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Responses of two genetically superior loblolly pine clonal ideotypes to a severe ice storm

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ABSTRACT

An increase in the frequency and magnitude of extreme weather events, such as major ice storms, can have severe impacts on southern forests. We investigated the damage inflicted by a severe ice storm that occurred in February 2014 on two loblolly pine (*Pinus taeda* L.) ideotypes in Cross, South Carolina located in the southeastern coastal plain. The "narrow crown" ideotype allocates more resources to stem growth while the "broad crown" ideotype allocates more of its resources to leaf area. We sampled each clone in August of 2014 and assessed damage based on four mutually exclusive damage categories: crown damage (visual estimation of percent damage); bent bole (bending shape and angle); snapped bole (distance from ground to snapped height); and uprooted. Damage category was statistically different between clones ($\chi^2 = 120.36$; $p = 0.001$); 67% of the individuals of the narrow crown ideotype suffered crown damage compared to 94% of the broad crown ideotype; 27% of the individuals of narrow crown ideotype suffered immediate mortality after the bole snapped, compared to only 3% for the broad crown. Of the individuals that incurred crown damage, the degree of damage sustained was statistically different by clonal type ($F = 8.73$; $p < 0.01$). The broad crown ideotype incurred greater crown damage than the narrow crown (38.0 ± 1.34 and 31.8 ± 1.6, respectively). Damage that resulted in a bent bole was minimal, with 4% for the narrow crown ideotype and 3% for the broad crown. The observed clonal differences in response to damage that incurred from an extreme ice storm may be attributed to differences in morphology and carbon allocation strategies between the two ideotypes. These differences are important to carbon sequestration projects and ideotype development in regions that are prone to extreme glazing events.

1. Introduction

Catastrophic natural disturbances can result in severe impacts to forest resources (Bragg et al., 2003) and carbon sequestration projects (Galik and Jackson, 2009). Because major disturbances can transfer live biomass to dead respiring pools and change the size distribution of forests to smaller diameters and lower biomass stocks (Chambers et al., 2007a), even small increases in the frequency and/or intensity could substantially diminish terrestrial carbon sinks (Chambers et al., 2004; Johnsen et al., 2014), resulting in positive feedbacks to climate warming (Reichstein et al., 2013). Therefore, catastrophic natural disturbances, such as ice storms, hurricanes and fire, pose the greatest challenge to carbon offset projects due to their inherent unpredictability and the potential scale that often characterize such disturbances (Galik and Jackson, 2009). For example, one study reported that a single ice storm was estimated to have damaged the equivalent of approximately 10% of the forest carbon sequestered annually in the US (Birdsey and Heath, 1995).

Ice storms are among the most frequent and injurious large-scale disturbances in temperate forests (Irland, 2000; Smith, 2000). Among the temperate forests in the world, the eastern US experiences the most frequent ice damage, with the highest freezing rain occurrence observed in the eastern portion of the Appalachian Mountains, from northeast Georgia to Virginia (Robbins and Cortinas, 1996). Although less frequent than the northeast, ice storms also impact the southeastern US (Changnon, 2003), where southern yellow pines are an important economic resource and form some of the most intensively managed and productive plantations in the world (Allen et al., 2005). Glaze damage to southern pine species due to sufficient ice accumulation may cause stem

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bending, breaking, or uprooting (Belanger et al., 1996; Warrillow and Mou, 1999), with the amount of damage attributed to a wide variety of factors including stand and tree conditions, soil characteristics, variation in ice formation, and wind speed. In addition to direct mortality, ice storm damage can increase forest susceptibility to insect and disease (Bragg et al., 2003).

Loblolly pine (*Pinus taeda* L.) is the most economically important tree species in the southeastern US (Zeide and Sharer, 2001). In the past 50 years, loblolly pine plantations have increased from approximately 0.7 to over 13 million hectares. At the same time, advances in silviculture and tree improvement increased yields from 104 to 414 m^3 ha^{-1} (Fox et al., 2007). In 2007, approximately $14 million was spent to breed and improve southern yellow pine species (McKeand et al., 2007). There is an inherently high risk to such large investments in tree improvement and breeding if the development does not include ways to mitigate the impact of natural disturbances on genotypes. As timber and regional carbon storage demands increase in the future, the use of genetically superior loblolly pine genotypes is expected to play an increasingly critical role in forest management (Fox et al., 2007; Johnsen et al., 2014). However, current breeding and tree improvement programs are focusing on creating genotypes capable of producing high timber yield and disease resistance by selecting certain physiological and morphological traits over others, which could have significant implications to disturbance response. Understanding how these selected traits differ in their response to catastrophic natural disturbances is important to forest management and carbon sequestration projects because widespread planting of a susceptible clone in disturbance prone areas could have severe consequences, and how these genetically superior genotypes will respond to disturbances such as ice storms has never been evaluated. Indeed, one of the greatest challenges for forest management and planning is to quantify the acceptable level of risk associated with establishing clonal plantations across the broader landscape (McKeand et al., 2006).

The ice storm that occurred on February 11–13, 2014 resulted in an estimated direct timber loss of approximately 607,000 forest hectares and an estimated 360 million dollar loss of timber value in South Carolina alone (South Carolina Forestry Commission, 2014). Among many of the forest stands affected was a long-term carbon sequestration research project conducted by the US Forest Service (Tyree et al., 2009, 2013; Maier et al., 2012, 2013). By taking advantage of this well-designed study and data measured prior to the ice storm, we investigated how loblolly pine clones of two distinct ideotypes responded to glazing from a severe ice storm. We hypothesized that each clone would respond differently to ice accumulation based on their differences in morphology and carbon allocation strategies. Specifically, we hypothesized that the clonal ideotype with greater branch and foliar biomass and greater leaf area (i.e., Clone 32) would suffer greater glaze damage.

2. Methods

2.1. Site description

This study utilized the Cross Carbon Study in the town of Cross, located in Berkeley County, SC (33°16_N, 80°10_W), which is 24 m above sea level (Tyree et al., 2009; Maier et al., 2012). The Cross Carbon Study was designed to examine differences in growth efficiency, carbon allocation, and storage for two contrasting clones of loblolly pine. The dominant soil series is a Seagate series (sandy over loamy, siliceous, active, thermic Typic Haplohumods) (US Department of Agriculture: Natural Resource Conservation Service, 2012) with moderate levels of organic matter (0.5–2%) and is devoid of rocks. The soils are somewhat poorly drained, and have a fluctuating water table that approaches the surface after harvest. The average January and July temperatures are 8 and 27 °C, respectively, with an average annual rainfall of 1358 mm.

2.2. Experimental design

The previous stand was a 21-year-old loblolly pine plantation. In May 2004, the stand was whole-tree harvested and chipped (Maier et al., 2012). Site preparation included shearing of residual material in July and bedding in November of 2004.

The original study design was a 2 × 2 factorial, randomized, complete block design with three replicates. The two factors were clone ideotype (93 or 32) and logging residue. The two levels of logging residue were no logging residue incorporated into the soil (C = control) and the incorporation of logging residue into the mineral soil at a rate of 25 Mg oven-dry weight/ha that was concentrated into the beds (LR). Each 0.18 ha (48 × 38 m) plot was planted with 243 container-grown seedlings in 9 rows at 1.8 m spacing within rows and 4.3 m between rows. Bedding and incorporation of logging residue was completed in November of 2004 and clones were planted in January of 2005. Two ArborGen® loblolly pine clones that exhibit superior height growth but represent two distinct ideotypes were selected for the original study. Clone 93 (ArborGen® varietal Clone AA93), or the "narrow crown" ideotype, allocates more of its resources to stem growth. Clone 32 (ArborGen® varietal Clone AA32), or the "broad crown" ideotype allocates more of its resources to leaf area (Tyree et al., 2009; Maier et al., 2013). The stands were nine years old in January 2014, one month prior to the ice storm. Both clones had similar stem biomass, but Clone 32 (broad crown ideotype) had 13% greater foliage and 15% greater biomass, while Clone 93 (narrow crown ideotype) had 14% greater coarse-root biomass (>2 mm) (Maier, unpublished data). By 2013, the crowns had been in canopy closure for several years, with maximum (September) and minimum (January) leaf area of 3.6 and 3.1 for Clone 93 and 2.5 and 2.1 for Clone 32, with little individual mortality (<4% of all individuals) prior to the storm.

Diameter at breast height (DBH) and tree height were measured using a diameter tape (to the nearest 0.1 cm) and a laser (to the nearest 0.1 m), respectively, in December 2013. We re-measured each tree in September of 2014 to determine the impact of the February 2014 ice storm on the two loblolly pine clones. To reduce the influence of any edge effects from ice damage, we established 20 × 30 m plots within the original design, leaving a 5-tree buffer on the row and 3-row buffer from the side. We measured DBH and assigned a damage class to each tree within the plot (Fig. 1). The damage categories included: Crown Damage (CD) as a visual estimate of percent damage (in 5% increments, up to 95%; if 95% or greater it was determined to be a snapped bole) to the live crown, Bent Bole (BB), Snapped Bole (SB), and Uprooted (UR). For the BB category we measured bending shape or degree of angle. Angle, or degree of bend, was determined by deriving angles a_1 [$a_1 = \cos^{-1}(X_1/H_2)$] and a_2 [$a_2 = a\cos(H_1^2 + C^2 - \text{hyp}^2)/(2 \times H_1 \times C^2)$] from the measured height to bend on the bole of the tree (H_1), height from ground to terminal (H_2), and distance from bole to terminal (X_1) (Fig. 2). The angle of bend is the deviation from 90° of a straight growing tree, with angles closer to 90° resulting in less bend in the main stem. The second angle (a_2) was used to determine the degree of departure from a straight bole and was compared between the two clonal ideotypes. For SB we measured height (m) to the snapped point, and measured tree height on UR individuals. A SB was only recorded if the entire live crown was removed (greater than 95% percent CD, with no remaining branches); otherwise it was considered percent CD with the terminal leader recorded as broken. Mortality was assumed for