Evaluating Reforestation Success on a Surface Mine in Eastern Kentucky

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Abstract: Reclamation through reforestation is becoming more common in Kentucky as studies uncover what treatments are most effective for successful tree establishment. "Success" is defined by the Commonwealth of Kentucky in terms of height and survival percentage of outplanted and naturally regenerated species. While this definition of success provides a measure of site occupancy, it does not produce an adequate method for characterizing the quality of the reforested mine land as compared to the natural landscape. In response to this, a method of site evaluation was developed for two high-value hardwoods, white oak (*Quercus alba* L.) and yellow-poplar (*Liriodendron tulipifera* L.). Tree growth data were gathered from 80 even-aged, naturally regenerated reference stands located in the eastern Kentucky coal fields. For each species, eight stands for each of five age classes were sampled (5, 10, 20, 40, and 80). Tree height and diameter measurements taken from reforestation plots planted on reclaimed mined land in eastern Kentucky were compared to the reference sites. Loose-dumped and, in some instances, strike-off reclamation produced tree growth that was somewhat similar to what was found in the natural stands of eastern Kentucky, whereas conventional reclamation techniques largely inhibited tree growth. Yellow-poplar and white oaks grown on mine soils were shorter but larger in diameter than what was found in the reference stands. Mulch was a necessary component for the establishment and growth of both species on mined land.

Keywords: site quality, white oak, yellow-poplar, reforestation, reclamation

Introduction

Reforestation of surface-mined lands is becoming more common in the eastern United States as studies uncover what reclamation techniques are effective for successful tree establishment and growth (Angel and others 2009). "Success" is currently defined in terms of the height and survival of outplanted and naturally regenerated species. The Commonwealth of Kentucky mandates that to achieve final bond release, the mining company must show that every tree counted has at least one-third of its height in live crown and that at least 80% of the counted trees used to determine success have been in place for 3 years or more (Commonwealth of Kentucky 1993). Although these criteria provide some information on reforestation status, they fail to grasp the overall quality of the trees or site. Further, current methods of height assessment are based on the use of regional site indices that were developed from the analysis of 50-year-old trees. Even though site indices have been shown to be very useful on maturing stands, these indices are not suitable for evaluation of 5-year-old seedlings.

The site index (SI) has had widespread use throughout Appalachia to determine timber volume and site quality (Stout and Schumway 1982; Lamson 1987). The benefits of using SI to evaluate a forest stand include good correlation with site productivity, easy measurement, and independence from stand density (McQuilkin 1989). In order for SI to be accurate and meaningful, the site must have suitable trees within the required height and age range, and there needs to be accurate SI curves available by which to measure the site (Sims 1994). Suitable trees are those that have been free to grow into a dominant or codominant crown position, have a straight single stem, have been free from suppression, and have not been significantly damaged (McQuilkin 1989).

Despite the advantages and widespread use of SI, it has limitations, especially when considering overall stand development. Site index curves cannot be applied to stands without suitable trees or for the conversion of species (Pritchett and Fischer 1987). When measurements are taken in stands that represent a suite of age classes, problems arise because 5- to 40-year-old stands may not be comparable to indices generated from measurements taken from older trees. In this case, it is recommended to sample multiple stands and develop new curves fitted to the existing data (Carmean 1975). Spurr and Barnes (1973) found that curves constructed in this manner did not accurately represent actual stand growth curves, and that SI ranges need to be equally represented at all ages, which may not be feasible due to harvesting or other land practices. Harrington and Loveall (2006) reported problems using SI in southwestern US ponderosa pine (*Pinus ponderosa* [Dougl. ex Laws.]) stands due to the high index age and the extended time it took for the stand to attain adequate size for measurement. Site index also assumes that the growth rate is proportional at all ages and for all qualities of sites, which is not the case (Beck and Trousdell 1973). Finally, even though the SI is a good estimator of a single variable, volume, it provides scarce information towards understanding the biology and development of a site (Pritchett and Fischer 1987).

The aforementioned methods of site quality evaluation are traditional and based on minimally disturbed land; however, methods are needed that compare stands on highly disturbed sites with a reference, or natural, stand of trees to determine site quality and reforestation success. The concept of a reference system approach for site quality is a relatively new one. Moore and others (1999) gave three definitions of the concept: 1) a standard used to measure the variability of natural conditions in an ecosystem (Kaufmann 1994; Swanson and others 1994; Kaufmann and others 1998); 2) a standard used to measure change in an ecosystem (Morgan and others 1994; Kaufmann and others 1998); and 3) a standard used to measure the success of ecological restoration or management objectives (Christensen 1996). This system of site quality evaluation has been used to measure restoration success of watersheds (Hessburg and others 1999), tallgrass prairie (Brye and others 2002), giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) (Stephenson 1999), and ponderosa pine (Moore and others 1999). Even though ecologists use the term "reference system" to mean a pristine system not tampered with by humans, it may also represent the ultimate goal, regardless of disturbance, of any restored ecosystem.

Carmean (1975) reported the need to develop integrated methods of site quality evaluation and landscape classification that include information about mensuration, soils, and ecology; he further stressed the need for information about both yield quality and quantity. Based on previous methods of site-quality evaluation, a method specific to the Appalachian coal fields needs to be developed that characterizes the vast diversity and abundance of these forestlands. Although this method will not restore forests to their former ecological status, it will help provide a greater understanding on whether current reforestation methods are working effectively.

The forests of central Appalachia are diminishing at a high rate due to surface mining. For many reasons, these forests are essential to the identity, productivity, and stability of the region's ecology and economy. There is a need for a method that can be used to evaluate survival on mined lands and concurrently determine if the stand is on a similar growth trajectory as that found in a naturally regenerated forest on non-mined land. Quality is desired by landowners as much as, if not more than, quantity. Properly managed forests provide the landowner with a long-term investment not only in the form of income from wood and fiber production, but also through water supply and filtration, land stabilization, wildlife habitat, ecosystem biodiversity, air filtration, carbon sequestration, and numerous other non-wood forest products (Zipper and others 2011). Burger (1999) stressed that reforestation success must not be a matter of numbers and percentage of survivability; rather, emphasis must be placed on developing stands that produce the products listed above at optimum levels. It was recognized that the current methods of reforestation assessment were inadequate and served few purposes other than achieving bond release for the mining company.

Given that efforts to re-establish stands disturbed by surface mining have not been completely effective, a study was designed to develop growth curves based on observations of tree height, diameter, and age that accurately characterize even-aged, naturally regenerated white oak (*Quercus* alba L.) and yellow-poplar (*Liriodendron tulipifera* L.) forests found in eastern Kentucky. This reference data was then used to assess outplanted tree growth on reforested mine lands in eastern Kentucky.

Materials and Methods

Species Selection

Two hardwood species were chosen for this project, white oak and yellow-poplar. Both species are native to the region, highly valued for a variety of reasons, and key components of the native ecosystem (Beck 1990; Rogers 1990). Further, there is an abundance of each species in the region that provided ample opportunities for finding suitable study areas.

Study Area Description

The majority of the study area was located in the Eastern Coal Fields physiographic region of Kentucky, with a small number of sites falling into the Eastern Pennyroyal region. This section of the Cumberland Plateau has been thoroughly described in two parts, the Northern Cumberland Plateau (Smalley 1986) and the Cumberland Mountains (Smalley 1984) that border the southern edge of this section of the plateau. A historical description of the region is found in Braun (1950).

Reference Study Sites and Measurements

Within 20 counties in the study area, 80 reference study sites (40 for each species) were identified, established, and measured. The 40 study sites per species were further subdivided into five age classes (5, 10, 20, 40, and 80 years old); each age class was composed of eight study sites. These criteria were established to show a chronosequence of development that could be used to describe the reference range for various silvicultural variables. Most of the study sites were located on public land, namely the Daniel Boone National Forest (DBNF), Kentucky Nature Preserves, Kentucky State Parks, and the University of Kentucky's Robinson Forest. A majority of the 5-year-old sites were found on private land.

Requirements for site selection included: even-aged; ample sampling points (n=30); favorable slope position and aspect for the species measured; relatively free of pest and disease damage; within the correct age range; and similar land use history as the majority of the other sites. Age ranges for the various stand classes were organized as depicted in Table 1.

Once a suitable area was identified, a 10-m (33-ft) buffer was paced off from any road or other edge and the start point was randomly established and flagged as 0. Using an engineering tape, a 20-m (66-ft) transect was laid out parallel to the contour of the slope, and flags were placed at 10-m (33-ft) and 20-m (66-ft) points. From the 0-, 10-, and 20-m flagged points, perpendicular transects were established to a length of 20-m, making a 400-m2 (4300-ft2) site. On these per-

Table 1. Age class determination for even-aged cuts.

Age Class	Age Range	Years Cut
5	4 to 6	1999 to 2001
10	8 to 12	1993 to 1997
20	17 to 23	1982 to 1988
40	36 to 44	1961 to 1969
80	75 to 85	1920 to 1930

pendicular transects, the 10-m and 20-m distances were flagged and designated as six replicated plot centers within the site.

The 5 closest dominant or codominant trees to each plot center were measured as sample trees. Each site had 30 sampling trees for a total of 2,400 sampling trees measured. On older stands exhibiting low tree density, the overall sampling area was increased to obtain the necessary 30 sample trees. Sampled trees had to be healthy, dominant or codominant canopy trees, single stemmed, unsuppressed, relatively undamaged, and not significantly bigger or smaller than the age class being sampled (McQuilkin 1989).

Thirty trees on each site were measured for total height using a Haglof Vertex Laser Hypsometer (Haglöf Sweden AB, Långsele, Sweden). Diameter-at-breast height (DBH) was determined with a standard dbh tape. Due to their short height, all 5-year-old seedlings were measured 2.5 cm (1 in) above mineral soil for a ground line diameter. Two trees per study site were cored and the cores were sanded and analyzed in the lab for stand age. Due to small girth, trees in the 5- and 10-year-old study sites were lopped and a section was cut, sanded, and evaluated for stand age.

Other information recorded for each study site included slope, aspect, elevation, GPS location, directions, and plot layout. For each species, total vegetation observations per age class were summed and plotted to show diversity trends in yellow-poplar and white oak plots between 0 to 80 years of growth.

Mine Site and Measurements

The Starfire Mine is located in Perry and Knott Counties, Kentucky. It is a mountain top removal mine that has been in operation since the early 1980s. In 1996 and 1997, the University of Kentucky established nine 1-ha (2.5-ac) reforestation test cells (Thomas and others 1999). These cells were constructed to represent three subsurface treatments: conventional (3 cells); strike-off (3 cells); and loose-dump reclamation (3 cells). Conventional reclamation that results in a highly graded, smooth, and compact surface is the accepted practice of surface mining. Strike-off reclamation is a method in which the spoil is loosely dumped in piles, and then the tops of the piles are "struck off" with the use of a bulldozer, resulting in a moderately compact surface. Loose-dumped reclamation occurs when the spoil is loosely dumped in piles and left alone, and creates the least compact planting material. Micro-topography of the three subsurface treatments varied greatly, ranging from completely smooth ground (conventional) to extremely rough (loose-dumped) (Angel and others 2006). Surface amendments (straw-manure compost) were also applied to portions of each cell at a rate of 125 tons/ha (50 tons/ac), and other areas were left alone to serve as the control.

Each cell was divided into twenty-one 0.04 ha (0.1 ac) growth plots into which a particular species was planted. Six bare-root (1+0) tree species, including yellow-poplar and white oak, were planted in 1996 and 1997 (Angel and others 2006). One corner of each plot was permanently marked with rebar and metal tags identifying plot number and species planted within the plot. Each tree species was randomly allotted to three plots (three replications) within each reclamation cell. Tree seedlings were planted on 1.8- by 1.8-m (6- by 6-ft) spacing, providing 121 trees in each growth plot. The growth plots are separated by 3-m (10-ft) wide alleyways that provide access to the plots without damaging the growing trees.

Since the inception of the Starfire Mine reforestation plots, annual measurements of height, survival, and diameter have been recorded and compiled into a database. These measurements were obtained, organized, analyzed, and used as a test for the method developed by this study. Nine years of data from Starfire were obtained, but because growth was negligible in the first 4 years, only the past 5 years of data were used for tree height and diameter comparison.

It is important to note that the reforestation plots on Starfire Mine were too young at the time of measurement to have reached canopy closure. These were planted stands at predetermined spacing that created a more open growing condition than what is typically encountered naturally; it is therefore likely that trees in these plots did not experience the same intense competition for resources as would be found in a natural stand. When stand density is not excessive, a seedling does not have to grow in height as fast to outcompete its neighbors, and it can allocate more resources to diameter growth. For example, a mature tree grown in an open field will likely be shorter than one found in a fully-stocked forested stand, given the same site quality, due to the reduced pressure on available resources.

Statistical Analysis

For each species, tree heights and diameters were totaled and averaged per age class. The reference range for early (0 to 20 years) height growth was developed by plotting the averages and upper and lower standard deviations for height at 5, 10, and 20 years. All three lines were then linearly regressed to show the average growth trajectory and the upper and lower standard deviation trajectories around it. Linear regression was used to depict early growth because of competition pressure and self-thinning typical of young stands.

To depict the long-term (0 to 80 years) reference range for height growth, a similar method was used, with the exception of using averages from all age classes (5, 10, 20, 40, and 80), and regressing them logarithmically. Early and long-term diameter reference ranges were developed in an identical manner as was done for the height reference ranges. Independent t-tests assuming unequal variance were used to compare reference height and diameter means to mine plot height and diameter means for the past 5 years of growth on the mine (SAS Institute 1999).

Results and Discussion

Characterization of Reference Study Sites

Yellow-poplar and white oak were favorable species to study due to the abundance of both in eastern Kentucky forests. The defined patterns of site preference, both temporal and spatial, for both species became clear as sampling progressed. The majority (37.5%) of yellow-poplar sites had a northwest aspect, although northeast, north, and east aspects were also common (25%, 17.5%, and 10% of sites, respectively). Usable yellow-poplar sites were found on lower (42.5% of the sites), mid (40%), and upper (17.5%) slope positions. Elevation of the yellow-poplar sites averaged 374 m (1227 ft), with a low of 263 m (864 ft) and a high of 679 m (2229 ft).

For white oak sites, 40% were situated on southwest aspect, but sites were also found on southeast (25%), south (15%), west (10%), and northwest (5%) aspects. White oak sites were mainly found on upper slope positions (47.5%), with fewer sites on the lower (27.5%) and mid (25%) slope positions. Average elevation was 380 m (1247 ft) for white oak sites with the highest at 645 m (2115 ft) and the lowest at 286 m (939 ft).

Reference Height Development

Nyland (2002) summarized the four phases of even-age stand development as: 1) stand initiation, which can last up to two decades and in which there is a rapid accumulation of living vegetation; 2) stem exclusion, characterized by high mortality caused by competition pressure and self-thinning; 3) transition, during which the permanent understory forms in gaps created over time; and 4) steady-state, in which the biomass of the stand fluctuates only slightly and remains fairly stable (after Bormann and Likens 1979; Oliver 1981; Spies 1997). Reference height ranges were depicted to reflect the above stand development phases by showing a linear trend for the 0 to 20 year old stands and a logarithmic trend for the 0 to 80 year stands (Figure 1).

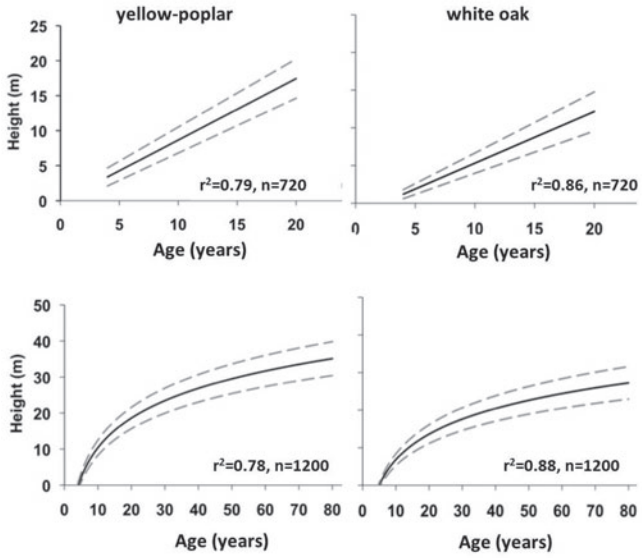

Figure 1. Reference height range for yellow-poplar and for white oak at 0 to 20 years and 0 to 80 years.

Measured yellow-poplar heights corresponded well to those observed by Beck (1990) in unthinned second-growth Appalachian stands. He reported mean heights at age 20 of 15.8 m (51.8 ft), at age 40 of 27.1 m (88.9 ft), and at age 80 of 35.1 m (115.2 ft). Another study from Robinson Forest, Breathitt County, Kentucky, by Eigel (1978) reported mean heights of yellow-poplar on side slopes at age 41.8 to be 29.1 m (95.5 ft) on YP SI (102). The mean SI at age 50 for all yellow-poplar stands in this study, calculated through regression, was 29.5 m (96.8 ft). An SI of 80 at age 50, indicating an average site quality, was obtained for the 80-year-old yellow-poplar stands in this study using the Southern Appalachian Mountains curves (Beck 1992).

Information on white oak heights at specific ages was not as readily available. Rogers (1990) reported that on the poorest sites, the SI for white oak exceeded that of yellow-poplar; on better sites where white oak co-dominated with yellow-poplar and other oaks, however, the SI for white oak was generally less than that of yellow-poplar. Honeycutt (1981) examined white oak growth in Robinson Forest and found, at a mean age of 57 on Shelocta soils on mid slope position, a mean height of 21.0 m (68.9 ft). The mean height of 40-year-old stands in this study was 20.1 m (65.9 ft), indicating that the site quality for this age class, when compared to the sample from Honeycutt's study, was likely higher. The mean SI at age 50 for all white oak stands in this study was 22.6 m (74.3 ft). When the 80-year-old mean height was used to calculate SI based on the upland oak SI (Carmean and others 1989), an index of 75 was obtained, which indicates high-quality site for white oak.

Reference Diameter Development

For reasons explained earlier, diameter curves were plotted linearly for 0 to 20 years and logarithmically for all age classes sampled (Figure 2). Height was easily comparable among stands due to its relative independence from the effects of density; diameter, however, was not as comparable since it was directly affected by stand density (Schifley 2004).

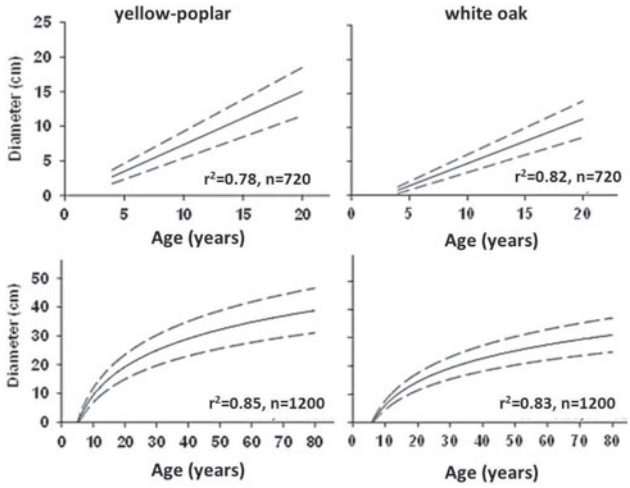

Figure 2. Reference diameter range for yellow-poplar and for white oak at 0 to 20 years and 0 to 80 years.

Yellow-poplar diameter measurements from this study were similar to those reported in the literature. Beck and Della-Bianca (1970) examined naturally regenerated yellow-poplar stands in the southern Appalachians and found a mean diameter at age 20 of 20.8 cm (8.2 in); this was higher than our study mean. Another study by Beck (1989) reported the mean diameter for yellow-poplar stands at age 40 to be 28.5 cm (11.2 in) on YP SI (120)that was almost identical to the corresponding mean in our study. The same study revealed that at age 80 on YP SI (100) the mean diameter was 44.7 cm (17.6 in), slightly higher than the study mean. Eigel (1978) reported a mean diameter of 29.0 cm (11.4 in) at age 39 for six yellow-poplar trees measured in Robinson Forest.

Honeycutt (1981) studied white oak in relation to topography and soil in Robinson Forest and found a mean diameter of 23.0 cm (9.1 in) at age 40; this was slightly higher than the average for this study. Crown position has been cited as the single most important factor in tree diameter growth (Trimble 1969). An oak that has a superior canopy position will gain diameter faster than an overtopped oak. While collecting data, an attempt was made to sample trees that were as similar as possible, and crown position was always considered. Regardless, the standard deviations for diameters for both species in age classes 20, 40, and 80 were consistently higher than standard deviations for height, indicating that variation in diameter was influenced by changes in stand density during the stem exclusion phase (Schifley 2004).

Tree Height in Reference and Reclamation Sites

The primary objective of this study was to discern the quality of degraded lands in eastern Kentucky; there are no lands in this state that have been disturbed more than those affected by surface mining. The Starfire Mine presented a good opportunity to test the method against trees growing on reforestation plots outplanted on land reclaimed by three different methods with or without straw-compost amendment: conventional; strike-off; and loose-dumped reclamation.

Table 1. Yellow-poplar and white oak survival percentages for Starfire Mine reforestation cells, 1997 to 2005. Treatments, by species, for 2005 followed by the same letter are not significantly different (α ≥ 0.05).

Species	Method	1997	1998	1999	2000	2001	2002	2003	2004	2005
Yellow-poplar	Loose-Dump	93	86	77	64	83	82	79	80	77 a
	Strike-off	94	63	61	51	59	57	54	52	52 b
	Conventional	59	50	30	9	15	15	9	11	10 c
White Oak	Loose-Dump	88	69	87	70	83	80	84	81	80 A
	Strike-off	94	55	78	66	68	71	70	69	69 B
	Conventional	49	25	49	25	27	27	24	21	25 C

Tree survival has consistently been over 50% in the loose-dumped and strike-off cells since 1997 (Table 2). These numbers may be satisfactory with respect to obtaining bond release for the mining company, but they tell us nothing about the quality of these sites, nor do they provide us with any information about the suitability of the site for long-term forest development. With this in mind, height growth (Figure 3) and diameter growth (Figure 4) were analyzed and compared to growth trajectories from the reference sites.

Caution must be exercised in interpreting the height growth trajectory for yellow-poplar in the conventional reclamation because the straw-amended plot was unusually high (Figure 3). Although the heights of the yellow-poplars in these plots were comparatively tall, there was very low survival (<3%) for the conventional plots in 2005. The height growth trajectory for white oak seen in Figure 3 more accurately reflected the conditions that trees typically faced on conventionally reclaimed mine land—both growth trajectories for the straw-amended and control plots were almost flat and well below that of the reference. The high degree of compaction hindered root development, hydraulic conductivity, and nutrient uptake, and thereby caused the trees to grow at a stunted pace (Conrad and others 2008). Surface water on these plots either ponded or ran off at a rapid pace due to the compaction. Anoxic conditions were an additional problem facing tree development in these areas.

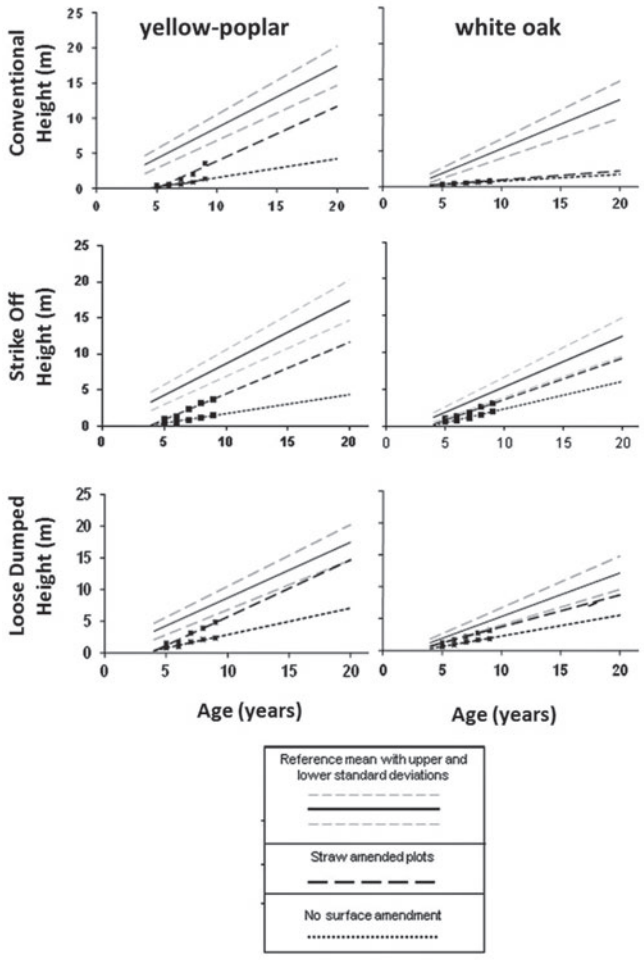

Figure 3. Chronosequence of height development for yellow-poplar and white oak comparing reference stands to reforestation plots on Starfire Mine, with and without straw mulch amendment, and reclaimed with conventional reclamation, strike-off reclamation, and loose-dumped reclamation.

Tree heights in the strike-off and loose-dumped plots came closer to reference range (Figure 3), and reflected the looser spoil material that allowed better rooting capacity, water retention, and nutrient flow. White oak heights were closer to reference range than yellow-poplar in the strike-off plots, possibly because they were more drought tolerant. Strike-off reclamation produced slightly more compact spoil that may have resulted in higher runoff amounts and drier conditions.

Loose-dumped reclamation (Figure 3) resulted in tree heights in both species that most closely approached the tree heights found in the reference stands. If conditions remain the same in the yellow-poplar plots, these heights may reach reference heights just before they reach age 20. Thomas and others (1999) reported using yellow-poplar in reclamation plots on Starfire Mine because it was native, fast growing, had a rapidly growing market, and had a documented performance in land reclamation. Early research on sites mined before the Surface Mining Control and Reclamation Act of 1977 (pre SMCRA) in southern Illinois (Ashby 1978) showed that uncompacted sites resulted in some of the most productive areas in the state for growth of yellow-poplar and white oak. Another study found that five of six hardwood species (including white oak and yellow-poplar) showed increased survivability as compaction was minimized on Starfire Mine (Angel and others 2006). White oak seedling establishment is best on loose soil because the radicle cannot penetrate excessively compacted surfaces (Rogers 1990).

Statistical analyses indicated that the average heights on all surface and subsurface treatment plots for the most recent year collected (growing year 9 or 2005) were significantly less ($P < 0.001$) than the reference mean of the same age. This was not surprising, even on loose-dumped spoil, due to the open growing conditions the outplanted trees experienced on the mine.

It must be emphasized that a surface amendment must be used when tree planting on mine-reclamation sites to achieve acceptable performance after outplanting. The straw-amended plots outperformed the control plots for all three reclamation methods (Figure 3). The use of mulch is a common practice in reclamation due to its ability to control erosion, supply nutrients, protect seedlings, alleviate compaction, reduce evaporation, and stabilize soil temperatures (Angel and others 2006; Evangelou 1981; Plass 1978). Francis (1979) reported that on frangipan soils, yellow-poplars grown on bedded plots were taller than those planted without bedding. Another study revealed that bedding reduced soil bulk density values for loblolly pine stands and

increased total porosity and macroporosity by 19% and 24%, respectively (Lister and others 2004). While these benefits are important, the addition of nutrients through mulch cannot be understated, as mine spoils are often deficient in nutrients. Early investigations of spoil material found that these soils were deficient in nitrogen (Schramm 1966); however, later studies reported that nutrient availability in spoils was as variable as the spoil itself (Lindsay and Nawrot 1981). Rodrigue (2001) concluded that the nutrition of a spoil was dependent on the surface overburden material, its pH, and its degree of weathering, and that the variability of the nutrient content was reflective of variable site conditions after mining.

Tree Diameter in Reference and Reclamation Sites

Diameter growth was also examined in the same manner as height, using the reference range graphs (Figure 2) as a base against which we compared diameter development of outplanted trees on Starfire Mine (Figure 4). Compared to height growth, diameter growth of trees on the reforestation plots was similar to the reference stands in some instances. Often, tree plantings on mines are measured only for height and survival because these attributes are key to bond release, and there exists sparse information about comparable diameter measurements.

As with height, the results for yellow-poplar in the conventional reclamation plots reflected an inflated straw-amended growth trajectory due to the low survival of yellow-poplar trees from those cells in that year (Figure 4); white oak diameters, however, showed little response to growing on conventionally-reclaimed mine land (Figure 4). The compacted spoil in these cells inhibited diameter growth primarily by restricting water and nutrient flow to the tree. When tested, mean diameters for both species produced from conventionally reclaimed mine land, with or without mulch, were significantly different and lower than those found in the reference stands.

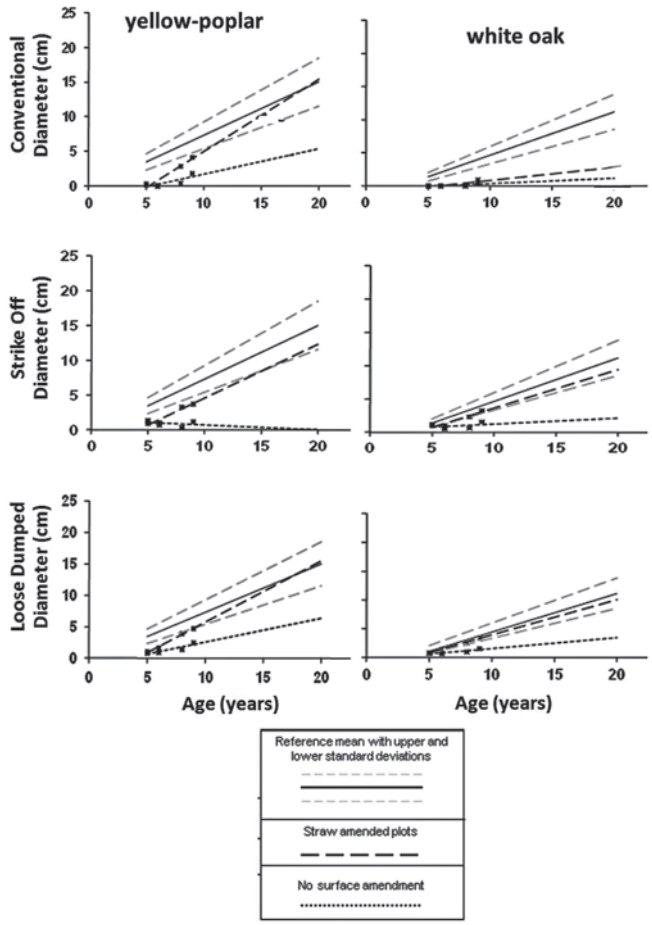

Figure 4. Chronosequence of diameter development for yellow-poplar and white oak comparing reference stands to reforestation plots on Starfire Mine, with and without straw mulch amendment, and reclaimed with conventional reclamation, strike-off reclamation, and loose-dumped reclamation.

Diameter growth was dramatically improved on strike-off reclamation for both yellow-poplar and white oak when amended with straw mulch (Figure 4). When mean diameters at age 9 were compared between reference stands and mine plots, there was no significant difference between the two ($P = 0.06$) for white oak, indicating that, with respect to diameter, this surface and subsurface combination (strike-off and straw mulch) achieved conditions similar to reference stands for white oak growth. Although it appeared that yellow-poplar diameter growth was very close to reference, the means were significantly smaller ($P < 0.001$).

A similar trend occurred in the loose-dumped plots. White oak diameters from the mine plots at age 9 were actually significantly larger than those in the reference sites ($P = 0.0026$) (Figure 4), which suggested that the open-grown conditions and surface and subsurface treatments resulted in white oaks allocating more carbon to diameter than to height growth. On the other hand, yellow-poplar mean diameters were significantly smaller than those found in the reference stands, but are expected to be similar within the next 2 years.

From the analysis of height and diameter growth found on the mine plots, we are growing shorter trees with larger diameters compared to those found in reference stands in the eastern Kentucky coalfields. We believe this is occurring for a couple of reasons. First, the growing medium on the mine plots did not, for the most part, have the same nutrient or water availability as what was found in the reference stands. Second, the open growing conditions and predetermined spacing of the outplanted trees on the mine plots created less competition pressure that likely allowed the trees to allocate more resources to diameter growth versus height growth.

Conclusions

There is a need to qualitatively evaluate reforestation projects on mined land in eastern Kentucky to ensure future economic and ecologic benefits, goods, and services that healthy forests provide. Conventionally reclaimed land often holds little promise in the way of future forest development. Tree heights and diameters from conventional stands were consistently lower than those found in undisturbed reference stands. On the other hand, loose-dump and strike-off reclamation had positive effects on yellow-poplar and white oak development. Additionally, the use of mulch proved to be essential for producing height and diameter growth similar to that found in reference stands through its ability to mitigate compaction and nutrient availability. Mulch likely served to jump-start the establishment of a microbial population that was necessary to cycle essential nutrients on a newly formed, unweathered soil. Mulch may also have alleviated compaction through reducing bulk density and increasing total porosity. Finally, mulch seemed to enhance the initial nutrient availability of the spoil where there was none before and allowed seedlings an early source of nutrients. The hardwood reference system of evaluation described in this paper appears to be a good means to assess stand quality on disturbed sites. Its value is two-fold in that one may evaluate the surrounding natural forests as well as the disturbed land. In this way, it may provide an additional tool to evaluate and predict stand quality and future development of the unique forests found in eastern Kentucky.

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