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ILLINOIS BARREN LONGWALL MINE WASTE, FIFTY YEARS AFTER ABANDONMENT

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ABSTRACT

The establishment of vegetation in mined areas where conditions have not been restored is often very difficult because of generally steep topography, poor soil conditions, and low moisture levels. The Third Vein Subdistrict of the Longwall District in north-central Illinois is no exception. Although some areas have partially revegetated, many of the mine waste piles remain barren after more than 50 years of abandonment.

During May through August of 1982 and during June of 1983, an inventory and extensive sampling of plant species were performed on four sites of the Longwall Mine District. The mine spoil material was analyzed for over 20 characteristics.

Major factors contributing to unfavorable conditions for plant growth in this area included (1) inadequate soil moisture, (2) high soil (surface) temperatures, (3) high soil acidity (low pH), (4) nutrient deficiencies, (5) high salt levels, (6) instability and erodibility of the mine material, and (7) heavy metal toxicity. The purpose of this study was to assess the feasibility of revegetating the mine waste areas by examining (1) plant species currently existing on the sites and (2) potential soil modifications that might improve conditions for the establishment of vegetation.

INTRODUCTION

Illinois has an abundance of coal, with approximately 65% of the state overlying coal-bearing strata (Nawrot et al., 1982). Prior to the passage of the Federal Surface Mining Control and Reclamation Act of 1977, however, adequate reclamation was frequently not accomplished and a large number of sites have never been reclaimed. One such area, the Longwall Mine District of north-central Illinois, contains over 100 refuse piles, the result of deep mining of Colchester (No. 2) coal between 1875 and 1930 (Bradford, 1983). The refuse material, locally called "gob," is unique because of the mining technique employed and because of the nature of the coal seam mined (Krapac and Smyth, 1982). The seam was about 1 m thick and a large amount of roof rock was also taken during the mining process. As a result, the refuse is composed of shales from the roof rock, along with coal scraps and clay cut out from under the coal. Since these refuse piles were flammable, they often burned, generally producing two types of material in addition to the unburned original gray refuse (Bradford, 1983). The partially heat-affected material is soft and reddish in color. The more completely burned refuse is hard (clinker) and brick-red in color.

The revegetation of most of the mine waste by natural processes, even after more than 50 years, is negligible. Most vegetative growth is confined to the lower slopes, especially the north-facing slopes (Nawrot et al., 1982; Iverson et al., 1983). Soil-water condition is often the most important factor in determining the success or failure of vegetation on mine spoils, but soil type, wind exposure, slope, surface material, surface temperature, nutrient status, and pH are also very important (Bramble and Ashley, 1955). Many edaphic factors affect plant establishment, particularly if water stress results (Croxton, 1928).

We report here on the vegetation of four mine waste sites that are similar in substrate and mining history but different in revegetation.

MATERIALS AND METHODS

The study sites are located in Illinois near the towns of Spring Valley, Standard, Ladd, and Wenona (Figure 1). Since the same coal seam has been mined across the entire region, the wastes were relatively homogenous. Compared to other mine wastes in Illinois, they are characterized by low potential acidity (Krapac and Smyth, 1982). Two of the sites (Spring Valley and Standard) are almost barren; two (Ladd and Wenona) have revegetated.

The mine at Spring Valley, which is located in Bureau County, opened in 1886 and closed in 1947. At one time this site had two mine piles. The larger was almost entirely removed years ago and the area it occupied has partially revegetated. The smaller remains and is essentially barren. Its steep slopes are severely eroded with extensive gullies. In an attempt to contain the mine waste, a ditch was dug to the south of the pile. More recently, removal of material from the eastern side of this pile has resulted in the loss of some adjacent vegetation.

The Standard site, located in Putnam County, had two large waste piles just outside a residential area. One was extensively burned, but both are extensively eroded and have affected neighboring farm fields and a nearby drainage ditch.

The Ladd site, in Bureau County, consists of two extensively burned mine waste piles that were barren and extensively eroded. One was planted with black locust (*Robinia pseudoacacia*) in the mid-1970s.

The Wenona site, in Marshall County, is confined on three sides by roads; a railroad borders the fourth. The top of the pile was removed by the Army Corps of Engineers in the 1950s, and the site was extensively modified for revegetation.

Black locust, honeysuckle (*Lonicera* sp.), and smooth brome (*Bromus inermis*) were planted.

Plant inventories at Ladd, Standard, and Spring Valley were conducted by dividing each pile into octants, thoroughly searching each octant, and recording all species encountered. The point-intercept method (States et al., 1978) was used to sample the extensively revegetated Wenona site. Woody vegetation was recorded along the transect; herbaceous vegetation was surveyed in rectangular plots (3 × 1 m) at predetermined intervals of 15 m. The inventories were carried out twice during May through August in 1982, and once during June of 1983. Specimens for all species encountered were pressed, dried, and deposited in the Illinois Natural History Survey herbarium. The nomenclature of Mohlenbrock (1975) and Hitchcock (1951) was followed.

The chemical and physical analysis of the mine wastes was conducted by dividing each of the four sites into quadrants. Eight samples were collected at a 10 cm depth from each quadrant between 2 to 3 m above the line of vegetation, a total of 32 samples per site. Soil water potential was determined from samples taken at a depth of 5 cm. The samples were ground to pass through 60-mesh.

Soil water potential was determined with a thermocouple psychrometer within 24 hours of sampling. Soil-moisture release curves were obtained by wetting the mine waste to saturation and allowing it to dry at room temperature. After a 24 hour equilibration period, percent moisture was determined by drying the waste at 100°C to constant weight.

Electrical conductance and pH measurements were made on waste material in suspension. Wastes were ground until they could pass through a 60-mesh screen and were then mixed 1:1 by weight with distilled water. Readings were taken after 24 hours (Sobek et al., 1978).

In order to determine the lime requirement of the mine wastes, the wastes were incubated with 0.04 N $Ca(OH)_2$ and a few drops of chloroform (Sobek et al., 1978). Lime requirements were then determined by adjusting the pH of the waste to pH 6.5.

Total nitrogen of the samples were determined by the Kjeldahl method (Bremner, 1965). Digestion was for 60 minutes with concentrated H_2SO_4, in the presence of the catalysts HgO and K_2SO_4. The ammonium ion produced by this oxidation was determined by making the solution strongly alkaline and distilling the ammonia into boric acid and back-titration with H_2SO_4.

Prior to cation analysis, samples were shaken on a rotary shaker for 1 hour and extracted with 0.05 N HCI and 0.05 N H_2SO_4 (Perkin-Elmer, 1976). Analysis was by direct-reading emission spectrophotometry with an inductively-coupled argon radio-frequency plasma torch source unit. Accuracy was determined by means of matrix-matched standards, which were run after every sixth sample. Limits of detection for the various elements were (mg/kg): Al 1.30, Be 0.05, B 0.10, Cd 0.18, Ca 0.18, Co 0.13, Cu 0.18, Fe 0.53, Mg 0.15, Mn 0.13, Ni, 0.38, P 2.05, K 2.90, Si 0.70, and Zn 0.28. Extraction of Hg was with $HCI:HNO_3$ (1:1, v/v) in the presence of $K_2S_2O_8$ and $KMnO_4$ (Jacobs and Keeney, 1974). Reduction of Hg to its vapor form, which was trapped as an amalgam on an activated silver wool plug, was with $SrCI_2$ (Long et al., 1973). The limit of detection was 5.0 ug/kg.

RESULTS AND DISCUSSION

Vegetation at the naturally revegetating sites was generally very sparse and was established primarily around the perimeters of the piles, on slumps, or in gullies. In total, 122 species were found on the four non-reclaimed study sites; richness at individual sites ranged from 39 to 71 species of vascular plants (Appendix). For comparison, Rastorfer and Wilhelm (1983) found 250 taxa of vascular plants on a reclaimed gob pile and surrounding areas in Macoupin County, Illinois. However, they included areas off the refuse area, such as abandoned pasture, woodlands, and pond margins. The relatively higher number of species found in the present study on the highly vegetated Wenona site was not unexpected, but the Standard site, which was nearly barren, had the next highest number (54). This site had been influenced greatly by the invasion of species from localities adjacent to the lower slopes of the pile. In general, vegetated areas had slopes that were less than 30° in steepness; steeper neighboring areas were generally barren. The steeper slopes tended to shed both water and seeds during periods of rapid runoff. These seeds settled on nearby flatter areas and germinated in less hostile environments.

Half of the average number of species found per octant at Spring Valley, Standard, and Ladd were "weedy" in nature; only 28 percent of the total species on the Wenona site were "weedy" (Table 1, Appendix). The major means of seed dispersion to the barren piles is generally via birds or wind (Ashby, 1964). The first invaders of mined areas or abandoned fields are primarily annual weeds (i.e., *Polygonum* sp., *Ambrosia artemisiifolia*, *A. trifida*, *Daucus carota*, and *Echinochloa crus-galli*) that are able to tolerate harsh conditions (McDougall, 1925; Quarterman, 1957; Leisman, 1957; Raynal and Bazzaz, 1973; Pickett and Bazzaz, 1978; Glenn-Lewin, 1979; Schafer and Nielsen, 1979; Iverson and Wali, 1982; Bares and Iverson, 1984).

The diversity of grasses were quite low at all sites, including the revegetated Wenona site (Table 1). Giant foxtail (*Setaria faberi*), a plant of open places, ditches, and waste ground, and Kentucky bluegrass (*Poa pratensis*), found in sparsely wooded areas, meadows, and open ground (Vogel, 1981), were among the more dominant grasses at the sites. Grasses made up roughly 20 percent of the species on the barren sites, but smaller proportions on the partially (Ladd) and completely vegetated (Wenona) sites (Table 1).

Herbaceous forbs consisted primarily of common ragweed (*Ambrosia artemisiifolia*), a native annual herb; white heath aster (*Aster pilosus*), often found in waste places and along railroads; and sour dock (*Rumex acetosella*), an introduced perennial often found on acidic soils (Wyman, 1971). Other common species included tall goldenrod (*Solidago canadensis*), dandelion (*Taraxacum officinale*), and horsetail milkweed (*Asclepias verticillata*) (Appendix). Forbs were the major component form on all sites (Table 1).

The dominant tree species, all native to Illinois, were box-elder (*Acer negundo*), a short-lived tree that grows well in poor, wet or dry soils and full sun; cottonwood (*Populus deltoides*) and large-toothed aspen (*Populus grandidentata*), often found in disturbed areas; black cherry (*Prunus serotina*), which volunteers frequently on mined sites; American elm (*Ulmus americana*), confined to more moist microenvironments, and slippery elm (*Ulmus rubra*), in moist to dry, slightly acidic areas.

Vegetation patterns by slope aspect for all sites except Wenona showed higher numbers of species for northern and eastern than for southern or western aspects (Table 2). Drier conditions due to higher solar irradiation and higher temperatures on southern and western slopes, conditions that were also found on North Dakota sites by Bares and Iverson (1984), probably contributed to the reduction in species numbers and cover. Species richness was five times greater on lower slope positions than on upper positions, a finding that relates to the availability of moisture as well as to the proximity of seed sources (Table 3).

The mine waste was generally of two types, a gray material and a red material. The gray material was the less altered, basically retained the original color, and consisted largely of shale, clay, and some pyritic material (Bradford, 1983). The red material resulted from oxidation of the gray waste, a process that also produced yellow to brown material. The gray waste was more acidic and saline than the red material (Table 4). Both types of waste had similar levels of Al, but the gray spoils, had higher levels of Fe and Mg. N and P levels were higher in the oxidized red waste.

Spoils at the barren sites had the lowest pH values, 3.3 at Spring Valley and 3.7 at Standard (Table 5). These acidities are usually toxic. The partially revegetated Ladd mine spoil had a pH of 3.8; the completely revegetated Wenona site had a pH of 5.0. Lime requirement and electrical conductance showed similar trends; spoils from the two barren sites had the highest lime requirement and conductance; the vegetated site at Wenona had the lowest (Table 5). The Al level at Spring Valley was twice (942 mg/kg that of the Wenona spoils (485). This level in combination with the high acidity at Spring Valley probably resulted in Al toxicity of sensitive plants (Byrnes et al., 1980). High Al levels also complicates susceptibility to water stress, since root growth in many soils will be restricted by the Al. Boron, Co, Fe, and Mg were in general also higher in spoils from the poorly vegetated mine sites; conversely Ca, Zn, K, and N were higher in the material from the revegetated site. Nitrogen was well below the minimum requirement for plant growth at the two barren and one partially vegetated sites (Hewitt and Smith, 1974). Phosphorus, another important plant nutrient, was low at all sites including the vegetated site at Wenona. Mercury, a very toxic heavy metal, was below 40 ppb at all sites.

Soil pH has a direct effect on the availability of nutrients. Acidity reduces the availability of P, Ca, Mg, K, and Mo, and increases the availability of Mn, Al, Fe and certain other heavy metals (Truog, 1951); the latter often leads to uptake by plants in toxic quantities (Jackson, 1967). Low soil pH also creates an unfavorable biotic environment.

The amount of moisture that is available to a plant depends on the relationship between soil water potential and plant water potential (Meidner and Sheriff, 1976). The percent of soil moisture is a direct measure of available water; however, it does not indicate the force required by the plant to remove that moisture from the soil. Soil water potential refers to this force, and Figure 2 shows the relationship between percent moisture content and its water potential for mine waste from the Standard site. To provide a point of reference, Figure 2 also shows the moisture-release curve for clay loam and sand. In general, the mine waste had a fair percentage of moisture but lost that water rapidly during drying, much as sand does; that is, the waste was quite "wet" after a rain but dried out rapidly.

Probably the most critical limiting factor for plants on the abandoned mine spoils was the unavailability of water (Figure 3). The barren site at Spring Valley had the lowest available moisture. Even though more than 15 cm of rain were recorded during the first 15 days of July, at the end of July the water potential had dropped below 4 mPa on the southeast aspect. The vegetated site (Wenona) was able to conserve its moisture; and its potential did not drop to 1.5 MPa (often considered the permanent wilting point) until the middle of September, even after several weeks of below normal rainfall. Further, the availability of moisture on the poorly vegetated sites fluctuated greatly during the growing season compared to the Wenona site (Figure 3). During dry periods seed germination and establishment of plants is difficult but the vegetation itself influences the water status of the mine waste. The effect of vegetation on the conservation of moisture is quite evident at the Wenona site (Table 1, Figure 3). Precipitation that does not penetrate the soil is lost through runoff. The most important factors generally influencing runoff are steepness of slope, texture of material, and lack of vegetation. We estimate that runoff can exceed 80 percent of rainfall interception during certain storm events since slopes often exceed 30° and vegetation cover is minimal on most piles.

Another limiting factor for plant establishment could be salinity. Wenona had relatively low electrical conductivity readings; Spring Valley, on the other hand, had higher values which could inhibit plant growth (Table 5, E.C. values from 1:1 soil/water suspension). Other intensely salinized localities were observed on several piles in zones surrounding seepage areas. In these cases, E.C. values on a 1:1 suspension exceeded 12 mmhos/cm, and even tolerant plant species would be unlikely to survive under this kind of stress (Bradshaw and Chadwick, 1980).

CONCLUSIONS

Natural revegetation of mine waste piles in the Longwall Mining District has been slow. Based on the present investigation, the factor that most severely limits plants is the unavailability of moisture. The maximum moisture loss of the mine waste occurred at low soil water potential similar to sand. During the summer months the mine spoils showed great moisture deficiency. In addition, the slopes of the piles were very steep; many exceeded 35°. Rainfall did not readily penetrate the material and most of the moisture presumably was lost as runoff. In addition, the steep slopes facilitated erosion, which tended to undercut and bury establishing seedlings and to flush seeds downslope. The establishment of vegetation by natural means was, therefore, difficult.

A reduction in slope steepness would permit the penetration of rainfall and reduce erosion. Water harvesting and erosion-stabilizing structures would also be beneficial. Since the mine material had a poor structure, both water-holding capacity and cation exchange capacity could be improved through the addition of such soil amendments as sewage sludge or other mulching products. Greenhouse studies reported earlier (Iverson et al., 1983) showed substantial vegetation response to the addition of sewage sludge to mine waste.

Even though the pH of the mine waste was acidic, the lime requirement was quite low and the addition of lime might ameliorate acid conditions. Toxic materials, including heavy metals, did not present a major problem. Only elevated levels of Al and Zn were found; these elements can be tolerated by many plant species, especially when the soil pH is nearly neutral. Salinity of the mine waste was at moderate levels and should in general not create special problems, with the exception of a few areas surrounding seeps. The mine waste was low in plant nutrients, and the application of fertilizers is required for adequate plant growth. The addition of organic matter would also improve the condition of the soil. To achieve minimum reclamation, the application of lime and fertilizer is necessary. The area must also be seeded with an appropriate species mix and mulched to conserve moisture during the critical period of plant establishment. A more extensive approach would include reduction of slope steepness, the installation of water-harvesting or water-supplying mechanisms, and the addition of organic material.

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Table 1. Vegetation characteristics of four abandoned mine sites. Mean of eight replicates (the eight cardinal directions of the pile), including both upper and lower positions of the slope.

	Average number of species per quadrant location				
	Spring Valley	Standard	Ladd	Wenona	P
Total species	4.6^{a}	16.3^{b}	13.1^{b}	34.4^{c}	≤ 0.001
Woody species	1.8^{a}	5.0^{a}	5.5^{a}	13.1^{b}	≤ 0.001
Forbs	1.9^{a}	9.0^{b}	6.5^{b}	18.9^{c}	≤ 0.001
Grasses	0.9^{a}	2.3^{bc}	1.1^{bc}	2.4^{c}	≤ 0.001
Weedy species	1.9^{a}	8.0^{bc}	5.8^{b}	9.8^{c}	≤ 0.001

Values followed by the same letters within a row do not differ significantly using Tukey's HSD test.

Table 2. Vegetation characteristics by aspect for Spring Valley, Standard, and Ladd sites. The Wenona site was excluded from this analysis because it was completely vegetated. Each number represents a mean of nine replicates.

	Average number of species per aspect								
	N	NE	E	SE	S	SW	W	NW	P
Total species	10.2^{ab}	8.9^{ab}	11.8^{a}	8.3^{ab}	7.9^{ab}	5.6^{ab}	5.9^{ab}	4.8^{b}	≤ 0.05
Woody species	3.8^{ab}	3.3^{ab}	5.3^{a}	2.7^{ab}	3.2^{ab}	1.6^{b}	1.3^{b}	1.2^{b}	≤ 0.01
Forbs	4.7^{a}	4.6^{a}	4.1^{a}	3.7^{a}	4.1^{a}	2.4^{a}	3.7^{a}	2.6^{a}	NS
Grasses	1.8^{a}	1.0^{a}	2.3^{a}	2.0^{a}	1.2^{a}	1.6^{a}	0.9^{a}	1.0^{a}	NS
Weedy species	4.3^{a}	3.9^{a}	4.9^{a}	4.6^{a}	4.1^{a}	2.9^{a}	3.0^{a}	2.2^{a}	≤ 0.05

Values followed by the same letters within a row do not vary significantly using Tukey's HSD test.

Table 3. Vegetation characteristics by position for Spring Valley, Standard, and Ladd sites. The Wenona site was excluded from this analysis because it was completely vegetated. Each number represents a mean of 24 replicates.

	Average number of species per position		
	Upper	Lower	P
Total species	2.1	10.6	≤ 0.001
Woody species	0.7	3.7	≤ 0.001
Forbs	0.8	4.6	≤ 0.001
Grasses	0.6	2.4	≤ 0.01
Weedy species	1.0	4.9	≤ 0.001

Values within each row differ significantly using Tukey's HSD test.

Table 4. Chemical characteristics of red and gray mine waste.

	Red (n = 15)	Gray (n = 17)	P
pH	4.44	3.50	≤0.05
E.C., mmhos/cm	0.30	2.04	≤0.01
Al, mg/kg	626.0	725.0	NS
Be, mg/kg	0.08	0.09	NS
B, mg/kg	0.52	0.60	NS
Cd, mg/kg	0.28	0.14	≤0.001
Ca, mg/kg	1125.0	1129.0	NS
Co, mg/kg	0.29	0.87	≤0.001
Cu, mg/kg	0.53	1.15	≤0.001
Fe, mg/kg	25.7	104.1	≤0.05
Hg, ug/kg	29.1	38.8	NS
Mg, mg/kg	180.3	460.1	≤0.001
Mn, mg/kg	22.4	33.4	NS
N, mg/kg	1448.0	890.0	≤0.05
Ni, mg/kg	1.06	2.66	≤0.001
P, mg/kg	4.86	2.51	NS
K, mg/kg	1361.0	361.0	≤0.001
Si, mg/kg	103.4	41.1	≤0.001
Zn, mg/kg	9.9	6.7	NS

Table 5. Chemical characteristics of spoils from the four mine sites. Each number represents a mean of eight replicates, except for lime requirement, which is based on four replicates.

	Spring Valley	Standard	Ladd	Wenona	P
pH	3.33^{a}	3.70^{a}	3.80^{a}	4.95^{b}	≤ 0.001
Lime requirement (tons/1,000 tons)	8.65	7.13	7.58	4.68	NS
E.C., mmhos/cm	2.40^{a}	1.53^{ab}	0.85^{bc}	0.13^{c}	≤ 0.001
Al, mg/kg	942.0^{a}	531.0^{b}	756.0^{ab}	485.0^{b}	≤ 0.001
Be, mg/kg	0.07	0.06	0.10	0.11	NS
B, mg/kg	0.67	0.69^{a}	0.63^{a}	0.24^{b}	≤ 0.01
Cd, mg/kg	0.14^{a}	0.12^{a}	0.15^{a}	0.40^{b}	≤ 0.001
Ca, mg/kg	1013.0	1202.0	787.0	1507.0	NS
Co, mg/kg	1.24^{a}	0.49^{b}	0.33^{b}	0.34^{b}	≤ 0.001
Cu, mg/kg	1.28^{a}	0.67^{b}	1.17^{a}	0.32^{c}	≤ 0.001
Fe, mg/kg	73.9^{ab}	132.6^{a}	56.9^{ab}	5.9^{b}	NS
Hg, ug/kg	33.5	37.8	29.7	36.2	NS
Mg, mg/kg	574.0^{a}	326.0^{b}	151.0^{b}	264.0^{b}	≤ 0.001
Mn, mg/kg	41.6^{a}	23.5^{ab}	14.3^{b}	33.6^{ab}	≤ 0.05
N, mg/kg	905.0^{a}	597.0^{a}	952.0^{a}	2360.0^{b}	≤ 0.001
Ni, mg/kg	3.4^{a}	1.7^{b}	1.0^{b}	1.5^{b}	≤ 0.001
P, mg/kg	0.8	4.0	7.4	2.2	NS
K, mg/kg	418.0^{a}	446.0^{a}	874.0^{a}	1581.0^{b}	≤ 0.001
Si, mg/kg	43.7^{a}	57.3^{ab}	73.2^{b}	106.9^{c}	≤ 0.001
Zn, mg/kg	4.8^{a}	3.5^{a}	3.7^{a}	20.9^{b}	≤ 0.001

Values followed by the same letters within a row do not vary significantly using Tukey's HSD test.

APPENDIX

Species List of Vascular Plants for the Study Sites

Species	Spring Valley	Standard	Ladd	Wenona
Acer negundo L.	+	+	+	+
A. saccharinum L.	+	+	+	+
Achillea millefolium L.		+		
Agropyron repens (L.) Beauv.	+	+		
Agrostis alba L.		+		
A. hyemalis (Walt.) B.S.A.		+		
Ailanthus altissima (Mill.) Swingle			+	+
Ambrosia artemisiifolia L.	+	+	+	+
A. trifida L.				+
Antennaria plantaginifolia (L.) Richards		+		
Arctium minus (Hill) Bernh.		+		+
Asclepias syriaca L.	+	+	+	+
A. verticillata L.	+	+	+	+
Aster pilosus Willd.	+	+	+	+
Atriplex sp.	+			
Atriplex patula L.		+		+
Bidens frondosa L.			+	
B. vulgata Greene				+
Botrychium dissectum Spreng.		+		
Bromus commutatus Schrad.				+
B. inermis Leyss.				+
Catalpa bignonioides Walt.				+
Celtis occidentalis L.				+
Chenopodium album L.				+
Cichorium intybus L.	+	+		
Cirsium discolor (Muhl.) Spreng.				+
C. vulgare (Savi) Tenore				+
Commelina communis L.				+
Convolvulus arvensis L.		+	+	+
Dactylis glomerata L.				+
Danthonia spicata (L.) Beaur.	+			
Daucus carota L.	+	+		
Digitaria Sanguinalis (L.) Scop.	+			
Echinochloa pungens (Poir.) Rydb.	+		+	
Elymus canadensis L.	+	+		
Erechtites hieracifolia (L.) Raf.			+	+
Eupatorium altissimum L.	+		+	+
E. rugosum Houtt.			+	+
Euphorbia spp.				+
Euphorbia helioscopia L.				+
Fragaria virginiana Duch.	+			+
Fraxinus americana L.	+			+

F. pennsylvanica var. *subintegerrima* (Vahl) Fern.			+	+
Geum laciniatum Murr.				+
Hackelia virginiana (L.) I. M. Johnston				+
Helianthus annuus L.		+		
Hordeum jubatum L.	+	+		
Ipomoea batatas (L.) Lam.	+			
Juncus tenuis Willd.		+		
Juniperus virginiana L.		+		
Lactuca spp.		+		
L. floridana (L.) Gaertn.				+
L. serriola L.	+			+
Lonicera spp.		+		+
Maclura pomifera (Raf.) Schneider				+
Malus pumila Mill.		+		
Medicago lupulina L.		+		
Melilotus alba Desr.		+		+
M. officinalis (L.) Lam.	+	+		
Mentha arvensis L.				+
Mirabilis nyctaginea (Michx.) MacM.				+
Morus rubra L.		+	+	+
Nepeta cataria L.			+	+
Oenothera biennis L.				+
Oxalis stricta L.				+
Panicum capillare L.				+
P. dichotomiflorum Michx.			+	+
P. virgatum L.	+			
Parietaria pennsylvanica Muhl.				+
Parthenocissus quinquefolia (L.) Planch.		+		+
Phleum pratense L.		+		
Physalis subglabrata Mack. & Bush			+	
Phytolacca americana L.				+
Plantago lanceolata L.	+			
Poa pratensis L.	+	+	+	+
Polygonum sp.				+
Polygonum aviculare L.	+			+
P. lapathifolium L.			+	
P. pensylvanicum L.				+
P. pensylvanicum var. *laevigatum* Fern.	+	+		
Populus deltoides Marsh.		+	+	
P. grandidentata Michx.		+	+	
Potentilla sp.			+	
Prenanthes alba L.	+			
Prunus serotina Ehrh.	+	+	+	+
Pyrus communis L.		+		
Quercus macrocarpa Michx.	+			
Q. velutina Lam.	+			
Ribes cynosbati L.				+

R. missouriense Nutt.		+		
Robinia pseudoacacia L.			+	+
Rosa carolina L.		+		
R. multiflora Thunb.		+	+	+
Rubus spp.		+	+	+
Rumex acetosella L.	+	+	+	
R. altissimus Wood		+		
R. crispus L.			+	
Setaria faberi Herrm.	+	+	+	+
Silene cucubalus Wibel			+	+
Solanum americanum Mill.	+		+	+
S. dulcamara L.				+
Solidago canadensis L.	+	+	+	+
S. graminifolia (L.) Salisb.		+		
S. juncea Ait.	+			
S. nemoralis Ait.	+	+		
S. rigida L.				+
S. speciosa Nutt.	+			
Sonchus asper (L.) Hill				+
Symphoricarpos orbiculatus Moench.		+		
Taraxacum officinale Wiggers	+		+	+
Toxicodendron radicans (L.) Kunze	+	+		
Tragopogon dubius Scop.			+	
Trifolium pratense L.		+		+
Ulmus americana L.	+	+	+	
U. pumila L.		+		+
U. rubra Muhl.	+		+	+
Verbena bracteata Lag. & Rodr.	+			
V. urticifolia L.			+	+
Viburnum opulus L.				+
Viola spp.				+
Vitis riparia Michx.		+	+	+
Xanthium strumarium var. *canadensis* (Mill.) Torr. & Gray		+		
Totals (122 species on all sites)	42	54	39	71

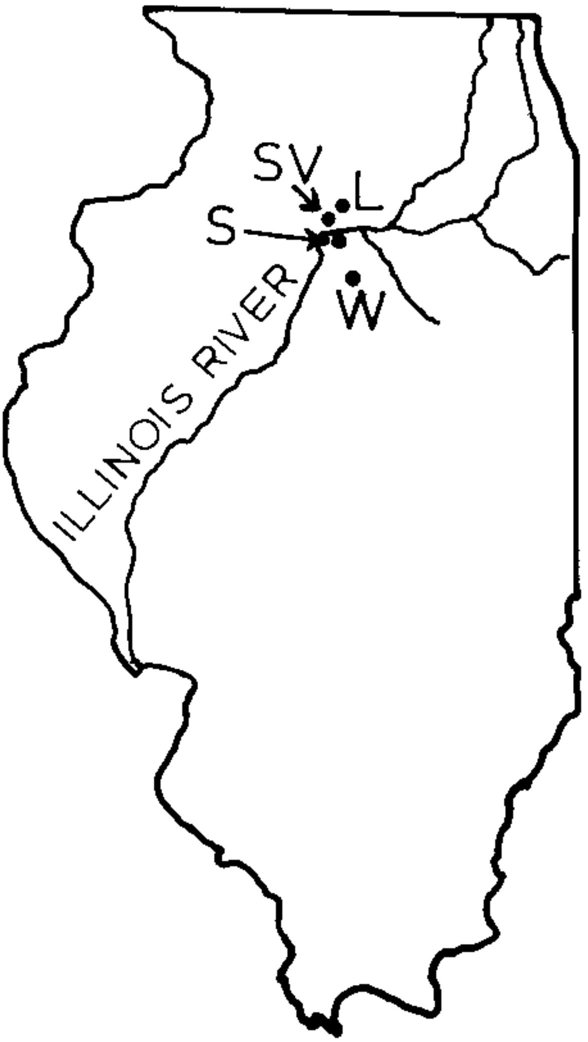

Fig. 1. Location of Illinois study sites: Spring Valley (SV), Standard (S), Ladd (L), and Wenona (W).

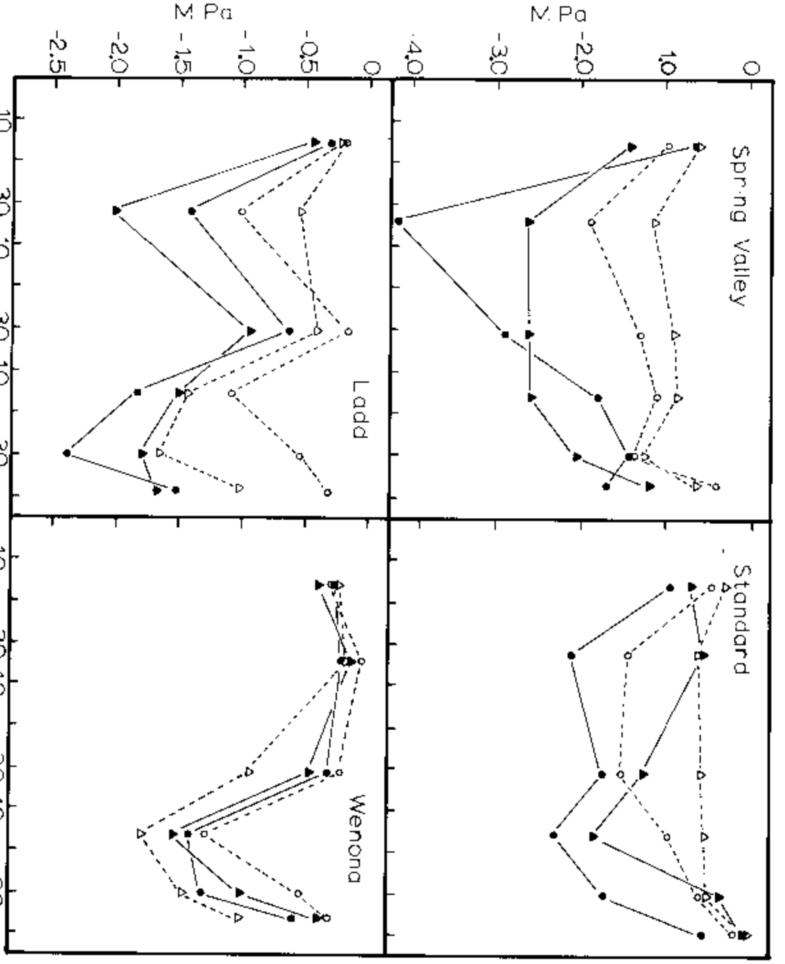

Fig. 2. Moisture release curve of mine waste from the Standard site. For comparison, curves of typical sand and clay loam are also given.

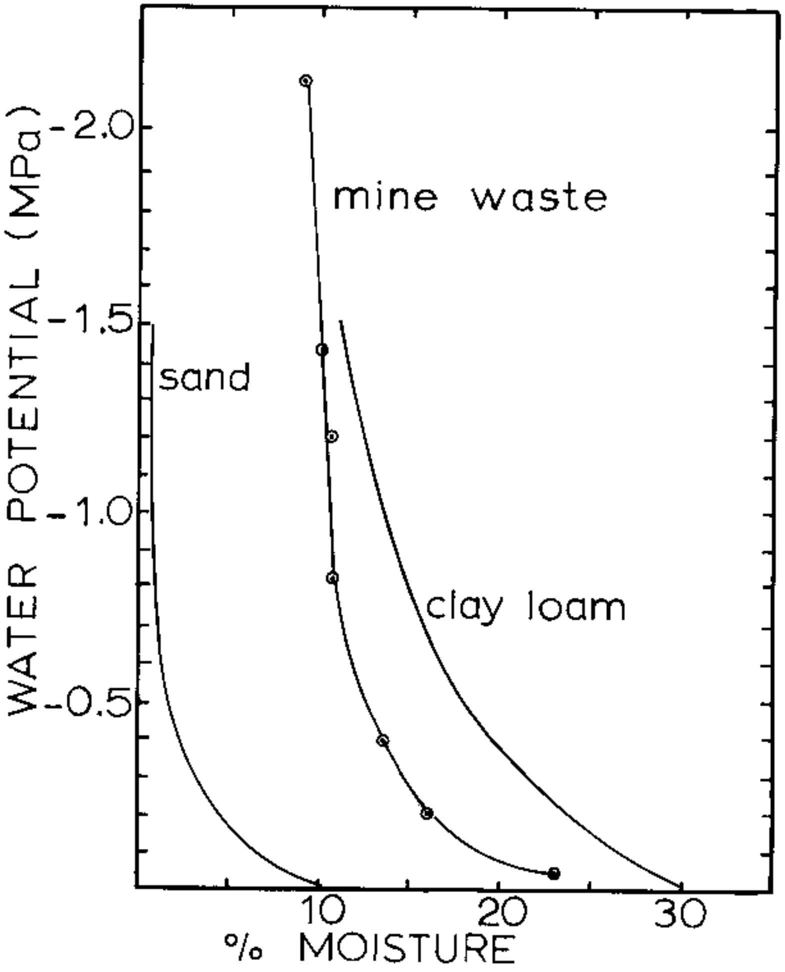

Fig. 3. Soil water potential of the four mine sites from 16 July through 5 October 1982. Slope aspect southwest (▲), southeast (●), northwest (△), and northeast (○).