forests

Conference Report

The 2018 Woody Crops International Conference, Rhinelander, Wisconsin, USA, 22–27 July 2018

Emile S. Gardiner [1,*], Solomon B. Ghezehei [2], William L. Headlee [3], Jim Richardson [4], Raju Y. Soolanayakanahally [5], Brian J. Stanton [6] and Ronald S. Zalesny Jr. [7]

1 Center for Bottomland Hardwoods Research, Southern Research Station, USDA Forest Service, Stoneville, MS 38776, USA
2 Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695, USA; sbghezeh@ncsu.edu
3 Arkansas Forest Resource Center, University of Arkansas, Monticello, AR 71656, USA; headlee@uamont.edu
4 Poplar and Willow Council of Canada, Ottawa, ON K1G 2C5, Canada; jrichardson@on.aibn.com
5 Indian Head Research Farm, Agriculture and Agri-Food Canada, Indian Head, SK S0G 2K0, Canada; raju.soolanayakanahally@agr.gc.ca
6 GreenWood Resources, Inc., Portland, OR 97201, USA; brian.stanton@gwrglobal.com
7 Institute for Applied Ecosystem Studies, Northern Research Station, USDA Forest Service, Rhinelander, WI 54501, USA; rzalesny@fs.fed.us
* Correspondence: egardiner@fs.fed.us; Tel.: +1-662-336-4820

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Abstract: The 2018 Woody Crops International Conference was held from 22 to 27 July 2018 throughout Minnesota and Wisconsin, USA to unite world-leading short rotation woody crop (SRWC) organizations at a forum designed to enhance information exchange while also building a platform for developing future collaboration around SRWC production systems. The meeting included pre-conference and post-conference tours in Minnesota and Wisconsin and technical sessions in Rhinelander, Wisconsin. Technical sessions were framed under the topics: Genetics and Physiology, Phytotechnologies, Stakeholders, Bioproducts, Harvesting and Logistics, Biomass Production, and Ecosystem Services. This Conference Report provides a compilation of abstracts from each of the 38 oral and poster presentations delivered during the technical program. It should serve to enhance future discussions among scientists, academicians, regulators, and the general public relative to sustainable application of SRWC technologies for a multitude of current objectives.

Keywords: *Populus* L.; *Salix* L.; biomass production; bioenergy; tree breeding; ecosystem services; environmental technologies; phyto-technologies; ecological restoration; production systems

1. Preface

International efforts supporting the development of short rotation woody crops (SRWCs) have historically focused on the production of biomass for bioenergy, biofuels, and bioproducts while research and deployment over the past decade have expanded to include broader objectives of achieving multiple ecosystem services [1]. In particular, silvicultural prescriptions developed for SRWCs have been refined to include woody crop production systems for environmental benefits such as carbon sequestration, water quality and quantity, and soil health [1]. In addition, current systems have been expanded beyond traditional fiber production to other environmental technologies that incorporate SRWCs as vital components for phyto-technologies (e.g., phytoremediation), urban afforestation, ecological restoration, and mine reclamation [2].

The 2018 Woody Crops International Conference was held from 22 to 27 July 2018 throughout Minnesota and Wisconsin, USA, under the sponsorship of the Short Rotation Woody Crops Operations

Working Group, the Poplar and Willow Council of Canada, the International Union of Forest Research Organizations (IUFRO) Working Party 2.08.04 (Physiology and Genetics of Poplars and Willows), the IUFRO Working Party 1.03.00 (Short Rotation Forestry), the International Energy Agency Task 43 (Biomass Feedstocks for Energy Markets), and the International Poplar Commission Environmental and Ecosystem Services Working Party. The goal of the Conference was to unite these world-leading SRWC organizations at a forum designed to enhance information exchange while also building a platform for developing future collaboration around SRWC production systems. In particular, the event consisted of an optional pre-conference tour (22–23 July 2018) that showcased poplar (*Populus* spp.) tree improvement in Minnesota, a technical program (23–25 July 2018) held on the campus of Nicolet College in Rhinelander, Wisconsin, that delivered 38 presentations on current advancements in science and technologies and an optional post-conference tour (25–27 July 2018) that highlighted phyto-technology applications in Wisconsin. The technical program began with plenary presentations from four speakers and continued with five technical sessions and a poster session. Technical sessions were framed under the topics: Genetics and Physiology, Phyto-technologies, Stakeholders, Bioproducts, Harvesting and Logistics, Biomass Production, and Ecosystem Services. The conference attracted accomplished scientists, students, practitioners, business managers, and policy advocates from nine countries. This conference report provides an abstract of each of the 38 oral and poster presentations delivered during the technical program. The reader is referred to Appendix A for an index listing of each presentation title. We hope these efforts will enhance significant future discussions among scientists, academicians, regulators, and the general public.

2. Summary of Scientific Presentations

2.1. Current Trends and Challenges in North American Poplar Breeding

Thomas, B.R.

Background: Poplar (*Populus* spp.) breeding in North America, like everywhere, is dependent on funding and markets. The opportunities afforded by poplars and poplar breeding, however, remain far greater and more diverse than with conifer programs. As the needs have shifted, so have the selection traits, while the basics of any breeding, testing, selection, and production remain the same. Diverse parent populations are costly to maintain and programs are always at the mercy of changing priorities. In Canada, the number of active programs has diminished while the basic resources are still in place. Government programs have become the only programs able to maintain long-term genetic and landrace trials and only such programs have the luxury of conducting the testing that is required to fully determine if new clones are stable in a given set of environments. Examples of current poplar breeding and research are presented, which highlights the risks faced to maintain these programs. In the USA, the number of active poplar and willow (*Salix* spp.) breeding programs has also significantly decreased while those that are active have become integrated across much of the country. The regional nature of programs and poplar adaptability, however, make integrating programs challenging while the installation of plantations on private land ensures new hybrids with potential can be deployed and used to their maximum potential for energy, reclamation/restoration, phytoremediation, or fiber.

Conclusions: Poplar and willow programs are under threat and this primarily means having the funds and local interest to maintain live plant material in a clone bank or in situ genetics trial. Markets driving demand for poplar wood and fiber are also often cyclical. Parent material that is typically of exotic pure species often takes decades to acquire and bring to full flowering production for breeding and this material is always at risk due to reprioritization, diseases and insects, or simply neglect. Despite these challenges, poplars remain one of the most flexible timber species available for the industry (forestry and energy sector), communities, farmers, and individual homeowners. Collaborative efforts across North America and globally continue to allow us to benefit from the exchange of genetic material, institutional knowledge, and continued learning about the potential uses of this fiber including uses as varied as fuelwood from structural building materials to nanocrystals.

2.2. Investigation of Phytoremediation Potential of Poplar and Willow Clones in Serbia: A Review

Pilipović, A.; Orlović, S.; Nikolić, N.; Borišev, M.; Župunski, M.; Arsenov, D. and Kebert, M.

Background: The Institute of Lowland Forestry and Environment (ILFE) at the University of Novi Sad was established in 1958 as the Poplar Research Institute with the objective of implementing and improving forestry practices for the production of poplar (*Populus* spp.) and willow (*Salix* spp.) in the Socialist Federal Republic of Yugoslavia. Decades of research and international and national cooperation resulted in registration and implementation of 16 poplar and 4 willow clones exhibiting nearly 10-fold increases in biomass compared to 1958 productivity levels. Following contemporary worldwide trends in research and practice related to poplars and willows, which are collaborations since the early 2000s with colleagues from the Faculty of Sciences-Department of Biology and Ecology at the University of Novi Sad have focused on the investigation of phytoremediation potential of poplar and willow clones from the Institute's genepool. This resulted in numerous publications and methods. The objective of this presentation is to review 15 years of research results obtained at the University of Novi Sad, which are related to phytoremediation using poplars and willows.

Methods: Phytoremediation research has focused on fast-growing trees from two genera (*Populus* L. and *Salix* L.) and three different groups of contaminants (nitrates, heavy metals, and petroleum hydrocarbons). Poplar clones studied were primarily *Populus* × *canadensis* Moench, *Populus deltoides* Marsh. and intersectional hybrids while willow clones studied were primarily *Salix alba* L., *Salix viminalis* L., *Salix nigra* Marsh., and *Salix matsudana* Koidz. Research was conducted in the greenhouse with hydroponics and pot experiments and, to a lesser extent, in the field. Traditional growth variables, physiological variables, morpho-anatomical variables, biochemical markers, and degradation/extraction efficacy were investigated for various clones.

Results: Research results have shown broad variability in the response of clones relative to their phytoremediation potential. For example, growth responses ranged from high phytotoxicity to a lack of growth impacts in the presence of contaminants. Physiological processes were either suppressed or increased depending upon species and genotype. These responses are often the result of different metabolic and anatomical changes expressed as genotype × environment interactions.

Conclusions: Results obtained have led to the overall conclusion that there is extensive diversity among the clones in the Institute's gene banks. The best performance for phytoremediation of both heavy metals and organic compounds was shown for *P. deltoides* clones. The *P.* × *canadensis* clones most commonly used in Europe showed limitations for phyto-extraction due to their anatomical properties. In contrast, differences among willows were not driven by their species origin. Their potential for heavy metal phytoremediation, as expressed through high phyto-extraction, was even more pronounced than that of poplars.

2.3. Potential for the Agricultural Sector to Produce Poplar Wood as Contribution to the Forestry Wood Industry Chain

Van Acker, J.

Background: The potential of woody biomass production in both volume and quality is key for the future of the forest-based sector. The balance between wood material use and bioenergy use will inevitably lead to a higher competition for the same resource and could evolve into a critical shortage. Vertical integration alongside a better tree and wood quality concept should lead to a more structured approach for dealing with whether some wood products need to be prioritized and how we could deal with the substitution of man-made (building) materials that require more energy. Combining the production of low energy input wood products with the important option to produce green energy based on woody biomass is a major challenge for the future.

The wood resource obtained from the fast growing tree species of the genera *Populus* (poplars) and *Salix* (willows) is considered important in order to enable higher production in the future. Selection and breeding of these deciduous trees has long been a major part of silvicultural and even agricultural frameworks. Furthermore, in many ways, poplar trees can be considered having a potential as a prime alternative for softwood species use in engineered wood products. Applications related to biomass for energy and other end uses that do not require high tree quality should be part of an integrated approach as well.

For traditional products like plywood, but also for constructional timber, poplars are readily available. For example, aspen-OSB (Oriented Strand Board) has been an established product for decades in North America given specific strength and stiffness, which are surely interesting characteristics. However, the ability to select quality trees with a major impact on production yield are also an asset. Today, researchers are reassessing the potential of solid timber products using poplar wood. Dimensional stability and biological durability are improved by using modern wood modification methods besides traditional treatments. In this respect, both glulam and CLT (cross laminated timber) show major potential.

Conclusions: Short rotation woody crops are primarily intended for the production of biomass for energy but can also contribute in the future to an integrated forestry wood industry chain. Both the production of chips and small trees are options and different new production methods are emerging partly based on agroforestry. Among the new methods to produce woody biomass, options to produce chips as well as timber are being assessed in a wide range of agricultural systems. Some are indicated as polycyclic plantations while others are classified under short rotation agroforestry systems. These dual-purpose production systems could be an option to provide, in a sustainable way and based on mid-term strategic decision-making processes, lignocellulosic raw materials for material and energy use. The use of fast growing poplar for high end-products will also profit from developments in using hardwoods for construction and several wood modification options.

2.4. Reaching Economic Feasibility of Short Rotation Coppice (SRC) Plantations by Monetizing Ecosystem Services: Showcasing the Contribution of SRCs to Long Term Ragweed Control in the City of Osijek, Croatia

Kulišić, B.; Fištrek, Ž.; Gantner, R.; Ivezić, V.; Glavaš, H.; Dvoržak, D. and Pohajda, I.

Background: In Europe, biomass for the energy from Short Rotation Coppice (SRC) plantations is seldom feasible except in unique site-specific cases. If society placed priority and value on ecosystem services, then SRC plantations would increase in favorability for providing bioenergy feedstock. Showcasing examples of plantations providing multiple ecosystem services along with monetizing those services could prove important in moving public opinion. We report the case study of Osijek, which is a city of 100,000 inhabitants in Northern Croatia, where an interdisciplinary team of experts investigated planting SRCs for bioenergy as a long-term measure for control and eradication of an allergen and invasive plant, common ragweed (*Ambrosia artemisiifolia* L.). The ultimate goal is to improve living standards of the citizens of Osijek.

Methods: Based on a literature review of ragweed biology and the effectiveness of eradication trials, an assumption was made that SRC plantations in the outer ring of the town could serve as wind/pollen barriers and, thus, a long-term hygiene measure at infestation pathways. Based on local meteorological data, prevailing wind currents for pollen distribution were established and suitable locations for SRC wind barriers were identified. Our analysis considered the attractiveness of planting SRC willow (*Salix* spp.) plantations on agricultural land, public funds spent for short-term interventions against ragweed, and costs (days of sick leave) to the local economy. Economic models used in our analysis were based on: (1) a societal interest in planting SRC plantations for long-term ragweed control that would offset public money invested in the compensation for allergy symptoms and (2) opportunities for farmers to change land use from agricultural crop production to SRC plantations. Net revenues from expected biomass yields for bioenergy markets were assessed to offset investment costs.

Results: Positioning SRC investments as wind barriers together with net revenues from biomass for bioenergy illustrated a new perspective on the economics of SRCs. While production of biomass for bioenergy from SRC plantations was not an attractive option to crop farmers, the addition of ecosystem services from strategically located planting sites changed investment attractiveness. A high replicability potential has been identified based on model results for common ragweed distribution, projected climate change, and expected increased sensitivity of the human population to ragweed pollen.

Conclusions: Biomass for bioenergy is needed to supply the society with renewable carbon. SRC plantations have demonstrated carbon savings, various ecosystem services, and sustainable biomass supply. Yet, the feasibility of SRC plantations remains a challenge. Overlapping ecosystem services with biomass production can yield positive benefits, but interdisciplinary research is needed to identify and monetize ecosystem services that would have positive economics and high reproducibility. This case demonstrates viable methods that can be presented to policy makers and the general public who are not directly familiar with SRC plantings, bioenergy, or ecosystem services.

2.5. Genetic Parameter Estimates for Coppiced Hybrid Poplar Bioenergy Trials

Gantz, C.; Stanton, B.J.; Shuren, R.; Espinoza, J. and Murphy, L.

Background: Selection of highly productive hybrid poplar (*Populus* spp.) varieties is perhaps the most cost-efficient way of increasing biomass plantation yields. Genetic parameters such as clonal repeatability and genetic correlations among different traits obtained from clonal trials are critical to make informed selection decisions. As part of the Advanced Hardwood Biofuels program for sustainable bioenergy production, GreenWood Resources established four hybrid poplar clonal screening trials in Western USA. Trials were established at Hayden, Idaho, and Jefferson, Oregon, in 2012 and at Pilchuck, Washington, and Clarksburg, California in 2013. Our objective was to estimate genetic parameters for coppiced clonal trials to understand the level of genetic control and relationships among traits during the coppice cycle. We discuss our work from Jefferson and Hayden in this report.

Methods. Seventy clones were established in clonal trials at Jefferson, Oregon, and Hayden, Idaho, using a biomass density of 3600 trees per ha. Trials were coppiced two years after planting. Diameter at breast height, diameter of the largest stem of the stump, and number of stems per stump were measured three years after coppice. Mean diameter, basal area, and dry matter per stump were estimated. Specific gravity and moisture content were measured the third year after coppice on the best twenty clones. Statistical analysis was done using mixed linear models with Proc Mixed in Statistical Analysis Software (SAS version 9.4, Cary, North Carolina, USA) to estimate variance components. Clonal repeatability, genetic correlations among traits, and age-age genetic correlations were estimated. Genetic gains in biomass from selecting the best clones are also reported.

Results: Agronomic traits showed a two to three-fold increase between years one and three after coppice and a decrease in the number of stems per stump. Clonal repeatability for agronomic traits were moderate to high at the Jefferson trial. Wood traits repeatability was higher than for agronomic traits. Genetic correlations among traits were high and positive between diameter related traits, but negative between the diameter and the number of stems per stump. Specific gravity had a high negative genetic correlation with wood moisture content. The genetic correlations between age three and age two after coppice were all high. Important genetic gains in dry matter per tree can be obtained by selecting the best 10 clones in the trials.

Conclusions: Clonal repeatability at the Jefferson trial indicated that agronomic traits were under strong genetic control after the second and third coppice seasons. Genetic correlations among agronomic traits suggested that it would be possible to select clones based on the measurement of the main stem of each stool. Age-age genetic correlations indicated that it would be possible to reduce the selection cycle by selecting after the second growing season instead of waiting for one additional year. Important genetic gains in dry matter per stump were obtained by selecting the best five clones at each site.

2.6. Genetic and Environmental Effects on Variability in First-Rotation Shrub Willow Bark and Wood Elemental Composition

Fabio, E.S. and Smart, L.B.

Background: The elemental composition of woody biomass has important consequences for both energy conversion processes and agronomic management of nutrient budgets. Elemental ash content in bark and wood can be problematic for thermal conversion and can decrease pretreatment efficiencies in liquid fuel conversion. It is assumed that a high bark-to-wood ratio in short-rotation crops like shrub willow (*Salix* spp.) will necessarily contribute to high elemental ash content, but little data exists on the genetic and environmental contributions to elemental composition in willow. In support of previous research describing variability in biomass composition of shrub willow crops, we sought to evaluate the contributions of genotype, environment, and their interactions on elemental composition of shrub willow biomass. Specifically, we tested concentrations of macronutrients and micronutrients as well as heavy metals in biomass along with export rates across a range of species and growing environments.

Methods: First rotation biomass samples from six genotypes in four yield trial locations were separated into bark and wood samples, milled and analyzed for C, N, and H by the combustion method, and, for elemental composition, inductively coupled plasma atomic emission spectroscopy (ICP-AES) with acid digestion. An additional set of biomass samples for the same six genotypes from an additional six yield trial locations were milled whole (bark + wood) and analyzed for C, N, H, and elemental composition, which resulted in 252 total independent observations. Factorial analyses of variance were conducted separately for each of the 19 elements in bark and wood to assess the influence of cultivar, the environment, and their interaction. Tukey's honestly significant difference test was used to determine significant differences among factor levels. Multivariate principal components analysis (PCA) bi-plots were used to visualize relationships among elements and growing environments. Lastly, yield values were combined with biomass elemental concentrations to obtain nutrient harvest export rates.

Results: There were significant genotypic differences in elemental concentrations especially for macronutrients and micronutrients. The general trends were that *Salix purpurea* L. genotypes had high N, Mg, and Fe concentrations in bark while *Salix miyabeana* Seemen genotypes had high Ca concentrations in both bark and wood. Hybrids between these two species displayed intermediate values in elemental composition, which suggests an additive mode of inheritance for these traits. Multivariate analyses of the broader suite of biomass samples showed strong environmental effects on elemental composition, but there were a number of significant genotype $\times$ environment interactions. Nutrient export rates at harvest were largely a function of yield, but some genotypes showed signs of luxury uptake when N was abundant. Evidence from this study did not support the expectation that greater bark-to-wood ratios increase total ash content, but rather there are strong genotypic effects on element deposition in stems.

Conclusions: These results showed important genotype-specific preferences in nutrient uptake, which will likely need to be addressed through nutrient management plans. Although our test sites did not include heavy metal contaminated soils, significant genotype $\times$ environment interactions for a number of elements suggest that there may be capacity to exploit existing genetic resources for improving phytoremediation applications and for the development of effective riparian buffer strips to reduce excess nutrient export.

2.7. Is Hybrid Vigor Possible in Native Balsam Poplar Breeding?

Hu, Y. and Thomas, B.R.

Background: When two or more species are crossed to produce hybrid progeny, some of them can be expected to yield growth performance far superior than either parent (i.e., hybrid vigor/heterosis). To date, there have been few attempts to examine whether hybrid vigor can be achieved by crossing disparate populations of the same species. Balsam poplar (*Populus balsamifera* L.) is a transcontinental tree species in North America ranging from Alaska to Newfoundland. This wide range makes balsam poplar an ideal species to study intraspecies hybrid vigor as a tool for increasing genetic gain in growth through increased genetic diversity (i.e., heterozygosity). We tested the hypothesis that intraspecies breeding of widely spaced populations of balsam poplar would lead to the expression of hybrid vigor through both field and greenhouse assessments. We determined the role of exogenous hormones linked to physiological and growth performance.

Methods: In September 2009, three field trials (two in Alberta (AB), Canada (Field 7 and 23), and one in Quebec (QC), Canada (Field QC)) were established in conjunction with Alberta-Pacific Forest Industries Inc. (Al-Pac) and Mr. Pierre Périnet (Ministry of Forestry, Quebec). Five male parents from each province with five female parents from Quebec and four female parents from Alberta were used for breeding intra-region and inter-region crosses. Based on six-year height and diameter results from the Alberta field trials, the AB × QC cross type was selected for further study. In 2016, clones from within this cross-type were grown in a randomized complete block design under near-optimal greenhouse conditions with families identified as slow and fast growing in cross-type AB × QC to use extremes for examining the relationship of hormone levels and growth performance of the genotype and/or family. Diameter and height growth was measured biweekly and gas exchange data were collected on Day 33 (after transplanting) just prior to harvest. In late June, internode tissue samples were collected from two to three trees from each cross to analyze for the hormones that included gibberellic acids (GAs), indole-3-acetic acid (IAA), and abscisic acid (ABA). These hormones have been shown to play a role in regulating plant growth and will help to elucidate whether hybrid vigor was correlated with hormone levels and/or linked to photosynthetic performance. All growth data (height, diameter, stem volume) were analyzed with ANOVA procedures using Statistical Analysis Software (SAS version 9.4, Cary, North Carolina, USA). Following significant main effects, multiple comparisons among means were completed by using the Student-Newman-Keuls test. Correlation coefficients (r or r^2) and probability (P) were determined with Pearson's correlation analysis using the statistical package in SigmaPlot 13.0 (Systat Software, Inc., Chicago, Illinois, USA). We used $\alpha \leq 0.05$ to indicate the significance of all tests.

Results: Preliminary results indicated that stem volumes calculated from height and diameter of two-month-old rooted cuttings grown under optimal greenhouse conditions were positively and significantly correlated with stem volumes of eight-year old field-grown trees (Field 7, $R^2 = 0.396$, $p = 0.012$; Field 23, $R^2 = 0.384$, $p = 0.014$, Field QC, $R^2 = 0.346$, $p = 0.021$, respectively). Additionally, hybrid vigor is correlated with hormone levels and linked to photosynthetic performance (i.e., $R^2 = 0.679$, $p = 0.001$) for the greenhouse photosynthesis rate (A) vs. GA_{19} content (ng g^{-1} DW).

Conclusions: The project will determine the potential of using disparate, native populations of balsam poplar to produce superior progeny with enhanced stem growth traits.

2.8. Uncovering the Genetic Architecture of Growth-Defense Tradeoffs in a Foundation Forest Tree Species

Riehl, J.F.; Cole, C.; Morrow, C. and Lindroth, R.

Background: Physiological tradeoffs in plant allocations to growth and defense govern the ecology and evolution of tree-insect interactions and influence the sustainable production of forests. Despite the importance of plant defenses to forest health, a fundamental gap remains in our knowledge concerning genetic architecture of growth-defense trade-offs. *Populus* L. provides an ideal model system to study the underlying genetic architecture of different resource allocation strategies since phenolic defense compounds (e.g., phenolic glycosides, condensed tannins) are strongly and negatively correlated with growth. This study aims to identify the genetic architecture underlying variation in key growth and chemical defense traits that determine growth-defense trade-offs in a foundation forest tree species (*Populus tremuloides* Michaux) by using genome-wide association analysis combined with complementary methods (e.g., multiple marker association analysis, extreme phenotype sampling, and transcriptomic data).

Methods: A large association mapping common garden of *P. tremuloides* was established in 2010 with four replicate blocks of genotypes (n = 515) collected from a north-south transect throughout Wisconsin, USA (WisAsp population). We evaluated a suite of important tree traits (including tree height and diameter at breast height (DBH), leaf morphology, bud break, and phenolic glycoside concentrations) between 2014 and 2017. Approximately 45,000 probes were used to perform sequence capture genotyping of the full WisAsp population via the Illumina HiSeq2000 platform (San Diego, California, USA), which resulted in the discovery of ~170,000 single nucleotide polymorphisms (SNPs) used in the genome-wide association (GWA) analyses. Leaf material from a subset of genotypes with very high or very low levels of phenolic compounds were collected for RNA (ribonucleic acid) sequencing during the last phenotypic data collection in 2017.

Results: In our preliminary analysis, bud break and phenolic glycosides showed high broad-sense heritability (H^2 = 0.70–0.89) while growth traits (volume, relative growth, leaf morphology) showed low to moderate heritability (H^2 = 0.24–0.49). Traditional single-marker GWA analysis revealed significant SNPs in only two traits known as the specific leaf area (SLA) (uncharacterized gene putatively involved in growth regulation) and the spring bud break (three genes involved in cell wall biogenesis and environmental stress response). Multiple-SNP GWA analysis further elucidated potentially why so few significant SNPs were identified. Traits with both high and low heritability, bud break, and SLA, respectively, exhibited a higher amount of variability explained by our SNP set as compared to other growth and defense traits. This indicated that our SNP set may not have covered portions of the genome controlling the other highly heritable traits (e.g., phenolic glycosides). However, for all traits, no more than 40% of the variation explained by our SNP set was attributed to SNPs with larger effects, which means that these traits were likely controlled by many small-to-moderate effect genes.

Conclusions: From these initial results, we have determined that traditional single-marker GWA alone is unlikely to provide concrete answers as to what genes underlie important tree traits. Thus, future association analyses should begin incorporating complementary methods such as multiple-SNP GWA and expression data (in progress) to help dissect the genetic architecture of important quantitative tree traits to improve tree breeding and conservation.

2.9. The Great Lakes Restoration Initiative: Reducing Runoff from Landfills in the Great Lakes Basin, USA

Zalesny, R.S., Jr.; Burken, J.G.; Hallett, R.A.; Pilipović, A.; Wiese, A.H.; Rogers, E.R.; Bauer, E.O.; Buechel, L.; DeBauche, B.S.; Henderson, D.; Peterson, M. and Seegers, R.

Background: Increasing human population growth and associated industrial development since the 1960s has greatly influenced water quality in the Great Lakes and their watersheds. Closed landfills, dumps, and similar sites contribute to non-point-source pollution of nearshore health especially given the potential impacts of runoff and leakage from such sites. Short rotation woody crops such as poplars (*Populus* spp.) and willows (*Salix* spp.) are ideal for phytoremediation (i.e., the direct use of plants to clean up contaminated soil, sediment, sludge, or groundwater) because they grow quickly, have extensive root systems, and hydraulic control potential. All of these factors serve as biological systems that remediate such pollution. The United States Department of Agriculture Forest Service researchers have developed phyto-recurrent selection, which is a tool for choosing generalist plant varieties that remediate a broad range of contaminants, or specialist plants that are matched to specific pollutants. The ability to select varieties across contaminants allows for broad applicability of these phytoremediation systems. While the science of phytoremediation has undergone rapid growth in the last two decades, there is some uncertainty about the efficacy of using existing forests to remediate liability sites. However, the recent development and patenting of phytoforensic technologies promote the use of plants not only for remediation but also to delineate polluted sites and to monitor remediation progress. Phytoforensics is the use of plant sampling as a way to detect and quantify pollutants in the environment around the plants. Using both phyto-recurrent selection and phytoforensics, the overall objective of this project is to establish 15 phytoremediation buffer systems throughout the Great Lakes Basin to reduce untreated runoff from landfills, which mitigates non-point-source pollution impacts on nearshore health. The objective of this presentation was to describe the landfill runoff reduction project in the context of the overall Great Lakes Restoration Initiative Program, so as to provide context for potential collaborations as well as for abstract 2.10 (Hallett et al.), which is a study within the overall research program. To date, a total of 10 phytoremediation systems have been established, which included 10,000 trees being planted. During summer 2019, we will establish another 5000 trees across five more phytoremediation systems.

2.10. Evaluating Poplar Genotypes for Future Success: Can Phyto-Recurrent Selection Assessment Techniques be Simplified?

Hallett, R.A.; Zalesny, R.S., Jr.; Rogers, E.R.; Wiese, A.H.; DeBauche, B.S.; Bauer, E.O. and Pilipović, A.

Background: Anthropogenic impacts (e.g., runoff from landfills) have been detrimental to water quality and quantity in the Great Lakes. Phyto-technologies could contribute to reducing these ecological impacts. Short rotation woody crops such as poplars (*Populus* spp.) and willows (*Salix* spp.) are ideal for these systems given their elevated biomass relative to slower-growing species and their associated hydraulic control potential. Phyto-recurrent selection is a phyto-technologies method that is used for genotype selection of generalist varieties that are adapted to broad productivity zones or specialists that are matched to specific site conditions such as those at landfills impacted from runoff. We developed phyto-recurrent selection techniques to select poplar and willow genotypes that are best suited to individual field sites by evaluating performance in the greenhouse using weighted rank summation indices consisting of height, root number, root dry mass, leaf number, leaf area, leaf dry mass, and stem dry mass. These variables were selected based on their importance for early establishment. Our overarching objective was to test whether total biomass during evaluation in the greenhouse may be an indicator of future success in the field.

Methods: We used three greenhouse phyto-recurrent selection cycles to reduce a base population of 174 poplar and willow genotypes (cycle 1) to 60 and 24 varieties in cycles 2 and 3, respectively. To make final genotype selections for planting (i.e., cycle 4) at five landfills along the western shore of Lake Michigan, we tested whether genotypes differed for the previously mentioned traits when grown in soil treatments from the five landfills and a commercial potting soil control. For the current presentation, data from cycle 3 ($n = 270$) were compared by using stepwise linear regression techniques to create a simplified model that predicted growth in the greenhouse, which was defined by the total biomass.

Results: We found that the diameter and total leaf number can be used to predict total biomass ($R^2 = 0.82$, $p < 0.001$). In addition, total biomass was significantly correlated with height growth ($r = 0.85$, $p < 0.001$), which is another key factor in rapid establishment.

Conclusions: Diameter and leaf number are easily measured in the greenhouse and may be the only variables needed to predict success in the field. Future studies will need to establish the broad scale applicability of this relationship and include field trials and validation.

2.11. Growth of Poplars in Soils Amended with Fibercake Residuals from Paper and Containerboard Production

Rogers, E.R.; Zalesny, R.S., Jr.; Wiese, A. and Benzel, T.

Background: Phyto-technologies that use poplars (*Populus* spp.) and other woody plants are commonly implemented to remediate polluted soils and groundwater. In addition to environmental clean-up applications, phyto-technologies include the reuse of industrial byproducts. For example, fiber cake residuals are byproducts from paper and containerboard production that have been used as amendments to provide nitrogen and other benefits (e.g., increased organic matter content) to agricultural and forest soils. In this study, we tested early survival and development of poplars grown in fiber cake residual-amended soil treatments to determine the most effective soil-fiber cake combinations for future nursery and field production of selected poplar genotypes.

Methods: Fiber cake residuals were obtained from two different Northern Wisconsin, USA sources. Expera Specialty Solutions (Rhinelander, WI, USA) provided papermaking residuals while Packaging Corporation of America (PCA) (Tomahawk, WI, USA) provided residuals from containerboard production. Both residuals were combined primary (wood fiber) and secondary (bacterial biomass) blended byproducts. The Expera fiber cake was known to release available N while the PCA residual was known to immobilize N when applied to agricultural sites. Three hybrid poplar genotypes (*Populus deltoides* Marsh. × *Populus maximowiczii* Henry 'DM114'; *Populus* × *canadensis* Moench 'DN170'; *Populus nigra* L. × *P. maximowczii* 'NM2') were grown in a greenhouse for 35 days. Cuttings (12.7 cm long) were established in eleven soil treatments that included a commercial potting mix control, a nursery soil collected at the United States Department of Agriculture Forest Service, Rhinelander Experimental Forest, Rhinelander, WI (site of the future out planting), and nine nursery soil-fiber-cake mixes that were blended based on expected N uptake of the trees and the Wisconsin Department of Natural Resources regulations for field N loading. In particular, there were three blends of nursery soil mixed with Expera residuals and three blends with PCA residuals as well as a three-component blend of nursery soil + Expera + PCA. Soil concentrations were determined volumetrically and mixed to achieve application rates of 50, 100, and 200 kg available N ha^{-1}. Analyses followed a split-plot experimental design with three blocks, 11 soil treatments (whole plots), three clones (subplots), and five trees per treatment × clone combination.

Results: Trees grown in the 50 kg N ha^{-1} nursery-Expera blend (A1) had the largest average height (19.54 cm) and diameter (3.02 mm) among all nursery-fiber-cake treatments. Expera soil treatments produced the darkest average leaf color overall (2.92 out of 3) and, thus, the healthiest trees. Trees grown in treatment A2 (100 kg N ha^{-1} nursery-Expera blend) had the lowest average above-ground and below-ground biomass (4.26 g and 0.032 g, respectively) while treatment A1 had the greatest aboveground biomass (4.52 g) and treatment B1 (50 kg N ha^{-1} nursery-PCA blend) had the greatest belowground biomass (0.11 g). Treatments B2 (100 kg N ha^{-1} nursery-PCA blend) and B3 (200 kg N ha^{-1} nursery-PCA blend) produced trees with the smallest average leaf area (48.95 cm^2 and 48.60 cm^2, respectively).

Conclusions: Based on preliminary analyses, there is a wide variability in the measured traits across the differing blends of nursery and fiber cake residuals from both industrial sources. Further data analyses are being conducted to identify the optimal soil treatments for each genotype.

2.12. Growth and Physiological Responses of Three Poplar Clones Grown on Soils Artificially Contaminated with Heavy Metals, Diesel Fuel and Herbicides

Pilipović, A.; Zalesny, R.S., Jr.; Orlović, S.; Drekić, M.; Pekeč, S.; Katanić, M. and Poljaković-Pajnik, L.

Background: Land use associated with agricultural practices is often limited by environmental degradation including soil contamination. Biologically sustainable cleanup methods such as phytoremediation are needed to rehabilitate such soils for agricultural and forestry production. Short rotation woody crops such as poplars, cottonwoods, and aspens (*Populus* spp. and their hybrids) have proven effective for phytoremediation of a broad spectrum of contaminants, which results in economic and ecological benefits. The objective of this study was to test the growth and physiological responses of three different poplar clones grown on soils contaminated with heavy metals, diesel fuel and herbicides.

Methods: Poplar trees belonging to three clones (*Populus deltoides* Marsh. 'Bora' and 'PE 19/66', and *Populus* × *canadensis* Moench 'Pannonia') were grown for three years at the Experimental Estate of the Institute of Lowland Forestry and Environment, University of Novi Sad (former Poplar Research Institute), Serbia. Trees were spaced 2.0 × 0.5 m apart, which is consistent with biomass production plantings throughout Europe. The field was divided into seven plots containing an uncontaminated control and the following six artificially polluted soil treatments: (1) 10.6 kg Ca ha^{-1}, (2) 183.3 kg Ni ha^{-1}, (3) 247 kg Cu ha^{-1}, (4) 6667 L diesel fuel ha^{-1}, (5) 1320 g Pendimethalin ha^{-1}, and (6) 236 g Oxyfluorfen ha^{-1}. Net photosynthesis, transpiration, stomatal conductance, and chlorophyll fluorescence were assessed during the first two vegetation periods while height and diameter were measured after cessation of growth each year. After the third growing season, plants were harvested and weighed to assess biomass production.

Results: There were significant differences among clones for growth and biomass production ($p < 0.0001$). Treatment with heavy metals affected growth of clones at the beginning of the experiment but the effects were not significant during the third growing season ($p > 0.05$). Net photosynthesis, stomatal conductance, and transpiration were significantly affected by the treatments in the first growing year for all clones ($p < 0.0001$) while chlorophyll fluorescence showed fewer differences between treatments and investigated clones.

Conclusions: Preliminary results showed promise for clones 'Bora' and 'PE 19/66', which had 5.3 and 7.9 times greater biomass than 'Pannonia', respectively, across all soil treatments. Despite non-significant genotype × treatment interactions at the end of the study, 'Bora' and 'PE 19/66' grown in all treatment soils exhibited greater biomass than 'Pannonia' with trees growing in the control soils exhibiting 13.8 and 19.6 times greater biomass than 'Pannonia', respectively. Unfavorable and favorable genotype × soil treatment interactions need to be considered along with the applicability of using 'Bora' and 'PE 19/66' in larger-scale systems.

2.13. Mitigating Downstream Effects of Excess Soil Phosphorus through Cultivar Selection and Increased Foliar Resorption

Da Ros, L.M.; Soolanayakanahally, R.Y. and Mansfield, S.D.

Background: Phosphorus is a non-renewable resource pivotal to global food security since it often limits plant growth and development. Concomitantly, due to its diffuse source run-off from agricultural land and role in promoting algal growth, phosphorus is also characterized as a pollutant in aquatic environments. Movement of nutrient contaminants such as phosphorus into riparian ecosystems could be limited via the widespread planting of *Populus* L. (poplar) and *Salix* L. (willow) hybrids on the agricultural landscape. A comparative study using commercially available high biomass-producing tree species was performed to: (1) evaluate the natural variation in phosphate uptake, storage, and resorption in Salicaceae hybrids, (2) recommend promising genotypes for field trials, and (3) identify current barriers to the efficient phytoremediation of phosphorus-rich sites.

Methods: Multiple greenhouse trials involving 15 genotypes were conducted at the University of British Columbia Horticulture Greenhouse, Vancouver, British Columbia, Canada. Trees were grown from cuttings and are exposed to five phosphorus treatments ranging from optimal (0.4 mM P) to 15× optimal levels (6.3 mM P). Half of the trees were harvested at bud-set after 100 days of growth while the remaining trees were harvested after autumnal leaf senescence. Phenotypic differences in phosphorus storage and allocation were analyzed by using inductively coupled plasma atomic emission spectroscopy (ICP-AES) and high-performance liquid chromatography (HPLC). Semi-quantitative polymerase chain reaction (SQ-PCR) was used for gene expression analysis. R version 3.3.2 (R Core Team 2016; https://www.r-project.org/) was used to fit linear mixed-effects models with the packages lmerTest and nlme. Bland-Altman analysis for the method comparison was done using the package MethComp.

Results: Toxicity symptoms were not observed in any genotype across the phosphorus treatments. Species that demonstrated luxury uptake and storage of phosphorus had leaf concentrations >5 mg P g^{-1} as opposed to the 3–4 mg P g^{-1} observed in low or non-accumulating species at optimal levels of external phosphorus. Phosphorus resorption efficiencies ranged from 0% to 32% for hybrid poplar and 35% to 52% for hybrid willow with a high concentration of mobile phosphate remaining in leaves after senescence.

Conclusions: A high degree of intraspecies and interspecies variation in luxury consumption and resorption efficiency exists in poplar and willow genotypes. The poplar hybrid genotype 'Tristis' (*Populus* Tristis) is a promising candidate with luxury consumption of phosphate, large root systems, and the highest resorption efficiency among the poplar. An alternative candidate would be the hybrid willow genotype 'AAFC-5' (*Salix discolor* Muhlenberg × *Salix dasyclados* Wimmer) since it has higher biomass allocation to the stem, which allows for greater phosphorus removal from the site after coppice and higher phosphorus resorption efficiency. For the efficient-use of poplar and willow in agro-ecological and phytoremediation applications, improvements in the translocation of phosphate out of leaves during autumnal senescence would be beneficial.

2.14. Survival and Growth of Poplars and Willows Grown for Phytoremediation of Fertilizer Residues

Zalesny, R.S., Jr. and Bauer, E.O.

Background: Species and hybrids belonging to the genera *Populus* L. (poplar) and *Salix* L. (willow) have been used successfully for phytoremediation of contaminated soils. However, genotypic screening using phyto-recurrent selection is necessary prior to large-scale deployment because of the broad amount of variation among and within poplar and willow clones. To identify promising genotypes for potential use in future phyto-technologies, the objectives of the current study were to: (1) evaluate the genotypic variability in survival, height, and diameter of poplar and willow clones established on soils heavily contaminated with nitrate fertilizer residues and (2) assess the genotypic stability in survival and diameter of selected poplar clones after one and eleven growing seasons.

Methods: We evaluated traits after the first year bud set by testing 27 poplar and 10 willow clones planted as unrooted cuttings along with 15 poplar clones planted as rooted cuttings. The cuttings were planted in randomized complete blocks at an agricultural production facility in the Midwestern United States. After eleven growing seasons and using phyto-recurrent selection, we surveyed survival and a measured diameter of 27 poplar clones (14 unrooted, 13 rooted) that were selected based on superior survival and growth throughout plantation development.

Results: There was a broad amount of genotypic variability in survival, height, and diameter during the establishment. Overall, willow exhibited the greatest survival while poplar had the greatest height and diameter. At eleven years after planting, superior clones were identified that exhibited an above-average diameter growth at establishment and rotation-age in which most had stable genotypic performance over time.

Conclusions: Our results verified that the broad clonal variation among and within poplar and willow genotypes was an important positive indicator for the potential of long-term phytoremediation of NO_3^--contaminated soils because the selection is proportional to variation and establishment is the first requirement for any long-term success of the system. Given the broad range in height and diameter among genotypes and the ability to select better clones within this variation, our findings suggest that the selection of specific clones was favorable to genomic groups based on the geographic location and soil conditions of the site.

2.15. Stakeholder Assessment of the Feasibility of Poplar as a Biomass Feedstock and Ecosystem Services Provider in Rural Washington, USA

Hart, N.M.; Townsend, P.A.; Chowyuk, A. and Gustafson, R.

Background: Growing poplar (*Populus* spp.) as an energy crop in southwestern Washington, USA could also provide ecosystem services for wastewater management and flood control. Models of poplar growth and land use show that the region has enough suitable land to support a poplar-based bio-products industry. In addition, the region's economically depressed rural communities could benefit from new cropping and industrial production opportunities. Evaluating the feasibility of a poplar-based industry requires an understanding of the local social-ecological context and stakeholder opinions on converting land to poplar. This study was conducted as part of Advanced Hardwood Biofuels Northwest, a United States Department of Agriculture, National Institute of Food and Agriculture-funded consortium of university and industry partners developing the framework for a poplar-based biofuel and bio-based chemical industry in the Pacific Northwest. We conversed with stakeholders to: (1) capture information about the context of the agricultural landscape in the study region, (2) identify perceived opportunities and challenges to growing poplar for a bio-products industry, (3) explore the validity of techno-economic modeling assumptions and ecosystem services potential, and (4) compile stakeholder questions.

Methods: During the winter of 2018, we conducted 15 in-depth, semi-structured interviews (30–60 min each), a focus group meeting (90 min), and a short discussion (20 min). The stakeholder conversations were recorded and then fully transcribed. The transcripts were coded using descriptive and initial (i.e., open) coding methods to sort the data based on recurrent topics.

Results: Stakeholders expressed a desire for a new economic opportunity that "pencils out" and were generally optimistic about win-win scenarios for floodplain management (when outside of riparian restoration buffers). Stakeholders had questions about the business model for farmers, the inputs and outputs of the biorefinery, and the technical feasibility of growing and harvesting poplar in the region. They also discussed several salient obstacles to growing poplar for bio-products such as past failures to profit from poplar production (for pulp/sawlogs), competing land use practices (for conservation and forage), and limited drivers for alternative wastewater solutions.

Conclusions: A successful poplar-based bio-products industry could meet multiple needs in rural, Southwestern Washington. Given a credible business model, participants did not think it would be difficult to find suitable land and secure willing growers. However, landowners require assurance of turning a profit to convert to poplar and large initial investments (e.g., covering the costs of bio-refinery construction, harvesting equipment, and poplar farm establishment) would be needed to start the industry.

2.16. Barriers and Opportunities for Use of Short Rotation Poplar for the Production of Fuels and Chemicals

Townsend, P.A.; Dao, C.; Bura, R. and Gustafson, R.

Background: Poplar (*Populus* spp.) is widely recognized as excellent feedstock for the production of bio-based fuels and chemicals. The rapid growth of poplar, ease of fractionation, ample sugar content, and potential for year round harvesting make it an attractive candidate as a dedicated feedstock for a bio-refinery. To demonstrate this potential, Advanced Hardwood Biofuels Northwest (AHB) established four demonstration sites with short-rotation poplar in the Pacific Northwest. To produce a reliable biomass supply, we envision that poplar tree farms would be harvested approximately every three years allowing for coppice regeneration. Whole tree harvesting would be enabled by forage harvesters that cut and chip the poplars in a single pass. The short rotation cycle and use of biomass from the entire tree that includes wood chips as well as leaves, stems, and bark results in a poplar feedstock that is quite different from clean poplar chips that have been investigated in past bioconversion research projects. It is important that the bioconversion of poplar biomass be thoroughly investigated before commercial short rotation tree farms are established. The objective of this research is to investigate the bioconversion of whole tree poplar biomass to produce fuels and chemicals. Specific issues investigated were: (1) the impact of leaves on conversion processes, (2) the ease of sugar release from different poplar clones, and (3) the efficacy of preprocessing poplar chips to improve enzymatic hydrolysis and fermentation processes.

Methods: Whole tree poplar biomass harvested at the AHB tree farms were processed at the University of Washington laboratories by acid catalyzed steam explosion, enzymatic hydrolysis, and fermentation to ethanol. Liquid and solid phases from each processing step were analyzed to assess sugar release and fermentation yields.

Results: Our results show that leafy material had a significant impact on enzymatic hydrolysis and that poplar leaves would need to be removed either prior, during, or after harvesting to have reasonable product yields. Differences in sugar release were found between various poplar clones grown at the same demonstration sites. Moreover, consistent differences in sugar release were observed even when the same poplar clones were grown at different tree farm locations. More rapidly growing clones tended to have lower sugar releases. Lastly, we observed whole tree poplar chips with both inorganic and organic components that should be removed for good sugar release and fermentation yields. Use of acidic preprocessing, followed by water washing, was more effective than just water washing of poplar chips to remove detrimental components. Water washing alone, however, resulted in higher sugar and fermentation yields than was observed with poplar chips that were not preprocessed.

Conclusions: Poplar remains an excellent feedstock for the production of fuels and chemicals. Different poplar clones have significant differences in their ease of sugar release and this will need to be investigated further before establishing commercial tree farms. Effective use of whole tree poplar biomass obtained from trees grown on short-rotation cycles may require some additional processing steps to increase sugar and final product yields. The potential to extract high value chemicals from whole tree biomass using preprocessing needs to be investigated further.

2.17. Short Rotation Eucalypts: Opportunities for Bioproducts

Rockwood, D.L.; Ellis, M.F.; He, Z.; Liu, R. and Cave, R.D.

Background: Eucalypts (*Eucalyptus* spp.) are the world's most valuable and widely planted hardwoods (18 million ha in 90 countries) and have numerous potential applications as short rotation woody crops (SRWC) due to many well understood conversion technologies and several promising technologies under development. Using experience in Florida, USA, we describe the potential for eucalypts to maximize SRWC productivity through site amendment and genetic improvement, document their current energy applications, and assess their potential for short-term and likely long-term bio-products.

Methods: An intensively cultured eight plus ha demonstration plot of *Eucalyptus grandis* W. Hill ex Maiden × *Eucalyptus urophylla* S.T. Blake cultivar 'EH1' was planted in May 2011 on former citrus beds near Hobe Sound, FL. Plantings were established on two spacings and they were monitored through harvest in December 2017. In 2012, a *Eucalyptus grandis* cultivar 'G2' was commercially planted near Ft Pierce, FL along with *Corymbia torelliana* (F. Muell.) K.D. Hill & L.A.S. Johnson progenies. Stemwood samples from these and two other species were assessed for biochar characteristics. Biochar and organic fertilizer treatments applied to a windbreak of *E. grandis* W. Hill ex Maid. Cultivars and *C. torelliana* progenies at the Indian River Research and Education Center (IRREC) in February 2018 were periodically evaluated through soil, foliage, and tree growth monitoring.

Results: Through 81 months, the 'EH1' cultivar was more productive at the nominal 3.05 × 1.22 m spacing than the 3.05 × 2.13 m spacing (63.6 vs. 57.6 green MT ha^{-1} $year^{-1}$). 'EH1', *C. torelliana*, and 'G2', as well as *Eucalyptus amplifolia* Naudin and live oak (*Quercus virginiana* Mill.) are suitable for commercial biochar production in Florida. Soils data from the IRREC biochar test suggest that biochar greatly enhances the nutrient properties of inherently poor Florida soils and four-month foliage and growth results document rapid response to the biochar amendment. We also review other potential *Eucalyptus* bio-products that may be classified as naturally occurring, generated by biochemical processes, or as the result of thermochemical processes.

Conclusions: Eucalypts can be very productive when intensively grown as SRWCs. Biochar produced from *Eucalyptus* spp. and other species may be a useful soil amendment for their intensive culture. Many products currently derived from petrochemicals can be produced from SRWCs and these bio-products have a broad and exciting range of applications for enhancing the value of SRWCs.

2.18. Variability of Harvester Performance Depending on Phenotypic Attributes of Short Rotation Willow Crop in New York, USA

de Souza, D.P.; Volk, T.A. and Eisenbies, M.H.

Background: Fossil fuels remain the dominant energy source despite current environmental, social, and economic concerns. However, renewable energy sources such as short rotation woody crops (SRWC) like shrub willow (*Salix* spp.) have been receiving more attention in recent years. Harvest is the single largest cost in the production of SRWC, but the systems previously used in North America have not been optimized for these crops. Contemporary research has focused on the performance of single pass cut and chip systems and, while there is implicit recognition that crop attributes such as standing biomass, field size and condition, and operator experience could affect the system, there is little concrete information about their effects. The objective of this project is to determine if phenotypic attributes of shrub willow crops in New York State are related to the operating performance of a New Holland FR9090 (Turin, Italy) forage harvester fitted with a 130FB coppice header.

Methods: The study is based on data collected from a 5-ha harvest conducted in Solvay, New York. Prior to harvesting, willow characteristics such as height, stem diameter, number of stems, and plant form were measured. Material capacity (Mg hr^{-1}), field capacity (ha hr^{-1}), standing biomass (Mg ha^{-1}), and other attributes of the harvest operation were determined.

Results: Despite promising results shown by the FR-series forage harvester in past harvests, up to 10 percent of woody biomass is not processed by the harvester and remains on the field. Drop losses (biomass left on the site) were collected after the harvest to determine the amount of harvestable biomass remaining on site and its relationship with the crop's phenotypic attributes. Preliminary results show slight but positive effects of diameter ($p \leq 0.0001$), height ($p = 0.0002$), and stems > 50 mm ha^{-1} ($p \leq 0.0001$) on material capacity and negative (also slight) effects of stems ha^{-1} ($p = 0.0359$) and yield ($p \leq 0.0001$). Additionally, field capacity appears to be slightly and negatively affected by diameter ($p = 0.0119$), stems > 50 mm ha^{-1} ($p = 0.0178$), yield ($p = 0.0009$), and cultivar ($p \leq 0.0001$).

Conclusions: This ongoing study will help illuminate the characteristics of willow crops that limit the harvester's operation and what plant phenotypes optimize harvester performance and minimize operating costs.

2.19. Cover Protection Affects Fuel Quality and Natural Drying of Mixed Leaf-On Willow and Poplar Woodchip Piles

Therasme, O.; Eisenbies, M.H. and Volk, T.A.

Background: Short-rotation woody crops (SRWC), which include shrub willow (*Salix* spp.), have the potential to make substantial contributions to the availability of biomass feedstock for the production of biofuels and bio-products. The objective of this study was to evaluate changes in fuel quality of stored leaf-on willow and poplar (*Populus* spp.) chips with respect to the degree of protection, location within the storage piles, and duration.

Methods: Harvested leaf-on willow and poplar wood chips with moisture content in the range of 42.1% to 49.9% (wet basis) were stored at the State University of New York, College of Environmental Science and Forestry field station in Tully, New York in piles for five months from May to October 2016. Three piles contained 25–30 Mg and three piles contained 35–40 Mg of wood chips. Three protection treatments were randomly assigned within each of the two groups of piles. The unprotected treatment exposed piles to direct solar radiation and rainfall. The second treatment had canopies covering the piles to limit direct rainfall. The final treatment had canopies plus a dome aeration system installed over the piles.

Results: Results indicate that cover protection can play a significant role in reducing and maintaining low moisture content in wood chip piles. Within 30 days of storage, moisture content in the core of covered piles decreased to less than 30% and was maintained between 24% to 26% until the end of the storage period. Conversely, there was an increase of moisture content in unprotected piles during the first two months of storage. For the conditions tested, core material (>45 cm deep) dried faster than shell material (<45 cm deep). The lower heating value, which strongly depends on the moisture content, was the highest for covered piles at the end of the storage.

Conclusions: Leaf-on SRWC biomass stored in piles created in late spring under climatic conditions similar to central and northern New York showed differing moisture contents when stored for more than 60 to 90 days. Overhead protection could be used to preserve or improve the fuel quality in term of moisture content and heating value.

2.20. Historical Perspective and Evolution of the Short Rotation Woody Crops Program at Rhinelander, Wisconsin, USA

Isebrands, J.G.

Background: Tree improvement research began in Rhinelander, Wisconsin, USA in 1931 at the Hugo Sauer Nursery. It was part of the United States Department of Agriculture (USDA) Forest Service, Lake States Forest Experiment Station's effort to develop superior planting stock of northern forest species for reforestation. In 1957, the Northern Institute of Forest Genetics (IFG) was founded at the present location near the Nursery. Over time, the IFG staff expanded with increased political support and funding for USDA Forest Service research priorities. The expansion was largely due to significant accomplishments of IFG scientists. Soon the IFG rose to national and international prominence in disciplines of radiation biology, ecology, physiology, genetics, and phytoremediation.

In 1966, the IFG became part of the North Central Forest Experiment Station and later became the Forestry Sciences Laboratory (FSL). There were several building additions as the research program grew. In 1971, the multidisciplinary Maximum Yield Program was founded under the direction of David H. Dawson with the goal to maximize wood production to meet growing national needs. A worldwide oil embargo and energy shortage in 1973–1974 accelerated the need for increasing wood yields on short rotations for wood and bioenergy. After testing, poplars (*Populus* spp.) and willows (*Salix* spp.) surfaced as promising species because of their rapid growth rate and ease of genetic improvement and culture. The Program soon became known as the Short Rotation Intensive Culture research program. Then the United States Department of Energy became a continuing important funding partner for the research.

There was close collaboration with Canadian scientists from the beginning as well as numerous university scientists. In the 1980s, global climate change became an international issue as the world population grew. Poplars and willows became model forest species for studying bioenergy and global climate change.

Research at the FSL led to the first genetically modified tree in the world, which was a poplar at Rhinelander. It also led to the establishment of the world's largest field experiment on carbon dioxide and tropospheric ozone enrichment of forest trees at the Harshaw Experimental Farm near Rhinelander. Canadian forest scientists were part of the multidisciplinary team along with numerous international university scientists.

Conclusions: More recently, the FSL became part of the reorganized Northern Research Station. Today's emphasis is on landscape ecology and ecosystem services research such as phytoremediation. The FSL has a long history of phytoremediation research since the late 1980s. Archiving important genetic materials for bioenergy and phytoremediation is also a priority. The FSL was renamed the Institute of Applied Ecosystem Studies to reflect these priorities. Numerous examples of historical photos, scientific milestones, international awards received, and international meetings held at Rhinelander are given throughout the presentation.

2.21. Tree Willow Root Growth in Sediments Varying in Texture

McIvor, I. and Desrochers, V.

Background: Willows (*Salix* spp.) are used for riverbank stabilization in New Zealand where they are planted into a range of sediments. River engineers have expressed concern that willow root systems failing under flood conditions may be weakened by the giant willow aphid (*Tuberolachnus salignus* (Gmelin)). However, the river engineers lack sound information on how a 'normal' root system develops in varying river sediments. We investigated the early root development of *Salix nigra* Marsh. in sediments typical of the sediments found in New Zealand riverbanks. The sediment types largely sort on particle size including silt, sand, and stones.

Methods: Cuttings of *S. nigra* were grown for 10 weeks in layered sediment types in five large planter boxes established outside. Each box differed in the proportion of silt, sand, and stones (gravel) with stones layered in the bottom and silt layered on the top in each box. Boxes were kept in ambient conditions and watered by the overhead sprinkler twice a day. Three, 90-cm long cuttings were planted to 5 cm off the floor of each box. At 10 weeks, the boxes were disassembled to extract roots and roots were sorted into diameter classes, according to sediment type and depth. Root length and dry mass were measured and root length density (RLD) and root mass density (RMD) calculated. Shoot number and mass were also recorded.

Results: Root development of *S. nigra* cuttings varied with sediment type, either silt, sand, or stones. Roots were initiated from the entire length of the cutting in the substrate, but root initials were concentrated at the bottom and close to the bottom of the cutting. There was substantial root extension into all three sediments and at all depths. Root length for roots $\geq$1 mm diameter was greatest for plants grown in approximately even proportions of silt, sand, and stones and least for plants grown in the lowest proportions of silt (30%, 20%) and the highest proportions of stones (50%, 70%). Root mass was greatest for cuttings in the box with the highest proportion of silt. Generally, RMD was highest in the stones because it was influenced by having the bottom of cuttings located in stones for four of the five treatments. RMD was highest for roots <1 mm diameter. However, RLD for roots >0.5 mm diameter was highest in sand while RLD of roots with diameter <0.5 mm was lowest in sand. Roots were extracted easiest from sand and with the most difficulty from silt.

Conclusions: Roots of *S. nigra* were least effective in binding sand primarily because of the low RLD of root <0.5 mm diameter. It is surmised that sand lacks water and nutrients sufficient to sustain growth of fine roots compared with silt and even stones. RLD for roots >0.5 mm diameter was the lowest in silt likely due to the greater resistance of the substrate to root penetration or possibly the greater investment into smaller roots that have stronger absorption capability.

2.22. Environmental Benefits of Shrub Willow as Bioenergy Strips in an Intensively Managed Agricultural System

Cacho, J.F.; Negri, M.C.; Zumpf, C.R.; Campbell, P.; Quinn, J.J. and Ssegane, H.

Background: Integrating perennial biomass crops into predominantly agricultural landscapes is gaining interest because of the potential to address sustainability issues in commodity crop production while providing multiple environmental benefits. This approach takes advantage of intra-field variation in soil productivity and suitability of second-generation biomass crops with their perennial growth characteristics and distinct physiological traits (e.g., deep rooting system, greater resiliency to marginal conditions, etc.). To test the viability of such a system, we are conducting a study in east-central Illinois where shrub willow (*Salix miyabeana* Seemen 'SX61') was introduced in areas of a 6.5-ha intensively managed corn (*Zea mays* L.) field that were considered less productive and/or vulnerable to environmental degradation (marginal areas). Specifically, we were interested in evaluating (1) the ability of shrub willow to intercept and utilize leached nutrients (particularly nitrate) from adjacent corn and (2) relative influence of shrub willow on other environmental quality indicators including water quantity, soil health, and greenhouse gas emissions.

Methods: Our research site was established using a randomized blocked design with plots of shrub willow and corn blocked on lowland floodplains in Comfrey loam soil (fine-loamy, mixed, superactive, mesic Cumulic Endoaquolls) with 0% to 2% slope (northern or N-plots) and on upland plains in Symerton silt loam soil (fine-loamy, mixed, superactive, mesic Oxyaquic Argiudolls) with 2% to 10% slope (southern or S-plots). The N-plots served as a pseudo-control located in fertile, floodplain soil with limited nitrate leaching. Conversely, the S-plots with higher nitrate leaching were categorized as marginal areas. Nutrient cycling was assessed by sampling soil, soil water, groundwater, and vegetation for nutrient loss and uptake. Additionally, biomass, groundwater elevation, soil moisture, transpiration, and greenhouse gas flux were measured.

Results: Results show that, where the shrub willow was established, annual soil water nitrate concentrations were reduced by up to 87% as compared to where corn was established. Rates of water use and soil nutrient utilization in areas under the shrub willow were comparable to areas planted in corn. Furthermore, soils under shrub willow cover showed subsoil carbon sequestration potential and nitrous oxide (N_2O) emissions were reduced when compared to soils planted in corn.

Conclusions: Our study demonstrates that careful placement of perennial biomass crops such as shrub willow within intensively managed agricultural fields can provide multiple environmental benefits in addition to bioenergy feedstock.

2.23. Quantifying the Unknown: The Importance of Field Measurements and Genotype Selection in Mitigating the Atmospheric Impacts of Poplar Cultivation

Kiel, S.; Potosnak, M.J. and Rosenstiel, T.N.

Background: Many woody crops including *Populus* (poplar) and *Salix* (willow) emit significant quantities of volatile organic carbon (VOCs) especially the reactive hemiterpene isoprene to the atmosphere. The emission of VOCs from these woody crops play important roles in influencing regional and local atmospheric chemistry including influencing the formation of ground-level ozone and secondary organic aerosols. However, despite this knowledge, relatively few field-based studies have attempted to quantify the magnitude and diversity of VOC emissions from woody crops under actual field conditions or have evaluated how woody crop genotype selection and the cultivation method may affect overall VOC emissions. To address this general lack of understanding, the objectives of the present study were to deploy a novel field-based method to quantify VOC emissions in situ (relaxed eddy accumulation flux analysis) from a large-scale poplar biomass plantation established as part of the Advanced Hardwood Biofuels Northwest (AHB) Project. In addition, we evaluated leaf-scale variation in VOC emission from field-grown poplar genotypes over multiple growing seasons and we examined the impact of genotype selection on the potential for whole canopy VOC emission as a consequence of poplar cultivation.

Methods: We evaluated leaf-scale VOC emissions from eleven field-grown bioenergy poplar genotypes over multiple seasons as part of a large-scale field trial near Jefferson, Oregon, USA. In addition, we developed and deployed a field-based whole-canopy flux measurement system to quantify peak summer-time VOC emissions associated with the genotypes of this high-productivity coppiced poplar system.

Results: There was surprising and significant variation in leaf-level VOC emissions among the poplar genotypes examined. In addition, using our field-based relaxed eddy accumulation methods, we have observed some of the largest ecosystem fluxes of isoprene emission to date with whole canopy surface fluxes in excess of 100 nmol m^{-2} s^{-1}.

Conclusions: Results from this field-based study suggest that intensive woody crop cultivation is generally proposed for both poplar and willow and may represent a significant and poorly characterized, landscape-level source of VOC emissions with potentially significant implications on regional atmospheric chemistry. However, the observation of significant variation in VOC emissions among poplar genotypes suggests that both targeted breeding and genetic engineering may be an effective strategy for reducing the unintended atmospheric consequences associated with woody crop cultivation.

2.24. Greenhouse Gas and Energy Balance of Willow Biomass Crops Are Impacted by Prior Land Use and Distance from End Users

Volk, T.A.; Yang, S.; Fortier, M.-O. and Therasme, O.

Background: Few life cycle assessment (LCA) studies of willow (*Salix* spp.) biomass crops have investigated the effects and uncertainty of key parameters, e.g., soil organic carbon (SOC) changes associated with land use change and transportation distance with a spatially-explicit perspective.

Methods: This study uses a spatial LCA model that incorporates Geographic Information System (GIS) data in Central and Northern New York, USA to provide specific estimates of greenhouse gas (GHG) emissions and energy return on investment (EROI) of land use conversion and willow biomass production with SOC change in the model.

Results: Ninety-two percent of 9718 suitable parcels for willow biomass production had negative GHG emissions in willow biomass production indicating climate change mitigation potential. The average life cycle GHG emissions in the region were −126.8 kg CO_2eq Mg^{-1} biomass on cropland or pasture land and ranged from −53.2 kg to −176.9 kg CO_2eq Mg^{-1} biomass across the region. However, for grassland converted to willow biomass crops, there was a modeled decrease in SOC resulting in a slightly positive (27.7 kg CO_2eq Mg^{-1} biomass) GHG balance. Changes in SOC associated with land use change, willow crop yield and transportation distance had the greatest impact on GHG emissions. The uncertainty analysis showed large variations of probability distributions of GHG emissions in the five counties arising from differences in these key parameters. The average EROI of 19.2 was not affected by land use change but was influenced by transportation distance and yield.

Conclusions: The results showed substantial potential to reduce GHG emissions in the region by growing willow biomass crops as well as the potential to provide a woody biomass feedstock with a high EROI. Furthermore, these results suggest that willow biomass can serve as a low carbon and high EROI energy source in other regions of the world with similar infrastructure and soil conditions.

2.25. Growth Patterns and Productivity of Hybrid Aspen Clones in Northern Poland

Niemczyk, M.; Kaliszewski, A.; Wojda, T.; Karwański, M. and Liesebach, M.

Background: Rapid growth and favorable wood properties make aspen (*Populus tremula* L.) suitable for production of pulp and paper as well as reconstituted panels and pallets. Thus, plantations of fast-growing aspen and its hybrids seem to be a promising source of wood for satisfying the increasing need for wood-based products. In this study, we assessed the potential of tree improvement to enhance the productivity of aspen and its hybrids in northern Poland.

Methods: We studied a common garden trial that included 15 hybrid aspen clones of *Populus tremula* L. × *Populus tremuloides* Michaux, four hybrid clones of *P. tremula* × *Populus alba* L., and one *P. tremula* intraspecific cross. Hybrid clones had been crossed and selected in Poland and Germany and their growth was previously tested in the countries they were bred. For a comparison, clones of *P. tremula* plus trees selected in Białowieża Forest were studied. Tree height and diameter at breast height (DBH) were measured after four, five, six, and seven growing seasons. We calculated tree volume and the mean annual increment (MAI) for each clone at a given age. Data were analyzed using the Zero Inflated Generalized Linear Mixed Models (ZI-GLMM). Survival probability was calculated with the logistic model and the log-ANOVA model was used for trees that survived. Choice of the optimal model was based on the Akaike Information Criterion (AIC). All statistical analyses were performed with the Statistical Analysis Software (SAS version 9.4, Cary, North Carolina, USA).

Results: Survival probability for all clones was generally high (0.820 to 0.998). Biometric characteristics differed noticeably among clones but were significantly greater for all hybrids (inter- and intraspecific crosses) compared to pure species. Of the 21 analyzed clones, 'Białowieża' as a progeny of pure species had the poorest growth. In contrast, the clone 'Wä 13' (*P. tremula* × *P. tremuloides*) showed the highest DBH, height, volume production, and MAI (25.4 m^3 ha^{-1} $year^{-1}$) among all studied clones. The mean estimated stem volume of 'Wä 13' at age 7 was 4.6 times greater than pure *P. tremula*. Overall, significant clone by year interaction was observed for height and MAI. During the studied period, clones showed an increasing MAI that progressed over each analysis year.

Conclusions: All hybrid clones performed better than the offspring of pure *P. tremula*. Results of this study contribute to our understanding of aspen hybrid vigor (heterosis) and growth patterns. Experiments with aspen have been rarely completed in Poland. Therefore, our study has important practical implications since we demonstrated that aspen breeding can result in increased biomass productivity that could bring significant economic benefit.

2.26. The Economics of Rapid Multiplication of Elite Hybrid Poplar Biomass Varieties: Expediting the Delivery of Genetic Gains

Stanton, B.J.; Haiby, K.; Shuren, R.; Gantz, C. and Murphy, L.

Background: Poplar (*Populus* spp.) hybridization is key to advancing biomass yields and conversion efficiency. Once superior varieties are selected, there is a lag in commercial use while they are multiplied to scale. Considering the density of bioenergy plantations (3600 stems ha^{-1}) and the sizable area required for refinery operations, the length of the multiplication period impedes the expeditious delivery of genetic gains. The purpose of this study was to determine the level of gain in biomass yield and quality that justifies investment in advanced propagation techniques to speed the time to commercial deployment. Underlying objectives were: (1) quantify varietal variation in the efficiency of in vitro micro-propagation and greenhouse hedge and serial propagation and (2) determine the investment rate of return (IRR) into these propagation techniques at varying levels of genetic gains in biomass yield and quality throughout a 20-year rotation comprising a two-year establishment cycle and six three-year coppice cutting cycles.

Methods: Five varieties were studied by using the Finnish *Populus* × *wettsteinii* Hämet-Ahti model of in vitro shoot proliferation [3], which was followed by greenhouse propagation of succulent cuttings. Micro-cuttings were produced by in vitro culture and used in establishing greenhouse hedges that were sheared five times for succulent cuttings. Cutting yield and survival at each of the five hedgings were compared to five successive rounds of serial propagation. Data were analyzed as a 2 × 5 factorial analysis of variance.

Results: Variation in the time to initiate in in vitro culture (i.e., 26 to 47 days) and in the rate of laboratory shoot proliferation (i.e., 1.7× to 2.1×) was observed among the five varieties. Analysis of variance in the yield of succulent cuttings during greenhouse propagation showed that the main effects and the interaction of the propagation method and the timing of propagation were highly significant. The production of succulent cuttings during hedge propagation exceeded serial propagation by 72%. The seasonal effect was also quite strong with succulent cutting yield maximized during the late spring and the early summer. Economic modeling of returns from investment into the in vitro and greenhouse propagation system following a 20-year rotation of seven biomass harvests showed that attractive IRRs between 5% and 12% were achievable when revenues were increased due to: (1) premium pricing among refineries for improved feedstock that undergoes hydrolysis more cost effectively and (2) incremental biomass yield. The presentation demonstrated the relative change in IRR per-unit increases in yield and price.

Conclusions: Tacamahaca inter-specific hybrids adapted well to the Finnish propagation system. Variation during laboratory and greenhouse propagation can be exploited to improve propagation efficiency. Ultimately, increases in biomass yield and quality are required to justify investment in advanced propagation techniques to speed the deployment of elite varieties.

2.27. The Biomass Production Calculator: A Decision Tool for Hybrid Poplar Feedstock Producers and Investors

Shuren, R.A.; Busby, G. and Stanton, B.J.

Background: GreenWood Resources managed four large-scale hybrid poplar (*Populus* spp.) biomass demonstration farms under the United States Department of Agriculture-National Institute of Food and Agriculture, Agriculture and Food Research Initiative, Coordinated Agriculture Projects (AFRI CAP) program, Advanced Hardwood Biofuels Northwest (AHB) from 2012 to 2018. Each demonstration was managed for a five-year rotation comprised of a two-year establishment cycle and an ensuing three-year coppice cycle during which biomass yields and production activities and costs were compiled and documented. A principal AHB deliverable is an interactive decision tool—the biomass production calculator (BPC)—that growers and developers can use in evaluating hybrid poplar as a renewable energy feedstock crop or as a biomass investment opportunity. The BPC was also designed as a strategic planning tool to optimize feedstock production economics.

Methods: BPC employs a set of linked Excel worksheets that detail the full range of agronomic production activities, the costs of land, equipment, labor, chemicals, fuel, and the expense of biomass harvesting, and transportation. These are integrated with yields and anticipated biomass pricing in deriving internal rates of return specific to each of the main poplar production regions of the Pacific Northwest and northern California, USA. The calculator allows users to specify rotation lengths along with the regularity and duration of the constituent coppice cutting cycles. The frequency of each production activity, the extent of treated area, types of farming equipment, hours of operation, and manual labor needs can be tailored to each grower's situation. Harvesting assumptions are based on single-pass operations that cut, chip, and transfer biomass to off-loading equipment for farm gate delivery and reloading into trucks for bio-refinery transport. Yields are taken from actual inventories of mono-varietal production blocks within each demonstration farm. Users can adjust yields as percent increases or decreases from regional averages for specific varieties and growing conditions.

Results: Biomass yields of the top performing varieties varied among the four farms from 38 to 66 dry metric tons per ha (DMT ha^{-1}) and averaged 51 DMT ha^{-1} for the three-year coppice cycle. The combined costs of crop care and harvesting during the coppice cycle varied between $1904 and $2835 per ha. Delivered biomass cost for the coppice ranged from $60 to $119 per DMT with higher prices driven by crop care costs including irrigation at the California site.

Conclusions: The biomass production calculator is a valuable decision tool for organizations considering the advisability of adopting poplar as a woody energy crop once basic cost information has been determined. The calculator is used to determine the relative importance of cost components in optimizing production systems. It can be used nationwide to refine future assessments of biomass production potential.

2.28. Growth and Yield of Hybrid Poplar Mono-Varietal Production Blocks for Biofuel Production

Espinoza, J.; Shuren, R.; Zerpa, J. and Stanton, B.J.

Background: GreenWood Resources managed large-scale hybrid poplar (*Populus* spp.) farms ranging in size from 20 to 38 ha in Idaho, Oregon, California, and Washington, USA to demonstrate biomass yields, production costs, and harvesting technology in growing renewable feedstocks under the Advanced Hardwood Biofuel Northwest project (AHB). The purpose of this study was to quantify biomass yields and associate variation in productivity with leaf area indices for a range of clonal varieties suited to each of the four regions in which the demonstration farms were established.

Methods: Between seven and eleven mono-varietal production blocks of hybrid varieties were established at a density of 3588 trees ha^{-1} for each location. Mono-varietal production blocks varied from 2 to 4 ha at each farm. Inventory of permanent plots and destructive sampling of 1, 2, and 3-year-old coppice stands were conducted annually for each variety at all four locations. Yield equations were developed for each variety by least squares regression to predict individual tree dry weight from measurements of breast height diameter and tree height. Fertilizers were not applied during the coppice cycle. The leaf area index (LAI) was measured with a LAI-2200C Plant Canopy Analyzer (LI-COR, Lincoln, Nebraska, USA) for all varieties during the latter part of the third coppice season of the second production cycle.

Results: Yield of top-performing hybrid varieties during the three-year coppice production cycle at the Idaho, Oregon, California, and Washington farms was 15.7, 18.1, 12.9, and 22.2 dry metric tons per ha per year (DMT ha^{-1} $year^{-1}$), respectively. Varieties of the *Populus maximowiczii* Henry × *Populus deltoides* Marsh. taxon predominated at the Oregon farm while *Populus* × *generosa* Henry and *Populus trichocarpa* Torrey & Gray × *Populus nigra* L. taxa predominated at the Idaho farm. Top-rated varieties at the California farm belonged to the *Populus* × *canadensis* Moench taxon. Production at the Washington farm was highest for *P. deltoides* × *P. maximowiczii* and *P.* × *generosa* varieties. Linear correlations between yield and LAI consistently exhibited moderately good and positive associations at all four farms (e.g., r = 0.75–0.89). LAI generally ranged between 3.7 and 5.6. Taxa with the highest LAI were *P. deltoides* × *P. maximowiczii* followed by *P.* × *generosa.*

Conclusions: Important differences in biomass production were found among hybrid varieties at each location with the top-performing clones showing mean annual biomass increments of 13 to 22 DMT ha^{-1} $year^{-1}$. LAI exhibited a moderately high correlation with biomass production, which implies the potential of LAI to predict biomass production and to use as a selection criterion for highly productive varieties.

2.29. Poplar Productivity as Affected by Physiography and Growing Conditions in the Southeastern USA

Ghezehei, S.B.; Hazel, D.W.; Nichols, E.G. and Maier, C.

Background: Poplars (*Populus* spp.) have high productivity potential as Short Rotation Woody Crops (SRWC) provided that site-suitable clones are planted. The Coastal Plain, Piedmont, and Blue Ridge Mountain physiographic regions make up a significant part of the eastern and the southeastern USA and the assessment of productivity and adaptability of poplars in these regions provides valuable information to support successful large-scale implementation of poplar stands. Our objectives were to examine how the physiography and growing conditions in the Eastern and Southeastern USA can affect green wood productivity of poplar clones.

Methods: Woody biomasses of four-year-old poplar clones were estimated by using a volume equation derived by destructively sampling trees obtained from three physiographic regions (Coastal Plain, Piedmont and Blue Ridge Mountains). Clonal rankings of wood biomass were compared across growing conditions (including irrigation, marginality of lands) and the three physiographic provinces.

Results: Productivity of poplars varied among sites due to differences in site conditions, presumably fertility. There were variations in clonal rankings of wood biomass due to physiography and growing conditions. Changes in wood productivity by poplar due to physiography and growing conditions were more structured at the genotype level than the clonal level.

Conclusions: Even though clones that showed greater biomass variation to growing conditions generally belong to the same genotype, clone-level selection could produce greater wood biomass gains than selection at the genotype-level.

2.30. Hybrid Poplar Stock Type Impacts Height, DBH, and Estimated Total Dry Weight at Eight Years in a Hybrid Poplar Plantation Network

Hillard, S.C. and Froese, R.E.

Background: There are a number of plantation initiation decisions a potential hybrid poplar (*Populus* spp.) producer must decide upon. Major considerations include clone selection as well as planting stock, which impact initiation costs, growth, and yield. The long-term consequences for the initial choices of clone and planting stock on productivity are not fully understood. The objectives for the study were to utilize an eight-year annual growth data set from a hybrid poplar plantation network in northern Michigan, USA, to evaluate: (1) tip dieback in the out-planted stock, (2) growth models for height and diameter at breast height (DBH) using a mixed model approach, (3) performance of the clone × stock combinations using the growth models, and (4) assess potential financial outlook.

Methods: Eight years of growth data for three plantations of hybrid poplar clones (*Populus* × *canadensis* Moench 'DN34' and *Populus nigra* L. × *Populus maximowiczii* Henry 'NM6') and three stock types (poles, rooted stock and cuttings) were utilized to develop mixed effects models describing height and DBH growth for each stock type and clone combination. Models used nested random effects for individual tree, site, and treatment type. Planting stock (poles and rooted stock) tip dieback were evaluated by using mixed models with random effects for treatment type and site. Differences were tested by using the general linear hypothesis within species while between species differences were evaluated with *t*-tests and the Tukey's honestly significant difference test. The DBH model was used to inform an allometric model for hybrid poplar biomass and a financial model developed based on recent economic parameters.

Results: Differences in dieback were significant between clones for rooted stock but not pole stock and not significant between 'DN34' rooted stock and 'NM6' pole stock. Cutting stock differences were not significant in the height models while pole and rooted stock heights showed significant differences with 'DN34' yielding greater growth compared to 'NM6' on these sites. All growing stocks showed significant differences in height yields. DBH models were only significant between cuttings for the clones, while within the clone, there was no difference in DBH for cuttings and rooted stock. Significant differences in DBH were found between poles and rooted stock and poles and cuttings within clone. The estimated productivity of these treatments produced plantations with varying financial outlook at estimated peak mean annual increment. Overall 'NM6' pole stock was the closest to achieving a positive financial outlook.

Conclusion: This study demonstrates an evaluation of many initial choices available to a potential grower and how they impact growth as well as financial outlook of the operation. Poles had the most positive height growth outlook. Due to the high cost of poles, cuttings that showed DBH growth similar to rooted stock may be a viable option to reduce initiation costs. Efforts to reduce costs of inputs and harvest as well as increase productivity would improve financial outlook for biomass production systems.

2.31. Developing Phytoremediation Technology Using Pseudomonas Putida and Poplar for Restoring Petroleum-Contaminated Sites

Dewayani, A.A.; Zalesny, R.S., Jr.; Jose, S.; Nagel, S.C. and Lin, C.H.

Background: The majority of energy sources used for daily life in Indonesia and the United States are derived from petroleum and natural gas. There are more than 750 chemicals used for mining processes and many of these chemicals behave as endocrine disruptors for humans and animals. The organic pollutants, benzene, toluene, ethylbenzene, and xylene (BTEX) have been found in contaminated soils and water at and/or near mining sites. Due to the increasing number of petroleum mining operations and the potential increase of shale gas exploitation, it is necessary to develop a cost-effective and environmentally-friendly restoration strategy to reduce exposure of the remaining toxic chemicals into ecosystems. The objective of this study was to develop methods to degrade BTEX compounds especially toluene by introducing the bacterium degrader *Pseudomonas putida* into the rhizosphere of *Populus* spp. seedlings.

Methods: *Pseudomonas putida* has the todC1 gene that is responsible for the production of toluene dioxygenase enzyme, which enables *P. putida* to use toluene as the sole carbon source and take up toluene from the soil ecosystem. The *P. putida* could be introduced to the rhizosphere of poplar for restoring petroleum-contaminated sites. Solid-phase micro extraction (SPME) followed by gas chromatography mass spectrometry (GCMS) analyses were used to determine the degradation rates of toluene by the bacterium in a liquid phase experiment. The persistence of the introduced degraders was assessed by quantitative real-time polymerase chain reaction (*q*RT-PCR).

Results: During the 24-h incubation time, the concentration of toluene in the system was reduced 97% from 412 to 8.7 ppm. Current efforts are to evaluate the persistence of the introduced degraders in the poplar system and calculate the degradation kinetics of the pollutants.

Conclusions: The overarching outcome of this research is that such methods show the potential for refinement and application to help protect public health and restore ecological balance at mining sites in Indonesia, the USA, and other oil producing countries.

2.32. Comparison of Statistical Techniques for Evaluating the Fiber Composition of Early Rotation Pine and Hardwood Trees for the Production of Cellulose

Foust, A.M. and Headlee, W.L.

Background: With characteristics such as high strength and flexibility, cellulose has garnered much attention for its potential use in producing nano-material for the biomedical and engineering fields. Because cellulose naturally occurs in wood, small diameter trees from early rotational thinnings could be prime source material for nano-cellulose products. Ideal source material for nano-cellulose production would contain high cellulose and low lignin concentrations to expedite the cellulose extraction process. The selection process for source material would be assisted by a statistical technique that employs a single test for differences in recalcitrance rather than separate tests for each fiber component. The purpose of this study was to determine the fiber composition (i.e., percentage of nonpolar extracts (NPE), hemicellulose, cellulose, and combined lignin and ash) of small diameter pine and hardwood trees, compare the results of a single cumulative logit model using ordinal multinomial regression (OMR) analysis with those of a nested analysis of variance (ANOVA) with type 3 sums of squares analysis for each fiber component, and to determine if the former could provide a simpler test for species and spacing effects on overall recalcitrance.

Methods: Tree cores were collected from three different sites that had undergone an early rotational thinning or were of similar size and age class that would benefit from such a thinning. Sites include a hardwood spacing trial near Monticello, Arkansas, USA, containing sweetgum (*Liquidambar styraciflua* L.) planted at two spacings that underwent two thinning treatments. A loblolly pine (*Pinus taeda* L.) spacing study near the University of Arkansas Pine Tree Research Station with three replications of four spacing arrangements and a study at the University of Arkansas Pine Tree Research Station with four replications each of three oak species: cherrybark (*Quercus pagoda* Raf.), Nuttall (*Quercus texana* Buckl.), and Shumard (*Quercus shumardii* Buckl.). The fiber composition of tree cores from each study was analyzed using the ANKOM 2000 Automated Fiber Analyzer (ANKOM Technology, Macedon, New York, USA). Results were analyzed cumulatively using OMR analysis and by individual fiber components using ANOVA.

Results: In general, *p*-values from most of the OMR analyses for total fiber composition fell within the range of *p*-values from the ANOVA analyses for individual fiber components. The only instance that the OMR *p*-value did not fall within the span of ANOVA *p*-values was the spacing effect for the loblolly pine. There was a significant shift in the fiber composition for the plot within-spacing effect of the loblolly pine, which indicates differences in fiber composition between plots that may be due to tree survival differences. There was also a significant change in fiber composition among the three oak species with cherrybark oak showing a significant difference in fiber composition compared to Shumard oak.

Conclusions: Fiber composition can be analyzed more efficiently by conducting one OMR analysis compared to an ANOVA for each individual component. Since the OMR analysis is able to assess overall recalcitrance, it can more readily track significant shifts in fiber composition in response to treatment variables and has the added benefit of its confidence intervals being constrained within values of 0% to 100%. Thus, using the OMR analysis is a more convenient and biologically sound method for evaluating ideal source material for cellulose production.

2.33. Freshkills Anthropogenic Succession Study: Phase I: Deer Cafeteria Study

Hallett, R.A.; Piana, M.; Johnson, M.; Simmons, B. and Zalesny, R.S., Jr.

Background: Freshkills Park is an 890-ha public park being built on top of a landfill reclamation project on Staten Island in New York City, New York, USA. The Freshkills anthropogenic succession study is a designed experiment that was installed "off cap" but is on top of a "legacy dump." The experimental goal is to test three planting palettes for their ability to out compete exotic invasive plant species and become established on a site with highly disturbed soils.

Methods: Palette 1 included willow (*Salix* spp.) and poplar (*Populus* spp.) genotypes selected using phyto-recurrent selection techniques. Palette 2 included a mix of 18 species of shrubs and trees selected by the New York City Department of Parks and Recreation for the site. Palette 3 was a 50/50 mix of Palettes 1 and 2. The study area was not fenced and there are 52 white-tailed deer (*Odocoileus virginianus* Zimmermann) per km^2 on Staten Island. Tree growth and diameter were recorded along with mortality and deer browse severity.

Results: Early successional species had the highest mortality and were preferentially browsed. In the spring of the second growing season after planting, there was over 82% mortality on the site.

Conclusions: The process of creating a designed experiment in New York will be described along with future plans for what will hopefully be a long-term study on how to grow a forest in the city.

2.34. Adapting an Aspen Short Rotation Yield Model to Represent Hybrid Poplar Yield for Regional Hybrid Poplar Production Estimation

Hillard, S.C. and Froese, R.E.

Background: The upper Great Lakes Region (i.e., Michigan, Minnesota, and Wisconsin, USA) has abundant underutilized agricultural land that is suitable for hybrid poplar (*Populus* spp.) production. Interest in primary woody crop production systems is often hampered by low energy prices. Equally important, however, is the lack of targeted policies to encourage deployment. Current regional production estimates could benefit from improvements in scale. Improving the scale of regional productivity estimates could provide needed context to local legislators, policy makers, and stakeholders, which reduces barriers to increased production and improves targeted policies. Hybrid poplar generally lacks specific site index curves and growth and yield models that tie into remotely-sensed data to estimate productivity. The objectives for this study were to: (1) adapt a short rotation aspen (*Populus tremuloides* Michaux) growth and yield model to represent hybrid poplar and developing a link between aspen site index and hybrid poplar productivity, (2) apply the new growth model to a regional site index model for aspen, and (3) compare the new regional production estimates to previous regional productivity estimates.

Methods: Hybrid poplar yield was adapted to estimated aspen yield by tuning an existing aspen growth and yield model for the Great Lakes Region. Tuning used observed hybrid poplar heights from a plantation network and modeled aspen heights. Linear regression was used to develop a scaling function between aspen yield and hybrid poplar yield, which resulted in the development of a link between aspen site index and poplar biomass. A regional site index model developed for aspen was used to apply the model to extrapolate predicted hybrid poplar yield across the region. Spatial outputs were compared to previous regional production estimates via gridded raster outputs.

Results: Linear models linking aspen and hybrid poplar biomass had R^2 values ranging from 0.72 to 0.91 with standard errors of 0.03 to 0.10 Mg ha^{-1}. Using a Moderate Resolution Imaging Spectroradiometer (MODIS) derived site index model for aspen improved resolution of poplar yield estimates from 32 km, as reported in previous efforts, to 250 m. Model-estimated productivity for the hybrid poplar clone *Populus* × *canadensis* Moench 'DN34' ranged from <2 Mg ha^{-1} $year^{-1}$ to 9 Mg ha^{-1} $year^{-1}$ at age 10 while that of clone *Populus nigra* L. × *Populus maximowiczii* Henry 'NM6' ranged from <2 Mg ha^{-1} $year^{-1}$ to 15 Mg ha^{-1} $year^{-1}$ at age 10. For both models, this was approximately 5 Mg ha^{-1} year^{-1} less on average compared to previous models. The new regional estimates captured the same longitudinal gradient in productivity found previously and improved upon more localized yield estimates, which may have been impacted before by data limitations. Modeled yield estimates were compared to literature values using equivalence tests with no evidence to reject the null hypothesis of similarity.

Conclusions: The results indicated that an intragenus yield model may be adapted effectively to represent a species lacking a yield model. This technique can be applied to take advantage of remotely sensed variables and improve spatial resolution of production estimations. Improving resolution of estimates is vital for more cost-effective targeting of potentially productive areas, which improves prospects for short rotation woody crop deployment.

2.35. Potential Biomass Production of Four Cottonwood Clones Planted at Two Densities in the Arkansas River Valley, USA

Liechty, H.O. and Headlee, W.L.

Background: Eastern cottonwood (*Populus deltoides* Marsh.) is frequently planted in afforestation projects on retired agricultural fields in the Arkansas and Mississippi Alluvial Valleys, USA. Interest in cellulosic bioenergy feedstock production has increased the need to better understand the biomass production potential of various cottonwood clones grown at high densities with short rotations within these regions. The purpose of this study was to: (1) assess potential biomass production of four eastern cottonwood clones ('S7C20', 'S7C8', 'S7C4', 'F2') grown on a six-year rotation and (2) evaluate differences in growth, stem, and crown dimensional characteristics with different planting densities (8442 and 16,885 trees ha^{-1}).

Methods: Cuttings were planted in eight double rows (0.76 m between rows, 1.83 m between double rows) on either a 0.46 m or 0.91 m spacing in 2011. This planting design was replicated at three locations (row lengths of 345 m) in a retired sod farm field adjacent to the Arkansas River levee in Central Arkansas. In 2016, survival was visually assessed along the six double rows at each of the three clone, density replications. A total of eight plots (6.4 m long) encompassing the two middle double rows were located within the three clone, density replications where 75% or more of the planted trees survived. Each plot include 28 or 56 planted cutting locations depending on the initial establishment spacing. Diameter at breast height (DBH), total tree height, height to live crown, crown dieback, and crown class were determined. Tree biomass was determined from DBH and height measurement using equations developed by Dipesh et al. [4].

Results: Total dry woody biomass accumulation averaged between 26.3 and 65.5 Mg ha^{-1} (4.38 and 10.91 Mg ha^{-1} year^{-1}) for the eight clone, density combinations. Mean annual dry wood production for the highest and lowest establishment densities was 9.78 $\pm$ 1.59 and 7.81 $\pm$ 1.71 Mg ha^{-1} year^{-1}, respectively. Production significantly differed between high and low planting densities (10.79 and 4.39 Mg ha^{-1} year^{-1}) for only the 'S7C20' clone. Production was similar among clones except within the low density treatment where 'S7C20' had significantly lower total wood accumulation than the other three clones. The lower production of the 'S7C20' clone at this density treatment appeared to be related to the site conditions at which the plots were located rather than any inherent survival or characteristics associated with the clone.

Conclusions: Potential production in this study represented a best case scenario where survival of the planting stock was optimal. Under these conditions, wood production after six growing seasons was similar for the four selected clones and two planting densities. Thus, any productivity advantage associated with higher planting density had dissipated by the sixth year. Rotations of less than six years may result in higher production rates with the higher planting density relative to the lower planting density.

2.36. Growth Performance and Stability of Hybrid Poplar Clones in Simultaneous Tests on Six Sites in Minnesota, USA

Nelson, N.D.; Berguson, W.E.; McMahon, B.G.; Cai, M. and Buchman, D.

Background: Commercial adoption of poplar (*Populus* spp.) plantations requires genetic improvements for increased and consistent yield, disease resistance, and broadened adaptability across a range of climate and soil types. Genotype × environment interaction (G × E) is a limitation that relates directly to adaptability, which complicates growth performance testing and reduces overall genetic gains. The objectives of this study were to: (1) identify clones that are superior in growth rate, disease resistance, and had acceptable genetic stability and G × E across different environments as candidates for moving into field tests approximating commercial conditions (i.e., yield blocks), (2) investigate clonal stability and G × E of the clones tested, and (3) discover general principles for understanding, controlling, and using clonal stability and G × E in hybrid poplar genetic improvement programs.

Methods: Growth, stability, and G × E were investigated for sixty-nine clones after five years at six agricultural sites in Minnesota, USA. Fifty-three of the clones were *Populus deltoides* Marsh. × *Populus nigra* L. (D × N) crosses, nine *P. deltoides* × *Populus maximowiczi* Henry, and seven other crosses of which most were previously screened in Minnesota. The experiment was a randomized complete block design with six blocks within each site and a clone trial, which is part of our sequential breeding and testing system.

Results: Five-year diameter (DBH) and basal area (BA) at 1.38-m height averaged 93.5 mm and 72.11 cm^2, respectively, over the six sites. DBH site means varied from 79.4 mm to 109.0 mm. The fastest-growing clone BA was 64% and 49% larger than the mean of the two commercial standards and the mean of the population, respectively. Clone, clone × site, and error were highly significant in the analysis of variance (ANOVA). The variance component for clone was over twice that of clone × site (G × E), which was promising for achieving genetic gains. Clonal rank did not change among sites. G × E interaction was dominated by relative performance differences of clones on the different sites with 26% of clones being stable (little change in growth among sites) and 74% unstable. Stability coefficients of the unstable clones varied over a 99% range. Only 15% of clones were both stable and fast growing. Seven D × N clones were selected for future testing in yield blocks based on growth, stability, and disease occurrence.

Conclusions: There was a strong and significant clone effect and it predominated over G × E. Clone stability and G × E are separate parameters. A collection of clones can be unstable, but exhibit low variance for stability, which results in low G × E. Most clones we studied were unstable and stability was widely variable. Selecting clones within the 85th percentile of growth gave an estimated genetic gain of 53% versus commercial control clones. Continuing large genetic improvements in yield are expected in further generations of a breeding system like ours that utilizes clonal selection within a family structure, which captures both additive and non-additive inheritance. Intentionally reducing G × E does not appear to be a feasible objective for inter-specific poplars in an applied breeding program i.e., without sacrificing productivity gains. This is because the fastest-growing clones have large variability in clonal stability and this variation is the driver of G × E.

2.37. Genetic Development, Evaluation, and Outreach for Establishing Hybrid Poplar Biomass Feedstock Plantations in the Midwestern United States

Nelson, N.D.; Host, G.E.; Lazarus, W. and Reichenbach, M.R.

Background: Hybrid poplar (*Populus* spp.) represents a promising long-term biomass feedstock for biofuels and the emerging bioproducts industry with significant potential for improving rural economies of the Midwestern United States. The economic viability of hybrid poplar is limited, however, by the current scale of breeding, selection, and testing and varies with shifts in commodity and petroleum prices and energy policies. Commercial adoption of poplar plantations requires genetic improvements for increased and consistent yield, disease resistance, and broadened adaptability across a range of climate and soil types. This project, commencing in 2018, leverages the extensive collection of *Populus* genetic material developed over several decades at the University of Minnesota Duluth-Natural Resources Research Institute to produce the next generation of genotypes for the Midwest, which is an epicenter for anticipated large-scale adoption of poplar culture. Specifically, we will test the hypothesis based on a preceding test in Indiana, that *Populus* inter-specific parentages incorporating *Populus deltoides* Marsh. originating from southern Minnesota and *Populus nigra* L. from a pan-European collection. Both species screened in northern Minnesota will provide fast growth and acceptable genotype × environment interaction (G × E) for sites as far south as southern Indiana. This will be accomplished by: (1) selecting promising genotypes based on our past breeding and field trials from a 500+ clone germplasm bank, (2) establishing replicated clonal field trials in Minnesota, Iowa, and Indiana, (3) annually monitoring survival, growth, and disease resistance, and (4) assessing G × E to identify broadly adapted clones. Ancillary novel experiments will test whether: (1) within-clone variation within sites can be used to predict G × E among sites and (2) nitrogen fertilization changes clonal rankings and G × E. The genetics component will be complemented by an assessment, which is closely linked to the genetics results of economic trade-offs between poplar versus other commodity production and integrated into regional Extension outreach programs. An Extension innovation will be the targeting of emerging bioenergy and bioproducts companies who may be seeking a captive biomass source from a dedicated energy crop on agricultural land.

Conclusions: This project will focus on the economically-viable deployment of improved poplar clones across the Midwest. Fundamental project outcomes are quantified genetic advances to improve the economics of poplar feedstock plantations and reduced production and investment risk for farmers and industry stakeholders.

2.38. Citizen Science in the Greenhouse: A Phytoremediation Case Study

Rogers, E.R.; Zalesny, R.S., Jr.; Hallett, R.A. and Westphal, L.M.

Background: Phyto-recurrent selection has been implemented for over a decade to determine superior *Salix* and *Populus* genotypes for field-scale phytotechnologies. Citizen science is the collection of data by scientifically-trained members of the general population. This study compares data collected by different citizen science cohorts and experts to determine the potential for citizen scientists to help with the phyto-recurrent selection process. The primary goals of this research were to: (1) assess the similarity of citizen-collected data compared with expert-collected data and (2) evaluate the effectiveness of a specifically-designed tree health rubric in collecting accurate phyto-recurrent selection data.

Methods: Three groups of eight citizens (high school students, science teachers, and young professionals) collected tree health data on 48, 49-day-old *Populus* and *Salix* trees. One group of eight experts also collected tree health data on the same trees. The trees were grown in six soils (five landfill soils and on control soil) in a greenhouse in Rhinelander, Wisconsin, USA. A health rubric developed for urban afforestation projects was adapted for the current study. Assessment variables were: height, diameter, leaf count, discoloration, and live crown ratio. Each group received the same training session on how to use the rubric and how to collect data. Comparisons were made assuming an acceptable range of accuracy of 10%.

Results: The citizen-collected averages for height, diameter, leaf count, and live crown ratio were all within 7% of the corresponding averages from the expert-collected data. The greatest variability occurred in the diameter average reported by the science teacher and student groups. The averages were 6.53% larger (*Salix*) and 5.02% larger (*Populus*) than that of the expert group, respectively. The least variability occurred in the average live crown ratio in which all citizen groups were within 2.53% of the expert group's average.

Conclusions: From these results, citizen-collected data were within an acceptable range of accuracy when compared to expert-collected data, which indicates that citizen scientists could play a valuable role in the evaluation of genotypes to predict future success when planted in the field.

3. Affiliations

Arsenov, D., Department of Biology and Ecology, University of Novi Sad, Novi Sad, Serbia.

Bauer, E.O., Institute for Applied Ecosystem Studies, Northern Research Station, USDA Forest Service, Rhinelander, Wisconsin, USA.

Benzel, T., Benzel Soil Services, LLC, Mercer, Wisconsin, USA.

Berguson, W.E., Consultant, retired Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA.

Borišev, M., Department of Biology and Ecology, University of Novi Sad, Novi Sad, Serbia.

Buchman, D., Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA.

Buechel, L., Waste Management of Wisconsin, Inc., Menomonee Falls, Wisconsin, USA.

Bura, R., Biofuels and Bioproducts Laboratory, School of Environmental and Forest Sciences, University of Washington, Seattle, Washington, USA.

Burken, J.G., Civil, Architectural, and Environmental Engineering, Missouri University of Science and Technology, Rolla, Missouri, USA.

Busby, G., GreenWood Resources, Inc., Portland, Oregon, USA.

Cacho, J.F., Environmental Science Division, Argonne National Laboratory, Lemont, Illinois, USA.

Cai, M., Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA.

Campbell, P., Environmental Science Division, Argonne National Laboratory, Lemont, Illinois, USA.

Cave, R.D., University of Florida, Institute of Food and Agricultural Sciences, Indian River Research and Education Center, Fort Pierce, Florida, USA.

Chowyuk, A., Biofuels and Bioproducts Laboratory, School of Environmental and Forest Sciences, University of Washington, Seattle, Washington, USA.

Cole, C., Department of Entomology, University of Wisconsin-Madison, Madison, Wisconsin, USA.

Da Ros, L.M., Department of Wood Science, University of British Columbia, Vancouver, British Columbia, Canada.

Dao, C., Biofuels and Bioproducts Laboratory, School of Environmental and Forest Sciences, University of Washington, Seattle, Washington, USA.

DeBauche, B.S., Civil, Architectural, and Environmental Engineering, Missouri University of Science and Technology, Rolla, Missouri, USA.

de Souza, D.P., College of Environmental Science and Forestry, State University of New York, Syracuse, New York, USA.

Desrochers, V., Plant Biology Research Institute (IRBV), Montreal, Québec, Canada.

Dewayani, A.A., Center for Agroforestry, and School of Natural Resources, University of Missouri, Columbia, Missouri, USA.

Drekić, M., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Dvoržak, D., Department for EU Programs and Projects & Economy, Section for Preparation and Implementation of Programs and Projects, City of Osijek, Osijek, Croatia.

Ellis, M.F., Green Carbon Solutions, Pepper Pike, Ohio, USA.

Eisenbies, M.H., College of Environmental Science and Forestry, State University of New York, Syracuse, New York, USA.

Espinoza, J., GreenWood Resources, Inc., Portland, Oregon, USA.

Fabio, E.S., School of Integrative Plant Science, Horticulture Section, Cornell University, Cornell AgriTech, Geneva, New York, USA.

Fištrek, Ž., Energy Institute Hrvoje Požar, Department for Renewable Energy Sources, Energy Efficiency & Environmental Protection, Zagreb, Croatia.

Fortier, M.-O., College of Environmental Science and Forestry, State University of New York, Syracuse, New York, USA.

Foust, A.M., Arkansas Forest Resource Center, University of Arkansas, Monticello, Arkansas, USA.

Froese, R.E., School of Forest Resources and Environmental Science, Michigan Technological University, Houghton, Michigan, USA.

Gantner, R., Faculty of Agriculture, J.J. Strossmayer University of Osijek, Osijek, Croatia.

Gantz, C., GreenWood Resources, Inc., Portland, Oregon, USA.

Ghezehei, S.B., Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, North Carolina, USA.

Glavaš, H., Faculty of Electrical Engineering, Computer Science and Information Technology, J.J. Strossmayer University of Osijek, Osijek, Croatia.

Gustafson, R., Biofuels and Bioproducts Laboratory, School of Environmental and Forest Sciences, University of Washington, Seattle, Washington, USA.

Haiby, K., GreenWood Resources, Inc., Portland, Oregon, USA.

Hallett, R.A., Urban Forests, Human Health, and Environmental Quality, Northern Research Station, USDA Forest Service, Durham, New Hampshire, USA.

Hart, N.M., Advanced Hardwood Biofuels Northwest, Washington State University Extension, Lynnwood, Washington, USA.

Hazel, D.W., Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, North Carolina, USA.

He, Z., University of Florida, Institute of Food and Agricultural Sciences, Indian River Research and Education Center, Fort Pierce, Florida, USA.

Headlee, W.L., Arkansas Forest Resource Center, University of Arkansas, Monticello, Arkansas, USA.

Henderson, D., AECOM, Milwaukee, Wisconsin, USA.

Hillard, S.C., Division of Forestry, Minnesota Department of Natural Resources, St. Paul, Minnesota, USA.

Host, G.E., Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA.

Hu, Y., Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada.

Isebrands, J.G., Environmental Forestry Consultants, LLC, New London, Wisconsin, USA.

Ivezić, V., Faculty of Agriculture, J.J. Strossmayer University of Osijek, Osijek, Croatia.

Johnson, M., Urban Forests, Human Health, and Environmental Quality, Northern Research Station, USDA Forest Service, Bayside, New York, USA.

Jose, S., Center for Agroforestry, and School of Natural Resources, University of Missouri, Columbia, Missouri, USA.

Kaliszewski, A., Department of Forest Resources Management, Forest Research Institute, Raszyn, Poland.

Karwański, M., The Faculty of Applied Informatics and Mathematics, Warsaw University of Life Sciences, Warsaw, Poland.

Katanić, M., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Kebert, M., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Kiel, S., Department of Biology, Portland State University, Portland, Oregon, USA.

Kulišić, B., Energy Institute Hrvoje Požar, Department for Renewable Energy Sources, Energy Efficiency & Environmental Protection, Zagreb, Croatia.

Lazarus, W., Department of Applied Economics, University of Minnesota Twin Cities, St. Paul, Minnesota, USA.

Liechty, H.O., Arkansas Forest Resource Center, University of Arkansas, Monticello, Arkansas, USA.

Liesebach, M., Thünen Institute of Forest Genetics, Grosshansdorf, Germany.

Lin, C.H., Center for Agroforestry, University of Missouri; and, School of Natural Resources, University of Missouri, Columbia, Missouri, USA.

Lindroth, R., Department of Entomology, University of Wisconsin-Madison, Madison, Wisconsin, USA.

Liu, R., University of Florida, Institute of Food and Agricultural Sciences, Indian River Research and Education Center, Fort Pierce, Florida, USA.

Maier, C., Southern Institute of Forest Ecosystem Biology, Southern Research Station, USDA Forest Service, Research Triangle Park, North Carolina, USA.

Mansfield, S.D., Department of Wood Science, University of British Columbia, Vancouver, British Columbia, Canada.

McIvor, I., Plant & Food Research, Palmerston North, New Zealand.

McMahon, B.G., Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA.

Morrow, C., Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, Madison, Wisconsin, USA.

Murphy, L., GreenWood Resources, Inc., Portland, Oregon, USA.

Nagel, S.C., School of Medicine, University of Missouri, Columbia, Missouri, USA.

Negri, M.C., Environmental Science Division, Argonne National Laboratory, Lemont, Illinois, USA.

Nelson, N.D., Natural Resources Research Institute, University of Minnesota Duluth, Duluth, Minnesota, USA.

Nichols, E.G., Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, North Carolina, USA.

Niemczyk, M., Department of Silviculture and Forest Tree Genetics, Forest Research Institute, Raszyn, Poland.

Nikolić, N., Department of Biology and Ecology, University of Novi Sad, Novi Sad, Serbia.

Orlović, S., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Pekeč, S., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Peterson, M., Waste Management of Wisconsin, Inc., Menomonee Falls, Wisconsin, USA.

Piana, M., Department of Ecology, Evolution and Natural Resources, Rutgers University, New Brunswick, New Jersey, USA.

Pilipović, A., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Pohajda, I., Croatian Agriculture & Forestry Advisory Service, Zagreb, Croatia.

Poljaković-Pajnik, L., Institute of Lowland Forestry and Environment, University of Novi Sad, Novi Sad, Serbia.

Potosnak, M.J., Department of Environmental Science and Studies, DePaul University, Chicago, Illinois, USA.

Quinn, J.J., Environmental Science Division, Argonne National Laboratory, Lemont, Illinois, USA.

Reichenbach, M.R., Cloquet Forestry Center, University of Minnesota Twin Cities, Cloquet, Minnesota, USA.

Riehl, J.F., Department of Entomology, University of Wisconsin-Madison, Madison, Wisconsin, USA.

Rockwood, D.L., Florida FGT, LLC, Gainesville, Florida, USA.

Rogers, E.R., Institute for Applied Ecosystem Studies, Northern Research Station, USDA Forest Service, Rhinelander, Wisconsin, USA.

Rosenstiel, T.N., Department of Biology, Portland State University, Portland, Oregon, USA.

Seegers, R., Waste Management of Wisconsin, Inc., Whitelaw, Wisconsin, USA.

Shuren, R., GreenWood Resources, Inc., Portland, Oregon, USA.

Simmons, B., New York City Urban Field Station, New York City Department of Parks & Recreation, Bayside, New York, USA.

Smart, L.B., School of Integrative Plant Science, Horticulture Section, Cornell University, Cornell AgriTech, Geneva, New York, USA.

Soolanayakanahally, R.Y., Indian Head Research Farm, Agriculture and Agri-Food Canada, Indian Head, Saskatchewan, Canada.

Ssegane, H., Climate Corporation, St. Louis, Missouri, USA.

Stanton, B.J., GreenWood Resources, Inc., Portland, Oregon, USA.

Therasme, O., College of Environmental Science and Forestry, State University of New York, Syracuse, New York, USA.

Thomas, B.R., Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada.

Townsend, P.A., Advanced Hardwood Biofuels Northwest, Washington State University Extension, Lynnwood, Washington, USA.

Van Acker, J., Laboratory of Wood Technology, Ghent University, Ghent, Belgium.

Volk, T.A., College of Environmental Science and Forestry, State University of New York, Syracuse, New York, USA.

Westphal, L.M., People and Their Environments, and The Strategic Foresight Group, Northern Research Station, USDA Forest Service, Evanston, Illinois, USA.

Wiese, A.H., Institute for Applied Ecosystem Studies, Northern Research Station, USDA Forest Service, Rhinelander, Wisconsin, USA.

Wojda, T., Department of Silviculture and Forest Tree Genetics, Forest Research Institute, Raszyn, Poland.

Yang, S., College of Environmental Science and Forestry, State University of New York, Syracuse, New York, USA.

Zalesny, R.S., Jr., Institute for Applied Ecosystem Studies, Northern Research Station, USDA Forest Service, Rhinelander, Wisconsin, USA.

Zerpa, J., GreenWood Resources, Inc., Barranquilla, Atlántico, Colombia.

Zumpf, C.R., Environmental Science Division, Argonne National Laboratory, Lemont, Illinois, USA.

Župunski, M., Department of Biology and Ecology, University of Novi Sad, Novi Sad, Serbia.

Author Contributions: W.L.H., J.R., R.Y.S. and R.S.Z.J. conceptualized this Conference Report. S.B.G., E.S.G., W.L.H., J.R., B.J.S., R.Y.S. and R.S.Z.J. reviewed, selected, and edited abstract submissions. E.S.G. compiled the first draft of this Conference Report for coauthor review. S.B.G., W.L.H., J.R., B.J.S., R.Y.S. and R.S.Z.J. provided review and editing of the initial draft. Authors of presentations contributed their individual abstract submissions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. List of presentations delivered at the 2018 Woody Crops International Conference, Rhinelander, Wisconsin, USA, 22–27 July 2018.

1.	Current Trends and Challenges in North American Poplar Breeding
2.	Investigation of Phytoremediation Potential of Poplar and Willow Clones in Serbia: A Review
3.	Potential for the Agricultural Sector to Produce Poplar Wood as Contribution to the Forestry Wood Industry Chain
4.	Reaching Economic Feasibility of Short Rotation Coppice (SRC) Plantations by Monetizing Ecosystem Services: Showcasing the Contribution of SRCs to Long Term Ragweed Control in the City of Osijek, Croatia
5.	Genetic Parameter Estimates for Coppiced Hybrid Poplar Bioenergy Trials
6.	Genetic and Environmental Effects on Variability in First-rotation Shrub Willow Bark and Wood Elemental Composition
7.	Is Hybrid Vigor Possible in Native Balsam Poplar Breeding?
8.	Uncovering the Genetic Architecture of Growth-defense Tradeoffs in a Foundation Forest Tree Species
9.	The Great Lakes Restoration Initiative: Reducing Runoff from Landfills in the Great Lakes Basin, USA
10.	Evaluating Poplar Genotypes for Future Success: Can Phyto-Recurrent Selection Assessment Techniques be Simplified?
11.	Growth of Poplars in Soils Amended with Fiber Cake Residuals from Paper and Containerboard Production
12.	Growth and Physiological Responses of Three Poplar Clones Grown on Soils Artificially Contaminated with Heavy Metals, Diesel Fuel and Herbicides
13.	Mitigating Downstream Effects of Excess Soil Phosphorus through Cultivar Selection and Increased Foliar Resorption
14.	Survival and Growth of Poplars and Willows Grown for Phytoremediation of Fertilizer Residues
15.	Stakeholder Assessment of the Feasibility of Poplar as a Biomass Feedstock and Ecosystem Services Provider in Rural Washington, USA
16.	Barriers and Opportunities for use of Short Rotation Poplar for the Production of Fuels and Chemicals
17.	Short Rotation Eucalypts: Opportunities for Bio-Products
18.	Variability of Harvester Performance Depending on Phenotypic Attributes of Short Rotation Willow Crop in New York, USA
19.	Cover Protection Affects Fuel Quality and Natural Drying of Mixed Leaf-On Willow and Poplar Woodchip Piles
20.	Historical Perspective and Evolution of the Short Rotation Woody Crops Program at Rhinelander, Wisconsin, USA
21.	Tree Willow Root Growth in Sediments Varying in Texture
22.	Environmental Benefits of Shrub Willow as Bioenergy Strips in an Intensively Managed Agricultural System
23.	Quantifying the Unknown: The Importance of Field Measurements and Genotype Selection in Mitigating the Atmospheric Impacts of Poplar Cultivation
24.	Greenhouse Gas and Energy Balance of Willow Biomass Crops are Impacted by Prior Land Use and Distance From End Users
25.	Growth Patterns and Productivity of Hybrid Aspen Clones in Northern Poland
26.	The Economics of Rapid Multiplication of Elite Hybrid Poplar Biomass Varieties: Expediting the Delivery of Genetic Gains
27.	The Biomass Production Calculator: A Decision Tool for Hybrid Poplar Feedstock Producers and Investors
28.	Growth and Yield of Hybrid Poplar Mono-Varietal Production Blocks for Biofuel Production
29.	Poplar Productivity as Affected by Physiography and Growing Conditions in the Southeastern USA
30.	Hybrid Poplar Stock Type Impacts Height, DBH, and Estimated Total Dry Weight at Eight Years in A Hybrid Poplar Plantation Network
31.	Developing Phytoremediation Technology Using *Pseudomonas putida* and Poplar for Restoring Petroleum-Contaminated Sites
32.	Comparison of Statistical Techniques for Evaluating Fiber Composition of Early Rotation Pine and Hardwood Trees for the Production of Cellulose
33.	Freshkills Anthropogenic Succession Study: Phase I: Deer Cafeteria Study
34.	Adapting An Aspen Short Rotation Yield Model to Represent Hybrid Poplar Yield for Regional Hybrid Poplar Production Estimation
35.	Potential Biomass Production of Four Cottonwood Clones Planted at Two Densities in the Arkansas River Valley, USA
36.	Growth Performance and Stability of Hybrid Poplar Clones in Simultaneous Tests on Six Sites in Minnesota, USA
37.	Genetic Development, Evaluation, and Outreach for Establishing Hybrid Poplar Biomass Feedstock Plantations in the Midwestern United States
38.	Citizen Science in the Greenhouse: A Phytoremediation Case Study

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