Biomass and Bioenergy 118 (2018) 115–125

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: www.elsevier.com/locate/biombioe

Research paper

# Growth performance and stability of hybrid poplar clones in simultaneous tests on six sites

Neil D. Nelson*, William E. Berguson[1], Bernard G. McMahon, Meijun Cai, Daniel J. Buchman

*Natural Resources Research Institute, University of Minnesota Duluth, 5013 Miller Trunk Highway, Duluth, MN, 55811-1442, USA*

ARTICLE INFO

*Keywords:*
Hybrid poplar
*Populus*
Forest genetics
Genotype x environment
Tree improvement
Bioenergy

ABSTRACT

Growth, stability, and genotype x environment (GxE) interaction were investigated for 69 clones after five years at six sites in Minnesota. Fifty-three clones were *Populus deltoides x Populus nigra* (DxN) crosses, nine were *P. deltoides x P. maximowiczi*, ten other crosses. Most clones were previously screened for growth and disease resistance in Minnesota. Five-year diameter (DBH) and basal area (BA) at 1.38 m averaged 93.5 mm and 72.11 $cm^2$, respectively, over the six sites. DBH site means varied from 109.0 to 79.4 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. Site, clone, and clone x site effects were highly significant in the ANOVA. The variance component for clone was over twice that of clone x site (GxE), indicating a relatively small reduction in genetic gain due to GxE. Clonal rank did not change between sites. GxE interaction was dominated by *relative* performance differences of clones on the different sites. Twenty-six percent of clones were stable (little change in growth between sites), 74% unstable. Stability coefficients of the unstable clones varied over a 99% range, indicating the population had high and variable phenotypic plasticity. Only 15% of clones were both stable and fast growing. Seven putatively superior clones, all DxN, were selected for future testing under near-commercial conditions. The results, if representative of other inter-specific *Populus* populations, suggest it will be difficult, and probably impractical, to reduce GxE with standard quantitative genetics methods in hybrid poplar tree improvement programs without sacrificing productivity gains.

## 1. Introduction

The hybrid poplars (*Populus* spp) represent a promising long-term biomass feedstock for biofuels and the emerging bio-products industry, as well as for traditional forest products, with significant potential for improving rural economies of the Midwestern United States and other regions [1]. Commercial adoption of poplar plantations requires genetic improvements for increased and consistent yield, disease resistance, and broadened adaptability across a range of climates and soil types. Genotype x environment (G x E) interaction is a limitation that relates directly to adaptability, complicating growth performance testing and reducing overall genetic gains [2].

There are several studies on G x E and clone stability in *Populus* [3–10]. G x E explained from 8% to 25% of the variation in diameter, basal area (BA), or derived tree volume in these papers. The ratio of clone to G x E variance components varied widely, from 2.70 to 0.40. Stable clones (lesser growth response to change in environment) varied from 44% to 67% of the clones tested in these studies, depending partly on the stability measure chosen. It is likely that the wide variability in clone × environment interaction and stability of *Populus* in the literature is affected by the variation of the growing sites and the composition and size of the clonal populations. Our hybrid poplar breeding and genetic tree improvement program at the Natural Resources Research Institute (NRRI) utilizes replicated clone trials of clones from tested superior full-sib families to select the best clones for testing in yield blocks representing near-commercial conditions. This approach captures both additive and non-additive genetic variation [11]. A clone trial established with the same 69 clones on six sites in central and northern Minnesota in 2008 provides a robust opportunity to identify clones putatively superior for growth rate, stability, and disease resistance. It also can supply information on the adaptability (G x E) of the clones, as well as derive some general principles underlying phenotypic plasticity and G × E interaction for hybrid poplars. Clones present a more powerful means than families or seed sources for detecting G × E interactions and analyzing genotypic stability [5,12]. The trial provides a rich source of data on clonal genetic variation, stability,

* Corresponding author.
*E-mail address:* nnelson2@d.umn.edu (N.D. Nelson).
[1] Retired.

https://doi.org/10.1016/j.biombioe.2018.08.007
Received 11 April 2018; Received in revised form 7 August 2018; Accepted 24 August 2018

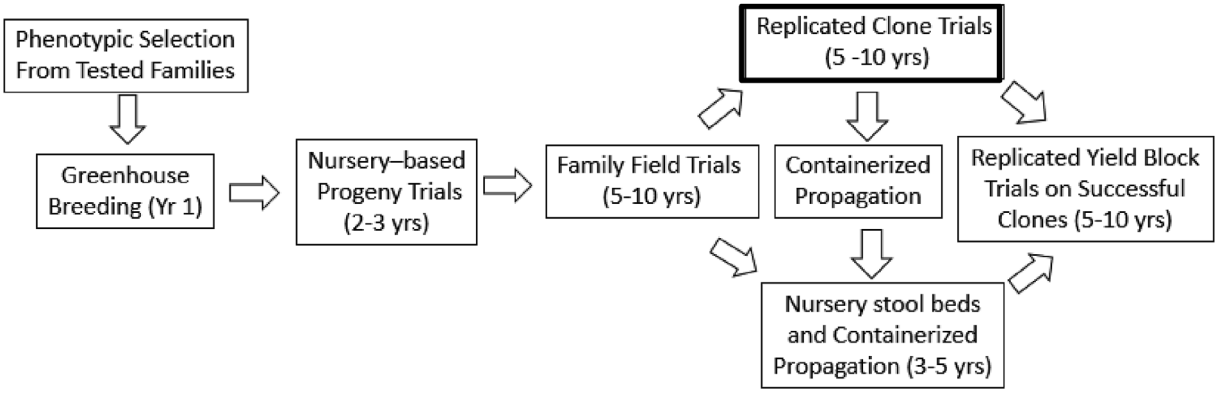


**Fig. 1.** A flow chart depicting the breeding and testing phases of our internal (NRRI) *Populus* genetic tree improvement program.

G × E interactions, and inter-site correlations, essential information for selecting clones to move forward in the testing process, calculating expected genetic gains, and designing an optimum breeding strategy.

The objectives of this study were to: (1) identify hybrid poplar clones that are superior in growth rate, disease resistance, and have acceptable genetic stability and G × E interaction across different environments as candidates for moving into field tests approximating commercial conditions (referred to in this paper as Yield Block tests); (2) investigate the relationship between clonal stability and G × E interaction; and (3) discover general principles for understanding, controlling, and using clonal stability and G × E interactions in hybrid poplar genetic improvement programs.

## 2. Materials and methods

### 2.1. Study design and breeding system

The experiment was a randomized complete block design with six blocks within each of six sites and a single-tree plot of each clone within each block. The study was a clone trial that is part of our sequential breeding and testing system, as depicted in Fig. 1.

### 2.2. Plant material

#### 2.2.1. Clone selection for tests

The 69 clones included in the tests reported here (Table 1) were initially selected from our family genetic field trials (*Populus* FFTs) in Minnesota and from external sources within the region. In addition, non-native parent materials were obtained in collaboration with *Populus* breeding programs in Canada and in the United States. Fifty-three of the crosses were DxN, and 16 were other crosses [DxM, TDx(D), NxM, Dx(TD)]. Details on derivation of the clones are in Tables A1–A2 in the Supplementary Electronic Material.

Selection of most clones for these trials was based on diameters measured in our family field trials (FFTs) from ages 3 through 5 years, along with canker scores and other categorical observations related to tree quality. These FFTs have a family genetic structure, including full-sib individuals and clones within families, and typically contain up to 900 genotypes. Selections from the FFTs were used in the clone trials reported here. In addition to new clones selected from the FFTs, a small subset of those clones that performed well in earlier tests was included as a comparison to the new set of clones. Also, two commercial standards, DN2 and NM6, were embedded within the clone trials.

#### 2.2.2. Plant propagation

The 1- and 2-year-old dormant branches from the top of the crowns of selected trees in FFTs were collected in January 2008, stored frozen, and processed into 'mini' cuttings 7.6 cm–10.1 cm in length containing at least two viable lateral vegetative buds. No terminal buds were used in this process. These 'mini' cuttings were rooted in a single-cell system of plastic racked containers of 107 ml volume filled with a coarse particle size peat blend mix (Berger BM6 All Purpose). Rooted shoots developed for a period of eight weeks inside the greenhouse (starting third week of March 2008) with no artificial lighting under intermittent watering cycles on an as-needed basis and periodic applications of a general 20-20-20 fertilizer formulation. Greenhouse temperatures ranged from 21.1 °C to 23.9 °C (day) and 18.3 °C–21.1 °C (night). Green leafy containerized plant racks were moved outside the greenhouse for a three-week period of exterior conditioning and environmental acclimation starting May 9, 2008, prior to sorting for the individual test sites. In the sorting process, six viable ramets for each clone and for each of the six test sites were arranged randomly in replication blocks.

### 2.3. Study locations

Six study sites were located across a latitudinal transect within central and north-central Minnesota and were all plantation locations of the former Verso Paper Company commercial hybrid poplar program on land previously in agronomic crops. The geographic coordinates and information on soils and climate for the test locations are presented in Table 2.

### 2.4. Plantation establishment and maintenance

The sites were prepared and planted in the spring of 2008, i.e., sprayed with glyphosate at 3.51 L of 41.0% active ingredient per hectare and tilled. These trials were embedded in operational poplar plantations. Containerized plants were hand planted on pre-marked fields at 3.05 m × 3.05 m spacing. The sites were immediately sprayed with the pre-emergent chemical Scepter 70DG (Imazaquin) at 292 ml of 70.0% active ingredient per hectare. Further weed competition was effectively controlled through mechanical means during the first three growing seasons. Sites were not irrigated.

### 2.5. Measurements

Measurement parameters were diameter breast height (1.38 m, DBH) in mm and BA in $cm^2$ at age five. Basal area was derived algebraically from DBH. A large volume of literature has established the direct allometric relationship between tree BA and tree volume and biomass in many species, including *Populus* [13]. In our experience in the region, clone growth performance at age 5 is indicative of ultimate performance through a typical commercial rotation ranging from 8 to 12 years.

### 2.6. Pathogen assessments

The primary plant pathogen of concern for hybrid poplar culture