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Reclamation of Mined Phosphate Land

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SUMMARY

Experiments were conducted at the Middle Tennessee Experiment Station to evaluate the productive capacity of soil that had been mined for phosphate and reformed or smoothed as compared to soil that had not been mined. The land was cropped 1955-59 before mining. The soil was mined in the summer of 1962 and the experiments on mined soil were begun in 1963.

Spring-seeded crops consisting of corn, grain sorghum, Sudangrass, and lespedeza were grown on soil that had been mined and on adjacent unmined soil. Wheat, oats, alfalfa, and rye and crimson clover were grown on the mined soil. Samples were taken from the mined and unmined soil to determine chemical and physical properties of the soil.

Some difficulties were encountered in seedbed preparation on the mined soil. When moisture conditions were ideal for plowing on the unmined check area, the mined soil did not pulverize and tended to turn up cloddy. The mined soil pulverized better by disking with a heavy disk rather than turning.

After excessive rains, the mined soil tended to crust more than the unmined soil. This was probably due to the increase in clay content, the reduction of the organic matter, and poor structure in the surface of the mined soil. During the second year of the experiment, the lespedeza was reseeded because the crusting inhibited emergence.

The mined soil tended to erode rather easily since no plant roots were present to help hold the soil in place and the mined soil was not as compact as the unmined soil. However, since vegetative covers were easily secured, erosion did not prove to be a major problem.

The first year after the soil was mined, very few weeds were observed growing on the mined soil. However, by the second and third years the weed population on the mined soil was as great as on the unmined soil.

The specific findings of this study may be stated as follows:

1. The sand and clay content of the surface 0 to 6 inches in the mined soil was greater than in the unmined.
2. Bulk density of the surface was lower in the mined soil.
3. There was a small increase in large pore space in the mined soil and a small decrease in small pore space for the 0 to 18 inches depth.
4. In the surface 0 to 6 inches of the mined soil, the wilting point was increased to 24% as compared to 15% for the unmined.
5. The organic matter content in the mined soil was lower than in the unmined for the 0 to 18 inches depth.
6. The pH of the surface 6 inches of the soil was about 6.1 before mining and 5.3 after mining.
7. Mining increased the available phosphorus content in the soil.
8. Mining did not greatly change the available potassium content in the soil.
9. When no fertilizers were applied, crop yields were lower on the mined soil than on similar unmined soil.
10. Zinc deficiencies were observed on corn on the mined soil. For the 2-year average, a significant response was obtained for micronutrient additions to alfalfa.
11. When adequate fertilizers were applied, yields on the mined soil were comparable to those on the unmined soil. The mined soil was deficient in nitrogen and required higher rates of this element.
12. Corn, grain sorghum, Sudangrass, and wheat gave a significant response to nitrogen on the mined soil.
13. Grain sorghum, Sudangrass, rye and crimson clover, and alfalfa gave a significant response to lime treatments on the mined soil.
14. Sudangrass gave a significant response to added potassium on the mined and unmined soil.
15. Due to winter heaving, difficulties in retaining stands of fall seeded crops proved to be a major problem on the mined soil.
16. Spring seeding of sod crops appeared to be the most desirable seeding establishment method on the mined soil.

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INTRODUCTION

The phosphate reserves which occur in the Central Basin were deposited millions of years ago when the area was covered by an inland sea. The Tennessee Brown Rock is the most important phosphate rock occurring in this area.

The phosphate industry started in Maury County when a stonecutter discovered the first rock in 1888. Since then, thousands of acres have been mined in Middle Tennessee. Until recently, very little land smoothing or land forming of the strip-mined areas had taken place. However, most mining companies are now forming the areas that they mine.

Unlike Tennessee's coal land, much of this land is very fertile and had been used for agriculture before mining. Coal mining leaves sulfur residues which may produce extremely acidic conditions. Phosphate mining does not leave residues conducive to acidity. Although some crops had been successfully grown by farmers on land that had been mined and formed, the productive capacity of the soil after mining as compared to premining was not known.

In order to evaluate the productive capacity of the soil before and after mining, the University of Tennessee initiated a project in cooperation with the Monsanto Company. Monsanto was responsible for the mining and land forming operations on a 285-acre tract of the Middle Tennessee Experiment Station. This tract is located about 1 mile south of Spring Hill and on the west side of U.S. highway 31. The University was responsible for conducting and evaluating the research on the productivity of the land before and after mining.

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PROCEDURE

Experiments were conducted on Maury soil before mining during 1955 through 1961. Yield data were obtained for corn, wheat, alfalfa, oats, barley, rye and crimson clover, Sudangrass, fescue, lespedeza, and clover-grass pasture at different levels of fertilization.

After the soil was mined, experiments were established to evaluate the yields of corn, grain sorghum, Sudangrass, lespedeza, alfalfa, fescue, oats, wheat, and rye and crimson clover. Fertilizer treatments applied to these crops included different rates of lime, potassium, nitrogen, phosphorus, and micronutrients. Additional plots were grown on adjacent unmined land as a climate check for the spring-seeded crops.

After mining, soil samples were taken from mined and unmined areas to determine chemical and physical properties of the soil. Also, the average daily moisture use rate was determined for the spring-seeded crops on the mined and unmined soil.

RESULTS AND DISCUSSION

Mining and Cost of Reforming

The layer of soil that covered the phosphate reserves varied in depth from 1 to several feet. During mining operations, the soil—which is known as overburden—was stripped and piled so that the phosphate could be removed (Figures 1, 2, and 3). When the overburden was shallow, the stripping was done with a bulldozer. During the land smoothing operations, some of these piles were not distributed evenly over large areas. This resulted in small areas within the mined area being very similar to the unmined surface soil. These areas not only showed up when crops were grown but also in the physical and chemical soil analyses.

The cost of land forming after mining depends on such factors as the terrain of the area, amount of limestone rock,

Figure 1. The soil overburden, the phosphate and the removed overburden in the phosphate mining operation.

Figure 2. Removing the phosphate in the mining operation.

Figure 3. The soil overburden after mining and before land forming operations.

the degree of smoothness desired, and the size of equipment used. Cost may vary from around $100 to as high as $400 per acre.

Approximately 100 acres were mined on the Middle Tennessee Experiment Station. The average cost per acre for land forming was $160 per acre. A heavy 200-drawbar horsepower bulldozer was used at a cost of $20 per hour. There was very little limestone rock and an excellent land forming job was obtained.

Sand, Silt, and Clay Content

The percent sand was higher in the mined soil than in the unmined soil (Figure 4). In the surface 6 inches of the unmined soil, the sand content ranged from 10.32% to 13.20%. In the surface 6 inches of the mined soil, the sand content averaged 23%, about 12% greater than in the unmined surface soil. Also the quantity of sand in the mined soil was approximately 10% to 13% greater than in the unmined soil at the 6- to 12-inch and 12- to 18-inch depths.

An average of 10% more clay was found in the mined soil as compared to the unmined. In the surface 6 inches of the unmined soil, the clay content ranged from 26% to 32%. In the same layer of the mined soil, the clay content range varied from 32% to 49%. The average clay content for the 6- to 12-inch layer was 6% greater and for the 12- to 18-inch layer was 3% greater than the unmined soil at the same depth.

Since the quantity of clay and sand was greater in the mined soil, the percent of silt was correspondingly lower in each soil layer.

Moisture Release Characteristics

At field capacity (1/3 bar tension), the 0- to 6-inch layer of the unmined soil contained 36.9% moisture; in the mined soil it contained 42.4% (Figure 5). The 6- to 12-inch layer in the unmined area had 40.4% moisture at field capacity, whereas in the mined area it contained 43.1% moisture.

At higher moisture tensions the mined soil retained a much greater percent moisture than did the unmined soil. At 15 bars tension (wilting point), the 0- to 6-inch layer of the mined soil contained 24.3% moisture compared to 15.2% for the 0 to 6 inches of the unmined soil. The 6 to 12 inches of the mined soil contained 26.0% moisture, whereas the unmined 6- to 12-inch layer contained only 19.7% moisture at wilting point. Thus, mining decreased the available water 4% and 5% in the 0- to 6- and 6- to 12-inch layers, respectively.

Consequently, during droughts the crops wilted on the mined soil before they did on the unmined. This was particularly true with corn as shown in Figure 6.

Pore Space and Bulk Density

On the unmined area there was a decrease in the percent of large pore space with depth and a small increase in the percent of small pore space (Table 1). Bulk density increased with depth.

The mined soil followed a similar pattern to that of the unmined in regard to pore size distribution. On the average, the percent of large pores was a little higher for the mined area as compared to that of the unmined and the percent of small pore space was a little lower. Bulk density was generally lower on the mined area than the unmined and did not show much increase with depth.

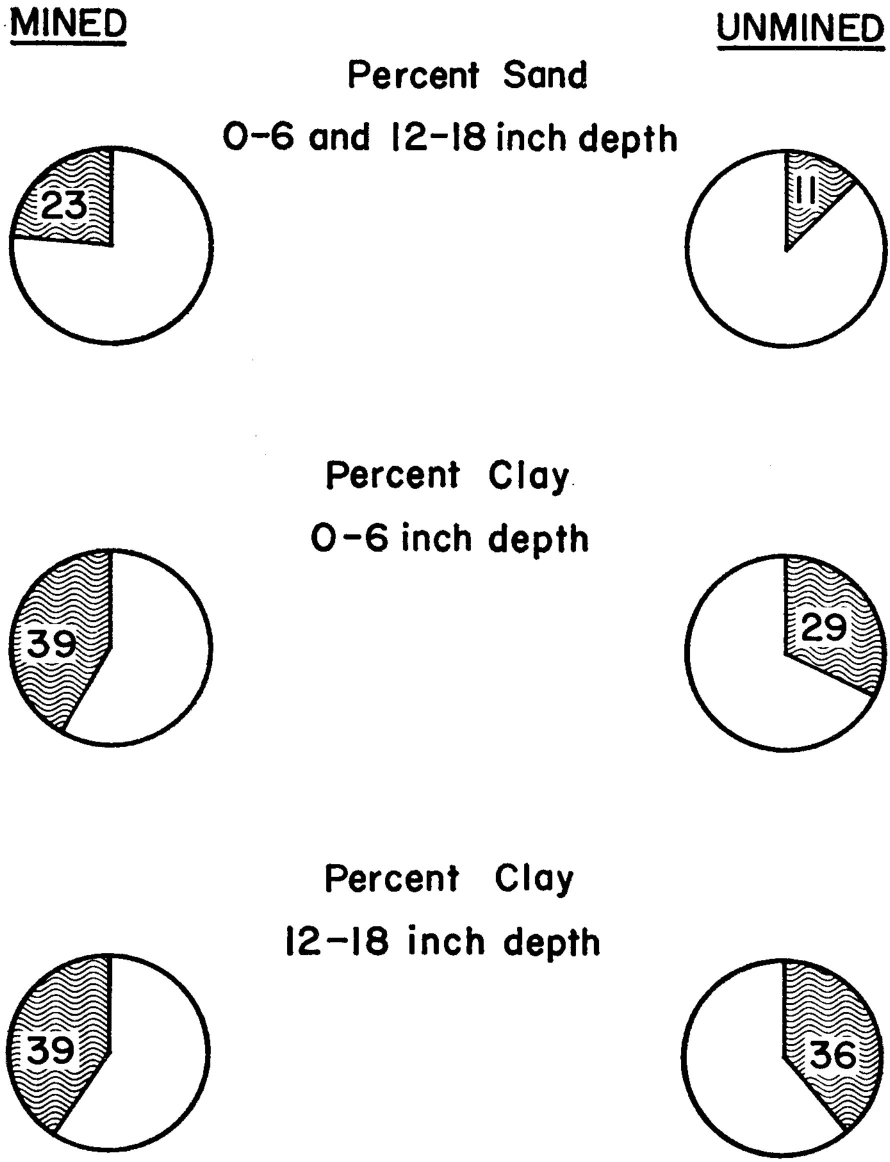

Figure 4. Percent sand and clay in mined and unmined soil.

Organic Matter

As depth increased in the unmined soil, organic matter decreased, whereas it changed very little in the mined soil

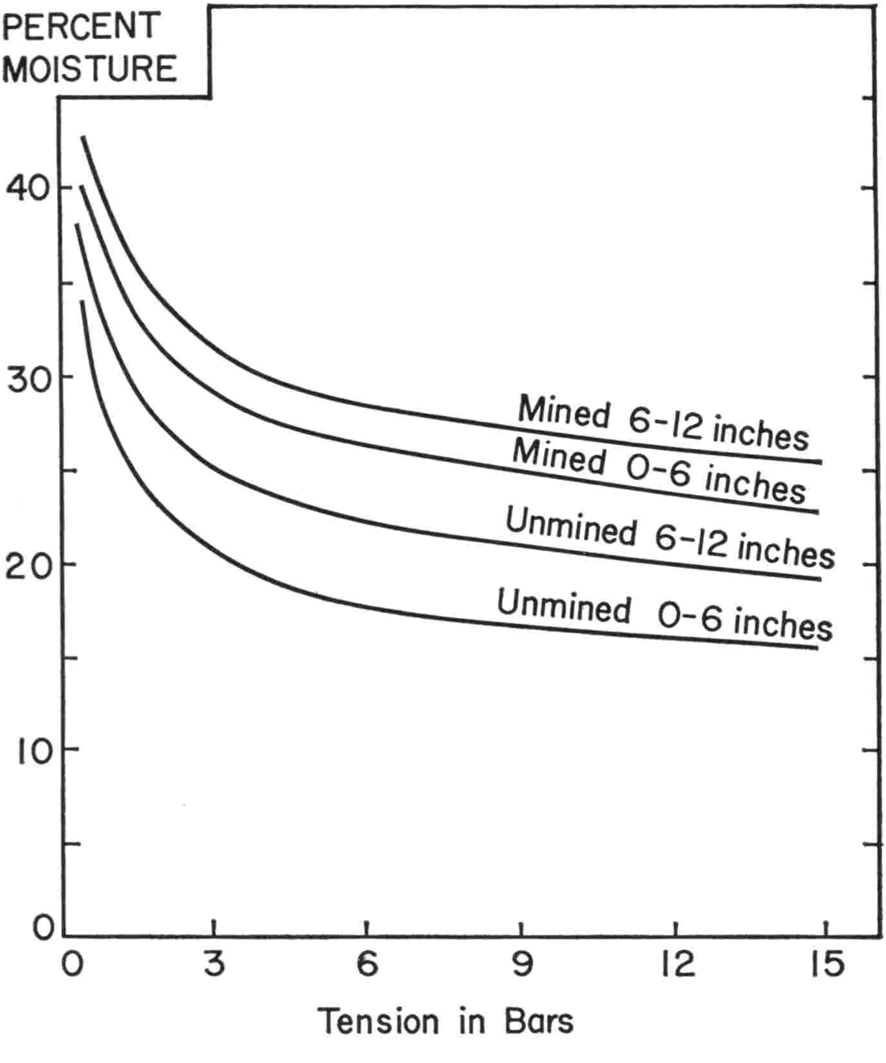

Figure 5. Volume percent moisture retained in mined and unmined soil at different moisture tensions.

(Table 1). In the 0- to 6-inch layer of the unmined soil, organic matter measured 1.71% as compared to 0.71% in the mined soil. At the 12- to 18-inch depth, the unmined soil contained 0.57% organic matter as compared to 0.69% for the mined soil.

As suspected from the low organic content, the mined

A B

Figure 6. Corn on unmined (A) and mined plots (B) showing moisture stress on the mined plots.

soil was very deficient in nitrogen and higher rates of this element were required for non-legume crop production than on unmined soil.

Table 1.—Bulk density and percent large pore space, small pore space, available water and organic matter for mined and unmined soil

Soil property	Soil Depth					
	0-6 In.		6-12 In.		12-18 In.	
	Mined	Unmined	Mined	Unmined	Mined	Unmined
Bulk density (gms/cm^3)	1.33	1.39	1.38	1.46	1.39	1.53
Percent large pores	20	19	17	17	15	13
Percent small pores	15	16	16	17	16	18
Percent available water	18	22	16	21	—	—
Percent organic matter	0.71	1.71	0.63	1.10	0.69	0.57

pH, Phosphorus, and Potassium

The pH on the unmined soil was higher in the surface and decreased with depth. At the surface, the average pH was 6.1 and decreased to 5.1 at the 30- to 36- inch depth (Table 2).

The pH on the mined soil, unlike that of the unmined soil, did not change with depth (Table 2). Mining tended to mix the surface layers with the lower portions and produced a soil that was rather homogeneous in relation to depth. Disregarding sample site II A, pH of the mined soil ranged from a low of 5.0 to a high of 5.7; the average pH was the same—5.3—for the surface 0 to 6 inches and the 30- to 36-inch depth. Sample site II A contained a high amount of original topsoil as indicated by chemical and physical soil analysis as well as plant growth.

All samples taken from the mined soil tested 150+ pounds of phosphorus per acre. The unmined soil ranged from 35 to 130 pounds of phosphorus per acre. Mining tended to increase the soil test values for phosphorus even though the soil was testing high (above 25) on the unmined soil. However, the acid extracting solution used in soil testing[1] will give higher phosphorus values for soils containing rock phosphate than for soils containing the same amount of plant-available phosphorus.

There was little difference in the soil test results for potassium on the mined and unmined soils. Most samples on both the mined and unmined soils were in the medium test range (130-190 lb./A).

The response to added potassium by the crops substantiate the soil test results. Sudangrass was the only crop that gave a significant response to added potassium. This was on both the mined and unmined soil and was probably related to the potassium removed in the forage.

Moisture Use

Moisture use rates were calculated from periodic soil moisture measurements by the neutron method. Measurements were made to a depth of 54 inches or in some cases to bed rock. The rainfall plus the net soil moisture change represents the moisture use for a given period. Such procedures assume no water loss from runoff or deep percolation.

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[1] For Tennessee soil testing procedures, see "Procedures used by State Soil Testing Laboratories in the Southern Region of the United States," Bulletin No. 102, Southern Cooperative Series, June 1965.

Table 2.—Results of chemical analysis for pH. phosphorus, and potassium on mined and unmined soil

Mined

Chemical analysis	Sample depth	Sample sites								
	Inches	IA	IB	IC	IIA	IIB	IIC	IIIA	IIIB	IIIC
pH	0-6	5.5		5.4	6.3		5.0	5.4		5.0
	6-12	5.4		5.3	6.4		5.3	5.5		5.3
	12-18	5.4	5.6	5.2	6.2	5.1	5.4	5.7	5.5	5.5
	18-24	5.5	5.5	5.4	6.4	5.0	5.3	5.6	5.3	5.3
	24-30	5.5	5.6	5.2	6.3	5.0	5.2	5.5	5.5	5.2
	30-36	5.4	5.7	5.3	6.4	5.0	5.2	5.4	5.5	5.2
Available Phosphorus Lb. per acre	0-6	150		150	150		150	150		150
	6-12	150		150	150		150	150		150
	12-18	150	150	150	150	150	150	150	150	150
	18-24	150	150	150	150	150	150	150	150	150
	24-30	150	150	150	150	150	150	150	150	150
	30-36	150	150	150	150	150	150	150	150	150
Exchangeable Potassium Lb. per acre	0-6	150		120	150		170	200		180
	6-12	160		120	180		150	160		180
	12-18	160	150	130	150	170	150	160	170	140
	18-24	150	150	140	140	170	140	170	150	140
	24-30	150	200	120	150	170	140	160	140	150
	30-36	130	170	140	130	180	180	140	140	140

Unmined

Chemical analysis	Sample depth	Sample sites		
	Inches	IA	IIA	IIIA
pH	0-6	6.1	6.1	6.2
	6-12			
	12-18	6.1	5.6	5.5
	18-24	5.9		5.3
	24-30	5.3	5.3	5.0
	30-36	5.0	5.5	4.9
Available Phosphorus Lb. per acre	0-6	65	65	70
	6-12			
	12-18	60	100	130
	18-24	50		100
	24-30	35	130	60
	30-36	35	130	65
Exchangeable Potassium Lb. per acre	0-6	150	140	150
	6-12			
	12-18	140	130	130
	18-24	130		140
	24-30	120	170	150
	30-36	140	170	150

Table 3.—Moisture use by corn on unmined soil

Sampling period	1963 Inches water	1963 Average daily use	1964 Inches water	1964 Average daily use	1965 Inches water	1965 Average daily use	Average Inches water	Average Daily use
				Mined				
June 17-June 30	1.23	.09	1.30	.09	2.76	.20	1.76	.13
July 1-July 14	3.24	.23	1.60	.11	3.78	.27	3.23	.21
July 15-July 28	5.22	.37	2.46	.18	2.20	.16	3.29	.24
July 29-Aug. 11	3.79	.27	3.44	.25	2.34	.17	3.20	.33
Aug. 12-Aug. 25	1.97	.14	2.27	.16	2.79	.20	3.34	.17
Aug. 26-Sept. 8	1.97	.14	2.03	.15			2.00	.14
Total 84 days	17.42	.21	13.09	.16	13.87	.20	16.83	.20
				Unmined				
June 17-June 30	1.80	.15	1.59	.11	2.79	.20	2.06	.15
July 1-July 14	3.67	.24	1.46	.10	3.65	.26	2.93	.20
July 15-July 28	4.38	.31	1.82	.13	1.59	.11	2.60	.18
July 29-Aug. 11	4.38	.31	2.69	.19	1.88	.13	2.98	.21
Aug. 12-Aug. 25	1.33	.10	2.98	.21	2.03	.15	2.12	.15
Aug. 26-Sept. 8	1.33	.10	.66	.05			1.00	.08
Total 84 days	16.89	.20	11.21	.14	11.94	.17	13.68	.16
Planting dates:	April 23, 1963		May 5, 1964		May 20, 1965			

Table 4.—Moisture use by grain sorghum on mined and unmined soil

Sampling period	1963 Inches water	1963 Average daily use	1964 Inches water	1964 Average daily use	1965 Inches water	1965 Average daily use	Average Inches water	Average Daily use
	Mined							
June 17-June 30	1.22	.09	.61	.04	3.41	.24	1.75	.12
July 1-July 14	3.88	.28	1.38	.10	3.90	.28	3.05	.22
July 15-July 28	4.53	.32	3.17	.23	1.62	.12	3.10	.22
July 29-Aug. 11	4.54	.32	2.87	.20	3.04	.21	3.47	.25
Aug. 12-Aug. 25	2.24	.16	2.62	.19	4.58	.33	3.15	.22
Aug. 26-Sept. 8	2.24	.16	1.80	.13			2.02	.14
Total 84 days	18.64	.22	12.45	.15	16.51	.24	16.54	.20
	Unmined							
June 17-June 30	1.93	.14	1.18	.08	2.52	.18	1.88	.13
July 1-July 14	2.41	.21	2.69	.19	3.14	.22	2.77	.21
July 15-July 28	4.22	.30	1.88	.13	2.68	.19	2.92	.21
July 29-Aug 11	4.22	.30	3.27	.23	1.65	.12	3.05	.22
Aug. 12-Aug. 25	1.76	.13	2.35	.17	2.68	.19	2.26	.16
Aug. 26-Sept. 8	1.76	.13	1.81	.13			1.79	.13
Total 84 days	16.30	.20	13.17	.16	12.67	.18	14.67	.17
Planting dates:	April 23, 1963		June 3, 1964		May 20, 1965			

The daily moisture use for corn during the period of ear development was greater on the mined soil than on the unmined plots (Table 3). For the period of July 15 to July 28, the daily moisture use on the mined soil was 0.24 of an inch as compared to 0.18 of an inch on the unmined plots. For the period of July 29 to August 11, the daily moisture use on the mined area was 0.33 of an inch compared to 0.21 of an inch on the unmined plots. Some difference was observed for the other periods; however, they were closer than for the periods mentioned.

The moisture use difference for grain sorghum (Table 4) was not as great as the difference for corn. The greatest difference occurred in the period of August 12 to August 25; then the daily use on the mined soil was 0.22 of an inch per day as compared to 0.16 of an inch per day on the unmined plots.

There was less difference in daily moisture use of Sudangrass between the mined soil and the unmined plots (Table 5). The unmined plots had a greater daily use during the early part of the growing season, but the daily use for the mined soil was greater during the latter part of the growing season. The greatest difference occurred during the period of August 26 to September 8 when the average daily use on the mined soil was 0.15 of an inch compared to 0.09 of an inch for the unmined plots.

For lespedeza (Table 6), the daily moisture use for the period of July 15 to July 28 was 0.21 of an inch for the mined soil as compared to 0.15 of an inch on the unmined. However, for the period of July 29 to August 11, the daily moisture use on the mined soil was 0.19 of an inch as compared to 0.23 of an inch for the unmined. There was little difference between the moisture use on the mined and unmined soil for the other periods.

Rainfall Distribution and Corn Yields

Rainfall distribution during the growing season greatly influences the yield of summer crops. This is especially true for corn which requires the greatest percentage of its moisture during ear formation and development. The period of ear development for most corn grown in Middle Tennessee is usually from July 1 to August 15. The rainfall during this period in 1955, 1956, and 1957 was below the average for all 3 years (Table 7). Also, the corn yields showed little re-

Table 5.—Moisture use by Sudangrass on mined and unmined soil

Sampling period	Year: 1963 Inches water	1963 Average daily use	1964 Inches water	1964 Average daily use	1965 Inches water	1965 Average daily use	Average Inches water	Average Daily use
				Mined				
June 17-June 30	1.48	.12	1.39	.10	2.20	.16	1.69	.12
July 1-July 14	2.27	.20	1.53	.11	3.43	.24	2.41	.18
July 15-July 28	5.12	.36	2.07	.15	1.14	.08	2.78	.20
July 29-Aug. 11	2.96	.20	2.29	.16	2.43	.17	2.56	.18
Aug. 12-Aug. 25	1.91	.14	2.33	.17	2.88	.26	2.37	.19
Aug. 26-Sept. 8	1.91	.14	2.23	.16			2.07	.15
Total 84 days	15.64	.19	11.83	.14	12.09	.17	13.87	.17
				Unmined				
June 17-June 30	1.60	.10	1.89	.14	2.48	.18	1.99	.14
July 1-July 14	3.87	.25	1.83	.13	3.24	.23	2.98	.20
July 15-July 28	3.11	.25	1.57	.11	2.85	.20	2.51	.19
July 29-Aug. 11	3.11	.25	2.20	.16	1.96	.14	2.43	.18
Aug. 12-Aug. 25	1.98	.10	2.48	.18	2.29	.16	2.25	.15
Aug. 26-Sept. 8	1.98	.10	1.27	.09			1.62	.09
Total 84 days	15.66	.19	11.23	.13	12.83	.18	13.78	.16
Planting dates:	May 6, 1963		May 19, 1964		May 10, 1965			

Table 6.—Moisture use by lespedeza on mined and unmined soil

Sampling period	Year							
	1963		1964		1965		Average	
	Inches water	Average daily use	Inches water	Average daily use	Inches water	Average daily use	Inches water	Daily use
				Mined				
June 17-June 30	1.31	.09	1.68	.12	2.39	.17	1.79	.13
July 1-July 14	2.71	.16	1 84	.13	3.75	.27	2.77	.19
July 15-July 28	5.04	.34	2.04	.15	2.08	.15	3.05	.21
July 29-Aug. 11	2.90	.17	2.26	.16	3.16	.23	2.77	.19
Aug. 12-Aug. 25	2.08	.15	2.36	.17	2.69	.19	2.38	.17
Aug. 26-Sept. 8	2.08	.15	2.07	.15	1.27	.10	1.80	.13
Total 84 days	16.11	.19	12.25	.15	15.34	.18	14.56	.17
				Unmined				
June 17-June 30	1.94	.15	2.31	.17	1.78	.13	2.01	.15
July 1-July 14	2.91	.18	.78	.06	2.56	.18	2.08	.14
July 15-July 28	2.67	.23	1.46	.10	1.80	.13	1.98	.15
July 29-Aug. 11	2.67	.23	3.45	.25	2.88	.21	3.00	.23
Aug. 12-Aug. 25	2.16	.15	2.23	.16	3.23	.24	2.54	.18
Aug. 26-Sept. 8	2.16	.15	.36	.03	2.02	.14	1.51	.11
Total 84 days	14.51	.18	10.57	.13	14.26	.20	13.11	.16
Planting dates:	March 29, 1963		March 24, 1964		March 23, 1965			

Table 7.—Rainfall data for years in which summer crop yields are reported

	Days	1955	1956	1957	1958	1959	1963	1964	1965	Mean
						Inches of rainfall				
April	1-15	3.15	3.65	3.26	3.20	2.09	0.65	6.85	1.86	3.08
	16-30	2.78	0.57	0.57	3.29	0.96	2.41	2.94	1.61	1.89
May	1-15	2.08	2.02	0.41	3.45	1.01	0.98	3.11	0.55	1.10
	16-31	3.68	1.01	7.71	0.84	3.13	1.99	1.10	4.13	2.94
June	1-15	1.15	0.82	2.26	1.83	1.62	0.13	1.99	4.06	1.73
	16-30	1.00	2.44	2.00	1.60	1.16	2.60	0.46	1.02	1.53
July	1-15	0.41	2.10	0.21	3.55	0.07	2.71	1.57	4.19	1.85
	16-31	0.67	0.70	1.92	3.74	6.19	4.80	1.55	0.90	2.55
August	1-15	1.70	1.64	0.13	1.17	1.42	4.07	1.43	0.70	1.53
	16-31	1.73	3.59	1.09	0.71	3.12	2.37	4.49	1.45	2.31
September	1-15	0.00	1.25	3.35	0.32	2.42	0.08	0.00	0.63	1.00
	16-30	2.09	0.26	2.45	5.27	0.35	0.56	2.66	1.15	1.84
Total April-September		20.44	20.05	25.36	28.97	23.54	23.35	28.15	22.25	24.01

sponse to N during these 3 years (Table 8). In 1958 and 1959, the rainfall averaged about 8.07 inches as compared to 3.16 inches for the previous 3 years during the same 6-week period. Corn yields also increased during 1958 and 1959 on the higher nitrogen treatments.

In 1963, 11.58 inches of rain was recorded during the 6-week ear development period. The yields for the higher nitrogen treatments on mined land were much higher in 1963 than for 1964 and 1965 when an average of 5.16 inches of rain was recorded for this same period (Table 9).

Table 8.—Yields of corn before the soil was mined

Treatment N-P-K	1955	1956	1957	1958	1959	5 Year Average
Lb./A			Bushels per acre			
50-0-0	85.6	74.6	80.5	80.0	94.4	83.0
100-0-0	84.6	81.7	77.4	100.9	113.3	91.6
50-0-25	70.4	66.0	75.9	69.3	112.3	78.8
100-0-25	83.5	72.0	81.7	93.6	117.3	89.6
50-0-50	77.6	73.4	75.5	79.6	121.2	85.5
100-0-50	87.2	77.5	88.1	95.2	117.5	93.1

Table 9.—Yields of corn after the soil was mined

Treatment N-P-K	1963	1964	1965	Average
Lb./A		Bushels per acre		
0-0-0	39.9	31.5	18.7	30.0
	Response to nitrogen			
50-0-50	62.3	49.8	25.8	46.0
100-0-50	89.6	71.8	42.9	68.1
150-0-50	100.8	67.4	54.4	74.2
L.S.D. (.05)	21.9	N.S.	15.7	11.6
	Response to potassium			
100-0-0	84.3	56.8	46.6	62.6
100-0-25	91.6	76.4	49.5	72.5
100-0-50	89.6	71.8	42.9	68.1
L.S.D. (.05)	N.S.	14.5	N.S.	N.S.
	Response to lime			
No Lime	88.5	68.3	46.3	67.7
3 Tons Lime	96.8	67.6	49.1	71.2
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.

The yields of corn were low after mining when no fertilzers were applied. The 3-year average yield was 30 bushels per acre. These plots were easy to distinguish by their poor growth and pale color as shown in Figure 7. However, increased yields were obtained when nitrogen was applied at the rates of 50, 100, and 150 pounds per acre. For the 3-year average, a significant yield response to nitrogen was obtained on the mined soil when the rate was increased from 50 to 100 pounds per acre (Table 9). The yield for the 150-pound per acre treatment was not significantly greater than for the 100-pound treatment.

No significant yield response to nitrogen above 50 pounds per acre was obtained on the unmined plots (Table 10). When nitrogen was applied at the rate of 50 pounds per acre, the average yields were higher on the unmined plots than on the mined soil. However, as the rates were increased to 100 and 150 pounds per acre, the average yields on the mined soil were as great as for the unmined. For the 3-year average, the yields on the mined soil were 74.2 bushels per acre for the 150-pound application of nitrogen as compared to 68.2 bushels per acre for the unmined.

Table 10.—Yields of corn on adjacent unmined soil

Treatment N-P-K	1963	1964	1965	Average
Lb./A		Bushels per acre		
50-0-50	102.3	50.3	46.5	66.4
100-0-50	94.4	49.9	49.2	64.5
150-0-50	99.7	53.3	51.5	68.2
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.

Application of 3 tons of lime per acre on the mined soil gave no significant yield response.

Potassium was applied at the rates of 25 and 50 pounds per acre. There was a significant yield response to potassium in 1 of the 3 years. However, no significant yield response to potassium was found for the 3-year average on the mined soil.

On corn, after the soil was mined, a uniform application of zinc sulfate was applied at the rate of 20 pounds per acre. Two border rows were left untreated. Each year, severe zinc deficiencies were observed on the corn rows that did

Figure 7. Corn plots on mined soil receiving 100 pounds of nitrogen per acre and no fertilizer.

Figure 8. Grain sorghum plots on mined soil receiving no fertilizer and 100 pounds of nitrogen per acre.

not receive zinc sulfate. However, zinc deficiencies have been observed on corn that was grown on similar unmined soil in the Central Basin area after liming.

Grain Sorghum Yields

The fertility treatments used on grain sorghum after mining were the same as those used on corn. On the mined soil, there was a significant response to nitrogen (Figure 8 and Table 11). The yield increase was significant as the nitrogen rate was increased to 100 pounds per acre. For the 3-year average, the 150-pound treatment yielded 77.2 bushels per acre for the mined as compared to 73.7 bushels per acre for the unmined plots. On the unmined plots a significant response to nitrogen was obtained in 1965, but the nitrogen response for the 3-year average was not significant (Table 12).

On the mined soil no significant response to potassium was observed during any of the 3 years or for the 3-year average.

Lime resulted in a significant yield reduction of grain sorghum.

Table 11.—Yields of grain sorghum after the soil was mined

Treatment N-P-K	1963	1964	1965	Average
Lb./A	Bushels per acre			
0-0-0	40.9	34.2	21.1	30.0
	Response to nitrogen			
50-0-50	59.5	55.1	68.2	60.9
100-0-50	70.6	68.6	86.7	75.3
150-0-50	73.1	63.7	94.7	77.2
L.S.D. (.05)	N.S.	N.S.	15.7	11.6
	Response to potassium			
100-0-0	76.2	65.5	90.9	77.5
100-0-25	73.7	65.0	94.1	77.6
100-0-50	70.6	68.6	86.7	75.3
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.
	Response to lime			
No Lime	73.5	66.3	90.6	76.8
3 tons Lime	61.6	55.8	86.2	67.9
L.S.D. (.05)	8.8	8.0	N.S.	4.8

Table 12.—Yields of grain sorghum on adjacent unmined soil

Treatment N-P-K	1963	1964	1965	Average
lb./A		Bushels per acre		
50-0-50	72.9	57.0	79.7	69.9
100-0-50	77.7	57.0	90.1	74.9
150-0-50	79.1	53.6	88.3	73.7
L.S.D. (.05)	N.S.	N.S.	5.8	N.S.

Sudangrass Yields

Nitrogen was applied at the rates of 0, 60, 90, and 120 pounds of nitrogen per acre after the soil was mined. There was a significant yield response to nitrogen when the rates were increased from 0 to 60 pounds and from 90 to 120 pounds (Table 14). No significant response was obtained when the rate was increased from 60 to 90 pounds.

When 3 tons of lime per acre was applied without the potassium treatments, no significant yield response to lime was obtained on the mined soil. However, when lime was applied with the K treatments, a significant yield response for the 3-year average was obtained on the mined soil.

The potassium treatments (after the soil was mined), were 0, 25, and 50 pounds per acre. A significant response was obtained at the potassium rate of 25 pounds per acre, but no significant yield increase occurred when the rates were increased from 25 to 50 pounds per acre.

Table 13.—Yields of Sudangrass before the soil was mined

Treatment N-P-K	1956	1957	1958	1959	Average
lb./A			Tons per acre		
0-0-0	2.88	1.40	1.36	1.49	1.78
30-0-0	3.10	2.16	1.87	1.58	2.18
60-0-0	3.97	3.12	1.97	1.72	2.70
90-0-0	3.90	2.69	1.80	1.65	2.51
0-0-25	3.17	1.42	1.34	1.75	1.92
30-0-25	3.89	2.32	2.33	2.07	2.65
60-0-25	3.82	3.25	2.03	1.96	2.77
90-0-25	3.80	2.71	2.17	1.92	2.65
0-0-50	2.91	1.34	1.19	1.54	1.75
30-0-50	3.51	2.33	1.93	2.22	2.99
60-0-50	4.15	3.60	2.00	2.19	2.99
90-0-50	4.13	3.35	2.14	2.07	2.92

Table 14.—Yields of Sudangrass after the soil was mined

Treatment N-P-K	1963	1964	1965	Average
Lb./A		Tons per acre		
0-0-0	1.32	1.74	.84	1.30
	Response to nitrogen			
0-0-0	1.32	1.74	.84	1.30
60-0-0	2.07	2.32	2.36	2.25
90-0-0	1.85	2.00	2.48	2.11
120-0-0	2.34	2.59	3.37	2.77
L.S.D. (.05)	.08	.54	.59	.24
	Response to potassium			
90-0-0	1.74	1.83	2.28	1.95
90-0-25	2.55	2.76	2.99	2.73
90-0-50	2.18	2.35	2.58	2.37
L.S.D. (.05)	.51	.51	N.S.	.08
	Response to lime			
No lime	2.16	2.31	2.62	2.36
3 Tons lime	2.32	2.75	3.04	2.70
L.S.D. (.05)	.14	N.S.	N.S.	.26

On the unmined plots no significant yield response to added potassium was obtained for any of the 3 years. However, the average yield response to potassium for 3 years was small but statistically significant (Table 15).

Lespedeza Yields

After the soil was mined, potassium treatments were applied to the lespedeza at the rates of 0, 25, 50, 75, and 100 pounds per acre. Lime was applied at the rate of 3 tons per

Table 15.—Yields of Sudangrass on adjacent unmined soil

Treatment N-P-K	1963	1964	1965	Average
Lb./A		Tons per acre		
90-0-0	2.26	1.97	1.91	2.05
90-0-25	2.39	2.15	2.13	2.22
90-0-50	2.44	2.64	2.28	2.45
L.S.D. (.05)	N.S.	N.S.	N.S.	.29

Table 16.—Yields of lespedeza afer the soil was mined

Treatment N-P-K	1963	1964	1965	Average
Lb./A		Tons per acre		
0-0-0 Plus 3 tons lime	2.74	1.92	1.77	2.14
	Response to potassium			
0-0-0 Plus 3 tons lime	2.74	1.92	1.77	2.14
0-0-25 Plus 3 tons lime	3.33	1.85	1.74	2.31
0-0-50 Plus 3 tons lime	2.79	1.63	1.86	2.09
0-0-75 Plus 3 tons lime	2.66	1.98	1.85	2.16
0-0-100 Plus 3 tons lime	2.94	1.72	1.76	2.13
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.
	Response to lime			
No lime	3.11	1.62	1.80	2.18
3 Tons lime	2.87	1.67	1.79	2.11
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.
	Response to micronutrients			
No micronutrients	2.94	1.72	1.72	2.13
Es-Min-El (100 Lb./A)	2.65	1.83	1.88	2.12
L.S.D. (.05)	N.S.	N.S.	.14	N.S.

acre and a micronutrient treatment, Es-Min-El, was applied at the rate of 100 pounds per acre.

For the 3-year average, no significant yield response to lime, potassium, or micronutrients was obtained on the mined soil (Table 16). Also no significant response to added potassium occurred on the unmined plots (Table 17).

Table 17.—Yields of lespedeza on adjacent unmined soil

Treatment N-P-K	1963	1964	1965	Average
Lb./A		Tons per acre		
0-0-0	2.72	2.04	2.29	2.35
0-0-25	2.88	2.20	2.41	2.50
0-0-50	2.68	2.15	2.44	2.42
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.

Alfalfa Yields

After the soil was mined, potassium was applied at rates of 0, 83, 166, and 249 pounds per acre. Other treatments were lime at the rate of 6 tons per acre, phosphorus at the

Table 18.—Yields of alfalfa before the soil was mined

Treatment N-P-K	1955	1956	1957	1958	Average
lb./A			Tons per acre		
0-0-0	2.05	3.08	3.03	2.97	2.78
0-0-42	2.69	3.73	3.88	3.41	3.43
0-0-83	2.46	3.07	3.21	3.28	3.01
0-0-166	2.87	3.46	3.79	4.16	3.57
L.S.D. (.05)	0.39	N.S.	N.S.	0.72	.34

rate of 26 pounds per acre, and a micronutrient mixture, Es-Min-El, at the rate of 100 pounds per acre.

A significant yield increase occurred when 6 tons of lime per acre was applied. No significant response for the potassium treatments was observed due to a significant lime x potassium interaction. The yields for the treatments receiving potassium plus lime were as great or greater on the mined soil than on the unmined soil. The phosphorus treat-

Table 19.—Yields of alfalfa after the soil was mined

Treatment N-P-K	1965	1966	2 Yr. avg.
Pounds/A		Tons per acre	
	Response to phosphorus		
0-0-166	3.74	4.06	3.90
0-26-166	4.13	4.16	4.15
L.S.D. (.05)	N.S.	N.S.	N.S.
	Response to potassium		
0-0-0	2.07	2.26	2.17
0-0-83	1.68	2.01	1.85
0-0-166	1.61	2.03	1.82
L.S.D. (.05)	N.S.	N.S.	N.S.
	Response to lime		
No lime	1.79	2.10	1.95
6 tons lime/A	3.84	3.72	3.78
L.S.D. (.05)	.83	.76	.51
	Response to micronutrients		
No micronutrients	3.74	4.06	3.90
Es-Min-El (100 Lb./A)	5.10	4.67	4.89
L.S.D. (.05)	N.S.	N.S.	.79

ment gave no significant yield increase. There was no significant response to micronutrients in 1965 or 1966; however, the average yield response to micronutrients for the 2 years was significant (Table 19).

Rye and Crimson Clover Yields

Prior to mining, significant yield increases from nitrogen were obtained each year (Table 20). However, no significant response to potassium was observed.

Table 20.—Yields of rye and crimson clover before the soil was mined

Treatment	1957	1958	1959	1960	Average
			Tons per acre		
	Response to nitrogen				
lb. N/A					
0	1.49	1.68	1.05	0.89	1.28
30	1.96	2.00	1.29	1.12	1.59
60	2.75	2.53	1.63	1.66	2.14
90	2.95	2.76	1.86	1.93	2.37
L.S.D. (.05)	0.17	0.32	0.18	0.37	0.12
	Response to potassium				
lb. K_2O/A					
0	2.25	2.12	1.39	1.36	1.78
25	2.26	2.36	1.49	1.41	1.88
50	2.36	2.25	1.50	1.42	1.88
L.S.D. (.05)	N.S.	N.S.	N.S.	N.S.	N.S.

On the mined soil, nitrogen was applied at the rates of 60, 90, and 120 pounds per acre. Potassium was applied at the rates of 0, 25, and 50 pounds per acre. Lime was applied at the rate of 4 tons per acre.

For the 2-year average after mining, no significant yield response to potassium was observed. There was a significant response to nitrogen at all rates the first year after mining. However, for the second year and the 2-year average, nitrogen did not show a significant response. No significant response to lime occurred the first year. A significant response to lime occurred the second year and for the 2-year average, as reported in Table 21.

Table 21.—Yields of rye and crimson clover after the soil was mined

Treatment N-P-K	1964	1965	Average
Lb./A		Tons per acre	
0-0-0 Plus 4 tons lime	.36	.56	.46
	Response to nitrogen		
60-0-50	1.44	2.02	1.73
90-0-50	1.89	1.96	1.93
120-0-50	2.40	1.89	2.15
L.S.D. (.05)	.36	N.S.	N.S.
	Response to potassium		
60-0-0 Plus 4 tons lime	1.32	1.22	1.27
60-0-25 Plus 4 tons lime	1.17	1.05	1.11
60-0-50 Plus 4 tons lime	1.27	1.19	1.23
L.S.D. (.05)	N.S.	N.S.	N.S.
	Response to lime		
No lime	1.88	1.44	1.66
4 Tons lime	1.91	1.96	1.94
L.S.D. (.05)	N.S.	.32	.26

Oat and Wheat Yields

After the soil was mined, nitrogen was applied at the rates of 15, 30, and 45 pounds per acre. Potassium was applied at rates of 25 and 50 pounds per acre.

Great difficulty was encountered in keeping stands of fall-seeded crops on the mined soil. Even though good stands were obtained in the fall, the stands did not remain through the winter due to freezing and heaving. On the

Table 22.—Yields of wheat before the soil was mined

Treatment N-P-K	1955	1956	1957	Average
Lb./A		Bushels per acre		
30-0-0	40.3	38.8	35.1	38.1
45-0-0	41.8	49.0	38.8	43.2
30-0-25	40.4	36.2	31.0	35.9
45-0-25	39.4	48.7	37.5	41.9
30-0-50	38.0	35.6	30.8	34.8
45-0-50	41.3	48.7	38.2	42.7
L.S.D. (.05)	N.S.	7.1	5.3	3.3

higher nitrogen treatments, the stands of small grain were better than on the lower nitrogen treatments.

The stands of wheat and oats were poor the first year after mining. The oats were not harvested the second year because of a very poor stand. With the exception of the plots that did not receive any fertilizer, the stands of rye and crimson clover were better than the oats and wheat.

No significant yield response to nitrogen by wheat was obtained in 1964. However, for 1965 and for the 2-year average, a significant response occurred (Table 23). Significant responses were obtained when the rates were increased from 15 to 30 pounds and from 30 to 60 pounds. The increase from 30 to 45 pounds was not significant.

The response to potassium was not significant for either of the 2 years or for the 2-year average.

Table 23.—Yields of wheat after the soil was mined

Treatment N-P-K	1964	1965	Average
Lb./A		Bushels per acre	
0-0-0	4.6	6.4	5.5
	Response to nitrogen		
15-0-25	13.6	8.4	11.0
30-0-25	23.1	16.4	19.8
45-0-25	30.7	23.0	26.9
60-0-25	33.1	26.8	30.0
L.S.D. (.05)	N.S.	10.7	7.3
	Response to potassium		
45-0-25	30.7	23.0	26.9
45-0-50	24.5	22.0	23.3
L.S.D. (.05)	N.S.	N.S.	N.S.

Lespedeza Yields Following Wheat and Oats

Lespedeza was overseeded each spring on the oat and wheat ranges. No additional fertility treatments were applied after the small grain was harvested. For 1964, 1965, and the 2-year average, there was no significant response to potassium as reported in Tables 24 and 25.

Table 24.—Yields of lespedeza following wheat after the soil was mined

Treatment N-P-K on wheat	1964	1965	Average
Lb./A		Tons per acre	
0-0-0	1.01	1.63	1.32
	Response to potassium		
45-0-25	1.10	1.19	1.15
45-0-50	1.25	1.24	1.25
L.S.D. (.05)	N.S.	N.S.	N.S.

Table 25.—Yields of lespedeza following oats after the soil was mined

Treatment N-P-K on oats	1964	1965	Average
Lb./A		Tons per acre	
0-0-0	.95	1.79	1.37
	Response to potassium		
45-0-25	.86	1.56	1.21
45-0-50	.84	1.71	1.28
L.S.D. (.05)	N.S.	N.S.	N.S.

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