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Ex situ growth and biomass of *Populus* bioenergy crops irrigated and fertilized with landfill leachate

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ABSTRACT

Merging traditional intensive forestry with waste management offers dual goals of fiber and bioenergy production, along with environmental benefits such as soil/water remediation and carbon sequestration. As part of an ongoing effort to acquire data about initial genotypic performance, we evaluated: (1) the early aboveground growth of trees belonging to currently utilized *Populus* genotypes subjected to irrigation with municipal solid waste landfill leachate or non-fertilized well water (control), and (2) the above- and below-ground biomass of the trees after 70 days of growth. We determined height, diameter, and number of leaves at 28, 42, 56, and 70 days after planting (DAP), along with stem, leaf, and root dry mass by testing six *Populus* clones (DN34, DN5, I4551, NC14104, NM2, NM6) grown in a greenhouse in a split–split plot, repeated measures design with two blocks, two treatments (whole-plots), six clones (sub-plots), and four sampling dates (sub–sub-plots, repeated measure). Treatments (leachate, water) were applied every other day beginning 42 DAP. The leachate-treated trees exhibited greater height, diameter, and number of leaves at 56 and 70 DAP ($P<0.05$). There was broad variation in clonal responses to leachate treatment for dry mass, with a general trend of leachate-treated trees exhibiting greater stem and leaf dry mass ($P<0.05$), but negligible differences for root dry mass ($P>0.05$). Overall, genotypic responses to the leachate treatment were clone-specific for all traits.

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1. Introduction

The use of *Populus* for fiber and bioenergy is more established in North America than deployment of these short rotation woody crops for technologies such as phytoremediation [1,2]. Nevertheless, merging traditional intensive forestry with waste management offers dual goals of fiber and bioenergy production, along with environmental benefits such as soil/water remediation and carbon sequestration [3,4]. From a tree improvement standpoint, the broad variation within the genus *Populus* [5–7] promotes the incorporation of traits that are necessary for multiple end-uses into strategic (selection of parental species) or operational (selection within specific genomic groups) breeding plans [8,9]. Such variation supports the opportunity for intra- and inter-specific selection of favorable genotypes, which is important for achieving high levels of success when the trees are established in field-based systems [1,10]. Regardless of the end-uses of the trees, however, field deployment of unfavorable clones often leads to inadequate plantation productivity or even complete failure. In addition, the elevated costs of testing tissue concentration levels and other physiological processes likely are not feasible at the initial stages of plantation management [11].

Therefore, it is vital during early establishment and growth to conduct inexpensive screening trials such as phyto-recurrent selection to evaluate allometric traits that are indicative of field-based performance [11,12], because

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successful establishment is the first biological requirement for long-term ecological sustainability. Thus, genotypes that exhibit successful early development are more likely than those that are erratic to accumulate adequate biomass for fiber and bioenergy, while serving as biological filters involved with uptake, storage, utilization, or volatilization of contaminants [13–15]. Our initial hypotheses for the current study were two-fold. First, an identical *Populus* genotype will exhibit different phenotypic responses when irrigated with municipal solid waste landfill leachate or non-fertilized well water (i.e. genotype × treatment interactions will exist). Second, phenotypic responses will differ among clones. Thus, as part of an ongoing effort to acquire data about initial genotypic performance, our objectives were to conduct a single cycle of phyto-recurrent selection in the greenhouse and to evaluate: (1) the early aboveground growth of trees belonging to currently utilized *Populus* genotypes subjected to irrigation with landfill leachate or non-fertilized water (control), and (2) the above- and below-ground biomass of the trees after 70 days of growth. Four of the six clones (DN34, DN5, I4551, NM6) tested in the current study were selected and established during June 2001 in a long term, bioenergy/phytoremediation plantation at the Oneida County Landfill in northern Wisconsin.

Table 1 – Composition of landfill leachate and well water (control) used for irrigation treatments in an experiment testing the early growth and biomass of *Populus*

Component	Leachate	Control
pH	8.0	6.3
Electrical conductivity	8.7	0.2
Nitrogen	420.0	0.2
Phosphorus	1.6	0.0
Potassium	420.0	1.1
Sodium	1100.0	2.4
Chloride	1000.0	3.5
Boron	12.0	0.1
Iron	33.0	0.7

Units for electrical conductivity are $m S cm^{-1}$, while those for elemental concentrations are $mg L^{-1}$.

2. Materials and methods

2.1. Clone selection and tree establishment

Six F_1-hybrid clones were selected across the current range of genotypes from three *Populus* genomic groups in January 2001 based on their growth in earlier studies and anticipated establishment potential. The clones and their parentages were: DN34, DN5, I4551 (*Populus deltoides* Bartr. ex Marsh × *Populus nigra* L.); NC14104 (*P. deltoides* × *Populus maximowiczii* A. Henry); and NM2, NM6 (*P. nigra* × *P. maximowiczii*).

Shoots were collected from stool beds established at Hugo Sauer Nursery in Rhinelander, Wisconsin, USA (45.6°N, 89.4°W). Hardwood cuttings, 20 cm long, were prepared during January 2001, with cuts made to position at least one primary bud not more than 2.54 cm from the top of each cutting. Cuttings were stored in polyethylene bags at 5 °C until planting in February 2001. Cuttings were soaked in water to a height of 15 cm for 5 days before planting in pots containing medium consisting of equal parts of sand, peat, and vermiculite (v:v:v). The medium per pot had a volume and dry mass of 6600 cm^3 and 3.5 kg, respectively. The trees were grown in a greenhouse at the Institute for Applied Ecosystem Studies (IAES), with a 16-h photoperiod and a constant temperature of 21 °C.

2.2. Experimental design and irrigation treatments

The trees were arranged in a split–split plot, repeated measures design, with two blocks, two treatments, six clones, and four sampling dates. Treatments were considered fixed whole-plots, clones were fixed sub plots, and sampling dates were fixed sub–sub plots. Sampling date was treated as the repeated measure. Clones were arranged in randomized complete blocks in order to minimize effects of any potential environmental gradients in the greenhouse, with four ramets per clone per block × treatment interaction. Treatments, clones, and sampling dates were treated as fixed in the analysis and, therefore, we evaluated means rather than variances.

The irrigation treatments, of equal volume, consisted of municipal solid waste landfill leachate from the Oneida County Landfill (OCL) and non-fertilized water (control) from a well at the IAES. The OCL and IAES were located 6 km west and 0.8 km north of Hugo Sauer Nursery, respectively. The composition of the leachate and water, including pH, electrical conductivity, and concentration of nitrogen (N), phosphorus (P), potassium (K), sodium (Na), chloride (Cl), boron (B), and iron (Fe), are listed in Table 1. The primary toxicity concerns were the relatively high Cl and Na concentrations. In addition, the concentrations of B and Fe were of concern, having exceeded United States Environmental Protection Agency maximum concentration limits by 600% and 165%, respectively [16]. Additional inorganic elements, along with organic compounds, generally were not detectable and were, therefore, not a concern with respect to plant establishment.

All trees were irrigated with water every other day for the initial 6 weeks following planting to ensure adequate survival and health. In the remaining 4 weeks of the study, trees were irrigated every other day with equal volumes of leachate or water. The amount of either irrigation treatment needed was calculated by measuring the saturation point of the potting medium as the plants developed. Six non-experimental trees were planted in pots and placed on the greenhouse benches, with one pot per clone studied. The saturation point in these pots was used to determine the amount of leachate and water needed for each clone as the trees developed over time.

2.3. Data collection and analysis

Height, diameter, and number of leaves were determined at 28, 42, 56, and 70 days after planting (DAP). Height was measured at the point of attachment between the stem and