55.6 bcd	31.8 a	12.1 a	0.5 a	87.4 a	12.6 a
PGR Treatment Significance		**	**	NS	NS	NS	NS
	B.9	80.4 a	18.4 b	1.1 b	0.0 b	98.8 a	1.2 b
	M.9 T337	39.5 b	38.4 a	20.5 a	1.6 a	77.9 b	22.1 a
Rootstock Significance		**	**	**	*	**	**
Significance of Interaction of PGR Treatment and Rootstock		NS	*	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=8 for PGR treatment means, n=44 for rootstock means and n=4 for Interaction means.

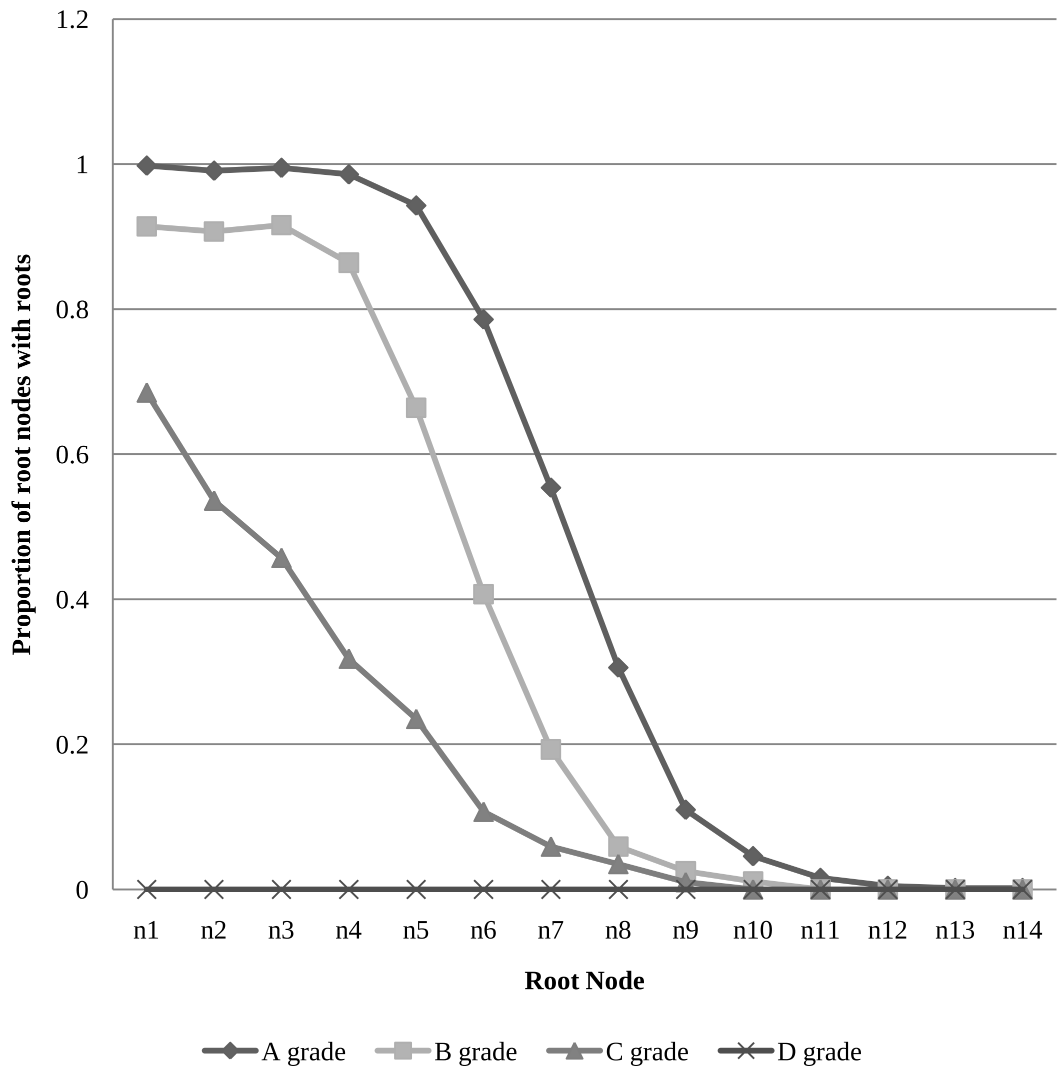

Figure 5.2 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 rootstocks and the 11 chemical treatments in Washington in 2009 n=40.

controls. Apogee 1000 ppm sprayed on August 3 and Apogee 1000 ppm sprayed on July 23 resulted in significantly more rooted nodes per liner than the controls. Liners which received Apogee 1000 ppm sprayed on July 23 had the largest percentage of rooted nodes, 6.4% more than the control (Table 5.4). Liner caliper, proportion of straight shoots and number of nodes below the sawdust line did not differ between the rootstocks. B.9 liners were taller, had fewer spines, more roots, more rooted nodes and a higher percent of rooted nodes than M.9 T337 shoots. There was no significant interaction between PGR treatment and rootstock on liner characteristics (Table 5.4).

France 2008

Neither chemical treatment nor rootstock affected the percentage of A, B and C grade liners at DL Nursery in France. Likewise, the combined percentage of A and B grade was not significantly different between treatments or rootstocks. There was no significant interaction between PGR treatment and rootstock on liner gradeout (Table 5.5).

The proportion of liner nodes below the soil line with roots and the number of roots per liner for all grades was greatest for A grade liners and least for D grade liners (Figure 5.3).

Liner caliper, straightness of shoot, number of nodes below the sawdust line and the number of rooted nodes varied by rootstock, but not by treatment. Likewise, the number of spines, number of roots and the percent of rooted nodes was not significantly different among rootstocks or treatments. There was no significant interaction between PGR treatment and rootstock on liner characteristics (Table 5.6).

France 2009

All Apogee spray treatments significantly changed the gradeout of liners compared to the control. Apogee sprays, regardless of timing, produced a higher

Table 5.4 Effect of plant growth regulator sprays on rootstock liner characteristics of B.9 and M.9 T337 in Washington in 2009.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Apogee 1000 ppm Aug 24		0.62 a[z]	63.2 e	0.6 a	0.847 a	18.7 a	6.3 a	4.9 ab	75.2 a
Apogee 1000 ppm Aug 3		0.60 a	72.4 cd	0.5 a	0.704 a	17.5 a	6.8 a	5.3 a	76.1 a
Apogee 250 ppm Aug 3		0.59 a	72.6 cd	0.3 a	0.759 a	16.2 a	6.1 a	4.4 bc	70.2 a
Apogee 1000 ppm July 23		0.61 a	37.1 de	0.3 a	0.800 a	17.3 a	6.4 a	5.2 a	79.3 a
Apogee 1000 ppm June 25		0.60 a	73.4 bcd	0.5 a	0.746 a	16.9 a	6.1 a	4.2 c	70.0 a
Apogee 1000 ppm June 25 and July 23		0.60 a	79.0 abc	0.7 a	0.723 a	16.4 a	6.8 a	4.8 abc	76.4 a
Control		0.61 a	79.8 ab	0.7 a	0.748 a	16.0 a	6.1 a	4.5 bc	72.9 a
IBA 1000 ppm June 17		0.60 a	80.0 ab	0.5 a	0.795 a	17.1 a	6.3 a	4.8 abc	73.1 a
IBA 10000 ppm June 17		0.59 a	82.6 a	0.6 a	0.639 a	16.4 a	6.2 a	4.5 bc	71.1 a
NAA 200 ppm Aug 3		0.62 a	80.5 ab	0.7 a	0.802 a	14.9 a	6.2 a	4.4 bc	70.5 a
NAA 50 ppm Aug 3		0.61 a	80.3 ab	0.5 a	0.726 a	15.8 a	6.4 a	4.8 abc	73.1 a
PGR Treatment Significance		NS	**	NS	NS	NS	NS	**	NS
	B.9	0.61 a	80.0 a	0.0 b	0.630 a	21.2 a	6.5 a	5.6 a	85.0 a
	M.9 T337	0.60 a	72.9 a	0.9 a	0.839 a	13.4 a	6.2 a	4.1 a	65.1 a
Rootstock Significance		NS	NS	**	NS	NS	NS	NS	NS
Significance of Interaction of PGR Treatment and Rootstock		NS	NS	NS	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=112 for PGR treatment means, n=618 for rootstock means and n=56 for Interaction means.

Table 5.5 Effect of plant growth regulator sprays on rootstock liner grade of M.9 EMLA and G.41 in France in 2008.

		Percentage of stoolbed shoots in grades A-D[z]					
Treatment	Rootstock	%A	%B	%C	%D	%AB	%CD
NAA 50 ppm		8.3 a[y]	41.7 a	48.6 a	1.5 a	50.0 a	50.0 a
Control		10.0 a	39.4 a	49.0 a	1.6 a	49.4 a	50.6 a
Apogee 250 ppm		12.6 a	36.7 a	47.4 a	3.3 a	49.3 a	50.7 a
Apogee 1000 ppm		9.8 a	36.2 a	50.7 a	3.3 a	46.0 a	54.0 a
PGR Treatment Significance		NS	NS	NS	*	NS	NS
	M.9 EMLA	3.9 a	39.3 a	55.2 a	1.6 a	43.2 a	56.8 a
	G.41	16.4 a	37.7 a	42.6 a	3.3 a	54.1 a	45.9 a
Rootstock Significance		NS	NS	NS	NS	NS	NS
Significance of Interaction of PGR Treatment and Rootstock		NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=8 for PGR treatment means, n=16 for rootstock means and n=4 for Interaction means.

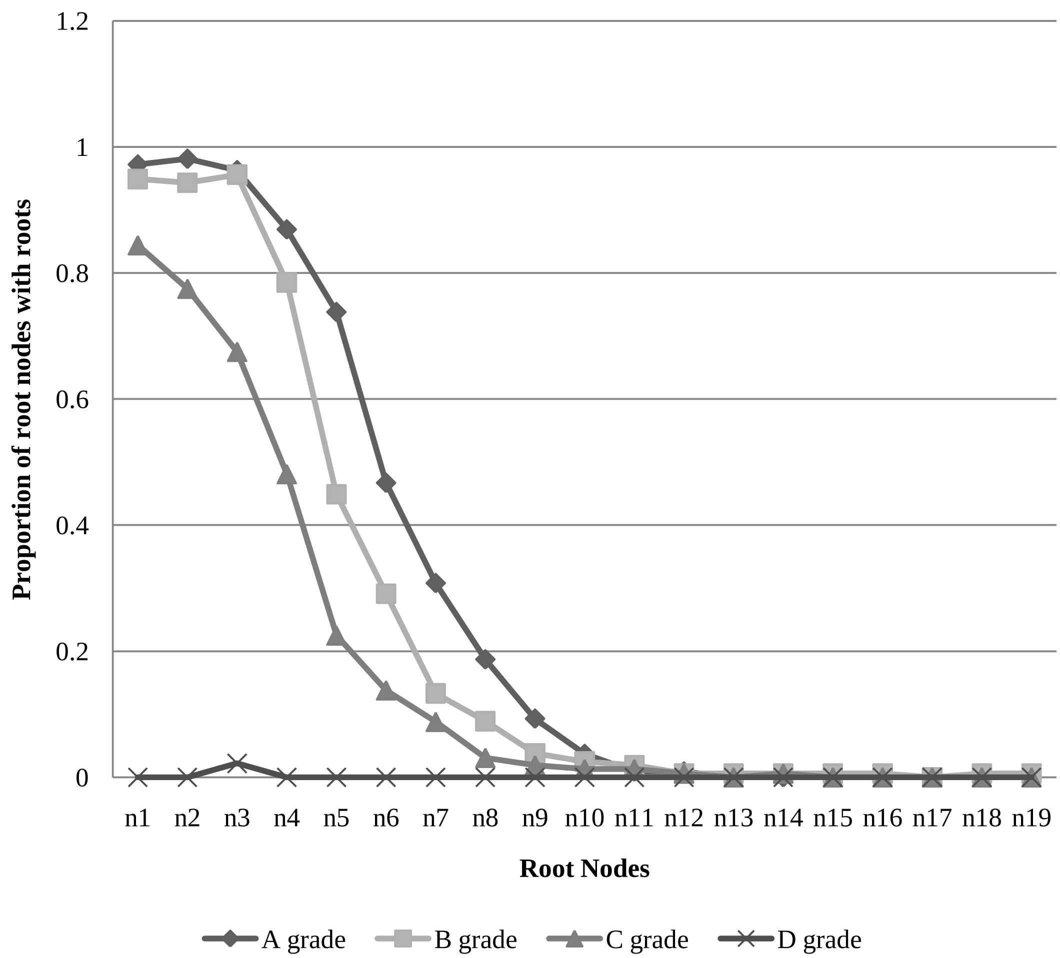

Figure 5.3 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 rootstocks and the 4 chemical treatments in France in 2008 n=40.

Table 5.6 Effect of plant growth regulator sprays on rootstock liner characteristics of M.9 EMLA and G.41 in France in 2008.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
NAA 50 ppm		0.66 a[z]	72.4 a	0.7 a	0.774 a	8.9 a	5.7 a	4.2 a	85.0 a
Control		0.65 a	69.1 a	0.9 a	0.847 a	10.1 a	5.8 a	4.3 a	74.6 a
Apogee 1000 ppm		0.62 a	69.9 a	0.7 a	0.832 a	9.2 a	5.7 a	4.0 a	75.7 a
Apogee 250 ppm		0.65 a	69.9 a	0.8 a	0.882 a	9.8 a	5.3 a	3.6 a	67.0 a
PGR Treatment Significance		NS	NS	NS	NS	NS	NS	NS	NS
	M.9 EMLA	0.60 b	64.3 a	0.5 a	0.983 a	10.3 a	4.1 b	3.3 b	77.7 a
	G.41	0.69 a	75.9 a	1.0 a	0.697 b	8.8 a	7.0 a	4.7 a	72.7 a
Rootstock Significance		*	NS	NS	**	NS	*	**	NS
Significance of Interaction of PGR Treatment and Rootstock		NS	NS	NS	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=118 for PGR treatment means, n=235 for rootstock means and n=59 for Interaction means.

percentage of A grade liners and a lower percentage of C grade and D grade liners than the controls. The percentage of B grade liners was not affected by Apogee sprays. The combined percentage of A and B grade liners was significantly higher in all Apogee treatments than in the control (Table 5.7). There were significant differences between rootstocks in 2009. M.9 EMLA produced a greater percentage of A grade and a lower percentage of B and C grade liners than G.41. The combined percentage of A and B grade was also significantly higher with M.9 EMLA than G.41. There was no significant interaction between PGR treatment and rootstock on liner gradeout (Table 5.7).

The proportion of nodes below the soil line which had roots was greatest for A grade liners and lowest for D grade liners (Figure 5.4).

Apogee treatment, regardless of timing, reduced the height of the shoots. Apogee at 1000 ppm sprayed on June 29 and Apogee at 1000 ppm sprayed on June29 and July29 increased the proportion of straight shoots by 13-17% compared to the controls. Apogee at 1000 ppm sprayed on June 29 and July 29 also increased the number of root nodes below the sawdust line compared to the control (Table 5.8). Apogee sprays did not affect liner caliper or number of spines. Liner height and total number of roots were significantly different between the two rootstocks. Liners of M.9 EMLA were shorter but had more roots than liners of G.41. In all other liner characteristic which we measured there were no significant differences between the rootstocks. There were some significant interactions between PGR treatment and rootstock on liner caliper, number of roots per liner, number of nodes below the sawdust line and number of rooted nodes below the sawdust line (Table 5.8).

Oregon 2009

In Oregon only G.41 rootstocks were used for the experiment. Apogee reduced the percentage of D grade liners. Apogee at 1000 ppm sprayed on June 29 and Apogee

Table 5.7 Effect of plant growth regulator sprays on rootstock liner grade of M.9 EMLA and G.41 in France in 2009.

		Percentage of stoolbed shoots in grades A-D[z]					
Treatment	Rootstock	%A	%B	%C	%D	%AB	%CD
Apogee 1000 ppm July 29		34.4 a[y]	31.3 a	27.1 b	7.3 b	65.7 a	34.3 b
Apogee 1000 ppm June 29		37.4 a	31.4 a	24.0 b	7.2 b	68.8 a	31.2 b
Apogee 1000 ppm June 29 and July 29		38.6 a	30.2 a	25.9 b	5.3 b	68.8 a	31.2 b
Control		24.9 b	25.8 a	37.5 a	11.9 a	50.7 b	49.3 a
PGR Treatment Significance		**	NS	*	**	**	**
	M.9 EMLA	54.4 a	24.4 b	16.0 b	5.2 a	78.8 a	21.2 b
	G.41	13.2 b	35.0 a	41.2 a	10.7 a	48.1 b	51.9 a
Rootstock Significance		**	*	**	NS	**	**
Significance of Interaction of PGR Treatment and Rootstock		NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=8 for PGR treatment means, n=16 for rootstock means and n=4 for Interaction means.

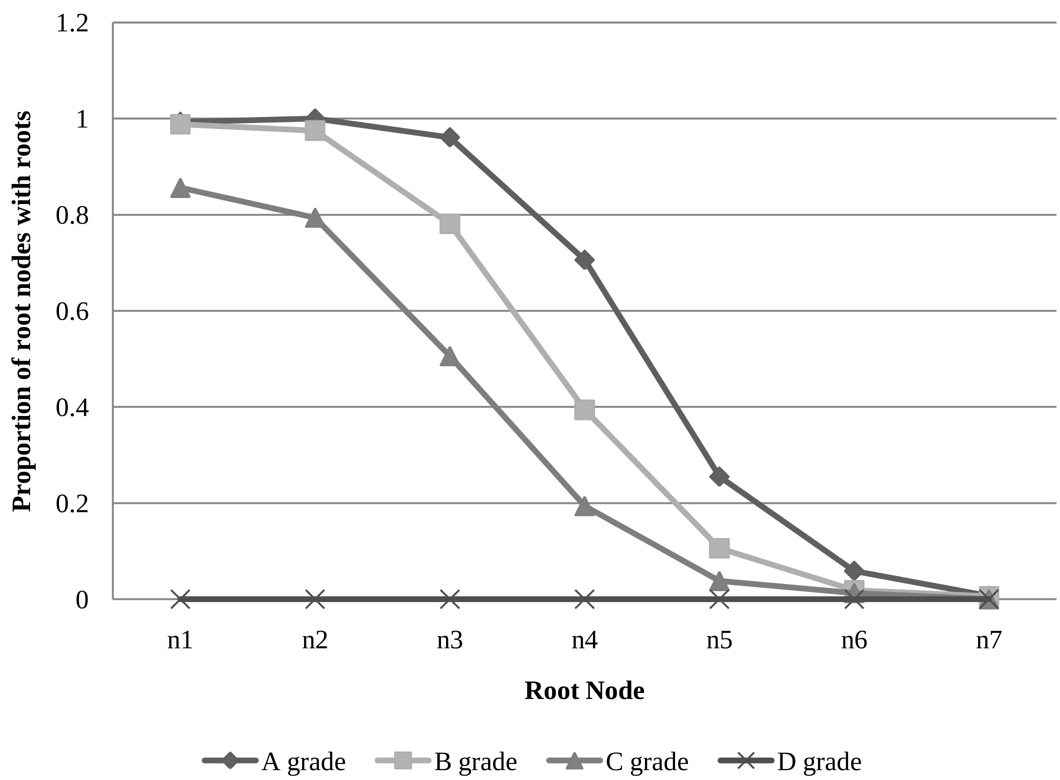

Figure 5.4 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 rootstocks and the 4 chemical treatments in France in 2009 n=40.

Table 5.8 Effect of plant growth regulator sprays on rootstock liner characteristics of M.9 EMLA and G.41 in France in 2009.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Apogee 1000 ppm July 29		0.60 a[z]	62.7 b	0.8 a	0.862 bc	8.9 a	3.3 a	2.3 b	64.7 a
Apogee 1000 ppm June 29		0.63 a	55.4 c	1.0 a	0.935 ab	9.0 a	3.4 a	2.5 ab	68.1 a
Apogee 1000 ppm June 29 and July 29		0.59 a	54.4 c	1.0 a	0.967 a	9.4 a	3.6 a	2.7 a	69.7 a
Control		0.62 a	67.6 a	0.9 a	0.799 c	8.1 a	3.4 a	2.4 b	64.2 a
PGR Treatment Significance		NS	**	NS	**	NS	NS	**	NS
	M.9 EMLA	0.59 a	58.2 b	0.1 a	0.939 a	11.2 a	3.3 a	2.3 a	65.4 a
	G.41	0.63 a	62.0 a	1.7 a	0.840 a	6.5 b	3.5 a	2.6 a	68.0 a
Rootstock Significance		*	*	NS	NS	**	NS	*	NS
Significance of Interaction of PGR Treatment and Rootstock		*	NS	NS	NS	*	*	*	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=155 for PGR treatment means, n=310 for rootstock means and n=78 for Interaction means.

at 1000 ppm sprayed on June 29 and July 29 had a lower percentage of D grade liners than the control (Table 5.9).

The proportion of nodes below the sawdust line which had roots and the total number of roots per liner was greatest with the A grade liners and least with the D grade liners (Figure 5.5).

Apogee sprayed at 1000 ppm on June 29 and July29 reduced the caliper of liners and increased the proportion of straight shoots compared to the control. Apogee sprayed at 1000 ppm on June 29 and Apogee sprayed at 1000 ppm on June 29 and July 29 varied the most from the control. The two treatments produced liners which were much shorter than the untreated liners, up to 20-25cm shorter. The two Apogee treatments also reduce the number of spines from 12.7 per liner in the control to 3.7 and 2.5 in the June and June + July Apogee sprays. The number of roots per liner, number of rooted nodes and percentage of nodes with roots was also increased by the two Apogee treatments (Table 5.10).

5.2 Dark Preconditioning Experiment

Washington 2008

Shading in the early season with the shade boxes increased the percentage of A grade liners by 14% over the control. Shading also reduced the percentage of D grade liners compared to the controls. The combined percentage of A and B grade liners of the shading treatment was also significantly greater than the control. There were significant differences in liner gradeout between the two rootstocks used in this experiment. B.9 had a higher percentage of A grade liners than M.9 T337 but there were no significant differences in the percentages of the other grades. There were no significant interactions between dark preconditioning treatments and rootstock on liner gradeout (Table 5.11).

Table 5.9 Effect of plant growth regulator sprays on rootstock liner grade of G.41 in Oregon in 2009.

Treatment	Percentage of stoolbed shoots in grades A-D[z]					
	%A	%B	%C	%D	%AB	%CD
Apogee 1000 ppm July 29	32.2 a[y]	31.2 a	35.3 a	1.3 a	63.4 a	36.6 a
Apogee 1000 ppm June 29	45.5 a	33.8 a	20.7 a	0.0 b	79.3 a	20.7 a
Apogee 1000 ppm June 29 and July 29	42.1 a	37.4 a	20.6 a	0.0 b	79.4 a	20.6 a
Control	36.2 a	28.1 a	33.7 a	2.0 a	64.3 a	35.7 a
PGR Treatment Significance	NS	NS	NS	**	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=4 for PGR treatment means.

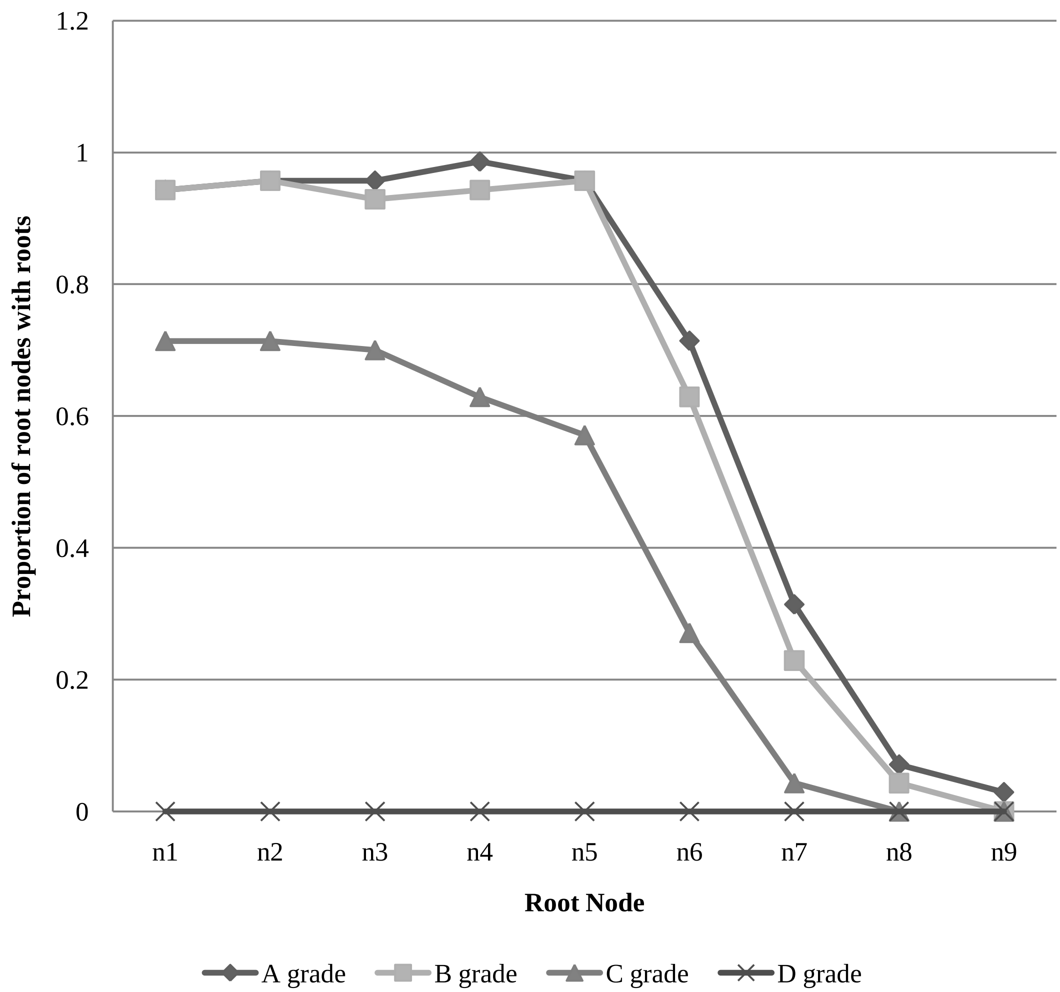

Figure 5.5 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over 4 chemical treatments in Oregon in 2009 n=20.

Table 5.10 Effect of plant growth regulator sprays on rootstock liner characteristics of G.41 in Oregon in 2009.

Treatment	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Apogee 1000 ppm July 29	0.68 a[z]	91.7 a	10.4 a	0.750 b	11.0 a	5.6 a	4.0 a	66.3 b
Apogee 1000 ppm June 29	0.66 ab	77.7 b	3.7 b	0.817 ab	14.0 a	5.9 a	5.5 a	92.7 a
Apogee 1000 ppm June 29 and July 29	0.59 b	73.4 b	2.5 b	0.967 a	13.7 a	5.6 a	5.4 a	94.2 a
Control	0.68 a	98.3 a	12.7 a	0.673 b	9.8 a	5.4 a	4.0 a	72.8 b
PGR Treatment Significance	*	**	**	*	NS	*	NS	**

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=56 for PGR treatment means.

Table 5.11 Effect of dark preconditioning treatments on rootstock liner grade of B.9 and M.9 T337 in Washington in 2008.

Treatment	Rootstock	Percentage of stoolbed shoots in grades A-D[z]					
		%A	%B	%C	%D	%AB	%CD
Control		19.6 b[y]	38.1 a	26.6 a	15.7 a	57.7 b	42.3 a
Early sawdust		25.8 b	37.2 a	25.5 a	11.5 a	63.0 b	37.0 a
Shade		33.6 a	40.2 a	20.7 a	5.5 b	73.7 a	26.3 b
Dark Preconditioning Treatment Significance		**	NS	NS	**	*	*
	B.9	34.8 a	36.3 a	21.6 a	7.3 a	71.1 a	28.9 a
	M.9 T337	17.8 b	40.7 a	27.0 a	14.5 a	58.5 a	41.5 a
Rootstock Significance		**	NS	NS	NS	NS	NS
Significance of Interaction of Dark Preconditioning Treatment and Rootstock		NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=8 for Dark Preconditioning treatment means, n=12 for rootstock means and n=4 for Interaction means.

The proportion of nodes below the sawdust line which had roots was greatest with the A grade liners and least with the D grade liners (Figure 5.6).

Shading in the early season with the shade boxes or early sawdust did not affect liner characteristics significantly compared to the control. Averaged over all grades, liners of M.9 T337 had smaller caliper than liners of B.9. However, M.9 T337 liners had a greater proportion of straight shoots, a greater number of roots and more nodes below the sawdust line than B.9 liners. Liner height, number of spines per liner, number of nodes below the sawdust line which had roots and the percentage of nodes below the sawdust line with roots did not differ significantly between the rootstocks. There were no significant interactions between dark preconditioning treatments and rootstocks liner characteristics (Table 5.12).

Washington 2009

In 2009 neither shading nor early mounding with sawdust affected liner gradeout. B.9 had a significantly better gradeout than M.9 T337. The percentage of A grade liners was significantly higher in B.9 compared to M.9 T337, while the percentage of B and C grade liners were lower in B.9 compared to M.9 T337. The combined percentage of A and B grade liners was higher in B.9 than in M.9 T337. There were no significant interactions between dark preconditioning treatments and rootstocks on liner gradeout (Table 5.13).

The proportion of nodes below the sawdust line which had roots was greatest in A grade liners and least in D grade liners (Figure 5.7).

Neither shading nor early sawdust application had an effect on liner characteristics. There were no significant differences of liner characteristics between the two rootstocks. No significant interactions were observed between dark preconditioning treatments and rootstock on liner characteristics (Table 5.14).

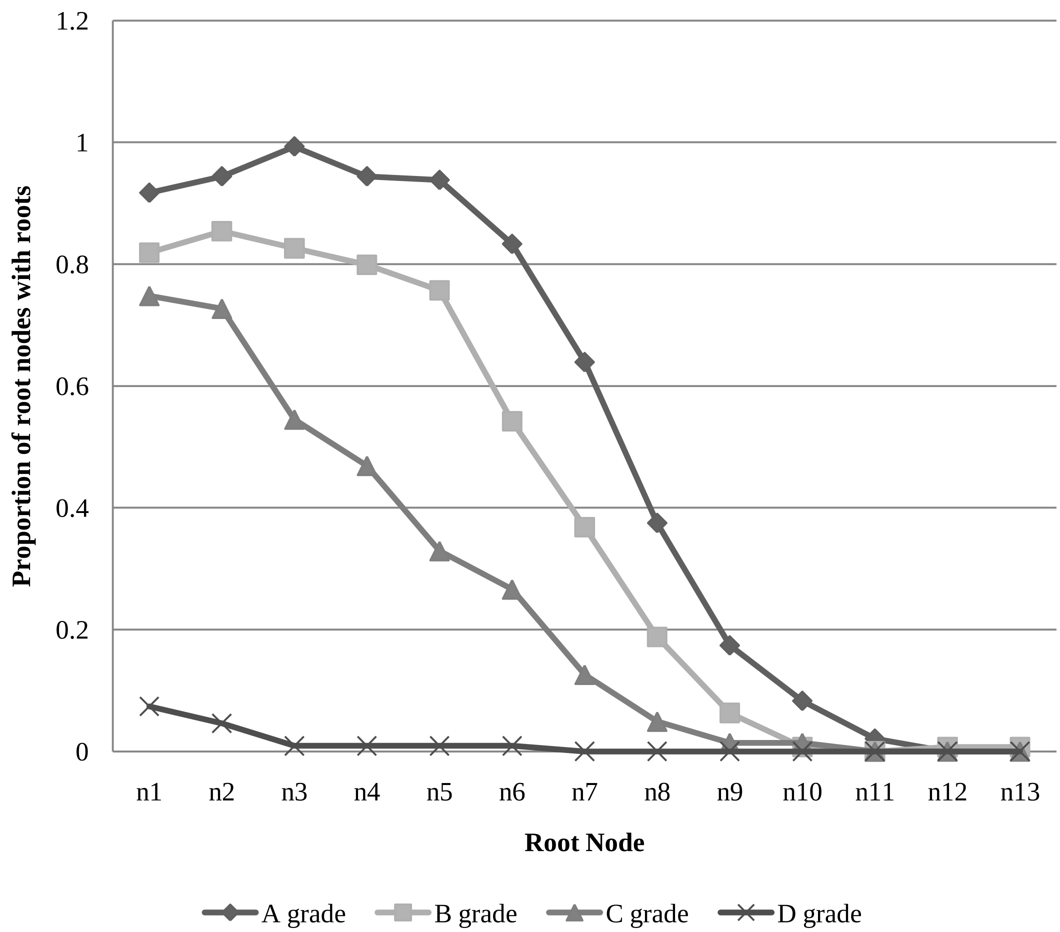

Figure 5.6 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 rootstocks and the 3 dark preconditioning treatments in Washington in 2008 n=40.

Table 5.12 Effect of dark preconditioning treatments on rootstock liner characteristics of B.9 and M.9 T337 in Washington in 2008.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Control		0.66 a[z]	85.9 a	0.2 a	0.870 a	10.6 a	7.3 a	3.8 a	51.1 a
Early sawdust		0.65 a	85.9 a	0.6 a	0.909 a	12.0 a	7.4 a	4.0 a	51.7 a
Shade		0.67 a	85.9 a	0.4 a	0.789 a	15.7 a	7.4 a	4.8 a	63.7 a
Dark Preconditioning Treatment Significance		NS	NS	NS	NS	NS	NS	NS	NS
	B.9	0.69 a	88.6 a	0.0 a	0.733 b	11.9 a	7.0 a	3.9 a	55.7 a
	M.9 T337	0.63 b	83.3 a	0.8 a	0.978 a	13.3 a	7.7 a	4.3 a	54.5 a
Rootstock Significance		*	NS	NS	*	NS	NS	*	NS
Significance of Interaction of Dark Preconditioning Treatment and Rootstock		NS	NS	NS	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=180 for Dark Preconditioning treatment means, n=270 for rootstock means and n=90 for Interaction means.

Table 5.13 Effect of dark preconditioning treatments on rootstock liner grade of B.9 and M.9 T337 in Washington in 2009.

Treatment	Rootstock	Percentage of stoolbed shoots in grades A-D[z]					
		%A	%B	%C	%D	%AB	%CD
Control		54.0 a[y]	34.6 a	11.1 a	0.4 a	88.5 a	11.5 a
Early sawdust		53.6 a	33.4 a	12.1 a	1.0 a	86.9 a	13.1 a
Shade		59.6 a	32.7 a	7.3 a	0.4 a	92.3 a	7.7 a
Dark Preconditioning Treatment Significance		NS	NS	NS	NS	NS	NS
	B.9	70.6 a	25.9 b	3.4 b	0.1 a	96.4 a	3.6 b
	M.9 T337	40.9 b	41.2 a	16.9 a	1.0 a	82.1 b	17.9 a
Rootstock Significance		**	**	**	NS	**	**
Significance of Interaction of Dark Preconditioning Treatment and Rootstock		NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=8 for Dark Preconditioning treatment means, n=12 for rootstock means and n=4 for Interaction means.

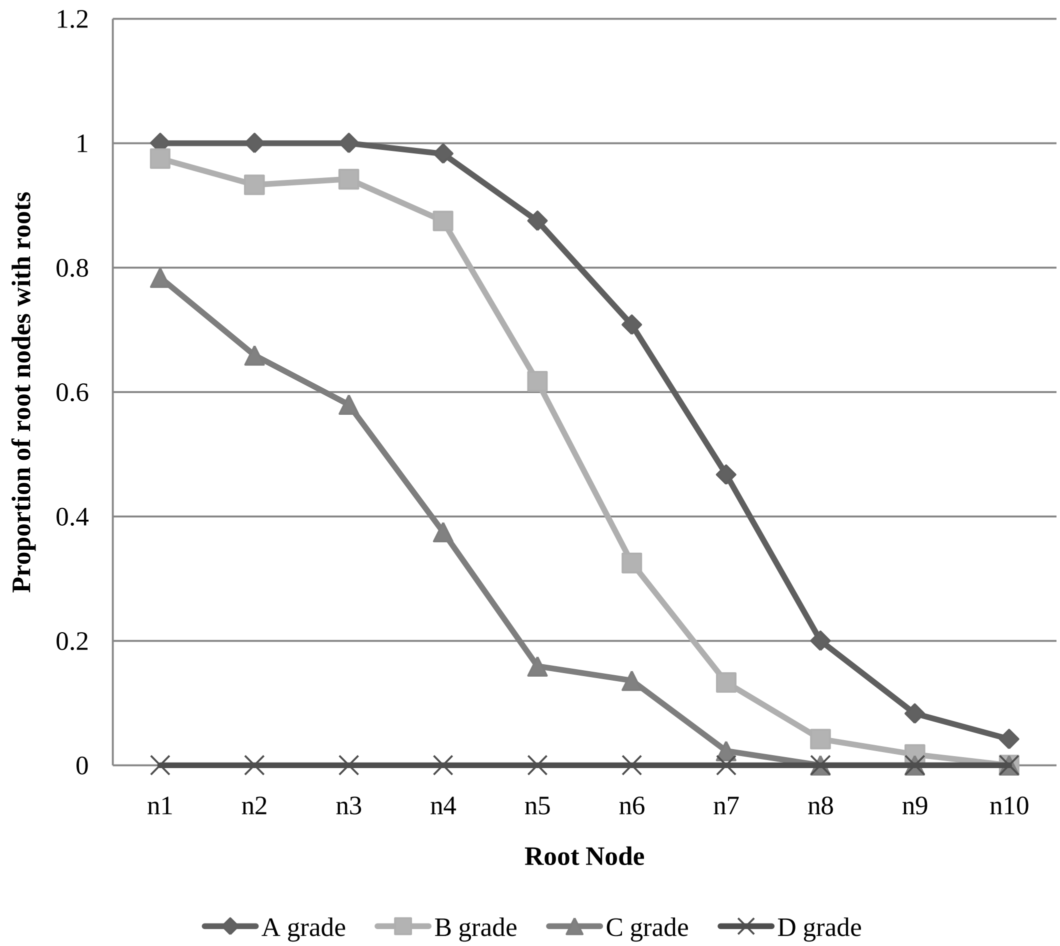

Figure 5.7 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 rootstocks and the 3 dark preconditioning treatments in Washington in 2008 n=40.

Table 5.14 Effect of dark preconditioning treatments on rootstock liner characteristics of B.9 and M.9 T337 in Washington in 2009.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Control		0.62 a[z]	84.3 a	1.0 a	0.687 a	15.3 a	6.0 a	4.7 a	76.8 a
Early sawdust		0.60 a	83.1 a	0.6 a	0.798 a	15.1 a	5.9 a	4.7 a	77.3 a
Shade		0.61 a	82.0 a	1.1 a	0.556 a	15.2 a	5.5 a	4.5 a	80.0 a
Dark Preconditioning Treatment Significance		NS	NS	NS	NS	NS	NS	NS	NS
	B.9	0.61 a	83.8 a	0.0 a	0.639 a	17.7 a	6.1 a	5.2 a	83.3 a
	M.9 T337	0.61 a	82.8 a	1.6 a	0.722 a	13.1 a	5.6 a	4.2 a	73.7 a
Rootstock Significance		NS	NS	NS	NS	NS	NS	NS	NS
Significance of Interaction of Dark Preconditioning Treatment and Rootstock		NS	NS	NS	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=114 for Dark Preconditioning treatment means, n=171 for rootstock means and n=57 for Interaction means.

5.3 G.41 Experiment

Washington 2008

This study evaluated the effect of the combination of early season shading and an application of IBA sprayed at 2000 ppm on rooting of G.41 shoots in a stoolbed. The treatment of shade early in the season plus IBA sprayed at 2000 ppm did not significantly affect the percentage of A grade liners compared to the control; however, there was a small non significant decrease. Percentages of all other grades were not significantly different than the control (Table 5.15).

The proportion of nodes below the sawdust line which had roots was greatest with A grade liners and least with D grade liners (Figure 5.8).

Liner characteristics were not significantly affected by the shade plus IBA treatment with the exception of the percentage of nodes below the sawdust line with roots which was increased by 2.4% compared to the control (Table 5.16).

Washington 2009

The gradeout of liners in 2009 was not significantly affected by the combination of early season sawdust application and an IBA spray at 2000 ppm (Table 5.17).

The proportion of nodes below the sawdust line which had roots was greatest in A grade liners and least in D grade liners (Figure 5.9).

Liner characteristics were not significantly affected by the combined treatment of early season sawdust application and an IBA spray at 2000 ppm with the exception of number of spines per liner. Early sawdust mounding plus IBA sprayed at 2000 ppm resulted in 1.7 more spines per liner than the control liners (Table 5.18).

Table 5.15 Effect of shade + IBA on rootstock liner grade of G.41 in Washington in 2008.

	Percentage of stoolbed shoots in grades A-D[z]					
Treatment	%A	%B	%C	%D	%AB	%CD
Control	64.6 a[y]	18.9 a	11.4 a	5.1 a	83.5 a	16.5 a
Shade + IBA 2000 ppm	43.0 a	32.6 a	20.7 a	3.7 a	75.6 a	24.4 a
Combination Treatment Significance	NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner
[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=3 for Combination treatment means.

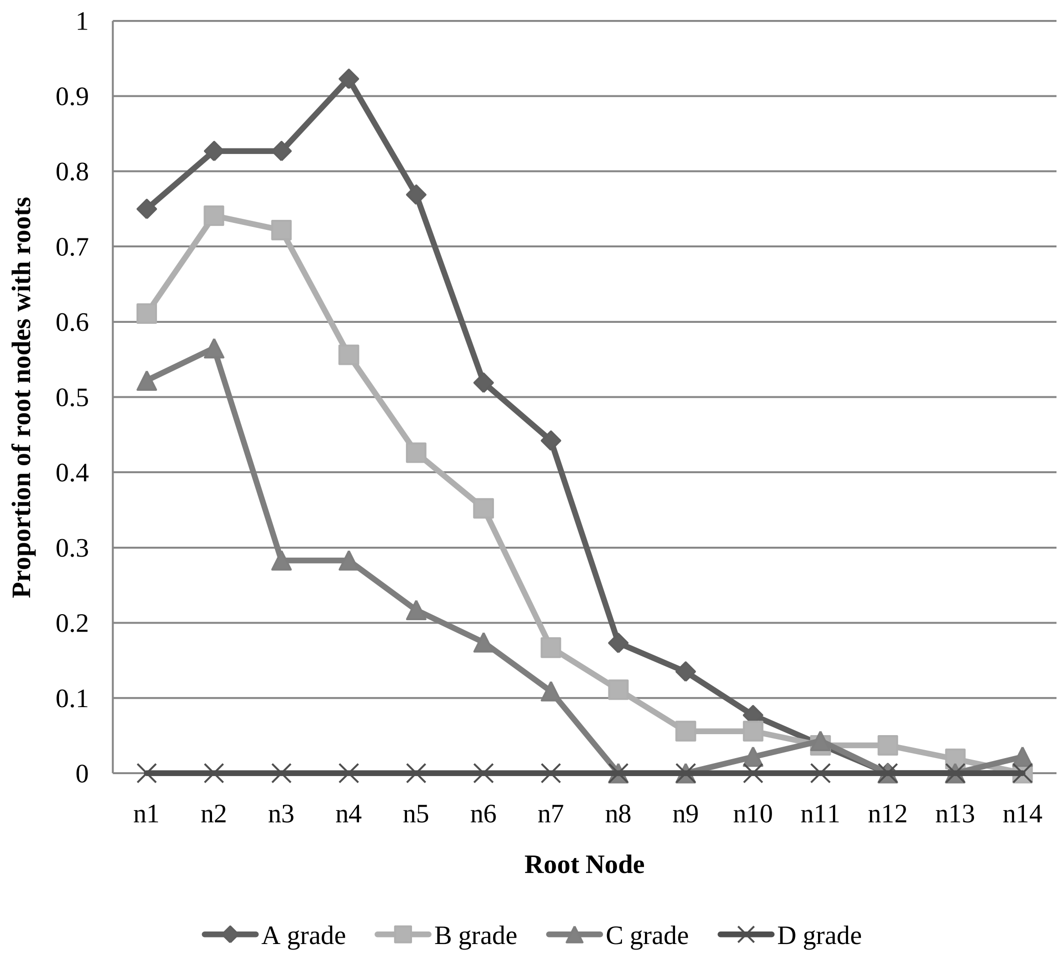

Figure 5.8 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 G.41combination treatments in Washington in 2008 n=20.

Table 5.16 Effect of shade + IBA on rootstock liner characteristics of G.41 in Washington in 2008.

Treatment	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Control	0.67 a[z]	79.0 a	4.9 a	0.684 a	4.3 a	7.0 a	3.2 a	47.0 a
Shade + IBA 2000 ppm	0.67 a	82.3 a	4.9 a	0.694 a	5.8 a	7.6 a	3.9 a	49.4 a
Combination Treatment Significance	NS	NS	NS	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=83 for Combination treatment means.

Table 5.17 Effect of early sawdust + IBA on rootstock liner grade of G.41 in Washington in 2009.

Treatment	Percentage of stoolbed shoots in grades A-D[z]					
	%A	%B	%C	%D	%AB	%CD
Control	36.3 a[y]	33.0 a	27.9 a	2.8 a	69.3 a	30.7 a
Early + IBA 2000 ppm	36.9 a	34.9 a	25.1 a	3.1 a	71.8 a	28.2 a
Combination Treatment Significance	NS	NS	NS	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=3 for Combination treatment means.

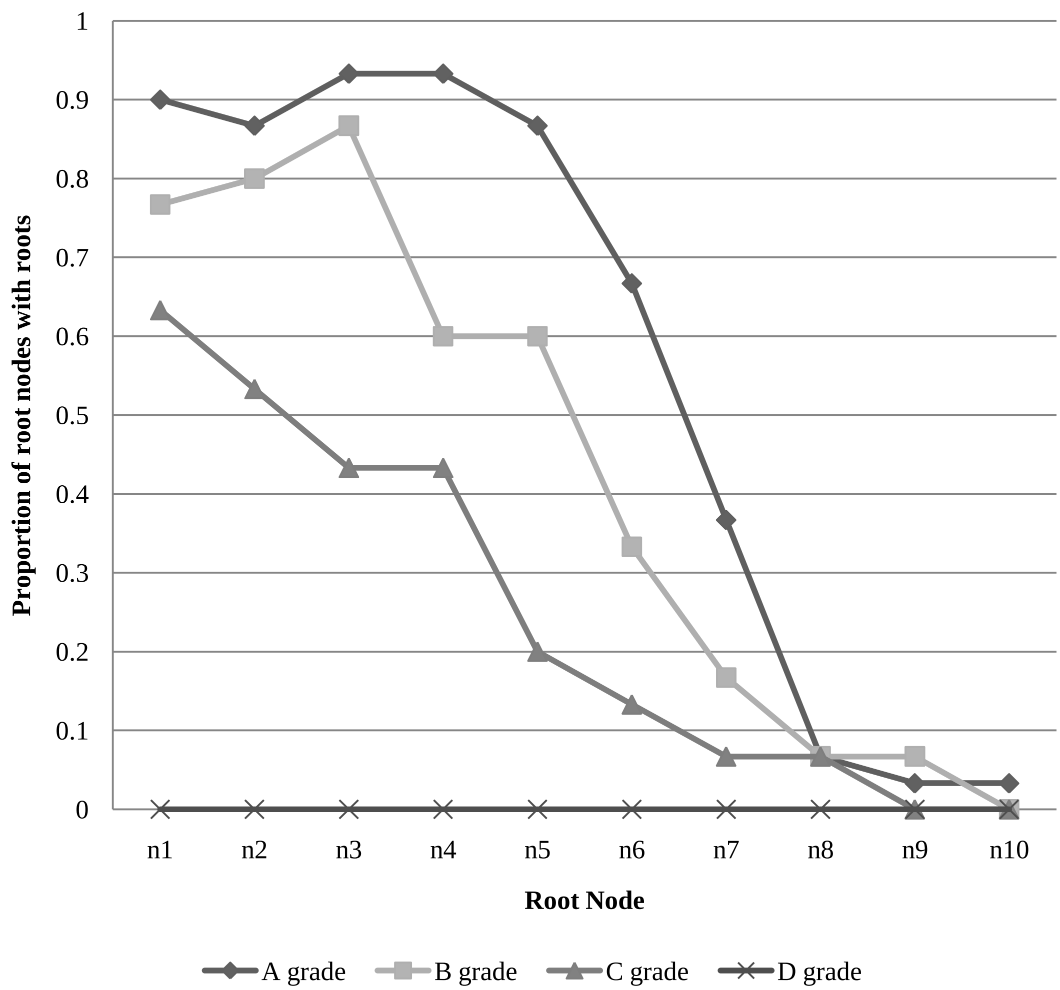

Figure 5.9 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 2 G.41combination treatments in Washington in 2009 n=20.

Table 5.18 Effect of early sawdust + IBA on rootstock liner characteristics of G.41 in Washington in 2009.

Treatment	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Control	0.65 a[z]	81.0 a	3.2 b	0.365 a	8.0 a	6.0 a	3.7 a	60.0 a
Early + IBA 2000 ppm	0.69 a	85.3 a	4.9 a	0.269 a	7.5 a	6.0 a	3.5 a	57.7 a
Combination Treatment Significance	NS	NS	*	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=52 for Combination treatment means.

5.4 Planting Style Experiment

Washington 2008 – first year crop

The upright planting styles had a larger number of liners per meter than the angled planting styles. The upright planting style at a low density had the greatest number of liners per meter at 20.5. Gradeout was also affected by planting style with the angled planting style at a low density having the worst performance (Table 5.19). There were also significant differences between rootstocks. G.935 had fewer total liners per meter of stoolbed than B.9 and M.9 T337. G.935 also had the most D grade liners (73.5%) compared to M.9 T337 and B.9 which had 43.2% and 46.3% D grade liners respectively. The combined percentage of A and B grade liners was significantly lower in G.935 liner (3.3%) compared to M.9 T337 (17.4%) and B.9 (22.1%). There were some significant interactions between planting style and rootstock on the percentage of B and D grade liners, as well as on the combined percentage of A and B grade liners (Table 5.19)

The proportion of nodes below the sawdust line which had roots was greatest in A grade liners and least in D grade liners (Figure 5.10).

The angled planting styles had a significantly greater proportion of straight shoots than the upright planting styles (Table 5.20). Among rootstocks, M.9 T337 liners had the most spines per liner. G.935 liners had significantly fewer roots and percentage of nodes below the sawdust line with roots compared to M.9 T337 and B.9 liners. There were significant interactions between planting style and rootstock on the proportion of straight liner, number of roots per liner and on root node characteristics (Table 5.20).

Washington 2009 – second year crop

In 2009 there were significant differences in the gradeout of shoots from the different planting styles and densities. The angled planting style at a high density had

Table 5.19 Effect of planting style and density on rootstock liner grade of B.9, G.935 and M.9 T337 in Washington in 2008.

			Percentage of stoolbed shoots in grades A-D[z]					
Treatment	Rootstock	Liners per m	%A	%B	%C	%D	%AB	%CD
Angled high density		9.8 c	1.0 a	15.1 a	24.7 b	59.2 b	16.1 a	83.9 b
Angled low density		9.5 c	0.8 a	3.9 b	18.7 b	76.5 a	4.7 b	95.3 a
Upright high density		16.5 b	3.5 a	16.5 a	38.3 a	41.7 c	20.0 a	80.0 b
Upright low density		20.5 a	2.2 a	13.6 a	42.2 a	42.0 c	15.8 a	84.2 b
Planting Style Significance		**	NS	**	**	**	**	**
	B.9	15.0 a	3.2 a	18.9 a	31.6 ab	46.3 b	22.1 a	77.9 a
	G.935	12.8 b	0.3 a	3.0 a	23.2 b	73.5 a	3.3 a	96.7 a
	M.9 T337	15.1 a	2.1 a	15.4 a	39.4 a	43.2 b	17.4 a	82.6 a
Rootstock Significance		*	NS	NS	*	**	NS	NS
Significance of Interaction of Planting Style and Rootstock		NS	NS	**	NS	*	*	*

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner

[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=10 for Planting Style means, n=13 for rootstock means and n=3 for Interaction means.

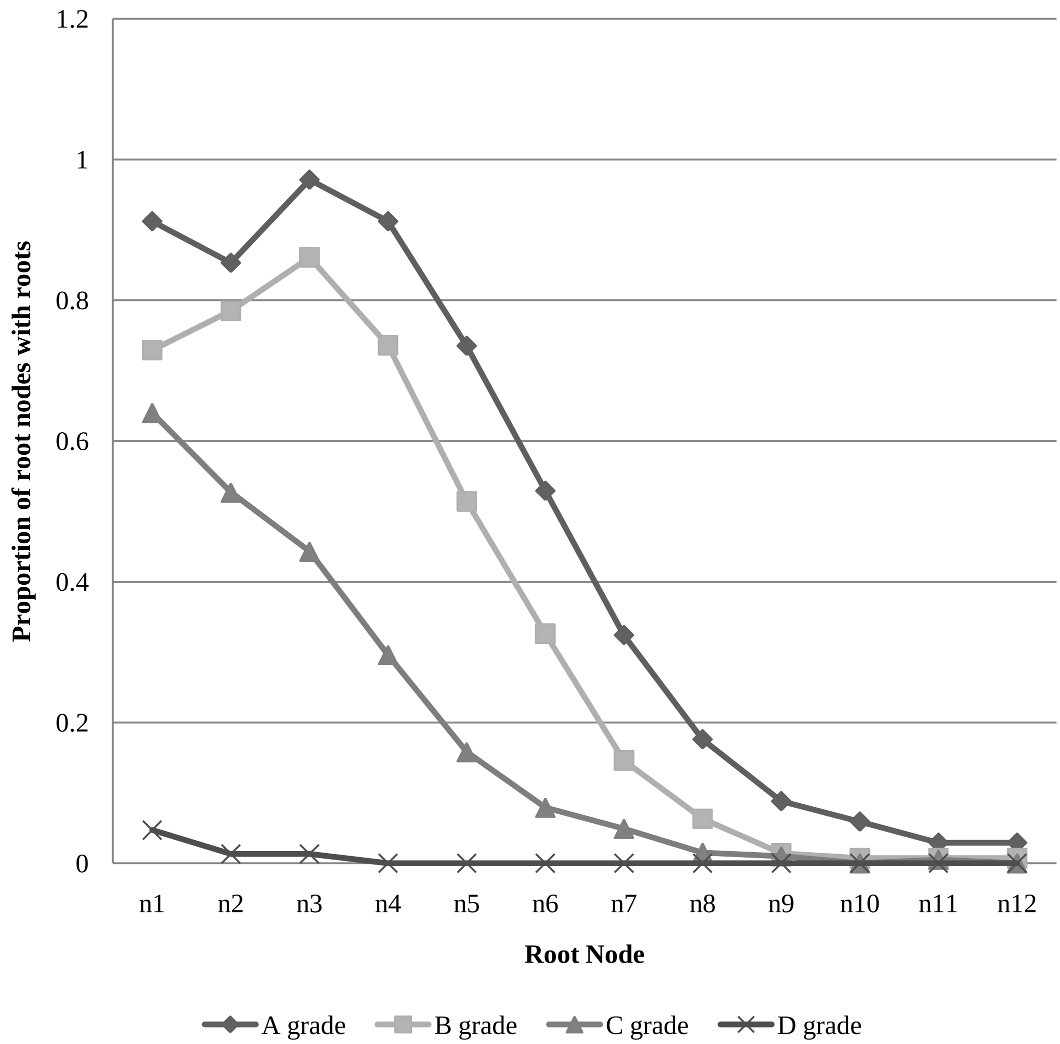

Figure 5.10 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 3 rootstocks and the 2 planting styles and 2 planting densities in Washington in 2008 n=60.

Table 5.20 Effect of planting style and density on rootstock liner characteristics of B.9, G.935 and M.9 T337 in Washington in 2008.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Angled high density		0.65 a[z]	81.5 a	0.7 a	0.986 a	4.9 a	7.1 a	2.0 a	27.4 a
Angled low density		0.67 a	77.7 a	1.3 a	0.945 a	3.3 a	6.7 a	1.5 a	21.2 a
Upright high density		0.68 a	85.3 a	0.4 a	0.839 b	5.2 a	6.7 a	2.2 a	30.8 a
Upright low density		0.74 a	90.9 a	0.4 a	0.851 b	5.8 a	6.6 a	2.2 a	32.6 a
Dark Preconditioning Treatment Significance		NS	NS	NS	**	NS	NS	NS	NS
	B.9	0.69 a	84.1 a	0.0 b	0.880 a	6.0 a	6.7 a	2.4 a	33.4 a
	G.935	0.74 a	97.8 a	0.2 b	0.805 a	2.1 b	6.8 a	1.3 a	18.9 c
	M.9 T337	0.67 a	77.5 a	1.4 a	0.970 a	5.9 a	6.8 a	2.2 a	30.8 b
Rootstock Significance		NS	NS	**	NS	*	NS	NS	*
Significance of Interaction of Planting Style and Rootstock		NS	NS	NS	**	**	*	*	**

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=154 for Planting Style means, n=205 for rootstock means and n=51 for Interaction means.

Table 5.21 Effect of planting style and density on rootstock liner grade of B.9, G.935 and M.9 T337 in Washington in 2009.

Treatment	Rootstock	Liners per m	Percentage of stoolbed shoots in grades A-D[z]					
			%A	%B	%C	%D	%AB	%CD
Angled high density		16.1 b[y]	39.5 a	28.3 a	19.6 c	12.6 a	67.9 a	32.1 a
Angled low density		20.2 a	31.2 a	27.7 a	27.7 a	13.4 a	58.9 a	41.1 a
Upright high density		20.1 a	35.0 a	32.4 a	23.8 b	8.8 a	67.4 a	32.6 a
Upright low density		24.1 a	34.0 a	26.7 a	26.6 ab	12.7 a	60.7 a	39.3 a
Planting Style Significance		**	NS	NS	**	NS	NS	NS
	B.9	20.0 a	57.4 a	28.7 b	12.2 c	1.7 b	86.1 a	13.9 c
	G.935	19.7 a	13.7 c	21.2 c	35.4 a	29.7 a	34.9 c	65.1 a
	M.9 T337	21.0 a	33.9 b	36.1 a	25.6 b	4.3 b	70.0 b	30.0 b
Rootstock Significance		NS	**	**	**	**	**	**
Significance of Interaction of Planting Style and Rootstock		NS	NS	NS	**	NS	NS	NS

[z] A grade = 16 + roots per liner, B grade = 9-15 root per liner, C grade = 1-8 root per liner, D grade = 0 root per liner
[y] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=10 for Planting Style means, n=13 for rootstock means and n=3 for Interaction means.

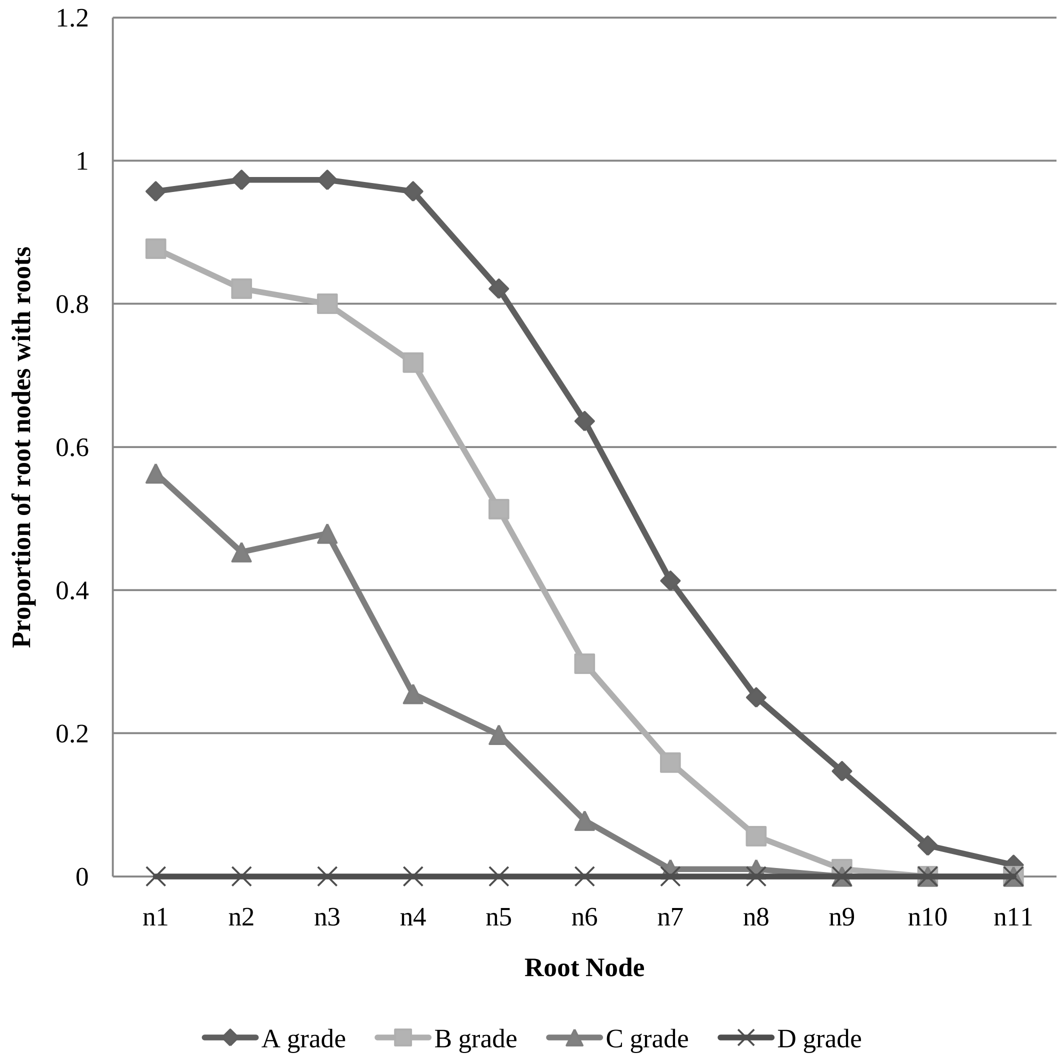

Figure 5.11 Proportion of nodes below the sawdust line with roots for the 4 rootstock grade classifications averaged over the 3 rootstocks and the 2 planting styles and 2 planting densities in Washington in 2009 n=60.

Table 5.22 Effect of planting style and density on rootstock liner characteristics of B.9, G.935 and M.9 T337 in Washington in 2009.

Treatment	Rootstock	Liner caliper (cm)	Liner height (cm)	# Spines per liner	Proportion of straight liners	# Roots per liner	# Root nodes below sawdust line	# Rooted nodes per liner	% Rooted nodes below sawdust
Angled high density		0.72 a[z]	91.2 a	0.6 a	0.517 a	10.1 a	5.6 a	3.5 a	59.3 a
Angled low density		0.75 a	88.9 a	1.2 a	0.500 a	10.2 a	5.4 a	3.1 a	53.4 a
Upright high density		0.74 a	91.2 a	0.9 a	0.556 a	10.8 a	5.6 a	3.5 a	57.5 a
Upright low density		0.81 a	92.2 a	1.4 a	0.445 a	10.8 a	5.9 a	3.7 a	58.7 a
Planting Style Significance		NS	NS	NS	NS	NS	NS	NS	NS
	B.9	0.83 a	93.2 a	0.1 b	0.522 b	14.3 a	6.1 a	4.3 a	67.1 a
	G.935	0.75 b	93.0 a	0.5 b	0.241 c	5.4 c	5.0 b	2.6 c	47.1 c
	M.9 T337	0.69 c	86.6 b	2.3 a	0.771 a	12.6 b	5.9 a	3.7 b	59.8 b
Rootstock Significance		**	**	*	**	**	**	**	*
Significance of Interaction of Planting Style and Rootstock		NS	NS	NS	NS	NS	NS	NS	NS

[z] Means with the same letter are not significantly different using Duncan multiple range test p value ≤ 0.05, n=170 for Planting Style means, n=227 for rootstock means and n=57 for Interaction means.

the least total liners per meter (Table 5.21). There were no significant differences in total liner production per meter between the three rootstocks. There were significant differences in the gradeout between the rootstocks. B.9 had the greatest rooting with 86.1% A and B grade liners. M.9 T337 had 70% of the shoots in the A and B grades while G.935 had only 34.9% of the shoots in the A and B grades. There was a significant interaction between planting style and rootstock on the percentage of C grade liners (Table 5.21).

The proportion of nodes below the sawdust line which had roots was greatest in A grade liners and least in D grade liners (Figure 5.11).

Planting style did not affect liner characteristics in 2009. There were significant differences in all liner characteristics according to rootstock genotype. B.9 had the greatest liner caliper and M.9 T337 the least. M.9 T337 liners were the shortest, had the most spines per liner and had the greatest proportion of straight shoots. G.935 liners had the least proportion of straight shoots, significantly lower than both B.9 and M.9 T337 liners. G.935 liners had the least roots, nodes below the sawdust line and number and percentage of nodes below the sawdust line with roots compared to B.9 and M.9 T337 liners. There were no significant interactions between planting style and rootstock (Table 5.22).

CHAPTER 6 – DISCUSSION

A common theme seen in the data from our studies is that rootstocks behave differently across climates and from year to year. The first year of our studies (2008) was a poorer rooting year for B.9 and M.9 T337 in Washington than the second year (2009). The combined percentages of A and B grade liners in control plots for B.9 went from 86% in 2008 to 99.2% in 2009 while with M.9 T337 saw a jump from 39.4% in 2008 to 72.2% in 2009. M.9 EMLA in France follow a similar pattern with 41.7% A and B grade liners in 2008 and 69.6% in 2009. However, G.41 in France did much worse in 2009 than in 2008 with 31.7% A and B grade liners in 2009 compared to 52.8% A and B grade liners in 2008.

It is hard to say what exactly contributes to the fluctuation in growth and rooting from year to year. Some fluctuation can be attributed to the environmental conditions. Washington tends to have a shorter growing season (shoots form in May and shut down in September) compared to Oregon, but has higher summer temperatures and sunlight. Warmer spring temperatures could help increase shoot production initially while warmer temperatures in September and October could give the mounded shoots more time to form roots. The soil may also have an effect on how well the rootstocks grow. The soil at Willow Drive Nursery in Ephrata, Washington is a Timmerman soil consisting of coarse sandy loam while the soil at Willamette Nursery in Canby, Oregon is a Latourell soil consisting mainly of loam (Soil Survey Staff). The loamy soils of Oregon hold moisture better than the sandy loam of Washington, which can contribute to rooting. Rooting percentage may also be affected by the quality of labor during the mounding process. A stoolbed that is mounded very well will have a higher chance of rooting compared to one that has lots of holes not filled with sawdust. Adequate water is also important for active root growth. There are many variables involved in maximizing rooting.

Regardless of the environmental conditions and quality of labor, certain plant growth regulator treatments did improve rooting of shoots each year (Figure 6.1). In Washington, where B.9 and M.9 T337 were the rootstocks for the experiment, IBA sprayed at both 1000 ppm and 10000 ppm consistently improved the rooting success in the stoolbeds. This is consistent with increased rooting of IBA treated cuttings described by Hartmann et al. (1997)   In 2008 the spraying was done over the top of the stoolbed with the intent that the chemical would run down the shoots. This resulted in crooked tips and increased branching, with the worst cases on B.9 liners with IBA sprayed at 10000 ppm (Figure 6.2). In an effort to solve this problem the height of the spray wand was lowered in 2009 to be below the shoot canopy, applying the hormone as close to the root zone as possible. Apogee sprayed at 1000 ppm also helped increase the rooting percentage in both years. Although not statistically significant, Apogee sprayed at 1000 ppm on August 25, 2008 gave a numeric increase in the percentage of A grade liners of 5% compared to the untreated control. Apogee sprayed at 1000 ppm at various timings in 2009 also increased the percentage of A grade liners by at least 5% compared to the control. The best results in Washington were seen again in the late August spray which resulted in an 11% increase in A grade liners compared to the control. It should be noted that Apogee reduced shoot height in 2009. Apogee is a gibberellin biosynthesis inhibitor and effectively slows shoot growth. A visible symptom of Apogee is the shortening of the internodes (Green, 2003; Figure 6.3).

NAA sprayed at 50 ppm and 200 ppm and Apogee at 250 ppm never increased the combined percentage of A and B grade liners by more than 2% compared to the control and in some cases actually reduced the percentage of A and B grade liners compared to the control.

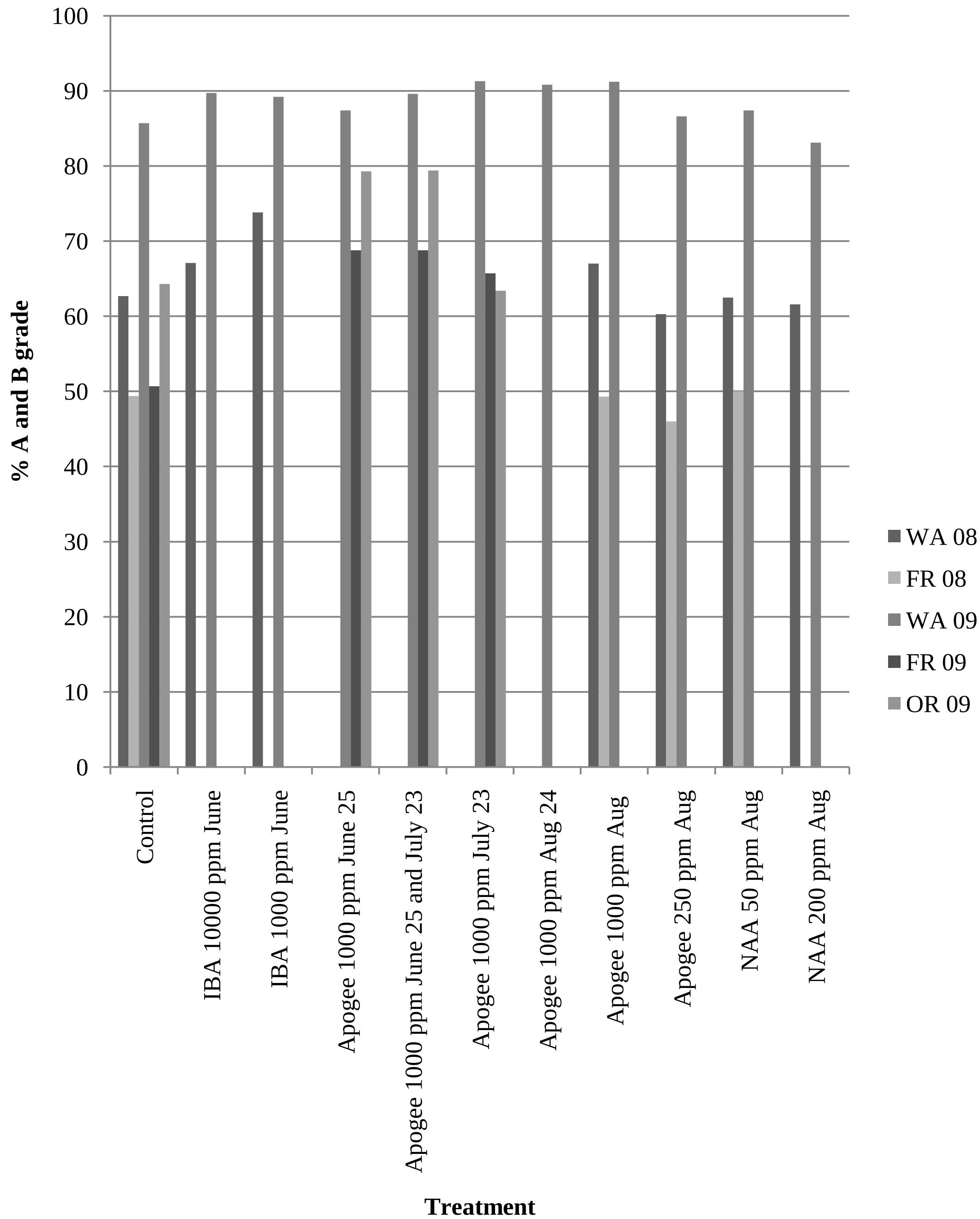

Figure 6.1 Combined percentage of A and B grade liners from plant growth regulator treatments in 2008 and 2009 at all locations.

Figure 6.2 Shoot tip bending caused by foliar spray of IBA in 2008.

Figure 6.3 Shortened internodes caused by Apogee at 1000 ppm sprays on M.9 T337 in 2009.

In France, where M.9 EMLA and G.41 were the rootstocks used in the experiments, there were no significant results in 2008. This was probably due to short plot lengths and some vertebrate pest pressure caused by rabbits which affected some plots near the edge of the field and increased variability. This was corrected in 2009 by increasing the plot length from 2m to 4m and setting the experiment back from the edge of the field. In 2009 all Apogee sprays at 1000 ppm, regardless of application timing, consistently increased the rooting of both M.9 EMLA and G.41 liners. As with B.9 and M.9 T337 liners in Washington, Apogee sprays reduced shoot height of both M.9 EMLA and G.41 liners in France compared to the control.

Apogee sprays consistently increased the proportion of straight shoots in France in 2009. Similar results were seen in Oregon in 2009 where G.41 was the rootstock for the experiment. Since a straighter shoot is worth more money than a bent one this result has significant economic impact. It is also worth noting that the early Apogee sprays (late June) reduced the total number of spines and side branches per liner in Oregon where spines are typically a problem with spines on G.41. Apogee sprayed at 1000 ppm in June and June + July reduced the total number of spines from 12.7 spines per liner in the control to 3.7 spines per liner. This result would effectively reduces the labor that would be required to hand remove the spines during the season or after harvest and before sale. Apogee was cost effective in all location in both years (Table 6.1).

Anti-gibberellins, such as Apogee, either: 1) antagonize the synthesis of gibberellins which normally inhibit rooting; or 2) reduce shoot growth which may compete with the root zone for assimilates to the detriment of root formation (Davis and Sankhla, 1988; Hartmann et al. 1997). Although there has previously been very little work with anti-gibberellins on apple rootstocks, our results are consistent with those seen on other plants such as bean cuttings (Davis and Sankhla, 1988). Other

Table 6.1 Cost analysis of chemical treatments in Washington, France and Oregon.

Year	Location	Rootstock	Treatment	Profit ($US) from A grade liners /3m	Profit ($US) from B grade liners /3m	Cost ($US) of treatment /3m	Net profit from A and B grade ($US) /3m
2008	WA	B.9	Apogee 250 ppm Aug	17.25	4.05	0.06	21.23
2008	WA	B.9	Apogee 1000 ppm Aug	16.88	4.16	0.25	20.79
2008	WA	B.9	IBA 1000 ppm	16.91	4.61	0.78	20.75
2008	WA	B.9	Control	15.18	4.58	0.00	19.76
2008	WA	B.9	IBA 10000 ppm	20.05	3.28	7.75	15.58
2008	WA	M.9 T337	IBA 1000 ppm	7.45	4.12	0.78	10.79
2008	WA	M.9 T337	Apogee 1000 ppm Aug	5.99	3.37	0.25	9.11
2008	WA	M.9 T337	Control	4.73	3.24	0.00	7.97
2008	WA	M.9 T337	Apogee 250 ppm Aug	3.86	2.45	0.06	6.25
2008	WA	M.9 T337	IBA 10000 ppm	4.79	3.27	7.75	0.31
2008	FR	M.9 EMLA	Apogee 1000 ppm Aug	1.48	5.88	0.25	7.11
2008	FR	M.9 EMLA	Control	1.68	5.16	0.00	6.84
2008	FR	M.9 EMLA	Apogee 250 ppm Aug	1.06	5.11	0.06	6.11
2008	FR	G.41	Control	6.20	11.70	0.00	17.90
2008	FR	G.41	Apogee 1000 ppm Aug	8.76	8.87	0.25	17.37
2008	FR	G.41	Apogee 250 ppm Aug	7.00	10.04	0.06	16.97
2009	WA	B.9	IBA 1000 ppm	24.50	1.79	0.78	25.51
2009	WA	B.9	Apogee 1000 ppm August 3	23.63	2.12	0.25	25.49
2009	WA	B.9	Apogee 1000 ppm July 29	22.32	2.81	0.25	24.87
2009	WA	B.9	Apogee 1000 ppm August 24	22.43	2.66	0.25	24.84
2009	WA	B.9	Apogee 1000 ppm June 29	22.12	2.88	0.25	24.75
2009	WA	B.9	Control	21.48	3.25	0.00	24.73
2009	WA	B.9	Apogee 250 ppm August 3	21.81	2.98	0.06	24.73
2009	WA	B.9	Apogee 1000 ppm June 29 July 29	21.90	2.98	0.51	24.37
2009	WA	B.9	IBA 10000 ppm	24.81	1.54	7.75	18.60
2009	WA	M.9 T337	Apogee 1000 ppm August 24	14.84	4.31	0.25	18.89
2009	WA	M.9 T337	Apogee 1000 ppm August 3	12.54	5.56	0.25	17.85
2009	WA	M.9 T337	Apogee 1000 ppm July 29	11.51	6.08	0.25	17.33
2009	WA	M.9 T337	Apogee 1000 ppm June 29 July 29	12.15	5.30	0.51	16.94
2009	WA	M.9 T337	IBA 1000 ppm	12.10	5.10	0.78	16.42
2009	WA	M.9 T337	Apogee 1000 ppm June 29	11.51	5.01	0.25	16.27
2009	WA	M.9 T337	Apogee 250 ppm August 3	9.30	5.98	0.06	15.21
2009	WA	M.9 T337	Control	9.52	5.52	0.00	15.04
2009	WA	M.9 T337	IBA 10000 ppm	10.81	5.96	7.75	9.02
2009	OR	G.41	Apogee 1000 ppm June 29	20.02	9.19	0.25	28.96
2009	OR	G.41	Apogee 1000 ppm June 29 July 29	18.52	10.17	0.51	28.19
2009	OR	G.41	Control	15.93	7.64	0.00	23.57
2009	OR	G.41	Apogee 1000 ppm July 29	14.17	8.49	0.25	22.40
2009	FR	M.9 EMLA	Apogee 1000 ppm June 29 July 29	17.61	3.02	0.51	20.13
2009	FR	M.9 EMLA	Apogee 1000 ppm June 29	16.38	3.33	0.25	19.45
2009	FR	M.9 EMLA	Apogee 1000 ppm July 29	14.53	4.08	0.25	18.35
2009	FR	M.9 EMLA	Control	12.40	3.64	0.00	16.05
2009	FR	G.41	Apogee 1000 ppm June 29	7.13	10.83	0.25	17.70
2009	FR	G.41	Apogee 1000 ppm July 29	7.39	9.36	0.25	16.49
2009	FR	G.41	Apogee 1000 ppm June 29 July 29	6.25	10.72	0.51	16.46
2009	FR	G.41	Control	2.38	7.15	0.00	9.53

Liners per 3m based on percent of 100 shoots (33 liners per meter).
A grade profit based on sale price ($ 0.68 for B.9, M.9 T337 and M.9 EMLA. $ 0.84 for G.41) minus cost to grow ($ 0.40 for all varieties). B grade profit based on sale price (20% reduction from A grade) minus cost to grow. Cost and profit in US dollars.

plant growth regulators have shown conflicting results. In Poland, tests with ethephon increased the number of rooted M.26 liners, while growth retardant Cyclocel showed no benefit to rooting (Webster, 1995)

With the dark preconditioning experiments there were also different results from year to year. In 2008 B.9 had a combined percentage of A and B grade liners of 60.3% while M.9 T337 liners had 55.2%. In 2009 the percentage of A and B grade liners with B.9 jumped up to 96.3% while with M.9 T337 the percentage jumped to 80.8%.

The early season shading consistently improved rooting of both B.9 and M.9 T337 (Figure 6.4). In 2008 the percentage of A and B grade liners with B.9 was increased by 22.5% compared to the control while with M.9 T337 the percentage of A and B grade liners was increased by 9.5% compared to the control. In 2009 the results were not quite as clear with B.9 since even the controls had a very high percentage of rooting. However, with M.9 T337 liners there was a similar improvement in rooting in 2009 as in 2008 with an increase in the percentage of A grade liners by 9.7% and an increase in the percentage of A and B grade liners of 5.3% over the control. Unfortunately, early season shading also tended to reduce the proportion of straight liners, possibly because the shoots were tender and easier to bend when the shade boxes were removed and sawdust was applied. In contrast the early sawdust mounding treatment also increased the proportion of straight liners, but did not increasing the rooting compared to the untreated liners. Cost analysis shows that it would take at least 2-3 years to actually earn a profit from shading while early season sawdust mounding never turned a profit (Table 6.2).

Under conditions of etiolation, like the shade boxes and early sawdust mounding used in our experiment, there is a decrease in stem sclerification which is

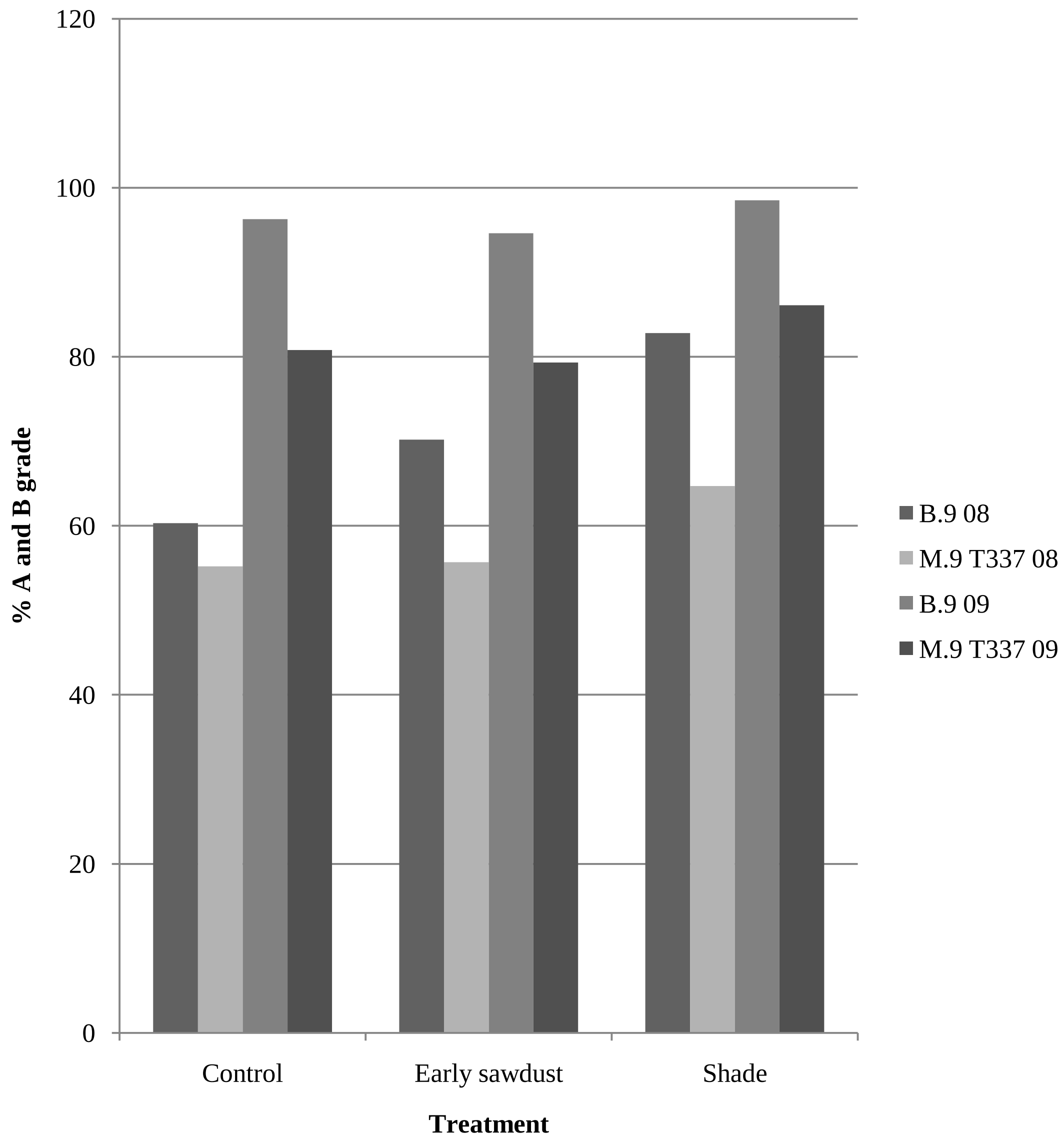

Figure 6.4 Combined percentage of A and B grade liners of rootstocks from dark preconditioning treatments in 2008 and 2009.

Table 6.2 Cost analysis of dark preconditioning treatments in Washington.

Year	Rootstock	Treatment	Profit ($US) from A grade liners /3m	Profit ($US) from B grade liners /3m	Cost ($US) of treatment /3m	Net profit from A and B grade ($US) /3m
2008	B.9	Control	6.89	5.13	0.00	12.01
2008	B.9	Early sawdust	9.77	5.08	3.20	11.66
2008	B.9	Shading	12.57	5.46	41.20	-23.17
2008	M.9 T337	Control	4.09	5.83	0.00	9.92
2008	M.9 T337	Early sawdust	4.68	5.62	3.20	7.09
2008	M.9 T337	Shading	6.22	6.12	41.20	-28.86
2009	B.9	Shading	20.16	3.82	0.00	23.98
2009	B.9	Control	19.68	3.74	0.00	23.43
2009	B.9	Early sawdust	19.43	3.61	3.20	19.85
2009	M.9 T337	Shading	13.24	5.59	0.00	18.83
2009	M.9 T337	Control	10.53	6.22	0.00	16.75
2009	M.9 T337	Early sawdust	10.56	5.99	3.20	13.35

Liners per 3m based on percent of 100 shoots (33 liners per meter).

A grade profit based on sale price ($ 0.68 for B.9 and M.9 T337) minus cost to grow ($ 0.40 for all varieties). B grade profit based on sale price (20% reduction from A grade) minus cost to grow. Cost and profit in US dollars.

negatively correlated with adventitious rooting (Rom, 1987). Our results are consistent with those previously conducted on apple rootstocks and other species (Maynard and Bassuk, 1987; Maynard and Bassuk, 1988; Maynard and Bassuk, 1992; McDonald, 1986; Sun and Bassuk, 1991).

Our experiments with G.41 gave different results in different climates. In Washington where we had limited plant material with which to work we applied a combination treatment of shading and an IBA spray to G.41.Although IBA sprays increased rooting success with both B.9 and M.9 T337 in the plant growth regulator study, in the G.41 study as part of a combination treatment it did not improve rooting but rather reduced rooting. Similarly in the dark preconditioning study, shading increased the rooting success of both B.9 and M.9 T337 but with G.41 as a part of the combination treatment it reduced the rooting success. G.41 is typically a very brittle rootstock and break easily in stoolbeds. We noticed that the shading made the rootstocks even more susceptible to breakages. In 2009 the early sawdust mounding was used in place of shading but with no improvement in rooting success compared to the control. Early sawdust mounding plus IBA sprayed at 2000 ppm increased the percentage of A and B grade liners by only 2.5% compared to the control.

The planting style study gave promising results that rooting of several rootstock genotypes could be improved with different planting styles and densities in the first two years after planting. Overall, the high planting density had the highest percentage of A and B grade liners. The combination of angled style and low planting density consistently gave the poorest rooting in both years. This style had the lowest number of liners per meter in their first year but had comparable liners per meter in the second year. The upright style planted at low density, had the most liners per meter in both years, probably because there was less competition at planting. This resulted in larger caliper and taller liners but not increase rooting. The best overall planting style

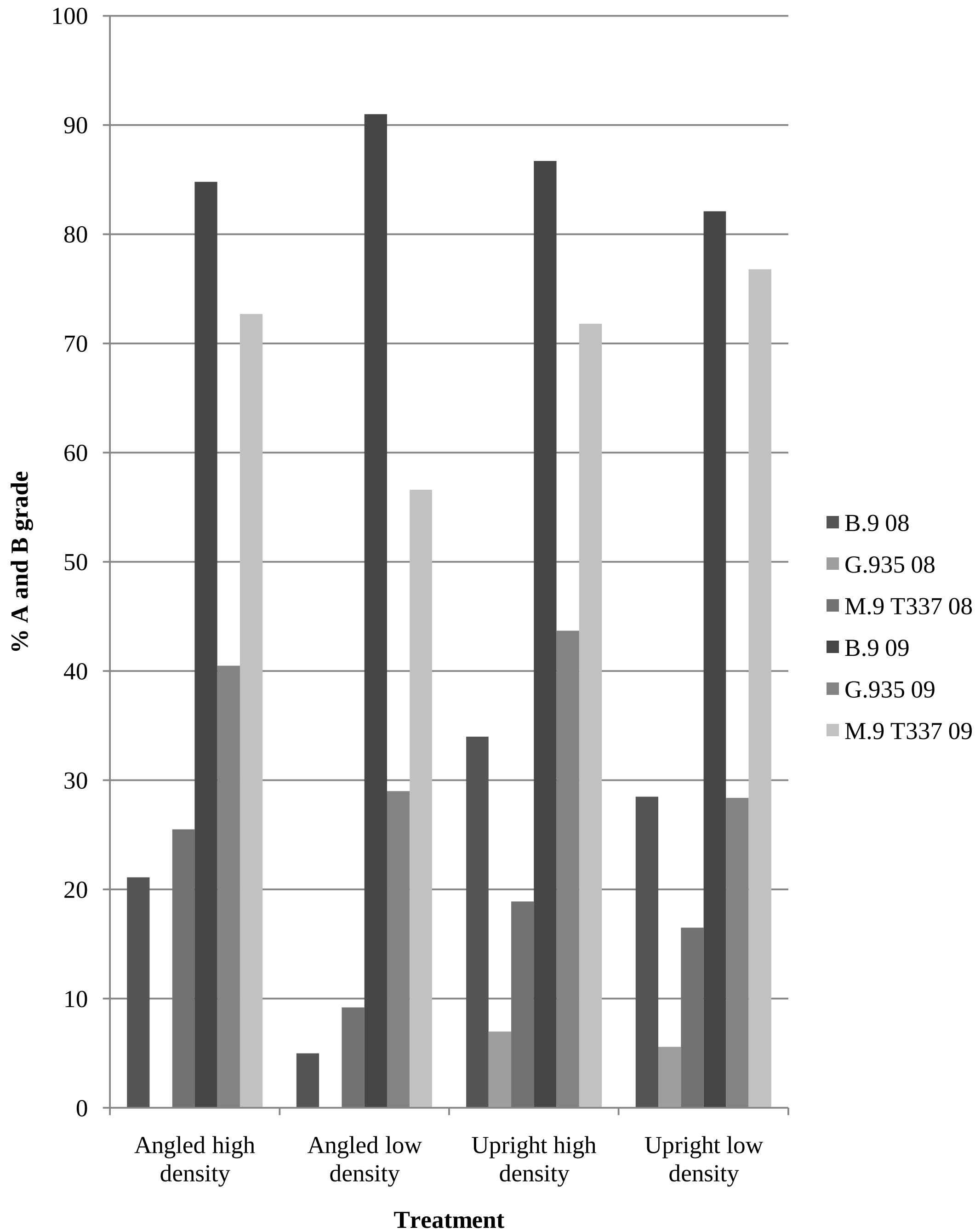

Figure 6.5 Combined percentage of A and B grade liners of rootstocks from planting style and planting density treatments in 2008 and 2009.

tended to be the upright style planted at a high density. Upright, high density, stoolbeds consistently had high rooting success and many liners per meter among all rootstocks in the trail (Figure 6.5).

CHAPTER 7 – CONCLUSION

Apple rootstocks are an essential part of apple production. They provide dwarfing, precocity and disease and insect resistance to the tree. Rootstocks can be propagated through various methods such as cuttings, tissue culture but the most common method of propagating apple rootstock is layering. Many rootstocks have been bred for specific characteristics, but in many cases the best rootstocks are difficult to propagate. The purpose of this study was to find ways to improve the propagation of rootstocks with desirable characteristics such as dwarfing capabilities, high yield, early fruit bearing and disease and pest resistance, but have poor rooting in stoolbeds. This project was divided into four groups of experiments: plant growth regulator experiments, dark preconditioning experiments, the combination of plant growth regulators and dark preconditioning experiment with G.41 rootstock, and a planting style and planting density experiment.

Planting style and planting density are the first considerations when starting a stoolbed or layerbed and should also be the first consideration when attempting to improve rooting. Our studies show that an upright planting style with high planting density is an important strategy to improve rooting. The disadvantage of this strategy is that it requires a larger number of initial plant materials with a high initial investment. Although this strategy gives the best production of liners, the economics of this strategy have not been evaluated.

Cultural practices also offer potential methods to increase the rooting of most rootstocks propagated by stoolbeds. Our studies showed that B.9 and M.9 T337 liners responded very well to early season shading. However, shading techniques have a high startup cost and resulted in more shoot breakage with G.41 which has brittle shoots. Early sawdust mounding can slightly improve the rooting potential of B.9 and

M.9 T337 liners but the added labor required to mound sawdust an additional time may cancel out the increase in rooting.

Plant growth regulator treatments are the least labor intensive tools to use for improving rooting in stoolbeds. Our studies showed that IBA improved rooting but the targeting of the spray must be precise to not damage the growing shoot tip. IBA could be used on a small scale with a backpack sprayer could easily get the spray to the root zone without affecting the shoot tips. It might be more difficult to use IBA on a large scale with boom sprayers which would not be able to accurately spray only the root zone. High concentrations of IBA are typically not cost effective.

Our studies showed that Apogee consistently improved rooting of the rootstocks we evaluated. It had very few negative side effects and could be adapted by either large or small scale growers. It can easily be broadcast over the top of the stoolbeds. Early application in June can also help control spines on problematic rootstock varieties. Most importantly, Apogee improves the rooting success in the stoolbeds and is cost effective.

Although our studies have shown that there are several approaches to improve the rooting of dwarfing apple rootstocks, it is important to understand that different rootstock genotypes may not react in the same way to the successful treatments. For example, G.41did not do well under shade treatments in our study. Rootstock growers should understand how each rootstock variety grows in their specific climate. There is still a lot of progress that needs to be made in improving rooting success of dwarfing apple rootstock in stoolbeds.

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