

NORTH CENTRAL REGIONAL RESEARCH PROJECT NC-140

PROJECT NUMBER: NC-140
PROJECT TITLE: **IMPROVING ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY IN TREE-FRUIT PRODUCTION THROUGH CHANGES IN ROOTSTOCK USE**

REQUESTED DURATION: October 1, 2007, to September 30, 2012

STATEMENT OF ISSUES AND JUSTIFICATION:

The NC-140 Regional Research Project is designed to address a number of high-priority areas within the North Central Region as well as other parts of North America. This project seeks to enhance economically and environmentally sustainable practices in temperate fruit production by focusing on rootstocks. The NC-140 project meets the guidelines presented by the North Central Regional Association (NCRA) in *Guidelines for Multistate Research Activities* (May 2001). Specifically, this project addresses high priorities defined by NCRA, within the crosscutting research areas of agricultural production, processing, and distribution, genetic resource development and manipulation, integrated pest management and economic development and policy. The project involves researchers from multiple states and is multidisciplinary. Researchers involved in this project have leveraged Federal and state dollars to add significant resources to address this research area. Lastly, outreach is integral to the project and includes electronic information transfer through web sites, written material for growers and other stakeholder groups, and numerous educational programs in individual states and at national and international grower and scientific meetings.

With the competitive international market, the demand for high quality fruit by consumers, the strong pressure to reduce chemical use, and a need to enhance the economic efficiency of production, tree-fruit growers must look to alternative, economically and environmentally sustainable management schemes of production. Growers who want to stay profitable must establish high-density plantings with much smaller trees using new cultivars. These high-density plantings may cost 10 to 20 times more to establish than low-density plantings, thus greatly enhancing the economic risk. Potential returns of high-density plantings, however, far exceed those of low-density plantings, particularly during the first 10 years after planting, often returning the grower's initial investment much sooner than the initially less-costly, low-density plantings. The central component of high-density systems is the rootstock, the part of the tree which provides size control to allow for high-density plantings. As part of the tree, the rootstock influences many factors in addition to tree size, particularly productivity, fruit quality, pest resistance, stress tolerance, and ultimately profitability.

As the industry moves from low- to high-density plantings, several rootstock-related problems must be addressed. New pome- and stone-fruit rootstocks cannot be recommended unless there is sustained research investigating soil and climatic adaptability, root anchorage, size control, precocity, productivity, pest resistance, and propagation. In general, field testing of rootstocks in an orchard setting requires a minimum of eight years to accurately assess the

potential for improved profitability, reduction of external farm inputs, and enhancement of production efficiency. With year-to-year variation in weather, this time span is necessary to obtain a true indication of rootstock performance across multiple environments.

With the establishment of the NC-140 technical committee, researchers from the North Central region were able to develop a coordinated research effort in apple rootstock research through the uniform testing of rootstocks and multiple genetic systems, and to discuss, evaluate, and coordinate other rootstock research. As the project has continued, multiple temperate-zone fruit tree crops have been evaluated. With cooperators in various geographical regions across the country these research efforts allow the results from NC-140 studies to be interpreted directly. Since NC-140 is the only regional committee focusing on rootstock research, researchers from around the country, along with Canadian provinces, and Mexico (see table of participants) have joined and continue to participate.

A stable tree-fruit industry based on economically and environmentally sustainable orchard systems is one of the primary goals of NC-140 research. Prior to organization of NC-140, knowledge of rootstock and multiple genetic system performance and adaptability had to be obtained from a number of unrelated studies. The lack of common planting materials, spacing, and cultural procedures made comparison of the results of these studies difficult, and slowed the accumulation of knowledge that could be applied by orchardists. These difficulties coupled with the industry shifting to smaller trees with closer spacing resulted in serious planning and management errors leading to loss in revenue. Also, such unrelated studies were incomplete or slow in evaluating rootstock tolerances to biological, environmental, and edaphic stresses. Through the uniform cooperative testing undertaken by NC-140, new rootstocks are exposed quickly and systematically to widely varying soil and climatic conditions to shorten the time necessary for thorough evaluation.

Management systems

Any newly developed rootstock must exist ultimately as an integrated orchard-management system. Current economic trends make production efficiency of multi-genetic combinations under various management systems one of the most important factors that must be evaluated thoroughly before specific combinations are recommended for large-scale plantings by fruit growers. Uniform trials replicated within sites and across varying climatic and edaphic conditions have been established by the NC-140 Committee for many of the temperate-zone fruit trees.

Orchard systems, focusing on the rootstock, must be designed to meet the specific needs of each temperate-zone tree fruit crop. In northern Europe, where labor is expensive and new land is unavailable, the apple and pear industries have developed orchard systems with a high number of trees per acre, with all tree maintenance occurring from the ground by using size controlling rootstocks. In past years, the free-standing, central-leader system has been very profitable for North America, particularly with the weak, spur-type Delicious cultivar. As labor became more expensive and the list of profitable cultivars has changed, North American growers converted to smaller, high-density orchard systems on size controlling rootstocks. However, no

system can be taken in its entirety from one area and implemented in another without modifications. Growth characteristics of rootstocks under North American conditions are much different than in northern Europe where most high density systems were developed. Also, tree response under a particular management system in different areas in North America can vary greatly. These problems require that various rootstocks be tested under many North American climates and that modifications of training and pruning techniques be developed to match local growing conditions.

Rootstock development and improvement

If the temperate-zone fruit industry is going to continue to remain competitive in international markets and meet the needs of the consuming public, new genetic material will need to be incorporated into existing material to enhance performance of rootstocks. Through traditional plant breeding and novel genetic engineering methods including gene transfer, researchers can incorporate insect and disease resistance into existing rootstock material, as well as develop rootstocks with enhanced horticultural performance. Obtaining genetic material from research programs from throughout the world and testing those new rootstocks through the NC-140 cooperators has been an integral part of the project. Clonal materials of different rootstocks have been obtained from many countries since the inception of the NC-140 project and will continue. Rootstocks developed with new genetic engineering techniques can also be tested efficiently and effectively within the committee structure.

One of the major roadblocks that stands in the way of testing these new rootstocks is the very slow propagation time that is characteristic of clonal rootstocks. Usually new rootstocks are available in small numbers, because it takes several seasons (years) to propagate. Research on alternative ways of quick propagation of rootstocks is very much needed to shorten the time when these rootstocks will have a major positive impact on the industry

Genetics and developmental physiology

Knowledge of the physiological characteristics of newer rootstocks and the potential interactions with scion cultivars is important. The mechanism of how rootstocks control size either through genetic or physiological means needs to be studied at a basic level for the trait to be maximized in the orchard setting. Research on incompatibility between cultivars and rootstocks is a continuing need. Some promising temperate-zone fruit tree rootstocks cannot be considered for commercial production because of potential incompatibility. Understanding the mechanism of these incompatibilities will ultimately increase rootstock options for growers. In addition, techniques must also be developed to screen plant material early for desirable characteristics such as disease and insect resistance.

With many new rootstocks available for growers and nurseries, the need to be able to identify these plants via morphological and molecular methods is imperative. Some rootstocks stand out morphologically because of a difference in bark and leaf characteristics, but most do not. Developing methods for use in the laboratory and in the field will help all who use rootstocks to decrease the likelihood of planting mistakes.

Biotic and abiotic stresses

Low temperatures, soil adaptability, and susceptibility to pests limit the use of some existing rootstocks, and potentially will limit the adaptability of some new rootstocks within the North Central Region and across North America. Understanding how different rootstocks respond to biotic and abiotic stresses can lead to recommendations for use or non-use under certain orchard conditions. Such studies must include factors contributing to stress tolerance, development of practical means for controlling various stresses, or development of rapid means for screening potential rootstock candidates for susceptibility to various stresses. A better understanding of the physiological mechanisms behind these responses may allow for development of cultural practices which can relieve the detrimental effects of stress.

Cooperative testing of new and existing rootstocks by NC-140 researchers continues to generate interest and support from the fruit and nursery industries. This interest has resulted in industry financial support for the establishment of cooperative plantings, grants for state rootstock research, and propagation of trees for several of the NC-140 plantings. It is estimated that over the term of the current project (2002-2007), nearly \$2,000,000 will be received to support NC-140 research from sources other than universities, Hatch funds, and RRF funds, and more than one half of this total will come from grower organizations. A compelling need exists to continue the present coordinated studies and to initiate new studies on a regional basis for temperate-zone fruit tree rootstocks as new plant materials are made available. Continued testing will provide a thorough evaluation of promising rootstocks, multiple genetic systems, and planting and training system efficiencies. This research project has led and will lead to sound recommendations to growers and nurseries based on widespread knowledge of adaptability and performance of the plant material.

RELATED, CURRENT, AND PREVIOUS WORK:

Evaluation of rootstock influence on fruit tree characteristics under different management and environmental conditions

Promising new tree-fruit rootstocks are continually being introduced from worldwide sources (Beckman et al., 1997; Beckman and Lang, 2003; Bessho and Soejima, 1992; Cummins and Aldwinckle, 1994; DeJong et al., 2001; Fischer, 2001; Johnson, et al., 2001a; 2001b; Perry et al. 2000; Reighard et al., 2001a; Webster, 2001). Many of these new introductions will be propagated by North American nurseries for sale to U.S., Canadian and Mexican producers and to international markets. Without a coordinated, unbiased scientific approach to their evaluation, pome- and stone-fruit growers, who together plant about 30 million fruit trees a year, will be left with very little and often conflicting information on which to base a rootstock and planting system choice (Barritt et al., 1997b; DeJong et al., 1997). The wrong choice can be economically devastating (Barritt, 2000) for the grower and jeopardize the long-term supply of pome and stone fruits for North American and international customers.

Past studies document the effects of rootstock on survival, tree size, and cropping (Autio et al., in press; Hampson et al., 2004a; 2004b; NC-140, 1996b; 1996c; Perry et al., 2001a;

Reighard et al., 2004; Robinson et al., 2004; Whiting and Lang, 2004), horticultural characteristics (NC-140, 1996a), bud development and flowering (Conrod et al., 1996; Hirst and Ferree, 1995; Maguylo et al., 2004; Warmund et al., 2002), fruit ripening and quality (Autio et al., 1996), xylem structure (Olmstead et al., 2004), orchard systems (Robinson et al., 2005a; 2005b) and winter injury (Quamme and Hampson, 2004; Domoto et al., 2001; Warmund et al., 1996). The review cites these studies and concludes that no single rootstock is widely adapted to the range of conditions in North America. Superior productivity, precocity, and vigor control are still very important for new orchard designs. New rootstock cultivars, with added pest resistance, increased hardiness, and better root anchorage are urgently needed. Since rootstocks are the foundation of the orchard (Barritt, 2000) they remain a key to the design of a profitable high-density orchard system (Perry and Byler, 2001). Orchard designs are now more complex, as new cultivars like the low-vigor Honeycrisp and new tree-training systems such as the tall spindle and the super spindle with their inevitable interactions are added to the high-density design puzzle. It is necessary to answer these questions through coordinated, uniform testing prior to making rootstock recommendations. Only then will increases in competitiveness and profitability (Barden and Marini, 2001) be assured. NC-140 rootstock studies currently in progress will identify genotype response across a wide array of soils and climates in the fruit growing regions of the United States, Canada and Mexico (Autio et al., 2005a, 2005b). Documenting differences across climatic and edaphic conditions, whether it is longevity for peach (Perry et al., 2000; Reighard et al., 2004) or vigor control, fire blight tolerance and general performance for apple (Autio et al., 2001b; Barritt et al., 1997a; Marini et al., 2000a; 2000b; Norelli, et al, 2003; Robinson et al., 2005b), pear (Azarenko, et al., 2000), and cherry (Perry et al., 1997; Robinson et al., 2005a) is the common goal for new NC -140 collaborative studies.

In many trials, rootstock and location interact to affect tree performance (Autio et al., 2001a). Finding the exceptions and interactions with cultivars and the rootstocks (Autio et al., 2001b; Domoto et al., 2001; Reighard et al., 2004; Robinson et al., 2005b) on which they are grafted is of considerable value for the local producing region. The NC-140 committee is gaining confidence in predicting performance of certain genetic combinations, yet there is hesitancy to reduce the scope of the trials to just the sites with extremes in environment. The science of biometrics which strives to extract useful information from old data may be able to play a useful role in this perplexing question. This is especially important for the low vigor sites. Interactions highlight problems with our generally accepted view that harsh growing conditions would yield greater losses. Frequently, some of the top performers in one site perform poorly in another.

Marini et al. (2000b) points out that there are low-vigor sites at which none of the semi-dwarf rootstocks differed in size. If these NC-140 trials make it possible to classify tree growth for the North American production regions into high, low, and medium vigor it could be a major accomplishment. Regional planting recommendations will become much more data-dependent rather than subjective as is sometimes the case today. Much more work on tree mortality and management effects need to be analyzed and interpreted. A shift to rootstocks that fit an environment-first approach for orchard systems is gaining attention and may require new efforts or at the least the redirection of some (Reighard et al., 1997; Webster, 2001).

An unforeseen benefit of these cooperative studies is the building of an important data base. This resource could be highly valuable for numerous other research purposes, such as providing quantitative data on the impact of climate change. Repeatable findings which show the rootstock and interstem effects on field performance for pome- and stone-fruit trees grown across the major fruit producing regions of North America require long-term, well managed, and carefully documented field experiments (Autio, 1999; Johnson et al., 2001a; Perry et al., 2000). Using these data to determine the extent and patterns of climatic effects on orchard-system performance is a research goal of NC-140 with apples (Johnson et al., 2001b), pears (Azarenko et al., 2000), cherries (Perry et al., 1997), and peaches (Reighard et al., 2001a).

Rootstock development and improvement using multiple genetic resources

New tree fruit rootstocks have been and are being introduced from worldwide sources (Beckman et al., 1997; Bessho and Soejima, 1992; Cummins and Aldwinckle, 1994; DeJong et al., 2001; Johnson et al., 2001a; Perry et al., 1997; Reighard, 2000; Reighard et al., 2004; Reighard et al., 2001a; Khanizadeh, et al., 2005; Webster, 2001). Within the NC-140 technical committee each commodity has a committee which is chaired by one of the cooperators. This person takes the lead in assembling plant material from around the world for future trials. Since the plant material often must be quarantined before it is released it often takes a number of years from first contacts until the trial is ready to plant (Kappel et al., 1998). Since there are many weaknesses in many of the currently recommended rootstocks this search is considered an important part of the project activity list.

Utilization of diverse genetic resources in rootstock breeding has enabled the addition of several novel traits that have increased productivity and tolerance to biotic and abiotic stresses. These traits include dwarfing and precocity in cherry rootstocks (Vercammen, 2004), nematode resistance in peach rootstocks (Salesses et al., 1998) and fire blight, woolly apple aphid and powdery mildew resistance in apple rootstocks (Robinson et al., 2003). Another example of important traits identified in exotic material is resistance to fungal components of replant disease in *Malus sieversii* accessions from Kazakhstan – crosses with this source have already been made and selected progeny represent the future of apple rootstocks (Fazio et al., 2005).

Novel technology like gene transfer (Aldwinckle et al., 2000) may play an important role in the development of the next generation of rootstocks. The potential for rootstock improvement is enormous; however, field performance of genetically modified rootstocks will still be a prerequisite to recommendation for industry adaptation. This NC-140 committee is strategically positioned to advance this technology.

Genetics and physiology of rootstock/scion interactions

A more critical understanding of the fundamental traits and physiology of rootstock performance in combination with various scions is an important step in advancing rootstock science (Fernandez et al., 1997; Ferree and Schmid, 2001; Johnson and Lakso, 1991; Fazio et al., 2006). The fundamental reasons for the large differences in vigor between regions have, for example, not yet been discovered and documented (Domoto et al., 2001; Tartachnyk and Blanke,

2001). It is also recognized that fruit trees are compound genetic plants in which the rootstock and the scion interact which increases the complexity of fruit tree study (Lang et al., 1997; Psarras et al., 2000; Reighard et al., 2001b; Robinson, et al., 2003). Real advancements in our current knowledge of whole-tree physiology helps the committee focus on the critical unknown elements of performance thereby increasing research efficiency for the overall goals of the project as well (Psarras and Merwin, 2000).

Biotic and Abiotic Stress

Current and previous research has attempted to determine the spectrum of environmental adaptability for currently available rootstock genotypes. Their sensitivity to cold stress as measured by blackheart in the trunk (Domoto et al., 2001; Embree et al., 2000; Warmund et al., 1996) or tree survival (Robinson et al. 2006; Robinson et al., 2007) is becoming well documented. Controlled environment studies have also attempted to screen a large array of new rootstock genotypes for hardiness (Privé and Embree, 1997) and to simulate weather events (Privé et al., 2001). Finding new high-performing rootstocks less susceptible to the rigors of the North American production areas for apples, pears, cherries, and peaches is a clear necessity (Autio et al., 2001b; Barritt, 2000; Conrod et al., 1996). New emphasis is targeted to address the anticipated change in climate. Some predict that rootstocks will have to be more competitive for nutrients and water as inputs decline because of environmental concerns and loss of agricultural chemicals (Webster, 2001).

Evaluation of tolerance or resistance to biotic stresses has been the subject of considerable research. Numerous rootstocks from around the world have been screened for resistance to fire blight of apple (Noreli et al., 2003; LoGiudice et al., 2006). Cherry rootstocks have been screened for sensitivity to latent viruses (Lang et al., 1997), and peach rootstock have been screened for resistance to peach tree short life. Sources of resistance to specific pests will be sought as well. Already members of NC-140 have identified resistance to fire blight (*Erwnia*) in apple (Fazio et al., 2006; LoGiudice et al., 2006), and the peach tree short life complex in peach (Beckman et al., 1997) but much more progress is needed. Certainly progress in the area of marker-assisted selection of new rootstocks is key to NC-140 progress on behalf of fruit growers in North America. Some progress has been made in the understanding of traits that may be targeted for selection of rootstocks in apple and in peach (Boonprakob et al., 2001; Fazio and Mazzola, 2004; Horn et al., 2005).

In all field studies, it is recognized that trees may be variably subject to a number of biotic and abiotic stresses due to varying environmental and edaphic conditions. In each study, careful note is taken of causes of tree decline and death. Not only does this enable the committee to determine which rootstocks may be resistant or tolerant to certain biotic and abiotic stresses, but this will allow NC-140 to locate ideal sites for future efforts to make stress specific studies of resistance as appropriate materials are identified. As new tree-fruit rootstock trials are planned by NC-140 these concerns will be given careful consideration. It is also recognized that basic studies are needed to advance this area of knowledge. New hybrid *Prunus* rootstocks which confer precocity, and/or vigor control to sweet cherry are being tested for sensitivity to virus inoculations and cold stress (Lang et al., 1997). New rootstocks for peach that are more resistant

to biotic and abiotic stresses such as soil diseases, fine soil texture and cold temperatures still need to be found (Perry et al., 2000).

OBJECTIVES:

1. To evaluate the influence of rootstocks on temperate-zone fruit trees characteristics grown under different management systems and environmental conditions.
2. To develop and improve rootstocks for temperate-zone fruit trees with breeding and genetic engineering, to improve propagation techniques for rootstocks, and to acquire new rootstocks from worldwide sources.
3. To study the genetics and developmental physiology of rootstock/scion interactions in temperate-zone fruit trees.
4. To better understand the response to and impacts of biotic and abiotic stresses on scion/rootstock combinations in temperate-zone fruit trees.

METHODS:

Objective 1: To evaluate the influence of rootstocks on temperate-zone fruit trees characteristics grown under different management systems and environmental conditions.

To evaluate performance of rootstock material in different climatic and edaphic environments, current replicated and randomized uniform trials will be maintained, and new trials will be established across North America as part of the NC-140 project. Promising new and existing rootstocks and multiple genetic systems possessing desirable characteristics have been or will be selected. They will be evaluated with respect to precocity, productivity, size control, anchorage, suckering, pest resistance, adaptability, and production efficiency.

These trials will be maintained and data will be collected according to specific uniform guidelines established by the technical committee. For each trial, data to be collected will include root suckering, tree growth as measured by changes in trunk cross-sectional area, tree height, canopy spread, precocity, yield, fruit size, temperature, and rainfall/irrigation. Trials will be concluded after 10 growing seasons. Data will be transmitted annually to trial coordinators in British Columbia (1998 Western sweet cherry), Michigan (1998 Eastern sweet cherry), Michigan (1998 tart cherry), New York (1998 apple), Massachusetts (1999 dwarf apple), Massachusetts (1999 semidwarf apple), South Carolina (2001 peach), Oregon (2002 pear), California (2002 peach), Massachusetts (2002 apple), Pennsylvania (2003 apple), Oregon (2004 pear), Oregon (2005 pear), British Columbia (2009 sweet cherry), Michigan (2009 tart cherry), and Massachusetts (2009 apple). Standard statistical analyses will be performed on all data, and trials will be summarized for joint publications after five and 10 years of testing.

Plantings being maintained for evaluation or proposed for future establishment are as follows:

- (a) **1998 Western Sweet Cherry.** In 1998, a sweet cherry rootstock trial was established at 7 locations (CA, CO, two in OR, UT, WA, and BC) with Bing on Mazzard seedling, Mahaleb

seedling, Gisela 4, Gisela 5, Gisela 6, Gisela 7, Giessen 195/20, Giessen 209/1, Giessen 318/17, Weiroot 10, Weiroot 13, Weiroot 53, Weiroot 72, Weiroot 154, Weiroot 158, and Tabel Edabriz.

- (b) **1998 Eastern Sweet Cherry.** In 1998, a sweet cherry rootstock trial was established at 5 locations (MI, NY, PA, SC, and ON) with Hedelfingen on Mazzard seedling, Gisela 5, Gisela 6, Gisela 7, Giessen 195/20, Weiroot 10, Weiroot 53, Weiroot 72, Weiroot 158, and Tabel Edabriz.
- (c) **1998 Tart Cherry.** In 1998, a tart cherry rootstock trial was established at 5 locations (MI, NY, UT, WI, and ON) with Montmorency on Mahaleb seedling, Gisela 5, Gisela 6, Gisela 7, Giessen 195/20, Weiroot 10, Weiroot 13, Weiroot 53, Weiroot 72, Weiroot 158, and Tabel Edabriz.
- (d) **1998 Apple.** In 1998, an apple rootstock trial was established at 13 locations (MA, MI, MO-UM, NC, NJ, OH, three in NY, UT, WA, BC, and NS). Cultivars included Gala and Jonagold, and rootstocks were G.16N, G.16T, M.9, and M.9 EMLA.
- (e) **1999 Dwarf Apple.** In 1999, an apple rootstock trial was established at 18 locations with McIntosh (MA, MI, MN, two in NY, PA, VT, WI, ON, and NS) and Fuji (CA, KY, MO-UM, NC, two in PA, SC, and UT) as scion cultivars. Rootstocks included were G.41, CG.4013, CG.5179, G.202, G.935, G.16N, G.16T, M.26 EMLA, M.9 NAKBT337, Supporter 1, Supporter 2, and Supporter 3.
- (f) **1999 Semidwarf Apple.** In 1999, an apple rootstock trial was established at 16 locations with McIntosh (MA, MI, MN, two in NY, PA, VT, WI, ON, and NS) and Fuji (CA, KY, MO-UM, NC, SC, and UT) as scion cultivars. Rootstocks included were CG.4814, CG.6210, CG.7707, G.30N, G.30T, M.26 EMLA, M.7 EMLA, and Supporter 4.
- (g) **2001 Peach.** In 2001, a peach rootstock trial was established at 11 locations, including Redhaven (MO-MSU, NJ, UT, and ON), Cresthaven (CO, TX, and WA), and Redtop (CA, GA, MD, and SC) as scion cultivars. Rootstocks used were BH-4, SLAP, SC-17, Lovell, Bailey, Cadaman, Julior, P30-135 (Controller 9), Jaspi, Pumiselect, Hiawatha, K146-43 (Controller 5), K146-44, and VVA-1 (Krymsk 1).
- (h) **2002 Peach.** In 2002, a peach rootstock trial was established at 19 locations with Redhaven (CA, GA, MA, MD, MO-UM, OH, PA, SC, ON, and MEX) and Cresthaven (CO, IL, MO-MSU, NJ, NY, TX, UT, WA, and MEX) as scion cultivar. Rootstocks included were Adesoto 101, MRS 2/5, Penta, VSV-1 (Krymsk 2), VVA-1 (Krymsk 1), Pumiselect, Cadaman, and Lovell.
- (i) **2002 Pear.** In 2002, a pear rootstock trial was established in 4 locations with Anjou (OR, WA), Bartlett (WA), and Bosc (WA). Rootstocks included were 708-36, Fox 11, Fox 16 (except OR), OHxF40, OHxF87, Pyrodwarf, Pyro 2-33, and Winter Nellis.

- (j) **2002 Apple.** In 2002, an apple rootstock trial was established at 11 locations (AR, IL, IN, KY, MA, MI, NJ, NY, OH, BC, and MEX) with Gala as the scion cultivar. Rootstocks included were B.9Tresco, B.9Europe, M.9 Burgmer 756, M.9 Nic 29, M.9 NAKBT337, M.26 EMLA, M.26 NAKB, P.14, and Supporter 4. Some sites also included CG.3007, G.41, G.935, G.11, JM.1, JM.2, JM.7 PiAu 36-2, PiAu 51-11, PiAu 51-4, or PiAu 56-83.
- (k) **2003 Apple.** In 2003, an apple rootstock trial was established at 14 locations (AR, CA, GA, IA, KY, ME, MI, NY, OH, PA, UT, WI, BC, and MEX) including Golden Delicious as the scion cultivar. Rootstocks included B.62-396, B.9, G.41, CG.5179, G5935, CG.6210, G.16, JM.1, JM.2, JM.4, JM.5, JM.7, JM.8, JM.10, JTE-G, JTE-H M.26, PiAu 36-2, PiAu 51-11, PiAu 51-4, PiAu 56-83, M.9 Pajam 2, M.9 NAKBT337.
- (l) **2004 Pear.** In 2004, a pear rootstock trial was established at 3 locations (NY, WA, and, NS) with Concorde and Taylor's Gold on OHxF87, OHxF97 and Pyrodwarf.
- (m) **2005 Pear.** In 2005, a pear rootstock trial was established at 9 locations (3 in CA, NY, OR, 3 in WA, and Mex) with Anjou (OR and WA), Bartlett (2 in CA, NY, WA, and MEX), and Bosc (CA, and WA). Rootstocks included were 708-36 (except WA and MEX), BM 2000, Fox 11 (except WA and MEX), Horner-4 (except MEX), Pyrodwarf (except WA Anjou), and Pyro 2-33 (except WA and MEX). Some sites also included 28-119, BU-2, and BU-3.
- (n) **2009 Sweet Cherry.** In 2009, a sweet cherry rootstock trial will be established. Specific rootstocks and scion will be determined in early 2007.
- (o) **2009 Tart Cherry.** In 2009, a tart cherry rootstock trial will be established. Specific rootstocks and scion will be determined in early 2007.
- (p) **2009 Apple.** In 2009, an apple rootstock trial will be established with Honeycrisp as a scion cultivar. Likely locations include IA, IL, MA, ME, MI, MN, MO-UM, NC, NJ, NY, OH, PA, UT, WA, WI, BC, NB, ON, QC, and MEX. Possible rootstocks include P.60, P.559, B.112, AR 86-1-20, AR 86-1-25, AR 295-6, AR 931-15, AR 440-1, AR 680-2, AR 486-1, AR 628-2, AR 69-7, AR 360-19, M.20, CG.5087, CG.995, CG.12-3, CG.57-57, CG.6213, B.57-195, B.60-160, B.61-31, B.62-396, B.64-194, B.65-838, B.57-5(32), B.70-8-8, B.70-20-20, B.70-20-21, B.71-3-150, B.71-7-22, M.9 NAKBT337, and M.26 EMLA.
- (q) **2009 Peach.** In 2009, a peach rootstock trial will be established with clonal stocks from European breeding programs.

Other multi-state/province rootstock trials will be conducted on a regional basis, but will not involve the entire committee in the coordination. However, these will be reported as being under the work of NC-140. Tree performance in the projects will be evaluated as in previously mentioned rootstock trials.

These projects include the following:

- (a) In 2002, an apple rootstock evaluation trial was established in MA and NJ comparing M.9 NAKBT337, B.9, and G.16 with Cameo as the scion cultivar. Trees will be evaluated through the 2011 growing season.
- (b) In 1999, 2000, and 2001, apple trials were established in NY, MI, and WA of 5-10 promising new CG rootstocks from the USDA/Cornell rootstock breeding program to obtain an intermediate-stage evaluation of the rootstocks prior to NC-140 testing.

NC-140 participants will continue individual research to evaluate various aspects of performance and physiology as they relate to rootstock and training system: (1) evaluating performance of Honeycrisp apple on G.16 and M.26 EMLA (ME); (2) evaluating the performance of Fuji and Honeycrisp apple cultivars on G.11, G.16, CG.2034, CG.3041, CG.4213, CG.4214, CG.5012, CG.5087, CG.5463, CG.5890, CG.5935, and M.9 NAKBT337 (PA); (3) evaluating the performance of Fuji and Honeycrisp apple cultivars on G.30, CG.7037, CG.7480, CG.8534, and M.7 EMLA (PA); (4) evaluating the performance of John Boy peach on Controllor 5, Controllor 9, Krymsk 1, Krymsk 2, MRS 2/5, Penta, and Tennessee Natural (PA); (5) evaluating performance of Aurora Golden Gala apple on V.1, V.2, V.3, V.4, and M.9 NAKBT337 (BC); (6) evaluating the performance of Nittany on Mark, M.9 EMLA, B.491, and B.9 (PA); (7) evaluating the performance of Honeycrisp on several Cornell-Geneva rootstocks (MI); (8) evaluating the suitability of Sweetheart sweet cherry trees on MxM 14, MxM 39, MxM46, and MxM60 rootstocks for mechanically harvested brine cherries (OR); (9) evaluating the performance Regina sweet cherry on Giselas 5, 6 and 12 (OR); (10) evaluating the performance of Sweetheart and Stardust sweet cherry on Gisela 6, MxM14, Gi196-4 and Mazzard trained to either multiple leader, central leader, or Y trellis (OR); (11) evaluating the performance of Bing, Tieton, Sunset Bing, Sylvia, Benton, 13N07-39, Early Robin, Rainier, Sweetheart, and Skeena sweet cherries on Gisela 6, MxM14, Gi196-4, and Mazzard (OR); (12) evaluating the performance of dAnjou pear on 428 Horner rootstock clones (OR); (13) evaluating the performance of dAnjou, Bartlett, and Bosc pear on selected Horner rootstock clones (OR); (14) evaluating the performance of Cameo apple on M.9 NAKBT337, B.9, and G.16 (MA, NJ); (15) evaluating the performance of Gala, Honeycrisp and Fuji apple on G.16, G.11, G.41, G.4210, G.30, G.202, G.935, G.6210, M.9, B.9, M.26 and M.7 in 5 different orchard training systems covering a range of tree densities at 2 locations (NY); (16) evaluating the performance of 4 pear varieties (Bartlett, Bosc, Taylors Gold and Concorde) on 5 pear rootstocks (seedling, OHF97, OHF87, Pyrodwarf, Pyro2-33 and Quince) in 4 training systems covering a range of tree densities (NY); (17) evaluating the performance of Lapins, Regina, and Hudson on Gisela 5, Gisela 6, Gisela 12 and Mazzard rootstocks in 4 different orchard training systems covering a range of tree densities (NY); (18) evaluating European and Japanese plum varieties with several plum rootstocks (Cadaman, Penta, Ishtara, GF8-1, Torinel, Jaspi, and Krymsk-1) (NY); (19) evaluating MN apple selections on various rootstocks (MN); (20) evaluating vertical axis, slender spindle, V-axis, hytec, and minimally pruned York Imperial apple trees on M.9 NAKBT337 and on B.9 (PA); (21) evaluating Ginger Gold, Gala, and Fuji apple trees on M.9 NAKBT337 trained to a 4-wire trellis, vertical axis, slender spindle, or V-axis (PA); and (22) evaluating performance of York Imperial and Jonagold apple trees on M.9 NAKBT337, B.9, and G.41 under various spacings and training systems (PA).

Objective 2: To develop and improve rootstocks for temperate-zone fruit trees with breeding and genetic engineering, to improve propagation techniques for rootstocks, and to acquire new rootstocks from worldwide sources.

To enhance tree performance and pest resistance, traditional breeding programs will develop improved rootstocks for apples (NY), cherry (MI), and peaches (SC). Tolerance of rootstocks and multiple genetic systems in relation to pathogenic organisms will be investigated through evaluation of performance of trees in the trials listed under Objective 1. Additional work will be conducted, including: (1) apple rootstock tolerance of or resistance to fireblight, crown rot, latent viruses, lesion nematode, and specific apple replant disease (NY); (2) peach rootstock tolerance or resistance to nematodes (SC), peach tree short life syndrome (SC), and *Armillaria* root rot (GA, SC); (3) cherry rootstock tolerance or resistance to ilarviruses (WA), *Armillaria* (MI), and bacterial canker (OR); (4) genetic engineering procedures will be used to enhance pest resistance of apple rootstocks (NY); (5) mapping *Prunus* genome (MI and SC) and isolate markers for nematode resistance and use them in breeding programs (SC); (6) using cyclanilide to enhance the production of feathered nursery trees (WA); (7) genetic engineering virus-resistant cherry rootstocks (MI); and (8) improvement of propagation practices and techniques including tissue culture, layering and cuttings (NY, OR).

Significant effort also will be made to acquire new or unique material from around the world for future tests (MI, NY, SC, BC, and NS).

Objective 3. To study the genetics and developmental physiology of rootstock/scion interactions in temperate-zone fruit trees.

Rootstock and scion interact to define the characteristics of the fruit tree. The physiology of that interaction will be studied in a coordinated apple, peach, and sweet cherry trials:

- (a) **2003 Apple Physiology.** A trial was established at 20 sites (AR, CA, GA, IA, IN, KY, MA, ME, MI, NJ, NY, OH, PA, UT, WI, BC, NB, NS, ON, and Chih, MEX). All trees are Golden Delicious planted in spring, 2003, and rootstocks include M.9 NAKBT337, M.26 EMLA, and G.16. Beginning with the fourth growing season and continuing for three seasons, fruit set will be adjusted to give a range of crop loads for each rootstock from 2 to 14 fruit/cm² trunk cross-sectional area. Trial data will be annually transmitted to the trial coordinator (PA). The study will assess the varying influence rootstock and climate has on fruit development under conditions of varying fruit set.
- (b) **2004/05 Peach Physiology.** A trial was established in 2002 , including Cresthaven peach at six locations (CA, GA, MD, NJ, NY, and SC), to evaluate peach fruit-size potential under varying environmental conditions and crop load. Trial data will be annually transmitted to the trial coordinator (CA).
- (c) **2006 Sweet Cherry Physiology.** A trial was established in 2006 with Rainer cherry as the scion cultivar at four locations (CA, MI, NY, and WA), to evaluate the interaction of pruning strategy on fruit-size potential with the excessively precocious dwarf cherry rootstock Gisela

5 under varying environmental conditions. Trial data will be annually transmitted to the trial coordinator (MI).

Proposed research at individual institutions includes the following: (1) water and nutrient relations of peach rootstocks (CA); (2) relating susceptibility of peach rootstocks to peach tree short life to the presence or absence of specific genetic markers (SC); (3) the influence of 25 commercial and experimental rootstocks on liner architecture (size, branching, habit) and quality of finished nursery trees (NY, USDA); (4) developing an understanding of the genetic mechanisms underlying important rootstock traits (dwarfing, precocity, and disease resistance) using a segregating/mapping population from an interspecific apple rootstock cross (O.3 X Robusta 5 - designated O3R5), both on their own roots and with Gala as a scion (data from trees on their own roots and those with Gala will be combined with a genetic molecular marker map with the potential of using markers for screening for specific traits) (NY, USDA); and (5) evaluation of the impact of pruning severity on cherry fruit size with a range of cherry rootstocks (NY).

Objective 4. To better understand the response to and impacts of biotic and abiotic stresses on scion/rootstock combinations in temperate-zone fruit trees.

Studies will be conducted to elucidate stress tolerance of fruit trees as influenced by rootstocks. Basic rootstock performance data will be collected as part of the evaluation of rootstocks in the trials listed under objective 1; however, additional, more-detailed studies will be conducted by individual cooperators using these same rootstocks.

A uniform, coordinated trial was established in 2006 at 11 locations (IL, NC, 2 in NY, 2 in NJ/MA, PA, WA, NS, Chih and Coahuila, Mex) with a potential for apple replant disease. Gala apple on B.9, M.9 NAKBT337, M.9 Pajam 2, M.26 EMLA, M.7 EMLA, G.11, G.16, G.30, G.41, G.935CG.4210, and CG.6210 were utilized. At each location, one half of the plots were fumigated, thus allowing an assessment of the relative effects of apple replant disease on various rootstocks. Severity of apple replant disease was characterized at each site prior to planting. Trial data will be annually transmitted to the trial coordinator (NY).

Other stress-physiology studies will include: (1) adaptation of rootstocks to alkaline desert soils with pH higher than 8 and saline irrigation water (UT); (2) cold tolerance (including an assessment of freeze damage and tree recovery from freezing stress) of ungrafted apple rootstocks (M.26 EMLA, G.30, G.16, and CG.5935) (ME); (3) the cold hardiness of rootstocks and the influence of rootstock on scion cold hardiness for apple (IA, MN); (4) cultural management of peach to mitigate *Armillaria* root rot (GA); (5) interaction of girdling and rootstock as they affect peach fruit quality (GA); (6) evaluation of alternative nematicides in apple replant settings with various rootstocks (NJ); (7) evaluation of Lovell, Guardian® BY520-9, Adesoto, Monegro, VVA-1, VSV-1, K146-43, MRS 2/5, Pumiselect, Cadaman, and Penta with Redhaven peach as the scion cultivar on sites with severe *Armillaria tabescens* and peach tree short life (SC); (8) assessment of the effects of various rootstocks on low-temperature susceptibility of peach flower buds (MO-UM); (9) evaluation of the influence of apple

rootstocks (B.9, M.9, and M.27) and scions (Suncrisp and Fuji) on blackheart injury and determine the relationship between blackheart and tree growth (MO-UM); (10) evaluation of Rainier sweet cherry on Gisela 5, Gisela 6, and Gisela 12 under high plastic tunnels (MI); (11) evaluating new apple rootstocks for fire blight tolerance in the field by inoculating the scion cultivar and measuring rootstock infection and death (NY); (12) evaluating yield, plant growth, and economic costs and returns for Honeycrisp apple on M.26, B.9, and G.16 in replant and virgin soils under canola and wheat cover crops (WI).

MEASUREMENT OF PROGRESS AND RESULTS:

Outputs. The information developed through this project is vital to the economic success of the North American fruit industry by preventing mistakes by the industry and identifying rootstocks that are more productive and thus more profitable than existing rootstocks. This project has already become the primary source of information on rootstocks for the North American tree-fruit industry in each fruit production region of the continent. The primary outputs of this project have been and will continue to be unbiased information on the field performance, biotic and abiotic stress tolerance, and propagation of fruit tree rootstocks in different climates and soils across North America. This is measured by the continued flow of information to our stakeholders (fruit growers and nurserymen) through both oral presentations and publications (refereed, grower, and internet) from each of the uniform multi-state orchard plantings and from rootstock development and evaluation work done by the individual cooperators. Since the last project revision, this project has published 17 refereed reports on nine multi-state rootstock trials (1992 apple planting, 1993 apple planting, 1994 peach planting, 1994 dwarf apple planting, 1994 semidwarf apple planting, 1998 apple planting, 1998 Western sweet cherry planting, 1999 dwarf apple planting, 1999 semidwarf apple planting). Publications from individual researchers or groups or researcher under the objectives of this project are also an important measure of success, and since the last rewrite of this project, there have been more than 140 publications by individual researchers.

Outcomes or Projected Impacts. The expected outcome of this project is a more profitable and competitive tree fruit industry in North America. To remain competitive in the world fruit market, fruit growers need to replant old orchards, but the high level of investment required and the long-term nature of the investment to plant new orchards require that growers make sound research-based decisions of which rootstock and cultivar to plant. If the wrong rootstock is used, it can result in low production and reduced profitability or in the worst case, death of the trees and significant economic losses. If superior rootstocks are used, yields, fruit quality and hence profitability can be improved.

As results from this project are made available, the fruit industry has made and will continue to make changes in the rootstocks used. The impact of this project will be measured by the changes the fruit industry makes in adopting new improved rootstocks and by the prevention of serious rootstock failures and associated economic losses. This will be measured by surveying rootstock propagation nurseries to determine trends in which rootstocks are being planted by North American fruit growers.

In addition, data from the National Agricultural Statistics Service http://www.nass.usda.gov/Census_of_Agriculture/index.asp is analyzed to determine planting trends. The Census of Agriculture is published every five years and contains valuable data. This is then incorporated into our impact statements. Impacts are posted on our website <http://www.NC140.org> Many individual states also conduct tree fruit planting surveys periodically that are utilized to track planting trends of dwarfing tree fruit rootstocks and will be utilized to measure the impact of NC140 in individual states.

Milestones. The primary milestones of progress by this project over the next 5 years will be the publication of 5-year interim and 10-year final reports on the existing multi-state uniform plantings and the continued planning and planting of new uniform trials. Our plans for publication and planting milestones over the next 5 years are:

Year	Interim Reports Planned	Final Reports Planned	New Plantings Planned
2007	2002 Apple 2002 Peach 2002 Pear	1998 Apple Rootstock 1998 Western Sweet Cherry 1998 Eastern Sweet Cherry	
2008	2003 Apple	1998 Tart Cherry 2002 Peach Physiology	
2009	2004 Pear	1999 Dwarf Apple 1999 Semidwarf Apple 2003 Apple Physiology	2009 Apple 2009 Sweet Cherry 2009 Tart Cherry 2009 Peach
2010	2005 Pear		
2011		2001 Peach 2006 Apple Replant	
2012		2002 Peach 2002 Apple 2002 Pear 2003 Apple 2006 Cherry Physiology	

We expect to publish each interim and each final report in three formats: a refereed publication, a grower oriented publication, and on the internet at our website.

OUTREACH PLAN:

The NC-140 project is committed to disseminating research based results and information to the major clientele groups it serves, including commercial orchardists, fruit-tree nursery operators, industry representatives, professional colleagues, and small-scale orchardists and homeowners. The vehicle of outreach will primarily be through the Cooperative Extension System and our Professional Associations. Most project participants have joint extension and research appointments.

Results dissemination will be multifaceted. Our results will be communicated through: 1) the sharing of annual reports among all participating states at our annual technical committee meeting; 2) refereed research publications (print and internet); 3) presentations at professional meetings such as the American Society for Horticulture Science <http://www.ashs.org> and the International Society for Horticulture Science <http://www.ishs.org>; 4) grower publications in national fruit-grower magazines and via our website; 5) extension publications (print and internet) prepared by individual participants in the project for each state they represent; 6) oral presentations at both national and international fruit-grower meetings such as the International Fruit Tree Association annual conference; 7) numerous presentations will be made annually at regional, state and local fruit-grower meetings sponsored by Extension, often in conjunction with state horticulture or grower associations meetings; 8) regularly scheduled meetings with fruit tree nursery representatives from North America and Internationally, usually held in conjunction with the IFTA annual conference.

Electronic outreach will occur primarily through our web site, <http://www.NC140.org>. Cooperator contact information, annual reports and minutes, rootstock planting descriptions, and research results are available on the website. Results will include: Abstracts of publications, with links to the journals to obtain the full article; full articles from the Journal of the American Pomological Society; reprints and or links to trade magazine, and extension newsletter articles and presentations of poster and professional talks. Links to related rootstock web pages will be available, some of which will include NC-140-generated information.

Plantings - our research results will be summarized for publication in professional journals. Most refereed journal publications will be placed in the *Journal of the American Pomological Society* and reprinted online in Adobe PDF format on the NC140 website at <http://www.nc140.org/plantings.html>. Some planting results will be summarized for grower audiences and published in trade publications. International publication will occur primarily through the International Fruit Tree Associations periodical, *Compact Fruit Tree* (available in a printed form and online at <http://www.ifruittree.org/>) and the International Society of Horticultural Science publications *Acta Horticulturae*.

State/province cooperators will also publish grower articles of results and recommendations in appropriate extension newsletters, fact sheets, and experiment station reports and bulletins. Additional outreach will occur through numerous educational programs at on-farm field days, twilight meetings, and winter education meetings within each state/province and annually at the Annual Meeting of the International Fruit Tree Association.

Clientele Input - On a state/province basis, stakeholder advisory groups will be convened annually as part of their extension mandates. Through this process, direction, feedback, and input for NC-140 research will be obtained and incorporated into individual cooperators work plans. Special effort will be made when assembling these advisory groups to be inclusive of under-served and under-represented farmers and non-farmer stakeholders, such as consultants, support-service providers, environmental advocates, and consumers. The NC-140 web site is open access and will have published policies on accessibility, privacy, and nondiscrimination modeled after CSREES and USDA.

ORGANIZATION AND GOVERNANCE:

This regional Technical Committee will be organized for the North Central Region as outlined in the *Guidelines for Multistate Research Activities*. The executive committee shall consist of the chairperson, vice chairperson, secretary, immediate past chairperson, the coordinator of each NC-140 trial, and the crop committee chairs. Each year a secretary will be elected to serve for one year, and the past vice-chairperson and the secretary will advance to the next higher office commencing in January. Members of the executive committee will set the annual meeting agenda, write and distribute the minutes and annual report, and act on the Committees behalf if necessary. An Administrative Advisor will act as an advisor to the Committee on procedures and policies related to regional research and provide coordination and communication with other regional projects and the North Central Directors. Annual meetings will be held for the purpose of evaluating current work, planning future work, and coordinating publications of a regional nature which may result from the work undertaken in the regional project. Each year, the chairperson will be responsible for organizing and the leading the annual meeting, the vice chairperson will submit the annual report, and the secretary will submit the meeting minutes.

For uniform, coordinated projects established under Objectives 1-4, coordinators will be appointed on a continuing basis to coordinate the trials: Kappel (BC)-1998 Western sweet cherry; Lang (MI)-1998 Eastern sweet cherry; Lang (MI)-tart cherry; Robinson (NY)-1998 apple; Autio (MA)-1999 dwarf apple; Autio (MA)-1999 semidwarf apple; Reighard (SC)-2001 peach; Johnson (CA)-2002 peach; Autio (MA)-2002 apple; Castagnoli (OR)-2002 pear; Marini (PA)-2003 apple; Marini (PA)-2003 apple physiology; Castagnoli (OR)-2004 pear; Johnson (CA)-2004/05 peach physiology; Castagnoli (OR)-2005 pear; Robinson (NY)-2006 apple replant, Lang (MI)-2006 sweet cherry physiology; Kappel (BC)-2009 sweet cherry; Lang (MI)-2009 sweet cherry, and Autio (MA)-2009 apple. These coordinators will provide technical oversight concerning those plantings, maintain contact with the participants through correspondence, transmit pertinent information to participants and the Committee to insure uniformity of the studies, prepare data collection forms and details of coordinated procedures which will permit a consolidation of the research findings, assemble and analyze combined data or summarize data previously analyzed, initiate all publications regarding the planting, and report annually to the Committee on progress of the planting.

Standing committees for each major crop will be appointed to plan, assemble plant material, and propagate trees for future multi-location uniform trials: Robinson (NY)-apple; Reighard (SC)-peach; Elkins (CA)-pear; and Kappel (BC) and Lang (MI)-cherry.

The Hatch Multi-State Research Funds expended on NC-140 (among all the cooperating states) will leverage approximately \$2,000,000 of additional funds from various granting organizations, including Federal and state agencies, local grower organizations, and the International Dwarf Fruit Tree Association. The Executive Committee will oversee funding requests in support of the NC-140 project.

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