

RECLAMATION OF PRIME FARMLAND IN KENTUCKY¹

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Abstract.--Target yields have been achieved for grain crops such as corn, soybeans, and wheat as well as forage crops, alfalfa, timothy, and tall fescue. These crops respond to soil depth, ripping treatments, and soil-handling methods that affect the physical properties such as bulk density. Yields were influenced by past soil reconstruction management such as crop rotation, organic amendments, and crop cultivars (varieties).

INTRODUCTION

Prime farmland reconstruction methodology that was drafted and later implemented into law was general by technical nature and did not give ample attention and flexibility to site-specific conditions. Conditions encountered in Western Kentucky for typical prime farmland situations are not like those encountered in Illinois, Missouri, Iowa, etc. Prime farmland soil series from these regions (with some exceptions) usually exhibit thicker A horizons, higher organic matter content, more fertile and neutral subsoils, and deeper effective rooting depths than do typical prime series encountered in Western Kentucky. As a result, expected and required target level yields for reconstructed prime farmland are significantly lower than those from the more traditional "corn belt" states. Therefore, it was the belief of the authors that thickness of

subsoil may have a lesser effect on the yielding capacity of reconstructed prime farmland. Furthermore, post-reconstruction soil and crop management inputs may be just as important in attaining target yields as is depth of soil replacement.

As a result, we began a series of long-term experiments to evaluate a number of objectives. Among those included are: optimum and practical depth of soil replacement needed, the best reconstruction methods to use in relation to soil, handling operations, response of soil ripping after replacement and its effect upon crop yields and soil bulk density, and various post-reconstruction management inputs needed to maximize crop yields. This paper is intended to serve as a progress report related to what we have determined, to date, in relation to restoration of prime agricultural lands as a postmining land use in Western Kentucky.

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METHODS

Soil Depth Replacement Studies

Alston Soil Reconstruction Study

In 1978, a field study was begun at Alston Surface Mine in Ohio County, Kentucky. Details of plot construction are given elsewhere, Barnhisel et al., 1979. The objectives of this study were: (1) Determine what practices in relation to soil replacement depth are (or are not) needed to return reclaimed prime farmland to a state of equal or higher productivity, (2) determine if the graded overburden was suitable for rooting medium and for which specific crops, (3) determine the extent and

severity of soil compaction, and (4) determine if a response to liming of the typically acidic subsoil materials would occur. An area of spoil was graded to a 2% slope and a 3 x 2 x 2 factorial experimental design was used to evaluate the following factors. The three main blocks were subsoil (B2t horizon) thickness variables. In one case this was 32 inches thick or equivalent to the thickness for prime land. For the second treatment the subsoil was not replaced, and in the third case it had a thickness of 16 inches. Each of these main treatments was divided into two areas prior to replacement of the topsoil (Ap horizon); to one-half, 20 T/A of Ag limestone was incorporated into the subsoil (or spoil) before the 8 inches of Ap horizon was replaced. After the soil was replaced the area was divided into plots of 24 x 36 feet for the three test crops. There were 4 replications for each crop, corn, soybeans and alfalfa. Each of these 72 plots was divided into half and one-half was subsoiled to a depth of 20 inches; the other half was not subsoiled. The soil reconstruction process was completed in 1978 and seeded to a wheat cover crop.

Soil samples were collected periodically for analysis, and based upon these results appropriate fertilizers were applied for each crop using high management recommendations. Additional samples were collected for bulk density measurements.

Alfalfa (Medicago sativa L.) was established in April 1979 by broadcasting seed to a freshly-disked soil surface. Corn (Zea mays L.) was planted in May from 1979 to 1984. Soybeans (Glycine max L.) was planted in 1979 through 1983. Wheat (Triticum aestivum L.) was planted in 1981 and was followed by soybeans using a double-cropping system. In addition, 30-foot wide equipment turn-strips were seeded to tall fescue (Festuca arundinacea Schreb.); however, these areas were not harvested for yield measurements. A crop-rotation system was used for the corn-soybeans-wheat portion of the experiment. In 1984 (and 1985) the entire area was plowed and planted to corn.

Yields of corn, wheat, and soybeans were collected by a combine modified to harvest small plots. Alfalfa yields were collected using a rotary mower. (See paper by Barnhisel et al., 1985, this publication, for specific details used for harvesting).

Sinclair Soil Depth and Ripping Study

Initial bulk density data taken from the Alston Study indicated that soil compaction had occurred and that the agricultural subsoiler used was less effective at abating high density than hoped for. Therefore, in 1979 another experiment was established at Sinclair Mine which held the following objectives: (1) determine the maximum soil replacement depth at which significant yield

response no longer occurs for several important agronomic crops growing in reconstructed soil over toxic overburden, (2) determine how various lime incorporation treatments, for the toxic overburden, affect crop yield at various depths of soil replacement after the overburden liming operations, and (3) determine the effects of intensive soil ripping after soil replacement and its effects to crops growing on the ripped sites. Specific details of plot construction are given elsewhere (Huntington et al., 1980).

An area of spoils which had a 30 T/A lime requirement was graded to a 2% slope. A 3 x 3 x 2 factorial design was used to evaluate the effect of lime incorporation, soil depth, and ripping. Three trenches, 33 x 165 feet, were excavated into the spoils at each of two depths, 10 and 20 inches, in each of the four replications. Lime was then broadcast with spreader trucks at 30 T/A over the entire area. Three lime incorporation methods were used (non-incorporation, disked, and shallowly ripped) in the trenches previously excavated to the two depths, as well as on equal-sized unexcavated areas. This resulted in nine main blocks per replication. The trenches were back filled with soil with an additional 10 inches placed on the entire area. This resulted in three soil depths: 10, 20, and 30 inches. One-half of each of these areas was ripped to the soil-spoil interface parallel to the direction the trenches were dug. This resulted in 18 treatment blocks per replication.

Five, 33-foot wide strips were then established in a direction perpendicular to the trenches. These strips were used to test crop response to the above treatments and included corn, wheat, alfalfa, timothy, and soybeans. Yields were measured by appropriate methods as described earlier. Soil samples were collected to provide recommendations for fertilizer applications. Soils samples were also taken for bulk density measurements.

Gibraltar Soil-Handling Method Studies

By 1982 a considerable amount of knowledge had been acquired pertaining to prime farmland reconstruction in Western Kentucky from both experimental plot applications and larger scale field operations. From preliminary studies, we had determined that soil compaction would be a problem to initially restoring productivity potential. At this time we established another experiment which held the following objectives: (1) Determine the relative soil quality (chemical and physical attributes) of reconstructed prime farmland generated by truck and endloader versus standard scraper reconstruction operations, (2) determine the subsequent crop yield response to both methods, (3) perform these tests for both a typical upland and a typical alluvial soil, and (4) subject all combinations of the above to both a stockpiling phase and a direct respread phase

for each reconstruction method for each separate soil series.

In 1982 and before the area was to be mined, three one-acre blocks of Sadler silt loam (Glossic Fragiudalf; fine-silty, mixed mesic) and two 1.5 acre blocks of Belknap silt loam (Aeric, Flavaquent; coarse-silty, mixed, acid, mesic) were extensively sampled for characterization of their physical and chemical properties. The Sadler soil was removed and reconstructed in three separate lifts (representing significantly different horizons), and the Belknap soil was removed and reconstructed in two separate lifts. Table 1 shows the approximate depths and associated horizons removed and subsequently reconstructed for the two soil series.

Table 1. Horizon designation and horizon depths of Sadler and Belknap soil.

Soil Series	Horizon	Depth from Surface (in.)
Sadler	Ap	0-7
Sadler	B2t, A'2	7-25
Sadler	Bx (fragipan)	25-40
Belknap	Ap	0-8
Belknap	B21, B22g, B23g	8-36

The experimental treatments have been assigned a number to be used in the following text:

- Treatment 1: Belknap, truck with direct respread.
- Treatment 2: Belknap, scrapers with direct respread.
- Treatment 3: Belknap, truck with stockpiling phase.
- Treatment 4: Belknap, scrapers with stockpiling phase.
- Treatment 5: Sadler, truck direct respread.
- Treatment 6: Sadler, scrapers with direct respread.
- Treatment 7: Sadler, truck stockpiling phase.
- Treatment 8: Sadler, scrapers with stockpiling phase.

The general sequence in the reconstruction of the soil is as follows. A suitable area of overburden spoil materials from the No. 9 coal on Peabody's Gibraltar Mine in Muhlenberg Co., Kentucky, was graded to about 4 percent slope. For the truck method, dozers pushed the appropriate soil horizons into mini stockpiles. A 7 cu. yd. endloader loaded this soil into 50-ton capacity end-dump trucks. The soil was transported either to a storage stockpile (treatments 3 and 7) or directly to the soil reconstruction site (treatments 1 and 5). Later

when the stockpiles were to be transported, the same equipment was used. After all the soil of each horizon had been moved to the soil reconstruction site, dozers were used to level it to a uniform thickness before the next horizon was transported. For the Sadler soil, three layers of soil were replaced over the spoil, the Bx on the bottom; B2t, A'2, next, and the Ap on top. For Belknap, this was done in two lifts, the B2 on the bottom lift and the Ap placed on top.

The scraper method was similar to the truck method except 24 cu. yd. twin-engine scraper pans were used. The direct-haul scraper treatments were 2 and 6, with the stockpiled treatment being 4 and 8. Each soil lift was leveled prior to placement of the next. The eight reconstructed soil treatments were placed adjacent to each other, and each was approximately 70 x 320 feet. The soil relocation phase was completed in the spring of 1983.

Three test crops have been used to evaluate this experiment: corn, soybeans and alfalfa. These crops were established in strips perpendicular to the main blocks of reconstructed soil. Alfalfa was seeded at both ends, and 12-row wide strips of corn and soybeans were alternated in the center area. Four replications of each crop were used. Fertilizer and lime were applied according to soil test recommendations based on soil samples collected for each test-crop area. Samples were collected to characterize each reconstructed soil horizon for each treatment. Data were collected for bulk density, organic matter, pH, total nitrogen, and exchangeable cations; however, due to the size of this project, most of these data will not be reported here.

After collection of 1984 crop yields, it was evident that distinct differences existed among crop yields as affected by soil-handling methods. Target level yields for corn had not been attained, and the major reason was attributed to the severe soil compaction that had occurred (bulk density data to be given later in the paper). Therefore, in March of 1985 the main experimental treatments were split, with a ripping variable being introduced. One-half of each treatment was ripped with a tractor-drawn triple shank 'Rome' ripper. The ripper was operated at a depth of approximately 24 inches. Corn and soybean rotations were then abandoned. For the remaining duration of the study, corn will be the only row crop tested. The established alfalfa plots will be continuously harvested until the end of 1985. In 1986, the alfalfa plots will be planted to corn to evaluate the interactions of a deep-rooted crop on each soil-handling method.

Permanent access tubes (for gamma and neutron radiation scattering) were set into the alfalfa plots and access tubes are set into the

corn plots on a yearly basis. In addition, extensive soil coring operations are performed (for bulk density analysis) on a yearly basis.

Post-Reconstruction Management Studies

An area of state-of-the-art (scraper method reconstructed) prime farmland was selected to conduct various post-reconstruction management studies. The area was located at River Queen Mine in Muhlenberg County, Kentucky. The area was reconstructed in the fall of 1983. The soil was reconstructed over spoils consisting of a mixed acid spoil (sandstone, shale, mudstone, and siltstone) which had been covered with a lift of subsoil (mixed fine-silty) to a depth of approximately 32 inches. This lift of subsoil was then capped with an 8-inch lift of topsoil (predominantly A horizon materials) which had a silt loam texture but a low organic matter content of about 1.5 percent.

Soil Moisture/Multiple Ripping Studies --

An area of land on the 1983 reconstructed block was prepared for the purpose of determining the effect of soil moisture upon the overall effectiveness of ripping. Sixteen individual plots with dimensions of 25 x 300 feet were established side by side with five-foot borders in between. Ripping treatments (with the 'Rome' ripper as previously described for the Gibraltar Study) were performed at various times so that four main treatments could be performed. These treatments were: (1) a non-ripped control, (2) soil ripped dry, (3) soil ripped when at approximately 1/2 field capacity (the intermediate treatment), and (4) soil ripped when wet (approximately at field capacity). The moisture status of the soils had been determined by neutron scattering techniques from access tubes that had been placed into the non-ripped controls. Four replications of this experiment were performed.

Running lengthwise and crossing the ripped treatments, areas were then established for various test crops. These included a 70 x 480-foot block for corn, a 30 x 480-foot block for tall fescue, another 70 x 480-foot block for soybeans, a 30 x 480-foot block for another fescue area, a 50 x 480-foot block for alfalfa, and a 50 x 480-foot block for black locust.

During the spring of 1984 alfalfa, black locust, and tall fescue areas were established by drill seeding methods, and permanent access tubes (for gamma and neutron probes) installed into all reps of main treatments for alfalfa and black locust areas. Fertilizers and lime were applied as needed, determined from soil tests taken earlier, for all crop areas within the experiment. The black locust used was a "common" seed lot collected locally, and the alfalfa variety used was 'Vernal.' The tall fescue used was 'KY 31.' Corn and soybeans were planted in their appropriate plots on May 16 by methods

previously developed for the Sinclair Study. Corn and soybean areas were then subdivided into three equal-width segments (for future reference). These areas would be used to determine the effectiveness of multiple ripping treatments that would follow each succeeding crop. By establishing three equal areas, "base" yields could be determined from 1984 yield data as affected by initial soil moisture content at the time of initial ripping. From then on 2/3 of the remaining corn and soybean strips will be reripped and yields determined yearly. The black locust will be out with a rotary mower each spring, with plant litter being allowed to accumulate on the soil surface. Tall fescue areas will be managed so as to maintain the stand. After five years the black locust, tall fescue, and alfalfa strips will be established to corn so as to determine the effects of these different types of long-term soil-stabilizing and soil-building crops and to determine if any of these treatments (biological amendments) are as effective as mechanical ripping treatments.

Soil Organic Amendments -- An experiment designed to determine the effects of organic amendments to initial yield of grain sorghum was established at the same relative location just described. Individual plots were 30 x 60 feet. The main treatments included (1) a control (no organic amendment), (2) 10 tons per acre (dry wt. basis) of sewage sludge, (3) 20 tons per acre (dry wt. basis) of sewage sludge, (4) 10 tons per acre of 'Real Earth' (a commercially-available garbage/sewage sludge compost), and (5) 20 tons per acre of 'Real Earth.' Before the organic amendments were applied, the main treatment blocks were split (30 x 30 feet) with one-half of each treatment being ripped with the 'Rome' ripper, as previously described. The organic amendments were then applied on their appropriate area to the soil surface and incorporated by a single pass with a disc harrow. Both the sludge and 'Real Earth' materials were applied by using a lime-spreading truck. The check plot received an application of 241 pounds per acre of actual N. This value represents the estimated N content that would be released from the highest sewage sludge treatment (20 tons/acre). Originally we had planned to establish corn but we experienced delays in receiving the 'Real Earth' material. Consequently, the area was not ready for planting until June 6, so we opted to plant grain sorghum due to the lateness of the season. 'Northrup King 1580' grain sorghum (*Sorghum bicolor* (L.) Moench) was planted with a John Deere Conservation planter into 30-inch rows at a rate of 8 pounds per acre.

Crop Variety Studies -- Within the same general area, experiments were begun to test the relative suitability of various varietal selections of corn, soybeans, and grain sorghum for use on reconstructed prime farmland. A Latin Square design was used for the corn variety study (3 replications each of 64 separate varieties).

The soybean and grain sorghum studies utilized randomized block designs with 4 replications. The soybean variety and grain sorghum variety studies are designed to accommodate 13 entries each of soybeans and grain sorghum. As is the case of all our studies, the yields are determined by combine harvest and yields reported are based upon standard test weights. These variety studies were started in 1984 and will be continued through crop year 1987.

RESULTS AND DISCUSSION

Soil Depth Replacement Studies

Alston Soil Reconstruction Study

Bulk density and water-holding capacity analyses were performed immediately after reconstruction and 11 months after reconstruction. The results of these determinations are given in Table 2.

Table 2. Available water-holding capacities and bulk densities of the reconstructed horizons.

Horizon	Bulk Density ¹ (g/cc)		Water- Holding Cap. (%)
	Aug. 1978	July 1979	Aug. 1978
	Reconstructed A'	1.58	1.43
Upper B'	1.69	1.61(1.56) ²	24.5(29.9) ³
Lower B'	1.72	1.65(1.67) ²	22.0(28.9) ³

¹ Mean of all treatments of all appropriate plots and horizons.

² Numbers in parentheses for 1979 bulk density represent the zone in which the subsoiler passed.

³ Numbers in parentheses are average water-holding capacities of premining soils at relative depth prior to reconstruction.

Water-holding capacities for the reconstructed soil were less than those of the soils in their premining condition. The largest reductions were for the subsoil horizons. However, the reduction in available water of 4 to 6% in the 25% moisture range should not significantly reduce plant growth. The most important interrelated factor is the corresponding change in soil bulk density.

The bulk density of all three horizons sampled in August 1978 was greater than the premining condition. The density of the surface layer decreased significantly with time to where 11 months later values were the same as the

premining condition. This is probably the result of both freezing and thawing cycles and mechanical tillage. Bulk density of the upper and lower subsoil horizons did not change substantially over the 11-month period and generally ran 0.2 g/cc greater than original values. Roots of crops commonly produced in the western Kentucky region will begin to be seriously impeded at soil bulk densities of 1.58 to 1.60. The replaced B horizon (subsoil materials) had been compacted during the reconstruction process. The subsoiler did decrease soil bulk density of the upper B horizon but this was a very narrow zone; this particular subsoiler did not change the bulk density in the lower subsoil zone.

Table 3 presents summaries for crop yields attained from 1979 through 1983. From observing the crops that had been established initially and 1979 yield data, it was apparent that plants growing on the treatments with lesser amounts of subsoil, in general, produced greater yields. Statistical comparisons are not presented due to the size of the table. In addition, regulations require that revegetation success is attained when 90 percent of expected target level yield is attained, based upon a statistical confidence of 80 percent for non-prime land and 90 percent for prime land. From a practical standpoint of land reclamation, any treatment that provides for attainment of target yield is "significant" regardless of its relative ranking within other comparisons. The particular target level yields will be footnoted for all tables presenting yield data, and the target level yield reported will be the actual yield level required based upon the site-specific condition of each study.

Initially, yields (1979 data) for all treatments and all split treatments were higher for all crops grown on the non-prime and intermediate treatments. We contend that this is the result of the "below topsoil" bulk density. Plant roots were apparently effectively penetrating the spoil and thinner lift of subsoil but not the fully-reconstructed treatment. In addition, 1979 had ample rainfall that was evenly distributed throughout the growing season. Since that time (initial crop year), the yields have more or less evened out, with the intermediate soil depth treatment generally producing the best yields.

Alfalfa yields mirrored the following trends. For sequences in which the submedia was limed prior to topsoil replacement, the non-prime treatments were greater than or equal to the intermediate treatment, which was greater than or equal to the prime land treatment. In other words, when the submedia was limed (regardless of whether it was spoil or subsoil) additional soil thickness was not an advantage.

The effect that soil thickness contributed toward corn yields varied from year to year based

upon climatic conditions. Crop years 1980 and 1983 were severe drought years (1983 was classified as a 50 yr. drought). Corn production on all treatments was so poor that yields were not determined (no grain filling occurred). For the first crop year the highest corn yield occurred on the intermediate treatment, and the limed split of this variant equaled the expected target level yield. This was the only treatment that ever equaled or exceeded the target level yield for corn through crop year 1983 (corn/soybean rotation). However, over the long term, intermediate and prime land treatments produced near equal yields, and both of these treatments were nearly always greater in yield than the non-prime treatment.

Soybean yields were generally good for all treatments. Soybeans showed more response to subsoiling than any other crop. Soybean yields for 1982 appear to be low, but soybeans produced in this year were by a double-cropping system. All treatments surpassed target level yields for 1979, and the subsoiled variety of the non-prime and intermediate treatments surpassed target level yields for double-cropped soybeans in 1982. In 1980 and 1983 no treatments surpassed target level yields due to extreme drought. Crop year 1981 was "a good" year for soybeans, but no treatments equaled or exceeded target yields. The soybeans in that year had a target level yield potential, but yields were severely reduced because of the herbicide's failure to effectively control giant foxtail (*Setaria faberis* L.).

With wheat it was determined that neither soil depth or subsoiling greatly influenced yields. The obvious reason for wheat's insensitivity is related to its growth cycle. Wheat is a winter annual crop and moisture stress will seldom occur when wheat is in the grain-filling stage. Hence, a shallow rooting depth (due to either lack of soil or high bulk density) will not greatly reduce wheat yields.

In general, the data indicate that topsoil only is not sufficient to consistently produce acceptable yields of corn, and in some years soybeans. Also, of importance is the indication that the fully-reconstructed treatments generally show no greater yield than the intermediate soil depth treatments. To further test this conclusion, the entire plot area was placed into corn production for crop year 1984. This would test the effects of the permanent soil-stabilizing crop (alfalfa) on the yield of corn compared to the other crop rotation management schemes. The result of this trial is shown in Table 4.

The results of these trials show that the best corn yields were attained on treatments where subsoil had been replaced and where continuous alfalfa had been established as a soil-stabilizing crop prior to corn production.

Table 4. Yield of corn following five years in a corn-soybean rotation or five years in alfalfa.

Reconstruction Treatment	Corn-Soybean Rotation		Alfalfa	
	SS	NSS	SS	NSS
	-----bu/A-----			
Prime-L	74.0	63.3	84.3	90.8
Prime N-L	90.8	81.0	105.6*	103.6*
Intermediate-NL	84.5	85.8	105.2*	98.1*
Intermediate-L	85.0	86.4	99.5*	100.0*
Non-Prime-L	28.7	18.3	52.1	49.8
Non-Prime-NL	24.2	10.4	30.3	26.0

* Indicates that target level yield of 95.6 was exceeded.

¹ SS = Subsoiled; NSS = not-subsoiled; L = limed; and NL = not-limed.

Both variants of the intermediate treatment (limed and non-limed submedia) for both subsoiled and non-subsoiled treatments equaled or exceeded the target level yield. Subsoiled and non-subsoil treatments of the unlimed submedia variant of the prime treatment exceeded target level yields. It was surprising to discover that the prime limed submedia variants did not attain target yields. However, one replication of each of these treatments was adjacent to an active coal-haul road and dust damage was severe. If data from these reps would have been thrown out, other prime land averages would have attained target yield levels. Corn produced on the corn/soybean rotation areas did not equal target level yield for any of the treatments. However, the same general trend that had been established from previous crop years continued to be exhibited, i.e., the intermediate treatment provided for highest yields. Corn yields for all variants of the non-prime treatment were low and were no where near the expected target level yield. Crop year 1984 was a "fair" year for corn production, and in general the non-prime treatments had previously produced yields much higher than 1984 yields. Most of the non-prime treatments produced good ears, but unfortunately the location of the non-prime plot areas was very close to a maintenance area and a road. Many ears "disappeared" from the corn stalks at "roasting ear" time.

Sinclair Soil Depth and Ripping Study

The Sinclair study held similarities to the Alston Study when one considers the agronomic principles employed, i.e., soil depth, subsoil tillage, and submedia lime treatments. However, the subsoiling performed at this study was done with a larger 'Caterpillar' ripper and the soil

resource did not contain a segregated A horizon. As a result, the data generated from this study enables us to evaluate the effects of more intense ripping on soil bulk density and the effect of soil depth in a pure sense, i.e., soil depth as an influence of depth, entirely free from any 'A' or 'B' horizon effects. In addition, this particular depth study was placed on a worse case situation (extremely toxic overburden).

Table 5 represents typical bulk density data that has been obtained throughout the duration of this experiment. The data show that ripping did reduce bulk density in all crops for all depths, and that crops were showing a response three years after the ripping treatments had been performed. Table 6 presents a summary of crop response to soil ripping for all years in which yield data were collected for the appropriate crop.

Table 5. Average* bulk density as a function of ripping.

Soil Depth Treatment inches	Bulk Density	
	Ripped	Non-Ripped
10	1.61	1.72
20	1.65	1.71
30	1.65	1.72

* Average bulk density below six inches; therefore the number of values averaged varies with soil depth.

Table 6. Effect of ripping on wheat, soybean, and corn yields averaged over all soil depth and spoil-lime-incorporation treatments.

Crop-Treatment*	Year**		
	1980	1982	1984
Wheat-NR	35.2a ⁺	43.2a	43.0a
Wheat-R	35.8a	45.4b	44.5a
Soybeans-NR	28.9a	10.4a	-
Soybeans-R	31.0a	12.9b	-
Corn-NR	22.2a	25.5a	43.6a
Corn-R	34.8b	40.8b	50.6a

* NR = not ripped; R = ripped.

** Data collected in 1981 and 1983 not presented here, soybeans were not planted in 1984.

⁺ Means followed by the same letters are not significantly different at alpha = 0.10. Comparisons are not valid between years or crops.

Wheat and soybeans showed significant responses to ripping two out of four years, and corn showed a significant response two of the three years in which corn was harvested. In all cases, the ripped treatments produced higher numerical yields than their non-ripped counterparts. This becomes "significant" from a practical standpoint. Soil ripping will increase yields as opposed to not ripping. For the case of corn yields reported in Table 6, when all years were averaged the total response to soil ripping was approximately 38 percent. If one happens not to attain a target yield by a small margin, the addition of a ripping treatment just might enable the target yield to be attained, i.e., the result may not be statistically significant but "significant," none the less, from a bond release viewpoint.

Table 7 reports crop yields at the Sinclair soil-depth and ripping study. These yields are averaged over all ripped and non-ripped treatments and lime-spoil-incorporation treatments. Target level yields for soybeans were equaled or exceeded in 1980 for all 20-inch and 30-inch soil depths. In 1982, all yields for

Table 7. Yield of test crops as a function of depth, averaged across ripping and spoil-lime-incorporation treatments.

Crop-Soil Depth in Inches	Year		
	1980	1982	1984 ⁺
Soybean-10	23.2	7.1	25.7*
Soybean-20	31.8*	4.0	30.8*
Soybean-30	34.9*	4.8	32.2*
Corn-10	6.1	13.2	36.3
Corn-20	17.7	35.7	59.9
Corn-30	20.0	50.3	80.3
Wheat-10	32.7	40.5*	39.5*
Wheat-20	36.6*	42.1*	44.0*
Wheat-30	37.3*	47.1*	47.8*
Hay	Seed	Hay	
	1983	1983	1984
	T/A	lbs/A	T/A
Timothy-10	2.25	112	2.96*
Timothy-20	2.37	153	3.15*
Timothy-30	2.47	173	3.54*

⁺ Values for soybeans under 1984 were actually collected in 1982 using a double cropping system after the wheat was harvested.

* Equaled or exceeded respective crop target yield levels: soybean = 27 bu/A (conventional), 22 bu/A (double-crop); wheat = 36 bu/A; and timothy = 2.7 T/A.

double-cropped soybeans (these data are listed in Table 7 as 1984) for all depths equaled or exceeded the target level yields, but the 10-inch depth treatments were lowest numerically. This indicates that a 20-inch depth of replacement is sufficient to attain target level yields for soybean production. This agrees with the Alston data where the intermediate soil depth treatments generally produced the best soybean yields.

Wheat yields exceeded target level yields in 1980 on the 30-inch and 20-inch treatments. In 1982 and 1984, all treatments exceeded target level yields. In 1983 (data not shown), none of the treatments exceeded target yields. This was due to severe disease damage (smut) that occurred during that year.

Corn yields never equaled or exceeded target level yields for all years tested when averaged across ripping and non-ripping treatments. However, some of the ripped treatments did exceed the target level yield in 1984. This shows that intensive soil ripping will increase the productivity of severely compacted soils, especially with thicker soil lifts. Table 8 represents 1984 corn yield data for all treatments considering the ripping and non-ripping splits.

Table 8. Effect of ripping and soil depth on 1984 corn yields at Sinclair Mine averaged over all lime incorporation treatments.

Soil Depth Treatment	Ripped	Non-Ripped
	-----bu/A-----	
10	39.7	37.6
20	68.3	59.1
30	94.1*	77.4

* Exceeded target yield of 90 bu/A.

Only the deeper soil treatments (30 inches) which had been ripped equaled or exceeded the target level yield. The ripping effect was being exhibited four years after the ripping had been performed. We contend that this is very significant. We can produce corn equal to or greater than target level yields over toxic overburden with just 30" of soil cover, especially when one considers that the soil cover was predominantly subsoil material. Also, these areas had been in a corn/soybean rotation, and a permanent soil-stabilizing crop had not been produced prior to this production.

Timothy yields (like wheat) are more influenced by climatic conditions and the plant's

growth cycle more so than by soil depth. In 1983 (one year after establishment) none of the treatments attained target level yields. In 1984, all treatments had equaled or surpassed the target level yield. Timothy is a perennial crop that would represent a typical species established for the purpose of erosion control, land stabilization, and so forth. Even yields from shallow soil-depth treatments exceeded the yield that would be expected under prime farmland conditions. One can conclude that a four-foot cover of non-toxic material over toxic material, as required, is excessive and unnecessary, at least when lime is applied to the spoils.

Gibraltar Soil-Handling Studies

This particular field experiment is relatively new. The agronomic data that has been generated to date is limited because crop yields for 1983 were not collected due to the extreme drought that occurred. Table 9 reports crop yields attained for 1984.

In general, the yields were fairly good considering the fact that this data represents just the second crop year after reconstruction. In most cases the overall averages of all truck treatments were higher yields than for the scraper treatments. Belknap soil treatments generally produced the higher yields for alfalfa, while Sadler soil treatments generally produced the highest yields for corn. This lends further support to the practice of liming the subsoil (if replaced subsoil materials are acid) prior to topsoil replacement. With this experiment the subsoil materials were not limed and the much greater relative acidic condition of the Sadler subsoil (compared to Belknap subsoil) is probably limiting yield of alfalfa (an acid-sensitive crop).

All stockpiling treatments averaged over all other treatments produced higher yields of corn than did direct treatments. For soybeans and alfalfa, the differences between stockpiling and direct redistribution were not as great. To date, we have not analyzed enough supporting data to allow us to explain this observation nor to predict that it will hold over time.

The different soil reconstruction methods did show differences in soil bulk density. Table 10 presents data taken in 1985 after the soil ripping variable had been introduced into the experiment. The non-ripped values reported in Table 10 are essentially the same as those bulk densities immediately after reconstruction for sub-surface horizons. We have determined from other experiments that soil bulk density does not significantly change in the "below topsoil" zone within a two-year period after soil reconstruction with standard corn/soybean rotations.

Truck methods appear to provide for a reconstructed soil of lower bulk density than do scraper methods, particularly at greater depths. This same trend is present for stockpiled treatments compared to direct treatments. In general, truck treatments produced bulk densities for intermediate depths with ranges of 1.60 to 1.65, while scraper treatments at similar depths ranged from 1.65 to 1.72. This represents a small analytical difference. However, in terms of plant root growth it may be very significant, because the 1.65 value is the point at which plant root growth may become very restricted.

By comparing bulk densities of ripped and non-ripped treatments, it appears that the ripping treatment was effective at reducing soil bulk density. The ripping treatments will probably be the most effective with respect to crop yields for scraper treatments, because scraper treatments were the most compacted to begin with.

Post-Reconstruction Management Studies

Soil Moisture/Multiple Ripping Studies -- Since this study was established in 1984, only preliminary data are available. Crop yields available from this study are given in Table 11.

Table 11. Yield of corn, soybeans and alfalfa as a function of soil moisture at the time plots were ripped.

Moisture Conditions	Soybeans	Corn	Alfalfa
	1984 bu/A	1984 bu/A	1985* T/A
Dry	23.8	25.1	3.03
Intermediate	21.8	26.6	3.18
Wet	20.9	21.2	3.19
Non-Ripped	20.3	18.0	3.37

* Yields are from first 3 cuttings made in 1985.

Although there is very limited data, two important trends have been established. First, there is a response to ripping for both corn and soybeans (alfalfa yields for 1984 were not taken because 1984 was the establishment year). Second, it appears that the drier the soil at the time of ripping, the greater the subsequent crop yield will be.

Soil Organic Amendment Studies -- Yield data from this experiment are shown in Table 12. Although we have data for only one year, grain sorghum responded to both ripping and organic matter amendments. It is very interesting to note that the 10-ton rate of sludge (the low rate) provided the highest yield for both ripped

and non-ripped treatments. The overall mean of all non-ripped treatments was 47.1 as opposed to 67.4 for ripped treatments. Ripping accounted for a 30.1 percent yield increase overall. Both 'Real Earth' treatments yielded lower than the control for both ripped and non-ripped variables. This is probably the result of low nitrogen availability (nitrogen fertilizer was not applied to 'Real Earth' and sewage sludge plots). The manufacturer of this material cites continuous nitrogen release as one of the advantages of this material; apparently this was not the case during 1984.

Table 12. 1984 Yields of grain sorghum as a function of organic matter rate and ripping.

Organic Matter Source	Application Rate T/A	Ripping Treatment	
		Non-Ripped	Ripped
		-----bu/A-----	
Sewage Sludge	10	58.9	88.3
Sewage Sludge	20	57.0	81.7
'Real Earth'	10	37.3	57.4
'Real Earth'	20	34.3	52.0
Control	0	47.9	57.6

Crop Variety Studies -- Results of crop variety testing for 1984 are given in Table 13.

Yields for soybeans and, to some extent grain sorghum, are low for this newly-reconstructed prime farmland. This area had not been ripped. The area also experienced a dry period in late June and early July that could have reduced yields.

In general, the group IV and group V varieties, or mid- to late-season maturity varieties, exhibited higher yields than group III varieties. These data indicate that early maturity varieties may not be good for mined land in Western Kentucky, although theoretically they should be suitable.

Grain sorghum yields were slightly lower than the 1984 state average of 75 bu/A. The varieties that gave the highest yields were those that had less lodging (data not given).

CONCLUSIONS

Soil Depth Studies

- (1) Subsoiling with a conventional farm type subsoiler increased yields of agronomic crops, especially corn and soybeans, the first one or two years but the effect diminished with time.

Table 13. 1984 Soybean and grain sorghum yields from a variety test at River Queen Mine.

Variety (Maturity Group)	Yield bu/A
-----Soybeans-----	
Union (III)	16
Williams (III)	14
Pella (III)	12
RA 405 (IV)	20
NK 545-01 (IV)	18
Douglas (IV)	17
AP 420 (IV)	17
Pixie (IV)	9
FFR 561 (V)	17
Mitchell (V)	17
Essex (V)	14
Forrest (V)	14
-----Grain Sorghum-----	
TE D'Inero	72
Funk's 5220R	66
Asgrow Topaz	59
NK 2344	59
TE Y45G	58
Funk's 2308	51
NK 2778	48
TE Y101G	48
NK 1580	41

- (2) Ripping with a large 'Caterpillar' ripper produced significantly greater yields that lasted for at least four years. These yield responses were greatest for crops having the largest demand for stored water such as corn and soybeans. The ripping effectively reduced bulk density.
- (3) Liming the upper six inches of subsoil before topsoil replacement increased yields of most agronomic crops. There appeared to be an interaction between this lime treatment and soil depth. Lime applied to the subsoil apparently increased rooting depth and yields improved. This response is greater when lesser amounts of soil are used.
- (4) At the Alston study site, the non-prime and intermediate treatments generally produced higher crop yields, except for corn, i.e. non-prime treatments were generally lowest in yield after passage of time. The intermediate soil thickness (1/2 of prime land subsoil depth requirements) produced the best yields initially and over time.

- (5) From a chemical and a crop performance point of view, highly acidic spoils (toxic spoils) do not need to be buried by four feet of non-toxic cover material, provided adequate lime is applied to the spoil prior to replacement of topsoil. The burial depth must be increased up to 30 inches if high-water demand crops such as corn are to be produced. A 10-inch burial depth was more than adequate to produce perennial vegetation (alfalfa or timothy).

Soil-Handling Method Studies

- (1) Truck methods of soil handling appear to produce a soil material of better quality than do scraper methods, and crops apparently respond to the difference.
- (2) A tractor-drawn 'Rome' ripper is effective in reducing soil bulk density.
- (3) Soil that has been handled through a stockpiling phase, as opposed to direct respread methods, is initially more productive.

Post-Reconstruction Management Studies

- (1) In general the drier the soil at time of ripping, the greater the subsequent crop yield will be.
- (2) Crops produced on first-year reconstructed prime farmland will respond to both soil ripping and additions of organic matter (sewage sludge).
- (3) Varietal differences of like plant types in relation to yield are occurring on reconstructed land and probably at a greater magnitude of difference than would occur on "undisturbed" land.

LITERATURE CITED

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2. Huntington, T.G., R.I. Barnhisel, and J.L. Powell. 1980. The role of soil thickness, subsoiling and lime incorporation methods on the reclamation of acid surface mine spoils. In G.H. Graves (ed.) Proceedings - 1979 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. Univ. of Kentucky, Lexington, KY. pp. 8-13.

Table 3. Total treatment effects on corn, soybean, alfalfa and wheat yields at Alston Mine.

Treatment	1979			1980	1981			1982				1983	
	Corn -----bu/A-----	Soybeans --T/A--	Alfalfa --T/A--	Alfalfa --T/A--	Corn -----bu/A-----	Soybeans --T/A--	Alfalfa --T/A--	Corn -----bu/A-----	Wheat -----bu/A-----	Soybeans --T/A--	Alfalfa --T/A--	Wheat bu/A	Alfalfa --T/A--
Non-Prime Limed													
Subsoiled	89.4	46.8*	2.03	3.08	41.6	24.7	3.62*	38.1	42.4*	22.1*	4.47*	32.1	2.69
Non-Subsoiled	83.8	42.7*	2.12	3.01	42.6	17.7	3.68*	39.0	37.3	16.6	4.14*	25.8	2.94
Non-Prime Not Limed													
Subsoiled	89.9	49.8*	1.75	2.30	29.7	9.9	3.54*	31.0	31.4	15.1	3.89*	30.1	2.40
Non-Subsoiled	77.3	44.2*	1.99	2.40	33.2	12.4	3.35*	28.8	30.8	15.1	4.12*	30.4	2.11
Intermediate Limed													
Subsoiled	95.6*	46.1*	2.07	2.52	83.4	20.8	3.54*	69.5	42.0*	22.6*	4.38*	34.4	2.24
Non-Subsoiled	81.9	40.0*	1.94	2.47	61.6	18.6	3.71*	63.6	39.6	18.2	4.15*	31.9	2.31
Intermediate Not Limed													
Subsoiled	79.4	47.0*	1.47	1.37	76.9	26.4	3.60*	65.1	44.1*	20.1	3.67*	27.9	2.16
Non-Subsoiled	76.8	40.4*	1.37	2.12	64.7	24.2	3.28*	65.3	38.0*	19.7	3.57*	26.3	2.40
Prime Land Limed													
Subsoiled	80.7	45.8*	1.58	2.19	76.4	21.2	3.50*	57.9	34.5	20.4	4.21*	26.2	1.84
Non-Subsoiled	83.5	39.1*	1.36	2.14	64.3	18.6	3.57*	58.5	37.3*	17.1	4.23*	27.9	1.77
Prime Land Not Limed													
Subsoiled	83.3	47.1*	1.64	2.29	81.74	22.6	3.73*	56.7	39.4*	19.1	4.21*	27.2	2.08
Non-Subsoiled	81.7	43.3*	1.64	2.19	61.0	24.8	3.82*	60.2	37.1*	18.8	4.42*	25.6	2.06

Wheat was not grown for crop years 1979, 1980, and 1981.

Corn and soybeans were established but not harvested in crop years 1980 and 1983 due to serious drought injury.

* Equals or exceeds target level yields (1982 yield for soybeans is for a double crop system target yield of 20.7 bu/acre) other target yields are 95.6, 32.6, 34.9, and 3.15 for corn, soybeans, wheat, and alfalfa, respectively.

Table 9. 1984 Yields of corn, soybeans, and alfalfa as affected by soil reconstruction method.

Soil Series Reconstructed	Method	Crops		
		Corn -----bu/A-----	Soybeans	Alfalfa --T/A--
Belknap	Truck-direct	34.60 ¹	22.5ab	2.10a
Belknap	Truck-stockpiled	53.0ab	24.7ab	1.71abc
Belknap	Scraper-direct	32.4c	20.7b	1.73abc
Belknap	Scraper-stockpiled	45.7bc	24.0ab	1.95ab
Sadler	Truck-direct	52.6ab	25.6a	1.21c
Sadler	Truck-stockpiled	62.7a	23.5ab	1.47bc
Sadler	Scraper-direct	47.6abc	23.8ab	1.43bc
Sadler	Scraper-stockpiled	52.8ab	16.2c	1.09c

¹ Means followed by same letter are not significantly different at alpha = 0.10.

Table 10. Bulk densities of replaced soil as affected by reconstruction method and soil ripping, 1985 data.

Soil Series Reconstructed	Method	Depth ¹ (in)	Bulk Density	
			Ripped	Non-Ripped -----g/cc-----
Belknap	Truck-direct	0-6	1.54	1.50
		6-36	1.64	1.66
Belknap	Truck-stockpiled	0-6	1.51	1.53
		6-36	1.64	1.65
Belknap	Scraper-direct	0-6	1.34	1.46
		6-36	1.68	1.67
Belknap	Scraper-stockpiled	0-6	1.57	1.54
		6-36	1.66	1.73
Sadler	Truck-direct	0-6	1.46	1.49
		6-18	1.54	1.62
		18-36	1.68	1.72
Sadler	Truck-stockpiled	0-6	1.49	1.50
		6-18	1.60	1.60
		18-36	1.68	1.70
Sadler	Scraper-direct	0-6	1.74	1.65
		6-18	1.64	1.72
		18-36	1.73	1.75
Sadler	Scraper-stockpiled	0-6	1.52	1.47
		6-18	1.55	1.65
		18-36	1.69	1.74

¹ Bulk densities are averages of four locations taken from ripped and non-ripped treatments. Cores were taken from each treatment each six-inch increment of depth. Thus, values reported for surface (0-6) are average of 4 duplicate samples, for Belknap the (6-36) average of twenty values. For the Sadler soil two "below topsoil" values are reported, i.e., 6-18 and 18-36 inches. These bulk density values are averages of 8 and 12 cores respectively.