THE EFFECT OF SOIL THICKNESS ON CROP YIELDS[1]

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Abstract: Data from several reclamation projects of non-prime, non-prime cropland, and prime farmland soil research projects are summarized. As one would expect, the soil thickness of reclaimed surface mined land had a significant effect on various crop yields. The soil thickness was most important for corn, followed by grain sorghum, soybeans, wheat, and alfalfa. Soil compaction also affected crop yields, especially for corn. Since the primary standard used to determine Phase III bond release in the mid-western states is based on corn yield, several studies were conducted on the effect of both soil depth and bulk density data as controlling factors in determining corn yield. Soybeans and wheat yields are less affected by soil depth than was found for corn. Alfalfa yield was least affected by soil depth and this crop helped reduce soil compaction. Corn yields were significantly improved following five years in alfalfa production. Yield data were collected on most areas as a part of continuing activities for at least ten years. Most of the corn, soybean, and wheat yields were collected with a combine equipped with a yield monitor.

In many of these projects, subsoiling or ripping, liming, cropping practices prior to planting corn, and organic amendments to the subsoil prior to replacement of the topsoil were also variables that were evaluated as to their role in corn yield. Although these studies illustrated significant effects on corn yield, space does not allow them to be summarized here.

Additional Key Words: Phase III bond release, bulk density, soil compaction, non-prime, non-prime cropland, and prime farmland

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Introduction

During the late 1970's to the early 1990's, several experiments were initiated concerning the restoration of prime farmland in western Kentucky. The objectives varied across experiments. Some of these experiments evaluated the effect of soil thicknesses on crop yields, specifically corn, since yields are often tied to performance standards that must be achieved by the company in order to obtain final bond release. Other experiments involved sub-soiling or ripping to reduce compaction that occurred in the restoration process. Not all of these experiments will be presented here in what should be considered as an overall summary of these research projects.

The University of Kentucky received grants from several agencies to support this research and stipends for the graduate students. These funds mainly came from: College of Agriculture, University of Kentucky; Title V money from the Office of Surface Mining; a Special Grant from the USDA-CSRES; and in-kind monies from Peabody Coal Company. A total of 12 graduate students were trained or associated with these projects. This paper is not intended to be a literature review but a summary of a few studies on the effect of replaced soil over spoils as expressed or measured by crop yields.

Methods

Alston Study

This project was started in the fall of 1978, in Ohio Co. Kentucky, shortly after the interim regulations were published. Details on the plot construction are in Barnhisel, et al., 1979, and a detailed summary of this study also may be found in Powell, et al., 1985. The basic design was a 3x2x2 factorial with three soil depths: 8" (20 cm) of topsoil (A horizon) over spoils which is considered non-prime hay or pasture land use; 24" of soil (8" (20 cm) of topsoil over 16" (40 cm) of subsoil, Bt horizon) which is considered as non-prime cropland; and 40" of soil (8" (20 cm) of topsoil over 36" (80 cm) of subsoil) which is considered prime farmland use. The overburden spoils were graded to give a stair-step configuration as shown in gray in Fig. 1. Then subsoil was replaced on the left two-thirds portion of this area shown in dark orange. This resulted in a smooth surface having a 1.5% slope from right to left. Agricultural grade ground limestone was then incorporated into two portions consisting of one-half of each of the three primary treatments (in light orange, Fig. 1). A 20 cm lift of topsoil was replaced over the entire area. Agricultural lime was incorporated into the upper 10 cm of the topsoil layer (the light orange portion of Fig. 1), while the lower portion (green) did not receive lime.

The soil materials were characterized and fertilizer rates applied accordingly (Powell et al. 1985). Five test crops were established in subsequent years on subplots: wheat (Triticum aestivum L.), tall fescue (Festuca arundinacea Schreb.), alfalfa (Medicago sativa L.), corn (Zea mays L.), and soybeans (Glycine max (L.) Merr.). Yield data were collected on these crops over a 10-year period.

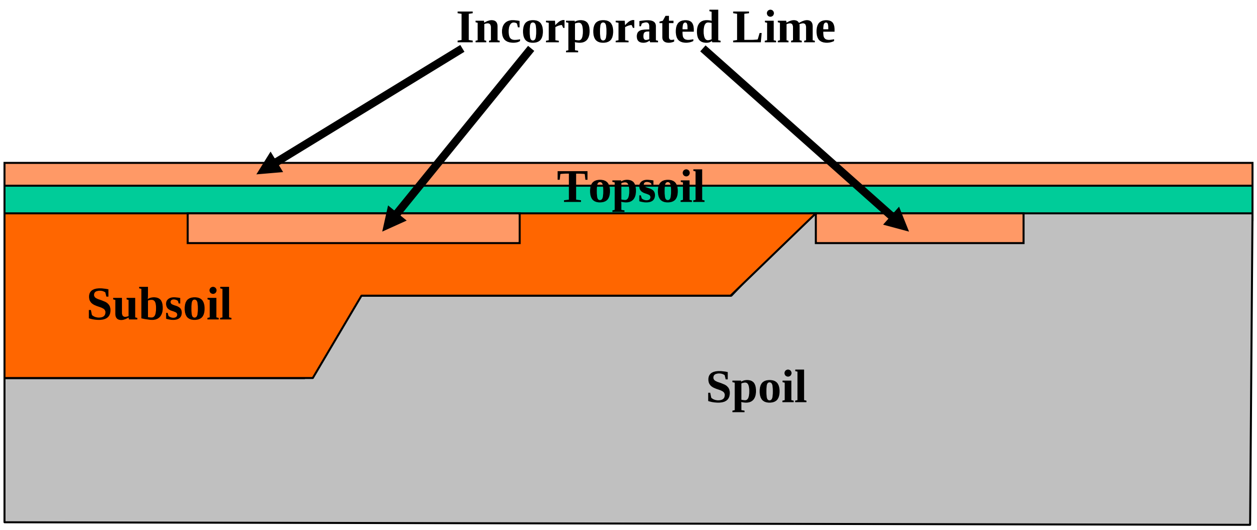

Figure. 1 Cross section of experimental treatments at Alston Surface Mine.

Sinclair Soil Depth Study

This study was established in 1979 with four objectives: 1) to determine the depth of soil required to cover potentially toxic spoils, 2) to determine the need for lime incorporation into toxic spoils for the prevention of upward migration of acid into the replaced soil cover, 3) to determine the effect of ripping on crop yields, and 4) to determine the effect of soil thickness on crop yields. Details of this study may be found elsewhere in an article by Huntington et al., (1980).

The plot construction was accomplished by excavating trenches with a bulldozer 10m wide and 50 m long. The depth of these trenches was either 25 cm or 75 cm deep. A total of 12 trenches were prepared for each depth with 5 m separating the trenches. In addition, an area of equal width and length was left without excavation for the third depth treatment. Agricultural lime was placed in all the trenches as well as on the un-graded areas at a rate of 67 Mg/ha (30t/a). The lime in one-third of these lime treatments was either incorporated by disking, by shallow ripping, or left on the surface. Topsoil was then placed in all trenches with an additional 25 cm soil over the entire area. A cross section schematic of a portion of the experiment is shown in Fig. 2. In this drawing, the shaded area represents all three lime incorporation methods described above which actually occurred in separate trenches. Also noted in Fig. 2 is the fact that lime was incorporated into the upper 10 cm of the entire surface. A total of 12 treatments were prepared with 4 replications. One-half of the 10 m wide plots were sub-soiled.

Five test crops were used to evaluate the various treatments, which included corn, wheat, soybeans, timothy (<u>Phleum</u> <u>pratense</u> L.), and grain sorghum (<u>Sorghum</u> <u>bicolor</u> Moench.).

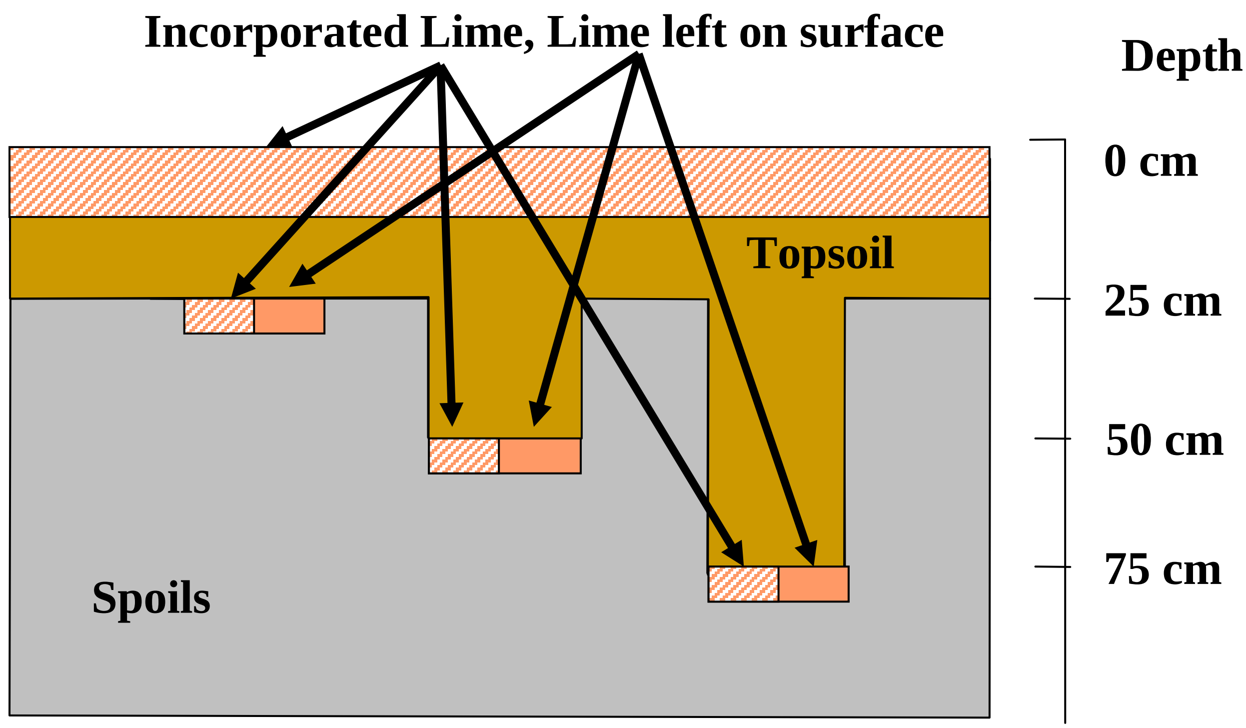

Figure. 2. Cross section of experimental treatments at Sinclair Surface Mine.

Results and Discussions

Yield Response to Soil Depth.

Alfalfa. With respect to the effect of soil depth on reclamation, a good method of evaluation is relating it to crop response/yield. These results have been expressed graphically according to the crop that may require the least amount of soil to achieve the yield standard for Phase III bond release to the crop that requires the thickest soil to accomplish bond release. Our study indicates that forage, in this case alfalfa, may be the crop that can produce good yields with the minimum of replaced topsoil or A horizon material. (Note that in some cases “topsoil” may actually be obtained from some other genetic horizon and is considered as a topsoil substitute.) We have collected yield data for alfalfa and other forages at several locations not shown here but the Alston experiment, began in 1978, was our first. Differences in soil depth did not produce dramatic differences in yield in any given year (see Fig. 3). However, yields were very good, especially in 1981 and 1982. The most striking effect was that all yields increased with time regardless of topsoil depth replacement. This increase is largely the result of alfalfa being able to reduce soil and/or spoil compaction with time. Roots were able to penetrate the good spoil materials and extract both moisture and nutrients.

Wheat. The effect of soil depth on wheat yield is shown in Fig. 4. These data are from the Sinclair study and are similar to what we observed at three other locations in which topsoil thickness was being evaluated. It appears that wheat will produce good yields with a minimum of replaced topsoil. Data were collected for two years at this location. Although these yields were not the best we have obtained, as at one site yields exceeded 100 bu/a for a soil depth of 75 cm, they are typical yields for average management practices used in simply establishing a cover for permanent grasses and legumes. High levels of management, used at the site with our top yield, often prevents establishment of these species due to competition. Since it is the grasses and legumes that are required, high management is not a desirable thing for wheat production on reclaimed mined land unless only the yield, and perhaps the straw, is the goal for this crop. Note there was a small significant (10% level) increase in yield between the 10” (25 cm) and 20” (50 cm) soil depth increment both years, but little if any further increase in yield when the soil depth was between 20” (50 cm)and 30” (75 cm). Yields were sufficient to meet Phase III bond release, especially in 1982. Wheat was not planted in 1981 at this location.

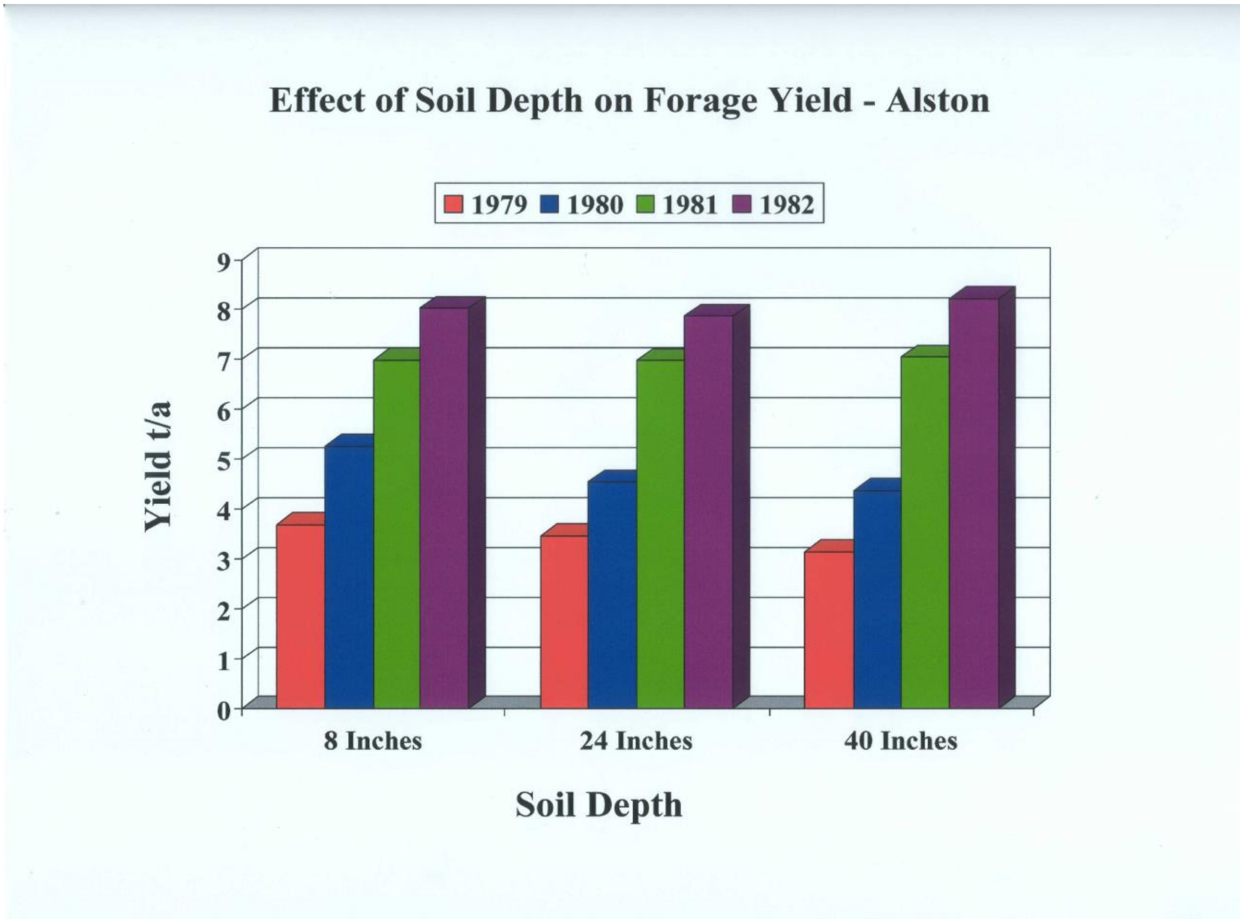

Figure 3. Effect of soil depth on the yield of tall fescue at the Alston Surface Mine.

<u>Soybeans.</u> Yields are presented in Fig. 5 and 6 for Alston and Sinclair Mines, respectively. Two management systems were evaluated in both of these studies; in one case, soybeans were grown full season and in the other double cropping was used where soybeans were planted immediately after the wheat was harvested. The yields at Alston <u>trended</u> downward for 1979 for the full-season management system although they were very good regardless of topsoil thickness, and all yields exceeded those required for Phase III bond release. Yields from the double-crop system tended to increase between the first two soil depths and were unaffected by the additional thickness of the soil. It was noted during soil sampling in 1980 that the subsoil was somewhat compacted at this site as scrapers were used in soil replacement. This was in spite of the plots having been initially subsoiled in 1978.

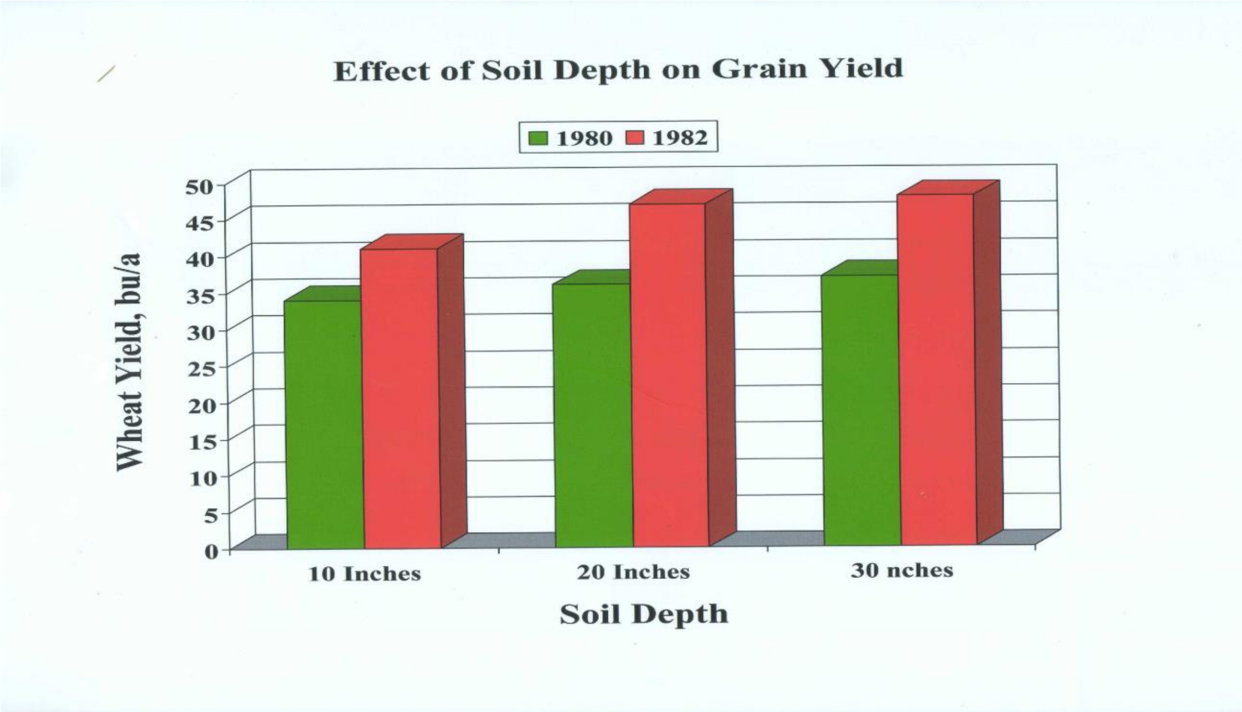

Fig. 4. The effect of soil depth on wheat yield at the Sinclair Mine location.

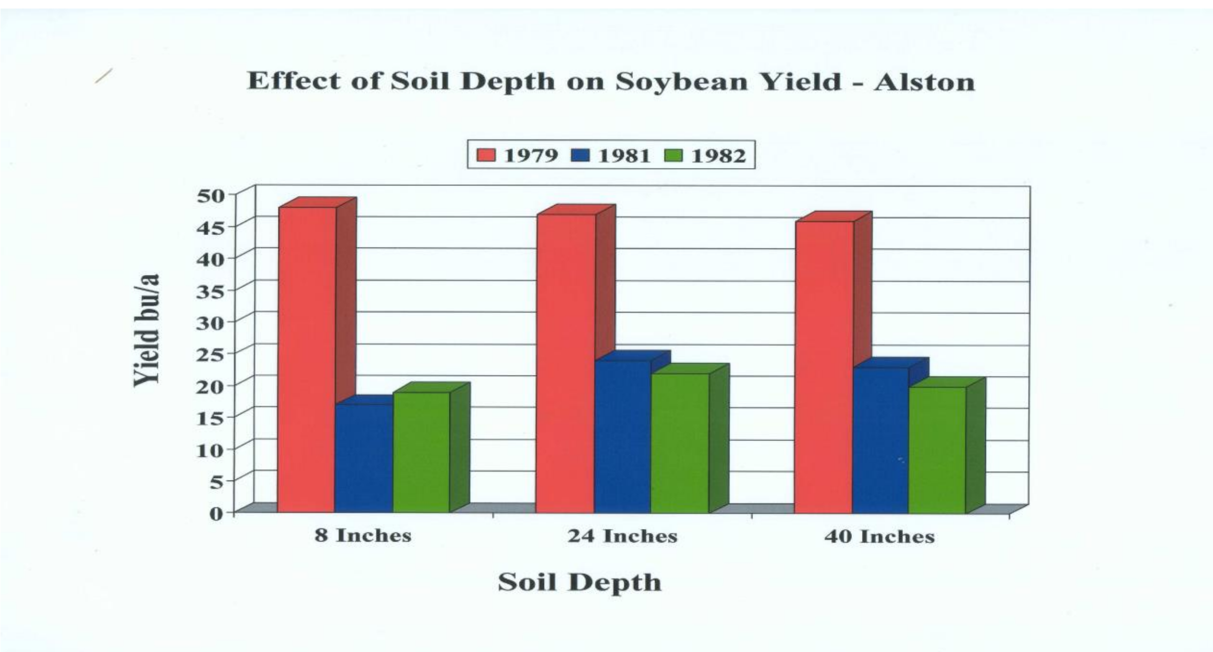

Fig. 5. Soybean yields as affected by soil depth. The 1979 yields were from full season and 1981 and 1982 yields represent double-crop management following wheat.

Soybean yields at Sinclair (Fig. 6) were more responsive to changes in soil depth, especially in 1980. Yields the first year were below bond release standards even for double-crop management, but exceeded the values needed for Phase III bond release in 1982. Full-season soybeans were also grown in 1981, but yields were so low, even for the thickest soil, because of a severe local drought we didn't harvest them.

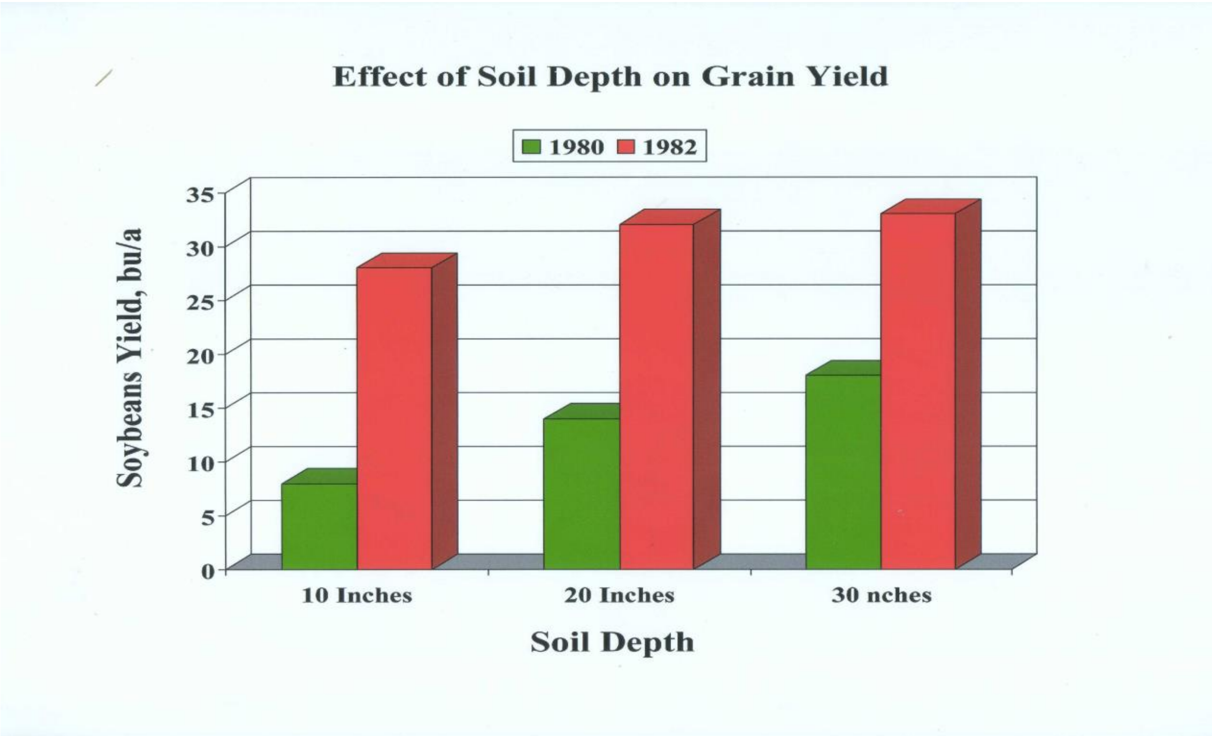

Fig. 6. Effects of soil depth on soybean yield using a double-crop management following wheat.

Corn. Corn must be grown in the mid-western states at least one year for Phase III bond release approval. Corn is the most affected by the soil properties, such as soil depth, water-holding capacity, and general soil structure, hence, the effect of soil reconstruction processes are critical if a coal company wishes to obtain bond release. We have, as was the case for the other crops, evaluated several methods of soil replacement and their effects on corn yields. Corn was one of the crops used at the Alston site in 1979 and these data are presented in Fig. 7.

Data are given for only a few years in Fig. 7, although corn was grown for 7 years at this site. The first year corn yields were good but were not sufficient to meet the bond release standard. If anything, yields had an inverse relationship to soil depth. Between 1980 and 1982, yields were lower than they were in 1979, as lower than normal precipitation occurred during the growing season, but more importantly, the soil bulk density increased within the subsoil (Bt horizon). The higher bulk density reduced the soil's ability to store water for the corn during dry periods. Between 1983 and 1984, the entire area was subsoiled to a depth of about 60 cm and corn was also planted on all the previous plots on which other crops had been grown. Corn yields in 1984 exceeded that required for Phase III bond release for prime farmland at both the 24- and 40-inch (60 cm and 100 cm) soil depth treatments. The standard yield value for this soil was 95 bu/a. Corn was also grown additional years on this entire area with similar yield trends with soil depths. Yields for the 8" (20 cm) soil thickness were always below 50 bu/a except in the first year. We believe the reason for the exception in 1979 and yields obtained later are related to the loose nature of the spoils material below this soil treatment during 1979 as well as an abundant and almost perfect rainfall distribution during the growing season. In subsequent years, the spoils under the 20 cm topsoil plots became more compacted, but this is speculation on our part, as bulk density data were never measured on these materials.

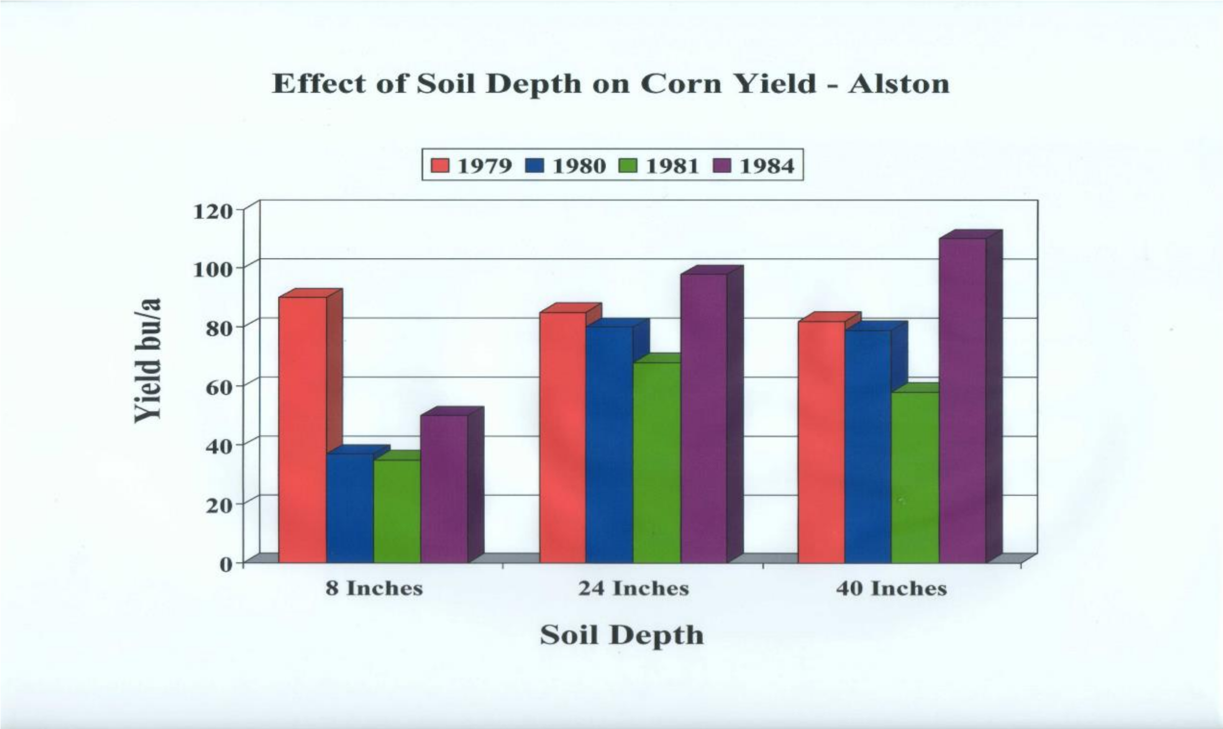

Fig. 7. Corn yield data for selected years from the Alston Surface Mine as affected by soil depth.

In addition to the effect of time on crop yields, the previous crop had an effect on corn yields as shown in Fig. 8. Yields from the deep-rooted alfalfa plots produced the greatest corn yields at all soil depths. The most logical explanation for these increased yields is that the effect of the alfalfa root system reduced the effects of soil compaction.

Bulk density data were collected in 1979, 1980, and 1983. The bulk density data and the corn yield data are given below in Tables 1, 2, and 3, respectively. Note that initially (Table 1) the bulk densities were high for the replaced subsoil, treatments 3 & 4 or 24” (60 cm) soil depth plots and treatments 5 & 6 or 40” (100 cm) soil depth, compared to the average of the undisturbed soils Belknap and Sadler. Statistical comparisons with this average of two samples would not be valid, whereas the other data points are means of our observations per treatment. The bulk densities were lower following subsoiling treatment (compare values with those in Table 2) but were nearly the same 5 years later (Table 3) prior to the second subsoiling treatment done in 1984.

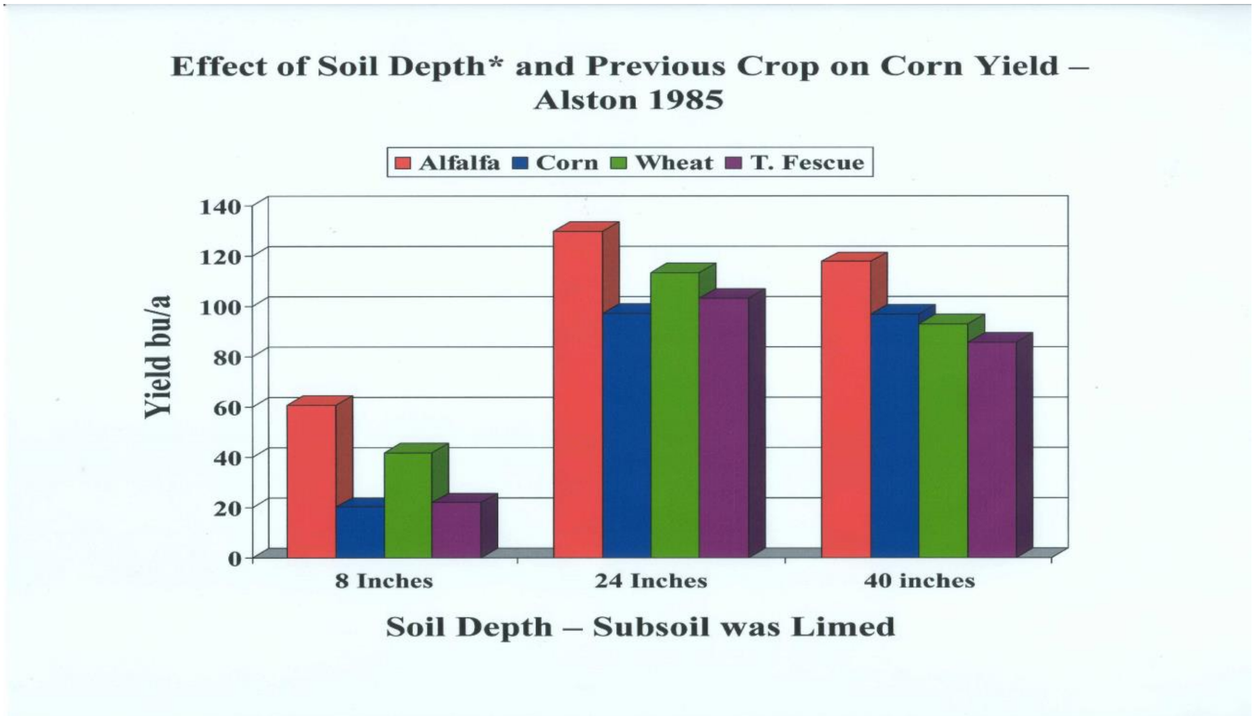

Fig. 8. Effect of previous crop and soil depth on corn yields.

Table 1. Initial bulk densities* at Alston Mine following soil reconstruction.

Bulk Densities – Alston Initial Values

Trt. No.	Sample Depth in Inches: 0 - 6	12 - 18	18 - 24
	g/cc		
1 & 2	1.54 a	- - - -	- - - -
3 & 4	1.55 a B	1.71 a A	1.73 a A
5 & 6	1.63 b B	1.67 b A	1.71 b A
S & B --	1.41	1.54 --	1.56 --

S = Sadler B = Belknap

*The letters in this and the following tables are associated with degree of significance. The small letters are indications of significance at $\alpha = 10\%$ between treatments (vertically in these tables) for a given soil depth. The upper case letters refer to the significance between soil depths within a given pairs of soil treatments.

Table 2. Bulk densities one year after soil reconstruction.

Bulk Densities – Alston After 1 Year

Trt. No.	Sample Depth in Inches 0 - 6	12 - 18	18 - 24
	g/cc		
1 & 2	1.45 a	- - - -	- - - -
3 & 4	1.42 a B	1.58 a A	1.64 a A
5 & 6	1.40 b B	1.59 b A	1.66 b A
S & B --	1.41	1.54 --	1.56 --

S = Sadler B = Belknap

Table 3. Bulk densities five years after soil reconstruction.

Bulk Densities – Alston After 5 Year

Trt. No.	Sample Depth in Inches 0 - 6	12 - 18	18 - 24
	g/cc		
1 & 2	1.51 a	- - - -	- - - -
3 & 4	1.55 a B	1.72 a A	1.68 a A
5 & 6	1.56 b B	1.69 b A	1.72 b A
S & B --	1.41	1.54 --	1.56 --

S = Sadler B = Belknap

Corn yields from the Sinclair study (Fig. 9) show linear increases in yields as a function of soil depth all four years corn was grown on this site. Due to a local drought, 1983 growth was very low; therefore, the plots were not harvested. Yields never were sufficient to allow Phase III bond release at this location largely, because there wasn't sufficient soil replacement. The increase in yields over time is likely due to two factors: 1) improvements in soil bulk density (data not shown) and 2) better availability of soil moisture, except in 1983. The effect of soil depth on corn height was also evident, Fig. 10. Note in this photo, soybean plant height was not noticeably affected by the drought, but also note the obvious drought stress expressed in the rolling of corn leaves and the inversion of soybean leaves. Recall that some of the plots at Sinclair were ripped. Those plots at the Sinclair site that had been ripped had greater plant height, Fig. 11. The path of the ripper shanks of a D 9 dozer are illustrated in the photo. This photo was also taken in 1983, but earlier in the season than the previous figure. Similar differences were also evident for plots that had thicker soil. Also note that the soybeans exhibited much less drought stress symptoms where ripping was done in that portion of the plot.

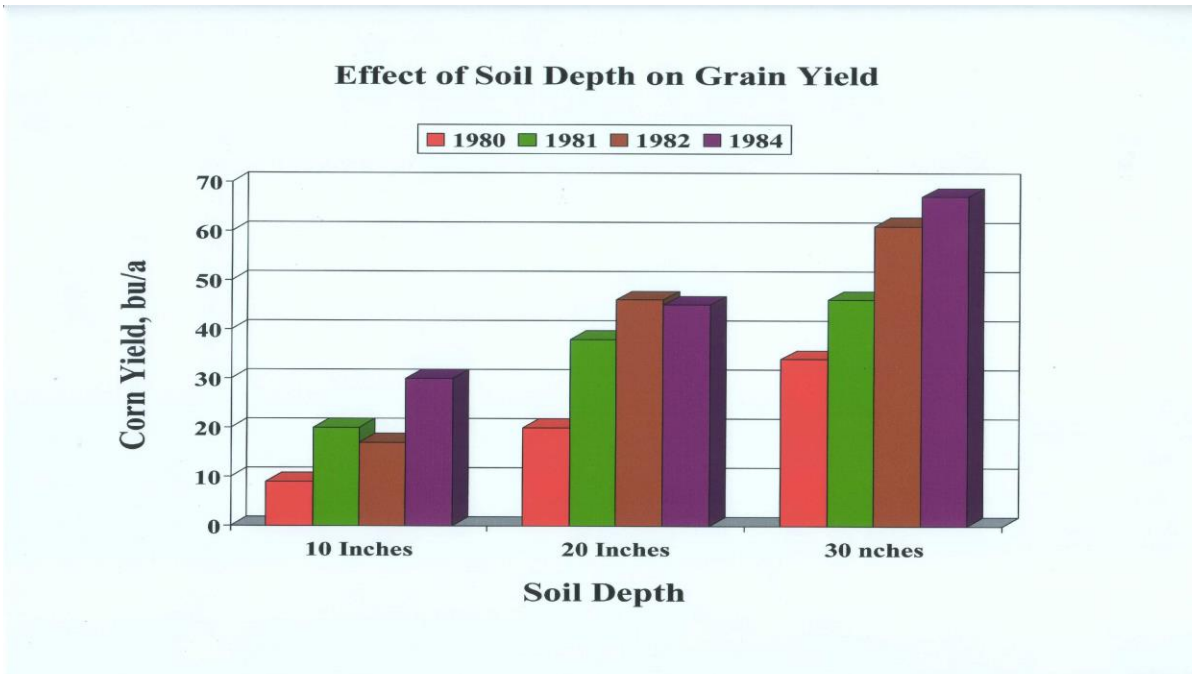

Fig. 9. Corn yields at Sinclair Surface Mine as a function of soil thickness.

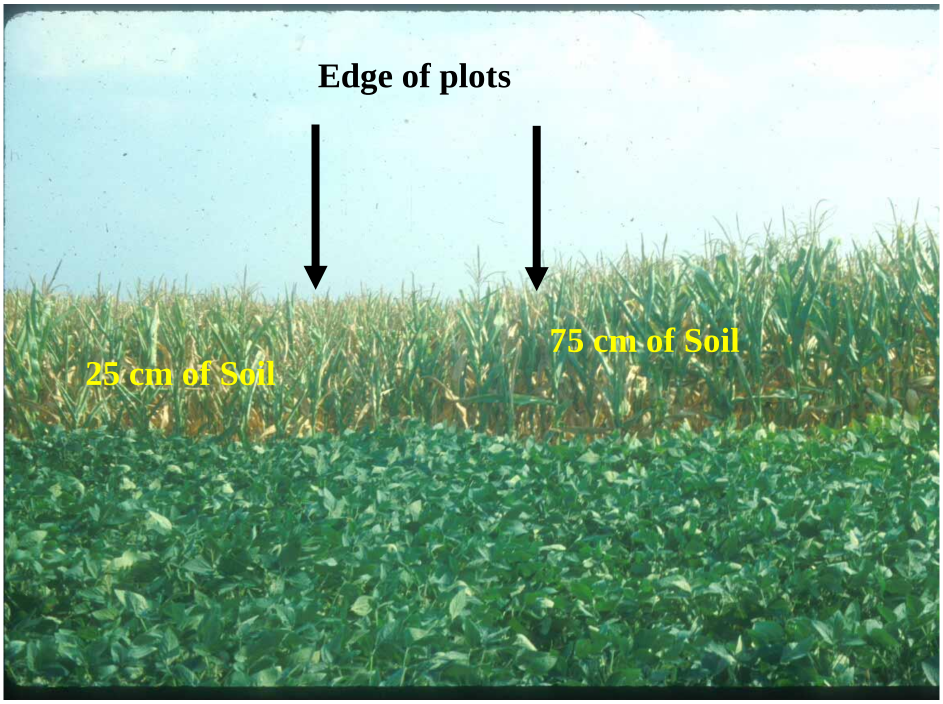

Fig. 10. Contrast in corn plant height as a function of soil thickness. Photo was taken 1983.

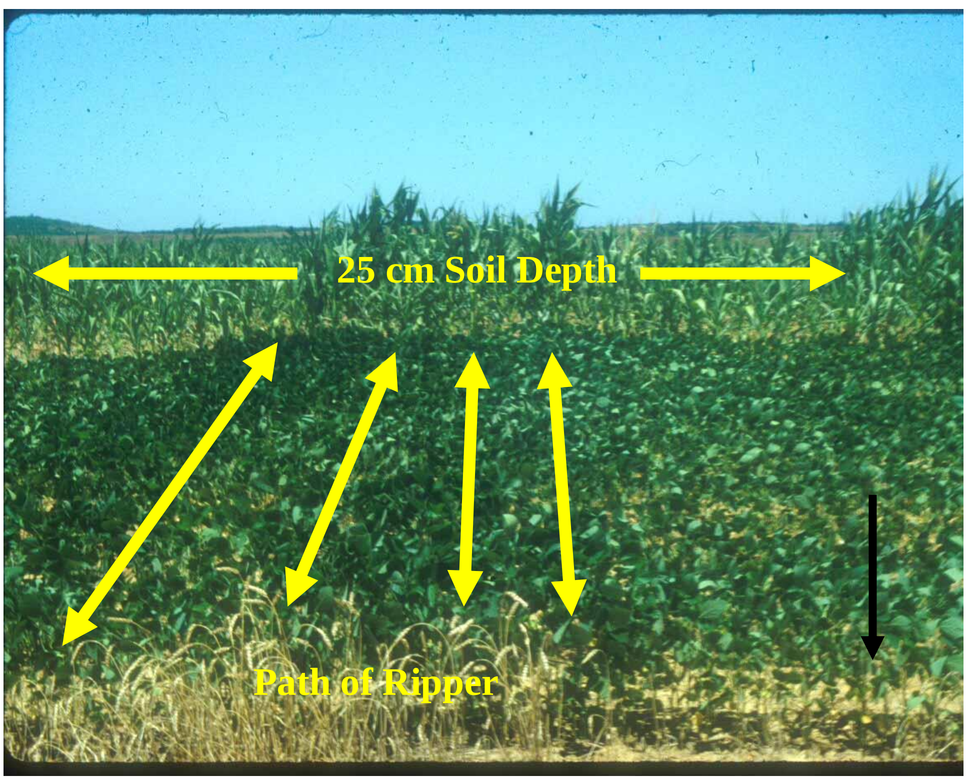

Fig. 11. Effect of ripping on corn plant height and soybean drought symptoms.

Ripping also produced lasting effects at the Sinclair location in soil structural properties. This is illustrated in Fig. 12 taken 5 years after the ripping treatment. The yellow ribbon outlines the zone within the 75 cm soil depth treatment affected by this ripping treatment. The improved soil structure extended downward about 60 cm, the original depth at which the ripper was operated.

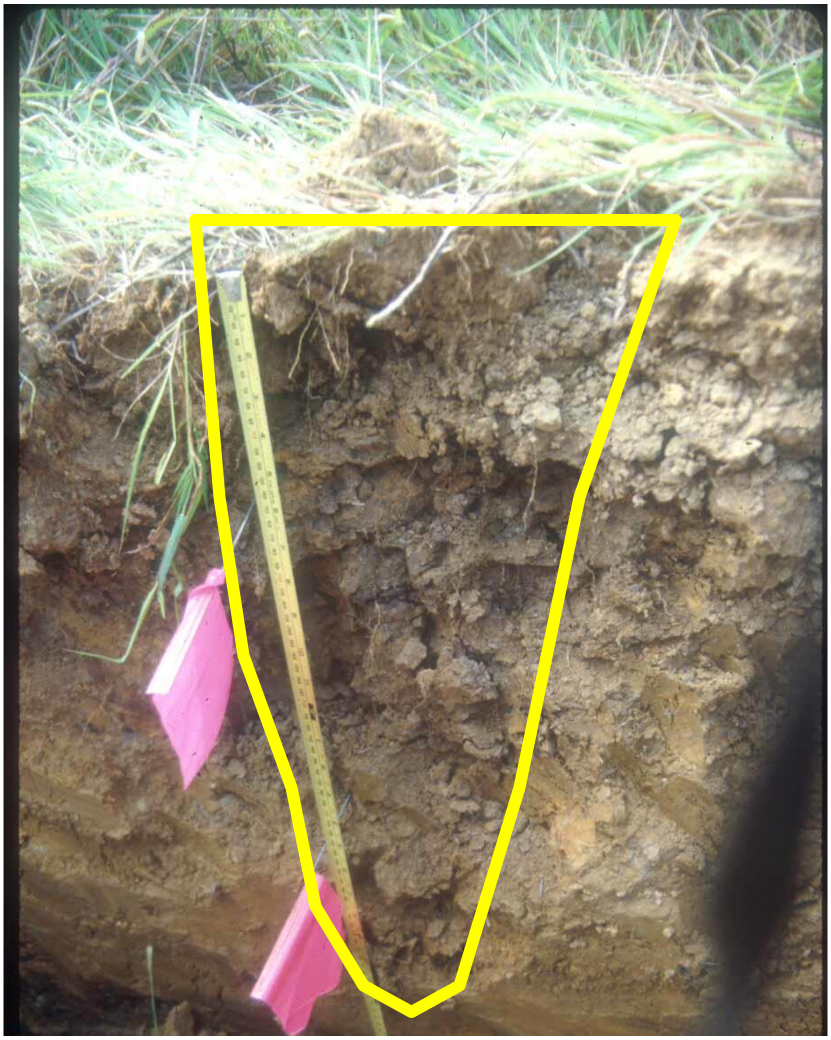

Fig. 12. The effect of ripping on the soil structure five years after the treatment was performed.

<u>Conclusions</u>

1) All crops respond differently to differences in soil thicknesses. This relationship was a controlling factor in producing yields large enough to meet Phase III bond release standards.
2) Alfalfa was the least sensitive to differences in soil depth.
3) Wheat responded to increases in soil depth, but the critical depth appeared to be 20" (50 cm) after which thicker soil did not produce significantly higher yields.

4) Soybeans responded to increased soil depth up to 30” (75 cm).
5) Corn required at least 40” (100 cm) of soil to produce yields sufficient to obtain Phase III bond release.
6) Subsoiling with a conventional subsoiler, reduced bulk densities, but this effect was short lived unless a wider shank or shoe was used as was the case at the Sinclair Study.

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