EFFECT OF SOIL DEPTH, LIMING, AND SUBSOILING OF RECONSTRUCTED PRIME FARMLAND ON ALFALFA PRODUCTION.[1]

R. I. Barnhisel, J.L. Powell, J.R. Armstrong, M.L. Ellis, and F.A. Craig[2]

Abstract. -- Differences in crop yield and bulk density were evaluated using two sites in Kentucky to study various soil depths and liming, subsoiling, and ripping treatments. The effect of soil moisture at the time of subsoiling was also evaluated. At the Alston Surface Mine site, alfalfa (Medicago Sativa L.) yields exceeded target levels for prime farmland Phase III bond release 2 of the 5 years. Liming the subsoil prior to replacement resulted in increases in alfalfa yields, whereas neither subsoiling nor alfalfa cultivar selection produced significant differences. In general, the highest alfalfa yields were from the shallowest soil depth treatments. All alfalfa yields from the River Queen Surface Mine site exceeded the target levels for Phase III bond release both years of this study. Soil moisture at the time the soil was ripped did not produce the expected results for either alfalfa yield or bulk density. Ripping and/or subsoiling had little effect on changes in soil bulk densities, and alfalfa yields were generally reduced by subsoiling.

INTRODUCTION

The passage of Public Law 95-87, the Surface Mining and Reclamation Act of 1977, was a complex piece of legislation which has affected every phase of surface mine reclamation. One aspect of this law and its ensuing regulations is restoration of prime farmland, which is the focus of the research data reported here.

It has been well established that subsoiling will reduce the bulk densities of soils used in agriculture (Akin, 1979; Allmuras et al., 1977; Barnes, et al., 1971; Henning and Colvin, 1977; Hodder, 1975; Olsen and Henning, 1980; and Trouse and Humbert, 1959). Subsoiling studies on restored prime farmland in Kentucky were conducted on the Alston Surface Mine, operated by Peabody Coal Co. in Ohio County. This was the first attempt to reduce the adverse effects of the increase in bulk density due to surface mining.

When the bulk density is increased to excessive levels, the growth rates of agronomic plants may be reduced. The term "excessive compaction" does not have a good working definition as it is not easily associated with an absolute value for all soil textures and moisture conditions.

1 Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA. Published with the approval of the Director of Ky. Agr. Exp. Stn., as Journal Article No. (88-3-20).

2 R.I. Barnhisel is Professor of Agronomy and Geology, University of Kentucky, Lexington, KY.; J.L. Powell is Senior Agronomist, J.R. Armstrong is Land use Analyst, M.L. Ellis is Reclamation Supervisor, Peabody Coal Co., Greenville, KY.; and F.A. Craig is Environmental Program Coordinator, DSMRE, Frankfort, KY.

Proceedings America Society of Mining and Reclamation, 1988 pp 266-273

DOI: 10.21000/JASMR88020266

There is a lack of information as to how bulk density affects plant growth under field conditions. This problem is further complicated in that plants do not respond equally to a given set of bulk density conditions. Furthermore, differences in nutrient availability and other chemical properties may also interact with bulk density.

Many articles have been written on the effect that bulk density may have on plant root development (Carson, 1974; Lowry et al., 1970; Meredith and Patrick, 1961; Russell, 1977; Taylor and Gardner, 1963; Viehmeyer and Hendrickson, 1948; Wali and Sandoval, 1975; and Zimmerman and Kardos, 1961). Any increase in bulk density potentially reduces plant growth; this applies not only to soils affected by surface mining, but also to naturally-occurring soils that may have higher than desirable bulk densities.

The minimum depth of soil necessary to achieve post mining productivity equal to that before mining is an item needing further clarification even though several studies have been conducted on this topic (Deane, 1977; Farmer et al., 1974; Nielsen and Miller, 1980; Power, 1978; Power et al., 1981; Russell, 1977; Sandoval and Gould, 1978; Sindelar et al., 1973; Taylor and Gardner, 1963; and Zimmerman and Kardos, 1961). The crop being grown strongly influences the topsoil depth requirement as do the chemical, physical, and mineralogical nature of the spoil material underlying the topsoil. When spoil materials have good properties that do not restrict root growth, less topsoil is needed to provide a rooting media for optimum crop production (Grandt, 1978), if it is needed at all.

Over the past 10 years, six projects have been initiated in western Kentucky related to restoration of the productivity of prime farmland. This paper is to address only a very small part of this research which was conducted with the following objectives: (1) To determine the effect of soil depth, subsoil liming, and subsoiling on alfalfa yield; and (2) To determine the effect of soil moisture, at the time subsoiling was performed, on alfalfa growth and changes in bulk densities.

MATERIALS AND METHODS

Alston Site

Plot Construction

Three test plots with varying subsoil depths were established at this site following mining. Prior to this, the topsoil (A horizon), approximately 20 cm thick had been removed from two soils by scraper-pans and placed into a stockpile. About 75% of the area had been mapped as Sadler (Glossic Fragiudalf, fine-silty, mixed, mesic) and the remainder as Belknap (Aeric Fluvaquent, coarse-silty, mixed, acid, mesic). Approximately 80 cm of subsoil (B and C horizons) was also removed from these two soils and placed into a separate stockpile.

After the coal had been removed, the overburden spoils were graded and two areas of subsoil were replaced with scraper-pans, one at each of two depths, 40 and 80 cm. Each area of subsoil was at least 75 by 100 m. In addition, one area of graded spoils with the same approximate size was established. The surface of all these plots had a slope of 2%. These three plots were sub-divided into 2 areas, each 75 by 50 m; and to one of each, lime was applied at a rate of 45 Mg/ha. The entire plot area was disked twice to a depth of 15-20 cm with a heavy-duty disk. Following this operation, 20 cm of topsoil was placed on all three of the main plots.

Fertilization

Agricultural limestone was applied to the topsoil of all three main plots at a rate of 11.2 Mg/ha. Phosphorus and potassium were applied at 100 kg/ha, P and K, respectively, and all materials were incorporated by disking. Nitrogen was applied to all plots being seeded except alfalfa.

Subsoiling

Subplots, 7.3 by 11 m in size, were established for each of the three test crops with four replications each. These subplots were further divided in half (3.7 by 11 m), and one-half of each subplot was subsoiled with a straight-shank subsoiler with a 90 cm spacing to a depth of approximately 50 cm. Assignment of the locations of the test crops and subsoiling was made randomly. The test crops used were corn (*Zea mays* L.), soybeans (*Glycine max* (L.) Merr.), and alfalfa (*Medicago Sativa* L.), however, data for only alfalfa are reported here. The borders separating plots were seeded to tall fescue (*Festuca arundinacea* Schreb.).

Alfalfa Seeding and Management

Two cultivars of alfalfa, 'Apollo' and 'Vernal', were broadcast in midApril 1979 at a rate of 26 kg/ha. The position of each cultivar was assigned randomly on each subsoiled subplot. A cultipacker was used to provide soil-seed contact.

In 1979 two alfalfa cuttings were made, one in late July and the other in September. In the following four years (1980-1983), the first cutting was made in May at the 50% bloom stage, with subsequent harvests every 35 days until the fall months. This management allowed at least 4 harvests each year.

At each harvest, the alfalfa forage from a known area was collected with a rotary mower at a height of 7.5 cm. and the fresh weight determined to the nearest

10 g. Small subsamples were taken from each plot with electric hand clippers. These samples were placed into sealed plastic bags and weighed in the field with a battery-operated digital balance to the nearest 0.01 g. The subsamples were then frozen with dry ice for transport to the laboratory, where they were maintained at -12°C until removed from the freezer for drying at 60°C. The moisture lost was used to calculate oven-dry hay yields from the lawn mower clippings. The dried alfalfa samples were ground to pass a 40 mesh screen. These samples were used for all chemical analyses.

In early March of 1980 and 1982 soil samples were taken from each alfalfa plot for soil tests. Based on these data, P and K fertilizers were applied to each sub-plot at recommended rates based on tables in AGR-1 (Agronomy Staff, 1979). In general, the soil test data resulted in recommendations ranging for P of 40 to 50 kg/ha and 70 to 90 kg/ha for K.

River Queen Site

Plot Construction

A large area of reconstructed prime farmland was selected from a part of the general reclamation of the mine. The soil had been replaced as two horizons with scraper-pans. The thickness of the topsoil and subsoil materials was approximately 20 and 90 cm, respectively, and each had been stockpiled for at least 18 months. This area was divided into blocks; the size of each varied in width as required to accommodate each of the five test crops, but all were 150 m long. Data for only alfalfa will be given here from the area 15 by 150 m.

Ripping

The entire block of replaced prime land was treated as a unit. The five test crops were the main blocks, with the ripping treatments randomly assigned in each sub-block with four replications each. The ripping treatments included a control (nonripped) and ripping performed at three soil moistures.

Ripping was done using a three-shank parabolic ripper, pulled by a dual-wheeled, four-wheel drive tractor, at a depth of approximately 60 cm. One sub-block was ripped when the soil was dry, approaching the wilting point of this soil. The next ripping treatment was done when the soil was at the midpoint between field capacity and the wilting point, and the last treatment was ripped at a soil moisture near field capacity.

Alfalfa Fertilization and Management

Soil samples were taken for estimation of lime, P, and K needs. Tables in AG1-1 (Agronomy Staff 1979) were used for lime recommendations to raise the pH to 6.8, and for P and K. The alfalfa test area was seeded in the spring of 1984 using the 'Vernal' cultivar at a rate of 26 kg/ha. Soil samples were also collected in mid-March of 1986 from each treatment and appropriate levels of P and K applied.

Since there was less than adequate precipitation, harvests were not made in 1984. In 1985 and 1986, the first cutting was taken in May and subsequently every 35 days through September. A self-propelled forage harvester was used to collect forage from areas of each plot. Hand-clipped samples were taken as described earlier for the determination of oven-dry weight hay yields.

Soil Testing Methods

Soil Bulk Densities

Soil core samples (5 cm O.D.) were taken to the soil-spoil interface. These cores were first divided into 15cm segments, then trimmed to a flat surface on both ends, measured to the nearest 0.05 mm, placed in a plastic bag, and sealed for transport to the laboratory. The percent soil moisture and ovendried weight (100°C) of each core was determined. The bulk densities were expressed on a dry weight basis and soil moisture expressed on a volume basis.

Chemical Properties

Exchangeable cations, pH, Bray-1P, and lime requirement were determined by methods published in Black et al. (1965). The cations extracted with 1N NH_4OAc were determined with an atomic adsorption instrument. The pH's were measured in a 1:1 weight to volume of soil and distilled water. The lime requirement method was that proposed by Shoemaker et al. (1962), and phosphorus requirements were determined by the method described by Bray and Kurtz (1945).

RESULTS AND DISCUSSION

Alston Site

Data from the chemical analyses of the alfalfa forage are not reported since none of the treatments resulted in significant differences in chemical composition. There was a trend for the plots in which the subsoil had been limed to be slightly higher in Ca and lower in Total N. These data were collected to insure us that the differences in yields were not the result of differences in soil fertility as well as to confirm we were applying adequate P and K.

Effect of Soil Depth.

Three soil thicknesses were evaluated at the Alston site: 20, 60, and 100 cm of soil over graded overburden. Alfalfa yields were taken for 5 years, and these data are given in table 1. Significant differences in yields were obtained, but

Table 1.--Effect of soil depth and subsoil liming on alfalfa yield, averaged across subsoiling and cultivar subtreatments.

Depth/Lime*	Harvest Year 1979	1980	1981	1982	1983
cm	(kg/ha)				
20 NL	3650 b B†	4610 bc B	6740 b A	7825 b A	4425 b B
20 L	4070 a D	5955 a C	7125 ab B	8260 a A	5510 a C
60 NL	2790 d C	4155 d B	6720 b A	7065 c A	4470 b B
60 L	3920 ab C	4880 b C	7100 ab B	8345 a A	4450 b C
100 NL	3205 c B	4375 cd B	7375 a A	8435 a A	4040 b B
100 L	2870 d B	4230 c AB	6905 ab A	8245 a A	3525 c B

* Total soil depth, L = subsoil was limed, NL = subsoil was not limed.
† LSD (0.10), lowercase letters are for comparisons between treatment means for a given year, whereas, uppercase letters are for comparisons between years for any given treatment.

Table 2.--Effect of subsoiling and cultivar on alfalfa yield, for averaged soil depth and subsoil liming treatments.

Subtreatment	Harvest Year 1979	1980	1981	1982	1983
	(kg/ha)				
1*	3510 a D†	4765 a C	7140 a A	8190 a A	4375 a
2	3110 ab D	4610 a C	6945 ab B	8080 a A	4915 a
3	3360 ab D	4695 a C	6890 ab B	7890 a A	**
4	3015 b D	4450 a C	6520 b B	7840 a A	**

* 1 = Apollo, subsoiled; 2 = Apollo, non-subsoiled; 3 = Vernal, subsoiled; and 4 = Vernal, non-subsoiled.
† LSD (0.10), lowercase letters are for comparisons between subtreatment means for a given year, whereas, uppercase letters are for comparisons between years for any given subtreatment. Comparison between years for 1983 data was not included.
** In 1983, the effect of cultivars was not evaluated, data given represent averages of both, as cultivars were harvested together.

they were not consistently related to soil depth. The highest yield was obtained from the thinnest soil treatment the first and second years. In 1981 and 1982, the yield from the limed treatments for all three soil depths was not significantly different, with the deepest (nonlimed) soil having the greatest numerical value. The last year alfalfa was grown, the largest yield came from the shallow soil treatment, and in this case, lime had been incorporated into the spoils prior to topsoil replacement.

The target yield for alfalfa for the soils used in this study is 6,665 kg/ha for prime farmland and 6,000 kg/ha for non-prime cropland. The first 2 years neither target level was exceeded; however, in 1981 and 1982, all treatments surpassed the prime farmland target value.

Effect of Subsoil Liming

Liming the subsoil prior to topsoil replacement produced significant yield responses for 7 of the 15 possible pairs or treatments. However, alfalfa yields for the deepest soil treatment which the subsoil had been limed were significantly lower in 1979 and 1983 than the nonlimed treatment. There is a possibility that this reversal was related to the plot position that alfalfa occupied, in which 2 of the 4 replications were near an active haul road. These plots may have received dust from this road, although for the most part the road was kept "watered" and the prevailing wind direction would have carried dust away from the experimental area.

The subsoil lime treatment resulted in significantly higher levels of exchangeable Ca and lower exchangeable acidity in the upper 15 cm of the subsoil (data not given). All other chemical properties were not significantly related to the experimental treatments.

Effect of Cultivars

The two cultivars established were 'Apollo' and 'Vernal'. 'Apollo' is more disease resistant, especially to root rot, and is also believed to be more acid tolerant than 'Vernal'. However, when yield comparisons were made (table 2), only small differences in yield were observed and in no cases were these significant. On an average, 'Apollo' outyielded 'Vernal' by 200 kg/ha.

Effect of Subsoiling

Data for comparisons of subsoil treatments are also given in table 2. Although the subsoiling treatment produced higher yields, in none of these cases were the differences significant. The difference in yield due to subsoiling was also about 200 kg/ha.

The bulk densities of the two soils prior to disturbing are given in table 3. These data were collected on sites adjacent to the area, since the topsoil and subsoil horizons had been stockpiled prior to initiation of the study. The Sadler soil had a somewhat higher bulk density in the Btx horizon, typical of fragipan soils.

Table 3.--Bulk densities* of the Sadler and Belknap soils prior to being disturbed.

Soil	Horizon	Bulk Density
		(Mg/m^3)
Sadler	Ap	1.40
"	Bt	1.53
"	Btx	1.62
Belknap†	Ap	1.42
"	Cl	1.54
"	Cg	1.50

* These data are from typical sites in the area, as samples were not collected prior to surface mining.
† Series name changed at Alston site to Stendal after field correlation.

Density data taken approximately one month after the soil had been replaced are given in table 4. The bulk density for both the topsoil and subsoil materials had been increased from 0.1-0.3 Mg/m^3. There were decreases in bulk density after one year for both the topsoil and subsoil materials, as given in table 5. The largest decrease was for the topsoil, which was most likely the result of the tillage operation associated with seedbed preparation. The decrease in bulk density for the 3045 cm sampling depth was likely the result of both subsoiling and root growth.

Extensive bulk density sampling was performed (spring of 1984) after the last year alfalfa was grown, and these data are given in table 6. The bulk densities were generally higher than those shown in table 5 and nearer those given in table 4, especially for the subsoil materials. In other words, it would appear that none of the treatments (subsoiling, liming the subsoil prior to topsoil replacement, nor growing alfalfa for 5 years) caused major reductions in bulk density. Unfortunately, direct statistical analyses between data collected in 1978 and 1984 cannot be made due to differences in sampling frequencies; however, it is speculated that the change in bulk density of the topsoil would reflect a significant decrease, whereas the bulk densities for the two lower depths were not different.

Table 4.--Initial bulk densities at the Alston Surface Mine site.

Depth*	Sample depth in cm 0 - 15	30 - 45	45 - 60
(cm)	(Mg/m^3)		
20	1.54 a †	- - -	- - -
60	1.55 a B	1.71 a A	1.73 a A
100	1.63 b B	1.67 a A	1.71 a A

* Data averaged across lime subsoiling treatments.
† LSD (0.10), lowercase letters are for comparisons between treatment means within a given sampling depth, whereas, uppercase letters are for comparisons between sampling depths for a given soil depth treatment.

Table 5.--Bulk densities at the Alston Surface Mine site after 1 year.

Depth*	Sample depth in cm 0 - 15	30 - 45	45 - 60
(cm)	(Mg/m^3)		
20	1.45 a †	- - -	- - -
60	1.42 a B	1.58 a A	1.64 a A
100	1.40 a B	1.59 a A	1.66 a A

* Data averaged across lime subsoiling treatments.
† LSD (0.10), lowercase letters are for comparisons between treatment means within a given sampling depth, whereas, uppercase letters are for comparisons between sampling depths for a given soil depth treatment.

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5 and nearer those given in table 4, especially for the subsoil materials. In other words, it would appear that none of the treatments (subsoiling, liming the subsoil prior to topsoil replacement, nor growing alfalfa for 5 years) caused major reductions in bulk density. Unfortunately, direct statistical analyses between data collected in 1978 and 1984 cannot be made due to differences in sampling frequencies; however, it is speculated that the change in bulk density of the topsoil would reflect a significant decrease, whereas the bulk densities for the two lower depths were not different.

RIVER QUEEN SITE

Data from the chemical analyses of the alfalfa forage from this experiment are not be reported since they are similar to the other site and none of the treatments resulted in significant differences in chemical composition. These data were collected to insure us that the differences in yields were not the result of differences in soil fertility as well as to confirm we were applying adequate P and K.

Significant differences in the soil chemical properties did not occur at this location as a result of subsoiling, hence these data are not given.

Table 6.--Effect of soil depth, subsoil liming, and subsoiling on bulk densities averaged across alfalfa cultivars after 5 years.

Depth/Lime*	Subsoiled	Non-Subsoiled
(cm)	---- (Mg/m^3)	-----
	---- 0 - 15 cm	----
20 NL	1.49 a A†	1.47 b A
20 L	1.55 a A	1.54 a A
60 NL	1.51 a A	1.57 a A
60 L	1.50 a A	1.52 ab A
100 NL	1.52 a A	1.59 a A
100 L	1.54 a A	1.58 a A
	---- 30 - 45 cm	----
60 NL	1.75 a A	1.69 ab A
60 L	1.75 a A	1.69 ab A
100 NL	1.71 a A	1.79 a A
100 L	1.67 a A	1.58 b A
	---- 45 - 60 cm	----
60 NL	1.72 a A	1.62 b A
60 L	1.75 a A	1.62 b A
100 NL	1.71 a A	1.71 a A
100 L	1.72 a A	1.75 a A

* Total soil depth, L = Limed subsoil; NL = Not Limed subsoil.

† LSD (0.10), lowercase letters are for comparisons between treatment means within a given subsoiling treatment and within a single depth, whereas, uppercase letters are for comparisons between subsoiling treatments for a given depth and lime treatment.

Effect of Subsoiling

The alfalfa yields as a function of the soil moisture at the time the ripping was performed are given in table 7. Surprisingly all the ripping or subsoiling treatments significantly decreased alfalfa yield. The treatment which was believed to be the most beneficial, i.e., ripping under a dry condition, actually gave the lowest yield both years. In fact in 1986, the yield for this treatment (dry ripping) was significantly lower than for all other treatments.

The target yield for alfalfa (6,665 kg/ha) was exceeded both years for all treatments and represent a high production level for agricultural soils in western Kentucky. These high yields were the result of "ideal" management practices and the fact that rainfall distribution in 1985 and 1986 was reasonably good, unlike the lower than normal precipitation levels for the establishment year, in which harvests were not made.

Bulk density data collected after 6 and 42 months are given in table 8. Data from the surface or topsoil horizon were somewhat erratic. The bulk density from the control or nonripped treatment for the first sampling had the lowest value, whereas this same treatment had the highest bulk density at the end of the experiment. Some of these treatments produced significant differences with time. For example, the bulk density from the control plots and intermediate treatments increased from 1.45 to 1.69, and 1.55 to 1.60 Mg/m^3, respectively.

Table 7.--Alfalfa yields as a function of soil moisture at the time time plots were ripped.

Moisture Condition	-- Harvest Year 1985	-- 1986
	---- (kg/ha)	-----
Dry	8350 b A†	7960 c B
Intermediate	8770 b A	8605 b A
Wet	8725 b A	8640 b A
NonRipped	9420 a A	9300 a A

† LSD (0.10), lowercase letters are for comparisons between treatment means for a given year, whereas, uppercase letters are for comparisons between years for any given treatment.

For the 30-45 cm depth of sampling, ripping did not produce any significant differences at either the 6- or 42-month sampling periods. The difference in bulk density from the two extreme treatments was only 0.05 Mg/m^3 for either sampling. The only significant change that was observed was for the nonripped treatment, which increased in bulk density between the first and second sampling. The reason for changes in bulk density between these two or for any of the sampling dates is unknown. For the 45-60 cm depth, changes in bulk density were positive in two cases, i.e., dry and intermediate treatment, and negative for the nonripped control.

Table 8.--Bulk densities from alfalfa plots after 6 and 42 months as a function of soil moisture at the time plots were ripped.

Moisture Condition	Time after ripping 6 mo.		42 mo.	
	Mg/m^3			
	0 - 15 cm			
Dry	1.56 a	A†	1.52 b	A
Intermediate	1.55 ab	B	1.60 ab	A
Wet	1.58 a	A	1.58 b	A
NonRipped	1.45 b	B	1.69 a	A
	30 - 45 cm			
Dry	1.69 a	A	1.68 a	A
Intermediate	1.64 a	A	1.66 a	A
Wet	1.67 a	A	1.70 a	A
NonRipped	1.65 a	B	1.72 a	A
	45 - 60 cm			
Dry	1.65 c	B	1.81 a	A
Intermediate	1.72 bc	B	1.78 a	A
Wet	1.76 ab	A	1.73 a	A
NonRipped	1.82 a	A	1.78 a	B

† LSD (0.10), lowercase letters are for comparisons between treatment means for a given year, whereas, uppercase letters are for comparisons between years for any given treatment.

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