FOREST TOPSOIL SEED BANKS FOR INTRODUCING NATIVE SPECIES IN EASTERN SURFACE-MINE RECLAMATION[1]

by

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Abstract. Three pioneer communities, a mix of commonly used reclamation species, a community from a forest soil seed bank, and a mixed community of reclamation species plus seed bank species were established on surface-mine spoils in microplots. A total of 84 taxa originated from the soil seed bank, including five tree species. Adding the reclamation species to the seed bank soil resulted in significantly fewer established native species, including tree seedlings in the resulting community; many native species were stunted or phenologically delayed. The seed bank community produced more aboveground biomass and sequestered more N, P, K, Ca, and Mg in vegetation than in the other two communities. Speed of ground cover development ranked reclamation mix > reclamation mix plus seed bank > seed bank, but amounts of cover were not significantly different 16 weeks after the study was established. Differential effects of pioneer communities on ecosystem development on surface-mined lands and use of soil seed banks in their establishment are discussed.

Introduction

Reclamation of surface-mined land under current regulations requires the establishment of a permanent ground cover of herbaceous vegetation. This is usually accomplished by seeding mixtures of grasses and legumes. The effect of grass-legume mixtures on ecological succession and ecosystem development on these areas is of concern to individuals interested in the quality of reclamation, particularly those interested in forestry and wildlife habitat as postmining land uses.

Surveys of older revegetated surface-mines show that natural plant succession can be an important part of the revegetation process on both unplanted and planted sites (Thompson et al. 1984; Ashby et al. 1980). However, some of the exotic species used in revegetating surface-mined lands may inhibit the invasion and establishment of native species. Brenner et al. (1984) found a significant inverse correlation between total biomass and the number of native species that invaded surface-mined sites in Mercer County, Pennsylvania. Dense stands of *Coronilla varia* (crown vetch) and *Lotus corniculatus* (birdsfoot trefoil) appeared to inhibit invasion of native species. Native species also were more abundant when *Sorghum vulgare* (sorghum) was the ground cover than when *Avena sativa* (oats) or *Lolium perenne* (perennial ryegrass) was used as ground cover. They also found decreased basal areas of invading tree species when ground cover biomass was greater. Thompson et al. (1984) found plantings of *Lathyrus sylvestris* (flat pea) and *Coronilla varia* that remained monocultures after 18 years.

Many native species may have characteristics not possessed by commonly used reclamation species, such as different root system configurations useful for soil/spoil mass stabilization, roles as food sources for wildlife, roles in community succession, and adaptation to local edaphic and climatic conditions.

Seed or propagules of most native species generally are not available commercially, or the cost of assembling a diverse community mix of them is prohibitive. An alternative is to use seed banks of native species contained in the topsoils of existing native plant communities. These seed

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banks contain many species which are normally important in secondary succession following disturbance of natural ecosystems.

The idea of using topsoil seed banks in surface-mine reclamation is not a new one. A number of researchers have investigated the potential for using seed banks in topsoil for surface mine reclamation, but emphasis has been on arid and semiarid ecosystems in the western United States and Canada. Howard and Samuel (1979) investigated the use of topsoil containing seed and rhizomes of perennial plants in Wyoming and Colorado. Insufficient numbers of seedlings survived to meet reclamation requirements, but they found that this method did introduce native species. Beauchamp et al. (1975) found that additional seed was required to meet reclamation requirements when topsoil was used in Wyoming. Application of topsoils on mined lands after their removal from other locations resulted in higher components of native species in the resulting plant communities than when standard seed mixes were used. Iverson and Wali (1982) reported that seed banks are important in introducing some native species to reclaimed lands in North Dakota. They placed a higher importance on immigrant species, however. Farmer et al. (1982) investigated the potential of Appalachian forest topsoils to supply native species for reclamation in Tennessee. Seed banks from three forests produced 134 taxa when spread over two mine spoils and a control nursery soil. Further, they estimated that a large proportion of the nitrogen and phosphorus added as fertilizer in that trial was taken up by the plants growing from the seed banks. They speculated that such sequestration of nitrogen in vegetation could be important in later development of plant communities on spoils that are frequently deficient in essential nutrients. Important microbial populations also can be introduced in this manner (Argonne National Laboratory 1981). DePuit (1984) reviewed topsoiling studies in the Northern Great Plains region of the United States and discussed actual or potential effects of various topsoil application and management practices which could be used to enhance species diversity within and between plant communities.

The objectives of this paper[3] are:

1. To report the effectiveness of a forest soil seed bank alone and a forest soil seed bank plus additionally seeded reclamation species for establishment of native species.

2. To compare three pioneer communities on surface-mine spoil in terms of cover development, biomass production, nutrient capital sequestration, and root-system characteristics.

Methods

Twelve microplots were established by filling plastic-lined wooden boxes, 1.2 m square and 61 cm deep, with spoil collected from a surface mine on the Peewee coal seam in Campbell County, Tennessee. After filling, it was found that there were two chemically distinct spoils in the microplots, though they were similar in appearance. It was then possible to assign three replications of each of three planned vegetation treatments to the better quality, less acid spoil (pH 5.8) and one replication of each treatment to the lower quality spoil (pH 4.4). Spoil differences had little effect on the results to be presented here, however.

After the microplots were filled with spoil, a 10-cm layer of topsoil (A horizon) was collected from a secondary forest stand dominated by Carya sp. (hickory), Acer rubrum (red maple), Quercus alba (white oak), and Liriodendron tulipifera (yellow-poplar) on a west-northwest-facing slope in the Cumberland Mountains in Anderson County, Tennessee.

The collected topsoils were mixed and divided, and part of the soil was sterilized with methylbromide gas and spread in a layer 5 cm deep over the surface of the spoils in four microplots (Treatment 1). Unsterilized forest topsoil was spread over the spoils in the other eight microplots (Treatments 2 and 3). Ammonium nitrate and triple-super phosphate were applied to all microplots at a rate equivalent to 57 and 59 kg/ha of nitrogen and phosphorus, respectively.

The three treatments, or plant communities, were established on April 17, 1980, as follows:

Treatment 1 was a mix of commonly used reclamation species consisting of Lolium multiflorum (annual ryegrass), Eragrostis curvula (weeping lovegrass), Festuca arundinacea var. Kentucky-31 (Kentucky-31 tall fescue), and Lespedeza cuneata (sericea lespedeza) that was seeded into the sterilized forest topsoil in four microplots.

Treatment 2 was a mixture of native pioneer species which germinated from the seed bank in the unsterilized forest topsoil. No additional seed was added. This will be referred to as the seed bank community.

Treatment 3 was a combination of the first two treatments in which the reclamation species mix was seeded at one-half the rate used in Treatment 1 into the unsterilized forest topsoil and seed bank. This will be referred to as the seed bank plus reclamation mix community.

After seeding, all microplots were mulched with wheat straw equivalent to 4 tons per hectare. Microplots were sprinkled with uniform amounts of tap water between rainfall events whenever plants began to show signs of acute water stress. Microenvironment measurements to determine early effects of the vegetation cover were made in each plot from 1 to 2 pm on August 14 (4 months after seeding). The weather was sunny, the air temperature was 37°C, the bare soil had a surface temperature of 45°C, and 1.27 cm of rain had fallen 2 days prior. Three random sample points were chosen for each plot using a random number table to define x,y coordinates. Light measurements were taken at the soil surface by inserting a Seconic Studio Pro[4] incident light meter under microplot vegetation from the north side. The meter reading was then compared with another incident light measurement above the vegetation and recorded as percent of

[3]The material in this paper is drawn from an unpublished Ph. D. dissertation prepared by the author for The University of Tennessee, December, 1985.

incident light. One topsoil sample was removed from each plot at the point of the first light measurement. The soil samples were placed in snap cap film cans for return to the lab where they were weighed, dried at 105°C, and reweighed to determine surface soil moisture. Soil surface temperatures were determined with an infrared radiometer. Light measurements were log transformed before statistical analysis.

Vegetation growing in the microplots was harvested between the 1st and 17th of September. The mean growing season for the plots was 147 days. In each plot, all plants were clipped at ground level and counted as either individuals or clones. Several clones or individual plants of each important species were taken from each microplot for chemical analysis. Minor populations were pooled by species in each microplot for chemical analysis. Remaining individuals of large populations were pooled for biomass determinations. Individuals of important species in the different communities were tagged at ground level and the root systems were excavated hydraulically. Type, depth, and lateral extent of individual root systems were determined. Nutrient budgets for each plot were determined from species biomass and nutrient concentration data.

Results and Discussion

Five weeks after establishment, the reclamation mix (Treatment 1) had the greatest amount of vegetative cover (Fig. 1). The native seed bank community (Treatment 2) produced the least cover at 5 weeks. The grasses of the seed bank plus reclamation mix (Treatment 3) produced a cover that was similar to, but less than, that of Treatment 1.

Eight weeks after establishment, ground cover in Treatment 1 was obviously greater than that in Treatments 2 and 3 (Fig. 2). Treatment 3 still looked more like Treatment 1 than Treatment 2.

Measurements taken at 16 weeks after establishment showed that ground covers were essentially equal (Table 1). Soil Surface temperatures, topsoil moistures, and light intensity at the soil surface did not vary significantly among communities.

The character of the reclamation mix community, Treatment 1, after 20 weeks of growth is shown in Figure 3. Although 4 species were knowingly seeded, 18 were present at harvest. The Lolium multiflorum seed apparently was a mixture with Lolium perenne (perennial ryegrass). Digitaria ischaemum (smooth crabgrass) also was important in the community, but other invading species were of minor significance (Table 2). Seed of some of the invaders may have survived the methyl bromide treatment or may have been carried in by birds. The mulch is another probable source of contamination. It also was gassed, but it may not have been damp enough for full effects of the gas. Lolium multiflorum and Digitaria ischaemum dominated the treatment and with six other species accounted for 99 percent of the total biomass and 86 percent of the population of nearly 3.2 million individuals per hectare. Lespedeza contributed less than 1 percent of the biomass, but it accounted for 12 percent of the total population.

The native species seed bank in Treatments 2 and 3 produced 84 taxa. Sixty-five of these were identifiable to species, 14 taxa were identifiable only to genus, and 4 could only be placed in family. Several forb seedlings in different taxa which were too poorly developed for identification were classified in one taxon as "miscellaneous." Of taxa identified at least to genera, there were five tree species, seven shrubs or woody vines, 14 grasses, one sedge, and 53 forbs. Three leguminous species, including Robinia pseudoacacia (black locust), were from the soil seed bank. Other studies also showed high species diversity present in forest soil seed banks. Farmer et al. (1982) found 134 taxa, including six tree species, in three forest topsoils of the Cumberland Mountains. Dobberpuhl's (1981) study of forest soil seed banks in east Tennessee found 199 species, including 24 trees in topsoils and litter from eight sites in spring and fall collections.

The topsoil seed bank used in Treatment 2 (Fig. 4) produced 70 taxa, of which 65 were identifiable to genus or species. Digitaria ischaemum and D. sanguinalis (crabgrass) were important invaders in this treatment. Ten species made up 99 percent of the biomass and 50 percent of the total population of nearly 2 million individual plants per hectare (Table 3).

The addition of the reclamation species to the seed bank (Treatment 3) caused radical changes in the resulting community. The native species did not hold the position of dominance that they held in Treatment 2 (Table 4). A total of 52 native taxa were established from the seed bank. The native species generally were not as tall as they were in Treatment 2, and many of them were phenologically delayed (Fig. 5). In this treatment, the seed bank plus reclamation mix, 12 species make up 99 percent of the biomass and 23 percent of the population of nearly 4.4 million individuals per hectare.

The number of established native species derived from the forest soil seed bank was lower when the reclamation species were added to the community. The Treatment 2 community had 65 taxa identified to genus or species; the Treatment 3 community had 52. This difference was statistically significant at the $\alpha = 0.05$ level.

There were similar trends among tree species present in the seed bank (Table 5). Treatment 2 contained five tree species. Treatment 3 contained only two species, and their numbers were significantly reduced. This indicates that groundcover species used in reclamation might have an important inhibitory effect on the speed of forest development through natural succession on surface-mined and reclaimed lands.

Treatment 2, the seed bank community, produced the most biomass and sequestered more of the initial nutrient capital (Table 6). The amount of nitrogen

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[4]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that might be suitable.

in aboveground biomass of Treatment 2 was slightly more than the amount applied in fertilizer. The other two communities that included the reclamation species contained significantly less nitrogen. Treatment 2 also sequestered significantly greater amounts of phosphorus, potassium, calcium, and magnesium. This greater sequestration of initial nutrient capital may be important to later ecosystem development and productivity. Rapid uptake of available nutrients is an important mechanism of ecosystem recovery in normal ecosystems after severe disturbance (Likens et al. 1970; Marks and Bormann 1972; Marks 1974; Harcombe 1977). This mechanism for preservation of initial nutrient capital may well be important on surface-mined and reclaimed lands, especially on nutrient poor spoils, because those nutrients bound in vegetation are less readily lost by leaching or erosion.

Native species normally found in seed banks also may have an importance beyond their roles as vegetative cover and conservators of nutrient capital. Seed bank species established on mined lands also may establish new seed banks in these new soils to buffer the surface-mined ecosystem against erosion and nutrient losses after future disturbances. This possibility deserves future consideration and research efforts.

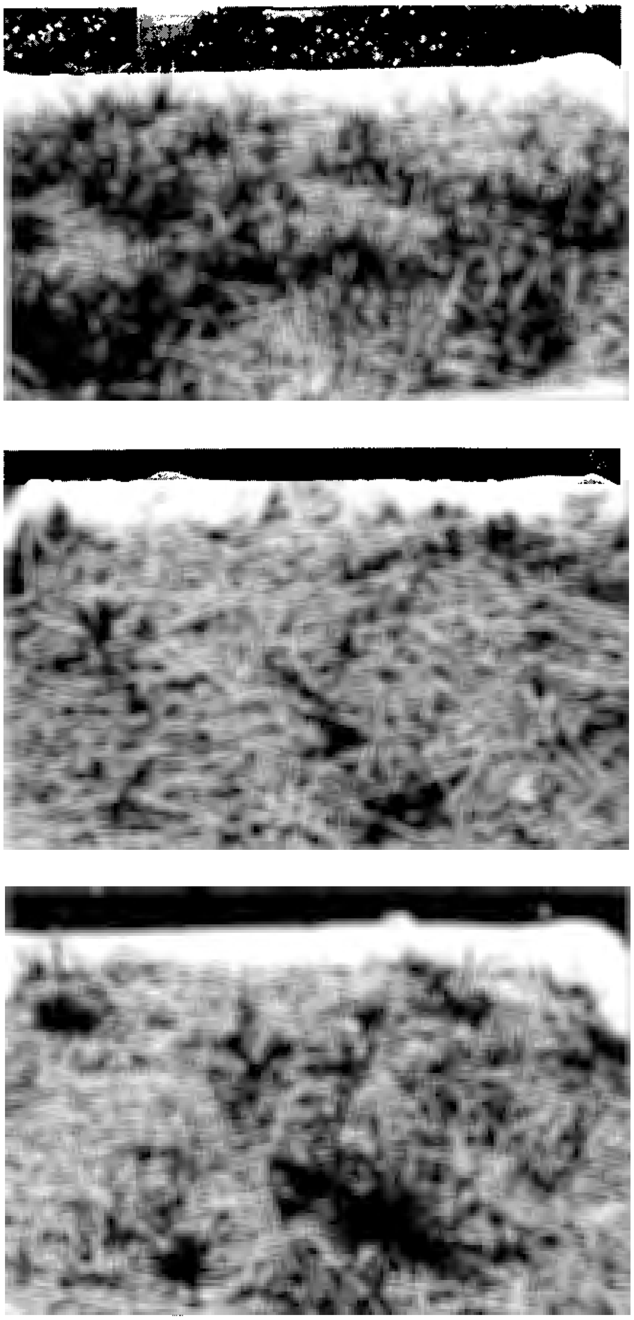

Figure 1. Cover development 5 weeks after establishment in Treatment 1, (top), Treatment 2, (middle), and Treatment 3, (bottom).

Figure 2. Cover development 8 weeks after establishment in Treatment 1, (top), Treatment 2, (middle), and Treatment 3, (bottom).

Table 1. Mean vegetation ground cover, light intensity at soil surface, soil surface temperature, and soil moisture under three community types after 16 weeks (standard deviations in parentheses; differences between means were not significantly different, ANOVA, $\alpha = 0.05$)

Treatment	Cover (%)	Light (% incident)	Soil Temp. (C)	Soil Moisture (%)
1. Reclamation mix	91.9 (4.0)	2.3 (2.3)	38.6 (1.3)	18.0 (2.0)
2. Seed bank community	90.6 (3.7)	6.8 (9.8)	37.9 (2.1)	17.8 (2.8)
3. Seed bank + reclam. mix	87.0 (4.4)	5.8 (6.4)	38.4 (1.9)	--

Figure 3. Treatment 1 as it was on September 1, 1980, 20 weeks after establishment.

Table 2. Composition of Treatment 1 showing species with 1 percent or more of the community biomass

Species	Biomass (kg/ha)	Population (n/ha)
Lolium multiflorum	1859	594,078
Digitaria ischaemum	1490	241,754
Eragrostis curvula	745	978,261
Festuca arundinacea	628	732,759
Digitaria sanguinalis	358	48,726
Lolium perenne	148	63,718
Datura stramonium	108	1,874
Dactylis glomerata	75	56,222
12 other spp.	122	448,275
Treatment sum	5533	3,165,667

Figure 4. Treatment 2 as it was on September 1, 1980, 20 weeks after establishment.

Table 3. Composition of Treatment 2 showing species with 1 percent or more of the community biomass

Species	Biomass (kg/ha)	Population (n/ha)
Phytolacca americana	2053	134,933
Erechtites hieracifolia	1965	170,540
Digitaria ischaemum	1138	65,592
Helianthus microcephalus	601	20,615
Eupatorium rugosum	475	461,019
Helianthus decapetalus	407	5,622
Digitaria sanguinalis	352	18,741
Eupatorium serotinum	270	110,570
Panicum dicotomiflorum	174	1,874
Agrostis gigantea	104	9,370
55 other spp.	692	983,883
Treatment sum	8231	1,982,759

Table 4. Composition of Treatment 3 showing species with 1 percent or more of community biomass

Species	Biomass (kg/ha)	Population (n/ha)
Digitaria ischaemum	1350	144,302
Eragrostis curvula	1148	910,795
Festuca arundinacea	636	655,922
Lolium perenne	483	138,681
L. multiflorum	460	198,651
Erechtites hieracifolia	438	101,199
Lespedeza cuneata	398	1,062,594
Phytolacca americana	247	93,703
Helianthus microcephalus	244	33,733
Digitaria sanguinalis	180	52,474
Helianthus decapetalus	163	3,748
Amaranthus hybridus	111	1,874
40 other spp.	404	995,128
Treatment sum	6262	4,392,804

Table 5. Tree species from the forest soil seed bank in Treatment 2 and Treatment 3

Species	Treatment 2 (n/ha)	Treatment 3 (n/ha)
Liriodendron tulipifera	129,310	54,348
Robinia pseudo-acacia	13,118	11,244
Sassafrass albidum	9,370	0
Carya cordiformis	1,874	0
Ulmus sp.	1,874	0
Total	155,546	65,592

Table 6. Biomass and nutrient contents of Treatment 1, Treatment 2, and Treatment 3

Treatment	Biomass	N	P	K	Ca	Mg
	----------------------		kg/ha	----------------------		
1	5533 b[1]	53 b	9.1 b	86 b	23 b	6.9 b
2	8232 a	62 a	12.5 a	172 a	66 a	15.3 a
3	6262 b	51 b	8.5 b	88 b	34 b	8.2 b

[1]Means followed by the same letter are not significantly different (Tukey's-*w* after ANOVA, $\alpha = 0.05$).

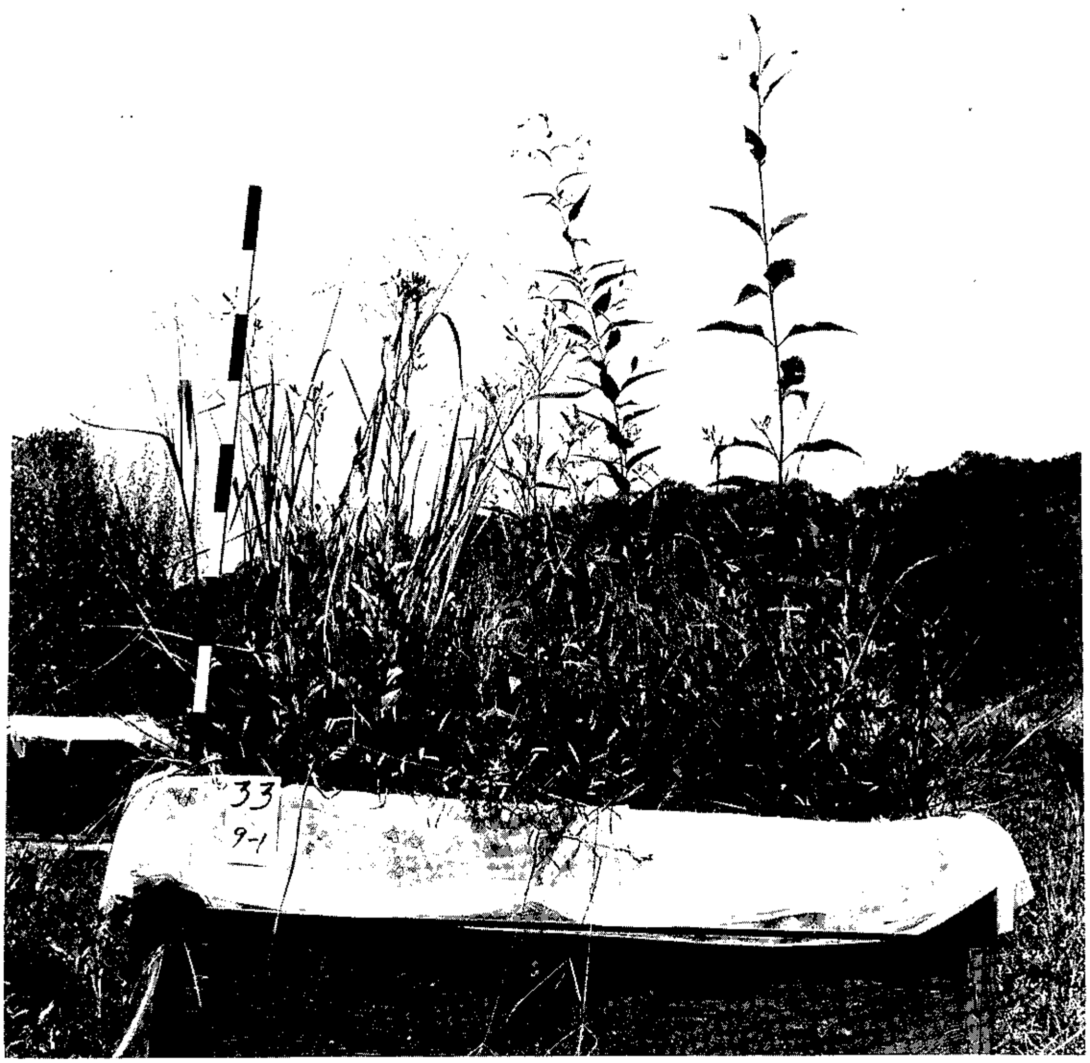

Figure 5. Treatment 3 as it was on September 1, 1980, 20 weeks after establishment.

The seed bank community and the reclamation mix community had quite dissimilar root system characteristics. The reclamation mix had very fine and diffuse root systems which were concentrated in the topsoil and the top 10 cm of the spoil, but some roots also reached the bottoms of the plots (about 50 cm deep). During the root washout procedure when the soils were saturated, this fine root mass was sufficient to keep the soil/spoil cube from collapsing after the plot sides had been removed. Roots of Digitaria ischeamum, D. sanguinalis, Eragrostis curvula and Festuca arundinacea were found at microplot bottoms, but roots of Lolium multiflorum and L. perenne were not traced to a depth greater than 25 cm.

The root systems of the seed bank community were diverse and the spoil mass was much more extensively exploited than under the reclamation mix. Tap and sinker roots of various species penetrated to the bottoms of all plots. Eupatorium rugosum (white snakeroot) and E. serotinum (late-flowering thoroughwort) had coarse branching root systems that exploited mid and lower spoil levels and reached to plot bottoms. E. purpureum (wide-leaved joe-pye weed) root systems were coarse and branching but were traced no lower than about 30 cm. Solidago flexicaulus (broadleaf goldenrod) root systems were similar in form to E. purpureum, but extended only to a depth of about 40 cm. Phytolacca americana (poke weed) had the largest taproots of any species. These reached plot bottoms and lateral roots originated at all levels. Root systems of Lactuca biennis (tall blue lettuce) were similar to P. americana, but the tap roots were not as massive. Helianthus decapetalus (thin-leaved sunflower) and H. microcephalus (small-headed sunflower) had widespreading root systems that predominantly exploited the top 15 to 20 cm of spoil, but a few roots were traced to plot bottoms. Acalypha virginica (Virginia three-seeded mercury), Amaranthus hybridus (common pigweed) and Aster divaricatus (white wood aster) were predominantly topsoil and upper spoil exploiters. The large mass of roots at all levels in this community contributed to a stable spoil mass that did not deform or collapse when the soil/spoil cubes were saturated and the sides were removed. Spoil stability was greater than in the reclamation mix.

Root systems at lower depths appeared to be less extensive in the seed bank plus reclamation mix than in the seed bank community, but roots did reach the bottoms of the plots. The surface soil root mass appeared to be slightly greater in this treatment than in the native species only plots. The additional topsoil root mass was contributed by the seeded grasses. Spoil stability due to root support did not appear to be less than that of Treatment 2, the seed bank community.

The results of this study emphasize possible benefits that may be gained from use of forest A horizon soils as sources of native species, rather than as topsoils applied as a growth medium. The use of topsoils as a seed source also can introduce soil microflora and fauna that have important roles in decomposition, nutrient cycling, soil organic matter formation, and soil formation generally. There also may be some disadvantages of topsoil use. Undesirable organisms such as Vitis (wild grape), Lonicera (honeysuckle), or soil-borne disease organisms might be transferred to a new ecosystem in some forest topsoils. As with potential benefits, the potential for such problems deserves attention.

A great deal more research on this topic is needed in the Eastern United States. Topics that should be covered include:

1. Field tests of eastern native species introduced via seed banks.

2. Topsoil collection techniques and their economics.

3. Topsoil application techniques with attention to:

   a. required thickness of topsoil,
   b. desirability of complete coverage or application in patches or strips,
   c. desirability of mixing applied topsoil with surface spoil,
   d. effects of season of collection and application,
   e. effects of topsoil storage on propagules, and
   f. desirability of mulching.

4. Competitive relationships of native species to desirable tree crops.

5. Desirability of fertilizer application.

6. Potential problems associated with undesirable organisms.

Summary and Conclusions

A forest topsoil from the Cumberland Mountains produced 84 taxa of predominantly native pioneer species when spread over surface-mine spoils. Sixty-five of these were identifiable to species, 14 were identifiable to genus, and 4 could only be placed in family. Of taxa identified to at least genus, there were five tree species, seven shrubs or woody vines, 14 grasses, one sedge, and 53 forbs. Three of the species were legumes.

The number of established species from the soil seed bank was significantly reduced when a commonly used reclamation mix of grasses and lespedeza was seeded into the seed bank soil.

The seed bank community in this study produced significantly more aboveground biomass and sequestered greater amounts of N, P, K, Ca, and Mg in aboveground vegetation than a reclamation mix of grasses and lespedeza or a combination of seed bank species plus the reclamation mix.

Ground cover developed fastest in the reclamation mix and slowest in the seed bank community, but there were no significant differences in ground cover 16 weeks after community establishment. Soil surface temperature, topsoil moisture, and light intensity at the soil surface did not differ significantly among the three community types.

Rooting systems were noticeably different between the seed bank community and the reclamation species mix community. The seed bank community was characterized by numerous tap roots, sinker roots, and deep lateral roots which apparently gave greater stability to the spoil mass than the reclamation species mix community.

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