THE HARDWOOD TREE IMPROVEMENT AND REGENERATION CENTER: ITS STRATEGIC PLANS FOR SUSTAINING THE HARDWOOD RESOURCE

Charles H. Michler, Michael J. Bosela, Paula M. Pijut, and Keith E. Woeste[1]

ABSTRACT.—A regional center for hardwood tree improvement, genomics, and regeneration research, development and technology transfer will focus on black walnut, black cherry, northern red oak and, in the future, on other fine hardwoods as the effort is expanded. The Hardwood Tree Improvement and Regeneration Center (HTIRC) will use molecular genetics and genomics along with traditional breeding, selection, and vegetative propagation to produce improved hardwoods, deployment systems and management strategies for these fine hardwood species. In addition, new knowledge of population genetic structure that will guide regeneration efforts through increased productivity and maintenance of genetic diversity in Central Hardwood forests.

The mission of the Hardwood Tree Improvement and Regeneration Center (herein after called "HTIRC", is to advance the science of hardwood tree improvement and genomics in the Central Hardwood region of the United States by:

1) Developing and disseminating knowledge on improving the genetic quality of hardwood tree species;
2) Conserving fine hardwood germplasm;
3) Developing elite hardwood trees for restoration and regeneration of sustainable hardwood forests and riparian zones for production of forest products and maintenance of genetically diverse ecosystems; and
4) Developing recognized and respected science leaders in forest genetics.

ORGANIZATION DESCRIPTION AND CHARACTERIZATION

The HTIRC program is a regional collaborative research, development, and technology transfer effort. This partnership includes the USDA Forest Service North Central Research Station, National Tree Seed Laboratory, and Northeastern Area State and Private Forestry; Purdue University Department of Forestry and Natural Resources; Indiana Department of Natural Resources Division of Forestry; Indiana Hardwood Lumbermen's Association; National Hardwood Lumber Association; Indiana Forestry and Woodland Owners Association; American Chestnut Foundation-Indiana Chapter; Walnut Council; and the Fred M. van Eck Forest Foundation. It is unique in several aspects:

1) The HTIRC has a regional focus on states comprising the Central Hardwood region;
2) It is a true partnership of federal, state, university, industry, and landowner groups who contribute financial support and advice; and
3) It will focus on the development of basic knowledge and technologies in hardwood tree genomics, improvement, and regeneration for tree nurseries, industry, agencies, and landowners.

HTIRC is located at Purdue University because of its role in the Midwest as a recognized center for agricultural genomics research. It is housed in the Whistler Hall of Agricultural Research with biotechnology and genomics faculty from six departments in the School of Agriculture. This co-location of genetics faculty is intended to stimulate the cross-fertilization of research ideas and multidisciplinary research. In addition, because of the high standards of achievement and international recognition of its faculty, high quality undergraduate and graduate students should be drawn to the various programs represented in Whistler Hall.

[1] Program Manager (CHM), Post-doctoral Plant Physiologist (MJB), Research Plant Physiologist (PMP), and Research Molecular Geneticist (KEW), Hardwood Tree Improvement and Regeneration Center, North Central Research Station, Purdue University, 1159 Forestry Building, West Lafayette, IN 47907-1159. CHM is corresponding author: to contact, call (765) 496-6016 or e-mail at cmichler@fs.fed.us

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OPERATING ENVIRONMENT

The idea for HTIRC was conceived in 1998 because of a perceived void in hardwood tree improvement research in the Central Hardwood region of the Midwest and Northeast. The birth of HTIRC occurred at the same time that the region was experiencing a severe shortage of hardwood seedlings estimated anywhere from 25 to 50 million trees annually and that shortage was increasing 20 percent annually (unpublished survey of Midwest state foresters). In addition, the majority of seedlings being produced in state nurseries were of unimproved genetic source because nurseries rely upon seed collectors to collect and transport seed to the point of purchase at the nursery. Thus, the majority of seedlings being produced had unknown fitness for sustainable forestry and unknown genetic diversity.

The hardwood industry was also concerned about the future quantity and quality of the resource for its lumber and manufacturing sectors. Due to political and social pressures, federal forests have significantly reduced the volume of hardwood timber that is being harvested annually. Small private woodlots that supply the majority of hardwood timber in the region are not being managed in a sustainable manner, ownership is not continuous over numerous rotations to insure sound forest management, and many woodlots are being converted to residential and recreational uses. In addition, the diameter of timber harvested today continues to be smaller than what it has been due to shorter rotations. Last, the hardwood industry was concerned that it was not taking advantage of new biotechnologies that could increase wood production through tree improvement activities that improve wood quality, growth, and pest resistance.

The professional forest community was also concerned about loss of genetic quality in remaining hardwood woodlots and natural forests. They felt that trees currently being managed for future timber harvest do not have the same desirable traits for straightness and vigor and that past forest harvest practices of continually taking the "best" trees may have resulted in loss of genetic quality of the remaining germplasm.

INTERNATIONAL ECONOMIC, SOCIAL, AND POLITICAL ENVIRONMENT

Human population growth continues to expand rapidly, and consumer demand for quality hardwoods, at some point, will outstrip the region's ability to produce it unless consumers are willing to accept substitute materials. Much of the US and European demand for hardwood lumber is currently met within the United States' Northern and Central Hardwood zones, and hardwood production has not shifted to developing countries in any significant manner. However, the time may come when this pattern of production for world markets can no longer be maintained because of decreased supply of quality hardwoods in North America and the environmental consequences of heavy timber extraction on natural environments.

In the Central Hardwood region, water quality has been degraded by agricultural intrusion along waterways, and flooding has further degraded these riparian zones along major rivers and their tributaries. A significant effort is being made to restore hardwood trees and other native vegetation in these riparian zones. For the most part, unimproved trees are being used, and the knowledge of how to restore these degraded areas has been lacking, resulting in failure of many plantings. The opportunity exists for this significant portion of the land base to be a future site for quality hardwood regeneration although political forces may influence that reality.

Funding for many conservation plantings comes from the Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), and Wetland Reserve Program (WRP). These programs currently account for the majority of hardwood tree planting and they are increasingly focused on improvement of water quality and wildlife habitat. The genetic characteristics of the trees being planted are unknown and the potential exists for genetic failures as these plantings mature.

Many consumers do not differentiate between a plantation forest and a natural forest. They readily accept that agronomic crops are grown for the purpose of food production rather than for regeneration of annual vegetation. Conversely, consumers have certain aesthetic and spiritual values for trees whether they are in an urban, plantation, or natural forest environment. If these values do not change, then plantations may not be viewed as an acceptable alternative method for growing highly productive crop trees which would then allow the country to maintain natural forests as preserves for biodiversity and recreation. These attitudes exist despite the fact that only a marginal set-aside of land currently in forest land cover would produce all of the wood necessary to meet human demands for wood consumption (Sedjo 1999).

Few cities have resolved the conflict that occurs when urban sprawl imposes upon adjacent rural and forest environments. As community planners continue to struggle with these issues, more forest and farmland continues to be converted into residential use. The increase in economic affluence of American households will continue to put pressure on the urbanization of these environments because the desirable qualities of forest environments for residential communing.

RELATIONSHIP WITH OTHER ORGANIZATIONS

For quality veneer, central and northern hardwoods are more desirable than southern hardwoods because of slow, more even growth. In addition, the supply of European hardwoods is limited. Because of this, the HTIRC will hold unique importance within the central United States to develop superior hardwood trees for markets that supply developed nations. There are few other hardwood tree improvement research centers in the world and few individual hardwood research programs that have a mandate to satisfy a regional clientele and are financially supported to undertake a long-term program in tree improvement.

HTIRC will be unique because of Purdue University's relationship with the Donald Danforth Plant Science Center in St. Louis, Missouri. The Danforth Center is a partnership of the Missouri Botanical Garden, Monsanto, Purdue University, University of Missouri-Columbia, University of Illinois, and Washington University in St. Louis. Its mission is to increase understanding of basic plant biology and apply new knowledge to sustain productivity in agriculture and forestry. HTIRC should benefit from its access to world-class plant scientists, and its ability to collaborate in the graduate education of its students.

HTIRC will be vertically integrated with molecular and classical geneticists, tree physiologists, silviculturalists, and nursery and regeneration specialists. Its strength will be its ability to perform basic, applied, and developmental research so the basic genetic knowledge that is created will be delivered to industry and private landowners in value-added products rather than knowledge that only benefits the scientific community.

HTIRC will not be the single or sole institution performing hardwood genetic research. The region has many outstanding scientists who perform valuable basic and applied research on various species, and it will be essential that the whole hardwood scientific community remains viable to meet these research needs. In addition, HTIRC does not plan to employ pathologists, entomologists, biochemists, enzymologists, economists, and the other scientific disciplines that are necessary for research collaborations to provide scientific data for evaluation of the ecological and environmental fitness of HTIRC products. Productive working relationships with scientists from other institutions are necessary for the success of the Center and for maintaining healthy, sustainable forestry in the Central Hardwood region.

FUNDING

Annual funding appropriations are expected from the USDA Forest Service North Central Research Station, Northeastern Area State and Private Forestry, Purdue University Department of Forestry and Natural Resources, the Fred M. van Eck Forest Foundation, the wood products industry and various landowner associations.

As products are developed and discoveries are made, protection of intellectual property and products may be patented or trademarked. Partners and HTIRC endowment would benefit from these sources of funds.

STRATEGIC DIRECTIONS

HTIRC has six (6) strategic directions:

1) Improve the genetic quality and regeneration of fine hardwoods, including black walnut, black cherry, and northern red oak, through application of classical breeding, genomics, molecular markers, genetic modification, advanced vegetative propagation, seed production technologies, and silviculture.
2) Establish a highly credible hardwood genetics research center that will be recognized as a leader in forest genetics, and thereby become a leading graduate education and training facility for future scientific leaders in hardwood forest genetics.
3) Hire and nurture pre-eminent scientists who will build the credibility of the research program and be highly competitive for federal research grants.
4) Establish the Martell Research, Education, and Conference Center as a significant site for education and training of consulting foresters, nursery practitioners, and landowners in nursery management and hardwood culture.

5) Communicate, convey, and market the work of HTIRC in order to be perceived as the pre-eminent international center for hardwood genomics and biotechnology.
6) Secure funding for an endowment to insure long-term organizational stability, provide for operating support of the research program, and establish funded research positions within the Center.

OBJECTIVES

The following are objectives for implementing the strategic directions:

1) To develop research and technology transfer programs that provide knowledge for management and maintenance of sustainable, genetically diverse natural forests and highly productive domesticated trees for plantation hardwood crops that provide a wide array of products.
   - For black walnut, black cherry, and northern red oak: develop genetic maps, molecular markers, tissue culture and genetic engineering technologies, advanced seed orchard, and seed handling technologies, breeding orchards, and experimental nurseries for production of elite families and cultivars, identification of superior seed trees, and assessment of genetic quality and diversity in natural stands.
   - Assess the need and develop a regional hardwood breeding and seed orchard cooperative for Central Hardwood seed zones as desired by state tree improvement cooperators.
2) To take leadership in documentation of hardwood research discoveries and dispersal of knowledge by hosting scientific conferences, symposia, workshops and field days, and publish books, proceedings, and brochures that convey this knowledge to a wide array of end users.
3) To provide for annual evaluation and other periodic review of HTIRC programs to ensure that the mission and vision remain focused and relevant.

ACCOMPLISHMENTS AND FUTURE PLANS

Since establishment in 1998, staff at the HTIRC have developed tissue culture systems for northern red oak and black walnut; developed over 500 black walnut and northern red oak molecular markers for use in genetic mapping, assessment of genetic diversity and marker-assisted breeding; established new breeding and seed orchards for black cherry and black walnut; established a field repository for fine hardwoods with unique genetic traits; initiated studies to develop trellis seed orchards; established a block of canker-resistant butternut; and established two field trials for screening Midwest-adapted blight resistant American chestnut. In the remainder of this paper, we will focus on current work in black walnut genetics and vegetative propagation.

Black Walnut Genetics

Research in black walnut genetics at HTIRC has been aided immeasurably by the publications, plantings, and meta-data generated by previous walnut researchers in the USDA Forest Service and at Purdue University. An outstanding example is the longitudinal data collected over the last 20 years on 80 black walnut families planted at the Southeast Purdue Agricultural Center (SEPAC, Jennings County, IN) as 1-0 seedlings. These seedlings were derived from open-pollinated seedlots of superior selections identified by the USDA Forest Service as part of study FS-NC-1151, 82-03. The trees planted at SEPAC were half-sibs of trees planted at the Kellogg Forest near Belmont, Michigan, as part of a cooperative agreement with Michigan State University, and at Big Creek, Hardin County, in southern Illinois. These resources permit us to test genetic theories on mature stands with known genetic and management histories.

Several geneticists have theorized that selection among walnut progenies at a relatively young age (4 to 6 years) could be effective at improving rotation height and diameter (Kung 1975, McKeand and others 1979, Rink 1984). This conclusion was based on relatively small data sets, quantitative genetic theory, results from other species, and data from young plantations (≤ 10 years). Two of these authors later suggested that selection any time after age 8 would be acceptable (Rink and Kung 1995) based on a 20-year-old progeny test. Evaluation of the data taken at SEPAC (FS-NC-1151) amplifies this finding. Results from SEPAC reveal a considerable amount of rank shifting for height and diameter at the level of individual trees, as well as among and within families, before age 10 (Woeste, unpublished data).

While results of studies on early selection in other species are important methodologically, the application of selection theory to walnut requires sensitivity to the biological and reproductive characteristics of the species. Walnut propagules of known ancestry have a high value because they are rare and/or expensive to produce as a result of low seed yield (compared to many species), the unpredictability of seed bearing, poor seed viability after one year of storage, long tree juvenility, the difficulty of producing controlled crosses, and the high cost of grafting.

It may be more cost effective to delay selection until rank shifting within and among walnut families has been reduced to very low levels. The previously mentioned high value of propagules means that the marginal cost of an additional year or two of evaluation may be much smaller than the cost of prematurely discarding a valuable family. Lambeth (1980) cites similar reasons for delaying selection in the Pinaceae, and notes that, in general, the most efficient time for selection increases as the rotation age increases. Lambeth suggested a selection age of 6 to 8 years for the Pinaceae, which have a rotation age of 30 to 40 years, whereas the rotation age for walnut is often twice these values.

Large increases in heritability between ages 10 and 15 observed in the SEPAC planting indicate that selection after age 10 might permit breeders to maximize the value of observed differences among individual trees, although these increases in heritability have not been seen at all study sites. Rink (1984) found the heritability of height growth increased steadily after age 4 until age 10. Rink and Kung (1995) reported similar results, with heritability holding steady or decreasing slightly after age 10. Citing Namkoong and Conkle (1976), Rink predicted that heritability would continue to increase until a plantation reached a mature phase of growth, which he equated with crown closure. Perhaps that was why Rink and Kung found that heritability in their study site at Pleasant Valley leveled off at age 10. Crown closure at Pleasant Valley was as early as age 5. Trees at Pleasant Valley increased their diameter at a moderate 0.27 inches per year, and Rink and Kung reported a rising variance for block throughout the life of the plantation due to competition among seedlings.

The SEPAC planting was maintained with a minimum of crown closure for the entire 20 years for which data were taken, and diameter growth at SEPAC average 0.4 inches per year. These differences in management and inter-tree competition may explain why the heritability for diameter and height for the seedlings at SEPAC continued to increase from age 10 through age 20. Lack of spatial replication of the SEPAC plantation and its management methods probably inflated the heritability estimates derived at the site. But the argument for later selection, at least at sites like SEPAC where growth was excellent, is based not on the absolute magnitude of the heritability estimates, but on the timing of the cessation of rank shifting and the observed increases in the heritability of height and diameter after age 10. The large intra-block variation and a confusing planting scheme at the MSU study site makes family identification and analysis of the growth data from these trees difficult (Paul Bloese, personal communication) and greatly complicates comparisons with the trees at SEPAC and Pleasant Valley.

Tissue Culture Propagation

In order to propagate elite selections and to genetically modify fine hardwoods, we have developed several tissue culture systems. Embryogenic cultures of northern red oak and black walnut were established using cotyledon tissue explants. Cultures have been maintained on maintenance medium and upon transfer to maturation medium, somatic embryos can be matured and germinated. Germinated somatic emblings have successfully been transferred to soil. In addition, shoot cultures of black walnut were established from coppice shoots of greenhouse-grown trees. Recently, shoots have been successfully rooted and transferred to soil. Acclimatization studies for rooted microshoots and somatic emblings will be initiated in the near future.

Vegetative Propagation

A project is underway to determine the conditions necessary for successful cutting propagation of black walnut. Vegetative propagation will be required to produce clones of genotypes selected for improved wood quality, growth, and pest resistance. Successful propagation of black walnut on a commercial scale may be achieved if the type of cutting (hardwood versus softwood), date of collection (growth stage of development), rooting treatment (auxin type and concentration), and greenhouse parameters (mist bed, supplemental lighting, etc.) are carefully considered. Based upon successful propagation methods established for butternut (*J. cinerea*), the effects of the aforementioned parameters on rooting percentage, number and length of roots regenerated, and over-wintering survival of rooted cuttings will be determined. Plants transplanted to the field will be monitored for growth and survival.

CONCLUSION

HTIRC, guided by its Advisory Committee that consists of resource professionals, University and federal scientists, directors of industry and landowner associations, and research administrators, will seek to engage in collaborative hardwood research and development across the Midwest. Areas of opportunity include breeding and mass selection, genomics and gene discovery, seed and nursery production systems, hardwood silviculture, and technology transfer.

LITERATURE CITED

Kung, F.H. 1975. Development and use of juvenile-mature correlations in a black walnut tree improvement program. Proceedings, 12th Southern forest tree improvement conference; Baton Rouge, LA: 243-249.

Lambeth, C. 1980. Juvenile-mature correlations in Pinaceae and implications for early selection. Forest Science. 26: 571-580.

McKeand, S.E.; Beineke, W.F.; Todhunter, M. 1979. Selection age for black walnut progeny tests. Proceedings, 1st North Central tree improvement conference; 1979 August 21-23; Madison, WI. 1: 68-73.

Namkoong, G.; Conkle, M.T. 1976. Time trends in genetic control of height growth in ponderosa pine. Forest Science. 22: 2-12.

Rink, G. 1984. Trends in genetic control of juvenile black walnut height growth. Forest Science. 30: 821-827.

Rink, G.; Kung, F.H. 1995. Age trends in genetic control of *Juglans nigra* L. height growth. In: Proceedings, 10th Central Hardwood Forest conference. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 247-255.

Sedjo, R.A. 1999. Biotechnology and planted forests: assessment of potential and possibilities. Discussion Paper 00-06. http://www.rff.org.