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, 2012, to September 30, 2017

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 and in North America. This project seeks to enhance economically and environmentally sustainable practices in temperate fruit production by focusing on rootstocks and root systems. The NC-140 project meets the guidelines presented by the North Central Regional Association (NCRA) in *Guidelines for Multistate Research Activities* (July, 2010). 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 disciplines in multiple states. Researchers involved in this project have leveraged Federal and state dollars to add significant financial and in-kind resources to address this important 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 highly 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 economically and environmentally sustainable management schemes of production. Growers who want to stay profitable must establish high-density plantings with smaller trees using new cultivars. These high-density plantings cost 10 to 20 times more per land area to establish than lower-density plantings, thus greatly enhancing economic risk. Potential returns of high-density plantings, however, far exceed those of low-density plantings, particularly during the first 10 years. The central component of a high-density system is the rootstock, the part of the tree which provides control of final tree height allowing for closer tree spacing and greater number of trees per land area. 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. However, size-controlling rootstocks are lacking for many fruit crops, and those rootstocks that are available have inherent weaknesses. Past research has successfully identified size controlling and early bearing rootstocks for apple and cherry, but inefficient rootstocks remain a problem for other tree fruits. Continued tree losses due to cold temperature injury, disease, scion incompatibility, and poor soil conditions are an economic cost for the industry that can be ameliorated by improving rootstock choices for growers.

Success with new orchard systems depends on reliable recommendations that are based on sustained research. New pome- and stone-fruit rootstocks cannot be recommended unless there is coordinated multi-site research investigating soil and climatic adaptability, root anchorage, size control, precocity, productivity, pest resistance, and propagation. Tree fruits are long-lived perennials, so a minimum of eight years is necessary to obtain an indication of rootstock performance and to accurately assess the potential for improved profitability, reduction of external farm inputs, and enhancement of production efficiency. With ever-increasing use of high density systems, there is a concomitant demand by growers for research that solves problems and for timely information that prevents costly mistakes.

A stable tree-fruit industry based on economically and environmentally sustainable orchard systems is one of the primary goals of NC-140 research. Knowledge of rootstock performance has led to research-based recommendations that have been adopted by the industry and have led to increasingly efficient orchard systems. Prior to organization of NC-140, knowledge of rootstock performance and adaptability was obtained from unrelated studies resulting in serious planting and management errors thus a loss in revenue. Evaluating rootstock tolerances to biological, environmental, and edaphic stresses requires uniform, cooperative testing. New rootstocks are quickly and systematically exposed to widely varying soil and climatic conditions to shorten the time necessary for thorough continental evaluation.

Any newly developed rootstock must exist as an integrated orchard-management system. Current economic trends make production efficiency of multi-genetic plant combinations in 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.

Orchard systems, focusing on the rootstock, must be designed to meet the specific needs of each temperate-zone tree fruit crop. One of these needs is the high cost and scarcity of labor. In response, the apple and cherry industries have developed high density orchard systems with a smaller trees and a higher number of trees per acre, with all tree maintenance occurring from the ground using size controlling rootstocks. High density systems were originally developed in Europe with rootstocks adapted to a European climate. Research done by NC140 members demonstrated growth characteristics of rootstocks under North American conditions were different than in northern Europe, with tree responses varying greatly across regions in North America. Meanwhile, rootstock breeding programs have resulted in many new elite selections that may be better adapted to the range of North American environmental conditions. These new rootstocks combined with new management systems require testing under many North American climates and modifications of training and pruning techniques must be developed to match local growing conditions.

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 to enhance performance. Through traditional plant breeding and novel genetic engineering methods, 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.

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.

One of the major roadblocks that limits industry access to new rootstocks is the very slow propagation time that is characteristic of clonal rootstocks. New rootstocks are available in small numbers because it takes several years to propagate a sufficient number of plants for rapid multiplication. Research on alternative ways to quickly propagate rootstocks is very much needed to shorten the time when these rootstocks will have a positive impact on the industry.

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 in North America. Studies should include factors contributing to stress tolerance, controlling various stresses, or rapidly screening potential genotypes for susceptibility or tolerance. 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 and expand production into previously suboptimum soils and climates.

Outreach will continue to be integral to the project. Using eXtension, members of NC-140 will expand availability of information electronically, in addition to regional and local web sites. Additional outreach efforts will continue including written material for growers and other stakeholder groups, on-site educational programs in individual states and at national and international grower and scientific meetings

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. Individual researchers will use support from industry as seed money to leverage and seek state, federal and private foundation grants (competitive and non competitive) for associated studies. It is estimated that over the term of the current project (2012-2017), *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.

Uniform trial plantings, supported by local industry growers, have been used in the past as research sites in which researchers collected preliminary or critical data to support objectives of competitive extramural grant projects and proposals. For example, early trial work in apples identified an apple rootstock, B.9, which demonstrated little to no Fireblight infection of the scion canopy in field plots. Researchers at Cornell University used this site and field observations to launch more in-depth research, funded by larger competitive grants demonstrating and confirming the effects of B.9 in suppressing disease pathogenesis.

The proposed research will enhance economic viability of farms through improved selection of rootstocks leading to greater production efficiency and improved fruit quality. Orchards may use labor and land more efficiently leading to a faster return on investment with fewer tree losses.

A compelling need exists for these coordinated studies and to initiate new research on a large scale 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 and will continue to lead to sound recommendations to growers and nurseries based on widespread knowledge of adaptability and performance of plant material.

RELATED, CURRENT, AND PREVIOUS WORK:

Promising new tree-fruit rootstocks are continually being introduced from worldwide sources (DeJong et al., 2011; Khanizadeh et al., 2011b; Univer et al., 2011; Zhang et al., 2011; Zurawicz et al., 2011). Past studies document the effects of rootstock on survival, tree size, and cropping (Autio et al., 2011a; Autio et al., 2011b; Autio et al., 2011c; Reighard et al., 2011), horticultural characteristics (NC-140, 1996a), bud development and flowering (Maguylo et al., 2004; Warmund et al., 2002), fruit ripening and quality (Marini et al., 2008), xylem structure (Tworkoski and Fazio, 2011), orchard systems (Lang et al., 2011; Robinson et al., 2011) and winter injury (Moran et al., 2011). 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, they remain a key to the design of a profitable high-density orchard system (Dorigoni et al., 2011; Elkins and DeJong, 2011; James and Middleton, 2011). 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 (Robinson et al., 2011). Coordinated, uniform testing prior to making rootstock recommendations is essential. Only then will increases in competitiveness and profitability 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. Documenting differences across climatic and edaphic conditions, whether it is longevity for peach (Reighard et al., 2004) or vigor control, fire blight tolerance and general performance for apple (Robinson et al., 2005b), pear (Azarenko, et al., 2000), and cherry (Robinson et al., 2005a) is the common goal for new NC -140 collaborative studies.

New tree fruit rootstocks have been and are being introduced from worldwide sources. 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 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 (Beckman, 2011) and fire blight, woolly apple aphid and powdery mildew resistance in apple rootstocks (Fazio et al., 2006; Russo et al., 2007). 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., 2009).

Novel technology like gene transfer (Aldwinckle et al., 2009; Malnoy et al., 2010) 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 before industry adoption.

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. At the cellular level, rootstocks can modulate the expression of genes in the scion (Jensen et al., 2010; Jensen et al., 2011) resulting in changes in morphology, tree architecture, and disease resistance (Tworkoski and Fazio, 2011; Tworkoski and Miller, 2007). Although some of the genetic factors underlying differences in vigour and precocity are being investigated, (Celton et al., 2009; Fazio et al., 2011; Rusholme et al., 2004) 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). Fruit trees are compound genetic plants in which the rootstock and the scion interact which increases the complexity of fruit tree study (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.

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 or tree survival has been documented. Controlled environment studies have also attempted to screen a large array of new rootstock genotypes for hardiness 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. 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 due to environmental concerns.

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 (Norelli et al., 2003; LoGiudice et al., 2006). Cherry rootstocks have been screened for sensitivity to latent viruses, apple rootstocks have been evaluated for resistance to phytoplasma, and peach rootstocks have been screened for resistance to peach tree short life (Beckman, 2011; Lankes, 2011; Lankes and Baab, 2011). Tolerance to the replant disease complex is being characterized in rootstocks by NC-140 members (Auvil et al., 2011; Parker et al., 2011; St. Laurent et al., 2010). Replant disease has been characterized as a high priority by many fruit growers as fumigants become scarce (Mazzola et al., 2009).

OBJECTIVES:

1. To evaluate the influence of rootstocks on temperate-zone fruit tree characteristics grown under varying environments using sustainable management systems.
2. To develop improved rootstocks for temperate-zone fruit trees using state-of-the-art genomic tools in breeding programs.
3. To accelerate adoption of new rootstocks (a) by improving propagation techniques and (b) by acquiring new rootstocks from worldwide sources.
4. To better understand the impacts of biotic and abiotic stresses on scion/rootstock combinations in temperate-zone fruit trees.
5. To enhance the sustainability of temperate fruit farming through development and distribution of research-based information utilizing eXtension.

METHODS:

Objective 1

To evaluate the performance of rootstock material in different climatic and edaphic environments, established replicated 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. Evaluation for survival, precocity, productivity, size control, anchorage, suckering, pest resistance, adaptability, and production efficiency will occur.

Data will be collected according to specific guidelines established by the technical committee. For each trial, data 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 formally concluded after 10 growing seasons. Designated cooperators will serve as coordinators who will collect and archive data for the life of each trial. Data will be processed and annual progress reports shared with trial cooperators and the full membership at annual meetings. Trials are established by cooperators and coordinated by representatives from PA (2003 apple), CA (2004 pear), CA (2005 pear), SC (2009 peach), MI (2009 cherry physiology), CA (2009 peach physiology), MI (2010 sweet cherry), MA (2010 Honeycrisp apple), MA (2010 Fuji apple), OR (2012 pear), OR (2013 pear), NY (2014 organic apple), SC (2014 apple), MI (2015 sweet cherry), MI (2015 tart cherry), MA (2016 apple), SC

(2016 peach, plum, and apricot), and OR (2016 pear). Standard statistical analyses will be performed on all data, and trials will be summarized for joint publications after five and 8-10 years of testing.

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

(a) 2003 Apple. In 2003, an apple rootstock trial was established at 14 locations (AR, BC, CA, CH, GA, IA, KY, ME, MI, NY, OH, PA, UT, and WI) with Golden Delicious as the scion cultivar. Rootstocks included B.62-396, B.9, G.41, CG.5179, G.5935, 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.

(b) **2003 Apple Physiology.** A trial was established with Golden Delicious at 20 sites (AR, BC, CA, CH, GA, IA, IN, KY, MA, ME, MI, NB, NS, NJ, NY, OH, ON, PA, UT, and WI). Rootstocks in this trial are M.9 NAKBT337, M.26 EMLA, and G.16. Beginning with the fourth growing season and continuing for three seasons, fruit set was adjusted to give a range of crop loads for each rootstock from 2 to 14 fruit/cm^2 trunk cross-sectional area. The study is assessing the influence rootstock and climate has on fruit development with varying fruit set.

(c) **2004 Pear** trials were established in NY and NS to compare the performance of 'Concorde' and 'Taylors Gold Comice' on three rootstocks, Old Home x Farmingdale (OHxF) 87, OHxF97 and Pyrodwarf.

(d) **2005 Pear.** Eight trials were established in CA (Bartlett, Bosc), CH (Bartlett), NY (Bartlett, Bosc), OR (D'Anjou) and WA (Bosc) to compare several cultivars on 13 rootstocks. The number of rootstocks varied with trial and included 28-119, 708-36, BM2000, Fox 11, Horner 4, OHxF 69, OHxF 87, OHxF 97, Pyrodwarf, Pyro-233, Winter Nelis, BU-2, and BU-3.

(e) **2009 Peach.** In 2009, a peach rootstock trial was established with Redhaven as a scion cultivar at 16 locations (AL, CA, CHx2, CO, GA, IL, KY, MA, MO, NC, NYx2, PA, SC, and UTx2). Rootstocks included were Viking, Atlas, BH-5, Empyrean 1, Guardian, Lovell, KV010123, KV010127, Krymsk 86, Fortuna, Empyrean 3, Empyrean 2, HBOK 10, HBOK 32, *Prunus americana*, Krymsk 1, and Controller 5.

(f) **2009 Peach Physiology.** A trial was established in 2009 with three cultivars (Crimson Lady, Redhaven and Cresthaven) at 14 locations (AL, AR, CA, CO, GA, ID, IL, KY, MD, NJ, NY, NC, SC, and UT), to evaluate peach fruit size potential and fruit quality under varying environmental conditions.

(g) **2010 Sweet Cherry Systems.** In 2010, a sweet cherry rootstock x training systems trial was established with Benton (CA, IN, MI, and OH), Skeena (BC, CH, CO, and NS), Regina (NYx2), and Bing (OR) as scion cultivars. Rootstocks (Gi3, Gi5, and Gi6) were included in all combinations with training system (tall spindle, UFO, and KGB at all sites, plus super slender axe at MI and NY).

(h) **2010 Honeycrisp Apple.** In 2010, an apple rootstock trial was established with Honeycrisp as a scion cultivar at 15 locations (BC, CH, CO, IL, IN, IA, MA, MN, MI, NJ, NS, NY, OH, UT, and WI). Rootstocks included B.9, B.10, B.7-3-150, B.67-5-32, B.64-194, B.70-6-8, B.70-20-20, B.71-7-22, G.11, G.41N, G.41TC, G.202N, G.202TC, G.935N, G.935TC, CG.2034, CG.3001, CG.4003, CG.4004, CG.4013, CG.4214, CG.4814, CG.5087, CG.5222, PiAu 51-11, PiAu 9-90, Supp.3, M.26 EMLA, M.9 Pajam 2, and M.9 NAKBT337.

(i) **2010 Fuji Apple.** In 2010, an apple rootstock trial was established with Aztec Fuji as a scion cultivar at seven locations (CH, ID, KY, NC, NY, PA, and UT). Rootstocks included B.9, B.10, B.7-3-150, B.67-5-32, B.64-194, B.70-6-8, B.70-20-20, B.71-7-22, G.11, G.41N, G.41TC, G.202N, G.202TC, G.935N, G.935TC, CG.2034, CG.3001, CG.4003, CG.4004, CG.4013, CG.4214, CG.4814, CG.5087, CG.5222, PiAu 51-11, PiAu 9-90, Supp.3, M.26 EMLA, M.9 Pajam 2, and M.9 NAKBT337.

(j) **2012 Pear.** In 2012, a pear rootstock trial will be established with Bartlett (CA and OR) and d'Anjou (OR) as scion cultivars. Rootstocks will include the *Amelanchier* clones A1, A4, and A7.

(k) **2013 Pear.** In 2013, a pear rootstock x training system trial will be established with Bosc (NY), Bartlett (CA, WA), and d'Anjou (OR) as scion cultivars. Rootstocks at each site will include Pyro 2-33, OHxF 87 and OHxF 69. Rootstocks will be combined with three training systems (Bibaum, tall spindle, and perpendicular V) in all combinations at all locations.

(l) **2014 Organic Apple.** In 2014, an apple rootstock trial will be established in certified organic blocks at approximately 15 North American locations. Rootstocks will include releases from the Cornell-Geneva Apple Rootstock Breeding Program in comparison with M.9 NAKBT337.

(m) **2014 Apple.** In 2014, an apple rootstock trial at several locations, primarily in the southern U.S. Rootstocks will include several Geneva rootstocks, B.9, B.10, and M.9 NAKBT337.

(n) **2015 Sweet Cherry.** In 2015, a sweet cherry rootstock trial will be established at 6 to 12 locations across the U.S., Canada, and Mexico. Rootstocks will include Gi5 and new or previously untested introductions such as Gi12, Krymsk 5, Krymsk 6, MSU Cass, MSU Clare, MSU Clinton, MSU Kent, PiKu 1, PiKu 4 and MxM 14.

(o) **2015 Tart Cherry.** In 2015, a tart cherry rootstock trial will be established at 3 locations across the U.S. Rootstocks will include Mahaleb and new or previously untested introductions such as Gi12, Krymsk 5, Krymsk 6, MSU Cass, MSU Clare, MSU Clinton, MSU Kent, PiKu 1, PiKu 4 and MxM 14.

(p) **2016 Apple.** In 2016, an apple rootstock trial will be established at approximately 20 locations across the U.S., Canada, and Mexico. Rootstocks will include new introductions from the Cornell Geneva, European, and Asian breeding programs.

(q) **2016 Peach, Plum, and Apricot.** In 2016, a peach, plum, and apricot rootstock trial will be established at approximately 20 locations across the U.S. and Mexico. Rootstocks will include new U.S. and European introductions.

(r) **2016 Pear.** In 2016, a pear rootstock trial will be established at approximately 10 locations across the U.S., Canada, and Mexico. Rootstocks will include new quince rootstocks, among others.

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) **2010 Tart Cherry Systems.** In 2010, two separate tart cherry rootstock x training systems trials were established with Montmorency at MI (Gi3, Gi5, Gi6, Mahaleb, and Montmorency on its own roots) and UT (Gi3, Gi5, Gi6, and Mahaleb), with 3 high density training systems studied at each site.

(b) **2013 Vineland Apple.** In 2013, an apple rootstock trial will be established in ON, NS, and BC comparing Honeycrisp trees on V.5, V6, V.7, M.9 and M.26.

(c) **2014 Vineland Apple.** In 2014, an apple rootstock trial will be established at various locations in the U.S. and Mexico including trees on V.5, V.6, V.7 and other promising rootstock candidates.

NC-140 participants will continue individual research to evaluate various aspects of performance and physiology as they relate apple to rootstock and training system: (1) evaluation of G.11, G.16, CG.2034, G.41, CG.4213, CG.4214, CG.5012, CG.5087, CG.5463, CG.5890, G.935, and M.9 NAKBT337 (PA); (2) evaluation of G.30, CG.7037, CG.7480, CG.8534, and M.7 EMLA (PA); (3) evaluation of G.41, G.935, G.210, G.65, Ottawa 3, CG.4210, M.9T337, B.491 (PA); (4) evaluation of B.9 and Fuji on M.9 NAKBT337 trained to tall spindle, vertical axis, tall trellis or minimally pruned (PA); (5) evaluation of the effects of M.27, M.27/MM111 interstem, B.9, M.9 Fleuren 56, Supporter 4, G.30, MM.111 EMLA, M.7 EMLA on genetic expression of the scion (PA); (6) evaluation of Geneva rootstocks under high pH conditions (CO); (7) determination of sustainability, efficiency, productivity, and winter hardiness of SnowSweet and Minneiska apples on B.9, G.16, G.30, M.26 EMLA, M.7 EMLA, M.9 NAKBT337, V.1 and V.3 (MN); (8) evaluation of 31 rootstocks (IN); (9) evaluation of 47 Geneva rootstocks, with B.9 and 3 Malling stocks as controls (NY); (10) evaluation of 39 CG rootstocks, 4 Japan Morioka stocks, 4 PiAu stocks, 2 JTE stocks B.118, O.3 and 5 Malling stocks (NY); (11) evaluation of the performance of 11 apple rootstocks (G.16, G.11, G.41, G.4210, G.30, G.935 G.6210, M.9, B.9, M.26 and M.7) in 4 different orchard training systems (tall spindle, slender axis, vertical axis and slender pyramid) planted in a range of tree densities using 3 apple cultivars (NY); (12) evaluation of the performance 6 Geneva rootstocks (G.16, G.41, G.11, G.935, G.6210 and G.30) along with M.9, M.26, M.7 and B.118 as controls in 4 high density orchard systems (vertical axis, triple axis, tall spindle and super spindle) (NY); (13) evaluation of 34 Geneva rootstocks, 3 Malling controls, B.9, Vineland 1, Ottawa 3 and P.22 (NY); (14) evaluation of 42 Geneva rootstocks, 4 Malling controls, B.9, B.118 and Mark (NY); (15) evaluation of 4 Geneva rootstocks and 3 Malling controls (NY); (15) evaluation of 32 Geneva rootstocks, 6 Malling controls, 5 Budagovsky (B), 1 PiAu and 1 Vineland (V) (NY).

NC-140 participants will continue individual research to evaluate various aspects of performance and physiology as they relate peach to rootstock and training system: (1) evaluation of Controller 5, Controller 9, Krymsk 1, Krymsk 2, MRS 2/5, Penta, and Tennessee Natural (PA); (2) evaluation of the HBOK/Controller series (CA).

NC-140 participants will continue individual research to evaluate various aspects of performance and physiology as they relate cherry to rootstock and training system: (1) evaluation of tart cherry on Gi3, Gi5 and Gi6 rootstocks in a high density orchard (UT); (2) evaluation of the performance of 4 cherry rootstocks (Gi5, Gi6, Gi12 and Mazzard) in 4 different orchard training systems (vertical axis, Spanish bush, quad axis and central leader) with 3 sweet cherry cultivars (NY).

NC-140 participants will continue individual research to evaluate various aspects of performance and physiology as they relate pear to rootstock and training system: (1) evaluation of selections of *Amelanchier* as a potential pear rootstock (CA, OR); (2) establishment of a pear systems trial of 3 rootstocks, 3 training systems, and 3 spacings (CA, NY, OR); (3) evaluation of the performance of 6 pear rootstocks (seedling, OHxF97, OHxF87, Pyrodwarf, Pyro2-33 and Quince) in 4 training systems (central leader, vertical axis, tall spindle and super spindle) planted in range of tree densities using 4 pear cultivars (NY).

Objective 2

To enhance tree performance and pest resistance, traditional and marker-assisted breeding programs will develop improved rootstocks for apples (NS, NY), cherry (MI), peaches (GA, SC), and pears (WA). Each of these breeding program directors will supply progress reports and updates regarding the results of their work which will be shared at annual meetings with committee members. Where possible and needed, cooperators and members of the committee may serve as second- or third- phase testing sites for confirmation of biotic stress resistance. Eventually, offspring identified as having promise from these programs will enter the uniform trial testing process as described in Objective 1. Additionally, manuscripts or their published citations will be shared with the members at-large, regarding results from these studies.

Specific objectives of the breeding programs include: (1) peach rootstock tolerance or resistance to root-knot nematodes (GA), peach tree short life syndrome (GA), and *Armillaria* root rot (GA); (2) cherry rootstock tolerance or resistance to *Armillaria* (MI), and bacterial canker (OR); (3) mapping *Prunus* genome (MI and SC) and isolate markers for nematode resistance to use in breeding programs (SC); (4) development of new rootstocks for cherry trees, based on genotypes generated and selected from the sour cherry variety breeding program (MI); (5) evaluate tolerance of new cherry rootstocks to indigenous species of *Armillaria* (MI); (6) genetic engineering of potential virus resistance in cherry rootstocks (MI); (7) development of 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-ARS Geneva Breeding Program); (8) pear parental germplasm has been established and will be used to start *pyrus* rootstock breeding focusing on vigor control and resistance to various biotic and abiotic stresses (WA).

Objective 3

Research conducted to improve propagation capability of rootstocks will be conducted at individual institutions. Research directors and committee members involved in these projects will supply progress reports and updates regarding the results of their work which will be shared at annual meetings with committee members. Research results that will enhance propagule availability will be shared with the committee membership and especially those planning future trials where sourcing of propagules is a challenge. Additionally, manuscripts or their published citations will be shared with the members at-large, regarding results from these studies. Proposed research at individual institutions includes the following: (1) improvement of propagation practices and techniques including tissue culture and evaluation of that material in the field (CA, MD, ME, MI, NS, NY, ON, OR, and WA) and the use of layering and cuttings (NY and WA); (2) comparison of ease of propagation of the Weiroot series of cherry rootstocks (Weiroot 10, 13, 72, 158, and 12) with Gi6 and Mahaleb (ON); (3) development of novel nursery production techniques for small-scale, organic apple nurseries (MI); (4) comparison of stoolbed produced and tissue-cultured G.202 rootstocks with Gala and Cripps Pink as scion cultivars (MD); (5) study the use of benzyl adenine and cyclanilide to enhance the production of feathered nursery trees (NY); (6) evaluation of stoolbed management approaches with Geneva apple rootstocks, including source of plant material planting density, planting angle and plant growth regulators (NY); and (7) propagation of the Vineland series of apple rootstock via tissue culture to increase quantities available for U.S. nurseries (ON).

Significant effort also will be made to acquire new or unique material from around the world for future tests: apple (BC, ID, NS, NY), peach (SC), and cherry (MI). Of particular interest are new apple rootstocks from New Zealand and East Malling, UK.

Objective 4

Studies will be conducted by individual members and cooperators at various institutions 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 led and conducted by individual cooperators using these rootstock plantings as uniform multiple test sites. Trial coordinators or cooperators will canvas cooperators to determine interest in conducting separate, more detailed studies on a specific parameter. Those leading the effort will supply progress reports and updates regarding the results of their work which will be shared colleagues collecting the data and information and it will be shared with the full membership at annual meetings. Additionally, manuscripts or their published citations will be shared with the members at-large, regarding results from these studies. Stress-related studies will include the following.

Low-temperature stress: (1) assessment of the effects of various rootstocks on low-temperature susceptibility of peach flower buds (MO); (2) 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 fruit yield (MO); (3) determine the cold hardiness of rootstocks and the influence of rootstock on scion cold hardiness for apple (IA, ME, MI, MN, ON and UT); (4) evaluation of peach rootstocks on cold hardiness (UT); and (5) evaluation of cold resistance of quince rootstock for pear (OR).

General climate, water, nutritional, and physiological stress: (1) study the relationship between rootstock, soil, climate, moisture and nutrient uptake (BC, VA); (2) evaluation of the relationship of rootstock, nutrient uptake and fruit quality (ID, VA); (3) evaluation of peach and apple rootstocks on alkaline soil (UT); (4) evaluation of tart cherry rootstocks with and without irrigation (WI); (5) evaluation of cherry rootstock effects on water and nutrient relationships (MI); (6) development of climate-modifying systems, such as high tunnels in cherry and other stone fruit and the relationship to rootstocks (MI); (7) evaluate the impact of rootstock/scion combinations on fruit sunburn and crop load management (OH); (8) methods will be developed to connect bioassays for biotic and abiotic stresses with transcriptomics approaches for identification of genes-associated with the process of stress manifestation (WA); (9) transcriptomics datasets will be mined for allelic diversity of stress-related genes facilitating gene-assisted selection for breeding of improved crops (WA).

Biotic stress: (1) evaluation of several inoculation techniques to accelerate field evaluations of *Armillaria* resistance (GA); (2) evaluation of peach tree short life (GA, NC, SC), *Armillaria* (GA, SC), and root-knot nematode resistance (GA, SC); (3) study of the effects rootstocks (CO, NC, NJ and NY) and biofumigants (CO)on apple replant disease; (4) evaluation of rootstocks for replant diseases and organic cultivation (CO); (5) evaluation of the effects of rootstock on fireblight in apple (MD, MI and NY); (6) evaluation of the tolerance and resistance of 32 Geneva rootstocks, 6 Malling controls, 5 Budagovsky, 1 PiAu and 1 Vineland with Ace Spur Delicious as the scion cultivar to tomato ringspot virus (NY); and (7) evaluation of the relationships among rootstock, scion and fire blight in Asian pears (AL).

Objective 5

In 2010, an eXtension Community of Practice (CoP) was funded through USDA-SCRI, and initiated to assemble the vast quantity of apple-related information developed by NC-140 and other apple-related research. The Apple eXtension website launched in September 2011. This novel vehicle for information collection, organization and delivery will be developed further during the period of this project.

Participants will assist in developing articles to increase access to information generated from this research project and serve as experts answering questions when they arise (AL, CO, IA, ID, IL, MA, MI, MN, MO, NC, NJ, NS, NY, OH, PA, VA). New eXtension projects will be pursued to encompass peaches (AL, CA, CHI, CO, GA, KY, MA, MI, MO, NC, NJ, NY, OH, ON, PA, SC, VA), cherries (AL, BC, CA, CHI, CO, MA, MI, NJ, NM, NY, ON, OR, UT, VA, WI), and pears (AL, CA, NY, OH, OR).

MEASUREMENT OF PROGRESS AND RESULTS:

Outputs:

- Thirteen refereed articles will be published, including five interim and eight final trial reports, all based on uniform, cooperative research of NC-140.

- Approximately 150 additional articles will be published by NC-140 members, based on NC-140-related research. These will include refereed and non-refereed articles targeted for scientific and farmer audiences,

- Ten new tree-fruit rootstocks will be introduced from North American breeding programs under the guidance of NC-140.

- Thirty new tree-fruit rootstocks will be introduced from international breeding programs to North American fruit growers with detailed recommendations regarding their suitability.

- Fifty scientific and 300 grower presentations will be given based on NC-140 research.

- The NC-140 (www.nc140.org) and the eXtension Apple (www.extension.org/apples) websites will continue to be developed and better provide NC-140 results to all stakeholders.

Outcomes or Projected Impacts:

- NC-140 recommendations and educational programs will guide the planting of 200,000 acres of fruit trees in the next 5 years in North America resulting in a more economically and environmentally sustainable fruit industry.

- By utilizing NC-140 recommended rootstocks, farmers will receive significantly earlier returns on investments related to tree establishment, moving the average break-even year from 8 to 5 years after planting.

- With NC-140 recommended rootstocks, mature yields will increase by 20% per acre, fruit size by 10%, and the percent meeting the highest grade category by 20%.

- The financial benefit to U.S. fruit growers from earlier returns, greater yield, and higher fruit quality will be $250,000,000 as a direct result of the use of NC-140 recommendations.

- The use of NC-140 recommended and more dwarfing rootstocks will result in a 50% reduction in canopy volume and a concomitant 50% reduction in pesticide usage on 200,000 acres. The reduction in pesticide use will net environmental benefits and save $150,000,000 in pesticide cost and application.

- Because of the use of NC-140 recommended, disease-resistant rootstocks and better selection of susceptible rootstocks, tree losses will decline by 10%.

- Utilizing molecular approaches to breeding programs guided by NC-140, the efficiency of development and selection of the next generations of tree-fruit rootstocks will be enhanced, leading to the testing and release of many new apple, peach, cherry, and pear rootstocks.

- Cumulative state and federal investment in NC-140 will be about $10,000,000. Cumulative, measurable benefits to the U.S. temperate tree-fruit industries will be more than $400,000,000. Less easily measured benefits, such as averted losses and enhanced environmental quality, will increase the financial value of NC-140 to well beyond $500,000,000 in the next 5 years.

Milestones/Timeline:

Objective 1 timeline:

Year	Interim Reports Planned	Final Reports Planned	New Plantings Planned
2012		2002 Apple 2002 Pear 2003 Apple Physiology	2012 Pear
2013	2009 Peach 2009 Peach Physiology	2003 Apple	2013 Pear Systems
2014	2010 Sweet Cherry Systems 2010 Tart Cherry Systems 2010 Apple	2004 Pear	2014 Organic Apple 2014 Apple
2015		2005 Pear	2015 Sweet Cherry 2015 Tart Cherry
2016			2016 Apple 2016 Peach, Plum, & Apricot
2017	2010 Sweet Cherry Systems 2010 Tart Cherry Systems		

- 2012-17: All established trials will be maintained and data will be collected each year from establishment until completion (as defined in the Methods section of this proposal).

Objective 2 timeline:

- 2012-17: New rootstock releases will occur throughout the 5 years of this project. As these new rootstocks become available, they will be incorporated into the uniform trials detailed in Objective 1.

Objective 3 timeline:

- 2012-17: Several projects at cooperator locations are proposed and will address several aspects of propagation. As new information becomes available, it will be transferred immediately to tree-fruit nurseries to enhance the propagability of fruit trees on new rootstocks.

- 2012-17: New rootstocks from international breeding programs will be acquired throughout the 5 years of the project. They will be incorporated into the uniform trials described in Objective 1.

Objective 4 timeline:

- 2012-17: All uniform trials described under Objective 1 include the evaluation of abiotic and abiotic stress at the various locations of these trials. As appropriate, information will be disseminated along with other aspects of rootstock evaluation

- 2012-17: Many studies of biotic and abiotic stress will be conducted by individual NC-140 cooperators. Results from these trials will be reported to NC-140 annually and will be published or presented to scientific or grower audiences as appropriate.

Objective 5 timeline:

- 2012-17: Apples eXtension website will continue to be developed and serviced throughout the 5 years of this project.

- 2013-2015: Peach eXtension website will be proposed to the SCRI granting program in 2013, developed in 2014, and launched in 2015.

- 2014-2016: Cherry eXtension website will be proposed to the SCRI granting program in 2014, developed in 2015, and launched in 2016.

- 2015-2017: Pear eXtension website will be proposed to the SCRI granting program in 2015, developed in 2016, and launched in 2017.

OUTREACH PLAN:

The NC-140 project is committed to disseminating research-based results and information to the major clientele groups it serves, commercial orchardists, small-scale orchardists, fruit-tree nursery operators, industry representatives, professional colleagues, county extension educators, and home gardeners, master gardeners, and consumers.

Results will be communicated by state at our annual technical committee meeting; posted online at our web site, www.nc140.org. The site contains cooperator contact information, annual reports/minutes, rootstock research planting descriptions, report summaries, and research results.

Results include refereed publication abstracts, links to journals for the full article, links to trade magazines, extension newsletter articles, power-points of poster, and professional talks. Outreach efforts have been enhanced with our formal participation in **eXtension** for Apples, www.extension.org/apples. This website will increase access to results and information.

Results are made available in refereed journals, presentations at professional meetings, ie. American Society for Horticulture Science and the International Society for Horticulture Science and grower publications, major national trade publications (print and electronic format), and extension publications (print and electronic) prepared by each state participant; oral presentations at both national and international fruit-grower meetings and published in *Compact Fruit Tree.* Numerous presentations will be made annually at regional, state and local fruit-grower meetings (clientele and stakeholders) and producer field days sponsored by state extension programs, often in conjunction with state horticulture associations. In addition, cooperators will publish articles including results and recommendations in appropriate extension newsletters, fact sheets, and experiment station production manuals and bulletins.

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 1-5, coordinators will be appointed on a continuing basis to coordinate the trials: Marini (PA)-2003 Apple; Elkins (CA)-2004 Pear; Elkins (CA)-2005 Pear; Reighard (SC)-2009 Peach; Johnson (CA)-2009 Peach Physiology; Lang (MI)-2010 Sweet Cherry; Autio (MA)-2010 Apple; Einhorn (OR)-2012 Pear; Einhorn (OR)-2013 Pear; Reighard (SC)-2014 Apple; Robinson (NY)-2014 Organic Apple; Lang (MI)-2015 Sweet Cherry; Lang (MI)-2015 Tart Cherry; Reighard (SC)-2016 Peach, Plum, and Apricot; Einhorn (OR)-2016 Pear; and Autio (MA)-2016 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; Einhorn (OR)-pear; 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 Fruit Tree Association. The Executive Committee will oversee funding requests in support of NC-140.

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