EXAMINING THE ECONOMIC IMPACT OF BUSINESS FORM, PRODUCTION METHOD, AND ROOTSTOCK SELECTION FOR APPLE NURSERIES

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

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August 2022

ABSTRACT

Apples have received significant attention from economists as they are the second most valuable crop in the U.S. fruit industry. Nurseries, as the provider of rootstocks and finished trees, are a key player in the apple industry. Much of the current research has focused on the economic performance of apple growers, who purchase trees from nurseries and provide fruit to the apple industry. However, the economic problems faced by nurseries have been largely ignored. This study presents a snapshot of the realistic state of the nursery practitioner when making decisions, such as the choice of rootstock genotypes, production methods, and business models. To achieve this, we created customized tables, one that can be filled with data according to one's situation. The net present value (NPV) is used to present the economic results from different choices. At the same time, we use Geneva® 41 rootstock (G. 41), one of the commonly used rootstock genotypes, as an example to show its economic performance in different production methods and business models, respectively.

BIOGRAPHICAL SKETCH

Xi Chen was born in Chengdu, the capital city of Sichuan province. Before coming to Cornell, she completed her double degrees in Shandong University and George Mason University with a major in Economics.

This thesis is dedicated to Professor Bradley J. Rickard and Professor Gennaro. Fazio, my mentors in graduate school.

ACKNOWLEDGMENTS

I would like to express my deepest appreciation to my committee, Professor Bradley J. Rickard, and Professor Gennaro Fazio, for their patience, great suggestions, and wisdom as I finished this paper.

I would also like to extend my deepest gratitude to my family for the great emotional and financial support.

I would like to give a special thanks to my fiancé, Zhongwei Huang, for his love and support.

I also wish to thank Jingyi, Nan, Xiaoxiao, Jiacheng, Tony, Xiaoxi, and others in my cohort for their friendship and great memories.

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CHAPTER 1
INTRODUCTION

1.1 Apple industry

The total economic value of the U.S. apple industry is $19 billion of which $3.6 billion is generated at the farm gate (U.S. Apple Association, 2018). Apples are the second most valuable crop in the U.S. fruit industry. The apple industry supply chain has many levels, from rootstock and tree suppliers to farmers, to retailers, to consumers. We will focus on the pre-fruit production level of the supply chain. Breeding programs and nurseries are the main players in the pre-fruit stage. Breeding programs focus on the development and innovation of rootstocks and scions, which provide qualified materials for the nurseries. Breeding programs include scientists in the field of horticulture and plant breeding, while nurseries fulfill the market demand for apple trees. Nurseries produce the rootstocks and scions released by breeding programs and then sell them to orchard owners. The pre-fruit stage ends and is followed by the fruit production stage at the farm level. The subsequent stages, including selling apples to distributors or final consumers, are outside the scope of this study but could influence rootstock selection in nurseries. Figure 1 describes the main players in the apple industry.

Due to its sizable economic impact, both private and public institutions conduct research to understand and optimize apple supply chain. Most of these studies focus on the fruit phase. Mon et al., (2006) analyze both direct and indirect impacts of organic apple production compared to conventional production, which includes investment, sales price, employment, and house consumption. Busdieker-Jesse et al., (n.d.) investigate the economic benefits brought by genetically modified technologies. This work shows that some emerging technologies can help largely avoid incurring serious production losses, the uncertainty of its yield falls after its application, and farms start to adopt this technology to gain additional profits. Popp et al., (2016) present an economic forecasting model for organic apple orchards that predicts the net present value and break-even point of the business. They introduce a model that helps organic apple orchards understand fluctuations in market prices and yields. These studies provide information to apple growers and those interested in entering the market with a quantitative understanding of fruit production. This helps them make more informed business decisions about entering new industries or adopting new technologies. In addition, market intermediaries and consumer preferences have also been studied. Yue & Tong (2011) study consumers' willingness to pay on different varieties of apples and Gallardo et al., (2015) analyze market intermediaries', like processors and packers, preference on the apple flavor, color, and storage length. The discrete choice experiment finds out that market intermediaries pay more attention to the attributes that influence the appearance of apples.

1.2 Pre-fruit production

However, little attention has been paid to economic issues in the pre-fruit production stage of the supply chain. As the breeding program itself does not provide rootstocks for the market, the pre-fruit stage in this paper refers specifically to nurseries. Nurseries, as the main providers of quality apple trees, have a role in determining the traits of apples on the market. The main objective of nurseries is to produce finished trees (rootstocks and scions). Orchard owners, as the main customers, place orders with nurseries two years before planting to ensure that they get high quality finished trees on time. In addition to the scion variety, these orders may have special requirements, including the size of the finished tree, yield, early maturity, disease resistance, and survival rate etc., of which are mainly influenced by rootstock selection or can be referred to as rootstock genotypes. For nurseries, contracts with orchard owners account for 60 to 80 percent of their production, because producing under contract is less of an uncertainty for them. As seen in its business model, the nursery, as the selector and gatekeeper, is also influenced by other players. While this may reduce the influence of nurseries on the industry, the nurseries remain influential. For example, different rootstocks perform differently and may have different characteristics, so nursery owners need to balance these characteristics and choose the most appropriate rootstock to make available to orchard owners. Also, a nursery may choose whether to produce a particular rootstock based on profitability, as the cost of production may vary from rootstock genotypes. Of course, the rationale for judgment could be different. This decision may be made based on other considerations, including production experience or family or company habits. Nurseries also have different business models. Some are only in the nursery business without owning orchards for fruit production. Some companies choose to take on the role of both nurseries and orchards, thus producing rootstocks and finished trees, planting the finished trees produced into orchard ground, managing the orchard for optimum fruit production, and selling the fruit, this model is vertically integrated and does provide some efficiencies in terms of the supply chain of trees, but it complicates operations as the timing for many of the horticultural field operations for nursery management conflict with proper orchard management. However, for simplicity, the second business model will be ignored because we will only focus on the pre-fruiting stages, which is what a typical apple tree nursery looks like.

Rootstock and "finished-tree" production represent two substages in nursery production. The length of time for rootstock production varies from production methods. Finished-tree production follows rootstock production by adding (by means of grafting) and growing a scion onto it, which takes about one to two years depending on growing conditions and the quality of tree desired. The length of finished-tree production depends on the decision of the nursery, it may choose to produce one-year trees or two-year trees. A one-year tree will take one year in the tree production and a two-year tree will take two years. At the end of the production, the finished trees will be sold to fruit production companies or orchard owners.

The process of finished-tree production, for one-year grafted trees, regardless of scion varieties and production methods, will have rootstock liners grafted between February to April (a technique called bench-grafting) and then planted in the nursery field or greenhouse or planted as a rootstock and Spring chip budded (a type of grafting where the scion variety is joined to the rootstock after planting) grown for about eight months. The results of bench-grafting and Spring chip budding are similar and in general produce smaller trees than two-year finished trees. After this growing season, nurseries will dig up the grafted one-year finished trees from the field, bundle them, and transport the trees to a warehouse where they will be covered with sawdust and stored in specialized temperature and humidity controlled storage facilities. Before shipping finished trees to orchards, nurseries need to grade them according to their size, number of branches, and quality. For two-year finished tree production, rootstock liners will be planted in the spring without having any grafts. These rootstock plants are allowed to grow and form strong root systems prior to grafting (usually by chip-budding) with a selected scion in August to September. The grafted bud will heal and stay dormant in the field during the winter and then allowed to push and grow for a summer season before it is harvested the following Fall to Winter. The two seasons of growth allow for the development of stronger roots, more feathers (branches) and flower buds such that when these two-year trees are planted, they are ready for production. One-year grafted trees tend to have fewer feathers and are of smaller size than two-year grafted trees, which could lead a longer time to the bearing stage in the orchard. Thus, they are generally sold at a lower price. However, because our study focuses on the differences between different types of nurseries and the effects of rooting methods, we will not explore the effects of one-year and two-year trees. We will therefore use one-year grafted trees as a uniform endpoint.

Two methods in the rootstock liner production are stool bed production and micropropagation production. These two methods have differences in inputs, production length, and the quality of the root produced.

Stool bed production is a more conventional and cheaper method compared to micropropagation. It is cheaper because it can be carried out in fields or even in backyards and does not need a lab or controlled environment. However, the production length for stool bed production is about one year longer than the length required for micropropagation. The process of stool bed propagation has five phases, which are shown in Figure 2.

Phase 0 is the preparation. The original plant is selected and prepared for propagation. The source of the original plant can be rootstocks purchased from other nurseries, rootstocks from a previous production cycle, or rooted cuttings from mother trees in the nursery. After ensuring that the original plant is virus free, it is planted in the field in the early spring of year 1. Phase 1 is the growth stage. When the plant is vigorous and large enough, before the winter of year 1, it is ready for phase 2. Phase 2 happens in the early spring of year 2. The well-developed plant has generated several branches and these branches will be cut off at the ground level thereby leaving what will be called a "mother-plant" which will produce new shoots (and turned into rooted liners) every successive season. Shoots are produced above ground before summer. During the summer of year 2, the stool bed production will be processed into the core phase, which is phase 3. In this phase, shoots are partially covered with soil or well-decomposed sawdust to produce roots on each shoot. The sawdust treatment is renewed (or mounded) periodically during the growing season to prevent the base of the shoot from being exposed to sunlight, thus creating a conducive environment for adventitious root formation. Phase 4 is cutting these new rooted shoots and lifting them from the stool-bed before the winter of year 2 and the individual rooted shoots (also called rootstock liners) are separated. Rootstock liners can then be graded according to size, number of roots, straightness etc. Rootstock liners are stored in temperature and humidity controlled environment before being processed to the finished-tree phase by various types of grafting in vertically integrated nurseries (that grow rootstocks and make finished trees), or sold to other finished tree nurseries based on grading. The number of rootstock liners produced by a unit size (meter or hectare) of a stool bed depends on the variety of rootstocks and management practices (water, fertilizer and chemical treatments) used to plant and grow the stool-bed. The original mother plants could remain productive for 20 years or more if it is well-cared for the nursery owner. As the figure indicated, phase 0-1 are the preparation steps. The actual production length per cycle starts from phase 2 and takes about 1 year. Each production cycle could produce certain number of shoots per unit size of stool-bed. Different rootstocks would have different efficiency on shoot generation and thus would also make a difference in numbers of production cycles required to achieve a certain target production number. For rootstocks of the same type, the number of production cycles is depend on the target quantity of plants to be produced. Statements on shoot generation efficiency and numbers of production cycles are also true for another production method, micropropagation.

Micropropagation is more expensive but has the capacity to produce both a higher quantity and quality (higher number of primary roots) of rootstocks at a given time. The rootstocks produced by micropropagation tend to have more primary roots and more initial vigor. The process of micropropagation has five phases as shown in Figure 3.

Phase 0 is pre-selection and pre-treatment. The selected mother plant is placed in a sterilized environment to prepare for micropropagation. Phase 1 is transferring the explants into the media for in vitro culture. An explant is an organ or a fragment of tissue that is used as in vitro culture material usually containing apical meristems. It is cut off from the parent, a healthy plant, and is then transferred into the culture medium. Phase 2 is multiplication of shoots or shoot generation. The efficiency of phase 2 is different from nursery to nursery as different hormone, light, moisture and nutrition regimens can affect the final outcome and are often closely guarded trade secrets by each company. Therefore, in house expertise (obtained by research experience) is one of the intrinsic nursery aspects that could affect the efficiency of shoot generation and the whole micropropagation process. A nursery with rich experience may able to consistently produce 5 shoots from each plantlet while those with less experience may produce 3 shoots in phase 2. As discussed before, rootstocks genotypes also have an influence on the efficiency in phase 2. Phase 3 is the rooting session where the roots will be prepared first, followed by the rooting stage. Enhancing the size of in vitro culture in the preparation stage will help root the plantlets in the rooting stage[1]. All the production processes in micropropagation described above occur in a strictly sterilized laboratory. Depending on the nursery, the second stage of phase 3 could take place in a laboratory or greenhouse while phase 4 occurs in a greenhouse. At this point, the in vitro culture has been transferred into a new rootstock and would be transported into pots or flats in the acclimation tunnel for rooting. Once the roots have developed, the small rootstock will enter phase 4, acclimation to an open-air environment. The young rootstock will be placed in an environmentally-controlled greenhouse for further growth until it meets the requirements for commercialization. Success rate in acclimation largely depends on the genotype of the rootstocks and the management experience of the outfit. Some may have a success rate at 99% while others may at 50%. The numbers of cycles needed in micropropagation rootstock production depends on the expertise of the nurseries, genotypes of rootstocks, and the target numbers of plants to be produced.

[1] Note here that some nurseries may combine phases 1, 2, and the preparation stage of phase 3 into one phase.

Besides the diversity in the business model and production methods, the operations nurseries carry out can also vary according to in house application of knowledge and experience. For example, some nurseries are only in the rootstock liner business, equipped with talent for micropropagation or for stool bed propagation. Some nurseries lack the resources/skills to utilize these techniques, so they are only engaged in tree production and generally purchase rootstocks from specialized rootstock nurseries. Some have opted for a more "vertical" business where they are responsible for rootstock production as well as finished-tree production, in which the product of the previous stage is the raw material for the latter stage. While some other nurseries may only focus on rootstocks production. For a complete understanding of the nursery business, this research will explore the business of all operations, rootstock nurseries with both micropropagation and stool bed methods, and vertically integrated nurseries with both production types.

A nursery's core job is to propagate different rootstocks and bud the rootstocks with different scions. Nurseries are not like orchards that can order finished products from other institutions; they are like manufacturing plants that produce products from raw materials.

First, this core work requires nurseries to select the "right" rootstock for production among many. This is because rootstocks play an important role in determining the growth of the tree. Disease resistance, graft bond strength, fruit size, tree size, biennial fruit set, branch angle, growth cycle, and nutrient uptake (Fazio & Robinson, 2008) are all influenced by rootstocks. Secondly, to ensure that the finished trees will grow successfully and produce desirable fruit in the orchard, the nursery (in consultation with the final user orchard grower) needs to consider whether the rootstock and cultivar match together. For example, some cultivars demand rootstocks to provide specific nutrients, and more vigor. On top of this, the profitability of the scion variety should be considered.

Rootstocks are usually developed by specialized breeding programs. Breeding programs focus on improving farm profitability and consumer experience through the development of new scions and rootstocks (Fazio, Lordan, Francescatto, & Robinson, 2018). The Geneva® apple rootstock breeding program is one of a handful of breeding programs in the world aimed at improving the performance of apple trees by the selection of improved apple rootstocks that are resistant to biotic and abiotic stresses and more productive than conventional rootstocks. Root 2 Fruit (R2F) is a multi-institution and multi-disciplinary project aimed at accelerating the understanding and implementation of new rootstock technologies in U.S. orchard production. The Geneva apple rootstock breeding program has taken about 50 years to develop rootstocks that are outstanding in root multiplication, biotic soil adaptation, abiotic soil adaptation, nutrient uptake, fruit quality, and disease resistance, and this series of rootstocks is named Geneva® or G.### rootstocks (# is in place of the number identifier of a specific rootstock) (Fazio, 2017). G. rootstocks were first introduced to the market in 1991 and has thirteen rootstocks released so far (PennState Extension, 2020; Robinson, Aldwinckle, Fazio, & Holleran, 2003). To understand how stable the characteristics of G. rootstocks are under different environmental conditions and geographic locations, field trials led by the Geneva® breeding program and other institutions have been conducted in North America and other parts of the world. The field trial is usually maintained for more than five years and tests for indicators including root condition at planting (number of roots produced), tree size, tree survival, disease resistance, and fruit yield (PennState Extension; Robinson, Fazio, Black, & Parra, 2015). Robinson et al. 2015 compare the growth, fruit yield, and fruit quality of Honeycrisp trees under different rootstock systems by two field trails. In the 2010 field trail, for example, yield efficiency data is collected among G. rootstocks, Malling rootstocks or M., and Budgovsky rootstock or B. The trial shows that Honeycrisp has the highest yield efficiency when grafting with medium vigor rootstocks. M. and B. rootstocks are usually the references (control genotypes) for evaluating the performance of new rootstocks because they are commonly planted in U.S. nurseries and orchards. M.9, released in 1912-1914, is one of the most popular rootstocks in the world because it performs well in soil adaptation, control of tree growth, productivity, and fruit quality (Spornberger, Schüller, & Noll, 2020). Developed and released in Russia in 1962, B.9. is popular for its performance in cold hardiness, productivity, and it is more fire blight resistant than M.9 (PennState Extension, 2018; Washington State University Tree Fruit, n.d.; Autio et al., 2017).

In recent years, new cultivars have become increasingly available and this has become a trend in the apple industry. “Variety development” and its market management have grown rapidly since 2008. According to Brown & Maloney (2018), 50 new apple cultivars have been released in the United States from 2009 to 2019. Efforts to introduce new apple varieties are underway around the world. These new varieties could offer better or novel taste and appearance for consumers because of the enhanced or transformed characteristics (Volk, et al., 2013).

Released in 1991 by the University of Minnesota, Honeycrisp has a total business value (encompassing all aspects of value and value to the world) of 250 million dollars from 2000 to 2010 (Volk, et al.). Moreover, Honeycrisp has the potential to be the most influential cultivar in the US and around the world as it is highly recognized by the market and has great financial returns (Embree et al., 2007). The sales of Honeycrisp have increased by 68% since 2014.

However, Honeycrisp's success, namely its unique taste, crispness, and aroma, comes at a price. According to Embree, the development of new varieties requires a balance between efficiency (crop load and other production costs) and fruit quality (e.g., color, flavor, etc.). Baugher & Schupp (2010) also agree with the statement that Honeycrisp is a variety that needs extra care, but fortunately additional care is covered by higher market prices. The cost of its superior market position comes not only from higher production costs due to the need for more care, but also from long payback periods due to low productivity, particularly in the first few years.

As a weak cultivar, Honeycrisp requires a rootstock that provides the right amount of vigor and nutrition type that includes an optimal potassium to calcium balance which reduces the incidence of bitter pit (a physiological disorder that blemishes Honeycrisp apples) (Fazio et al. 2020; Lordan et al. 2019). If it is combined with a weaker rootstock, the tree will be too small. If it is combined with a stronger rootstock, the tree will be too large and unproductive. Neither of these two situations optimizes fruit quality and fruit yield. In addition, like other weak scions, Honeycrisp is less resistant to bending stress than other cultivars, especially when they are young (Robinson et al., 2015).

As new apple cultivars become more popular, more attention is being paid to rootstocks that can improve yield and quality of fruits (Robinson, et al., 2011). To optimized the performance of apple orchards, rootstocks recommendations for different regions and soil and scion has been given (Robinson & Fazio, 2019). In addition, several popular cultivars, such as Jonathan and Honeycrisp, are more susceptible to fire blight and more vulnerable to infection. Therefore, it is even more critical to find the rootstocks that can help these new varieties resist fire blight and other diseases. Severe disease damage could result in years without a harvest (Beckerman et al., 2009).

In the current nursery industry, some have chosen to apply stool bed (SB) technology because it requires lower initial investment and simpler techniques. SB technology allows propagation of rootstocks in an environment that is not strictly controlled and do not ask for investment in big projects, such as lab and greenhouse. On the other hand, micropropagation (MP) technology has been adopted by some nurserymen because of its high productivity and attractiveness to the labor force. They recognize that MP technology could provide them with more rootstocks in a short period of time, even though MP technology requires more initial investment and more complex techniques. According to Gennaro Fazio, the rootstock breeder at the Geneva Experiment Station and professor in Cornell Horticultural department, it could be up to 10 times more than SB technology. This would be true in most case because the amount of the land is limited. But if the land used to build stool bed is large enough, SB technology can produce the same amount of rootstocks as MP technology. However, this is not a typical choice for a new enterprise because of the additional costs associated with purchasing or renting and managing the land.

Nurseries apply MP technology are more attractive to the workforce compared to those apply SB technology. MP technology is less affected by weather and seasons, so production will not be seasonal and the demand for labor will be more constant. The production of SB technology is seasonal and the demand for labor increases significantly in the spring and late fall. SB nurseries will hire part-time workers to meet the increasing workload, which is more cost-efficient than hiring full-time workers and the length of employment is usually no more than two months. However, for those looking for work, part-time work is less attractive than full-time work, all else being equal, which is why SB nurseries often face labor shortages or need to attract labor at a higher unit labor cost. Labor shortages during the busy season can result in a reduction in profits or loss of plants in the field, which can have serious consequences for the nursery. This problem is magnified by the impact of the epidemic, where the flow of labor around the world has been hampered by the COVID-19 and policy. The labor shortage is more pronounced in rootstock nurseries. In SB rootstock nurseries, production tasks are more concentrated in certain seasons, and the rest of the year requires minimal maintenance to allow the rootstock to grow naturally, so seasonal labor needs are evident. In SB integrated nurseries, production tasks are spread out over the seasons and the workload is heavy, so the demand for labor is steady throughout the year. Tasks in spring consist of taking care of bench beds and mailing products harvested the previous year to customers; tasks in summer are taking care of finished trees; tasks in late fall focus on harvesting both rootstock and finished trees from the field; and in winter they will sort and label harvested rootstock and finished trees.

In recent years, G. rootstocks have become increasingly popular. According to our interviews with nursery owners, about 60-80% of the orders are for G. rootstocks. This popularity of G. rootstocks is not only due to their ability to increase tree yields and excellence in resistance to insects (e.g., woolly apple aphid) and bacteria (e.g., fire blight), but also because they can establish stronger root systems and optimize branch growth (Fazio, Aldwinckle, & Robinson, 2013). Because of these advantages, G. rootstocks can be sold at slightly higher prices, both for rootstocks and finished trees.

Scholars in horticulture have published research related to rootstocks and the main topics include the evaluation of the performance of different rootstocks and scions, including yield monitoring. But those studies do not include the economic impact brought by different rootstock selection. For example, questions like profits that a nursery could earn on rootstock A versus rootstock B with the control of other inputs are not answered.

The core responsibilities of the nurseries addressed above, which include the selection of rootstocks and the matching of rootstocks with the appropriate scion in consultation with customers, are their value to the industry. But the nurseries themselves also have important things to consider when choosing a new rootstock to grow. For example, they are faced with the questions of choosing between being a rootstock nursery or an integrated nursery, and choosing to produce via micropropagation or stool-bed methods. However, it can be very difficult for people in the nursery industry to make these decisions because it is hard to foresee the economic differences caused by different business forms and production methods. At the same time, there is no current research to answer this question.

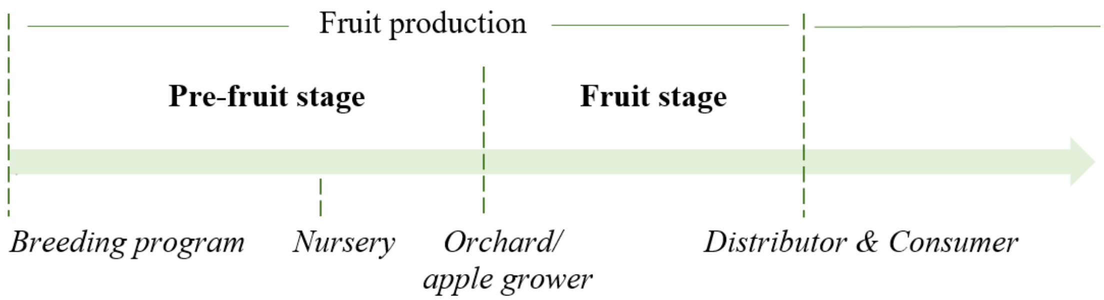
Although nurseries are integral parts of the industry, its influence is small compared to the fruit industry and their research needs rarely reach the other stakeholders, especially the research institutions. While orchard owners can influence nurseries' behaviors, nurseries' opinions and feedback are still very important. Ignoring what is happening in the nursery may prevent researchers from getting full-chain feedback in time, leading to confusion about the direction of future research. Researchers can understand how a particular type of rootstock performs in each form of nurseries and in each production method by the quantitative model. In addition to this, the factors affecting rootstock selection as revealed in my interviews can provide researchers with potential directions for rootstock improvement.

This paper would like to first emphasis the role of nurseries in the industry and demonstrate the needs to study the nurseries. In addition, we will examine the economic influence brought by two business forms and two rootstock production methods by NPV. Therefore, we could understand the nursery industry from a quantitative perspective. We will create models, which could be also called by customized tables, that readers could fill in the numbers that fit their situations to help them with the decisions such as which business forms to choose under the rootstock genotype chosen by readers.

A demo of systematic NPV analysis using G.41 as an example and customized tables that can predict the NPV and accommodate changes in key variables will be the primary tool to achieve these goals. The outcome of G.41 is a probability distribution, which is defined as USD per 20k rootstock liners for rootstock nurseries or one-year grafted trees from stool bed integrated nurseries or one-year grafted containerized trees from micropropagation integrated nurseries, instead of single values. This allows the NPV to capture fluctuations in costs and revenues. Due to its relative flexibility, the model can provide a quantitative reference for nurseries with different costs and efficiencies. An economic model that predicts the likelihood of returns will provide more confidence in the investor's decision. This is because typically there is uncertainty between investment and return. For example, fluctuations in the rootstock performance, production costs, and sales prices can all lead to changes in returns. The NPV probability diagram can provide the probability of obtaining a certain NPV and the factors affecting the NPV of that form of nursery and production method. The customized tables can catch changes in important factors, including variables that reflect the length of time required, and the success rate of the planting process, and automatically generate NPV or net returns.

To substantiate the claims above, we will first review past research to see what has been done in this area and what remains to be studied. We will then discuss the methodology using in the paper, which is the main content in Chapter 3. Chapter 4 will describe how we collect the data and how does the data look like. The results of the systematic NPV forecasting model and sensitivity test on G.41, as a demo, will be analyzed in Chapter 5. Chapter 6 will summarize the findings and further explain how to make use of the customized table. In addition, Chapter 6 will also include directions for further research.

Figure 1 Main players in the apple industry



Breeding program	*Nursery*	*Orchard*	*Distributor & Consumer*
Make innovations and release the rootstocks and scions	Get the licenses from breeding programs, produce rootstocks/apple trees, and sell to orchard owners	Purchase apple trees from nurseries, cultivate them, and harvest fruits	Purchase fruits from orchard owners

Figure 2 Five phases in stool bed propagation

Year 1		Year 2		
Early spring	Before winter	Early spring	Summer	Before winter
Phase 0 ***Preparation***	***Phase 1*** ***Growth***	***Phase 2*** ***Cut-off and growth***	***Phase 3*** ***Rooting***	***Phase 4*** ***Harvest***
Sterilize the selected original plant	Grow to ensure vitality and size of the original plant	Prune the original plant to the height of the ground leaving the "mother-plant" in the ground which will produce new shoots the next season	Cover the shoots partially with sawdust to produce roots	Cut and lift the stool out and separate the rooted shoots (called rootstock liners) from the mother-plant which remains in the ground to produce new rootstock liners for future seasons

Figure 3 Five phases in micropropagation

Phase 0 *Pre-selection & Treatment*	***Phase 1*** *In vitro transfer*	***Phase 2*** *Multiplication*	***Phase 3*** *Rooting*		***Phase 4*** *Acclimation*
Sterilize the selected mother plant	Cut off the explant and place it into correct media	The explant raises in the media for multiplication of shoots	Preparation: enhance the size of the shoots and root induction	Rooting: let in vitro culture rooted	Transfer the young rootstock into controlled green house

CHAPTER 2

LITERATURE REVIEW

2.1 Nursery production methods

Two different types of rootstock production methods are micropropagation and stool bed which will be reviewed in the following section.

2.1.1 Micropropagation

Micropropagation is a technology that produces plants from a small amount of tissue by generating micro-cuttings. Tissue-culture plants refer to the whole plant produced from this method. The shoot tip is ideal for micropropagation given that this section of the plant may have dividing meristematic cells with higher activity. Selecting and cutting a shoot top (explant) from a well-developed and virus-free mother plant is the first step for micropropagation. After the selection of an explant, the production will follow the five-stage process described in chapter 1.

A real-world decision on starting a nursery that produces rootstocks using the micropropagation technique (micropropagation nursery) will be influenced by initial investments (including infrastructures, procurement of raw materials, recruitment of talents), range of capacities, price of outputs, and family traditions. Before one decides to start a business in micropropagation, it is necessary to connect with local and national institutions for paperwork (Shukla 2008).

The techniques and principles of tissue culture production are constantly being improved and updated through the efforts of horticulturists. The advantages of micropropagation have been more widely recognized, such as its faster production of new rootstocks and better plant quality (Dobránszki and Silva 2010). A review in micropropagation synthesizes the studies of apple micropropagation over the last two decades. This includes recommended procedures for each stage of production, as well as ways to increase the number of shoots (Dobránszki and Silva 2010). Meneguzzi et al. (2017) study the protocols that are needed to develop a successful G. rootstock, G.814, when it was first introduced in Brazil. They had two parallel experiments in the multiplication stage and shoot generation stage. Different concentrations of Benzyl Amino Purine (BAP) have been used in the experiments. The relationship between the concentration of BAP and numbers of shoots, as well as the length of shoots, are revealed by graphs. It is shown that for successful propagation of G.814, the concentration of BAP in the multiplication stage is slightly lower than in the rooting stage.

Technology adoption is a complicated decision process and will be influenced by many factors. Besides those related to the technology, which refer to how the degree of difficulty of practical operation and profitability, good connection with the market, communication with research and public institutions, group effects, transportation, education, age, and health status will also have the impact on the adoption decision (L et al., 2004; Baerenklau, 2005; Timpanaro & Foti, 2016). However, it is difficult to predict whether people will adopt new technologies by qualitative research alone. Therefore, a quantitative study is needed to solve this problem.

2.1.2 Stool bed

Stool bed is a traditional vegetative method to propagate a stable and relatively good quality trees for orchard owners. This asexual propagation method has always been the first choice for many nurseries for its affordable cost. However, as the micropropagation technology has been well-studied, stool bed production has received less attention in the past ten years. When faced with a choice, nurseries may not know which approach is better for them or, more specifically, will bring greater benefits. To answer this question, a quantitative analysis is also needed.

2.2 Cost and economic analysis

Over the years, more interest has been growing in quantitative research to predict if new technology will be adopted (Kuehne et al., 2017).

Cost is a vital component of a business, especially for rootstock production. This is often the biggest concern for nurseries adopting micropropagation, even though the advantages of the technology are clear. One of the advantages of micropropagation is the ability to produce large numbers of plants in a relatively short period of time, which is ideal for today's ever-innovative world. Therefore, information on how much investment is required for micropropagation will be very important for those nurseries that have not yet made the transition.

Tomar et al. (2008) visualize the production volume of micropropagation through a two-year tissue culture production schedule recorded weekly. Among all the costs, labor accounts for the largest proportion and the second-year cost per plant is less than the first year, which is 20 percent less (Tomar et al., 2008). Another attempt at cost structuring is system engineering (Chen 2016). The components of systems engineering are the variables of each production phase. These variables will form the equation for the volume and cost of production at each phase in micropropagation. In addition to the conclusion that labor costs are the largest expense, Chen (2016) also examines the magnitude of the effect of different variables on costs. Essentially, it is a sensitivity test that examines the effect on the outcome by changing the target variable and holding the other variables constant. The ratio of the multiplication stage has the greatest effect on the cost. To be more specific, the higher the ratio, the larger the quantity produced, thus lower the unit cost.

Wannemuehler et al. (2019) examine the economic benefit and cost efficiency of breeding programs brought by marker assisted selection (MAS), which is a DNA-informed breeding technology. The study compares the costs incurred by using MAS technology and conventional methods from the University of Minnesota apple breeding program. The comparison is presented as total cost for both technologies. It turned out that the MAS method has a better cost-efficiency than the conventional one. To become more adoptable, given that breeding programs located in different locations could have very different costs, a sensitivity test was run to test how results change when using different inputs. The MAS model will be 18% cheaper than conventional methods, even though the critical costs in conventional methods (in this case, labor costs) are reduced by 20% due to automation.

However, these studies focus only on costs and do not include returns. Because we want to provide investors with quantitative information on how to make rootstock selections at different nurseries, this information needs to include returns prices and yields. The output of the study conducted by Buyukarikan & Gul (2014) is the net margin, which demonstrates a more complete picture of the nursery for us. The study analyzes economic performance of fruit tree nurseries in Turkey and the data is representative because they came from 50 certified nurseries in Turkey. Nurseries are categorized into three groups based on production capability. A subgroup analysis is conducted in each group, covering demographic and business aspects, which include the legal status of the nursery, age and education level of the owner, and the share of each fruit produced in the nursery. Besides the net margin per unit produced and absolute profit per decare (a measurement unit in Turkey corresponding to about 0.25 acres) in each group, the output also includes a series of questions on problems the nursery faced. It showed that a nursery with a larger size might have a better ability to gain profit. No matter the group, the two biggest concerns of a nursery are marketing and the root material supply shortage. However, the model in this paper did not take time and risk into account.

NPV, which is particularly useful in cases where there is uncertainty about inputs and outputs, incorporates the value of time, such as when determining if one should adopt alternative energy sources. In the single NPV analysis, projections of future revenue require making assumptions about key points, including labor costs, productivity, and revenue, which rely on previous data and professional knowledge. If there is not much data available, which is true in the apple nursery industry, skewness and bias in the reference data will influence the output to some extent. Therefore, it entails confirming whether past research and data are generally applicable. In addition, another problem with the single NPV approach is that it does not incorporate changes in production, policies, inputs, etc. In other words, the model has difficulty incorporating risk. The situation may arise when one variable, such as labor costs, changes and the model is no longer applicable. Gogic and Sanjin (2017) use sensitivity analysis in a way that accurately represents the risks that variables can pose, which is a more advanced version of the single NPV approach. In the sensitivity test, individual factors are analyzed to see how the NPV will change when this factor changes. Three sensitivity tests are applied in their research to rank the influential level of each factor. Nurseries in Serbia are divided into two categories by the ability to provide stable cash flow. Those nurseries that generate a steady annual income fall into the first category while those that do not have the ability are in the second category. After obtaining the NPV in a ten-year cycle for both nursery categories, sensitivity tests are conducted on three factors, which are initial investment, cash expenses, and revenue. The sensitivity tests take investment risk into account and conclude that nurseries with constant income are more risk resistant compared to constant expenditure. Applying the sensitivity test and NPV analysis, the results could not only give suggestions on the most profitable type of nursery in Serbia but also the least risky one.

A more advanced model is systemic NPV analysis following Bizimana & Richardson (2019). The study focuses on a farm simulation model that predicts the net present value, net profit, and household nutritional intake of farms in developing countries. The projection takes climate, market, and policy uncertainties into account through Monte Carlo simulations. The model predicts the production process over a 5-year period with pre-determined fluctuations based on historical performance, using probability distribution plots to show the distribution of variables such as yield, expenditure, and income. Richardson el at., (2007) further the discussion of Monte Carlo simulation by emphasizing its ability to describe the uncertainty, which is widely used in the study of economic feasibility. In addition, interval estimation can expose the risks that may be involved in the business compared to point estimation (single NPV). It delivers the probability that any specific NPV occurs.

The pre-determined fluctuations of the variables are largely influenced by the scion. This implies that there are different patterns among apple varieties. For example, different apple varieties may have different success rates in the field planting stage for a stool bed integrated nursery, indeed for rootstocks as well. Therefore, a NPV analysis either applies to only one variety or leaves some space to reflect varietal variation. Space is allowed for variety and rootstock selection in our customized tables, while Honeycrisp and G.41 are chosen as examples for systematic NPV analysis.

CHAPTER 3

METHODOLOGY

3.1 Production schedule

Before we move to the NPV analysis, we will discuss the production schedule that will be applied in this study. It is provided by Gennaro Fazio, the rootstock breeder at the Geneva Experiment Station, and is very close to a real production situation. It consists of two parts, a timeline in weeks and production steps. The genotype of the rootstock, like mentioned before, will affect the efficiency of each cycle in producing new shoots and the length of each cycle. Duration to produce a fixed number of plants will be influenced by the efficiency of the cycle, i.e., the more efficient it is, the shorter the time required. Thus, the production schedule will change with genotypes. This production schedule, using G.41 as an example, shows the length of time required to produce 20k plants for this genotype under both stool bed and micropropagation (MP) production methods with one original plant as a starting point. At the same time, it also shows the difference in the time and production steps required to produce the two different final outputs, the one-year tree and the two-year tree, although this part will not be explored in this study.

To produce 20k G.41 rootstock liners, MP production takes about 59 weeks and is broken into preparation phase (16 weeks), cycle production phase *8 (3*8weeks), and acclimation & growing phase (12 weeks). G.41 rootstock liner production via stool bed method takes about 59 weeks and is broken down into preparation phase (16 weeks), cycle production phase *8 (3*8weeks), and acclimation & growing phase (12 weeks). While stool bed (SB) production takes about 436 weeks and is broken into preparation phase (12 weeks) and cycle production phase *8 (48 weeks*8). To produce 20k G.41 one-year trees, we need to add grafting and grading in addition to the above. To grow a MP rootstock liner into a one-year containerized tree, it takes an additional 67 weeks which could be broken into grafting & transplanting phase (53 weeks) and harvesting & grading phases (14 weeks). To grow a SB rootstock liner into a one-year grafted tree, it takes an additional 48 weeks. The reason why the second stage takes so little time is that a SB nursery produces finished trees by yearly batches. Therefore, once a batch of rootstocks is produced, processed, graded, and stored, they can be bench-grafted (in February-April) and quickly transferred to the field to be grown, and harvested after one season. However, MP nurseries do not produce finished trees and rootstocks in batches; but rather produce enough liners from the same group and then transfer them to the green house for grafting and growth.

The customized tables that could be filled by readers will be built based on the timeline and production steps classified by the production schedule.

3.2 Economic analysis of nurseries

The calculation of the NPV consists of two parts: i) the sum of the cost in each year; and ii) the revenue generated at the end of year. This study takes the perspective of nursery operators or potential operators, and the simulated scenario is one in which these individuals make decisions about whether to adopt a new business form or about which production method should be adopted. Therefore, we will translate the costs and returns that occur in different years into year 1 to fit our simulation scenario.

Revenue is the multiplication of the simulated sales price, numbers of young finished trees planted per acre, simulated survival rate, and simulated percentage of sold.

Equation of revenue (Rev):

(1) $$\widetilde{Rev} = \tilde{P} \times N \times \tilde{R}sold$$

$\tilde{P}$ is simulated sales price per produced plant (rootstock liners for a rootstock nursery or one-year trees for an integrated nursery)

N is quantity of plants that produced (total numbers of rootstock liners or total numbers of one-year trees produced)

N is quantity of plants that produced (total numbers of rootstock liners or total numbers of one-year trees produced)

$\tilde{R}sold$ is simulated percentage of sold after the harvest

Cost is the sums of costs occur in year 1 (at the very beginning), year 2, and year k. For example, in the demo of G.41,

for SB integrated nurseries, k=9; for MP integrated nurseries, k=3;

for SB rootstock nurseries, k=8; for MP rootstock nurseries, k=1

Equation of total cost ($\widetilde{TC}$):

(2) $$\widetilde{TC} = \sum k\, \widetilde{C_k}$$

k represents for year k and

$\widetilde{C_k}$ is the simulated cost in year k.

Equation of net return ($\widetilde{Net}$):

(3) $$\widetilde{Net} = \widetilde{Rev} - \widetilde{TC}$$

Equation of total cost with time value for rootstock nurseries ($\widetilde{TC}t_r$):

(4) $$\widetilde{TC}t_r = \sum k \frac{\tilde{C}_k}{(1+r)^{k-1}} = \widetilde{C_1} + \frac{\text{Ccycle}}{r} \times \left(1 - \frac{1}{(1+r)^{k-1}}\right)$$

r represents for annual discount rate,

k represents for year k

$\widetilde{C_1}$ is the simulated cost in year 1, and

C_{cycle} is the costs for each production cycle.

Equation of total cost with time value for integrated nurseries ($\widetilde{TC}t_f$):

(5) $$\widetilde{TC}t_f = \sum k \frac{\tilde{C}_k}{(1+r)^{k-1}} = \widetilde{C_1} + \frac{\text{Ccycle}}{r} \times \left(1 - \frac{1}{(1+r)^{k-2}}\right) + \frac{\tilde{C}_k}{(1+r)^{k-1}}$$

r represents for annual discount rate,

k represents for year k

$\widetilde{C_1}$ *is the simulated cost in year 1*

C_{cycle} *is the costs for each production cycle, and*

$\widetilde{C_k}$ *is the simulated cost in year k.*

Equation of revenue with time value ($\widetilde{Rev}$t):

(6) $$\widetilde{Rev}\text{t} = \frac{\widetilde{Rev}}{(1+r)^k}$$

r represents for annual discount rate,

k represents for year k and

$\widetilde{Rev}$ *is the simulated revenue at the end.*

Net present value (NPV) is calculated by subtraction total cost from revenue:

(7) $$\widetilde{NPV} = \widetilde{Rev}\text{t} - \widetilde{TC}t$$

3.3 Formulation of critical variables in the customized tables

To build the customized tables that could capture the variations caused by rootstock genotypes and expertise, we will create formulas for critical variables, the numbers of production cycles required, length of times needed for production, and numbers of plants sold. The critical variables affecting the economic performance of the nursery will be expressed through formulas that are built on input variables. Input variables include number of initial plants (I), number of shoots produced per cycle or efficiency per cycle (E), success rate of acclimation in MP or rooted liner production in SB (S_1), and success rate of field or greenhouse growing (S_2). They affect the cost and NPV by influencing the production schedule. For industry professionals, these variables are relatively easy to obtain. For example, you can choose to use three initial plants to start the production. The critical variable will be estimated by substituting the input variables into the formula. This may give a more realistic NPV.

Equation of numbers of plants produced in the rootstock production ($\widetilde{Nr}$)

(8) $$\widetilde{Nr} = Np \times S_1$$

S_1 *is the success rate of acclimation in MP or rooted liner production in SB*

Np *is the numbers of rootstock liners that plan to have*

Another equation of numbers of plants produced in the rootstock production ($\widetilde{Nr}$):

(9) $$\widetilde{Nr} = I \times \widetilde{E^n}$$

$\widetilde{E^n}$ *is simulated numbers of shoots that could be generated in all production cycles, where E is numbers of shoots that could be generated per cycle,* n *is the numbers of production cycles required*

I is the number of initial plants

Equation of numbers of production cycle required (n):

(10) $$n = \log_E \frac{\widetilde{Nr}}{I}$$

(11) $$\widetilde{Nr} = I \times \widetilde{E^n}$$

(12) $$\widetilde{Nr} = Np \times S_1$$

(13) $$Np \times S_1 = I \times \widetilde{E^n}$$

(14) $$n = \log_E \frac{Np \times S1}{I}$$

E is numbers of shoots that could be generated per cycle, n *is the numbers of production cycle required*

Np is target the numbers of rootstock liners needed for the finished tree nursery stage

S_1 *is the success rate of acclimation in MP or rooted liner production in SB*

I is the number of initial plants

Equation of length of times (in weeks) needed for production cycles ($L_{production}$):

(15) $$L_{production} = n \times L_{cycle}$$

n is the numbers of production cycle required

L_{cycle} is the length of time (in weeks) needed for each cycle

Equation of length of times (in weeks) needed for whole rootstock liner production ($L_{rs\ total}$):

(16) $$L_{rs\ total} = L_{before} + L_{production} + L_{grow}$$

L_{before} is the length of time (in weeks) needed for stage before the production, will be different from SB to MP nurseries but less affected by the numbers of production and rootstock genotypes,

which is 16weeks for pre-stage in MP nurseries, and

12weeks for build-up stage in SB nurseries

$L_{production}$ is the length of time (in weeks) needed for production cycles

L_{grow} is the length of time (in weeks) needed for grow stage, will be different from SB to MP nurseries but less affected by the numbers of production and rootstock genotypes,

which is 17weeks in MP nurseries, and

0weeks in SB nurseries.

Equation of length of times (in weeks) needed for whole one-year grafted trees/ containerized trees production ($L_{integrated\ total}$):

(17) $$L_{integrated\ total} = L_{rs\ total} + L_{tree}$$

L_{tree} *is the length of time (in weeks) needed for tree production stage, will be different from SB to MP nurseries but less affected by the numbers of production and rootstock genotypes,*

which is 68weeks for MP nurseries, and

($L_{rs\ total}$ *+48) weeks for SB nurseries.*

Equation of numbers of one-year containerized/one-year grafted trees produced ($\widetilde{NI}$):

(18) $\widetilde{NI} = \widetilde{Nr} \times S_2$

S_2 is the success rate of field or greenhouse growing and

$\widetilde{Nr}$ is the numbers of plants produced in the rootstock production.

3.4 Practical steps for G.41 example

To give the readers a more intuitive understanding of how nurseries operate under different production methods and different business models, we will present G.41, a common rootstock genotype, as an example.

Because the example is expected to simulate fluctuations in production elements, such as labor costs that may fluctuate within a range, we will use Nursery-level Monte Carlo simulation for systematic NPV analysis, as well as sensitivity tests for each production element. Note that some factors affecting nursery profitability, such as rootstock genotypes, will not be explored in this example because G.41 was chosen for the case. However, we will discuss the influence of these factors in the customized tables.

We will introduce how the example is performed in two parts, first from the systematic NPV analysis and then from the sensitivity analysis. Both analyses will be performed four times for MP rootstock nurseries, SB rootstock nurseries, MP integrated nurseries, and SB integrated nurseries.

3.4.1 Systematic NPV analysis

One of the important features of systematic NPV analysis is that it can reflect the uncertainty caused by different regions and times. To capture this uncertainty, researchers use simulation analysis to examine situations with uncertainty and is also ideal for measuring the profitability of nurseries, where production and sales involve different levels of uncertainty.

We have adopted this idea in our study and the steps to perform the systematic NPV analysis are described below. The first step is to build up a baseline for Monte Carlo simulations. The baseline built includes all the costs and earnings of producing and selling plants that will be described in chapter 4. The second step is the addition of Monte Carlo simulations to the baseline (in our study, we used @Modelrisk for the analysis, an Excel add-on). Step three is to run the simulation where the number of samples is set to 10,000, which is the maximum number of simulations in @Modelrisk. The fourth step is to generate graphs and data, which allows the visualization of the results. The graphs include cumulative probability of NPV and ranks of variables. The data generated are a descriptive summary of NPV.

3.4.1 Sensitivity test on key variables

Our study will examine the importance of each variable on NPV. The assumption that the data needs to be bivariate normally distributed is not satisfied. Thus, this study does not apply Pearson's correlation, although it allows a more precise measurement on the relationship between two variables. Coefficient generated in our study describes if attribute is monotonically correlated with the NPV, and if it is negatively or positively correlated. Moreover, the ranking of an attribute could quantify the relationship between the attribute and NPV.

In the Spearman's correlation, the correlation coefficient of two variables ranges from 1 and -1. These numbers indicate, respectively, a strong, positive relationship and a weak, negative relationship between the variable and NPV. A value of 0 indicates that there is no monotonic relationship between the variable and NPV; however, other kinds of relationships could be happening between the variables, such as quadratic. A monotonic relationship implies that two variables will increase or decrease together at the same time. We will not perform a cause-type analysis because the ranking test is not one that demonstrates causality. The outcome of the test explains the strength and direction of the monotonic relationship, rather than a numerical linear relationship. After obtaining the correlation coefficient, we could then conduct Student's t test to check if the Spearman's correlation is statistic significant or not,

$t = \rho\sqrt{\frac{n-2}{1-\rho^2}}$, where ρ=correlation, n=numbers of sample

CHAPTER 4

DATA AND SURVEY DESIGN

In this section, we will discuss about data collection and present the scenario we choose as an example. Data from different business models, both rootstock nurseries and integrated nurseries, will be discussed and presented. In each type of business models, the following topics will be covered: primary data from field studies or interviews and secondary data from expert interviews, past studies, or industry sources.

4.1 Data from rootstock nurseries

As mentioned earlier, there are two different methods for rootstock production, known as micropropagation and stool beds, which require very different types of costs.

4.1.1 Data from micropropagation rootstock nurseries

We had interviewed two industry experts who have first-hand experience in micropropagation production.

4.1.1.1 Primary data for micropropagation rootstock nurseries

As it is difficult to find publicly available data from the nursery industry in the United States, we will collect primary data from the U.S. nurseries. In addition, as we use G.41 as an example, the nurseries contacted need to be users of G.41.

The first source of data is from the Geneva breeding laboratory. Although it may differ from commercial micropropagation nurseries in terms of efficiency and production stages because of its research nature (e.g., there are no sales and marketing costs in the laboratory), it can still provide a reliable reference. This knowledge includes, among other things, the actual cost structures, and the details about apple rootstock micropropagation (except the costs associated with marketing), the way costs are collected (for example, collect by day, by week, by plant). The Geneva breeding laboratory is in Geneva, NY and is run by horticultural experts.

The second source of data is a micropropagation rootstock nursery that has over 10,000 square meters for its lab. To find nurseries willing to be interviewed and provide data and insights for micropropagation, we sent emails to 3 micropropagation rootstock nurseries from the list of firms that work closely with the Geneva-rootstock breeding program. The first email included a few questions about micropropagation. This email was general and less complicated compared to the second email sent. One of the nurseries wrote back and we sent a second email which introduced the project in much more detail. This nursery was the main subject for the interview. The propagation business at the nursery includes not only apples, but also other fruits, nuts, and trees. It provides over 10 million rootstocks per year to its customers. This high productivity is a typical characteristic of micropropagation rootstock nurseries. Almost all their business comes from the wholesale market.

We made use of a tabular approach for the interview with the Geneva breeding lab. Moreover, we design a cost framework based on the production phase of micropropagation as an outline for the interview to have a more structured interview. The cost structure includes stage 0, plant selection and pre-treatment, stage 1, establishment of in vitro culture, stage 2, shoot multiplication, stage 3, rooting of micro shoots, and stage 4, acclimatization. Based on what has been mentioned earlier, different tissue culture nurseries may have different classifications for the stages of production.

Micropropagation in a lab does not have a particular stage for pre-treatment. Annual volume of rootstock liners produced is about 10,500 (10.5k) for the Geneva breeding lab. The Geneva breeding lab collects the cost by year instead of stages of production (year 0 to year 3). The rooting method applied in the lab is ex-vitro, indicating that explants will be placed into the field after getting the shoots. In each year, the stage covered and the cost category might be different. But no matter which year or stage it is, the costs are recorded in unit cost, quantity needed, year of use. Year 0 is the build-up process. Year 1, which is stage 1 and stage 2, covers the production cost in the lab. Year 2, which is stage 3 and stage 4, includes field operation cost given that the rooting and acclimatization process for Geneva breeding lab happen in the field. There is no concrete data on administrative and harvesting costs, given that the lab is for research rather than business. Although the laboratory does not include field production and harvesting, the field construction costs, field operation costs and harvesting construction cost estimates are based on educated guesses. Labor cost is calculated by adding unskilled, skilled, and management labor collected in stage 1 to stage 4.

Data of the micropropagation rootstock nursery are collected via a survey. Before the survey, an interview on the knowledge and insight is gathered. From the pre-survey interviews, we realized that for commercial nurseries, collecting data by broad cost categories is easier than by year or stage. The broad cost categories here refer specifically to equipment costs, electricity consumption, chemicals, glassware, administrative fees, and labor. As costs are calculated per individual plant, we can find the production cost per plant after obtaining the production volume corresponding to the collected cost. Due to the complexity of cost calculation, the following work is prepared in addition to the pre-survey interviews to assist the interviewed nursery in sorting out ideas and unifying units when calculating costs. The ideas of cost calculation are organized through the study of Tomar et al. (2008). For equipment, individual price, years of serviceability, and quantity needed information will be gathered. For electricity, the calculations are based on the amount of electricity consumed per hour per device, the number of hours per day per device, the number of days per year per device, and the number of devices required. For chemicals, administrative, and labor expenses, there is no breakdown and the calculation is based on the unit expenses and the quantity needed for a year. These are the costs required to produce 120k rooted plants.

The format of data filled in by the micropropagation rootstock nursery is different from the format of pre-designed sheet. The major difference is that the interviewed nursery does not break down the cost in such a detailed format. Costs in the micropropagation rootstock nursery are divided into two categories that are labor cost and non-labor cost. Within the labor costs, there are three types of labor, which are skilled labor, unskilled labor, and management labor. Within the category of non-labor cost, utility, chemical, glassware, equipment and depreciation, administrative, and other costs are included.

4.1.1.2 Secondary data for micropropagation rootstock nurseries

Expert interviews are also an important data source for our study. Expert's opinions come from Gennaro Fazio (USDA ARS), the rootstock breeder at the Geneva Cornell AgriTech Campus who has initiated several projects relating to micropropagation of apple rootstocks with commercial partners worldwide.

The Excel sheet is created with possible costs to each production stage based on the production schedule that is described in chapter 3 prior the expert interviews. Five stages are included in the Excel, which are build-up phase, phase 0 pre-treatment, phase 1-3, phase 4 acclimation, and phase 5 growth. Just like the production schedule, phase 1-3 are repeated for 8 multiplication cycles (8 times) to get 20k plants from three explants and “cycle” is used to represent each repetition. In this case, we will have cycle 1 - cycle 8. Build-up phase is divided into six types of costs, that are lab build-up costs, green house build-up costs, road build-up costs, other build-up costs, lab temperature & infrastructure build-up costs, and green house temperature & infrastructure build-up costs. Phase 0 is divided into three types of costs, that are equipment costs, raw material costs, and labor costs. Each cycle will have six types of expenses, that are equipment used, electricity used, chemical used, glassware used, other minor materials used, and labor used. Each cycle takes 21 days, or three weeks. The next cycle will start at the end of the previous cycle, making a total of 168 days or 24 weeks for the 8 cycles. Phase 4 and 5 are divided into similar sub-costs, that are equipment, electricity, chemical, glassware & pots, and labor. Expert’s opinions are collected via interviews and emails. The total cost of producing acclimated plants is obtained but there is no break-down available. At the end of the production, price range of 10-inch-tall rootstock liners are also collected. Because primary data are available for MP rootstock nurseries, and it has more details, we will mainly refer to the primary data in our cost analysis for MP rootstock nurseries.

To further improve the representation of the data, we also gather data from the nursery website.

For the revenue side, besides of the secondary data from expert interviews, we also try to collect data from the website of nurseries. In 2022, there is no price list available publicly and the purchase order and price are only available via form-filling. In this case, we may have to use the price list published on the website in 2021 as a reference. In 2021, we got a price list from the North American Plants nursery that is in Oregon, although this price list was not marked with a specific time point or heights or grades of the rootstock liners (our customized tables and production schedules for MP rootstock nurseries are based on the production of products with a height of 10 inches). According to the website, there is a list of products related to G. rootstocks, namely G.11, G.202, G.210, G.214, G.222, G.41, G.890, G.935, and G.969. Since the example used is G.41, we will only extract the sale price of G. 41. Different volumes of order, as well as different sizes of the rootstocks will be priced differently. According to it, the larger the order is, the lower the unit price will be. Similarly, rootstock size is used as a pricing variable as well. The price is arranged by those two variables. The medium rootstock is defined as 50/flat and the large rootstock is defined as 32/flat. There are 5 levels of ordered-size, and they are <1,000 plants, 1,000+, 10,000+, 20,000+, 50,000+. The only filter applied in the quotation table is the order volume. Because this study is conducted on nurseries that sell wholesale, we only collect prices for rootstocks where the order volume exceeds the wholesale volume threshold. The cut-off point for wholesale is set to 1,000. It is calculated by the percentage of changes of units between levels. The level with the largest percentage of changes ought to be the cut-off point for wholesale. The unit price for 1,000-quantity is about 42 percent less than a 100-quantity order. The unit price for 10,000-quantity is about 4 percent less than a 1,000-quantity order. The unit price for 20,000-quantity is about 4 percent less than a 10,000-quantity order. The unit price for 50,000-quantity is about 4 percent less than a 20,000-quantity order. From the results, we could see that there is a special discount for customers that order 1,000+ rootstocks. Therefore, we have extracted prices for the case where the order is 1,000+. There will be royalty fee for each G. rootstock sold that is $0.25/rootstock.

4.1.2 Data from stool bed rootstock nurseries

Although we did not hear back from corresponding nursery, we conducted interviews with experts to understand the costs and performance of stool bed rootstock nursery. In this case, we only have secondary data.

4.1.2.1 Secondary data for stool bed rootstock nurseries

Just like micropropagation, expert interviews are a critical secondary source for the study and Excel established is the guideline for the interviews (sheet-based interviews). For stool bed rootstock nursery, three stages are included, which are the build-up phase, phase 0 pre-treatment, and production phase. Similarly, with micropropagation rootstock nursery, the production phase will be calculated by cycle, composed of 8 cycles in total, to obtain 20k plants. Build-up phase is divided into four types of costs, that are temperature & infrastructure build-up costs, land preparation costs, road/aisles build-up costs, and storage build-up costs. Phase 0 is divided into three types of costs, that are labor costs, irrigation costs, and fertilizer costs. Each cycle will have four types of expenses, that are labor (including harvest & grading) used, irrigation fees, sawdust and soil used, and fertilizer used. Each cycle takes 9 months. The next cycle will start 3 months after the end of the previous cycle, mainly because of temperature limitations. Thus 8 cycles will take a total of 8 years. Based on an expert point of view, the process of stool bed liner production can be divided into build-up & pre-treatment and production cycles. The pre-treatment process is so minor to the overall production process that its cost is negligible. Costs per production cycle are divided into labor costs and material costs. Material costs for each production cycle include irrigation, sawdust, fuel (energy), fertilizers, and pest management.

We also collect online information. We understand from expert interviews and field research that the states of Washington and Oregon are major producers of rootstocks in the United States due to closeness to market, growing conditions and price advantages. As one of the largest nurseries who has its own stool beds in WA, Willow Drive nursery is chosen as a reference for the price of rootstock liners produced in stool bed technology. They released a price list for per-bud apple trees on their website in 2017. In 2020, a price list of post-bud apple trees was available but not for pre-bud apple trees. Pre-bud apple trees refer to the apple rootstocks, and the post-bud apple trees are the finished apple trees that are ready to sell to the orchard. The purpose of citing this data is to find out the earnings for stool bed rootstock nurseries, which are pre-bud plants, so we refer to the rootstock price list for 2017. Willow Drive nursery grades and prices rootstocks by three dimensions: variety, size, and order quantity. The price may be varied for different varieties with the same size and order quantity; for example, in the case of size and order quantity of 1/8 inch and 10,000 respectively, the price of G.11 is $0.869, while M9-337 is $0.739. It is easy to understand the size of rootstocks, under the same conditions, the larger the size the higher the price, such as when the order quantity is 10,000, the price of G.11 in 1/8 ich and 3/8 ich is $0.869 and $1.255 respectively. In the rootstock price list from Willow Drive nursery, BUD 9, BUD 118, EMLA 26, and EMLA 206 are classified as STANDARDS. M9-337 and M9-NIC29 are classified as M9 clones. G.11, G.41, G.202, G.210, G.890, and G.935 belong to the G.

series. Given that we are using G.41 as an example, we are going to refer the price of G. series. As explained previously, all the quotation will be collected if its order volume exceeds the wholesale volume threshold where 1,000 is set to be the threshold. For Willow Drive nursery, the unit price for an order volume of 1,000 to 10,000 is about 37% cheaper than for an order volume between 100 to 1,000 plants. The unit price for orders between 10,000 to 50,000 plants is about 5% cheaper than that for orders between 1,000 to 10,000 plants. It indicates that orders of 1,000 or more will enjoy wholesale prices. Also, inflation needs to be considered to obtain the nominal sales price for 2021. Sales price in 2021 could be the results of different factors, such as demand in the market, the improvement of production efficiency, overall quality of the products, and so on. But the impacts from those factors require a separate study in the attributes for the nursery market; here we simply refer to the CPI index from U.S. Bureau of Labor Statistics to determine the inflation rate.

4.2 Data from integrated nurseries

A more vertical type of business is the integrated nursery and is the second type of nursery that we are going to look at. From the expert's perspectives, which will be discussed later, costs for integrated nurseries are divided into rootstock production stage and field tree production stage regardless of the methods applied. In this case, an integrated nursery can be equated to the sum of the rootstock and tree nurseries, by simply removing sale that occurs at the rootstock nursery and the expense of purchasing raw materials at the tree nursery. We only received responses from rootstock nurseries and tree nurseries, but not from integrated nurseries. Therefore, primary data for complete nurseries in this paper will be obtained by combining primary data from tree nurseries and rootstock nurseries. We will integrate expert interviews with relevant data we find online in our secondary data analyses.

As we have discussed both primary and secondary data in rootstock nurseries previously, we will start this subsection by discussing the data sources for tree nurseries, both primary and secondary.

A tree nursery in the United States has two different types given by its size. The first one is the boutique nursery, which is mostly family-owned. The other type is a commercial nursery, which has more hired workers and more modern equipment. Most of the trees in boutique nurseries are sold to individuals and production scales are generally small. The difference between boutique nurseries and commercial nurseries is that boutique nurseries have a large percentage of business from individual buyers, whose purchase orders are defined as under 1,000 finished trees. Size is not the marker that distinguishes boutique nurseries, while many of them have this characteristic, some have a production scale of fifty acres or more. The ratio of boutique nurseries to commercial nurseries in the U.S. is 1:4.

4.2.1 Primary data for integrated nurseries

4.2.1.1 **Primary data for tree nurseries**

Because no email was received about micropropagation tree nurseries, we only have primary data from stool bed tree nurseries. There are very few nurseries who choose to only be in the micropropagation tree nursery business. Most of them are either in rootstock only business or are in integrated-chain business. In here, micropropagation tree nursery is discussed as a component of micropropagation integrated nurseries. Stool bed tree nurseries, however, are likely to choose between these three different types of business models.

4.2.1.1.1 Primary data for stool bed tree nurseries

Through several in-depth interviews with Gennaro Fazio, our study identified a list of tree nurseries that have adopted G. rootstocks. We make use of the information on their website to find an email address that we could contact.

The number of nurseries in the United States is not as large as the number of orchards, because the production volume of nurseries is high and production is more concentrated. There are about 100 nurseries in the Unites States. Most of them are in one of the three traditional areas of apple production, the Northeast (New York and Pennsylvania), Northwest (Oregon and Washington States), and the Pacific (California). The number of stool bed tree nurseries that meets our criteria and has an available contact is about 50. The contact information for five out of the 50 is incorrect and of the 45 with correct information, two agree to participate in the study, so the response rate is about 4 percent. The first nursery interviewed is in the Northeast of the United States, with a size of 60 acres. Revenue from wholesale accounts for more than 80% of the total revenue. Therefore, this nursery could represent the industrial nursery market. Also, it has many other advanced and innovative technologies, such as the green land-rest plan. This is a land-rest plan where the land rests every two to three years. During the rest period, the nursery plants greens that add nutrients to the land, such as vegetables. After several harvests, rootstocks will be replanted into the land.

The second nursery is also located in the Northeast. This nursery has two parts, one for the orchard and pick-up business and one for the nursery business. The size for the nursery is less than half of its total size, about nine acres. Some of its nursery business, although relatively small compared with that from orchards, comes from individual buyers, such as people who plant in their backyards. Thus, it has the features of a boutique nursery although it is of middle size.

Both nurseries provide different fruit finished trees to customers, from peach to apple. Within each fruit category, both nurseries have various varieties and rootstocks available. The two nurseries represent exactly two types of nurseries in the U.S. apple industry, which makes the findings of this study somewhat more informative and applicable. This generalization makes it easier and more specific for other nurseries to learn from the results of this study.

4.2.1.1.1.1 Survey design

The objective of the survey is to collect price and yields for stool bed tree nurseries producing G. rootstocks; this study is also interested in the attributes that will influence rootstock selection. To fulfill these purposes, we created a survey to collect data from each nursery that is shown in Appendix A. The categories of production costs are drawn from interviews, Mon & Holland, (2006), and Popp et al., (2016).

The survey consists of eight parts. The first component of the survey covers background information about the nursery, such as its size, location, and the length of time they have been in business. This is to ensure that NPV analysis is not be biased or skewed because of lack of experience in nursery activities. Information on nurseries' size allows for normalization of a unit size since not all inputs are be calculated in acres. Parts II to VII is the second component in the survey, which is for the core mission of cost-analysis.

They are ranked according to the time order of costs and returns associated with growing finished trees, from the initial investment to the revenue.

Part II is about the initial investment and the costs incurred before planting, including land preparation cost, build-up cost, and capital interest ratio. Part III is the establishment cost, where all costs are incurred when planting rootstocks, including the labor required and material cost. Although material costs will not be reflected in the integrated nurseries, we still include this cost to create a complete logic for tree nurseries. Tree nurseries, in most cases, will buy rootstocks from other nurseries; therefore, material cost is also the sales price of rootstocks. In this study, we are interested in G. rootstocks, or to be more specifically, G.41. For the labor required in each production stage, it is very hard for the interviewees to answer questions like labor cost per tree or per acre at the time of planting. In order to make it easier for the respondents to answer, we identify the labor cost at the planting stage in an indirect way, asking questions such as: How many minutes does it take to plant a tree? How many trees can a worker plant in one hour? What do you think is the difference between full time and part time in terms of work speed? The later sections of the survey cover the hourly wage and how many trees can be planted per acre, so the labor cost at the planting stage per acre can be calculated by dividing the number of trees planted per acre by the number of trees planted per hour and multiplying by the wage.

The contents of Part IV and Part V complement each other. Part IV is the yearly management cost, which covers the time between the moment after the planting is completed and before the harvest, including irrigation, sawdust, and labor costs. Part V focuses on the yearly overhead cost, which is the administrative cost, utility cost, and online inventory management cost. The content of Part VI is the cost related to the harvest, from grading to shipping, including labor required and shipping cost. Part VII is revenue related, including price per tree, survival rate, and percentage of trees sold. Costs are calculated by acre and the unit for the revenue portion is a tree. In order to facilitate the calculation of the NPV, this study assumes from the expert interviews that 10,000 trees are produced per acre.

In addition to the data section, the survey includes nurseries' preferences when adopting new rootstocks. To explore their preferences, the question "What factors do you consider when deciding whether to adopt a new rootstock?" is posed. To make this question more specific, seven factors are proposed in this study, and for each factor respondents will choose a number from 1-5 to rate the importance of that factor (1 being least important and 5 being most important). The level of importance among different factors could be the same. The influencing factors listed are: survival rate, ease of maintenance, market response, economic gain, ease of access to information on new varieties, sensitivity to viruses, yield, and family tradition or custom. To give respondents opportunities to submit additional thoughts, the questionnaire added the question of whether there are other factors that influence the respondent’s decision.

4.2.2 Secondary data for tree nurseries

This section will discuss two methods of collecting secondary data, one of which is expert interviews and the other is online information.

4.2.2.1 Secondary data for micropropagation tree nurseries

We designed a table based on the production process for the interviews. The table has two parts: the grafting & transplanting stage followed by the harvest & grading stage.

The grafting and transplanting stage takes about 44 weeks and includes the following costs: equipment cost, electricity cost, chemical cost, sawdust and soil cost, glassware cost, pots cost, scion cost, and labor cost. The harvest and grading stage takes about 22 weeks and also includes the costs for equipment, electricity, sawdust and soil, glassware, pots, and labor, as well as administrative costs. According to the expert opinions, the production process for one-year containerized trees made by micropropagation plants is complicated and requires at least two transplant operations. It would be hard to estimate the costs by stages and break-downs. Therefore, the grafting & transplanting stage and harvest & grading stage are merged and there is no subcategory cost available.

The wholesale price for one-year containerized trees produced in micropropagation nurseries is not released online. From our interviews, we learned that the wholesale price will be influenced by the size of the order and the grade of the trees. We inquired about wholesale prices for orders of more than 1,000 trees in the interviews. The price is expressed in intervals.

4.2.2.2 Secondary data for stool bed tree nurseries

As for expert interviews in other cases, a table that describes production process was built. In line with the production schedule discussed in the previous chapter, there are also two stages for each cycle, namely the grafting and growing and the harvesting and grading stages. The first stage takes nine months and the second stage takes three months. The sub-categories of the first stage include the following costs: preparation costs, utility costs, sawdust and soil costs, fertilizer costs, scion costs, irrigation costs, equipment costs, and labor costs. The sub-categories of the second stage include the following costs: administrative costs, online inventory management costs, and labor costs. Each cycle in stool bed tree nursery will take place after the harvest of the liners of this cycle. In other words, the production of the second set of liners is accompanied by the grafting and growing of the first set of liners. The entire process consists of eight cycles. According to the interviews, two stages in stool bed tree nurseries are merged into one and the sub-costs are labor costs and material costs (land preparation cost, utility costs, soil and sawdust, fertilizer cost, scion, irrigation costs, and equipment cost). Sales prices were derived from the two nurseries that were interviewed. Both nurseries have very similar formats of price data online, with prices broken down by order size and by the ranking of finished trees. The breakdown of order volume gives an indication of a nursery's primary clients. Compared to a typical wholesale-nursery, the smaller nursery offers more room for individual customers, as it has options for order sizes 1-19 and 20-49, while the minimum order posted by the bigger nursery (as presented in the price list) is 50-100. To screen out individual buyers, we only collect sales prices for orders of 1,000 or more. There is a uniform standard in the industry for the grading of the finished trees. The grade varies according to the diameter of the tree and the number of branches. For example, the two nurseries have similar definitions of the 1st and the 2nd grades: those with a diameter of 3/4 inch or more and multiple branches are 1st grade, those with a diameter of 1/2 to 5/8 inch and branches are 2nd grade. Finally, Honeycrisp does not have a markup given that it is not one of the varieties with an extra markup (Roseland Red Honeycrisp and Royal Red Honeycrisp are the varieties that require an extra markup). The primary source of data for the sales price of finished trees is the values provided by two nurseries for order volumes of 1,000+, regardless of grade.

Secondary data are also used in the sales price. Van Well Nursery, a WA nursery with high productivity, is the reference for the sales price of finished trees. There are three different components for the sales price: base price, surcharges of rootstocks, and surcharges of variety; it is the same for different varieties, but there will be different surcharges for different rootstocks. Specifically, the surcharge for finished trees with Geneva rootstock is $1.50 per rootstock, while the rest of the rootstock will be charged an additional $0.40. For post-bud apple trees, the variety grafted also affects the amount of additional costs. Furthermore, additional fees are not part of the royalty fee; royalties are included in the base price. Sales prices posted on the website in 2021 also varied depending on the order and the size of the plant. The volume of order also influences the price of the rootstocks. There are four volumes of order in the price list, which are 50 trees, 500 trees, 2,500 trees, and 5,000 trees. The cut-off point for wholesale is 2,500. For finished apple trees, the unit price for 500-quantity is about 2 percent less than a 50-quantity order. The unit price for 2,500-quantity is about 6 percent less than a 500-quantity order. The unit price for 5,000-quantity is about 2 percent less than a 2,500-quantity order. There is a special discount for orders that are over 2,500 trees. The prices that are in the category of 2,500+ will be extracted for the study. Moreover, since the royalties are included in the price listed on the website, we found that the royalties are quite stable, therefore a $0.25 royalty is deducted from the G. rootstocks and the other variety of rootstocks do not have a royalty fee. Therefore, the price per rootstock sold is obtained from Van Well Nursery will be calculated as follows: the base price minus royalties if any and then plus the surcharges accordingly.

4.2.3. Summary in data collection for integrated nurseries

Combining primary data from rootstock nurseries and secondary data from tree nurseries, we can map out a general picture of the micropropagation integrated nursery. Producing 20k grafted one-year trees takes about 125 weeks and the production process is divided into the following stages: the build-up stage, pre-stage, production stage (which has eight cycles), acclimation stage, growth stage, and grafted & transplanting & harvest stage.

The profile of the integrated stool bed nurseries will be obtained by patching the secondary data from the rootstock nurseries and the primary data from the tree nurseries. Producing 20k grafted one-year trees takes about 432 weeks and the production process is divided into build-up stage, pre-stage, production stage (has eight cycles), grafted & growing stage, and harvest & grading stage.

4.3 Data description

4.3.1 Rootstock nurseries

4.3.1.1 Micropropagation rootstock nurseries

Before I describe the results of an analysis of all relevant costs and revenues in the micropropagation rootstock nurseries, the sources of data should be specified. Data related to the costs come from interviews with the Geneva breeding laboratory and a micropropagation rootstock nursery producing tissue culture plants, while data related to the revenue come from expert interviews and the website of a typical micropropagation rootstock nursery.

Table 1 shows the costs and returns of producing 20,000 G.41 rootstock liners in micropropagation technique.

4.3.1.1.1 Build-up cost

According to the Geneva breeding laboratory, nine different build-ups will be needed to produce tissue culture plants, including lab and green house. They are categorized according to five types: lab build-up, lab temperature & infrastructure build-up, other lab build-up, green house temperature & infrastructure build-up, and green house build-up costs. We refer to the road build-up costs in the tree nursery in here. There will be five types of costs in total. The details are shown in table 2.

The study applies a straight-line depreciation method to calculate the amount of depreciation in each year. The costs to produce 20k rootstock liners are obtained by dividing the costs for 250k rooted plants by 12.5.

4.3.1.1.2 Equipment cost

The equipment cost will be depreciated at a rate based on the straight-line depreciation method. The Geneva breeding laboratory has 19 sub-costs in 2021, as shown in table 3. The details of equipment cost in the interviewed rootstock nursery are not known but we know that it counts for five percent of its total cost. Equipment costs are in the range of $188.38 and $468.75.

4.3.1.1 Stool bed rootstock nurseries

Data related to the costs and success rate come from expert interviews and data related to sales price come from the website of a typical stool bed rootstock nursery.

Table 4 shows the costs and returns of producing 20,000 G.41 rootstock liners using the stool bed technique.

4.3.2.1 Price list of SB rootstock liners

We use 23 price points in the material cost of producing G. rootstocks. The maximum value is $1.45, the minimum value is $0.85, the mean is $1.19, and the standard deviation is $0.17. The details of the material cost data are shown in table 5.

4.3.2 Integrated nursery

4.3.2.1 Micropropagation integrated nurseries

Table 6 shows the costs and returns of producing 20,000 G.41 one-year grafted trees using the micropropagation technique.

4.3.2.2 Stool bed integrated nurseries

Table 7 shows the costs and returns of producing 20,000 G.41 one-year grafted trees using the stool bed technique.

4.3.2.4 Discount rate

The discount rate is set to be five percent.

4.3.3 Summary

We will briefly discuss the preliminary results from three perspectives, one from the perspective of production methods, the second from the perspective of business forms, and the last from the perspective of speed of response.

The SB method seems to perform better economically than the MP method in integrated nurseries. Although the costs of SB integrated nurseries are little higher than those of MP integrated nurseries, the products from SB integrated nurseries are sold at a higher price, about 40-60% higher, making up for the higher costs. Meanwhile, for rootstock nurseries as opposed to integrated nurseries, the MP method seems to perform slightly better economically than the SB method. Although the costs of MP rootstock nurseries are higher than SB rootstock nurseries, the products are sold at a slightly higher price, about 15-25% more.

From the point of view of business forms, the integrated nursery is superior to the rootstock nursery in all cases because it can be more profitable for the nursery. The length of time used to produce rootstock liners and one-year trees does not vary much, especially for nurseries using the SB method that possess a fully developed (full production capacity) and operational stool bed.

Speed of response is also noteworthy as a measure of a nursery's ability to withstand risk and capture market opportunities. For those nurseries that are more productive, they can react faster to changes in the market to reduce losses or increase profits. In this case, MP nurseries may have an advantage over SB nurseries because it takes MP nurseries one year to produce 20,000 rootstock liners, compared to approximately nine years for SB nurseries to reach full production capacity. This difference is important for the implementation of newly bred apple rootstocks by the industry, where MP nurseries seem nimbler and quicker to respond to urgent market needs.

Based on the initial findings, we will conduct a systematic NPV analysis and sensitivity tests in the next chapter, which will provide us with more information about how different conditions affect the economic performance.

Table 1 Costs and Returns per 20,000 G.41 rootstock liners (MP technology)

	Production Years			
	Year 1		Year 2	
	Lower bound	Higher bound	Lower bound	Higher bound
Estimated sales price ($/rootstock liner)			1.10	1.80
Unit used in the study (20k rootstock liners)				20,000.00
Success rate of acclimation				0.90
Percentage of sold				1.00
Estimated production (rootstock liners)				18,000.00
Total returns	-		19,800.00	32,400.00
Costs ($/20,000 rootstock liners)				
Build-up				
Lab build-up	180.00	900.00		
Road build-up	138.56			
Minor build-up	10.20			
Lab temperature & infrastructure buil(	108.00	168.00		
Green house temperature & infrastruc	54.00	84.00		
GH structure 3000 sq ft	180.00	540.00		
Storage build-up	144.00	-		
Equipment				
Caster racks	9.00			
Media mix machine	16.56			
Glassware washing machinery	20.16			
Laminar flow	54.00			
pH meter	9.25			
Balance	10.80			
Magnetic stirrer	57.60			
Autoclave	12.15			
Distillation Unit	16.20	103.57		
Minor Equips	4.05			
Mist Chamber	14.40			
Air conditioners	58.50	204.75		
Fluorescent Tubes	32.40			
Shade House	4.24			
Media filling	13.82			
Air filter	6.08			
Tools	87.37	145.80		
Refrigerator	24.30			
Total	937.50			
Electric Usage	333.00	974.50		
Glassware	843.75			
Chemicals	1,181.47			
Pots	0.25			
Other materials	1,265.63			
Labor	10,783.41	17,179.16		
Total Costs ($/20,000rootstock liners)	16,610.64	25,109.94		
ESTIMATED NET PRESENT VALUE				**4,770.09**

Table 2 Micropropagation rootstock nursery build-up cost

a	Annual cost per 20k rootstocks
b	Salvage rate=0.1
c	Life of usage
d ■ *d1* ■ *d2*	Yearly costs for the whole nursery *yearly costs for the whole nursery (low bound)* *yearly costs for the whole nursery (high bound)*
e	Yearly production (in 20 thousand)
a=d×(1-b)÷c÷e ■ *a1* ■ *a2*	 *low bound* *high bound*

		b	c	d1	d2	e (in 20k)	**a1**	**a2**
Lab building	**Lab building (depends on size, repurposed or new building, location)**	0.10	40	100000.00	500000.00	12.5	**180.00**	**900.00**
Lab Temperature & infrastructure build-up	**Lab heating/cooling system**	0.10	30	10000.00	20000.00	12.5	**24.00**	**48.00**
	Lab adequate electrical capacity, water capacity	0.10	30	5000.00	20000.00	12.5	**12.00**	**48.00**
Other lab build-up	**Lab air purifier/ air filtering device**	0.10	20	1500.00		12.5	**5.40**	/
	Lab furniture (benches, carts, chairs)	0.10	30	2000.00		12.5	**4.80**	/
Green house (GH) building	**GH structure 3000 sq ft**	0.10	40	100000.00	300000.00	12.5	**180.00**	**540.00**
GH Temperature & infrastructure build-up	**GH electrical infrastructure**	0.10	20	5000.00		12.5	**18.00**	/
	GH water infrastructure	0.10	20	5000.00		12.5	**18.00**	/
	GH water treatment & fertilizer infrastructure	0.10	10	5000.00		12.5	**36.00**	/

Table 3 Micropropagation rootstock nursery equipment cost

a	Annual cost per 20k rootstocks
b	Salvage rate=0.1
c	Life of usage
d ■ *d1* ■ *d2*	Yearly costs for the whole nursery *yearly costs for the whole nursery (low bound)* *yearly costs for the whole nursery (high bound)*
e	Yearly production (in 20 thousand)
a=d×(1-b)÷c÷e ■ *a1* ■ *a2*	 *low bound* *high bound*

		b	c	d1	d2	e(in 20k)	**a1**	**a2**
Equipment	**Caster racks**	0.10	20	2500.00		12.5	**9.00**	/
	Glassware washing machinery	0.10	5	700.00		12.5	**10.08**	/
	Laminar flow	0.10	30	22500.00		12.5	**54.00**	/
	pH meter	0.10	7	800.00		12.5	**8.22**	/
	Balance	0.10	10	2000.00		12.5	**14.40**	/
	Magnetic stirrer	0.10	10	1500.00		12.5	**10.80**	/
	Autoclave	0.10	15	12000.00		12.5	**57.60**	/
	Distillation unit	0.10	10	1500.00		12.5	**10.80**	/
	Minor equipment	0.10	10	2000.00		12.5	**14.40**	/
	Mist chamber	0.10	40	2000.00		12.5	**3.60**	/
	Shade house	0.10	10	2000.00		12.5	**14.40**	/
	Air conditioners	0.10	30	15000.00		12.5	**36.00**	/
	Fluorescent tubes	0.10	10	4000.00		12.5	**28.80**	/
	Air filter	0.10	20	1500.00		12.5	**5.40**	/
	Refrigerator	0.10	7	2100.00		12.5	**21.60**	/
Tools	**Test tubes & racks**	0.10	10	1000.00	7500.00	12.5	**7.20**	**54.00**
	Tool sterilizers	0.10	7	3000.00	3500.00	12.5	**30.86**	**36.00**
	Culture vessels (glass jar, plastic tubs, or Magenta boxes) (1500 reusable containers and caps)	0.10	10	4000.00		12.5	**28.80**	/
	Culture tools (tweezers, scalpels, tool rest)	0.10	10	1500.00		12.5	**10.80**	/

Table 4 Costs and Returns per 20,000 G.41 rootstock liners (SB technology)

	Production Years										
	Year 1		Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	
	Lower bound	Higher bound								Lower bound	Higher bound
Estimated sales price ($/rootstock liner)										0.94	1.45
Unit used in the study (20k rootstock liners)											20,000.00
Success rate of lining											0.90
Percentage of sold											1.00
Estimated production size(rootstock liners)											18,000.00
Total returns	-		-	-	-	-	-	-	-	16,920.00	26,100.00
Costs ($/20,000 rootstock liners)											
Build-up											
Temperature & infrastructure build-up	104.00	168.00									
Land preparation	34.64	51.96									
Road/aisles build-up	138.56										
Storage build-up	519.60	1,039.20									
Materials (Irrigation, sawdust, fertilizers, pest manageme	525.00		525.00	525.00	525.00	525.00	525.00	525.00	525.00		
Labor	975.00		975.00	975.00	975.00	975.00	975.00	975.00	975.00		
Total Costs ($/20,000 rootstock liners)	2,296.80	2,897.72	1,500.00	1,500.00	1,500.00	1,500.00	1,500.00	1,500.00	1,500.00		
ESTIMATED NET PRESENT VALUE											**3,038.83**

Table 5 Price list of G. series rootstock liners

	$/rootstock liner				
	0.94	1.19	1.13	1.08	1.35
	1.29	1.23	1.25	1.20	1.15
G. series	1.10	1.45	1.40	1.35	1.30
	1.25	1.20	1.15	1.10	1.45
	1.40	1.35	1.30		

Table 6 Costs and Returns per 20,000 G.41 one-year grafted trees (MP technology)

	Production Years					
	Year 1		Year 2		Year 3	
	Lower bound	Higher bound	Lower bound	Higher bound	Lower bound	Higher bound
Estimated sales price ($/one-year grafted containerized tree)					5.00	8.00
Unit used in the study (20k one-year grafted containerized tree)						20,000.00
Success rate of acclimation						0.90
Success rate of transplanting						0.98
Percentage of sold						1.00
Estimated production size (one-year grafted containerized tree)						17,640.00
Total returns	-		-		88,200.00	141,120.00
Costs ($/20,000 one-year grafted containerized tree)						
Build-up						
Lab build-up	180.00	900.00				
Road build-up	138.56					
Minor build-up	10.20					
Lab temperature & infrastructure build-up	108.00	168.00				
Green house temperature & infrastructure build-up	54.00	84.00				
GH structure 3000 sq ft	180.00	540.00				
Storage build-up	144.00	-				
Equipment						
Caster racks	9.00					
Media mix machine	16.56					
Glassware washing machinery	20.16					
Laminar flow	54.00					
pH meter	9.25					
Balance	10.80					
Magnetic stirrer	57.60					
Autoclave	12.15					
Distillation Unit	16.20	103.57				
Minor Equips	4.05					
Mist Chamber	14.40					
Air conditioners	58.50	204.75				
Fluorescent Tubes	32.40					
Shade House	4.24					
Media filling	13.82					
Air filter	6.08					
Tools	87.37	145.80				
Refrigerator	24.30					
Total	937.50					
Electric Usage	333.00	974.50				
Glassware	843.75					
Chemicals	1,181.47					
Pots	0.25					
Other materials	1,265.63					
Labor	10,783.41	17,179.16				
Transplant & harvest & grade			30,000.00	50,000.00	30,000.00	50,000.00
Total Costs ($/20,000 one-year grafted containerized tree)	16,610.64	25,109.94	30,000.00	50,000.00	30,000.00	50,000.00
ESTIMATED NET PRESENT VALUE						**13,459.82**

Table 7 Costs and Returns per 20,000 G.41 one-year grafted trees (SB technology)

	Production Years																	
	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7		Year 8		Year 9	
	Lower bound	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**	**Lower bound**	**Higher bound**
Estimated sales price ($/one-year grafted tree)																	7.25	12.88
Unit used in the study (20k one-year grafted trees)																		20,000.00
Success rate of lining																		0.90
Success rate of field growing																		0.98
Percentage of sold																		1.00
Estimated production size(one-year grafted trees)																		17,640.00
Total returns	-		-		-		-		-		-		-		-		127,890.00	227,203.20
Costs ($/20,000 one-year grafted trees)																		
Build-up																		
Temperature & infrastructure build-up	104.00	168.00																
Land preparation	34.64	51.96																
Road/aisles build-up	138.56																	
Storage build-up	519.60	1,039.20																
Materials (Irrigation, sawdust, fertilizers, pest managem	525.00		525.00		525.00		525.00		525.00		525.00		525.00		525.00			
Labor	975.00		7,975.00	13,975.00	7,975.00	13,975.00	7,975.00	13,975.00	7,975.00	13,975.00	7,975.00	13,975.00	7,975.00	13,975.00	7,975.00	13,975.00	7,000.00	13,000.00
Land preparation cost			8.66	12.99	8.66	12.99	8.66	12.99	8.66	12.99	8.66	12.99	8.66	12.99	8.66	12.99	8.66	12.99
Irrigation and sawdust cost			173.20		173.20		173.20		173.20		173.20		173.20		173.20			173.20
Administrative cost			433.00	1,299.00	433.00	1,299.00	433.00	1,299.00	433.00	1,299.00	433.00	1,299.00	433.00	1,299.00	433.00	1,299.00	433.00	1,306.00
Utility cost			34.64	65.99	34.64	65.99	34.64	65.99	34.64	65.99	34.64	65.99	34.64	65.99	34.64	65.99	34.64	65.11
Other costs in the field growing (equipment, fertilizer, scion)			1,350.50	1,587.38	1,350.50	1,587.38	1,350.50	1,587.38	1,350.50	1,587.38	1,350.50	1,587.38	1,350.50	1,587.38	1,350.50	1,587.38	1,350.50	1,587.38
Online inventory management cost			138.56		138.56		138.56		138.56		138.56		138.56		138.56			138.56
Total Costs ($/20,000 one-year grafted trees)	2,296.80	2,897.72	10,638.56	17,777.12	10,638.56	17,777.12	10,638.56	17,777.12	10,638.56	17,777.12	10,638.56	17,777.12	10,638.56	17,777.12	10,638.56	17,777.12	9,138.56	16,277.12
ESTIMATED NET PRESENT VALUE																		**41,238.55**

CHAPTER 5

RESULTS

5.1 Assumptions

For nurseries producing rootstocks following the micropropagation technique, the study assumes that all the orders will be in the category of wholesale, given that the percentage of wholesale is more than 90 percent (NASS). This assumption is also supported by the BC government report in Canada. According to the report, nurseries in Washington (WA) plant less than 20 percent of the rootstocks and finished trees for pop-up orders to protect against the risks of a depressed market. Therefore, it will screen out the retail sale of the finished tree, which may be about twice as high as the wholesale price. It also filters out the retail price that is charged when the nursery proceeds with the procurement of the rootstock. So, this study sets the minimum purchase of rootstocks at 10,000, which is equal to the number of finished trees that can be planted per acre, as well as a minimum of 1,000 finished trees for wholesale.

The second hypothesis in this study is that there will be no significant differences in the number of different grades of trees, i.e., the proportion of each grade will be the same. The reason for this assumption is that it is difficult to predict the distribution of grades of trees, since the classes (height, width, number of roots, number of branches) could change over time and the standard of each nursery could be different.

Another assumption made in the study is a straight-line depreciation rate. This method is chosen because we don't know exactly when the model will be applied, possibly at the beginning of the nursery's establishment, or an intermediate point established at the nursery.

The study also assumes that the time required to acclimate the plants and grow the trees are related to growth patterns instead of quantity of plants produced.

The fifth assumption is that nurseries will not directly benefit from the additional fees, including the virus-fee and royalty fee. According to the 2013 Illinois Specialty Crops, Agritourism, and Organic Conference, nurseries charge a 1-2% surcharge on each virus-free tree sold. This is done as nurseries bear 1-2% of the cost of planting new varieties, including virus-free certification fees and annual maintenance fees. This surcharge is intended to fund other research projects, so it goes to the local government. Therefore, the virus-free certification and maintenance fee will not be considered as a cost or income in this study. This is also true with the royalties charged by the nursery.

The final assumption is that nurseries do not incur any additional costs or gain any additional income from having a surplus when the percentage of sales is not 100%. The surplus is only a loss to the nursery, incurring planting costs but no income. This problem is quite tricky, because the nursery can resell the leftovers the following year, or replant them in the orchard (if there is one). All these scenarios have the potential to bring variations into the nursery's costs and income in the future. However, the variations can be ignored because the percentage of sold finished trees is more than 80 percent of the produced trees. Secondly, there will be costs and revenue related to unsold finished trees, therefore, the impact to net present value is small.

5.2 Systematic net present value analysis, G.41

Systematic results for the example, G.41, under both business forms and production methods will be presented and discussed.

5.2.1 Net present value - rootstock nurseries

In rootstock nurseries, the NPV of stool bed technology (SB. NPV) is more likely to be superior to the NPV of micropropagation technology (MP. NPV), which is shown in graph 1. There is a 70% probability that the NPV of SB rootstock nurseries is higher than that of MP rootstock nurseries, which may be due to lower labor costs and the relatively small difference in selling prices. MP rootstock nurseries have a wider NPV distribution, which means that there is a higher ceiling for profitability, as well as a greater potential for losses. This can be confirmed from table 8 as well. From table 8, the MP. NPV appears to have a much lower value at 5% and higher value at 95%. The lower low and higher high values characterize the larger standard deviation of MP. NPV.

5.2.2 Net present value -integrated nursery

In integrated nurseries, the NPV of stool bed technology (SB. NPV) is superior to the NPV of micropropagation technology (MP. NPV), which is shown in graph 2. The better performance of SB nurseries is due to the higher selling price of the one-year trees, although their production costs are higher than those of MP nurseries. The numerical display is shown in table 9, where we can see that MP. NPV appears to have a much lower value at 5%, 50% and 95%.

5.2.3 Net present value -summary

From the systematic NPV analysis of the four types of nurseries with G.41 as an example, the integrated nursery appears to be a riskier business because it has a greater probability of generating a negative NPV. For those applying the stool bed approach, the decision to engage in a shorter or a more vertical business could be a matter of mindset. Shorter businesses, which refers to rootstock nurseries, gain less but also have a smaller amount and probability of loss; more vertical businesses, which refer to integrated nurseries, gain more but have a higher amount and probability of loss. Rootstock nurseries may be more profitable for those who apply micropropagation methods. Overall, it appears that micropropagation nurseries are more likely to generate negative NPVs than SB nurseries.

However, this is not to say that MP nurseries are inferior to SB nurseries in all aspects. It is important to note that because the scale of production varies from nursery to nursery, our study uses 20,000 plants (rootstock liners for rootstock nurseries, and one-year trees for integrated nurseries) as a unit for the NPV discussion that does not consider the scale of production. Hence a valid range for the discussion above is the production of 20,000 plants. The production capacity of MP nurseries is much higher than this, and rootstock nursery's economic impact on the nursery industry is magnified many-fold when production volumes are taken into account. They also have a large industry impact. MP rootstock nurseries are suppliers to the whole nursery and have technical barriers. In addition, as we discussed in Chapter 4, speed of response is also a measured component. MP nurseries have a better ability to withstand risk and capture market opportunities. This ability to ramp up production and scale down to quickly divert resources toward the production of other species in demand by the market is a very important characteristic of MP nurseries.

5.3 Sensitivity tests, G.41

Sensitivity tests are the analyses that quantify the impact that small changes in key variables have on result. In our study, we use two different methods, which are: 1) ranking of the key factors to NPV and 2) proportional contribution to the standard deviation.

5.3.1 Sensitivity tests- micropropagation rootstock nurseries

Graph 3 is the ranking correlations of different variables on MP. NPV in rootstock nurseries. There are two factors whose rank correlation is close to 0.5, which are sales price and success rate of acclimation. The top-ranked factor is the sales price of rootstock liners whose correlation coefficient is 0.83. As the correlation is close to 1, it refers to a strong monotonic positive correlation between the sales price of rootstock liners and the NPV. The second-most significant factor is the success rate of acclimation whose correlation coefficient is 0.48. This turns out to be a moderate to weak monotonic positive relationship between the success rate of acclimation and the NPV.

5.3.2 Sensitivity tests- stool bed rootstock nursery

Graph 4 is the ranking correlations of different variables on SB. NPV in rootstock nurseries. There are two factors whose rank correlation exceeds 0.5, which are sales price and success rate of stool bed rooted liner production. The top-ranked factor is the sales price of rootstock liners whose correlation coefficient is 0.76. As the correlation is close to 1, it refers to a strong monotonic positive correlation between sales price of rootstock liners and NPV. The second-most significant factor is the success rate of stool bed rooted liner production whose correlation coefficient is 0.59. This turns out to be a moderate monotonic positive relationship between success rate of stool bed rooted liner production and NPV.

5.3.3 Sensitivity tests- micropropagation integrated nursery

Graph 5 is the ranking correlations of different variables on MP. NPV in integrated nurseries. There are two factors whose absolute rank correlation exceeds 0.5, which are sales price and transplanting & harvesting cost. The top-ranked factor is the sales price of one-year containerized trees whose correlation coefficient is 0.64, which refers to a moderate to strong monotonic positive correlation between sales price of rootstock liners and NPV. The second-most significant factor is the transplanting & harvesting cost whose correlation coefficient is -0.55. This turns out to be a moderate monotonic negative relationship between transplanting & harvesting cost and NPV.

5.3.4 Sensitivity tests- micropropagation integrated nursery

Graph 6 is the ranking correlations of different variables on SB. NPV in integrated nurseries. There are two factors whose rank correlation is close to 0.5, which are sales price and success rate in stool bed rooted liner production. The top-ranked factor is the sales price of one-year grafted trees whose correlation coefficient is 0.76, which refers to a strong monotonic positive correlation between sales price of one-year grafted trees and NPV. The second-most significant factor is the success rate in stool bed rooted liner production whose correlation coefficient is 0.46. This turns out to be a moderate to week monotonic positive relationship between success rate in stool bed rooted liner production and NPV.

5.4.4 Sensitivity tests- summary

To summarize, the NPV of micropropagation integrated and tree nurseries is sensitive to the top two factors: sales price of produced plants and success rate in each stage.

The NPV of MP integrated nurseries are also sensitive to transplanting & harvesting cost.

5.4 Customized tables

We have established four customized tables for audience to cover different business models and production methods, namely MP rootstock nurseries, SB rootstock nurseries, MP integrated nurseries, and SB integrated nurseries. Based on this table, they could simulate the economic performance of a nursery to compare the differences in output under different options.

Each table has “to fill in” and “generate automatically” components. First component provides flexibility, where audience could fill in the numbers that best describe their situations. The second component consists variables with built-in formulars that will require no additional action.

Variables in the first “to fill in” component, called input variables, include E, efficiency per cycle (number of shoots produced per cycle), S_1, success rate in the rootstock production, S_2, success rate in the tree production, L_{cycle}, length of time needed for each production cycle, I, number of initial plants, $P_{\%}$, proportion of plants that used to grow finished trees, Np, numbers of plants that plan to have, P, sale price of the plants, and R_{sold}, proportion of plants sold. Although input variables include discount rate, it may be difficult for audience to come up with the discount rate is they do not have loans. To make the calculation more handful, we move discount rate in to the second component, which will be generated automatically. Besides, variables in the second component include critical variables, costs, and net present value or net return. Variables generated on input variables are $\widetilde{\mathrm{Nr}}$, numbers of plants produced in the rootstock production, $\widetilde{\mathrm{NI}}$, numbers of one-year containerized/one-year grafted trees produced, n, numbers of production cycle required, $L_{production}$, length of time needed for production cycles, L_{total}, length of time needed for whole production, and Q, number of plants sold. Costs will vary from business forms and production methods, which would include sub-costs and total costs accordingly. Net present value or net return could give some lights to the audience when they are deciding which business form and production method to choose.

It is to be noticed that there are other important aspects that should be consider other than the economic performance presented by customized tables, such as return rate, attraction to labor force, and ability to respond emerging demand.

Graph 1 Distribution on SB. NPV and MP. NPV on G.41 (rootstock nurseries)

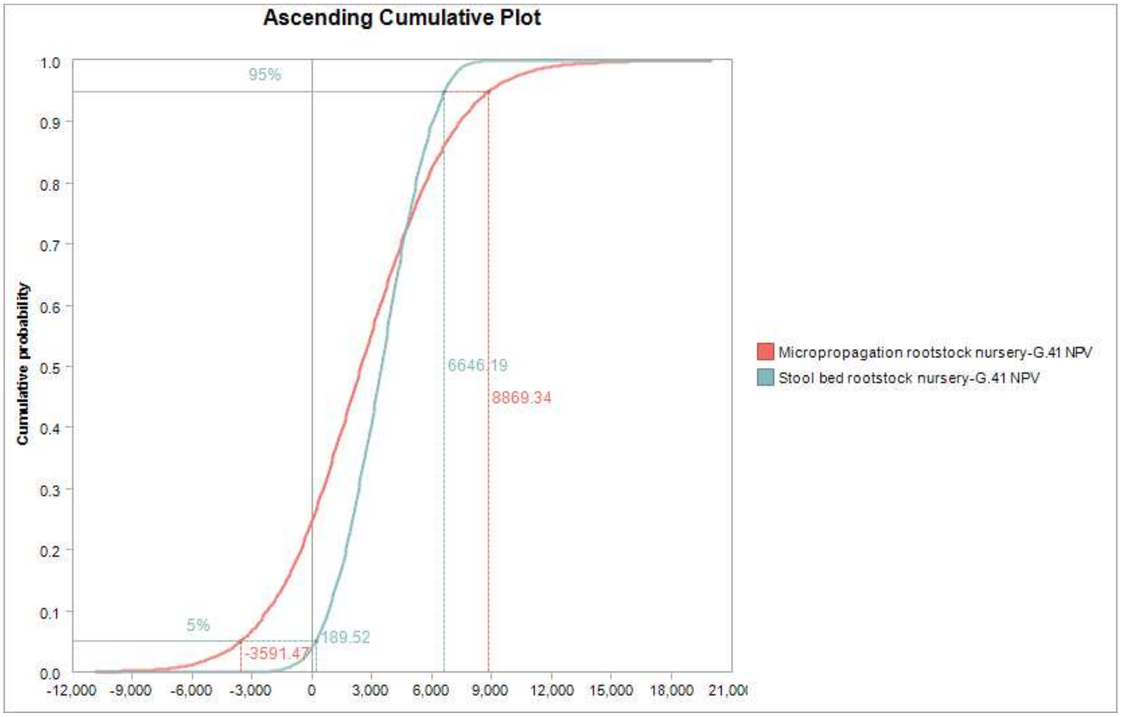


Table 8 Comparison of SB. NPV and MP. NPV on G.41 (rootstock nurseries)

Production methods	Mean	Standard Deviation	Distribution Percentile		Probability of having a negative value
			5%	95%	
Stool bed	3,449.19	1,972.06	189.52	6,646.19	4%
Micropropagation	2,554.69	3,821.66	-3,591.47	8,869.34	25%

Graph 2 Distribution on SB. NPV and MP. NPV on G.41 (integrated nurseries)

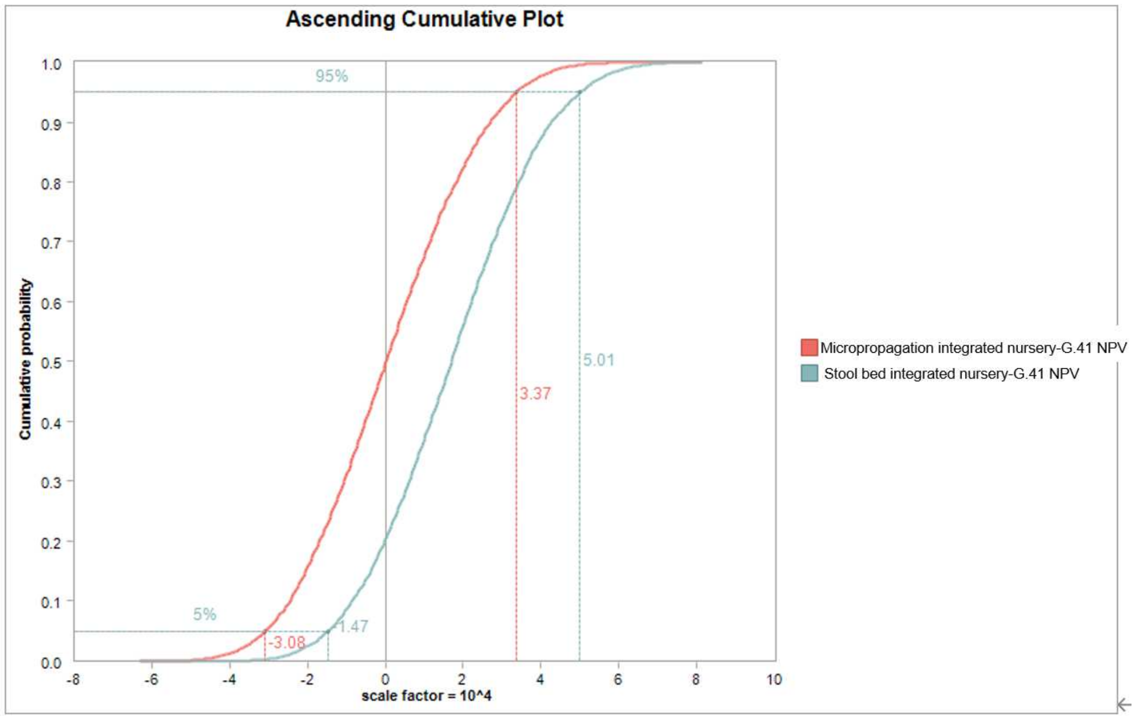
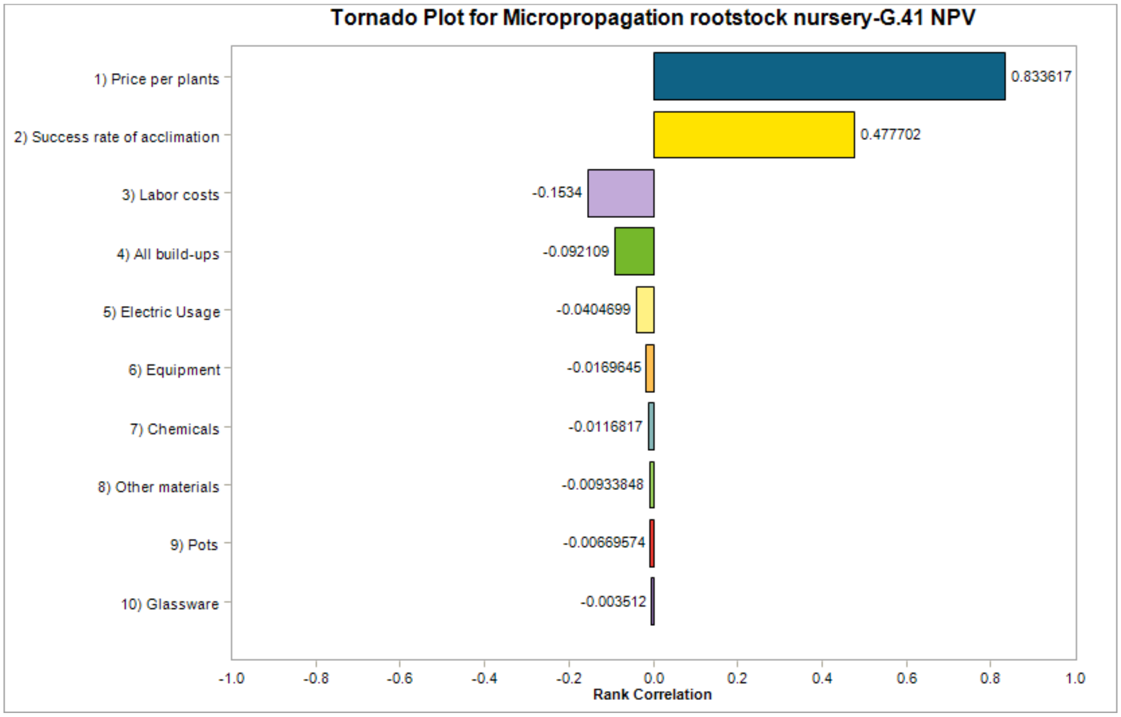


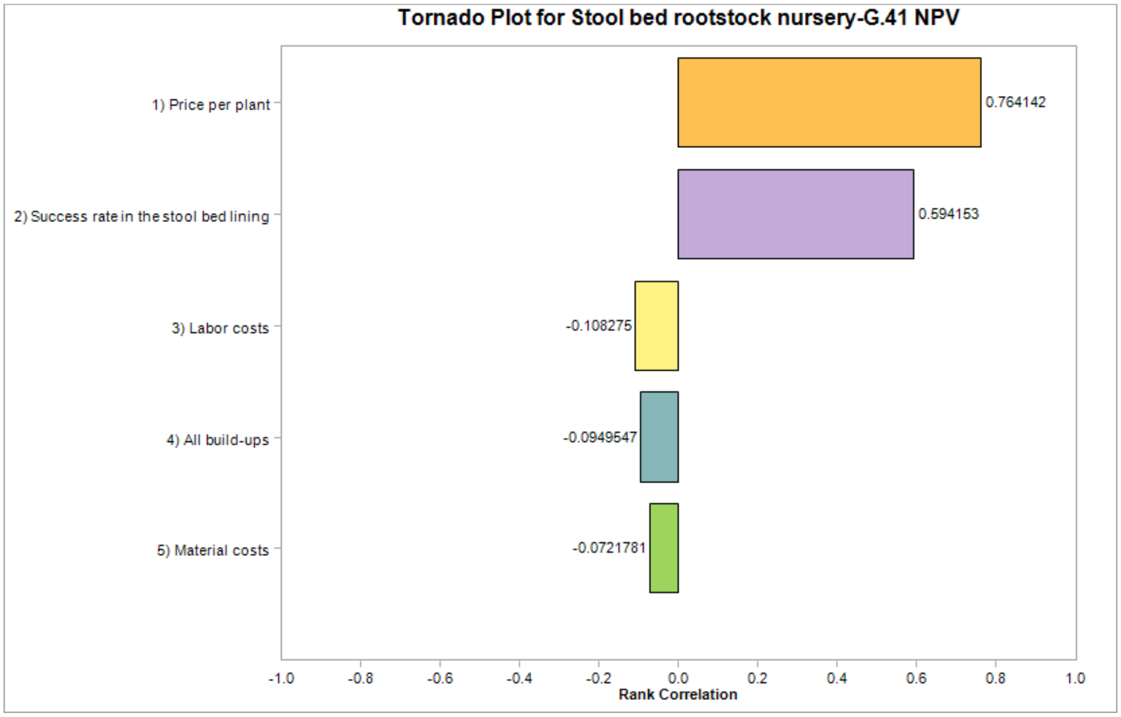
Table 9 Comparison of SB. NPV and MP. NPV on G.41 (integrated nurseries)

Production methods	Mean	Standard Deviation	Distribution Percentile		Probability of having a negative value
			5%	95%	
Stool bed	17,103.83	19,607.06	-14,732.81	50,065.58	21%
Micropropagation	663.75	19,692.46	-30,849.75	33,719.33	50%

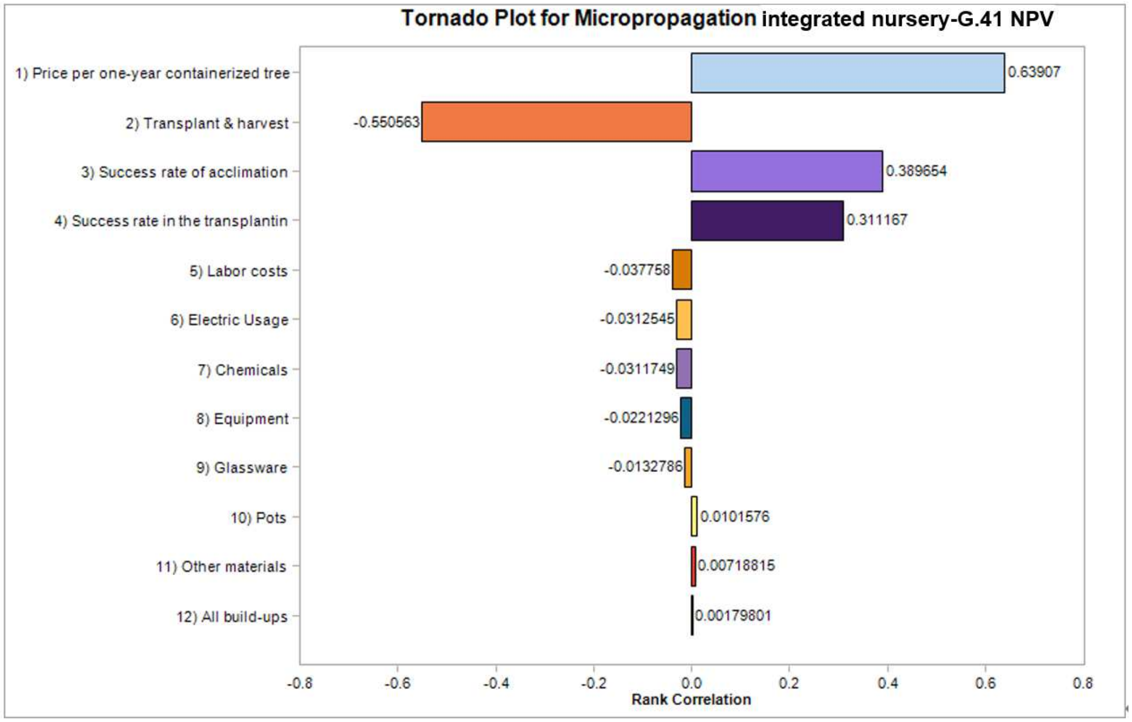
Graph 3 Rank correlation of key factors on G. 41 NPV (micropropagation rootstock nursery)



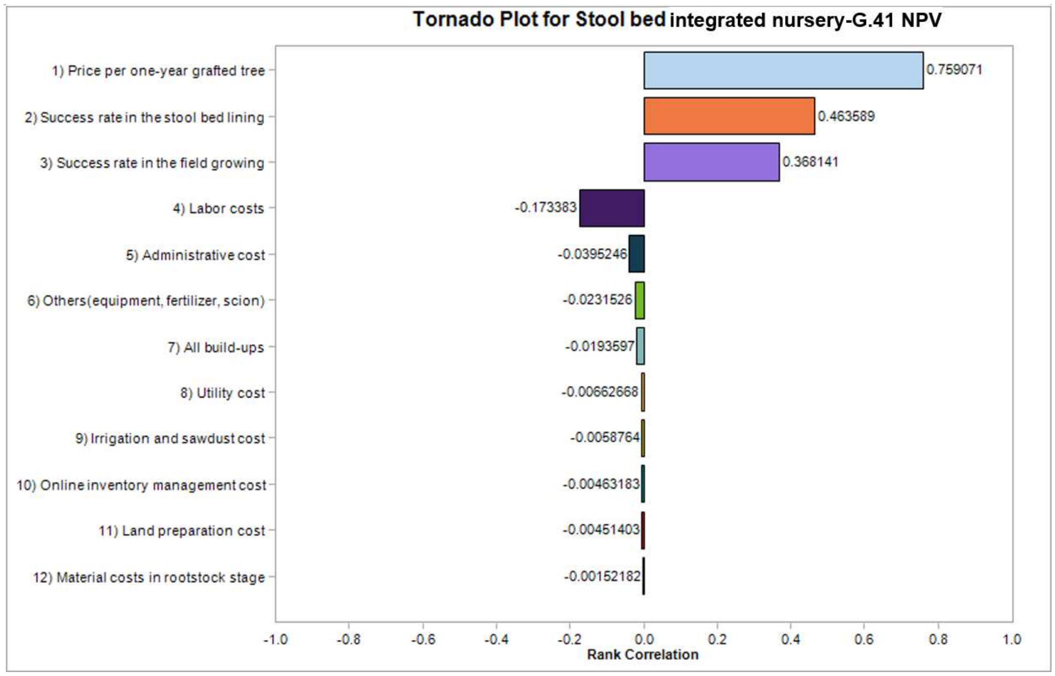
Graph 4 Rank correlation of key factors on G. 41 NPV (stool bed rootstock nursery)



Graph 5 Rank correlation of key factors on G. 41 NPV (micropropagation integrated nursery)



Graph 6 Rank correlation of key factors on G. 41 NPV (stool bed integrated nursery)



CHAPTER 6

CONCLUSION

6.1 Customized tables

We have designed four customized tables to allow the reader to simulate the NPV for their situation. These tables are applicable to the MP rootstock nursery, MP integrated nursery, SB rootstock nursery, and SB integrated nursery, respectively.

Each table consists of similar blocks, the first one needs to be filled in by readers, all highlighted in yellow; the second one is an automatic calculation based on the numbers filled in by readers.

What readers need to fill in are: estimated success rate (expressed as a range); total number of plants intended to be produced; number of shoots multiplied per production cycle; initial number of plants to start with; time required for each production cycle; estimated selling price (expressed as a range); inflation rate; and estimated percentage sold. They are related to the rootstock genotype selected by the operator, the nursery production efficiency, its market environment, and the production plan.

The automatic calculation will be divided into two parts: the first part is the key variables; the second part is the economic analysis. The key variables include: numbers of plants produced, numbers of production cycles required, length of times needed for all production cycles, and number of plants sold. The economic analysis includes production costs as well as revenues.

It is worth pointing out that since the simulation was done only in Excel, net return was used instead for more complex cases. For example, in MP nurseries, because the cycle is calculated on a weekly basis, it is difficult to include the time value in Excel due to the different cycle lengths. We performed an economic analysis using net return for MP nurseries, while for SB nurseries we performed NPV analysis. Although net return will have some impact on the accuracy, the impact would be limited because of the short production cycle of MP technology.

6.2 Example presented

In the example of G.41, SB nurseries may be a better choice compared with MP nurseries from an economic perspective. For different business models, integrated nurseries and rootstock nurseries have their own advantages and disadvantages and need to be analyzed case by case.

For nurseries that apply SB technique, integrated nurseries are much more profitable than rootstock nurseries in terms of the mean. But their probability of having a negative NPV is five times higher than for rootstock nurseries, being 20% for integrated nurseries and 3% for rootstock nurseries.

For nurseries that apply MP technique, each business model has its own unique characteristics. For integrated nurseries, the probability of having a negative NPV is two times higher than for rootstock nurseries, but the profit ceiling is three times higher.

SB. NPV in integrated nurseries is higher than MP. NPV because it sells one-year trees for 40-60% more, even though it costs slightly more than MP integrated nurseries.

SB. NPV in rootstock nurseries is slightly higher than MP. NPV because its production cost is lower, even though it sells rootstock liners at a lower price than MP rootstock nurseries.

Moreover, there are now innovations in business models in the industry. In addition to the rootstock and integrated nurseries, there are new models of cooperation. For example, MP rootstock nurseries can cooperate with SB integrated nurseries. New MP rootstock nurseries seeking investment can sell rootstocks to SB integrated nurseries at a lower price, and in return, SB integrated nurseries will invest in MP rootstock nurseries. This is a win-win operation as the MP rootstock nurseries will have the initial capital and SB integrated nurseries can pay less for the purchase of high-quality rootstocks and respond faster to market demand.

Factors that influence rootstocks selection have also been studied via the survey with two nurseries. According to our survey with tree nurseries, family tradition is an important factor in the decision to adopt a new rootstock. Other influencing factors include: whether the new rootstock is virus resistant, the popularity of the new rootstock in the market, and if it has a promising yield. A hybrid model which has been adopted by several nurseries in the industry for the implementation of new apple rootstocks could possibly have a better economic performance. This model features the initial production of rooted plants by MP companies that are then planted by SB companies to establish virus- and disease-free stool beds to produce rooted SB liners in a much quicker time than SB ramping up alone and providing cost efficient SB rooted liners to feed the apple tree industry. The MP can fill in the market demand until the SB production for a certain genotype matches the market demand. In addition, some orchard application might still require MP originated trees possessing more primary roots for stressful planting situations like replant disease soils.

6.3 Other aspects to consider

In addition to the economics, there are other aspects that nursery owners need to consider when making their decisions.

Labor availability is one of the angles. SB nurseries often suffer from labor shortages because they rely on part-time workers during the busy season, while MP nurseries can provide full-time work for their workers and are therefore favored by them. Labor shortages can lead to a few serious consequences such as reduced revenue, failure to deliver on time and loss of customer trust.

The response rate to new market demand also needs to be taken into account when making decisions. SB technology reacts more slowly to market demand. If there is a new demand for G.41, SB nurseries have to wait until the next growing season to start producing the variety. The longer production time requires consumers to wait for years, at least two years, to get the desired finished tree. This can leave orchards with a prolonged gap because there are no apple trees to plant. MP technology can produce new varieties in a timely manner because they do most of their work in a controlled environment. The shorter production time allows consumers to plant finished trees of new varieties earlier. From an efficiency standpoint, MP nurseries is a better choice for the customers, and the same is true for the nurseries.

The ability to withstand risk is also important. Land production (SB technology) can be riskier than laboratory production. In bad years, the market demand will drop, and some of the land will be left empty at that time. However, the land still needs to be maintained by workers for future production, which adds an extra burden to bad years.

6.4 Avenues for further research

This study is an economic analysis of a nursery after its adoption of different production methods, business models, and rootstock genotypes. The article includes customizable forms that can be filled by readers and a systematic NPV analysis using G.41 as an example. From the tables we can understand the possible economic impact of different rootstock genotypes. From the NPV analysis, we can learn about the differences in economic performance of the same rootstock between rootstock nurseries and integrated nurseries and under different business models.

This study has several shortcomings worth considering. First, it has relatively limited primary data, mainly because of the low response rate within the industry. Future studies could use other methods to increase the response rate so that more data can be collected. Potential methods include partnering with large industry conferences to send surveys to participants. With a trusted conference endorsement and broader scope of audience, this may increase the success rate of data collection. In addition, as more samples becomes available, future studies could be regionally segmented. For example, nursery data could be divided into the Northeast (New York state), Northwest (Oregon and Washington states), and Pacific (California) by major apple production regions. This might better match the costs of different regions, such as labor costs. Third, if the technology is available, it might be worth considering a tabular design on a web page or other medium so that it has the ability to perform NPV analysis for more complex scenarios.

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tor.aspx

APPENDIX

A. Survey for tree nursery

PART I Background

Size of the nursery (in acres)	
Where is your nursery (city, state)	
How long have your nursery run (in years)	
How many mother plants do your nursery have?	

PART II Initial Investment

land preparation cost (indicate the unit first)				
build-up cost (Temperature & infrastructure, Road build/aisles)	**name:** **service life:** **money spent:** **built-up year:**	**name:** **service life:** **money spent:** **built-up year:**	**name:** **service life:** **money spent:** **built-up year:**	**name:** **service life:** **money spent:** **built-up year:**
Interest rate				
Initial investment cost	**variety 1** _________		**variety 2** _________	

PART III Establishment

labor cost per tree (labor& machine)	**variety 1** ________	**variety 2** ________
material cost (indicate the unit here__)	**variety 1** ________	**variety 2** ________
Establishment Cost	**variety 1** _________	**variety 2** _________

PART IV Yearly Management

(Consider each variety separately, if difference exists)	**1st year**	**2nd year**	**3rd year (leave it blank if not applicable)**	**4th year (leave it blank if not applicable)**

sawdust cost per ___ (indicate unit here)	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____

irrigation cost per ___ (indicate unit here)	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____
labor required per tree (labor& machine)	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____
Management Cost	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____	**variety 1** ____-____	**variety 2** ____-____

PART V Yearly Overhead
Indicate the total overhead cost for each variety

	1st year	**2nd year**	**3rd year** (leave it blank if not applicable)	**4th year** (leave it blank if not applicable)
administrative cost unit: per variety, for 1 year				
utility cost (electricity &water &etc.)				
online inventory management cost				
Overhead Cost				

PART VI Sales

labor required per tree (labor& machine)	**variety 1** ________	**variety 2** ________
shipping fee per____ (indicate unit here), if applicable	**variety 1** ________	**variety 2** ________
Sales Cost	**variety 1** ________	**variety 2** ________

PART VII Revenue

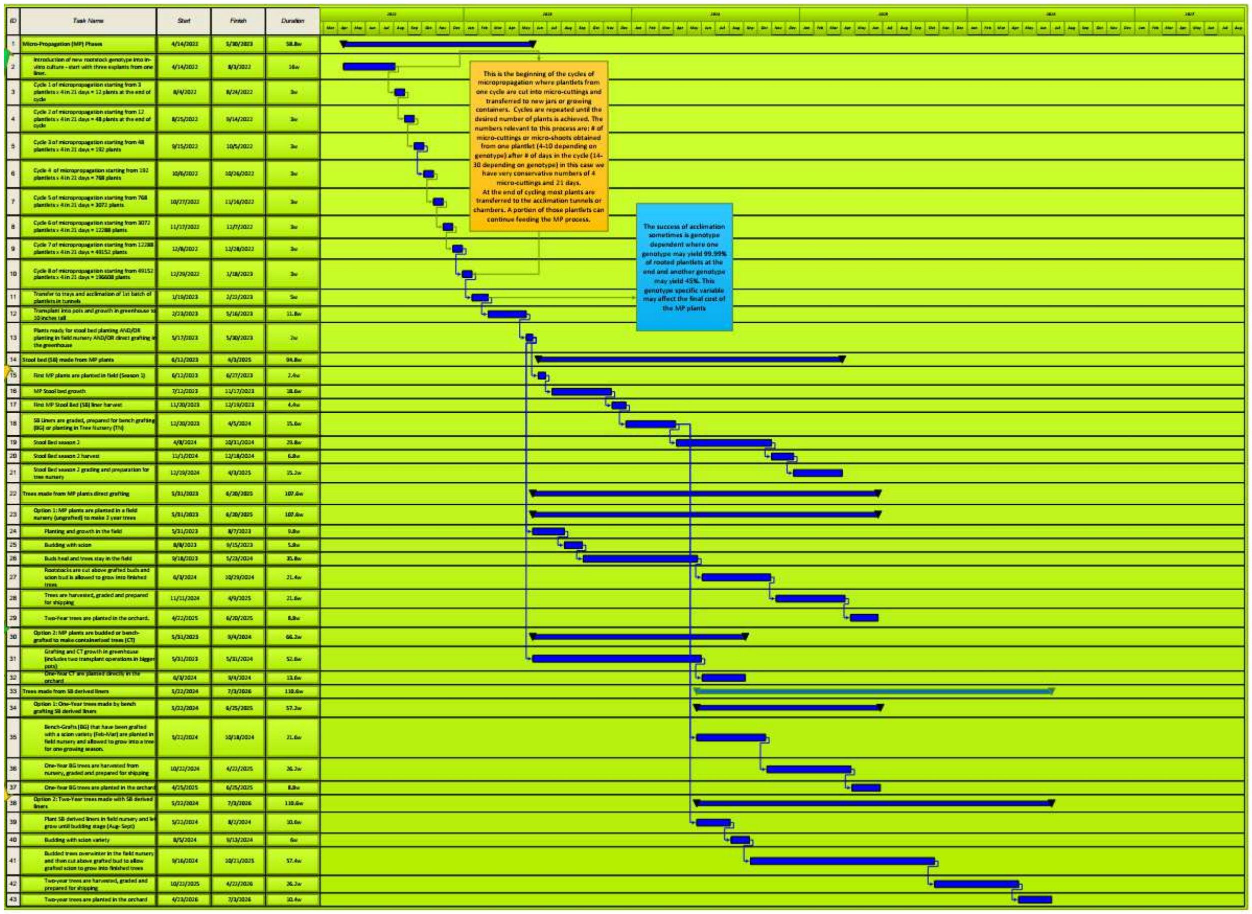
price per____ (indicate unit here)	**variety 1** ________	**variety 2** ________
quantity sold	**variety 1** ________	**variety 2** ________
survival rate: #Harvest/#Planted	**variety 1** ________	**variety 2** ________
Revenue	**variety 1** ________	**variety 2** ________

PART VIII Preference

What would be the factors that prevent you from adopting new cultivar?
Please indicate how important are the following factors by checking the box (1 for the least important and 5 for the most important)

	1	**2**	**3**	**4**	**5**
survival rate					
easy to maintain					
market reaction, revenue gain					
lack of access to the info or new cultivar					
sensitivity to virus					
yield					
personal belief					

B. Production schedule of G.41 under different business forms, production methods, and different outputs, created by Gennaro. Fazio (2022)



C. Customized tables-displayed version

C-1 Customized tables-MP rootstock nurseries

Micropropagation rootstock nurseries

Fill in the numbers

TO FILL IN			
Important variables	*Lower bound*	*Upper bound*	
S1: success rate of acclimation	0.90	0.95	In a range
Np: numbers of rootstock liners that you plan to produce	20,000.00	20,000.00	
E: numbers of shoots that could be generated per cycle	4.00	4.00	
I: number of initial explants to start with	3.00	3.00	
Lcycle: length of time (in weeks) needed for each cycle	3.00	3.00	
P: Sale price of the rootstock liners	1.30	1.80	In a range
Rsold: Percentage of rootstock liners sold	0.90	1.00	In a range

GENERATE AUTOMATICALLY			
Important variables		*Lower bound*	*Upper bound*
r: Discount rate (time value)		0.05	0.05
Crtical varibles		*Lower bound*	*Upper bound*
Nr: numbers of rootstock liners produced		18,000.00	19,000.00
n: numbers of production cycles required		7.00	7.00
Lproduction: length of times (in weeks) needed for production cycles		21.00	21.00
Q: Number of rootstock liners sold		16,200.00	19,000.00
Lrs total: length of times (in weeks) needed for whole rootstock liner production		54.00	54.00
Cost		*Lower bound*	*Upper bound*
Build-up stage	All build-ups	742.76	1,912.76
	Equipment	25.81	53.26
	Labor costs	1,078.34	1,717.92
Pre-stage (Pre-selection & treatment)	Equipment	50.35	117.19
	Electric Usage	37.00	117.19
	Chemicals	140.63	140.63
	Glassware	93.75	93.75
	Other materials	140.63	140.63
	Labor costs	1,078.34	1,717.92
Production cycle (In vitro transfer ,multiplication, rooting)	Equipment	352.45	820.31
	Electric Usage	259.00	820.31
	Chemicals	984.38	984.38
	Glassware	656.25	656.25
	Other materials	984.38	984.38
	Labor costs	7,548.39	12,025.41
Grow stage (Acclimation & Growth)	Equipment	22.24	67.24
	Electric Usage	37.00	37.00
	Chemicals	56.47	56.47
	Pots	0.25	0.25
	Labor costs	1,078.34	1,717.92

Outcome	*Lower income*	*Higher income*
Rev: Revenue	21,060.00	34,200.00
TC: Total cost	24,181.14	15,366.74
Net: Net return	-3,121.14	18,833.26

C-2 Customized tables-MP integrated nurseries

Microprogation integrated nurseries

Fill in the numbers

TO FILL IN	Lower bound	Upper bound	
Important variables	*Lower bound*	*Upper bound*	
S1: success rate of acclimation	0.90	0.95	In a range
S2: success rate of transplanting	0.98	0.99	In a range
Np: numbers of one-year containerized trees that you plan to produce	20,000.00	20,000.00	
E: numbers of shoots that could be generated per cycle	4.00	4.00	
I: number of initial explants to start with	3.00	3.00	
Lcycle: length of time (in weeks) needed for each cycle	3.00	3.00	
P: Sale price of the one-year containerized trees	5.00	8.00	In a range
Rsold: Percentage of one-year containerized trees sold	0.90	1.00	In a range

GENERATE AUTOMATICALLY			
Important variables		*Lower bound*	*Upper bound*
r: Discount rate (time value)		0.05	0.05
Crtical varibles		*Lower bound*	*Upper bound*
Ni: numbers of one-year containerized trees produced		17,640.00	18,810.00
n: numbers of production cycles required		7.00	7.00
Lproduction: length of times (in weeks) needed for production cycles		21.00	21.00
Q: Number of one-year containerized trees sold		15,876.00	18,810.00
Lrs total: length of times (in weeks) needed for whole rootstock liner production		54.00	54.00
Lintegrated total: length of times (in weeks) needed for whole one-year containerized trees production		122.00	122.00
Cost		*Lower bound*	*Upper bound*
Build-up stage	All build-ups	742.76	1,912.76
	Equipment	25.81	53.26
	Labor costs	1,078.34	1,717.92
Pre-stage (Pre-selection & treatment)	Equipment	50.35	117.19
	Electric Usage	37.00	117.19
	Chemicals	140.63	140.63
	Glassware	93.75	93.75
	Other materials	140.63	140.63
	Labor costs	1,078.34	1,717.92
Production cycle (In vitro transfer ,multiplication, rooting)	Equipment	352.45	820.31
	Electric Usage	259.00	820.31
	Chemicals	984.38	984.38
	Glassware	656.25	656.25
	Other materials	984.38	984.38
	Labor costs	7,548.39	12,025.41
Grow stage (Acclimation & Growth)	Equipment	22.24	67.24
	Electric Usage	37.00	37.00
	Chemicals	56.47	56.47
	Pots	0.25	0.25
	Labor costs	1,078.34	1,717.92
Tree stage (Grafting & transplanting and Harvest & grading)	All tree costs	60,000.00	100,000.00

Outcome	*Lower income*	*Higher income*
Rev: Revenue	79,380.00	150,480.00
TC: Total cost	124,181.14	75,366.74
Net: Net return	-44,801.14	75,113.26

C-3 Customized tables-SB rootstock nurseries

Stool bed rootstock nurseries

Fill in the numbers

TO FILL IN			
Important variables	*Lower bound*	*Upper bound*	
S1: success rate of lining	0.90	0.95	In a range
Np: numbers of rootstock liners that you plan to produce	20,000.00	20,000.00	
E: numbers of shoots that could be generated per cycle	4.00	4.00	
I: number of initial explants to start with	3.00	3.00	
Lcycle: length of time (in years) needed for each cycle	1.00	1.00	This is flexed
P: Sale price of the rootstock liners	1.00	1.50	In a range
Rsold: Percentage of rootstock liners sold	0.90	1.00	In a range

GENERATE AUTOMATICALLY			
Important variables		*Lower bound*	*Upper bound*
r: Discount rate (time value)		0.05	0.05
Crtical varibles		*Lower bound*	*Upper bound*
Nr: numbers of rootstock liners produced		18,000.00	19,000.00
n: numbers of production cycles required		7.00	7.00
Lproduction: length of times (in weeks) needed for production cycles		336.00	336.00
Q: Number of rootstock liners sold		16,200.00	19,000.00
Cost		*Lower bound*	*Upper bound*
Build-up stage	All build-ups	796.80	1,397.72
Production cycle	Labor cost	975.00	975.00
(incl. harvest and grading)	Materials	525.00	525.00
Outcome	*Lower income*	*Higher income*	
Rev: Revenue	16,200.00	28,500.00	
Revt: Revenue with time value	11,513.04	20,254.42	
TC: Total cost	11,897.72	11,296.80	
TCt: Total cost with time value	10,511.26	9,910.34	
NPV: Net present value	1,001.78	10,344.08	

C-4 Customized tables-SB integrated nurseries

Stool bed integrated nurseries

Fill in the numbers

TO FILL IN			
Important variables	*Lower bound*	*Upper bound*	
S1: success rate of lining	0.90	0.95	In a range
S2: success rate of field growing	0.98	0.99	In a range
Np: numbers of one-year grafted trees that you plan to produce	20,000.00	20,000.00	
E: numbers of shoots that could be generated per cycle	4.00	4.00	
I: number of initial explants to start with	3.00	3.00	
Lcycle: length of time (in years) needed for each cycle	1.00	1.00	This is flexed
P: Sale price of the rootstock liners	7.90	11.90	In a range
Rsold: Percentage of one-year grafted trees sold	0.80	1.00	In a range

GENERATE AUTOMATICALLY			
Important variables		*Lower bound*	*Upper bound*
r: Discount rate (time value)		0.05	0.05
Crtical varibles		*Lower bound*	*Upper bound*
Ni: numbers of one-year grafted trees produced		17,640.00	18,810.00
n: numbers of production cycles required		7.00	7.00
Lproduction: length of times (in weeks) needed for production cycles		336.00	336.00
Q: Number of one-year grafted trees sold		14,112.00	18,810.00
Lrs total: length of times (in weeks) needed for whole rootstock liner production		336.00	336.00
Lintegrated total: length of times (in weeks) needed for whole one-year grafted trees production		384.00	384.00
Cost		*Lower bound*	*Upper bound*
Build-up stage	All build-ups	796.80	1,397.72
Production cycle	Labor cost	975.00	975.00
(incl. harvest and grading)	Materials	525.00	525.00
Tree production cycle (incl. bench grafts & growing and harvest & grading)	Labor costs	7,000.00	13,000.00
	Land preparation cost	8.66	12.99
	Irrigation and sawdust cost	173.20	173.20
	Administrative cost	433.00	1,299.00
	Utility cost	34.64	65.99
	Others(equipment, fertilizer, scion)	1,350.50	1,587.38
	Online inventory management cost	138.56	138.56

Outcome	Lower income	Higher income
Rev: Revenue	111,484.80	223,839.00
Revt: Revenue with time value	79,230.17	159,078.20
TC: Total cost	125,837.57	75,266.72
TCt: Total cost with time value	92,009.59	55,175.54
NPV: Net present value	-12,779.42	103,902.66