THE EFFECTS OF MINESOIL CONSTRUCTION TECHNIQUES AND RIPPING ON THE LONG TERM SURVIVAL AND GROWTH OF BLACK WALNUT[1]

By

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Abstract. Minesoil compaction has occasionally been implicated in reducing root and plant growth and vigor on graded and topsoiled minesoils. To determine the long term effects of spoil compaction on tree growth, black walnut survival and growth after four growing seasons on four differently constructed minesoils and one unmined area in Southern Illinois were measured during 1985. Root excavations and soil bulk density measurements were carried out on all sites. Growth and soil data indicate grading-induced minesoil compaction reduced root growth, stem growth, and tree survival, sometimes acutely. Poor tree growth and severe dieback on compacted reclaimed sites during dry years implicate water stress caused indirectly by soil compaction as an important factor limiting growth. Topsoiled sites had the poorest growth and survival. Ripping the compacted graded spoil to 50-80 cm depth resulted in superior root and stem growth and proved to be effective in alleviating the negative impacts of soil compaction in this and other studies. When planning surface mine reclamation activities, ripping should be considered as a possible ameliorative technique when compaction of mined lands is unavoidable and trees are the desired final vegetative cover.

ADDITIONAL KEY WORDS: Grading, compaction, site preparation.

Introduction

Surface mine reclamation practices have undergone drastic changes during the past three decades, due in large part to progressively stricter regulations imposed over time by state and federal agencies. These regulations have been enacted to ensure successful revegetation of mined land. However, serious difficulties are currently being experienced in achieving acceptable survival and vigorous, long-term growth of trees planted on reclaimed mined land in the midwestern United States. Minesoil construction techniques involving grading and their negative effects (especially compaction) on mine-soil physical properties have been identified as having substantial impacts on the growth and eventual survival of trees planted on reclaimed lands (Ashby, et al, 1981; Bussler et al, 1984; Chapman, 1967a and 1967b; Kolar et al, 1981; and Limstrom, 1952).

The objectives of this study were to determine the extent and long-term (four year) effects of grading-induced minesoil compaction on tree growth. To achieve these goals, a series of black walnut (Juglans nigra) plantings which were established on a variety of minesoils in 1980 and 1981 by the Botany Department at Southern Illinois University @ Carbondale and Sahara Coal Company, Inc. of Saline County, Illinois were examined during 1985. The suitability of ripping as a means to alleviate mine-soil compaction and enhance tree growth was also measured.

Literature Review

Soil compaction has been implicated for some time by many investigators as a primary factor in the degradation of agricultural soil physical conditions (Greacen and Sands, 1980; Meredith and

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Patrick, 1961; Soane, Dickson and Cambell, 1982; Trouse and Humbert, 1961; Trouse, Parish and Taylor, 1971; Vomocil and Flocker, 1961). Except for a few pioneering efforts (Chapman, 1967a, 1967b; Curtis, 1973; Deitchman, 1950; Limstrom, 1952; Merz and Finn, 1951) the understanding that spoil grading induces compaction which limits the productivity of reclaimed surface minesoils has only relatively recently been recognized (Albright and Thompson, 1982; Ammons, 1979; Binns et al, 1983; Indorante, Jansen and Boast, 1981; Jobling and Carnell, 1985; Vogel, 1983).

Destruction of soil structure, reduced porosity and aeration, impaired infiltration and percolation, reduced nutrient uptake by plants, reduced water-holding capacity, increased runoff and erosion, increased bulk density, increased soil strength and resistance to root penetration, and reduced biological activity are often cited as reasons for reduced plant growth on compacted soils or spoils (Albrecht and Thompson, 1982; Binns et al 1983; Chapman, 1967; Curtis, 1973; Doubleday and Jones, 1977; Gerard, Sexton and Shaw, 1982; Grandt and Lang, 1958; Merz and Finn, 1951; Rimmer 1979; Sands, Greacen and Gerard, 1979; Swain, 1983; Taylor and Burnett, 1964; Taylor and Gardner 1963; Trouse, Parish & Taylor, 1971; Veilmeyer and Hendrickson, 1948; Wilson 1985; and Wright, Powell and Ross, 1984).

Restriction of tap and sinker root development has been often reported on compacted minesoils (Archer and Smith, 1972; Charasse, 1978; Deitchman, 1950; Duffy and McClurkin, 1974; Eis, 1978; Limstrom, 1952; Meredith and Patrick, 1961; Minore, Smith and Woollard, 1969; Rimmer, 1979). Impeded sinker root development on topsoiled mined sites was also noted for alfalfa (Ammons, 1979) and corn (Fehrenbacher, Jansen and Fehrenbacher, 1982; McSweeney and Jansen, 1984). Compacted soil layers and claypans existing in unmined agricultural soils also serve as barriers to root development and confine root growth to soil above the dense pan layer (Taylor and Burnett, 1964; Trouse, 1983). Soil compaction on minesoils is especially severe due to the use of heavy rubber tired machinery made for road construction (Ammons, 1979; Yeck, 1983) which causes deep subsoil compaction lying beyond the reach of natural soil structure-forming processes (Chapman 1967; Soane et al, 1982; Yeck, 1983; Powell et al, 1985).

Materials and Methods

Sites

A number of sites on land owned by Sahara Coal Company, Inc. in Saline County, Illinois were planted with black walnut in late 1980 and early 1981. Four of the study sites had been mined in the 1970's. The fifth site was on unmined land adjacent to the mined areas.

Five different minesite treatments were established: unmined former agricultural land, graded cast overburden, replaced silt loam topsoil (20cm) and clay loam subsoil (40cm) over graded cast overburden, ripped-graded cast overburden and ungraded cast overburden. The unmined site was characterized by a 15-20cm thick A horizon with a slight plowpan and a dense B horizon. The topsoiled site was composed of severely compacted soils over compacted spoil, long gentle slopes, very slow water infiltration below 15 cm depth. Trees were planted 2 years after final grading (Philo et al, 1983). Mined between 1971 and 1977, the graded sites consisted of stony silt loam to silty clay loam minesoils graded to long, gentle slopes. Coarse fragment content (>2 mm) of graded spoil ranged from 37% to 52% (Spaniol, 1982; Ashby et al, 1983). An adjacent plot of graded spoil was ripped using a single shark ripper on lines 2.5 m apart and .5 to .8 m deep prior to tree planting during spring 1981 . Tree seeds were planted directly in the ripped furrow (Philo et al, 1983). Coarse fragment content (>2 mm) was highly variable, averaging 44% at the 0-15 cm depth interval, and 55% between 15-30 cm (Philo et al, 1982). The ungraded site was characterized by hill and valley spoil bank topography with the minesoil consisting of a heterogeneous mixture of shales, sandstones, and limestone contained within a matrix of soil fines (silt loams) from unconsolidated or crushed overburden materials.

Black walnut was hand seeded (three seeds per planting spot) on a 2.5 m by 2.5 m spacing using seed gathered from several large So. Illinois trees. Two plots for each minesoil construction treatment (except the ripped plot) were established. Two rows of 20 trees per row per plot were planted on all except the ripped-graded plots, where six rows of 25 trees per row were established. An equivalent planted area on adjacent graded spoil not ripped was established. A 1.5 m diameter area at each planting spot was treated in the spring 1981 with a mixture of Roundup (41% glyphosphate) and Princep 4L (42% simazine) herbicides at rates of 9.4 l/ha (1 gal/A) as a 1.5% solution to control herbaceous and woody competition (Philo et al, 1982).

Measurements

Top Growth and Root Growth. During the spring of 1985, four-year tree survival, total height, basal stem diameter, and presence of dieback occurring in 1983 and/or 1984 were determined for all plots on all sites. Two trees from each site (1981 plots) were completely dry excavated using hand tools according to methods outlined by Bohm (1983). Detailed root measurements and sketches were made in the field of radial, horizontal, and vertical root size and position. Mean root depth and root extension were determined by averaging the five longest independent primary or secondary roots per tree. Tree biomass and root:shoot ratios were determined by separating shoot biomass and root biomass at the root collar, oven-drying at 70 degrees C. for 48 hours, and weighing.

Soil Physical and Chemical Properties. Bulk density measurements were made on all sites (1981 plots) at several soil depths within a meter of each excavated tree using a modification of the water balloon method (Black et al, 1965). Soil bulk density samples on the ripped-graded site were obtained from within the rip and from undisturbed spoil equidistant between the rips. Soil strength between stones was measured on all sites (1981 plots) during the fall 1985, using a Soil Test pocket penetrometer (Model CL-700). Two holes per site were tested at 5 cm depth intervals (ten measurements per depth). Soil samples were taken from two levels in each hole for determination of soil moisture content (by weight). Basic soil nutrient levels were determined from pooled soil samples (5 subsamples mixed for one mean sample) drawn from the top 20 cm of all sites

(1981 plots) during the fall, 1985 and replicated three times per site.

Results

Soil Physical Characteristics

Bulk Density. Statistically significantly differences existed between sites for mean soil bulk density (Table 1, Figure 1). Bulk density was uniformly low to 55 cm on both the unmined site and the ungraded spoil. Bulk density was high at all depths of the graded spoil and significantly different from all other plots except outside the rip (essentially undisturbed graded spoil) on the ripped plot. Bulk density increased substantially with depth on both the topsoiled and ripped (within the rip) sites.

Table 1. Average Minesoil Bulk Density on Five Sites in Southern Illinois.

Site	Average[1] Bulk Density g/cm^3	Low Bulk Density g/cm^3	High Bulk Density g/cm^3
Unmined	1.36bcd	1.28	1.42
Topsoil	1.55b	1.17	1.82
Graded	1.80a	1.70	1.94
Ripped (In Rip)	1.44bc	1.27	1.62
Ripped (Outside Rip)	1.60ab	1.47	1.78
Ungraded	1.27cd	1.22	1.35

1. Treatment means with the same letter are not significantly different at the .05 level using Tukey's Studentized Range (HSD) Test.

Soil Strength. Resistance to penetration varied markedly among site treatments (Table 2-Appendix, Figure 2) with the lowest values being recorded on the ungraded and unmined sites, followed by the ripped site. Trends in soil strength and soil bulk density between sites and with depth within each site were similar. Penetrometer resistance remained constant at all depths on the ungraded and ripped sites. Ripping reduced the average soil strength in the rip at all depths measured, although values were higher than that found on the ungraded site. Graded spoil had very high soil strength throughout the measured depth. Soil strength varied considerably with depth on the topsoiled site, with low values in the upper 10-15 cm of soil, but sharply increasing below 15 cm. The unmined site had relatively low soil strength similar in magnitude to the ungraded site, with a general tendency to increase with depth. Moisture content varied between sites, even though measurements on some sites were made the same day.

Soil Chemical Properties

No significant differences existed between sites for phosphorus (weak Bray), or CEC (Table 3). However, significant soil chemical differences existed between sites for potassium, magnesium, calcium, and reserve phosphorus (strong Bray), with the newly exposed stony spoils being superior to the heavily leached unmined and replaced topsoil soils. The most nutrient-deficient soil was on the unmined site. Some variations existed between the various stony spoil treatments, probably due to uneven mixing of the overburden strata during the mining process.

Table 3. Average Soil Chemical Properties on Five Sites in Southern Illinois (values in ppm.-percent base saturation).[1]

Site	P-1[2]	P-2[3]	K	Mg	Ca	pH	CEC
Unmined	3a	4c	84c	108b	1143c	5.7c	8.7a
Topsoil	9a	18bc	112bc	219a	1410bc	6.4bc	10.9a
Graded	12a	62ab	153ab	186ab	1790ab	7.3ab	10.9a
Ripped	8a	110a	162a	300a	1585a	7.4a	10.8a
Ungraded	5a	24bc	154a	176ab	2313a	7.5a	13.4a

1. Treatment means with the same letter are not significantly different at the .05 level using Tukey's Studentized Range (HSD) Test.
2. Phosphorus by the weak Bray method.
3. Phosphorus by the strong Bray method.

Top Growth

Overall ANOVA results indicated significant differences existing between sites for height, basal diameter and volume, but no significant interactions and no significant differences between fall, 1980 and spring, 1981 for the dependent variables measured. After four growing seasons there were statistically significant differences for tree height and diameter between the various sites (Table 4). The ripped-graded minesite clearly produced the best tree growth. The ungraded and ripped-graded areas had generally healthy trees with few signs of physiological stress. Browsing by deer occurred on 15% and 61% of the trees on the ungraded and ripped-graded plots, respectively. On the topsoiled, graded, and unmined sites the trees were usually stunted and appeared severely stressed, with frequent dieback, basal sprouting and sparse, necrotic foliage.

Walnut dieback during the very dry growing season of 1983 (NOAA, 1984) was severe on all sites, except for the ungraded area. During 1984 drought was less pronounced during the growing season (NOAA, 1985), but tree dieback was again severe on the topsoiled site (table 4). Many of the trees resprouted at the base of the stem after the 1983 dieback. This pattern of dieback suggests that trees growing on topsoiled sites experience a distinct and severe summer soil-water deficit during relatively short dry periods.

Table 4. Top Growth of Black Walnut Trees on Five Sites After Four Years of Growth in Southern Illinois.[1]

Site	Height (cm)	Stem Diameter (mm)	Volume[2]	1983 Dieback (%)	1984 Dieback (%)
Unmined	44.8bc	13.0bc	8784.6bc	59	0
Topsoil	37.5c	7.34c	2457.9cd	100	100
Graded	59.1b	11.9c	11446.9c	100	13
Ripped	81.5a	18.4a	38908.5a	97	1
Ungraded	79.6a	15.6ab	32295.2ab	29	5

1. Treatment means by column with the same letter are not significantly different at the .05 level using Tukey's Studentized Range (HSD) Test using harmonic means.
2. Volume=$(diameter^2)$(height).

Table 2. Soil Strength (SS)[1] and Black Walnut Root Frequency (# Roots)[2] on Five Sites in Southern Illinois.

Site:	UNMINED		TOPSOILED		GRADED		RIPPED		UNGRADED	
Depth[3]	SS	#Roots	SS	#Roots	SS	#Roots	SS	#Roots	SS	#Roots
2	66	1.0	94	2.5	316	1.0	213	1.0	65	1.0
5	78	2.5	101	4.0	396	2.0	251	2.5	73	10.0
10	117	11.0	116	6.5	380	8.5	225	10.0	83	5.0
15	111	11.5	234	5.0	396	10.0	227	11.0	80	7.5
20	112	8.0	305	4.5	393	11.0	231	13.0	108	7.5
25	121	6.5	393	2.5	369	11.5	225	7.5	103	7.5
30	127	6.0	340	1.0	367	6.5	228	10.0	92	10.5
35	147	5.0	346	0.0	416	6.0	204	11.5	119	9.5
40	Sat[4]	4.5	346	0.0	388	4.0	182	13.0	74	10.0
45	"	6.0	379	0.0	288	2.5	246	12.0	94	9.5
50	"	5.0	-	0.0	271	1.5	202	13.5	101	8.5
55	"	5.0	-	0.0	-	1.5	278	8.5	102	4.0
60	"	5.0	-	0.0	-	1.0	264	8.5	127	2.5
65	"	5.0	-	0.0	-	1.0	-	8.5	-	1.5
70	"	2.5	-	0.0	-	0.5	-	8.0	-	1.0
75	"	3.0	-	0.0	-	0.5	-	6.0	-	0.5
80	"	1.5	-	0.0	-	0.0	-	4.0	-	0.5
85	"	0.0	-	0.0	-	0.0	-	1.5	-	0.5
90	"	0.0	-	0.0	-	0.0	-	0.0	-	0.0
Mean	SS=110		265		362		230		95	
MC=	32.0%		23.8%		12.6%		15.2%		14.2%	

1. Soil strength in KPa (n=20 per depth per site).
2. Average number of roots (primary, secondary and tertiary) per depth (n=2 per site).
3. Depth in cm.
4. Soil moisture at saturation point.

SOIL BULK DENSITY (g/cc) BY DEPTH AND TREATMENT

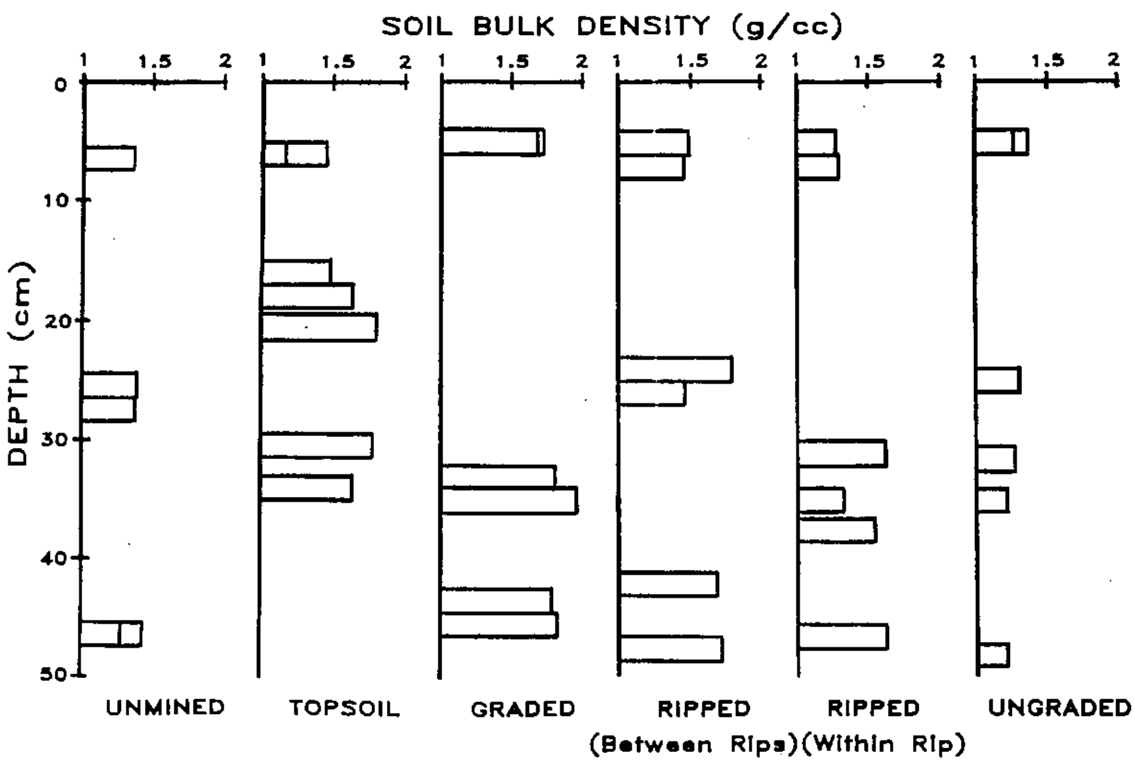


FIGURE 1.

Survival

After four growing seasons tree survival was the poorest on the topsoiled plots, followed by the unmined sites. Both sites each had less than 50% survival after the first year and less than 25% survival after two growing seasons. Survival exceeded 50% after four growing seasons on the ungraded plots, with 76% of the trees on the ripped-graded plots still alive in 1985 (Table 5).

Table 5. Black Walnut Survival on Five Sites After One, Two and Four Growing Seasons in Southern Illinois.

Site	July,1981[1] Survival (%)	Aug.,1982[2] Survival (%)	Apr.,1985[3] Survival (%)
Unmined	46	29	21
Topsoiled	41	22	15
Graded	75	68	43
Ripped	88	85	76
Ungraded	85	65	51

1. Survival after one growing season (Philo et al, 1982).
2. Survival after two growing seasons (Philo et al, 1982).
3. Survival after four growing seasons.

Root Growth

General Rooting Characteristics. Root growth was highly dependent upon minesoil physical characteristics and grading (Table 6). On the sites with lower bulk density and soil strength (i.e. unmined, ungraded, and ripped sites), root growth was profuse and extensive within the friable zones. On sites with higher minesoil bulk density (ie. graded and topsoiled), root growth and form were more limited and distorted.

Table 6. Black Walnut Rooting Characteristics on Five Sites in Southern Illinois.

Site	Average Depth	Maximum Depth	Average Lat. Extent.	Maximum Lat. Extent.
Unmined	52	80	91	142
Topsoil	25	33	62	80
Graded	45	75	82	160
Ripped	79	92	105	140
Ungraded	69	91	102	159

Unmined Site. Abundant root extension and some root mats composed of finely branched roots were confined predominantly to the more friable and less dense upper 20 cm of soil (the A and upper portion of the B horizons). The few sinkers which penetrated to 80 cm. became distorted and flattened with increasing depth. Crayfish burrows were detected below 30 cm. Numerous earthworms were seen in the topsoil.

Topsoiled Minesite. Very shallow rooting was characteristic of the topsoiled site. Rooting was almost completely confined to horizontal lateral extension in the disked and friable upper 20 cm of soil. The compacted, massive soil below 20 cm contained few roots, none of which were characterized by third order or higher branching. Many roots entering the compacted soil narrowed quickly to a blunt point and stopped growing. Lateral and vertical root extension was the poorest on this site. Earthworms were found in the upper 20 cm, but none were seen below 20 cm. (Figure 3).

Graded Minesite. The graded minesoil produced trees with sparse root systems and severely restricted root-mat development. Root growth generally followed planes of weakness between stones and soil, around stones or through fracture zones within the stones. Root development was shallow and lateral development was restricted especially at depths below 20 cm. Root branching beyond third order roots was limited throughout the minesoil profile. No earthworms were found, although ants were detected at 27 cm. (Figure 4).

Ripped-Graded Minesoil. Root growth was abundant within and predominantly oriented along the ripped zone. Extensive root branching and root-mat development was evident throughout the root system. Many roots penetrated downward through the ripped and fractured spoil beyond 90 cm depth and into the unripped, and thus mechanically unfractured spoil. Excavated root systems were larger, deeper, and more extensive on the ripped site than any other area measured. Although lateral root extension was somewhat confined to the fracture zone, a considerable number of long laterals penetrated the unripped zones, usually in the upper portion of the soil. Earthworms were occasionally present throughout the fractured minesoil. Standing water was found at 50 cm within the ripped zone, although the surrounding unfractured minesoil remained dry at this depth.(Figure 5).

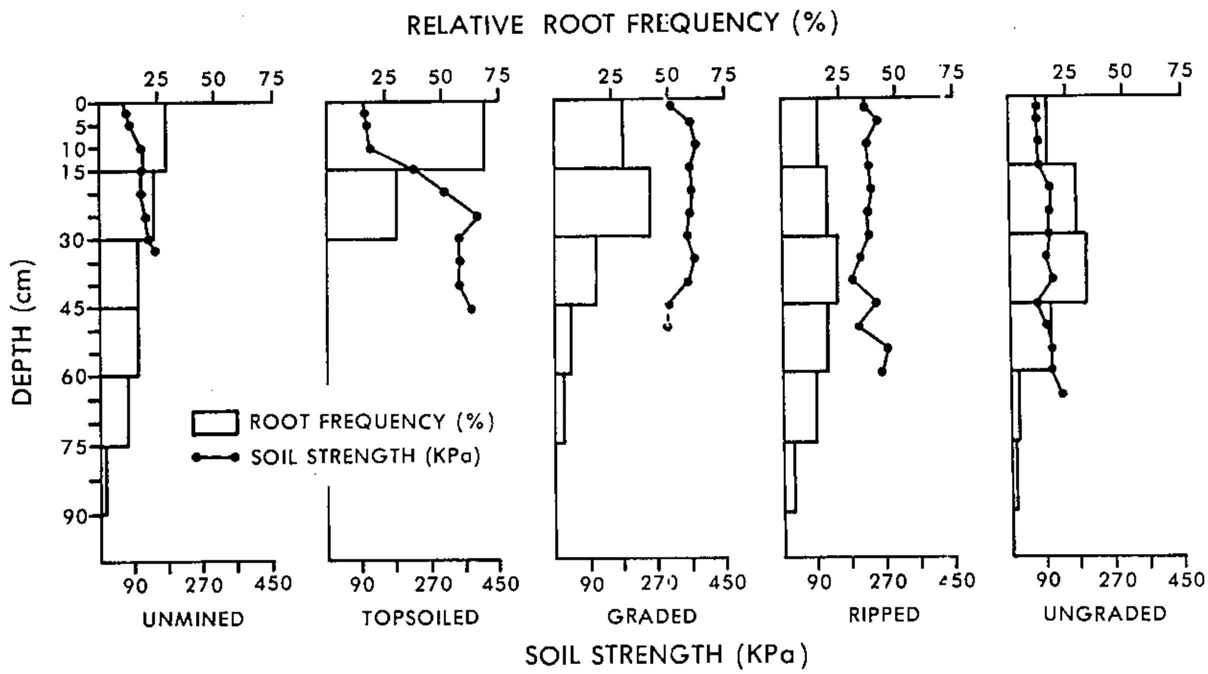
Ungraded Minesoil. Profuse root growth extended in all directions, both horizontally and vertically. Numerous root mats were found throughout the root system, often associated with bedding planes of weathered shale. Roots were rare or missing in the upper 20 cm of soil. Some roots extended to nearly a meter in depth. Roots encountering large stones grew around the obstruction in any direction. Numerous earthworms were found as deep as 70 cm.

Biomass and Root:Shoot Ratios

Total tree biomass per treatment generally paralleled the same trends exhibited by height, diameter and volume measurements (Table 4). A distinct difference existed in the root:shoot ratios of trees excavated from sites composed of fine textured silt loams (2:1) vs those growing on stony spoil (1:1).

Table 7. Excavated Tree Biomass and Root:Shoot Ratios From Five Sites in Southern Illinois.

Site	Average Root Biomass (g)	Average Shoot Biomass (g)	Root:Shoot Ratio
Unmined	115.5	65.7	1.8
Topsoil	14.4	6.6	2.2
Graded	76.5	79.3	1.0
Ripped	197.6	194.2	1.0
Ungraded	184.6	165.6	1.1



RELATIVE FREQUENCY OF ROOT (1°, 2°, 3°) OCCURRENCE
AND SOIL STRENGTH BY DEPTH AND TREATMENT

FIGURE 2.

ROOT EXCAVATION
TOPSOIL OVER GRADED SPOIL
SIDE VIEW

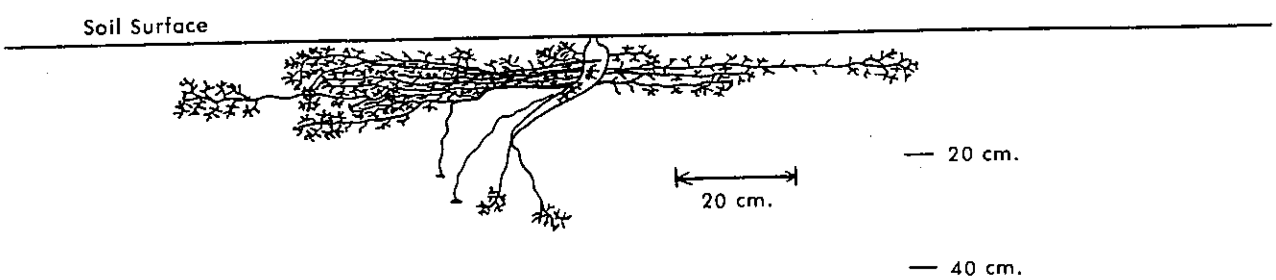


FIGURE 3.

Discussion

Walnut survival and growth after four growing seasons was highly dependent upon the rooting medium construction technique utilized. Heavy competition from other woody and herbaceous plants may have reduced walnut survival on the ungraded plots. Both unmined sites proved to be poor choices for establishing black walnut due to the presence of a dense B horizon, a high water table and, on one plot, excessive woody plant competition. Spaniol (1982) also encountered poor growth of walnut on unmined soils with a shallow A and dense B horizons in southern Illinois. Walnut grows best on deep, well-drained, moist soils (Schlesinger and Funk, 1977).

Analysis of soil bulk density, soil strength and root system form and extent clearly implicates minesoil compaction as a major factor reducing the survival, growth and vigor of trees in this study. The best height, diameter and root growth occurred on the lowest density and lowest strength minesoils. On sites subjected to grading but without ripping, tree growth and survival were strongly to severely inhibited by the compacted, massive minesoil structure. The current practice of replacing topsoil and B-horizon material with pan scrapers over graded spoil degrades soil physical properties and creates conditions which essentially preclude viable black walnut growth.

Bulk density values similar to those observed in this study have been reported by other researchers (Albrecht and Thompson, 1982; Bussler et al, 1983; Indorante et al, 1981; McRae, 1979; Peterson, Rogowski and Pennock, 1980; Smout, 1981) for graded minesoils and replaced topsoils on surface-mined lands. Soil bulk density values existing in compacted zones of agricultural soils are usually lower than those usually found in graded minesoils. Yet these lower bulk densities of agricultural soils have been repeatedly shown to severely impede root growth (Ahmad and Paul, 1978; Meredith and Patrick, 1961; Taylor and Gardner, 1963; Trouse, 1983; and Veilmeyer and Hendrickson, 1948)

Both shoot and root growth between sites followed similar trends, with the tallest, largest diameter trees having the deepest, most extensive root system. Minesoil compaction increased soil strength and reduced the number of macropores available for root penetration (Ammons, 1979), confined roots to the more droughty surface soils and reduced lateral root branching, all of which might have resulted in substantial reductions of water and nutrient availability during dry periods (Albrecht and Thompson, 1982; Yeck, 1983; Smout, 1981). Extensive stem dieback observed on the more compacted sites during dry years seems to support this hypothesis. Similarly poor survival and growth and extensive dieback were reported by Spaniol (1982) with black walnut planted on topsoiled and graded sites.

While soil bulk densities and soil strength for the graded and topsoiled plots were similar, root growth was distinctly more limited on the topsoiled sites. Root systems of trees on topsoiled sites were confined to the disked and friable upper 15 cm of soil above the compacted zone, while tree roots in the graded spoil penetrated to greater depths via planes of weakness between stones and compacted soil, or through highly weathered rocks contained within the soil matrix. Researchers have reported that increased soil coarse fragment content provide greater resistance to compactive forces (Ravina and Magier, 1984), reservoirs of free or low tension water (Ammons, 1979; Ashby et al, 1984), and increased soil water absorption, reduced evaporation and altered soil temperature (Lutz, 1968). In graded stony minesoils of high bulk density, Ammons (1979) also found that roots penetrated zones of weakness between stones or formed rootmats within the bedding planes of layered stones. Soils on the present compacted topsoiled plots lack these numerous planes of weakness, and therefore have relatively few macropores; consequently few roots could penetrate the fine-textured, poorly aerated, massive material. Other researchers have shown that roots cannot penetrate compacted, fine textured soils as readily as coarse textured soils (Albrecht and Thompson, 1982; Gerard et al, 1982; Jones, 1983; Yeck, 1983)

Trees on both the ungraded and ripped sites had a greater proportion of their root systems at greater depths, providing better access to deep soil water, greater resistance to droughty conditions and thus a lower incidence of dieback. Good to excellent long-term growth of trees planted on ungraded spoils has been documented for many years (Ashby and Kolar, 1977; Ashby et al, 1978; Chapman, 1967a and 1967b; Davidson, 1981; and Wade, Thompson and Vogel, 1985).

The ripping of compacted graded spoil clearly reduced graded minesoil bulk density and soil strength and created soil conditions favorable for root growth. The ripped plot had the highest tree survival, the best stem height and diameter growth and the best root growth of any plots examined in this study, even though many trees on this plot experienced heavy deer browsing. Soil moisture was observed during tree excavation to be much higher within the rip than immediately outside the ripped zone, as evidenced by standing water in the rip at 50 cm depth. Root growth was profuse at this depth within the rip. Bulk density and soil strength at the soil surface within the rip was considerably lower than surface bulk densities immediately outside the ripped zone, perhaps permitting increased infiltration of water into the rip.

Significant improvements in root growth are common on ripped sites. Characteristics such as wider spreading roots, improved root penetration, ubiquitous and deeper growing sinker roots, and a generally more profuse tree root system are usually reported (Jobling and Carnell, 1985; Berry and Marx, 1980; Hendrick, 1979; Francis, Bacon and Gordon, 1984; and Somerville, 1979). Roots of tree seedlings planted in the ripped zones of heavy clay soils and compacted stony silt loams have been observed to penetrate and strongly follow lines of fractured soil. Direct-seeded tree root systems followed the rip in a less pronounced manner (Berg, 1975; Guild, 1971; and Potter and Lamb, 1974). Similar root behavior was observed in this study.

Some researchers strongly advocate ripping as being essential to the success of planting on compacted surface mined sites. (Jobling and Carnell, 1985; Berry and Marx, 1980; Berry, 1985). Ripping each soil layer as it is deposited by pan scrapers is advocated by McRae (1979) to alleviate minesoil compaction.

ROOT EXCAVATION
GRADED CAST OVERBURDEN
SIDE VIEW

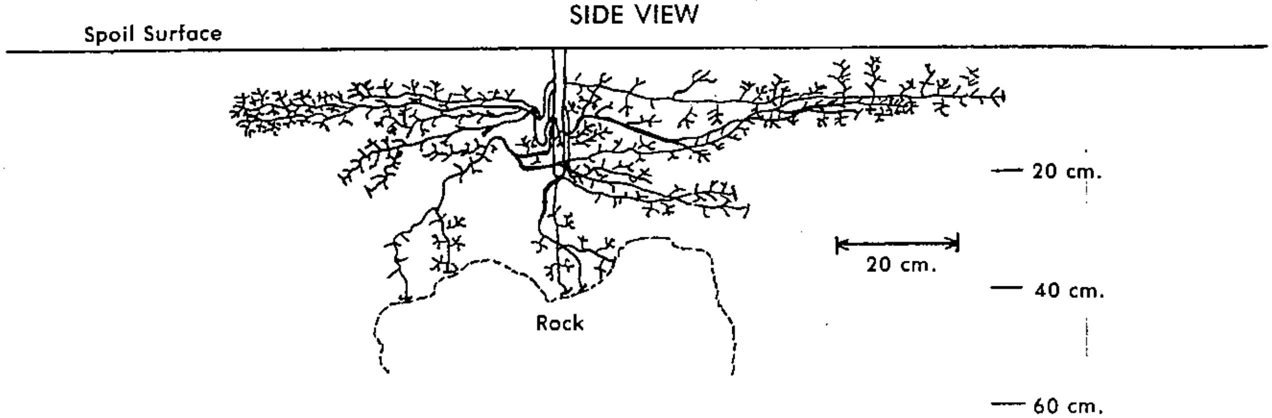


FIGURE 4.

ROOT EXCAVATION
RIPPED-GRADED CAST OVERBURDEN
SIDE VIEW

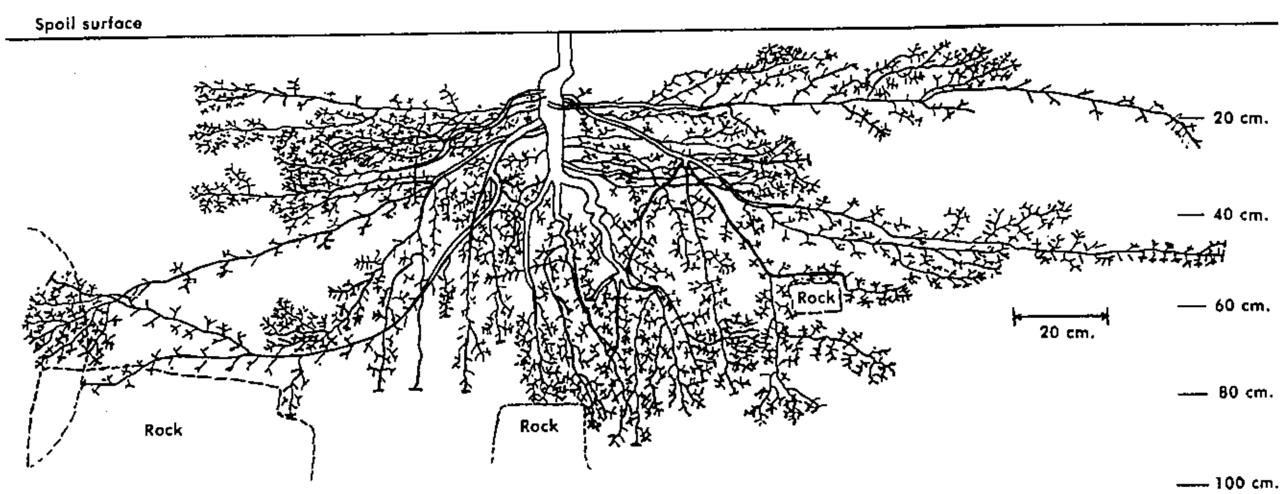


FIGURE 5.

Conclusions

Results indicate that the minesoil construction techniques examined in this study, which are representative of techniques commonly used in the midwest, cause severe minesoil compaction and do not create the proper soil conditions necessary for the survival and vigorous growth of black walnut. The current high traffic techniques used to replace topsoil created the poorest soil physical conditions (among the four mined sites measured in this study), conditions which proved to be inadequate for black walnut survival and growth. Ripping compacted spoil in this and other studies proved to be very effective in alleviating the negative impacts of minesoil compaction. When planning surface mine reclamation activities, ripping should be considered as a possible ameliorative technique when compaction of mined lands is unavoidable and trees are the desired final vegetative cover.

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