The Effects of Bulk Density on Available Moisture in Selected Surface Mine Soil Materials

G.C. Steinhardt, W.C. Moldenhauer and D.P. Franzmeier
Department of Agronomy
Purdue University
West Lafayette, Indiana

Introduction

There is considerable interest in the effects of surface mining and subsequent reclamation on soil productivity. One concern is the amount of soil compaction that results from current surface mine reclamation techniques. Previous work has looked at methods to improve drainage or promote root growth. This article considers the potential effect of soil compaction on plant available water in the soil.

Literature Review

Numerous studies have been conducted in the Midwest to evaluate properties and productivity of soils following reclamation after surface mining (Henning, 1979; Fehrenbacher et al., 1982; Stein, 1983; McSweeney and Jansen, 1984). Some have examined alternative reclamation techniques and others have examined soil management. Crop yields on reclaimed soils have in general been variable with weather, which is also typical of unmined soils. The reclaimed soils, however, show considerably more variability in yields, obtaining near normal yields with good rainfall but more drastic yield reductions if water content is deficient. This is very similar to results obtained in intentionally compacted plots (Gaultney, et al., 1982).

Soil compaction can lead to moisture stress (Byrnes, et al., 1982) and excessive soil compaction in the reclaimed soil may be causing the moisture stress observed due to reductions in available water.

Methods

Bulk soil samples were taken from each of three surface mine sites in southeastern Indiana. The location of these mine sites, original soil, classification and particle size analysis are shown in Table 1. Samples were taken from the surface layer of the reclaimed

Table 1. Surface Mine Locations and Soil Characteristics.

Mine	County	Original Soil	Classification	Particle-Size Analyses Silt %	Clay %
Ayrshire	Warrick	Hosmer silt loam	Typic Fragiudalf	70	21
Solar Sources	Pike	Alford silt loam	Typic Hapludalf	74	19
CHinook	Clay	Ava silt loam	Typic Fragiudalf	70	18

soil, which is a mixture of A and B horizons from the original soil at the site. The classification of the soils originally present indicates that a fragipan was present in two of the three original soils. The fragipan material was not used in this study.

The bulk soil samples were all silt loam texture. Even though it was a mixture of two horizons the soil materials were fairly uniform. To insure consistent packing the air dry soils were crushed and passed through a 2 mm sieve. Water was slowly added to the soil and thoroughly mixed. The final water content was in the range of 15 to 20% on an oven dry basis. Water content samples were taken and the exact water content determined. The container was sealed and the wet soil was allowed to stand overnight to equilibrate.

Soil cores of different bulk densities were obtained by placing a known weight of soil, corrected for water content, in a brass ring of known volume. The soild was compressed in the brass ring using a specially designed mold. When the mold was squeezed between the plates of a hydraulic press, the piston compressed the soil until it was confined within the volume of the brass ring. This resulted in bulk density samples that were quite predictable and consistent. Three replicate samples at each tested bulk density were prepared and the results averaged. Ten density levels for soils from the Ayrshire mine, five for Chinook and 12 for Solar Sources were used.

Water Retention Measurement

The compacted bulk density samples were saturated from below in a pan starting with water at approximately 1 cm depth for 24 hours and then raising the water level to the top of the core for another 24 hours. The soil samples were weighed at saturation and after equilibration at 0.01 MPa, 0.03 MPa and 1.5 MPa tension. The soil water tensions were produced using pressure plates and standard techniques (Richards, 1965). After determining the weight at 1.5 MPa tension the samples were oven dried and the water content at saturation and at each tension was calculated as a percentage of the oven dry weight of the soil. This permitted easy calculation of water content between various tensions measured.

Results and Discussion

The particle-size distributions are very similar for all of the mine sites (Table 1). This was expected due to the similar eolian nature of the parent materials of the natural soils.

Figure 1 contains the water retention data for all samples for all three sites. After plotting the results of each site separately it was found that all three sites followed the same relationship. This would probably not be the case if the particle-size distributions were not similar. The results for the three replicate samples of each bulk density were very close.

There is a close relationship between the saturated water content and the bulk density. The r^2 for the regression (Figure 2) of saturated water content on bulk density was 0.87. As bulk density is changed pore volume is directly affected. A similar r^2 value, 0.78, was found for soil water at 0.01 MPa tension. The r^2 value for 0.03 MPa tension is lower. Soil water content at a tension of 1.5 MPa is not related to bulk density. Moisture contents at 0.03 and 1.5 MPa are probably related more to particle-size distribution (Franzmeier et al., 1960) but these data do not address that issue.

In previous studies (Richards, 1965), the water contents at both 0.01 MPa and 0.03 MPa have been used to estimate field capacity. There is considerable controversy about whether or not either of these is a valid approximation of field capacity (Hillel, 1980). However, Franzmeier, et al. (1960) demonstrated a fairly close relationship of soil water at 0.006 MPa tension and field measurements of field capacity for over 90 Midwest soils. For this study 0.01 MPa was used as the estimated field capacity, realizing that there may be some limitations. If the water content at 1.5 MPa is taken as the permanent wilting point, the percentage of available water in the soil can be calculated as the difference between water content at 1.5 MPa and that at 0.01 MPa. This can be done from the data in Figure 2 for any bulk density from 1.3 Mg/m^3 to 1.9 Mg/m^3. This allows

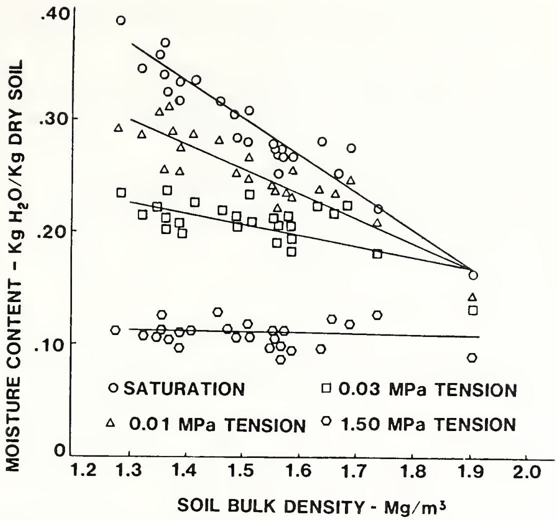

FIGURE 1. Moisture content at various soil moisture tensions.

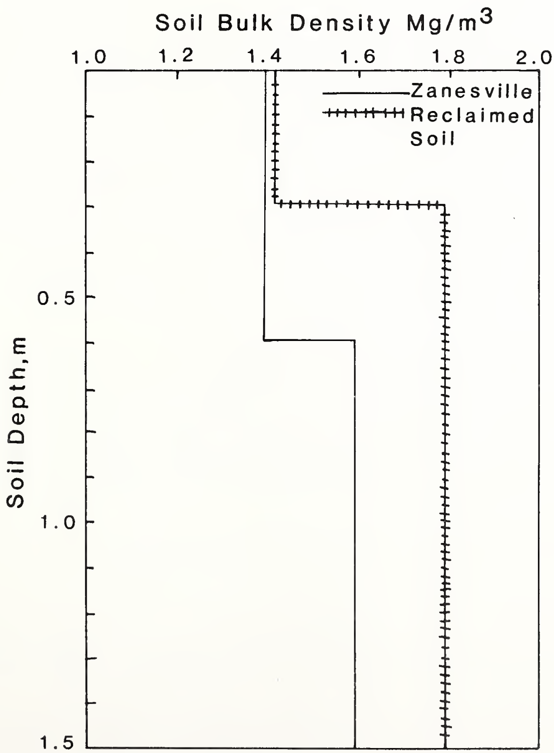

FIGURE 2. Bulk density of Zanesville silt loam and a reclaimed soil at Solar Sources Mine.

calculation of the available water that would be expected in a natural soil for comparison to what might be found with a reclaimed soil.

Approximate soil bulk density profiles for a Zanesville silt loam and the reclaimed soil at the Solar Source mine are shown in Figure 2 to a depth of 1.5 m. The Zanesville soil densities are from Wiersma (1984) and the reclaimed soil densities are from Stein (1983).

At a bulk density of 1.4 Mg/m^3 the water content is 0.28 Mg H_20/Mg soil at 0.01 MPa and 0.11 Mg H_20/Mg soil at 1.50 MPa for a difference (available water) of 0.17 Mg H_20/Mg soil. Assuming the density of water is 1.00 Mg/m^3 then:

$$\frac{1.40 \text{ Mg soil}}{\text{m}^3 \text{ soil}} \times \frac{0.17 \text{ Mg H}_20}{\text{Mg soil}} \times \frac{1.00 \text{ m}^3 \text{ H}_20}{1.00 \text{ Mg H}_20} = \frac{0.24 \text{ m H}_20}{\text{m soil}}$$

Similarly, the available water content is 0.20 m/m at a bulk density of 1.6 Mg/m^3 and 0.15 m/m at a bulk density of 1.8 Mg/m^3. Then assuming the bulk density profiles in Figure 2, the available water in 1.5 m of the Zanesville soil is

$$\frac{0.24 \text{ m H}_20}{\text{m soil}} \times 0.60 \text{ m soil} + \frac{0.20 \text{ m H}_20}{\text{m soil}} \times 0.90 \text{ m soil} = 0.32 \text{ m H}_20$$

and in 1.5 m of reclaimed soil it is

$$\frac{0.24 \text{ m H}_20}{\text{m soil}} \times 0.30 \text{ m soil} + \frac{0.15 \text{ m H}_20}{\text{m soil}} \times 1.20 \text{ m soil} = 0.25 \text{ m H}_20$$

The results are shown in Table 2.

TABLE 2. Comparison of Zanesville Silt Loam and Reclaimed Soil at Solar Sources Mine.

	Plant Available Moisture Stored 1.5 m	Moisture Required For Corn	Rainfall Required June-Aug	Approximate Probability of Adequate Rain
	mm	mm	mm	%
Zanesville Silt Loam	320	500	180	83
Reclaimed Soil	250	500	250	48

A corn crop requires approximately 500 mm of water to reach full yield potential Rainfall during the growing season must supplement the amount stored initially in the soil. Figure 3 shows the probabilities of a given amount or more of rainfall during the June through August period. These estimates are calculated from the gamma distribution parameters for two- and three-week precipitation totals based on 54 years (1901-1954) at Mt. Vernon, Indiana (Barger et al., 1959, p. 26). The Zanesville soil requires 180 mm of rainfall to obtain adequate water for a corn crop (Table 2). There is an approximate 83% chance this will happen. On the other hand there is only a 48% chance that the reclaimed soil will receive the necessary 250 mm of rainfall. These probabilities do not address the question of distribution or timeliness of the rainfall.

Although there may be room for interpretation as to the upper limit of available water or a specific density profile, the probability figures in Table 2 do point out one of the serious limitations of reclaimed soils. The compacted soils are so dense that they do not store enough water to supply crop needs in most years. Unfortunately deep tillage may not be a solution to this aspect of the compaction problem. Deep tillage may improve permeability and rooting but the dense clods may still not be capable of storing adequate moisture.

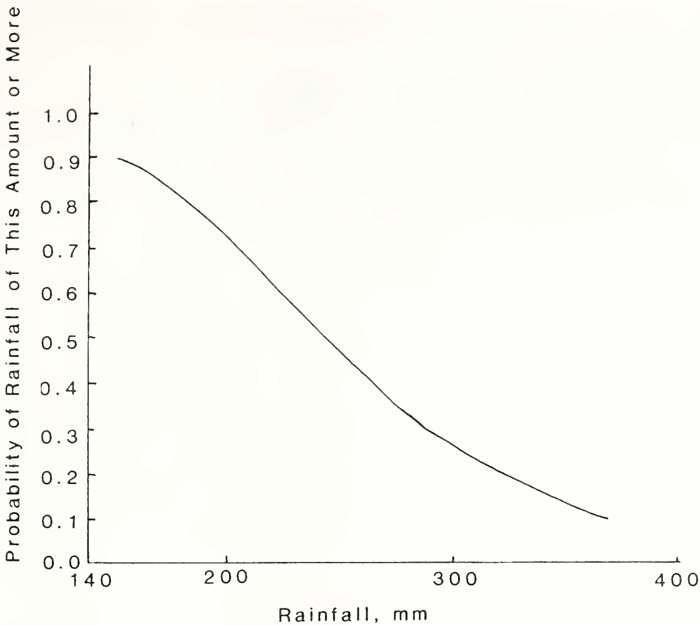

FIGURE 3. Rainfall probability, June thru August, Mt. Vernon, IN.

The ultimate solution may be selection of an alternative approach to reclamation that reduces reliance on scrapers and bulldozers working with relatively thin layers of soils.

Acknowledgments

Support for this work was provided by Research Grant No. G5115181 from the Office of Surface Mining, U.S. Department of the Interior. Journal Paper No. 10,996. Purdue Agric. Exp. Sta.

Literature Cited

Barger, G.L., R.H. Shaw and R.F. Dale. 1959. Gamma distribution parameters from 2 and 3 week precipitation totals in the north central region of the United States. Project 1280. Iowa Agricultural Experiment Station, Ames, IA. 183 pp.

Byrnes, W.R., W.W. McFee and G.C. Steinhardt. 1982. Soil compaction related to agricultural and construction operations. Sta. Bull. 397. Agr. Exp. Sta. Purdue Univ. 164 pp.

Fehrenbacher, D.J., I.J. Jansen and J.B. Fehrenbacher. 1982. Corn root development in constructed soils on surface-mined land in western Illinois. Soil Sci. Soc. Am. J. 46:353-359.

Franzmeier, D.P., E.P. Whiteside and A.E. Erickson. 1960. Relationship of texture classes of fine earth to readily available water. 7th Intl. Cong. of Soil Sci. Vol. 1 pp. 354-363.

Gaultney, L., G.W. Krutz, G.C. Steinhardt and J.B. Liljedahl. 1982. The effects of subsoil compaction on corn yield in Indiana. Trans. ASAE 25:3;563-569.

Henning, S.J. 1979. Experiences in farming reclaimed mined land — small operations and small sites. p. 70-79. In Proceedings Prime Farmland Reclamation Workshop, Ind. Univ.-Purdue Univ. Indianapolis, Indianapolis, IN.

Hillel, D. 1980. Applications of soil physics. Academic Press. New York, NY.

McSweeney, K. and I.J. Jansen. 1984. Soil structure and associated rooting behavior in mine soils. Soil Sci. Soc. Am. J. 48:607-612.

Richards, L.A. 1965. Physical conditions of water in soil. p. 128-152. In C.A. Black (ed) Methods of soil analysis Part 1. Am. Soc. Agron. Monograph 9. Madison, WI.

Stein, O.R. Jr., 1983. Erodibility and related soil properties of three reclaimed surface mined soils. M.S. Thesis. Purdue University, West Lafayette, IN.

Wiersma, D. 1984. Soil water characteristic data for some Indiana soil profiles. Stn. Bull. 452. Purdue Univ. Agr. Exp. Stn. W. Lafayette, IN 153 pp.