NATIONAL WORKSHOP ON FOREST PRODUCTIVITY & TECHNOLOGY: COOPERATIVE RESEARCH TO SUPPORT A SUSTAINABLE & COMPETITIVE FUTURE—PROGRESS AND STRATEGY

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Abstract—The Agenda 2020 Program is a partnership among government agencies, the forest products industry, and academia to develop technology capable of enhancing forest productivity, sustaining environmental values, increasing energy efficiency, and improving the economic competitiveness of the United States forest sector. In November 2006, the USDA Forest Service, in partnership with the Agenda 2020 Technology Alliance, the American Forest and Paper Association, the National Council for Air and Stream Improvement, and U.S. Department of Energy, organized a national workshop to document and discuss significant achievements and build support for the Agenda 2020 Sustainable Forest Productivity program and related research. The workshop was organized into sessions on: (1) Forest Management, Soil Productivity, and Information Technology; (2) Biotechnology and Tree Improvement; (3) Physiology, Growth, and Wood Quality; and (4) Ecological Functions of Managed Forests. Since 1999, Forest Service Research & Development and partners have funded 66 projects. A summary of key results and potential future research direction will be presented.

INTRODUCTION

The Agenda 2020 Program is a partnership among government agencies, the forest products industry, and academia to develop technology capable of enhancing forest productivity, sustaining environmental values, increasing energy efficiency, and improving the economic competitiveness of the United States forest sector. In 1994, the forest products industry developed a technology vision and the research pathways required for a sustainable future (American Forest and Paper Association 1999). Six broad research areas were identified, including sustainable forestry, with the goal of promoting research and technology development for the sustainable management of forest resources to ensure future availability and use. Since 1998, U.S. Forest Service R&D (FS R&D), along with U.S. Department of Energy (DOE) and the American Forest and Paper Association (AF&PA), has supported the Sustainable Forest Productivity pathway in Agenda 2020. Initially, the Sustainable Forest Productivity pathway contained four areas of emphasis: biotechnology and tree improvement, soil productivity, physiology of forest productivity, and forest information technology. In 2006, the Agenda 2020 Forest Products Industry Technology Roadmap was developed (Agenda 2020 Technology Alliance 2006). The goal of the Roadmap is to develop and deploy wood production systems for our nation's forests that are ecologically sustainable, socially acceptable and economically viable, thereby enhancing our understanding of our forest ecosystems and the global competitiveness of forest-based manufacturing and biorefinery systems in the United States. Sustainable forest productivity continues to be one of the technology platforms used to meet this goal. Sustainable forest productivity focus areas are biotechnology and tree improvement, improving wood quality delivered to mills, forest management, and optimizing ecological functions of managed forests.

Since 1997, a total of 94 research projects have been funded under the Sustainable Forest Productivity Platform of Agenda 2020 through a competitive process. Twenty-eight projects have been funded by DOE since 1997 and 66 projects have been funded by FS R&D since 1998. Of the 66 projects, 40 have been funded through Forest Service Research Stations in regional programs and 26 have been funded through the FS R&D Washington Office in the national program. The $12 million in FS R&D funding has leveraged an additional $8 million in cooperator contributions.

In November, 2006, the "National Workshop on Forest Productivity and Technology: Cooperative Research to Support a Sustainable and Competitive Future" was held with the objective of presenting key results and discussing future research direction of the Agenda 2020 Sustainable Forestry Program. The workshop was sponsored by the Agenda 2020 Technology Alliance, AF&PA, National Council for Air and Stream Improvement (NCASI), DOE, and FS R&D. This paper summarizes key outcomes presented at the Agenda 2020 Sustainable Forest Productivity Workshop.

FOREST MANAGEMENT, SOIL PRODUCTIVITY, AND INFORMATION TECHNOLOGY

This area focused on research leading to significant improvements in long-term soil productivity and new applications of information technology that will improve forest management systems and enable significant gains in fossil energy efficiency and environmental quality. Deployment of results will be through application of state of the art management practices and technologies to improve forest health and productivity. The following are key results presented.

Long-term Implications of Management Practices on Site Productivity and Controlling Processes

This work focuses on enhancing understanding of the consequences of biomass manipulation, ground-based harvesting, and vegetation control for short and long-term forest productivity in the Pacific Northwest (Ares and others 2007). Removal of organic matter at the time of harvest did not have a detectable influence on soil water content (SWC) during

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Citation for proceedings: Stanturf, John A., ed. 2010. Proceedings of the 14th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 614 p.

the 4th and 5th years after plantation establishment (Devine and others 2006) and there was no significant difference in tree size associated with amount of biomass removed (Roberts and others 2005). The ratio of total carbon above the mineral soil to total carbon within the mineral soil was markedly altered by biomass removal, but proportions of total N stores were reduced only three to six percent owing to the large soil N reservoir on site (Ares and others 2007). Soil compaction in traffic lanes affected soil properties but did not exceed critical levels (Ares and others 2005). These results help refine understanding of how different soils respond to management, provide data to support the design of best management practices (BMPs), and provide critical information for the practice of precision forestry at multiple scales.

Options for Increasing the Sustainable Harvest Level and Value of Spruce-Fir in Maine

The objective of this study is to improve the management, health and productivity of, as well as economic returns from, northeastern spruce-fir forests. Initial results show that precommercial thinning in spruce-fir forests in Maine increases total stand volume over unthinned stands. In addition, these treatments can double maximum net present value (NPV) of the stand and cause the maximum (NPV) to be reached 10 to 15 years sooner than in unthinned stands (Keefe and Wagner 2004, Wagner 2006,Wagner and Keefe 2005).

Science to Develop Silvicultural Practices to Enhance Carbon Sequestration

Intensive silviculture of loblolly pine (*Pinus taeda* L.) provides potentially large increases in biomass production and net ecosystem productivity (NEP). Increasing site resources enhanced the rate of carbon sequestration (Maier and others 2004) and relationships between temperature, soil type, region, and stand development and soil CO_2 efflux were variable (Gough and others 2005). Work is continuing to quantify the effects of added organic matter on soil carbon dynamics, soil nutrient supply, and pine productivity; as well as the response of contrasting genotypes to management practices and resource manipulations.

Extension of Light Detection and Ranging (LIDAR) as a Tactical Management Tool

This research and development effort is focused on creating useful, cost-effective applications of LIDAR remote sensing for precision forest management. Current efforts are focused on relating LIDAR observations to plot validation data. Results show that LIDAR height is a good predictor of basal area and LIDAR-based canopy cover is a good predictor of tree density (Evans and Hudak 2007, Falkowski and others 2006, Hudak and others 2006).

Genetic Markers for Pathogenic *Armillaria ostoyae* and Web Tool for Risk Estimation

Genetic markers were successfully developed to distinguish pathogenic *Armillaria ostoyae* from other beneficial or non-pathogenic *Armillaria* species (Hanna and others, In press). Genetic relationships among *Armillaria* species and genets have been evaluated (Kim and others 2006). Preliminary methods and tools to predict Armillaria disease risk based on environmental factors and to predict potential invasive risks posed by *Armillaria* spp. are being developed (McDonald and others [In press]).

BIOTECHNOLOGY AND TREE IMPROVEMENT

This area focuses on development and deployment of superior trees that will result in significant gains in forest productivity, fossil energy efficiency, and environmental quality. The goal is to develop and deploy genetically superior planting stock with demonstrated potential to reduce wood production costs and improve wood quality for a variety of uses.

Gene discovery for adaptive traits in Douglas-fir (*Pseudotsuga menziesii*)

Research on cold adaptation genes in Douglas-fir has led to the identification of 400 Douglas-fir unigenes as cold adaptation candidate genes. Eighty-eight amplicons produced useable sequences and these are being used to develop an automated pipeline for base calling and sequence alignment. Work continues to verify in Douglas-fir associations between candidate genes by wood property phenotype associations that were initially discovered in loblolly pine (Howe 2006, Krutovsky and Neale 2005, Krotovsky and others 2004).

Engineering Flowering Control in Poplar and Other Species

Genetically engineered flowering control is important as a means of confining transgenes, maintaining rapid growth, and preventing potential genetic pollution – all of which are important for developing trees as a biofuel feedstock. So far, poplar floral promoters with floral-specific expression that work in a variety of plants have been identified (Brunner and others 2000, Meilan and others 2001, Meilan and others 2004, Rottmann and others 2000, Skinner and others 2003, Wei and others 2005). Ongoing work is focused on modifying a variety of genes to build in redundancy and on determining the stability of transgene expression.

Engineering Cellulose Biosynthesis in Trees

This research is aimed at developing ways to genetically augment the syringyl-to-guaiacyl lignin ratio in low-lignin transgenic aspen in order to produce trees with reduced lignin content, more reactive lignin structures, and increased cellulose content. Results show that sinapyl alcohol dehydrogenase (SAD) is required for the biosynthesis of syringyl lignin in angiosperms (Li and others 2001). A multigene cotransfer system has been developed that should be broadly useful for plant genetic engineering and functional genomics (Li and others 2003). Results confirm that the coniferaldehyde 5-hydroxylase (CAld5H) gene is key to syringyl lignin biosynthesis, and that genetic manipulation of both lignin content and lignin composition in pulpwood species may be achieved via gene stacking (Tsai and others 2004a, Tsai and others 2004b). Future issues to be addressed include pilot-scale pulping analysis, and field and regulatory evaluations to complete the technology assessments.

Developing Genomic Knowledge Base for Facilitating Tree Breeding

A large number of high quality genetic markers are needed for marker assisted selection and breeding in loblolly pine. The effort to develop an expressed sequence tags (EST) database for loblolly pine has facilitated the development of 145 new short simple repeat (SSR) or microsatellite markers. On the order of 1 000 single nucleotide polymorphism (SNP) markers can be developed with existing EST database (Chagne and others 2004). The challenge is estimating the value of specific alleles in populations and optimally using the information in selection and breeding programs.

PHYSIOLOGY, GROWTH, AND WOOD QUALITY

Research in this area focuses on wood formation and wood quality, ecophysiology of planted forests, and nutrient use efficiency. Developments leading to significant gains in forest productivity and environmental performance result from more rapid advances in forest biotechnology and improvements in silvicultural practices.

Candidate Gene List Generation and Validation for Resource Allocation in Populus

This research has focused on determining the mechanisms that regulate the biochemical and genetic physiology of poplar trees with regard to nitrogen utilization. This will allow cost-effective strategies for applying nitrogen to be developed and deployed by matching the timing and quantity of nitrogen application to the specific requirements of the trees. Nitrogen-responsive cDNAs have been cloned and sequenced (Lawrence and others 2001). The gene expression data suggest that N availability modulates the partitioning of C and N resources into metabolic fates that have the potential to alter both wood quality and quantity (Cooke and others 2003). Nitrogen availability modulated parameters that affect carbon gain include light-saturated net photosynthesis and leaf area. Genes encoding vegetative storage proteins and starch biosynthetic enzymes exhibited contrasting patterns of expression under differential N availability (Cooke and others 2005).

Physiological Limits of Productivity

This study was designed to create optimal growing conditions for loblolly pine through intensive manipulation of water and nutrient regimes. Irrigation plus fertilization reduced annual soil carbon loss and greatly increased belowground carbon sequestration relative to a control, but soil CO_2 efflux (S_{CO2}) was not correlated to fine root mass. Annual S_{CO2} declined linearly with increasing belowground carbon content in root biomass at age six (Samuelson and others 2004b). Through age six, results show that changes in leaf-level physiology appeared important only at the seedling stage. There is little change in allocation between above- versus belowground tissues; there appears to be no threshold basal area observed after which stem production declines and increased growth appears to be a result of LAI maintenance and low tree mortality (Samuelson 1998, Samuelson and others 2004a, Samuelson and others 2001, Samuelson and Stokes 2006). Growth rate observations indicate that very intensive management can push loblolly pine closer to its genetic growth potential.

Preliminary Methods for Predicting Latewood-Earlywood Ratios from Foliar Stable Carbon Isotope Signatures

This research aims to improve wood quality in managed southern pine forests through better understanding of the relationships among tree xylem cell structure, tree water relations, and wood quality characteristics such as specific gravity and latewood:earlywood (LW:EW) ratio. It is hypothesized that genetic variation in LW:EW alters xylem hydraulic properties, which causes variation in physiological characteristics related to water relations, such as foliar stable carbon isotope discrimination (Δ13C). Understanding and quantifying these relationships should lead to increased understanding of adaptive structure-function relationships, and the development of practical tools for screening breeding populations for wood quality characteristics. Hypotheses regarding the relationships between water stress and latewood formation will be tested and corroboration of previously-documented correlations between foliar Δ13C and growth rate will be attempted. Initial results indicate that xylem hydraulic conductance, late wood percent, and specific gravity are generally higher in irrigated plots than in unirrigated plots across the genotypes tested (Personal Communication. Dr. Timothy A. Martin. 2007. Associate Professor, University of Florida, 359 Newins-Ziegler Hall, P.O. Box 110410, University of Florida, Gainesville, FL).

Effects of Growth Rate and Genetics on Wood Quality of Coastal Douglas-fir

Swiss needle cast disease resulting from *Phaeocryptopus gaeumannii* increases wood strength and stiffness in coastal Douglas-fir more than changes in growth rate alone (Johnson and others 2003). Phenotypic correlations of ring width and wood properties are statistically significant, probably of little practical importance, and mostly due to genetics (Johnson and others 2005). Genetic correlations indicate that wood properties are important to consider in breeding programs and can be incorporated because it is relatively easy to monitor the modulus of elasticity and wood density (Grotta and others 2005, Johnson and Gartner 2006).

Quantifying and Predicting Wood Quality of Intensively Managed Loblolly Pine and Slash Pine (*Pinus elliottii*)

Competition control does not appear to affect age-specific wood density or length of juvenility. Woody and herbaceous competition control combined did not significantly reduce annual ring specific gravity (SG) of earlywood or latewood, and did not significantly affect the proportion of latewood in the annual rings (Clark and others 2006b). Vegetation control treatments had no consistent effect on the length of juvenility (Clark and others 2006b). Precisely estimating the age of transition between juvenile and mature wood is difficult because transition in loblolly pine is gradual rather than abrupt (Clark and others 2006a). A model describing changes of earlywood and latewood microfibril angle (MFA) within the tree has been developed (Jordon and others 2005). Annual heavy fertilization alone or in combination with vegetation control significantly reduced toughness as well as strength and stiffness of juvenile wood (Clark and others 2004).

ECOLOGICAL FUNCTIONS OF MANAGED FORESTS

Research in this area focuses on methods and tools to understand, quantify, optimize, and communicate current and potential contributions of managed forests to ecosystem functions, including watershed management, carbon sequestration, wildlife habitat, and renewable feedstock supply for bioenergy and bio-based products and chemicals.

Estimating Cumulative Effects on Multi-ownership Landscapes

Research in this area has provided a tool for evaluating cumulative effects of forest management activities on multiple ownership landscapes (Gustafson and others 2007). Results can be used to simulate how the actions of each owner influence the overall pattern of vegetation and age arrangement on the landscape, and to help evaluate cooperative strategies to manage landscape patterns (Gustafson and Loehle 2006, Gustafson and others 2007).

The Role of Species and Climate in Carbon Cycling and Sequestration in Pine and Hardwood Forests

Carbon allocation and storage in coarse roots varies with stand age and species. Ecosystem carbon storage varies with age and species. Species did not alter soil carbon quality, but may alter the quantity of soil carbon. Across a geographical gradient in temperature in the United States, increasing mean annual temperature appears to modestly alter soil quality and quantity, and increase total belowground carbon allocation (Giardina and others 2005).

CONCLUSIONS

Our Nation's forests are a sustainable, strategic asset in achieving and enhancing United States energy security, economic opportunity, environmental quality, and global competitiveness. Substantial progress is being made in developing management systems that are sustainable, highly productive and energy efficient. However, we must consider the range and quantity of goods, services, and values demanded from forests in the coming decades. In significant measure, we will expect these lands to produce water, wood and non-wood products, recreational opportunities, varying habitats, climate change mitigation, and energy needed by our growing population and its economies. Continuing growth in global populations, economic development and prosperity, and demand for forest products and energy underscores the critical need to produce more wood on fewer acres.

Through collaboration and commitment, the Agenda 2020 Sustainable Forest Productivity Program has supported excellent forestry research projects that have produced new knowledge with important practical implications and applications. The program has played a key role in revitalizing public/private partnerships in the forestry research and development community in the United States. The strengths of the Agenda 2020 Sustainable Forest Productivity Program are: (a) the partnerships created between the research community and users of scientific information; (b) its regional and national components; (c) its unique, strategic focus on critical research and development priorities related to wood production systems and their linkages to economic development, environmental performance, and energy security; (d) the rigorous, competitive process is used to select projects; and (e) its inclusions of critical research and technology transfer. Current focus areas for Sustainable Forest Productivity in Agenda 2020 are biotechnology and tree improvement, improving wood quality delivered to mills, forest management, and optimizing environmental services from managed forests (Agenda 2020 Technology Alliance 2006). Future partnerships can build upon the strengths of our current Agenda 2020 Sustainable Forest Productivity Program.

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