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Vice Provost and Dean of the Graduate School

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To the Graduate Council:

I am submitting herewith a dissertation written by Donald Wesley Ott entitled "Comparative Analyses of Adjacent Vegetated and Bare Strip Mine Spoils." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology.

Frank W. Woods

Frank W. Woods, Major Professor

We have read this dissertation
and recommend its acceptance:

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H. R. DeSelm

Accepted for the Council:

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COMPARATIVE ANALYSES OF ADJACENT VEGETATED AND BARE STRIP MINE SPOILS

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Donald Wesley Ott
March 1978

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ABSTRACT

A study was undertaken on a strip mine in Campbell County, Tennessee to determine what site characteristics permit vegetation establishment and growth on some spoils while preventing it on adjacent ones. Fifty plots were established and spoil samples, 300 each on vegetated and nonvegetated spoils, were taken at depths of 0-5 cm, 10-15 cm, and 25-30 cm to be analyzed for pH, Ca, Mg, K, P, Fe, Al, Mn, Zn, compaction, moisture content, surface temperature, and color. It was found that K, P, Mn, and Zn were in the deficiency range of most plants. The solubility of aluminum and iron increases with low pH, thus increasing the probability of their interactions with and decreased availability of other plant nutrients. Applications of dolomitic limestone to some plots increased pH and may have decreased the availability of some nutrients such as iron.

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I. INTRODUCTION

The problems facing a growing industrialized nation are numerous. One basic requirement for expansion on all horizons is energy. Many hydroelectric and steam generating plants were established by the close of World War II, but it was apparent that vast amounts of energy, above and beyond that which could be produced by existing facilities, would soon be needed. Consequently, the first nuclear power plants were established in the mid 1960's. Public awareness of possible hazards in the development and production of nuclear power has increased required regulations and therefore the time schedule necessary for "in line" power production. Energy needs and demands are exceeding the production of power at an ever-increasing rate.

Coal mining is necessary for the maintenance of our present standard of living, for many workers in all fields of endeavor rely on coal-derived energy and the products it produces. It is needed for their livelihood as well as for personal satisfaction. Legal constraints can minimize damage, protect wilderness areas, and preserve our environment, but they will not and cannot stop our country's need for energy.

Surface mining results in the displacement of soil and rock strata. The term "strip mining" is generally associated with the surface removal of coal and in the lay person's mind, the ecological instability which can result (Boyer 1974).

The most prominent type of strip mining carried out in the eastern United States has been termed "contour stripping" or "contour surface mining," and is accomplished by the removal of overburden and mining of a coal seam in steep or mountainous terrain (Boyer 1974). Until recently, this type of mining resulted in pushing the overburden downslope to create a bench so that equipment could be operated with efficiency (Figure 1). Once the coal was removed, little was done to rehabilitate the site to prevent erosion and potential acid drainage.

Damage to the environment due to strip mining since 1945 has involved some 1.6 million hectares of land, of which only 810 thousand hectares have been revegetated. Unclaimed acreage includes over 81 thousand hectares in "orphan banks" for which no mine operator can be contacted for reclamation. In addition, strip mining of coal is continuing at an increasing rate, disturbing 1,620 to 2,025 hectares of land per week (Anonymous 1973). It is, therefore, necessary to rehabilitate lands that have been mined--to heal the environmental damages that have occurred in procuring fossil fuels and other raw materials. This problem must be attacked from an ecologically sound point of view.

Public awareness resulting from concerned citizens and ecologically oriented organizations has brought about changes in reclamation practices and legislative action to aid the rehabilitation of these sites. Numerous studies have been undertaken to describe and prescribe courses of action for controlling impending damage to the environment.

Strip mine areas are not natural "ecosystems." Very little is known concerning the environmental conditions which prevail on such sites, and it is not surprising that so little data have been utilized in their revegetation. Necessarily, any solution will be partially empirical, but based insofar as possible on a knowledge and understanding of spoil and microclimatic parameters characteristic of strip mine sites.

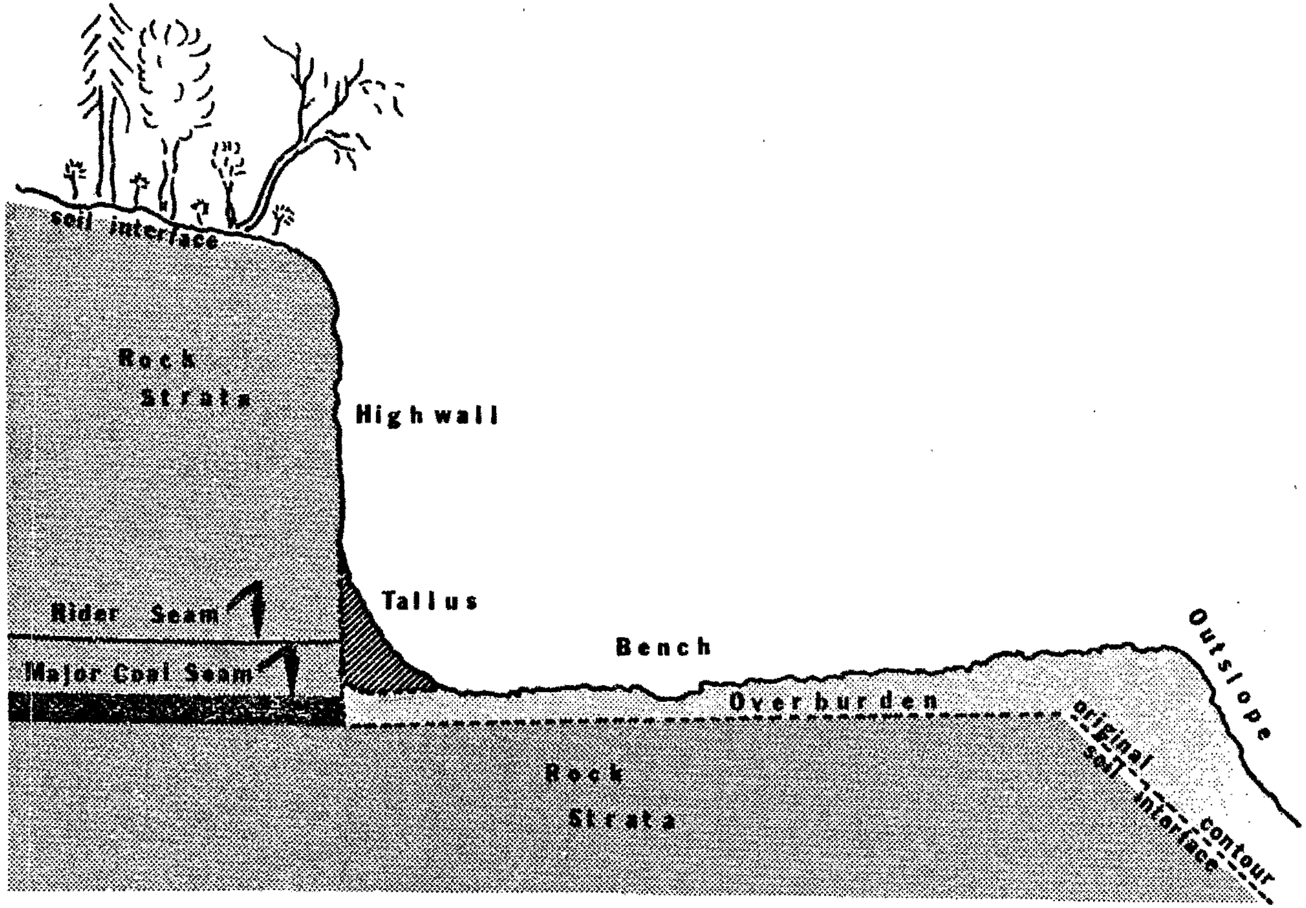

Figure 1. Cross-section of typical contour strip mine.

The objective of this study was to make microclimatic and spoil analyses for determining conditions prevailing on selected strip mined spoil banks which permit the invasion and establishment of certain plant species on some microsites while excluding them from others. Suggestions are offered as to how these growth limitations may be overcome so that natural succession can be reestablished.

II. THE STUDY AREA

The Ollis Creek strip mine, in Campbell County, Tennessee, was the study area. It is located N 36° 22' 30" longitude on the edge of the Cumberland escarpment. It is northwest of and parallel to Cumberland Mountain and is in both the Jacksboro and Ivydell Quadrangles (USGS nos. AMS 4156 I SW-Series V841 and AMS 4156 I NW-Series V853, respectively). The strip mine interrupts the drainage of the Ollis Creek Watershed which originates at the Tennessee Valley Divide (on Little Cumberland and Short Mountains). Tributaries to Ollis Creek which are also interrupted are Thompson Creek, Yellow Branch, and Laurel Branch.

The area is characterized by faulting due to the rise of the Cumberland Escarpment which delineates the Plateau from the Ridge and Valley province of Tennessee (Fenneman 1938). As a result, the Kent (or Coal Creek) coal seam, which is the primary object of mining, varies from 427 to 518 meters in elevation. Rock strata comprising most of the overburden is a shale interval of the Slatestone Group (Wilson, et al. 1956), sometimes called the Briceville Formation (Glenn 1925). The Kent seam is near the bottom of this group of the Pennsylvanian formation, and associated with it is a formation of the same period known as "Stephens Sandstone." This sandstone is distributed in both massive and thin phases throughout the entire extent of the Kent seam. An example of the massive phase can be found in area 3 (Figure 2) where it overlies the Kent seam. In contrast with other areas, the sandstone is seemingly nonexistent because it underlies the mined seam,

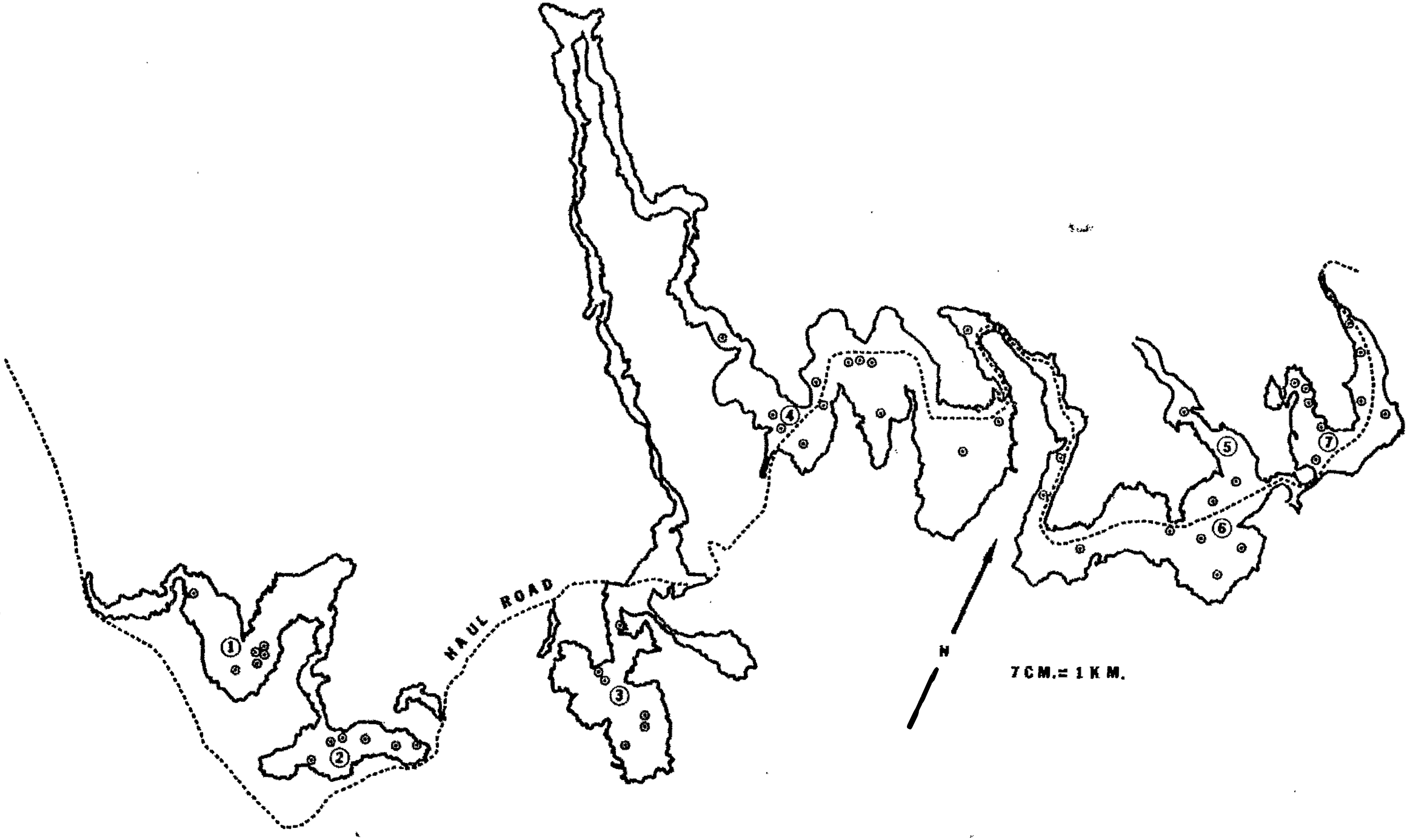

Figure 2. Strip mine study site showing areas (numbered) and plot locations (solid dots), Ollis Creek, Campbell County, Tennessee.

is found in extremely thin phases, or it is discontinuous (Wilson, et al. 1956). These formations are the result of erosion and siltation of brackish or fresh water swamp areas during the Pennsylvanian period. Impressions of fern leaves and other vegetation are prevalent in the shale structures immediately overlying the Kent seam, while casts of roots, such as Lepidodendron and Sigillaria occur in the underclays beneath the seam (Glenn 1925). Naiadites, a brackish or fresh water invertebrate species of the Pennsylvanian period occur in the blue-black (Slatestone) shales over the coal at Ollis Creek (Glenn 1925).

The Kent seam is the most widespread mined seam and is, therefore, the most economically important coal seam in Campbell County (Luther 1959). Coal has been mined in this area for more than 90 years, commercially for over 50 years. The seam at the Ollis Creek site, excluding partings, has a thickness from .76 to 1.27 meters with reserves in the Ivydell Quadrangle totaling 91,688,889 metric tons as of 1958 (Englund 1958).

The mine site has a rolling topography and was contour stripped. Consequently, overburden varies greatly in thickness and expanse from the highwall (Figure 1, page 3). The coal seam and its rider (a "stray" coal seam usually above and divided from the main coal bed by rock, shale, or other material) mined at Ollis Creek are generally known as the Coal Creek seam (Swingle 1960); peculiar to this area is the Kent seam (Wilson, et al. 1956).

Ollis Creek was strip mined in 1958 and abandoned without rehabilitation. The study area was again mined between April 1970 and

April 1972, disturbing 163 hectares for the removal of 542,767 metric tons of coal. The mining operation incorporated both stripping and augering where practicable. Standard reclamation technologies at that time included liming, fertilization, seeding herbaceous species, and the planting of both coniferous and deciduous cover. Many small water impoundments were left, particularly at the bases of highwalls.

The area is characterized by rolling to hilly topography and is covered by a thin soil, Muskingum, steep to hilly phase (Rudolph, et al. 1953). Recent studies identify the soils of the general area as being within the Muskingum-Gilpin-Jefferson soil association. Preliminary descriptions indicate that the Muskingum and Gilpin are thin soils from 46 to 91 cm to shale bedrock. They are formed on relatively steep slopes with grades of 20 to 60% (Personal communication, M. E. Springer 1977).

The mined area is within the boundaries characterized as being the Mixed Mesophytic Forest region (Braun 1950). The forests of the area were mixed hardwood forests of Quercus (oak), Carya (hickory), Castanea (chestnut) on intermediate sites, Tilia (basswood), Liriodendron (yellow poplar), and others on mesic slopes, and Pinus echinata Mill. (shortleaf pine) and Pinus virginiana Mill. (Virginia pine) on more xeric sites (Rudolph, et al. 1953). With the advent of underground mining, railway systems were constructed in the area. Local timber was used for constructing this system and for shoring in the mines (Glenn 1925). The locality is, since mining, predominately Quercus and Carya with some Tsuga (hemlock). Understory vegetation is sparse and includes

Kalmia (mountain laurel), *Vaccinium* (blueberry), and *Gaylussica* (huckleberry).

Virginia pine (*Pinus virginiana* Mill.) was the only volunteer tree species encroaching on the mined area but was sparse and irregular in distribution. Pokeweed (*Phytolacca americana* L.) occurred consistently throughout the area. Greenbrier (*Smilax bona-nox* L.), the frost aster (*Aster pilosus* Willd.), and Queen Anne's Lace (*Daucus carota* L.) occurred sporadically in the more mesic sites; cattail (*Typha latifolia* L.), sedges (*Carex* spp. and *Cyperus* spp.), and smartweed (*Polygonum pensylvanicum* L.) occur in varying abundance on hydric sites around water impoundments.

Planted tree species include locust (*Robinia pseudoacacia* L.), autumn olive (*Elaeagnus umbellata* Thumb.), and pitch pine (*Pinus rigida* Mill.). The wide variation in survival and growth rates was dramatic. Survival of seeded herbaceous species was greatest in the case of sericea lespedeza [*Lespedeza cuneata* (Dumont) G. Don] and Kentucky 31 fescue (*Festuca arundenacea* Schreb.). They vary from depauperate, isolated plants to lush, dense stands four to five feet tall.

Other introduced species found in varying abundance included weeping love grass [*Eragrostic curvula* (Schrad.) Nees.] and Korean lespedeza (*Lespedeza stipulacea* Maxim.). Introduced species far exceed the volunteers in numbers.

Estimates have been made that only 41 of the 163 hectares comprising the mine site have been satisfactorily vegetated. An estimate of vegetative cover based on 50 plots yielded an average of 26.1% (range of 0-95%, Table 1). Sharp and clear

TABLE 1. ESTIMATED PERCENTAGE OF VEGETATION OF SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Plot	Observations				Predominant Species
	1	2	3	Average	
no.	%	%	%	%	
1	15	45	65	41.67	*Festuca arundinacea* Schreb.
2	75	95	55	75.00	*Lespedeza cuneata* (Dumont) G. Don
3	85	95	85	88.33	*Lespedeza cuneata* (Dumont) G. Don
4	95	85	35	71.67	*Lespedeza cuneata* (Dumont) G. Don
5	65	45	55	55.00	*Lespedeza cuneata* (Dumont) G. Don
6	95	85	65	81.67	*Lespedeza cuneata* (Dumont) G. Don
7	65	75	85	75.00	*Lespedeza cuneata* (Dumont) G. Don
8	65	35	55	51.67	*Festuca arundinacea* Schreb.
9	65	75	75	71.67	*Festuca arundinacea* Schreb.
10	15	55	85	51.67	*Lespedeza cuneata* (Dumont) G. Don
11	55	85	55	65.00	*Lespedeza cuneata* (Dumont) G. Don
12	95	75	55	75.00	*Festuca arundinacea* Schreb.
13	95	95	95	95.00	*Trifolium agrarium* L.
14	25	55	45	41.67	*Festuca arundinacea* Schreb.
15	15	5	5	8.33	*Festuca arundinacea* Schreb.
16	25	45	55	41.67	*Festuca arundinacea* Schreb.
17	5	15	5	8.33	*Festuca arundinacea* Schreb.
18	5	5	5	5.00	*Festuca arundinacea* Schreb.
19	45	45	55	48.33	*Festuca arundinacea* Schreb.
20	85	85	95	88.33	*Lespedeza cuneata* (Dumont) G. Don
21	45	35	45	41.67	*Lespedeza cuneata* (Dumont) G. Don
22	55	45	55	51.67	*Secale* spp.
23	25	25	25	25.00	*Lespedeza cuneata* (Dumont) G. Don
24	25	75	85	61.67	*Festuca arundinacea* Schreb.
25	95	95	95	95.00	*Festuca arundinacea* Schreb.
26	25	25	35	28.33	*Festuca arundinacea* Schreb.
27	55	75	55	61.67	*Festuca arundinacea* Schreb.
28	65	95	95	85.00	*Festuca arundinacea* Schreb.

TABLE 1 (continued)

Plot	Observations 1	2	3	Average	Predominant Species
no.	%	%	%	%	
29	85	55	75	71.67	*Festuca arundinacea* Schreb.
30	45	85	45	58.33	*Lespedeza cuneata* (Dumont) G. Don
31	35	75	55	55.00	*Typha latifolia* L.
32	35	25	35	31.67	*Festuca arundinacea* Schreb.
33	45	55	35	45.00	*Festuca arundinacea* Schreb.
34	45	95	75	71.67	*Festuca arundinacea* Schreb.
35	25	55	55	45.00	*Festuca arundinacea* Schreb.
36	75	85	75	78.33	*Festuca arundinacea* Schreb.
37	15	25	15	18.33	*Festuca arundinacea* Schreb.
38	95	65	65	75.00	*Festuca arundinacea* Schreb.
39	45	35	65	48.33	*Festuca arundinacea* Schreb.
40	15	35	35	28.33	*Festuca arundinacea* Schreb.
41	15	25	25	21.67	*Festuca arundinacea* Schreb.
42	75	45	45	55.00	*Festuca arundinacea* Schreb.
43	35	55	55	48.33	*Festuca arundinacea* Schreb.
44	55	35	35	41.67	*Festuca arundinacea* Schreb.
45	25	15	35	25.00	*Festuca arundinacea* Schreb.
46	55	55	35	48.33	*Festuca arundinacea* Schreb.
47	35	25	55	38.33	*Festuca arundinacea* Schreb.
48	25	65	35	41.67	*Festuca arundinacea* Schreb.
49	35	75	55	55.00	*Festuca arundinacea* Schreb.
50	25	25	5	18.33	*Festuca arundinacea* Schreb.

boundaries delineate the majority of the vegetated and nonvegetated portions of the mine (Figures 3 and 4). The boundaries are, in general, perpendicular to the highwall.

Stations reporting precipitation and temperature are those in closest proximity to the study area. Precipitation of the area has been recorded and collated by the Tennessee Valley Authority at the LaFollette station, Campbell County, Tennessee, for the past 43 years. This station, located approximately two miles east of the mine site, receives an average 1,303 millimeters (Table 2) of precipitation per year (Anonymous 1974-1976).

Temperatures recorded by the National Weather Service at Norris, Anderson County, Tennessee, indicate an annual average temperature of 13.8° C (Table 3) and all monthly averages are above 0° C (United States Department of Commerce 1974-1976).

Figure 3. Typical plot with bare spoil adjoining vegetation.

Figure 4. Typical plot with herbaceous cover (*Festuca arundinarea* Schreb.) and trees (*Robinia pseudoacacia* L.) in the background.

TABLE 2. PRECIPITATION (MM) AT LAFOLLETTE STATION (EL. 1250), CAMPBELL COUNTY, TENNESSEE

Year	January	February	March	April	May	June	July
Average[1]	123	122	139	101	94	109	135
1974	230	113	129	104	195	40	26
1975	131	135	360	60	172	97	86
1976	91	46	177	27	211	152	133

Year	August	September	October	November	December	Annual[2]
Average[1]	103	82	69	101	125	1303
1974	127	199	46	98	131	1439
1975	80	133	150	74	94	1572
1976	48	82	130	30	77	1202

[1] Average is determined by data collected for the period from 1941 through 1970.

[2] Derived from unrounded data.

TABLE 3. TEMPERATURE (°C) AT NORRIS STATION (EL. 1150), ANDERSON COUNTY, TENNESSEE

Year	January	February	March	April	May	June	July
Average[1]	2.8	3.9	8.3	14.2	18.7	22.7	24.3
1974	8.5	5.3	11.9	14.6	18.9	20.7	24.8
1975	M[2]	M[2]	8.0	13.6	20.3M[2]	22.1	24.2
1976	.5	8.8	10.9	14.3	16.3	21.8	22.7

Year	August	September	October	November	December	Annual
Average[1]	23.8	20.7	14.8	8.0	3.5	13.8
1974	23.8	19.7	13.7	9.0	4.6	14.6
1975	25.1	19.7	14.9	9.1	3.8	----
1976	23.2	19.2	11.6	5.0	1.7	13.0

[1] Established using 1941-1970 data by procedures outlined by the National Oceanic and Atmospheric Administration.

[2] Denotes missing data. Averages have been computed for months with less than 10 days missed.

III. MATERIALS AND METHODS

Sampling Methodology

Preliminary investigations of the mine site were made prior to plot establishment in 1974. Boundary delineation, topography, distribution, and position were considered. Fifty plots were subsequently established at random (Figure 2, page 6). Plot centers were located on boundaries of vegetated and nonvegetated areas. From each plot center, three sample points were established five meters from each side of the boundary (Figure 5). Three spoil samples were taken at depths of 0-5, 10-15, and 25-30 cm at each of these six points in each plot, yielding a total of 900 spoil samples. Photographs were made to aid in verification of plot sites and to yield information concerning possible encroachment of vegetation into nonvegetated areas and changes in topography. Percent cover was estimated (Brown 1954) using a circle with an area of one square meter.

After the establishment of the 50 plots, seven areas were delineated based on homogeneity of site conditions. However, some plots were not included in any of the areas because of site differences. During the course of the study, three areas (1, 2, and 4) were limed (46 metric tons/hectare with dolomitic limestone) and fertilized ($N = 57$ kg/ha, $P_2O_5 = 114$ kg/ha).

Analytical Methods

Spoil samples were collected from each sample point and taken to the laboratory for drying at 70° C for 48 hours. They were crushed,

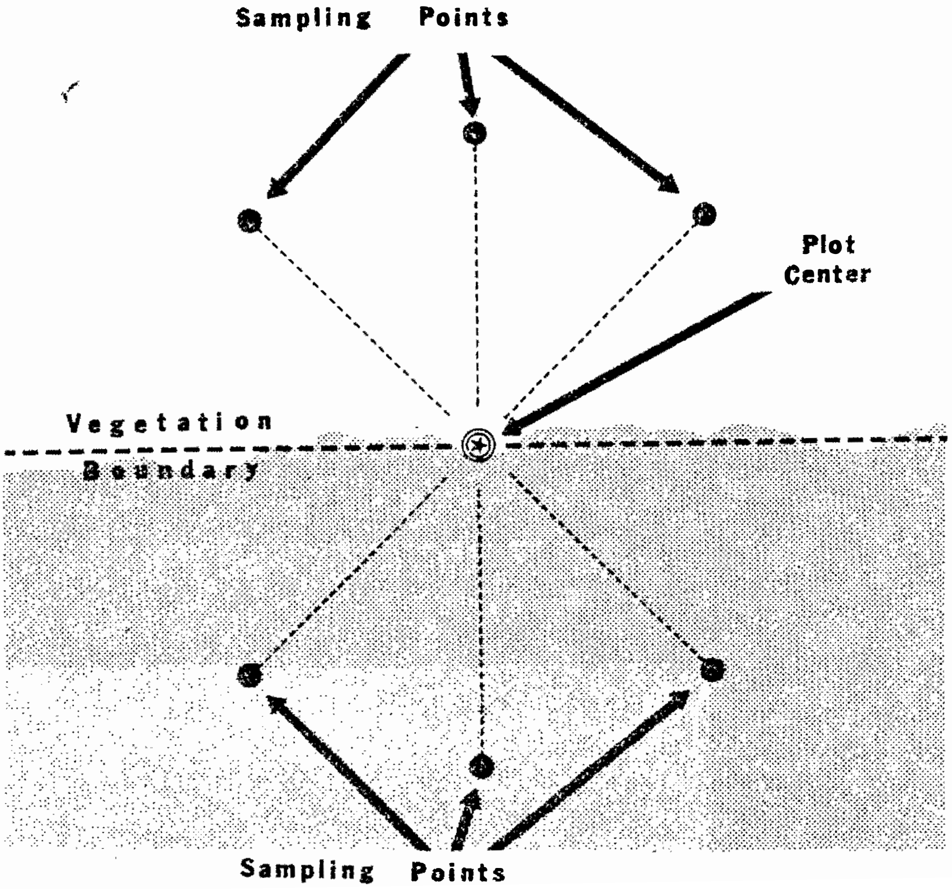

Figure 5. Plot layout with sampling points 45° from one another and five meters from plot center.

then sieved through a number 10 mesh to obtain particles less than 2 mm. Six hundred samples were used for analysis.

Chemical Analyses

The pH was determined using a 1:1 spoil to water ratio after it had been mixed, covered, and allowed to stand for 72 hours. As a check, samples were selected randomly and determinations made using a .01 molar solution of calcium chloride (Peech 1965). All measurements were made using a Fisher Accumet pH meter with a standard combination glass electrode.

A neutral 1 normal solution of ammonium acetate was used to extract calcium and magnesium (Heald 1965), exchangeable potassium (Pratt 1965), and manganese (Adams 1965). Extractable aluminum (Yaun and Fiskell 1959) and iron (Olson 1965) was extracted with 1 normal ammonium acetate, pH 4.8. Phosphorus was extracted using Nelson's double acid procedure (Olsen and Dean 1965) and zinc by a 0.1 normal hydrochloric acid solution (Viets and Boawn 1965).

Calcium and potassium were determined on a Technicon Autoanalyzer Flame Photometer III. Magnesium and phosphorus were determined colorimetrically using a Technicon colorimeter using magnesium blue and ammonium vanadate to delineate color. Aluminum, iron, manganese, and zinc were determined in a Perkin Elmer Atomic Absorption Spectrophotometer Model 403.

Physical Analyses

Color analysis of dry and moist spoil was made under a constant fluorescent artificial light source using standard soil color chips (Munsell Soil Color Chart 1954).

Penetrometry measurements were made in the field with a Proctor penetrometer (Davidson 1965). Moisture samples were taken at the same time as the penetrometry measurements and percent moisture determined in the laboratory (Gardner 1965).

Surface temperatures were measured using a Model 56D Mikron Radiometer to measure spoil under vegetation and bare spoil. Ambient temperature was measured using a standard mercury thermometer. Slope angle and aspect were determined using a Brunton Pocket Transit.

Statistical Analyses

Statistical analyses were made using the "t" test procedure as given in the User's Guide to SAS (Barr, et al. 1976). The paired "t" test compared selected elements in spoils under vegetation with those from nonvegetated sites. Comparisons were made on three levels of complexity: the individual plots, the seven areas, and a composite of the 50 plots by spoil depth.

IV. RESULTS AND DISCUSSION

Spoil Acidity

With each depth considered independently, spoil reaction was significantly lower (p = .01) on bare than on vegetated spoil (Table 4), the total range being from pH 2.6 to 7.9. Generally, the areas limed in 1974 (1, 2, and 4) had differences in pH (p = .05), while unlimed areas (3, 5, 6, and 7) (Table 5) had differences great enough to override those of the limed areas in the composite analysis (Table 4).

Comparison among surface samples (0-5 cm) had pH values of 6.1 and 4.0 on vegetated limed and vegetated unlimed sites while bare limed and bare unlimed sites yielded values of 6.2 and 3.1, respectively. Differences became less defined with sampling depth (Table 4).

The pH values indicated a fairly large response to the application of dolomitic limestone (46 metric tons/hectare) when compared with pre-limed spoils (Table 5). Low pH values may be attributed to weathering of overburden, thus increasing the number of exchange sites, the formation of hydrolyzed aluminum, and the oxidation of sulfides.

Magnesium

An average of all plots indicated more exchangeable magnesium in nonvegetated spoils than under vegetation at the 0-5 cm sampling depth (p = .01). No differences (p = .05) occurred at lower depths (Table 6). Differences (p = .05) were found in only three of the seven independently tested areas at the 0-5 cm sampling level (Table 7).

TABLE 4. HYDROGEN-ION ACTIVITY IN SPOIL FROM VEGETATED (V) AND NONVEGETATED (N) STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Spoil Depth	Average Activity V	Average Activity N	Difference[1]
cm	pH	pH	pH
0- 5	4.8	4.1	0.7
10-15	4.6	3.4	1.2
25-30	4.6	3.4	1.2

[1] All differences significant at 1% level in 100 paired observations.

TABLE 5. HYDROGEN-ION ACTIVITY IN SPOIL FROM SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

		Observations		Average Acidity				
Area	Spoil Depth	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Difference	Significance	
	cm	no.	no.	pH	pH	pH	.05	.01
1	0- 5	12	12	6.6	6.9	0.3	NS	NS
	10-15	12	12	5.4	4.1	1.3	S	S
	25-30	12	12	5.7	3.7	2.0	S	S
	Composite	36	36	5.9	4.9	1.0	S	NS
2	0- 5	12	12	6.4	6.3	0.1	NS	NS
	10-15	12	12	5.2	4.3	0.9	NS	NS
	25-30	12	12	5.3	4.2	1.1	S	NS
	Composite	36	36	5.6	4.9	0.7	NS	NS
3	0- 5	10	10	3.9	3.4	0.5	S	S
	10-15	10	10	4.2	3.3	0.9	S	S
	25-30	10	10	4.3	3.5	0.8	S	S
	Composite	30	30	4.1	3.4	0.7	S	S
4	0- 5	6	6	5.3	5.5	0.2	NS	NS
	10-15	6	6	4.2	3.4	0.8	S	S
	25-30	6	6	4.0	3.8	0.2	NS	NS
	Composite	18	18	4.5	4.2	0.3	NS	NS
5	0- 5	6	6	3.7	2.9	0.8	S	NS
	10-15	6	6	3.6	2.9	0.7	S	NS
	25-30	6	6	3.8	3.0	0.8	S	NS
	Composite	18	18	3.7	2.9	0.8	S	S
6	0- 5	6	6	4.3	3.2	1.1	S	S
	10-15	6	6	5.0	3.2	1.8	S	S
	25-30	6	6	4.9	3.1	1.8	S	S
	Composite	18	18	4.7	3.6	1.1	S	S
7	0- 5	8	8	4.1	3.0	1.1	S	S
	10-15	8	8	4.3	3.0	1.3	S	S
	25-30	8	8	4.4	3.0	1.4	S	S
	Composite	24	24	4.3	3.0	1.3	S	S

TABLE 6. MAGNESIUM, CALCIUM, AND POTASSIUM IN SPOIL FROM VEGETATED (V) AND NONVEGETATED (N) STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Mineral	Spoil Depth	Average Concentration V	Average Concentration N	Differences in 100 Paired Observations	Significance of Difference .05	Significance of Difference .01
	cm	ppm	ppm	ppm	.05	.01
Magnesium	0- 5	187	294	107	S	S
	10-15	207	227	20	NS	NS
	25-30	237	262	25	NS	NS
Calcium	0- 5	797	1187	390	S	NS
	10-15	432	787	355	S	S
	25-30	476	976	500	S	S
Potassium	0- 5	76	32	44	S	S
	10-15	70	28	42	S	S
	25-30	70	37	33	S	S

TABLE 7. MAGNESIUM, CALCIUM, AND POTASSIUM IN SPOIL FROM SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Area	Spoil Depth	Observations		Average Concentration		Difference	Significance	
		Vegetated	Non-vegetated	Vegetated	Non-vegetated			
				Magnesium				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	178	222	44	NS	NS
	10-15	12	12	194	211	17	NS	NS
	25-30	12	12	268	252	16	NS	NS
	Composite	36	36	213	229	16	NS	NS
2	0- 5	12	12	183	283	100	S	NS
	10-15	12	12	255	208	47	NS	NS
	25-30	12	12	255	265	10	NS	NS
	Composite	36	36	231	252	21	NS	NS
3	0- 5	10	10	98	127	29	NS	NS
	10-15	10	10	81	150	69	NS	NS
	25-30	10	10	92	113	21	NS	NS
	Composite	30	30	91	130	39	NS	NS
4	0- 5	6	6	262	781	519	S	NS
	10-15	6	6	274	397	123	NS	NS
	25-30	6	6	315	414	99	NS	NS
	Composite	18	18	284	531	247	S	S
5	0- 5	6	6	222	483	261	S	NS
	10-15	6	6	251	314	63	NS	NS
	25-30	6	6	268	440	172	S	NS
	Composite	18	18	247	412	165	S	S
6	0- 5	6	6	305	370	65	NS	NS
	10-15	6	6	336	251	85	NS	NS
	25-30	6	6	329	285	44	NS	NS
	Composite	18	18	323	301	22	NS	NS
7	0- 5	8	8	235	206	29	NS	NS
	10-15	8	8	217	237	20	NS	NS
	25-30	8	8	54	136	82	NS	NS
	Composite	24	24	233	242	9	NS	NS

TABLE 7 (continued)

		Observations		Average Concentration				
Area	Spoil Depth	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Difference	Significance	
				Calcium				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	2423	3754	1331	S	S
	10-15	12	12	914	1808	894	S	NS
	25-30	12	12	1233	1893	660	NS	NS
	Composite	36	36	1524	2485	961	S	S
2	0- 5	12	12	2085	3437	1352	S	NS
	10-15	12	12	911	1485	574	NS	NS
	25-30	12	12	727	2177	1450	S	S
	Composite	36	36	1241	2366	1125	S	S
3	0- 5	10	10	37	29	8	NS	NS
	10-15	10	10	35	30	5	NS	NS
	25-30	10	10	37	37	0	NS	NS
	Composite	30	30	36	32	4	NS	NS
4	0- 5	6	6	1342	3022	1680	S	S
	10-15	6	6	578	1433	855	NS	NS
	25-30	6	6	386	923	537	NS	NS
	Composite	18	18	769	1793	1024	S	S
5	0- 5	6	6	275	375	100	NS	NS
	10-15	6	6	373	632	259	NS	NS
	25-30	6	6	519	1014	495	NS	NS
	Composite	18	18	389	673	284	S	NS
6	0- 5	6	6	256	151	105	NS	NS
	10-15	6	6	342	300	42	NS	NS
	25-30	6	6	317	284	33	NS	NS
	Composite	18	18	305	245	60	NS	NS
7	0- 5	8	8	297	349	52	NS	NS
	10-15	8	8	324	1684	1360	NS	NS
	25-30	8	8	435	1670	1235	S	S
	Composite	24	24	352	1235	883	S	S

TABLE 7 (continued)

Area	Spoil Depth	Observations		Average Concentration		Difference	Significance	
		Vegetated	Non-vegetated	Vegetated	Non-vegetated			
				Potassium				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	110	69	41	S	S
	10-15	12	12	88	35	53	S	S
	25-30	12	12	87	34	53	S	S
	Composite	36	36	95	46	49	S	S
2	0- 5	12	12	110	49	61	S	S
	10-15	12	12	90	33	57	S	S
	25-30	12	12	84	42	42	S	S
	Composite	36	36	95	42	53	S	S
3	0- 5	10	10	33	24	9	NS	NS
	10-15	10	10	38	25	13	S	NS
	25-30	10	10	36	34	2	NS	NS
	Composite	30	30	35	28	7	S	NS
4	0- 5	6	6	91	25	66	S	S
	10-15	6	6	92	27	65	S	S
	25-30	6	6	71	42	29	NS	NS
	Composite	18	18	84	31	53	S	S
5	0- 5	6	6	69	5	64	S	NS
	10-15	6	6	60	11	49	S	S
	25-30	6	6	63	18	45	S	NS
	Composite	18	18	64	11	53	S	S
6	0- 5	6	6	78	22	56	S	S
	10-15	6	6	86	36	50	S	S
	25-30	6	6	101	40	61	S	S
	Composite	18	18	88	33	55	S	S
7	0- 5	8	8	57	13	44	S	S
	10-15	8	8	64	11	53	S	S
	25-30	8	8	61	17	44	S	S
	Composite	24	24	60	13	47	S	S

Magnesium in both vegetated and nonvegetated spoil was sufficiently abundant that adequate amounts (above 60 parts per million) would be available to the various plants (Embleton 1966).

Calcium

Dolomitic limestone had been applied to three of the seven independently tested areas from which samples were taken. In these areas (1, 2, and 4, Table 7), nonvegetated spoils had greater amounts of calcium than vegetated spoils (p = .05) at the 0-5 cm sampling depth. Remaining areas had no important differences. Only area three was low in calcium in both vegetated and nonvegetated spoil but not enough to retard plant growth.

When all plots were analyzed together, differences were great enough that treated plots overrode the remaining plots (Table 6) at the 0-5 cm sampling level. Comparative differences (p = .01) were greater in the remaining sampling depths, nonvegetated spoil having more calcium (Table 6). However, in both spoil under vegetation and in nonvegetated spoil calcium concentrations were probably adequate for plant growth (Loneragan and Snowball 1969).

Potassium

All plots considered, there was more potassium in vegetated than in nonvegetated spoil at all depths (p = .01, Table 6). Results were variable when each of the seven areas was tested independently (Table 7). Four areas, including two which had been limed and fertilized, had more potassium in vegetated than in nonvegetated spoils (p = .01, Table 7). The remaining three areas had differences that were less significant (p = .05). The general minimum required concentration of potassium in soil for crop growth is 112 kg per hectare (Ulrick and Ohki 1966). Nonvegetated spoil contained 83 kg per hectare or less, while spoil under vegetation contained approximately 157 kg per hectare (Table 6). Of the seven areas, only the 0-5 cm sampling depth of area 1 had a value above the general minimum in nonvegetated spoil (154 kg per hectare). In spoil under vegetation only area 3 yielded values below the critical level prescribed by Ulrick and Ohki (Table 7).

Phosphorus

No differences (p = .05) were found in amounts of phosphorus in vegetated and nonvegetated spoils, both when plots were considered as a group (Table 8) and when each area was tested independently (Table 9). However, the phosphorus levels indicated that plants should respond to amendments. Bingham (1966) and Sabbe and Breland (1974) suggest probable responses when levels in soil are 25 ppm and less.

Iron

When all plots were considered as a composite, nonvegetated spoils had more iron at each soil depth (p = .01) than vegetated spoils (Table 8). The seven areas, tested independently, had concentrations of iron in bare spoils that were either equal to or greater than (p = .05) those under vegetation (Table 9).

The availability of iron and its interaction with other ions makes it one of the more important elements under investigation in

TABLE 8. PHOSPHORUS, IRON, AND ALUMINUM IN SPOIL FROM VEGETATED (V) AND NONVEGETATED (N) STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Mineral	Spoil Depth	Average Concentration		Differences in 100 Paired Observations	Significance of Difference	
		V	N			
	cm	ppm	ppm	ppm	.05	.01
Phosphorus	0- 5	15	14	1	NS	NS
	10-15	20	17	3	NS	NS
	25-30	24	19	5	NS	NS
Iron	0- 5	74	173	99	S	S
	10-15	65	260	195	S	S
	25-30	70	270	200	S	S
Aluminum	0- 5	225	445	220	S	S
	10-15	217	445	228	S	S
	25-30	217	401	184	S	S

TABLE 9. PHOSPHORUS, IRON, AND ALUMINUM IN SPOIL FROM SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

		Observations		Average Concentration				
Area	Spoil Depth	Vegetated	Nonvegetated	Vegetated	Nonvegetated	Difference	Significance	
				Phosphorus				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	7	3	4	NS	NS
	10-15	12	12	18	9	9	S	NS
	25-30	12	12	27	17	10	NS	NS
	Composite	36	36	17	10	7	S	NS
2	0- 5	12	12	6	7	1	NS	NS
	10-15	12	12	31	24	7	NS	NS
	25-30	12	12	36	25	11	NS	NS
	Composite	36	36	24	19	5	NS	NS
3	0- 5	10	10	7	6	1	NS	NS
	10-15	10	10	8	6	2	NS	NS
	25-30	10	10	10	6	4	NS	NS
	Composite	30	30	8	6	2	NS	NS
4	0- 5	6	6	11	12	1	NS	NS
	10-15	6	6	29	17	12	NS	NS
	25-30	6	6	25	33	8	NS	NS
	Composite	18	18	22	20	2	NS	NS
5	0- 5	6	6	18	17	1	NS	NS
	10-15	6	6	23	11	12	NS	NS
	25-30	6	6	28	15	13	NS	NS
	Composite	18	18	23	14	9	NS	NS
6	0- 5	6	6	17	11	6	NS	NS
	10-15	6	6	17	11	6	NS	NS
	25-30	6	6	17	11	6	NS	NS
	Composite	18	18	17	11	6	NS	NS
7	0- 5	8	8	21	41	20	NS	NS
	10-15	8	8	24	51	27	NS	NS
	25-30	8	8	42	37	5	NS	NS
	Composite	24	24	29	43	14	NS	NS

TABLE 9 (continued)

		Observations		Average Concentration				
Area	Spoil Depth	Vegetated	Nonvegetated	Vegetated	Nonvegetated	Difference	Significance	
				Iron				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	90	72	18	NS	NS
	10-15	12	12	106	299	193	S	S
	25-30	12	12	115	381	266	S	S
	Composite	36	36	104	250	146	S	S
2	0- 5	12	12	61	106	45	S	NS
	10-15	12	12	61	458	397	S	S
	25-30	12	12	87	446	359	S	S
	Composite	36	36	70	337	267	S	S
3	0- 5	10	10	17	32	15	NS	NS
	10-15	10	10	10	43	33	S	NS
	25-30	10	10	6	32	26	S	NS
	Composite	30	30	11	36	25	S	S
4	0- 5	6	6	53	70	17	NS	NS
	10-15	6	6	58	173	115	S	NS
	25-30	6	6	84	96	12	NS	NS
	Composite	18	18	65	113	48	S	NS
5	0- 5	6	6	167	258	91	NS	NS
	10-15	6	6	120	349	229	S	NS
	25-30	6	6	93	339	246	S	NS
	Composite	18	18	135	341	206	S	S
6	0- 5	6	6	25	171	146	NS	NS
	10-15	6	6	14	157	143	NS	NS
	25-30	6	6	9	161	152	NS	NS
	Composite	18	18	16	163	147	S	NS
7	0- 5	8	8	118	514	396	S	S
	10-15	8	8	73	554	481	S	S
	25-30	8	8	79	655	576	S	S
	Composite	24	24	90	574	484	S	S

TABLE 9 (continued)

Area	Spoil Depth	Observations		Average Concentration		Difference	Significance	
		Vegetated	Non-vegetated	Vegetated	Non-vegetated			
				Aluminum				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	125	90	35	NS	NS
	10-15	12	12	213	302	89	NS	NS
	25-30	12	12	123	301	178	S	NS
	Composite	36	36	154	231	77	S	NS
2	0- 5	12	12	153	184	31	NS	NS
	10-15	12	12	199	418	219	S	S
	25-30	12	12	202	349	147	S	NS
	Composite	36	36	185	317	132	S	S
3	0- 5	10	10	273	424	151	S	NS
	10-15	10	10	265	432	167	S	NS
	25-30	10	10	301	385	84	NS	NS
	Composite	30	30	280	414	134	S	S
4	0- 5	6	6	258	447	189	NS	NS
	10-15	6	6	236	515	279	NS	NS
	25-30	6	6	358	399	41	NS	NS
	Composite	18	18	284	453	169	NS	NS
5	0- 5	6	6	261	682	421	S	S
	10-15	6	6	187	523	336	S	S
	25-30	6	6	191	452	261	S	S
	Composite	18	18	213	552	339	S	S
6	0- 5	6	6	235	770	535	S	S
	10-15	6	6	156	665	509	S	S
	25-30	6	6	132	566	434	S	NS
	Composite	18	18	174	667	493	S	S
7	0- 5	8	8	243	501	258	S	NS
	10-15	8	8	145	438	293	S	S
	25-30	8	8	156	445	289	S	S
	Composite	24	24	181	461	280	S	S

this study. All spoils samples exceeded the minimum (2 ppm) which could result in iron deficiency as indicated by Olson (1965). Even though concentrations to 655 ppm iron (Table 9) occurred in non-vegetation spoils, toxic levels were probably not reached, as some soils may contain 50,000 ppm iron with no apparent toxicity problems (Murphy and Walsh 1972). Plant uptake or low iron concentrations in the overburden are two possible reasons for the lower iron content of spoil under vegetation.

Aluminum

Nonvegetated spoils contained more aluminum ($p = .05$) than vegetated spoils in areas which had not been limed and fertilized (Areas 3, 5, 6, and 7) (Table 9). Limed areas were not different ($p = .05$) at the 0-5 cm sampling depth but had differences in amounts of aluminum in bare spoil equal to or greater than ($p = .05$) those under vegetation at lower sampling depths. However, where all plots were tested collectively by sampling depth, at each depth (Table 8) with nonvegetated spoils containing more available aluminum than vegetated ($p = .01$). Aluminum toxicity is due in part to (1) concentrations of other ions, (2) susceptibility of the species, and (3) solubility as a function of pH (Brady 1974, Black 1968, Pratt 1966), so that determination of its specific effect is difficult. Two plots containing _Festuca arundinacea_ Schreb. had the most (95%) and least (5%) vegetation cover, with an average for all spoil depths of 496 and 369 ppm extractable aluminum and pH levels of 3.4 and 4.2, respectively.

Manganese

In the composite analysis of all plots, nonvegetated spoil had as much manganese as or more manganese than vegetated plots (Table 10). Labanaukas (1966) stated that soils having 100 ppm or more manganese were adequate for most crops, while 21 ppm or less produced deficiency symptoms. Manganese concentrations on vegetated plots were in the deficient range at all sampling depths (Table 10).

No differences (p = .05) between vegetated and bare spoils were found when each area was tested independently (Table 11). All areas contained less than toxic amounts at each sampling point, with three areas (1, 2, and 3) in the deficient range (Table 11).

Manganese deficiency is therefore suspect as a cause of the little plant productivity on barren mine spoils.

Zinc

Zinc in both the composite spoil analysis (Table 10) and when the seven areas (Table 11) were independently tested was present in amounts neither deficient (4.00 ppm) nor toxic (100 ppm) (Chapman 1966b). As indicated in both types of analysis, there was as much or more zinc in nonvegetated spoils as in vegetated spoils (p = .05) (Tables 10 and 11). Of the three soil depths studied, the surface 0-5 cm was least likely to have differences (Table 10).

Penetration and Moisture

Penetration resistance between vegetated and nonvegetated spoils was measured at all plots. When considering all plots, resistances were greatest (p = .01) on nonvegetated spoils

TABLE 10. MANGANESE AND ZINC IN SPOIL FROM VEGETATED (V) AND NONVEGETATED (N) STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Mineral	Spoil Depth	Average Concentration V	Average Concentration N	Differences in 100 Paired Observations	Significance of Difference .05	Significance of Difference .01
	cm	ppm	ppm	ppm	.05	.01
Manganese	0- 5	26	38	12	S	S
	10-15	34	33	1	NS	NS
	25-30	30	38	8	S	NS
Zinc	0- 5	11	13	2	NS	NS
	10-15	9	13	4	S	NS
	25-30	8	13	5	S	S

TABLE 11. MANGANESE AND ZINC IN SPOIL FROM SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Area	Spoil Depth	Observations		Average Concentration		Difference	Significance	
		Vegetated	Nonvegetated	Vegetated	Nonvegetated			
				Manganese				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	8	4	4	NS	NS
	10-15	12	12	27	19	8	NS	NS
	25-30	12	12	22	25	3	NS	NS
	Composite	36	36	19	16	3	NS	NS
2	0- 5	12	12	14	11	3	NS	NS
	10-15	12	12	35	26	9	NS	NS
	25-30	12	12	24	32	8	NS	NS
	Composite	36	36	24	23	1	NS	NS
3	0- 5	10	10	17	20	3	NS	NS
	10-15	10	10	15	22	7	NS	NS
	25-30	10	10	17	16	1	NS	NS
	Composite	30	30	16	19	3	NS	NS
4	0- 5	6	6	39	66	28	NS	NS
	10-15	6	6	51	72	21	NS	NS
	25-30	6	6	56	64	8	NS	NS
	Composite	18	18	49	67	18	NS	NS
5	0- 5	6	6	31	79	48	NS	NS
	10-15	6	6	42	45	3	NS	NS
	25-30	6	6	30	62	32	NS	NS
	Composite	18	18	34	62	28	S	NS
6	0- 5	6	6	39	52	13	NS	NS
	10-15	6	6	37	32	5	NS	NS
	25-30	6	6	29	35	6	NS	NS
	Composite	18	18	35	40	5	NS	NS
7	0- 5	8	8	36	26	10	NS	NS
	10-15	8	8	43	25	18	S	NS
	25-30	8	8	32	34	2	NS	NS
	Composite	24	24	37	28	11	NS	NS

TABLE 11 (continued)

Area	Spoil Depth	Observations		Average Concentration		Difference	Significance	
		Vegetated	Non-vegetated	Vegetated	Non-vegetated			
				Zinc				
	cm	no.	no.	ppm	ppm	ppm	.05	.01
1	0- 5	12	12	5	5	0	NS	NS
	10-15	12	12	7	10	3	S	NS
	25-30	12	12	8	11	3	NS	NS
	Composite	36	36	7	8	1	NS	NS
2	0- 5	12	12	5	7	2	NS	NS
	10-15	12	12	8	8	0	NS	NS
	25-30	12	12	7	10	3	NS	NS
	Composite	36	36	7	9	2	NS	NS
3	0- 5	10	10	6	13	7	NS	NS
	10-15	10	10	6	25	19	NS	NS
	25-30	10	10	8	13	5	NS	NS
	Composite	30	30	7	17	10	NS	NS
4	0- 5	6	6	8	17	9	NS	NS
	10-15	6	6	8	11	3	NS	NS
	25-30	6	6	8	13	5	NS	NS
	Composite	18	18	8	14	6	S	NS
5	0- 5	6	6	6	16	10	S	NS
	10-15	6	6	11	14	4	NS	NS
	25-30	6	6	8	12	4	NS	NS
	Composite	18	18	8	14	6	S	S
6	0- 5	6	6	11	32	21	S	NS
	10-15	6	6	10	26	16	S	NS
	25-30	6	6	6	26	20	S	NS
	Composite	18	18	9	28	19	S	S
7	0- 5	8	8	8	11	3	NS	NS
	10-15	8	8	8	14	6	S	S
	25-30	8	8	8	13	5	S	NS
	Composite	24	24	8	13	5	S	S

(Tables 12 and 13). There were no differences in spoil moisture ($p = .05$) between vegetated and nonvegetated spoils when measurements were made (Table 14).

The degree to which compaction of spoil becomes limiting depends on many parameters including moisture, textural class, physical and chemical weathering of materials, and the degree of spoil scarification in preparing the seed bed.

Color

Spoil color ranged from strong brown (7.5 YR 5/6) to light gray (5 Y 7/2) when moist, and reddish yellow (7.5 YR 8/4) to pale yellow (5 Y 7/3) when air dry. Hue varied little between nonvegetated and vegetated parts of plots. However, there were some differences between areas.

The value and chroma of spoil color were used by Smith, et al. (1974) as indicators of lime requirements for spoils. Values of three or less are indicators of carbon containing rock (carboliths) which often contain appreciable amounts of sulfur and may be a source of extreme acidity. Chroma may indicate differences between weathered and nonweathered material. Chroma of 3 or more may indicate weathering of pyrites (and therefore iron oxidation has taken place) while that of 2 or lower may indicate iron is not present or is found in reduced forms which may present acidity problems.

Color values of all samples were 3 or more (Table 15) indicating that carboliths probably were not present.

In nonvegetated spoil a chroma of 2 or less was found in 84% of the composite samples and was 83% or greater in all areas except

TABLE 12. PENETROMETER MEASUREMENTS IN SPOIL (0-8 CM) AT SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Area	Observations		Average Resistance		Difference	Significance	
	Vegetated	Non-vegetated	Vegetated	Non-vegetated			
no.	no.	no.	kg/cm^2	kg/cm^2	kg/cm^2	.05	.01
1	18	18	45.64	63.13	17.49	S	S
2	18	18	49.55	60.35	10.80	S	NS
3	15	15	41.19	52.32	11.13	S	NS
4	9	9	46.89	70.63	23.74	S	S
5	9	9	25.44	47.13	21.69	S	NS
6	9	9	23.95	42.58	18.63	S	S
7	12	12	29.12	52.31	23.19	S	NS
Total	150	150	34.39	50.89	16.50	S	S

TABLE 13. PENETROMETER MEASUREMENTS AND MOISTURE IN SPOIL (0-8 CM) FROM VEGETATED AND NONVEGETATED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

Area	Observations Per Value		Vegetated		Nonvegetated	
	Vegetated	Nonvegetated	Resistance	Moisture	Resistance	Moisture
no.	no.	no.	kg/cm^2	%	kg/cm^2	%
1	18	18	45.64	10.41	63.13	9.99
2	18	18	49.55	10.48	60.35	9.26
3	15	15	41.19	8.69	52.32	9.11
4	9	9	46.89	9.26	70.63	8.24
5	9	9	25.22	11.54	47.13	11.79
6	9	9	23.95	13.23	42.58	13.11
7	12	12	29.12	11.96	52.31	12.70

TABLE 14. MOISTURE IN SPOIL (0-8 CM) FROM SELECTED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

	Observations		Average Moisture			Significance	
Area	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Difference		
no.	no.	no.	%	%	%	.05	.01
1	18	18	10.40	9.95	.45	NS	NS
2	18	18	10.46	9.22	1.24	NS	NS
3	15	15	8.67	9.13	.46	NS	NS
4	9	9	9.23	8.24	.99	NS	NS
5	9	9	11.53	11.76	.23	NS	NS
6	9	9	13.23	13.08	.15	NS	NS
7	12	12	11.98	12.68	.70	NS	NS
Total	150	150	11.58	11.00	.58	NS	NS

TABLE 15. COLOR VALUE AND CHROMA OF DRY SPOILS IN STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

			Value				Chroma			
	Observations		3 or Less		4 or More		2 or Less		3 or More	
Area	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Vegetated	Non-vegetated	Vegetated	Non-vegetated
	no.	no.	%	%	%	%	%	%	%	%
					7 Selected Areas					
1	36	36	0	0	100	100	64	89	36	11
2	36	36	0	0	100	100	36	100	64	0
3	30	30	0	0	100	100	10	63	90	37
4	18	18	0	0	100	100	89	100	11	0
5	18	18	0	0	100	100	83	100	17	0
6	18	18	0	0	100	100	33	83	67	17
7	24	24	0	0	100	100	38	96	62	4
		Average	0	0	100	100	50	90	50	10
					All Observations					
	300	300	0	0	100	100	48	84	52	16

area 3 (Table 13). In spoil under vegetation, the chroma divisions suggested by Smith, et al. (1974) were equally divided with 48% having chroma of 2 or less and 52% having chroma of 3 or more (Table 15).

Greater iron concentrations (Table 9, page 31) occurred in nonvegetated spoil than in spoil under vegetation which gives validity to "chroma" as an indicator of reduced forms of iron in the spoils under investigation.

Temperature

Spoil temperatures were higher on bare than on vegetated spoil surfaces (Table 16). Bare spoil temperatures were from 38° to 54° C (median = 46° C) while under vegetation they were from 29° to 42° C (median = 36° C). Differences on individual plots were from 6° to 18° C.

Normal temperature limits of 45° to 55° C for plant growth (Levitt 1972) were exceeded on bare spoil at Ollis Creek and consequently may induce high temperature injury to young plants. Such temperatures may also preclude establishment by most volunteer species. The question remains, however, as to how plants became established on areas which were bare prior to the establishment of vegetation.

Interactions

The availability of nutrients to plants depends upon many physical and chemical factors. In some of the areas which were studied, the additions of lime and other amendments were intended to alleviate deficiencies and toxicities, and decrease soil acidity.

TABLE 16. SPOIL TEMPERATURES ON VEGETATED AND NONVEGETATED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

				Surface		
Plot	Aspect	Slope	Ambient	Non-vegetated	Vegetated	Difference
no.		%	°C	°C[1]	°C[1]	°C
1	305	10	29	49	31	18
2	---	0	29	48	33	15
3	240	12	29	44	29	15
4	90	13	29	44	32	12
5	260	13	29	48	32	16
6	300	4	29	46	31	15
7	335	2	27	40	32	8
8	312	6	27	42	29	13
9	323	20	27	49	31	18
10	349	2	27	39	29	10
11	81	1	27	42	29	13
12	44	7	27	43	31	12
13	278	5	27	38	29	9
14	240	5	28	43	37	6
15	172	18	28	50	39	11
16	233	9	28	49	37	12
17	47	10	27	39	31	8
18	17	11	27	36	28	6
19	100	1	29	48	38	10
20	275	4	29	50	42	8
21	164	15	29	50	38	12
22	318	10	29	48	39	9
23	208	14	29	51	38	13
24	163	7	29	53	38	15
25	---	0	29	50	37	13
26	188	6	29	49	39	10
27	---	0	29	50	39	11
28	85	2	29	51	38	13
29	385	3	29	54	37	17
30	---	0	29	52	38	14
31	274	1	29	50	38	12
32	64	4	29	51	35	16
33	83	4	29	54	35	19
34	328	3	29	50	38	12
35	150	2	29	50	36	14

TABLE 16 (continued)

Plot	Aspect	Slope	Ambient	Surface Non-vegetated	 Vegetated	Difference
no.		%	°C	°C[1]	°C[1]	°C
36	117	15	28	52	37	15
37	99	14	27	50	39	11
38	147	8	27	48	39	9
39	82	2	27	49	35	14
40	158	2	27	44	36	8
41	252	3	27	51	37	14
42	160	4	25	39	31	8
43	310	3	25	37	30	7
44	357	7	25	37	29	8
45	---	0	25	33	27	6
46	123	17	27	45	36	9
47	96	3	25	39	32	7
48	125	2	25	39	34	5
49	202	6	25	42	32	10
50	126	9	27	49	34	15

[1] Each temperature value is an average of three observations.

While these treatments may have had positive influences on the availability of some elements, they undoubtedly decreased availability of others.

One of the primary goals of liming in reclamation in the eastern United States is to raise the pH of spoils to optimal levels for most farm crops. As a result, lime application rates usually have been set in most states by pH values (Adam and Pearson 1967) with little regard to other soil parameters. In this study pre- and post-sampling (46 metric tons/hectare dolomitic lime application) in spoil fertilized with 46 metric tons of dolomitic lime per hectare (areas 1, 2, and 4) resulted in a large increase of pH at the surface (4.13 to 6.55) and slight increases at lower sampling depths (Table 17), producing substantial increases in amounts of calcium and magnesium. Increases in potassium were also found, presumably from dolomitic limestone (Table 17) (Barber 1967). Liming increased concentrations of calcium, magnesium, and potassium from very low or low ranges to medium or high ranges of availability for plant growth.

As the amount of hydrogen ions in soil increases, the total supply of calcium usually decreases, as does its availability to plants (Chapman 1966a). This is also true when excess aluminum is present in the plant root environment (Black 1968). When calcium and magnesium are replaced by hydrogen ions, the solubilities of manganese, aluminum, and iron increase, and with increased solubility, insoluble phosphorus compounds are formed usually incorporating iron and aluminum. Jackson (1967) noted a soil which had a combination of magnesium and molybdenum deficiencies as well as manganese and

TABLE 17. SPOIL PROPERTIES BEFORE AND AFTER LIMING AND FERTILIZATION, CAMPBELL COUNTY, TENNESSEE

Property	Spoil Depth (cm)	In Sequence Before Treatment	 After Treatment
		pH	
Hydrogen-Ion Activity	0- 5	4.13	6.55
	10-15	4.17	4.75
	25-30	4.33	4.73
	Average	4.21	5.33
		ppm	
	0- 5	56	216
Magnesium	10-15	43	217
	25-30	65	260
	Average	55	231
		ppm	
	0- 5	111	2409
Calcium	10-15	138	1279
	25-30	149	1507
	Average	166	1904
		ppm	
	0- 5	9	84
Potassium	10-15	10	61
	25-30	12	62
	Average	10	69

aluminum toxicities. Liming alleviated these difficulties but induced a boron deficiency.

Potassium, under acid conditions, may be lost in great amounts by leaching. The addition of calcium significantly reduces this loss by (1) replacing exchangeable aluminum by calcium and (2) increasing the cation-exchange capacity, therefore increasing exchangeable potassium by a mass-action effect (Black 1968).

In soils which have sulfide and other sulfur compounds in abundance, calcium may be solubilized and be leached from the spoil. Where oxidation of sulfides is high, little or no change in pH will be noted (Sutton 1973).

With particles of lime, particularly dolomitic limestone, strong absorption of zinc ions occurs. It has been hypothesized that the zinc ion reacts with the magnesium of dolomitic limestone and replaces the magnesium ion in the crystalline structure (Buckman and Brady 1969), thus reducing its availability.

Recommendations for lime amendments on strip mine land have been made by Smith (1974). The methodology utilizes percent sulfur present in spoils times a constant to estimate the number of tons of calcium carbonate per thousand tons of material necessary to neutralize the potential acidity of spoil. This procedure does not give consideration to plant nutrient availability.

The presence of soluble iron has been noted in many water drainage areas on and below the Ollis Creek Mine. The spoil samples analyzed also have shown that iron was one of the most abundant elements investigated (Table 9, page 31). The effect of iron in high concentrations in spoil which are subsequently absorbed by plants may have an effect on the manganous ion. This antagonistic relationship between iron and manganese (generally written as the iron-manganese ratio) in plants indicates that an excess of one element could induce a deficiency of the other. Hewitt and Smith (1974) noted the mechanism in plants by which the manganous ion is oxidized to a short-lived trivalent form (manganic), which is not useable by plants, and then stabilized by a phosphate. Thus, iron can produce a manganese deficiency which has symptoms in plants easily confused with iron deficiency (Labanaukas 1966). Iron accumulation in plant roots and stems can be induced by a deficiency in potassium, resulting in iron deficiency chlorosis. This effect is linked with phosphorus metabolism. The enzyme system involving phosphorus utilization (ATP production and utilization) is dependent upon enzymes which contain potassium. The accumulation of iron is related to the build-up of inorganic phosphorus in the tissue, which immobilizes the iron (Hewitt and Smith 1974).

Phosphorus interactions with various elements have been well-documented. On acid strip mine spoils, the tendency of aluminum and iron hydroxides to react with phosphate ions increases with increasing acidity to form insoluble aluminum and iron phosphates resulting in less plant-available phosphate. Even though iron acts as an acidic element (undergoes hydrolization yielding hydrogen ions) at low pH levels (ca. 3.0), aluminum is the acidic metallic element of most acid soils. Soluble aluminum increases rapidly as the pH levels decrease below 4.7 (McLean 1976). In general, aluminum phosphates are more soluble than iron phosphates. Increasing pH and calcium, by liming, results in a slight decrease in the abundance of aluminum and iron phosphates and stimulates the formation of available calcium phosphates (McLean 1976) with subsequent precipitation of aluminum as a hydroxide $[Al(OH)_3]$.

Newly-formed aluminum phosphates are relatively unstable and the phosphorus is, therefore, more available to plants. However, "aging" renders phosphate much less available to plant absorption because the aluminum phosphate may either crystallize forming $AlPO_4 \cdot 2H_2O$, or revert to a less soluble iron phosphate (McLean 1976, Brady 1974).

V. SUMMARY AND CONCLUSIONS

Analyses of vegetated and nonvegetated spoil indicated that they contain low concentrations of nutrients. Mineral elements in the range of deficiency included potassium, phosphorus, manganese, and zinc. Aggravation of potential deficiencies can be brought about by their interactions with other elements in the spoil.

Aluminum and iron were found in amounts which were neither deficient nor toxic, but low pH levels increased their solubility. Their interactions at low pH with other ions such as potassium, phosphorus, zinc, calcium, and manganese may contribute to low spoil productivity. For example, soluble aluminum readily reacts with phosphates forming insoluble aluminum phosphates (Grime and Hodgson 1969). Deficiencies in potassium may cause an increase in the amounts of inorganic phosphates within a plant, which, in turn, may combine with iron (Hewitt and Smith 1974) and render phosphorus unavailable for plant growth. In severe cases, evidences of iron-phosphorus immobilization have been found in the vascular system of certain chlorosis-susceptible plant species in the form of insoluble ferric phosphates (Woolhouse 1969).

Applications of dolomitic limestone increased the availability of calcium, magnesium, and potassium, as well as the pH of surface spoils. Increases in calcium also decrease manganese availability. Dolomitic magnesium and manganese are metabolically antagonistic to one another (Boswell and Blount 1972). They suppress uptake and use by plants of one another as well as compete for activation sites within the plant. Zinc is absorbed into the crystalline structure of dolomitic limestone (replacing magnesium) and consequently, zinc solubility in the soil is decreased by excess use of dolomitic limestone (Boswell and Blount 1972). Liming can inhibit the uptake of both iron and manganese by reducing solubility and conversion of manganese to a stable form, resulting in immobilization. It is interesting to note that even under these conditions, the inhibition of manganese uptake by iron is still in evidence (Jackson 1967).

Available nitrogen was assumed to be at a very low level when this study was undertaken and, therefore, is considered limiting. Additions of nitrogen should be made to the mined area during the revegetation stage of reclamation.

In general, most nutrient levels need to be increased in the spoil. Caution should be taken during the application of dolomitic or other types of lime to avoid unwanted interactions.

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APPENDIX

TABLE 18. COLOR DETERMINATION OF SPOIL FROM PAIRED SAMPLES OF VEGETATED AND NONVEGETATED STRIP MINE SITES, CAMPBELL COUNTY, TENNESSEE

		Munsell Color Notation							
		Vegetated				Nonvegetated			
Plot	Spoil Depth	Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
1	0- 5	5Y 3/1	2.5Y 3/2	5Y 6/1	2.5Y 6/2	2.5Y 3/2	5Y 3/2	2.5Y 6/2	5Y 6/1
	10-15	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 7/2	5Y 3/2	2.5Y 4/2	5Y 6/2	2.5Y 7/2
	25-30	2.5Y 3/2	2.5Y 3/2	2.5Y 6/2	2.5Y 6/2	5Y 3/2	2.5Y 4/2	5Y 7/2	2.5Y 6/2
2	0- 5	10YR 4/4	10YR 4/3	10YR 7/4	10YR 7/3	2.5Y 4/2	5Y 4/2	2.5Y 6/2	5Y 7/1
	10-15	10YR 4/3	10YR 4/2	10YR 8/3	10YR 7/3	10YR 5/4	2.5Y 4/2	10YR 7/3	2.5Y 7/2
	25-30	10YR 5/6	2.5Y 4/2	10YR 7/6	2.5Y 6/2	5Y 3/2	5Y 3/2	5Y 6/1	5Y 6/1
3	0- 5	10YR 4/4	2.5Y 6/2	10YR 7/3	2.5Y 8/2	2.5Y 3/2	2.5Y 3/2	2.5Y 5/2	2.5Y 6/2
	10-15	2.5Y 4/4	2.5Y 4/2	2.5Y 7/4	2.5Y 8/2	5Y 3/2	10YR 3/3	5Y 6/1	10YR 7/3
	25-30	2.5Y 5/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/2	10YR 3/3	10YR 4/4	10YR 6/3	10YR 7/3
4	0- 5	5Y 3/2	2.5Y 4/2	5Y 5/1	2.5Y 6/2	2.5Y 3/2	5Y 3/1	2.5Y 6/2	5Y 6/1
	10-15	10YR 5/6	10YR 4/3	10YR 7/4	10YR 7/4	5Y 2/1	5Y 2/2	5Y 6/1	5Y 5/1
	25-30	2.5Y 4/2	10YR 4/4	2.5Y 7/2	10YR 7/3	5Y 3/1	5Y 3/2	5Y 5/1	5Y 5/1
5	0- 5	2.5Y 3/2	5Y 3/1	2.5Y 6/2	5Y 7/2	5Y 3/2	5Y 3/2	5Y 5/1	5Y 6/1
	10-15	2.5Y 3/2	5Y 3/2	2.5Y 6/2	5Y 6/3	5Y 3/2	5Y 3/1	5Y 6/1	5Y 6/1
	25-30	2.5Y 3/2	5Y 4/2	2.5Y 6/2	5Y 7/2	5Y 3/2	5Y 3/2	5Y 6/2	5Y 6/2
6	0- 5	5Y 2/2	5Y 2/1	5Y 5/1	5Y 4/1	5Y 3/1	5Y 2/2	5Y 6/1	5Y 6/1
	10-15	5Y 2/1	5Y 3/1	5Y 6/1	5Y 6/2	5Y 3/2	5Y 3/1	5Y 6/1	5Y 6/2
	25-30	5Y 2/2	5Y 3/2	5Y 5/2	5Y 6/2	5Y 3/2	5Y 3/2	5Y 6/2	5Y 6/2

TABLE 18 (continued)

Plot	Spoil Depth	Munsell Color Notation							
		Vegetated				Nonvegetated			
		Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
7	0- 5	2.5Y 4/4	2.5Y 4/2	2.5Y 7/2	2.5Y 6/2	2.5Y 3/0	2.5Y 3/0	2.5Y 5/0	2.5Y 5/0
	10-15	2.5Y 5/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/4	5Y 2/2	2.5Y 3/2	5Y 4/2	2.5Y 6/2
	25-30	2.5Y 4/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/4	5Y 3/2	5Y 3/2	5Y 6/1	5Y 5/1
8	0- 5	5Y 3/1	5Y 2/1	5Y 5/1	5Y 5/1	2.5Y 3/0	5Y 2/2	2.5Y 5/0	5Y 6/1
	10-15	5Y 3/2	5Y 3/2	5Y 6/1	5Y 6/1	5Y 3/1	5Y 2/2	5Y 5/1	5Y 6/1
	25-30	5Y 3/1	5Y 3/1	5Y 6/1	5Y 5/1	2.5Y 2/0	5Y 3/2	2.5Y 6/2	5Y 5/1
9	0- 5	2.5Y 3/2	5Y 3/2	2.5Y 7/2	5Y 6/2	5Y 3/1	5Y 3/2	5Y 5/1	5Y 6/2
	10-15	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 7/4	2.5Y 3/2	5Y 3/2	2.5Y 6/2	5Y 5/2
	25-30	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 6/4	2.5Y 4/2	5Y 3/2	2.5Y 6/2	5Y 6/2
10	0- 5	2.5Y 4/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/4	2.5Y 3/2	5Y 3/2	2.5Y 6/2	5Y 6/1
	10-15	2.5Y 3/0	10YR 4/3	2.5Y 5/0	10YR 7/3	2.5Y 3/2	2.5Y 4/2	2.5Y 5/0	2.5Y 6/2
	25-30	2.5Y 4/4	2.5Y 2/0	2.5Y 6/4	2.5Y 4/0	5Y 2/2	2.5Y 3/2	5Y 4/2	2.5Y 6/2
11	0- 5	5Y 4/4	2.5Y 4/4	5Y 7/3	2.5Y 7/4	5Y 3/2	5Y 3/2	5Y 6/1	5Y 6/1
	10-15	10YR 6/6	2.5Y 5/4	10YR 7/4	2.5Y 7/4	5Y 4/2	5Y 3/2	5Y 6/1	5Y 6/1
	25-30	2.5Y 5/6	10YR 5/4	2.5Y 8/4	10YR 7/3	5Y 4/2	5Y 3/2	5Y 6/1	5Y 6/1
12	0- 5	10YR 5/8	10YR 5/7	10YR 7/4	10YR 7/4	5Y 4/2	2.5Y 4/2	5Y 6/1	2.5Y 6/2
	10-15	10YR 6/8	10YR 5/6	10YR 8/4	10YR 7/3	2.5Y 4/2	2.5Y 5/4	2.5Y 6/2	2.5Y 7/2
	25-30	10YR 5/6	10YR 5/8	10YR 7/4	10YR 8/3	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2

TABLE 18 (continued)

		Munsell Color Notation							
		Vegetated				Nonvegetated			
Plot	Spoil Depth	Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
13	0- 5	10YR 5/2	10YR 5/2	10YR 7/1	10YR 7/1	2.5Y 4/2	5Y 4/2	2.5Y 6/2	5Y 7/1
	10-15	2.5Y 4/2	10YR 4/2	2.5Y 6/2	10YR 7/1	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	25-30	5Y 4/2	10YR 5/2	5Y 7/2	10YR 7/1	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 5/2
14	0- 5	5Y 7/2	5Y 4/3	5Y 7/1	5Y 6/3	5Y 5/2	5Y 5/2	5Y 7/2	5Y 7/2
	10-15	5Y 4/3	5Y 5/2	5Y 7/3	5Y 7/2	5Y 5/1	5Y 5/2	5Y 7/1	5Y 7/2
	25-30	5Y 4/3	5Y 5/2	5Y 6/3	5Y 7/2	5Y 5/2	5Y 5/2	5Y 7/1	5Y 7/2
15	0- 5	10YR 6/6	10YR 5/4	10YR 8/4	10YR 7/4	2.5Y 4/2	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2
	10-15	10YR 5/4	10YR 6/6	10YR 7/4	10YR 7/4	5Y 4/2	2.5Y 5/4	5Y 6/2	2.5Y 7/4
	25-30	5Y 5/6	10YR 7/4	5Y 7/4	10YR 8/3	2.5Y 4/2	10YR 5/4	2.5Y 6/2	10YR 7/3
16	0- 5	10YR 5/4	10YR 5/4	10YR 7/4	10YR 7/3	10YR 5/8	7.5YR 5/6	10YR 7/4	7.5YR 8/4
	10-15	10YR 5/6	2.5Y 4/4	10YR 8/4	2.5Y 7/4	10YR 6/8	10YR 5/8	10YR 8/4	10YR 7/4
	25-30	10YR 5/8	10YR 5/6	10YR 8/6	10YR 7/4	10YR 5/6	10YR 5/6	10YR 8/4	10YR 7/4
17	0- 5	10YR 5/4	10YR 5/6	10YR 8/3	10YR 8/4	10YR 5/2	2.5Y 4/2	10YR 6/2	2.5Y 7/2
	10-15	10YR 5/6	10YR 5/4	10YR 8/4	10YR 8/4	2.5Y 4/4	10YR 4/2	2.5Y 7/2	10YR 6/2
	25-30	10YR 5/6	10YR 5/4	10YR 7/4	10YR 7/4	10YR 5/4	2.5Y 4/4	10YR 8/3	2.5Y 7/2
18	0- 5	2.5Y 5/6	2.5Y 5/6	2.5Y 7/4	2.5Y 7/4	5Y 4/4	2.5Y 4/4	5Y 7/2	2.5Y 7/2
	10-15	10YR 5/8	10YR 5/6	10YR 7/4	10YR 7/3	5Y 4/2	10YR 5/8	5Y 6/2	10YR 7/4
	25-30	10YR 6/6	2.5Y 5/6	10YR 7/4	2.5Y 7/4	2.5Y 4/2	10YR 5/6	2.5Y 7/2	10YR 8/3

TABLE 18 (continued)

Plot	Spoil Depth	Munsell Color Notation							
		Vegetated				Nonvegetated			
		Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
19	0- 5	5Y 4/3	2.5Y 4/2	5Y 7/2	2.5Y 6/2	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 7/2
	10-15	2.5Y 4/2	5Y 4/3	2.5Y 6/2	5Y 7/3	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2	2.5Y 7/2
	25-30	5Y 4/3	2.5Y 4/2	5Y 7/3	2.5Y 6/2	2.5Y 5/2	5Y 4/3	2.5Y 7/2	5Y 6/1
20	0- 5	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	10-15	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 7/2	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 7/2
	25-30	2.5Y 4/2	2.5Y 4/2	2.5Y 7/2	2.5Y 6/2	2.5Y 4/2	2.5Y 4/2	2/5Y 6/2	2.5Y 6/2
21	0- 5	2.5Y 5/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 3/2	5Y 4/2	2.5Y 5/2	5Y 5/2
	10-15	5Y 4/2	2.5Y 4/2	5Y 6/2	2.5Y 6/2	2.5Y 3/2	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2
	25-30	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 5/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
22	0- 5	10YR 5/6	10YR 5/6	10YR 7/4	10YR 7/4	2.5Y 4/4	2.5Y 5/2	2.5Y 7/4	2.5Y 7/2
	10-15	10YR 5/6	10YR 5/6	10YR 7/6	10YR 7/6	2.5Y 4/4	2.5Y 4/2	2.5Y 6/4	2.5Y 6/2
	25-30	10YR 5/8	10YR 5/8	10YR 7/6	10YR 7/6	2.5Y 5/2	2.5Y 5/2	2.5Y 6/2	2.5Y 6/2
23	0- 5	5Y 3/2	2.5Y 5/4	5Y 6/1	2.5Y 7/4	5Y 5/2	5Y 4/3	2.5Y 7/2	5Y 7/2
	10-15	10YR 5/6	10YR 5/8	10YR 7/4	10YR 7/4	2.5Y 5/4	2.5Y 5/2	2.5Y 6/4	2.5Y 6/2
	25-30	10YR 5/4	10YR 6/6	10YR 7/4	10YR 7/3	2.5Y 5/4	2.5Y 4/4	2.5Y 7/2	2.5Y 7/4
24	0- 5	2.5Y 4/2	2.5Y 4/2	2.5Y 7/2	2.5Y 6/2	2.5Y 5/4	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2
	10-15	2.5Y 4/2	10YR 3/2	2.5Y 6/2	10YR 7/2	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	25-30	2.5Y 3/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 4/2	5Y 4/3	2.5Y 7/2	5Y 7/2

TABLE 18 (continued)

Plot	Spoil Depth	Munsell Color Notation							
		Vegetated				Nonvegetated			
		Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
25	0- 5	5Y 5/3	5Y 4/3	5Y 7/3	5Y 6/2	5Y 4/4	10YR 4/2	5Y 7/2	10YR 7/2
	10-15	2.5Y 4/2	5Y 4/3	2.5Y 7/2	5Y 6/1	5Y 4/3	5Y 4/3	5Y 7/2	5Y 7/2
	25-30	2.5Y 5/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	5Y 4/3	5Y 4/3	5Y 6/1	5Y 7/3
26	0- 5	2.5Y 4/4	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2	2.5Y 7/4
	10-15	2.5Y 4/4	2.5Y 4/4	2.5Y 7/2	2.5Y 6/2	2.5Y 4/2	2.5Y 5/4	2.5Y 6/2	2.5Y 7/4
	25-30	2.5Y 4/4	2.5Y 4/4	2.5Y 6/4	2.5Y 7/4	2.5Y 4/4	2.5Y 5/4	2.5Y 7/4	2.5Y 8/2
27	0- 5	2.5Y 4/2	5Y 4/2	2.5Y 6/2	5Y 6/1	5Y 4/2	5Y 4/2	5Y 6/2	5Y 5/1
	10-15	5Y 4/2	5Y 5/2	5Y 6/2	5Y 6/1	5Y 4/2	2.5Y 4/2	5Y 6/2	2.5Y 6/2
	25-30	5Y 4/1	2.5Y 4/2	5Y 6/1	2.5Y 6/2	5Y 4/2	2.5Y 4/2	5Y 6/1	2.5Y 6/2
28	0- 5	2.5Y 4/4	2.5Y 4/4	2.5Y 6/2	2.5Y 7/4	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 6/4
	10-15	2.5Y 4/4	10YR 6/6	2.5Y 6/4	10YR 7/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	25-30	10YR 5/4	10YR 5/6	10YR 7/4	10YR 7/4	2.5Y 5/2	2.5Y 4/2	2.5Y 7/2	2.5Y 6/2
29	0- 5	2.5Y 3/0	2.5Y 4/2	2.5Y 5/0	2.5Y 5/2	5Y 4/1	5Y 4/2	5Y 6/1	5Y 6/1
	10-15	5Y 4/1	2.5Y 3/2	5Y 5/1	2.5Y 5/2	2.5Y 3/0	5Y 4/1	2.5Y 5/0	5Y 5/1
	25-30	2.5Y 3/2	2.5Y 3/2	2.5Y 6/2	2.5Y 6/2	5Y 3/1	5Y 3/1	5Y 5/1	5Y 5/1
30	0- 5	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2	2.5Y 7/4	2.5Y 5/2	2.5Y 5/2	2.5Y 6/2	2.5Y 6/2
	10-15	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2	2.5Y 7/2	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2	2.5Y 6/2
	25-30	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 7/4	2.5Y 5/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2

TABLE 18 (continued)

		Munsell Color Notation							
	Spoil	Vegetated				Nonvegetated			
Plot	Depth	Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
31	0- 5	2.5Y 4/4	10YR 5/4	2.5Y 7/4	10YR 7/3	5Y 4/3	5Y 3/2	5Y 6/3	5Y 7/3
	10-15	2.5Y 4/4	10YR 5/4	2.5Y 7/4	10YR 7/4	2.5Y 4/4	2.5Y 4/4	2.5Y 6/2	2.5Y 6/4
	25-30	2.5Y 4/2	10YR 5/6	2.5Y 6/2	10YR 7/4	5Y 3/2	10YR 5/4	5Y 6/1	10YR 7/4
32	0- 5	10YR 5/4	10YR 5/4	10YR 7/4	10YR 7/4	2.5Y 4/2	2.5Y 5/4	2.5Y 7/4	2.5Y 7/4
	10-15	10YR 5/4	10YR 5/6	10YR 7/4	10YR 7/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	25-30	10YR 5/6	10YR 5/4	10YR 7/4	10YR 7/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
33	0- 5	10YR 5/4	10YR 5/4	10YR 7/4	10YR 7/4	5Y 4/1	5Y 3/1	5Y 5/1	5Y 5/1
	10-15	10YR 5/4	10YR 5/6	10YR 7/4	10YR 7/4	5Y 4/2	5Y 3/1	5Y 5/2	5Y 5/1
	25-30	2.5Y 5/4	5Y 4/3	2.5Y 7/4	5Y 6/3	5Y 3/2	5Y 3/1	5Y 5/1	5Y 5/1
34	0- 5	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 4/2	10YR 5/6	2.5Y 7/2	10YR 7/4
	10-15	2.5Y 4/4	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2	2.5Y 4/2	5Y 4/3	2.5Y 6/2	5Y 6/3
	25-30	2.5Y 3/2	2.5Y 4/2	2.5Y 5/2	2.5Y 5/2	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 6/2
35	0- 5	5Y 3/2	10YR 4/1	5Y 6/3	10YR 6/1	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2	2.5Y 7/2
	10-15	5Y 3/2	2.5Y 3/2	5Y 5/2	2.5Y 6/2	5Y 5/3	5Y 4/1	5Y 6/3	5Y 6/1
	25-30	2.5Y 3/2	2.5Y 3/2	2.5Y 5/2	2.5Y 6/2	2.5Y 4/4	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2
36	0- 5	2.5Y 3/2	10YR 5/4	2.5Y 5/2	10YR 7/4	5Y 3/2	5Y 3/2	5Y 5/2	5Y 6/1
	10-15	2.5Y 4/2	2.5Y 4/4	2.5Y 5/2	2.5Y 6/2	2.5Y 3/2	5Y 4/2	2.5Y 6/2	5Y 6/1
	25-30	2.5Y 4/2	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2	5Y 3/2	5Y 3/2	5Y 5/1	5Y 5/1

TABLE 18 (continued)

Plot	Spoil Depth	Munsell Color Notation							
		Vegetated				Nonvegetated			
		Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
37	0- 5	2.5Y 4/4	2.5Y 4/2	2.5Y 6/4	2.5Y 6/2	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 6/2
	10-15	2.5Y 4/4	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 4/2	2.5Y 3/2	2.5Y 5/2	2.5Y 6/2
	25-30	2.5Y 4/4	2.5Y 4/2	2.5Y 6/2	2.5Y 5/2	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 5/2
38	0- 5	2.5Y 4/2	2/5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 4/2	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2
	10-15	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 5/2	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	25-30	2.5Y 3/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2	2.5Y 3/2	2.5Y 3/2	2.5Y 5/2	2.5Y 6/2
39	0- 5	5Y 4/1	2.5Y 4/2	5Y 6/1	2.5Y 6/2	2.5Y 3/2	2.5Y 3/2	2.5Y 6/2	2.5Y 6/2
	10-15	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 5/2	2.5Y 2/0	2.5Y 5/0	2.5Y 5/0	2.5Y 7/0
	25-30	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 6/2	2.5Y 3/0	2.5Y 4/1	2.5Y 6/0	2.5Y 6/2
40	0- 5	10YR 5/4	10YR 5/6	10YR 7/4	10YR 7/4	10YR 5/4	2.5Y 4/4	10YR 7/4	2.5Y 6/4
	10-15	10YR 5/6	10YR 5/6	10YR 7/4	10YR 7/4	5Y 4/2	2.5Y 5/2	5Y 6/2	2.5Y 6/2
	25-30	10YR 5/6	10YR 5/6	10YR 7/4	10YR 7/6	5Y 4/1	2.5Y 5/2	5Y 6/1	2.5Y 6/2
41	0- 5	2.5Y 5/6	2.5Y 5/4	2.5Y 7/4	2.5Y 7/4	2.5Y 5/2	5Y 4/1	2.5Y 6/2	5Y 5/1
	10-15	2.5Y 5/4	2.5Y 5/4	2.5Y 7/4	2.5Y 7/4	2.5Y 4/4	2.5Y 4/0	2.5Y 7/2	2.5Y 6/0
	25-30	10YR 5/4	10YR 5/4	10YR 7/4	10YR 7/4	10YR 5/4	2.5Y 3/2	10YR 7/4	2.5Y 5/2
42	0- 5	5Y 4/1	2.5Y 3/2	5Y 5/1	2.5Y 5/2	5Y 3/1	2.5Y 4/0	5Y 5/1	2.5Y 6/2
	10-15	2.5Y 3/2	5Y 3/2	2.5Y 6/2	5Y 5/2	2.5Y 4/0	5Y 3/2	2.5Y 6/0	5Y 5/2
	25-30	2.5Y 3/2	2.5Y 3/2	2.5Y 5/2	2.5Y 5/2	2.5Y 4/0	2.5Y 3/0	2.5Y 5/0	2.5Y 6/2

TABLE 18 (continued)

		Munsell Color Notation							
	Spoil	Vegetated				Nonvegetated			
Plot	Depth	Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
43	0- 5	2.5Y 4/4	2.5Y 4/4	2.5Y 6/4	2.5Y 6/4	2.5Y 4/2	5Y 3/2	2.5Y 6/2	5Y 6/2
	10-15	10YR 5/4	10YR 5/4	10YR 7/3	10YR 7/3	2.5Y 4/2	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2
	25-30	2.5Y 5/4	2.5Y 5/4	2.5Y 7/4	2.5Y 7/4	2.5Y 3/2	2.5Y 3/2	2.5Y 5/2	2.5Y 6/2
44	0- 5	2.5Y 5/4	2.5Y 5/4	2.5Y 6/4	2.5Y 7/4	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 5/2
	10-15	2.5Y 4/4	2.5Y 4/4	2.5Y 6/4	2.5Y 7/4	2.5Y 4/4	2.5Y 4/2	2.5Y 7/4	2.5Y 6/2
	25-30	2.5Y 5/2	2.5Y 4/4	2.5Y 7/2	2.5Y 6/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
45	0- 5	2.5Y 5/2	5Y 5/3	2.5Y 7/2	5Y 6/3	5Y 3/2	2.5Y 3/2	5Y 5/1	2.5Y 5/2
	10-15	2.5Y 4/4	2.5Y 5/4	2.5Y 7/2	2.5Y 7/4	5Y 4/3	5Y 3/2	5Y 6/2	5Y 5/1
	25-30	5Y 4/4	5Y 5/3	5Y 6/3	5Y 6/3	2.5Y 4/2	5Y 4/2	2.5Y 6/2	5Y 5/2
46	0- 5	2.5Y 5/2	2.5Y 5/4	2.5Y 7/2	2.5Y 7/4	5Y 4/2	2.5Y 5/4	5Y 6/1	2.5Y 7/4
	10-15	2.5Y 5/4	2.5Y 5/4	2.5Y 7/2	2.5Y 7/4	10YR 5/6	2.5Y 4/2	10YR 7/6	2.5Y 5/2
	25-30	5Y 4/2	2.5Y 5/4	5Y 6/1	2.5Y 7/2	2.5Y 4/2	5Y 4/2	2.5Y 7/2	5Y 6/1
47	0- 5	10YR 5/4	2.5Y 4/4	10YR 7/4	2.5Y 7/4	2.5Y 4/2	2.5Y 3/2	2.5Y 6/2	2.5Y 6/2
	10-15	10YR 5/6	10YR 5/4	10YR 7/4	10YR 7/4	2.5Y 4/2	2.5Y 4/4	2.5Y 6/2	2.5Y 6/2
	25-30	10YR 5/4	10YR 5/6	10YR 7/4	10YR 7/4	2.5Y 4/2	5Y 3/2	2.5Y 6/2	5Y 5/2
48	0- 5	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2	2.5Y 6/2	2.5Y 5/4	2.5Y 5/2	2.5Y 7/2	2.5Y 6/4
	10-15	2.5Y 5/2	2.5Y 4/2	2.5Y 7/2	2.5Y 6/2	2.5Y 4/4	5Y 5/3	2.5Y 7/4	5Y 7/3
	25-30	2.5Y 4/2	2.5Y 5/4	2.5Y 6/2	2.5Y 6/2	10YR 5/4	2.5Y 5/4	10YR 7/4	2.5Y 7/2

TABLE 18 (continued)

Plot	Depth	Munsell Color Notation							
		Vegetated				Nonvegetated			
		Moist		Dry		Moist		Dry	
no.	cm	1	2	1	2	1	2	1	2
49	0- 5	2.5Y 4/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/4	2.5Y 3/2	2.5Y 4/2	2.5Y 5/2	2.5Y 6/2
	10-15	2.5Y 4/4	2.5Y 4/4	2.5Y 6/4	2.5Y 7/4	2.5Y 4/4	2.5Y 4/4	2.5Y 6/4	2.5Y 7/4
	25-30	2.5Y 4/4	5Y 5/4	2.5Y 6/4	5Y 7/4	2.5Y 4/4	5Y 4/2	2.5Y 6/4	5Y 6/1
50	0- 5	2.5Y 4/4	2.5Y 4/4	2.5Y 6/4	2.5Y 6/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	10-15	2.5Y 4/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 6/2
	25-30	2.5Y 4/4	2.5Y 4/4	2.5Y 7/4	2.5Y 7/4	2.5Y 4/2	2.5Y 4/2	2.5Y 6/2	2.5Y 7/2

VITA

Donald Wesley Ott was born to Mr. and Mrs. Howard F. Ott of Victor, New York on September 11, 1942. He attended Victor Central School and was graduated in June 1960.

He attended Lees-McRae College, Banner Elk, North Carolina majoring in education and was graduated with an Associate in Arts degree in 1963. He then attended Appalachian State University, Boone, North Carolina, majoring in Biology with a minor in Education. He received his Bachelor of Science degree in June 1965 and Master of Arts in 1968 from that institution.

He was employed by Lees-McRae College as an instructor of Biology (1965-1967) and Dean of Men (1967-1968). Moving to Talladega, Alabama in 1968, he taught Biology, Botany, and Comparative Vertebrate Anatomy at Talladega College until his acceptance to The University of Tennessee, Knoxville, in 1971.

He was enrolled in The University of Tennessee, Knoxville, Graduate Program in Ecology in 1971. He was graduated from that program with a Doctor of Philosophy degree in March 1978.

Since childhood, he has been active in community service. He was a Boy Scout attaining the rank of Life, a Scoutmaster (Troop 807, Banner Elk, North Carolina), and member of the Newland and Banner Elk Volunteer Fire Departments. In Tennessee, he joined the Knoxville Jaycees and held the office of Personnel Director and President of that organization.

He is married to the former Georgia K. Woods, Mountain City, Tennessee. They have one son, Thomas Frederick.