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SOIL-MOISTURE RETENTION IN SPOIL DURING DRY CONDITIONS AT THE ROSEBUD COAL MINE NEAR COLSTRIP, MONTANA

By David W. Moore and Reuben F. Miller

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square miles	2.59	square kilometers
degrees Fahrenheit (°F)	5/9 (°F-32) = °C	degrees Celsius (°C)

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SOIL-MOISTURE RETENTION IN SPOIL DURING DRY CONDITIONS AT THE ROSEBUD COAL MINE NEAR COLSTRIP, MONTANA

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ABSTRACT

Spoil in the upper 1.0-1.2 m at the "Plant Community Development Study" plot at the Rosebud Mine was studied at 6 sites. Sandy loam spoil that had been topsoiled and treated with various surface roughening methods in 1972 was sampled by auger in September during the driest part of the 1975 hydrologic year. Samples were analyzed in the laboratory for moisture content, void volume, and bulk density. Moisture-retention force of samples was determined using passive gravimetric stress sensors (filter paper method).

Moisture content in most samples was less than 0.1 g/g and was held by a soil-moisture retention force equal to or greater than 15 bars. Most native grasses can transpire moisture larger than this retention force. Introduced grass species were dormant indicating they were unable to transpire tightly adsorbed moisture in the spoil. Moisture levels observed in September indicate minimum levels at the end of a typical growing season having large evapotranspiration. It appears that most native grasses could grow on the spoil having available moisture at the levels measured.

Moisture levels for steeply sloping spoil (12 to 13 percent) treated by dozer basins were comparable to less steep spoil (7 to 8 percent). However greater grass cover on the steeper sites indicated that dozer basins effectively trapped runoff water and had increased available moisture for plant growth. Sites 3 and 4 on an abandoned haul road held slightly more moisture than sites on these hillslopes indicating enhanced moisture by runin or subsurface inflow from the nearby sloping spoil.

Moisture in spoil was comparable to that in native undisturbed soil (U.S. Geological Survey, 1975, 1977a, 1977b) and that measured by neutron methods by Dollhopf and others (1977). This indicates that soil moisture in the root zone of spoil during most growing seasons is sufficient to support native vegetative growth and consumptive use is comparable to native soil.

INTRODUCTION

The capacity of mine spoil to store moisture for plant growth is of interest to those who attempt to reclaim spoil in semiarid regions. In the mid 1970's, coal mining in the semiarid western United States was increasing, but few data on moisture relations in spoil existed. Some doubted that spoil could be revegetated in southeast Montana (Prouty, 1975; Winder and Lochner, 1974; National Academy of Sciences, 1974). Others suggested that heavy machinery used to replace "topsoil"--often a mixture of the original soil profile and spoil--would compact it, causing permanent reduction of moisture available for plant growth (U. S. Geological Survey, 1977a, p. 84). Subsequently, data on moisture in spoil have been obtained from instrumented watersheds at coal mines in the Northern Great Plains, for example Dollhopf and others (1977). Nevertheless, much can be learned about spoil having variable moisture retention characteristics, especially as such characteristics relate to moisture needs of native plants. Mining companies are required by law to grade and apply topsoil and to revegetate it with native plants (Montana Department of State Lands, 1980).

Soil moisture in natural geologic materials was studied previously in order to assess reclamation potential of coal lands in the Northern Great Plains (Moore, 1978). Moisture data for spoils at the Rosebud (Western Energy) Mine were obtained by methods used on native soils in the region (Branson and others, 1970). Samples were analyzed in the laboratory for moisture content, bulk density and other properties that affect moisture-holding capacity (Millar and others, 1965, p. 85).

Spoil at the "Plant Community Development Study" plot (PCDS plot) was studied because it had been roughened by machinery using various treatments designed to detain runoff. Newly graded spoil inhibits establishment of vegetation because its compact, bare, smooth hillslopes are susceptible to erosion, and they do not trap water as effectively as naturally vegetated hillslopes. A system of shallow gullies existed in the spoil that we sampled. They formed when spring snowmelt from a compacted area located uphill washed down over the spoil (R. L. Hodder, written commun., 1975). Rainstorms in the spring of 1975 rapidly enlarged the gullies (Dollhopf and others, 1977, p. 53).

We sampled the spoil in September in order to observe the effect of treatments on moisture-retention capacity during the driest part of the hydrologic year. Moisture in spoil, between maximum wetness and the period of greatest evapotranspiration, essentially is the minimum water available for native vegetation during the frost-free and potential growing season. Findings of this study can aid in selection of drought-tolerant species for revegetation and for modeling shallow ground water flow systems in spoil.

We recognize the limits of our attempts to understand reclamation potential in semiarid regions. Soil moisture is one of many interdependent factors, natural and manmade, that affect plant growth. Other factors, geochemistry of spoil, types of plants, and climatic cycles to mention a few, were not studied.

ACKNOWLEDGMENTS

The report was reviewed by Terrence J. Toy. Paul McElwain assisted in the field and Martha Mustard assisted in the laboratory. Cooperation of the Western Energy Company is gratefully acknowledged.

DESCRIPTION OF STUDY AREA

Physiography

Colstrip is in the Northern Great Plains on the Missouri Plateau. Elevations of the plateau range from 400 to 1,300 m above sea level. Sandstone and clinker mesas cap escarpments in the heads of branching ephemeral stream-drainage systems that cut subhorizontal layers of sedimentary rock. The kilometer-wide valley of Rosebud Creek cuts dissected uplands south of the Western Energy Mine. The valley floor is underlain by 6 to 9 m of clayey to gravelly alluvium and is flanked by low stream terraces. Sandy and silty fan alluvium rests on stream terraces at the foot of valley slopes.

The Tongue River Member of the Fort Union Formation of Paleocene age contains the coal being mined: the Rosebud and McKay coal beds (Dobbin, 1930). The member is 350 to 580 m of yellow-gray to pale olive-gray continential deposits: fine-grained, loose to weakly cemented sandstone, clayey siltsone, plastic clay shale, claystone, and coal (U. S. Geological Survey, 1977a). Resistant clinker zones, chiefly fused or baked shale oxidized to reddish brown by in-situ burning of coal beds, and sandstone layers form ridges wooded with pine and juniper.

Climate

Continental, cold winters and warm summers with large diurnal temperature variations are typical; precipitation can be highly variable. Average annual precipitation at the Colstrip National Weather Service (NWS) station is about 400 mm at elevation 980 m (Montana Department of State Lands, 1982). Extremes in total annual percipitation for the 1970 through 1980 period were 562 mm (1978) and 195 mm (1980). Weather stations record the following mean annual precipitation: Birney, 69 km to the south, 348 mm (21 years of record); Broadus, 108 km southeast of Colstrip, elevation 924 m receives 924 mm (37 years of record).

Three-fourths of the precipitation falls as rain during the growing season, which averages about 115 frost-free days (Toy and Munson, 1978). Growing season for hardy grasses near Birney lasts about 120-130 days between early May and late August (Southard, 1973). Normally, soil moisture is near field capacity during the early growing season, contributing to rapid growth of native range plants. At Colstrip, most precipitation falls in June, 78 mm on average, from 1964 through 1975; next highest is 45 mm in October (Toy and Munson, 1978). Typically evapotranspiration has depleted soil moisture by mid-July. Plants mature and become dormant. At Colstrip from July 1975 through May 1976, a 45 to 50 cm of water loss by evapotranspiration was measured (Dollhopf and others, 1977). Consumptive use requirements computed by the Blaney-Criddle Method using Broadus weather station data indicate that native grasses could use 570 mm of moisture if available, but that the mean annual precipitation of about 360 mm would be used by July 15 (U. S. Geological Survey, 1975, p. 11). However, less than 360 mm is probably available for plant use owing to loss by runoff and evaporation.

Spoil characteristics

Spoil is loose, piled-up aggregate of sandstone and shale pieces, sand, silt, and minor clay grains that is formed during the stripping of rocks of from above coal beds. It is synonymous with "spoil material" in reclamation literature. We examined only the uppermost meter of spoil, chiefly sandy loam in the USDA grain-size classification. Hillslopes of sampled spoil range from 1 to 13 percent. Clay minerals, determined by x-ray analysis (Dollhopf and others, 1977, p. 43), are chiefly kaolinite and illite (25 to 50 percent each) with minor smectite and chlorite (5 to 25 percent each) and less than 5 percent vermiculite The spoil is not greatly saline or alkali and trace elements were small to moderate in concentration. Nitrates were abundant compared to concentrations in undisturbed rangeland.

Spoil in the PCDS plot was graded in 1971 and was mechanically roughened in 1972. Roughening treatments included gouging, "dozer" basins, and chiseling to detain surface runoff and improve infiltration to recharge the root zone. Dollhopf and others (1977) reported that these methods, when used with topsoiling, effectively reduced runoff in the EPA (U.S. Environmental Protection Agency) Demonstration area at Colstrip. Topsoiled and roughened areas had one-fourth to one-sixth the runoff, and greater infiltration, compared to similar watersheds with roughening treatments but no topsoil.

A compacted surface zone formed by grading machinery has bulk densities of 1.7 to more than 2.0 g/cm^3 (Dollhopf and others, 1977, p. 82). Average bulk density of the upper 15 cm at the PCDS plot was 1.72 g/cm^3 in 1972 and 1.27 g/cm^3 in 1973 (Sindelar and others, 1974). Roots have difficulty penetrating sandy soils with bulk density of about 1.75 g/cm^3 and heavy clay soil with bulk density of about 1.5 to 1.6 g/cm^3 according to Veihmeyer and Hendrickson (1948). Further, compact spoil retards water infiltration and generally is poorly aerated.

Some properties of spoil at pit number 6 (includes the studied spoil at the PCDS plot) in the Rosebud Mine are summarized in Table 1.

Table 1.--Some properties of spoil at Colstrip, Montana

[From Schafer and others, 1977]

		Old spoil (1924, 1932)	Relatively young spoil (1948, 1969, 1973)	Native range soil
pH	0-5 cm depth	7.6-8.4	7.7-8.4	7.4-8.4
	>5 cm	7.9-8.6	7.4-8.7	7.6-8.4
Organic carbon (percent)		0.1-3.0	0.5-2.5	1.0-2.5
Electrical conductivity (micromhos per cm)		0.2-1.0	0.4-1.4	no data
Bulk density		1.43	1.38	1.46 (36 samples)
(g/cm^3)		average, all spoils 1.41 (76 samples)		

Table 1 shows that mine spoil generally contains less organic matter than natural soils. Average bulk density of surficial spoil exceeds that of the near-surface horizons of native range soils, and subsurface bulk density of spoil tends to be less than that at corresponding depths in native soils (Schafer and others, 1977, p. 26). Average bulk density of spoil samples exceeded that of typical native rangeland (1.4 g/cm^3) according to Sindelar and others (1974).

Infiltration rates for topsoiled spoil are about 14 to 16 cm/h (centimeters per hour) initially and decrease slightly to steady state of 8 to 14 cm/h after 30 minutes (Dollhopf and others, 1977, p. 48).

FIELD-SAMPLING PROCEDURE

Spoil was sampled at six sites near the northern part of pit number 6 in the Plant Community Development Study plot (NW1/4 NE1/4 NE1/4 sec. 18, T. 1 N., R. 42 E.) (fig. 1). Two sites were located in each of three types of spoil: sites 1 and 2 on chiseled spoil that formed grassy slopes facing northwest and downhill from a tree snag (figs. 2 and 3); sites 3 and 4 on a nearly level compacted, abandoned haul road near the tipple (figs. 4 and 5). The former haul road had been ripped, chiseled, and seeded to introduced grass species, and Russian thistle had invaded these sites. Sites 5 and 6 (figs. 6 and 7) were located on northeast-facing spoil hillslopes that had been roughened with dozer basins. Besides the initial grading in 1971, all sites had been topsoiled, chiseled, and broadcast seeded with a mixture of grass, shrub, and legume in May, 1972. The spoil was also then drill seeded with winter wheat and sudan grass to temporarily stablize the surface. Fertilizer was then applied.

During the second week of September, 1975 we collected a sample of surficial spoil at each decimeter depth using a 5.08-cm-diameter barrel-type soil auger. Each sample consisted of 202.7 cm^3 of material. Thus, sample 1 was material obtained from 1 to 10 cm depth, sample 2 was 10 to 20 cm and so on, to a depth of 1 to 1.2 m. Samples were sealed in airtight plastic zip-lock bags then placed in soil cans which were also sealed for transport to the laboratory. A filter paper to be used as a moisture-stress sensor was placed inside the zip-lock bag with each sample.

Ground cover was measured using the Bureau of Land Management pace method (BLM, 1969). Hillslope gradient and aspect were measured with a Brunton compass.

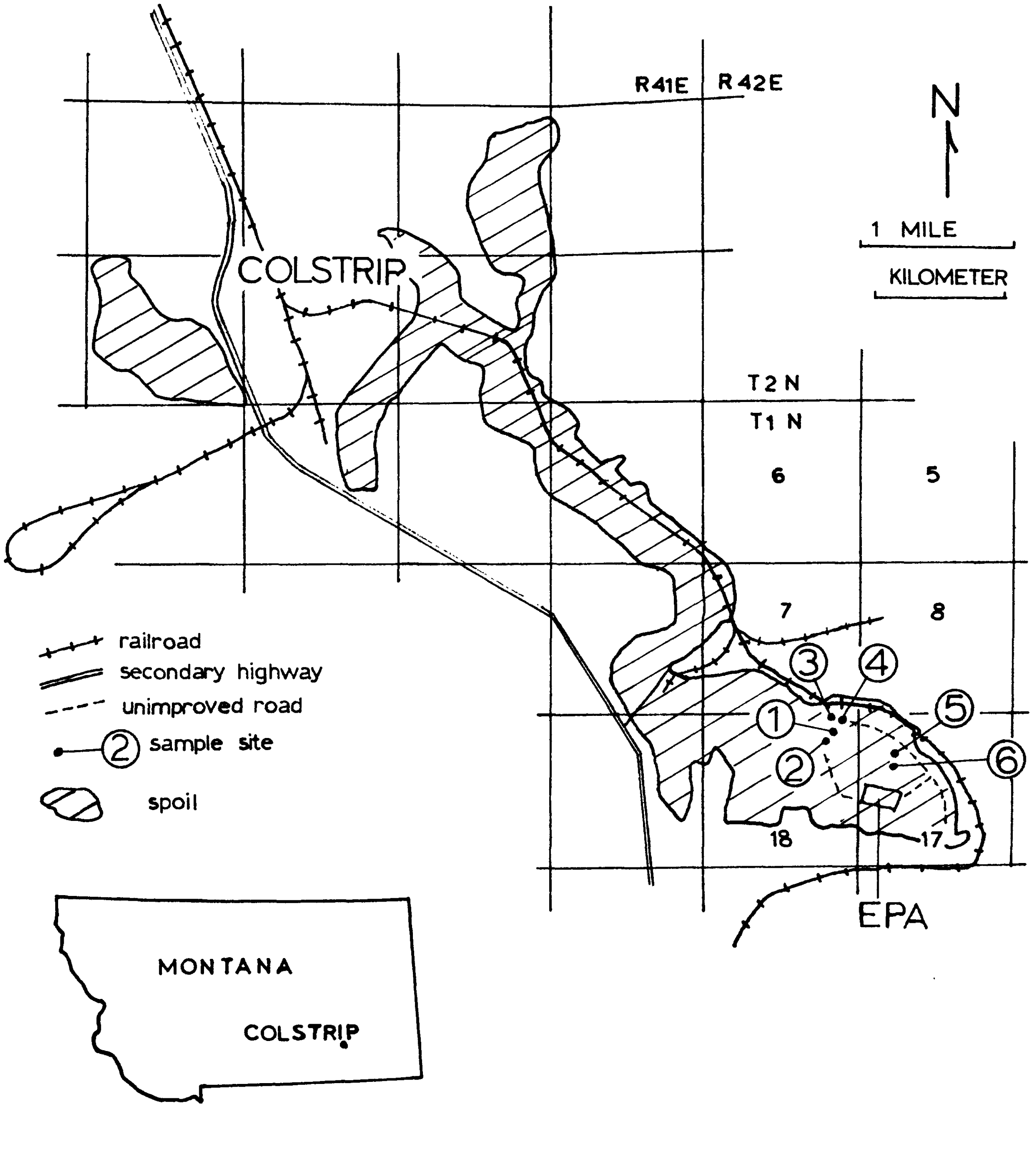

Figure 1.--Index map showing sampling localities. "EPA" is U.S. Environmental Protection Agency demonstration watershed (see Dollhopf and others, 1977).

Figure 2.--Site 1. Midslope on 7.5 percent slope that faces northwest (azimuth 335°). View southeast. Auger handle shown is 0.7 m long.

Figure 3. Site 2. Eight percent hillslope facing north-northwest (azimuth 345°). View south. One-half meter of auger handle is visible.

Figure 4.--Site 3. Abandoned haul road 15 m south of fence. Near-level spoil slopes 2.5 percent to south (azimuth 180°). View east. Auger handle is marked with decimeter-wide bands; 0.8 m of handle is visible.

Figure 5.--Site 4. Abandoned haul road 40 m east of site 3. Level spoil.

Figure 6 -- Site 5 is 26 m south of northeast corner of "dozer-basin" plot. View south across 13 percent hillslope that faces northeast (035°). Auger is centered in a 0.4-m deep dozer basin; downslope lip of basin follows the contour of the hillslope from the man toward the lower left.

Figure 7.--Site 6. Hillslope in "dozer-basin" plot sloping 12.5 percent northeast (040°). View south.

LABORATORY METHOD

Soil-moisture retention force of each sample was measured using a modification of the method of McQueen and Miller (1968). This method uses filter paper as a passive gravimetric moisture stress sensor which is sensitive to a wide range of moisture contents found in soils in the western United States. McQueen and Miller (1968) reported that retention forces may be determined by filter paper with an accuracy that is comparable to or better than the accuracy of other methods with limited ranges.

Retention force was determined from the moisture content of a standard filter paper after it reached equilibrium with spoil sample moisture content. To achieve this moisture equilibrium, the filter paper was stored in a sealed zip-lock bag with the spoil sample in an incubator at constant temperature (20 $\pm$ 0.1°C) for at least one week. During this time moisture is adsorbed to fibers of the filter paper at a retention force in equilibrium with that of the moisture in the spoil sample. Weight difference of filter paper before and after drying at 110°C equals the weight of water adsorbed to filter paper, or wetness of the paper (W_p). This weight is proportional to moisture in the sample according to a previously determined empirical relation. The relation is based on measurements made during calibration of the method using data of McQueen and Miller (1968) and Al-Khafaf (1972) (fig. 8A). The moisture-retention force is computed as pF, the log of the retention force in g/cm².

If W_p is less than 0.585 g/cm², then

$$pF = 5.75 - 5.94\, W_p \tag{1}$$

If W_p is greater than 0.585 g/cm², then

$$pF = 2.616 - 0.677\, W_p \tag{2}$$

Desorption characteristics of the spoil were approximated graphically. The influence of adsorptive surface of spoil particles on retained water over the moisture range from saturation to ovendry was approximated using a modification of the modeling technique proposed by McQueen and Miller (1974). It was assumed that moisture is completely desorbed from spoil at pF 5.75 and that there is a linear relation between the water content of spoil material and the log of the retention force in g/cm² as illustrated in figure 8B. The linear relation can be defined graphically by extending a line from 5.75 on the pF axis through the data point defining wetness of the spoil (W_s) relative to the log of the retention force in g/cm² (pF).

In figure 8B the retention-force scale is presented in exponential form with a base of 10. When retention-force units of grams per square centimeter are used, the exponents are equivalent to pF values as defined by Schofield (1935). Hewlett (1961) showed the relation of water content to water-retention force (soil-moisture stress) to be an exponential function appearing as a straight line on a semilogarithmic graph over the range of 40 to 11,000 g/cm² (or 41 to 11,220 millibars). Such a relation suggests that capillary forces are less effective than adsorbtive forces in a drying or draining soil even for large moisture contents.

This modeling technique allows estimation of moisture-holding characteristics of spoil, at each decimeter depth, from only one sampling of each depth. This method was useful because periodic monitoring of <u>in situ</u> moisture in the field was not feasible.

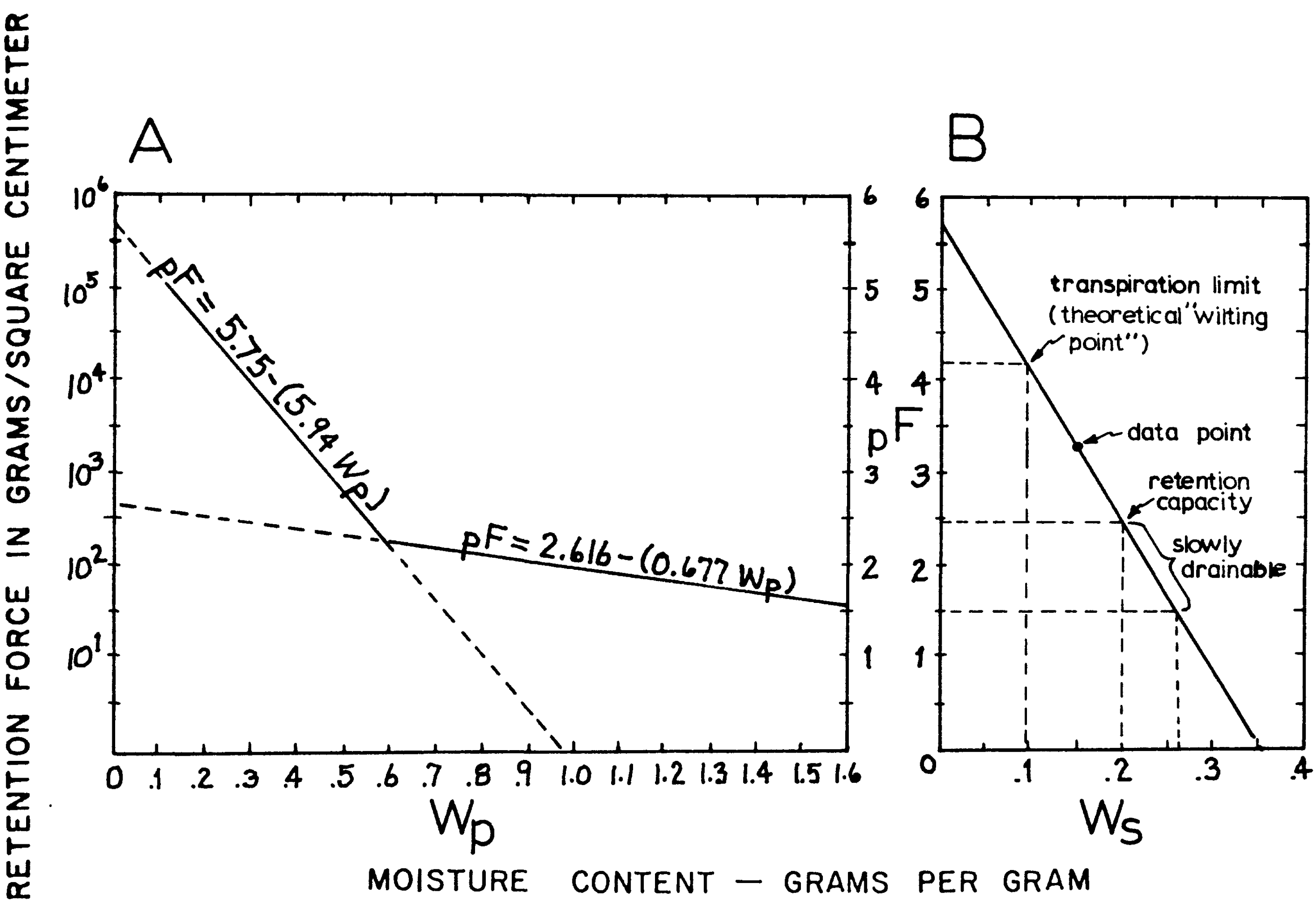

Figure 8.--(A) Regression relation used to determined pF, the log of the force in grams per square centimeter with which water is retained by soil; from W_p, the wetness of standard filter papers at equilibrium with the moisture content of each sample of spoil. (B) Graphic modeling procedure used to approximate regression relation between W_s, wetness of soil, and pF. Units of W_s and W_p are g/g, weight of water in grams per gram of dry soil.

Bulk density (BD) or volume-weight, was determined for samples obtained from each depth increment. The soil auger extracts a volume of 202.7 cm^3 as it penetrates each decimeter depth increment. Thus, bulk density, measured in grams per cubic centimeter was obtained by

$$BD = W_d/202.7 \qquad (3)$$

where W_d is the oven-dry weight of the sample in grams.

MOISTURE RELATIONS IN SPOIL

Moisture-retention capability in spoil is largely a function of interaction between void space and particle surfaces available to adsorb water per unit weight of material. Voids provide space in which water can be held to particle surfaces by adsorbtive forces and provide space through which water can move.

Void capacity is the <u>in situ</u> water capacity of spoil when all voids are full. It is the weight of water in grams that would fill the voids in a gram of spoil. It is expressed on a dry-weight basis (Miller and McQueen, 1978). Void capacity (VC) is computed from measured bulk density (BD) using the equation:

$$VC = [1/BD] - [1/2.65] \qquad (4)$$

In equation (4) above, 2.65 represents an assumed average soil-particle density (PD) in g/cm^3 (Richards and others, 1954) and the density of water is assumed to equal 1 g/cm^3. Equation (4) is obtained from principles of soil physics (Miller and others, 1969).

Soil particle surface area affects water in surficial spoil in two important ways: (1) as particle size decreases, total adsorptive surface of a given volume increases, therefore increasing water-retention capacity; and (2) as soil-particle surface area increases, a given quantity of soil water is spread over more area per particle resulting in a thinner film of water held with greater retention forces. Specific surface (surface area per unit of mass) for sand 0.1 mm diameter is 0.03 m^2/g (square meters per gram), but is 100 m^2/g for illite clay particles (Lambe and Whitman, 1969, p. 55).

Of the total force that holds moisture in spoil, it is chiefly the adsorptive force, sometimes called matric stress or potential, that is affected by specific surface of particles. Available particle surface was evaluated by a parameter called the Adsorption Moisture Capacity (AMC), the amount of water adsorbed as soil drains with a retention force of pF 10^0 or 1 g/cm^2 (1.02 millibars) (Miller and McQueen, 1978). The AMC for each spoil sample was determined graphically from a curve of the log of the retention force in grams per square centimeter (pF) versus wetness of a sample, as shown in figure 8B. Each sample of spoil collected defines a point "data point" as shown on figure 8B. A line is drawn through "data point" and the vertical axis at $10^{5.75}$ g/cm^2 moisture-retention force (ovendry at 110°C) at which all moisture is desorbed. The intercept of the sloping line with the horizontal axis is AMC.

RESULTS

Data derived from spoil samples obtained at sampling sites are given in the Appendix. Spoil moisture data are given in terms of weight ratios and volume ratios. Weight ratio is the ratio of weight of water to weight of an oven-dry sample. Moisture content expressed as a volume ratio is obtained by multiplying the weight ratio by bulk-density values.

Figure 9 graphically presents data obtained using the measurements and concepts previously described. Porosity of spoil is presented as void capacity. Moisture content, or wetness, of samples has been plotted for three basic levels of retention force: 32, 300, and 15,000 g/cm^2. Units of measure are compared in Table 2. Water contents at the three retention levels are functions of specific surface of spoil particles. They are fixed properties of particles of spoil and are related to particle size as earlier described. Areas between lines connecting water contents at incremental depths for the three retention levels represent partitioning of moisture in spoil profiles. Rapidly drained water lies between void capacity and line pF 1.51; slowly drained water between line pF 1.51 and 2.48; tightly adsorbed water that is transpirable by native plants is between lines pF 2.48 and 4.18.

Table 2.--Comparison of different conventions for expressing the three levels of moisture-retention forces used in this study

g/cm^2	pF	millibars	remark
32	1.51	32.6	At smaller forces soil water drains by gravity
300	2.48	306	"field capacity"
15,000	4.18	15,300	"wilting point"

Water content at pF 1.51 millibars is important because smaller adsorbtive forces can not resist drainage by gravity. At pF of 2.48, however, soil-water drainage by gravity ceases. Water content, between 2.48 and 1.51 is defined as slowly drainable and is referred to as the "retention capacity" (fig. 8B). The method for evaluating retention capability is not dependent on observation of the actual time when drainage becomes negligible. At pF 4.18 approximately five water molecules remain tightly adsorbed in layers to soil particle surfaces. This water cannot be taken up by most domestic plants and so serves as an estimate of the lower limit of moisture in spoil that is available for plant use, the so-called "wilting point" (fig. 8B).

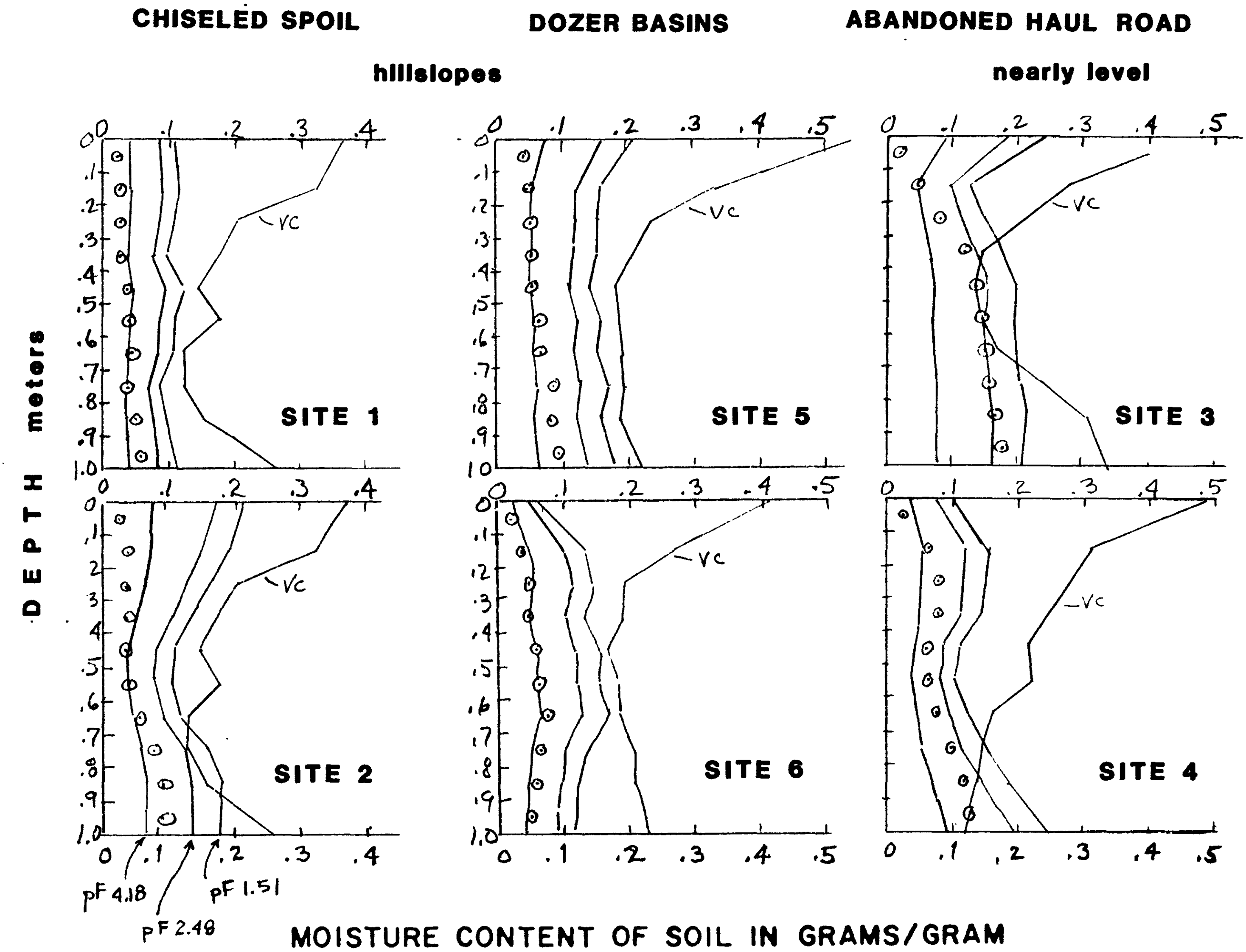

Figure 9.--Graphs showing variation in void capacity (line labeled vc) with depth compared to capacity of spoils to retain water at pF 1.51, 2.48, and 4.18 as indicated by solid lines, which near the surface occur from right to left in the order stated above (see site 2 for example). Water content of samples at time of sampling shown by circled points and units g/g are grams of water per gram of dry spoil.

The influence of three different spoil management procedures on void capacities and water-retention properties of spoils can be evaluated from the three pairs of graphs presented in figure 9. The first pair of graphs illustrates data acquired at sites 1 and 2, on deeply chiseled spoil. Sites 3 and 4 illustrate conditions in spoil compacted under an abandoned haul road. Sites 5 and 6 illustrate the influence of water entrapment in dozer basins on more steeply sloping spoil.

Ground cover indicates that roughening spoil with dozer basins has resulted in modest improvement of grass when compared to chiseled spoils (Table 3). However, because the dozer-basin sites are on relatively steep slopes that normally detain less water than gentle slopes, the dozer basins must have effectively trapped runoff and enhanced infiltration to produce dense grass. Field evidence, however, suggests that their effectiveness has diminished. Layers of silty fine sand in the basins and erosional channels cut in the downhill lip of many basins indicate that runoff water has filled and overflowed them.

At sites 3 and 4 compaction has reduced void space below values typical of other samples. Ground cover was least among all sites. Sparse grass and abundant Russian thistle suggests that dense spoil and poor aeration impeded root growth. The highest soil moisture among all sites appears to result from (1) low consumptive use by sparse vegetation or (2) surface inflow, and perhaps subsurface inflow. Sites 3 and 4 are on nearly level terrain near the foot of hillslopes. Drainage patterns of rills and widespread sheetwash alluvium indicate recent inflow from the hillslopes.

Local flowpaths of near-surface ground water may enhance moisture in low sites independent of roughening treatments. Greater moisture below 40 cm at sites 3 and 4 may reflect recharge from lateral or upward saturated or unsaturated flow, a type of inflow occurring in depressional sites. We could not observe such flow, but others have done so (Dollhopf and others, 1977). Long-lived ponds also have formed in nearby depressions. These ponds are believed to be fed by runoff and saturated and unsaturated subsurface inflow of moisture observed to move upward, downward, and laterally in spoil at various times (Dollhopf and others, 1977). These observations suggest to us that local shallow flow systems in spoil may behave like shallow flow systems in prairie environments (Meinzer, 1927; Meyboom, 1962). During wet periods upper to middle hillslopes of spoil are recharged by percolation while toe slopes and depressions may discharge water (seeps or springs). During dry periods, surficial spoil at perennial discharge sites may become saline if saturated upward flow occurs and dissolved solids are transported into the surficial spoil. However, subsequent leaching during wet seasons may leach excessive salts annually, preventing salt buildup.

Differences in void capacities relative to water-retention properties of spoil explain why compacted spoil stores little water, a relation evident in data from site 3 (fig. 9). Here void capacity approximately equals retention-capacity levels at depths below 30 cm. Possibly this reflects depth below root penetration. Site 4 also has restricted drainage below a depth of 80 cm. Void capacity in excess of retention capacity in upper parts of site 4 is evidence that water entering compacted spoil will expand it and increase porosity with the passage of time. Spoil material in site 3 is capable of retaining more water at any level of stress than site 4, indicating that finer materials are more susceptible to compaction and restriction of voids than coarser materials.

Water depleted from storage somewhat exceeds the theoretical wilting point (pF 4.18) in the upper half of the profile at all the sites on regraded and pitted spoil with a grass cover and with moisture reserves present at greater depths. The two sites on compacted spoil with a cover dominated by Russian thistle did not deplete water storage as near to the wilting point. In fact, available water was present at depths greater than 20 cm. One might suspect that grass establishment was impeded by the original compactness of the spoil, but reseeding of these sites under present conditions might well lead to greater vegetative cover.

CONCLUSIONS

Most spoil samples had void capacities large enough to store moisture in sufficient quantity to grow vegetation that is suited to reclamation and native to the Northern Great Plains (U.S. Geological Survey 1975, 1977a, 1977b.). Unfavorable conditions for most native grass species are illustrated by site 3 where available moisture is low in dense layers and held tightly by large retention forces. Such sites are better suited to halophytic shrubs such as Nuttall saltbush or big sagebrush which can transpire soil moisture held by large retention forces (Branson and others, 1970). Small void capacity in compacted spoil results from few, small voids, thus relatively thin water films, resulting in strong absorbtive forces that bind the water in place. Conditions at site 3 resemble findings of Arnold (1976) who reported lower hydraulic conductivities at various depths in compacted spoils than in undisturbed range soils at comparable depths. Such compact zones are local in extent at the Plant Community Development Study plot.

Sites 3 and 4 suggest that spoil under low nearly level areas receives and retains more moisture than spoil under hillslopes. However, because these sites were compacted during use as a haul road whereas the others were not, the increased moisture may result from the inability of sparse vegetation to transpire water being held by large retention forces in overly compacted spoil.

Dozer basin spoil had similar moisture as spoil at chiseled sites even though dozer basins elsewhere have been observed (Dollhopf and others, 1977) to detain runoff from heavy rains during May-July 1975. More grass on relatively steep dozer-basin sites than on chiseled sites suggests that surficial spoil under the dozer basins initially received more water than other sites, thus enhancing growth of grass. Alternatively, we can not verify from reports of previous workers that these areas received equal seeding and fertilizer treatments; perhaps they did not. If not, the greater vegetation at sites 5 and 6 may reflect more reclamation effort. Most of the runoff trapped by the basins following spring and summer rains was depleted by the time of our sampling (September 12, 1975) and vegetation was dormant. Although our one-time sampling did not permit study of water usage through time, we assume that depletion probably results from evapotranspiration characteristic for the summer period. Detention capacity of the dozer basins appears to have decreased owing to sedimentation during successive torrential summer rainstorms.

Table 3.--Ground cover, hillslope, and surface treatment of sample sites on topsoiled spoil at the Plant Community Development Plot

	Ground cover (percent)					Hillslope	Hillslope	Surface
Site	grass	mulch	shrub[1]	bare ground	rock	(percent)	direction	treatment
1	63	25	0	12	0	7.5	north-northwest	chiseled
2	64	25	0	11	0	8.0	north-northwest	chiseled
3	13	45	18	24	0	2.5	south	ripped and chiseled
4	16	44	12	28	0	1.0	south	ripped and chiseled
5	67	21	1	11	0	13.0	north-northeast	dozer basin
6	65	23	0	12	0	12.5	northeast	dozer basin

1 this catagory represents shrub in the BLM system but was used to tally Russian thistle since no true shrubs were observed near the sampling sites.

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Appendix --*Soil-moisture data for six sites at Rosebud Mine, Colstrip, Montana*

COLS SITE NO. 1 DATE OF SAMPLING: 9/12/75

SAMPLE DEPTH INC			BULK DENSITY	SOIL WETNESS		SOIL WATER STRESS		VOID CAPACITY		WETNESS PF 1.51 .03 B		WETNESS PF 2.477 .3 BAR		WETNESS MINIMUM PF 4.176		AVAILABLE WATER		SLOWLY DRAINABLE WATER
INC M	C I M	CI IN	G/CC	WT/WT	VL/VL	G/SQCM	PF	WT/WT	VL/VL	WT/WT	VL/VL	WT/WT	VL/VL	WT/WT	VL/VL	M	WT/WT	VL/VL
0.10	0.05	1.97	1.368	0.021	0.029	80649.	4.907	0.354	0.484	0.110	0.151	0.085	0.116	0.040	0.055	0.006	0.025	0.0347
0.20	0.15	5.91	1.426	0.025	0.036	62419.	4.795	0.324	0.462	0.116	0.166	0.089	0.128	0.043	0.061	0.007	0.027	0.0381
0.30	0.25	9.84	1.727	0.025	0.044	54105.	4.733	0.202	0.349	0.109	0.187	0.084	0.144	0.040	0.069	0.008	0.025	0.0431
0.40	0.35	13.78	1.800	0.024	0.043	45827.	4.661	0.178	0.321	0.095	0.171	0.073	0.132	0.035	0.063	0.007	0.022	0.0393
0.50	0.45	17.72	1.904	0.036	0.069	28200.	4.450	0.148	0.282	0.121	0.230	0.093	0.177	0.044	0.084	0.009	0.028	0.0529
0.60	0.55	21.65	1.799	0.039	0.070	16046.	4.205	0.179	0.321	0.109	0.196	0.084	0.151	0.040	0.072	0.008	0.025	0.0451
0.70	0.65	25.59	1.996	0.043	0.086	9732.	3.988	0.124	0.247	0.105	0.210	0.081	0.161	0.038	0.077	0.008	0.024	0.0482
0.80	0.75	29.53	1.986	0.039	0.078	6601.	3.820	0.126	0.251	0.087	0.173	0.067	0.133	0.032	0.063	0.007	0.020	0.0394
0.90	0.85	33.46	1.882	0.048	0.090	4680.	3.670	0.154	0.290	0.098	0.185	0.076	0.143	0.036	0.068	0.007	0.023	0.0426
1.00	0.95	37.40	1.642	0.055	0.091	3450.	3.538	0.232	0.380	0.107	0.175	0.082	0.135	0.039	0.064	0.007	0.025	0.0403

NAME COLS SITE 2 SMN NUMBER 1 BEFORE RUN DATE OF SAMPLING: 9/12/75

0.10	0.05	1.97	1.140	0.022	0.025	192059.	5.283	0.500	0.570	0.209	0.239	0.161	0.184	0.077	0.087	0.010	0.048	0.0549
0.20	0.15	5.91	1.615	0.035	0.057	88555.	4.947	0.242	0.391	0.193	0.312	0.149	0.241	0.071	0.114	0.013	0.044	0.0719
0.30	0.25	9.84	1.839	0.038	0.071	55784.	4.747	0.166	0.306	0.167	0.307	0.128	0.236	0.061	0.112	0.012	0.038	0.0705
0.40	0.35	13.78	1.864	0.036	0.067	41707.	4.620	0.159	0.297	0.138	0.257	0.106	0.198	0.050	0.094	0.010	0.032	0.0590
0.50	0.45	17.72	1.764	0.032	0.056	27221.	4.435	0.190	0.335	0.104	0.183	0.080	0.141	0.038	0.067	0.007	0.024	0.0421
0.60	0.55	21.65	1.764	0.039	0.068	13099.	4.117	0.190	0.335	0.101	0.179	0.078	0.138	0.037	0.066	0.007	0.023	0.0411
0.70	0.65	25.59	1.754	0.053	0.093	6869.	3.837	0.193	0.338	0.118	0.208	0.091	0.160	0.043	0.076	0.008	0.027	0.0478
0.80	0.75	29.53	1.835	0.079	0.145	4333.	3.637	0.168	0.308	0.160	0.293	0.123	0.226	0.059	0.107	0.012	0.037	0.0674
0.90	0.85	33.46	1.845	0.092	0.170	3698.	3.568	0.165	0.304	0.181	0.333	0.139	0.257	0.066	0.122	0.013	0.042	0.0766
1.00	0.95	37.40	1.843	0.091	0.168	3327.	3.522	0.165	0.305	0.175	0.323	0.135	0.249	0.064	0.118	0.013	0.040	0.0742

NAME COLS SITE 3 SMN NUMBER 1 BEFORE RUN DATE OF SAMPLING: 9/12/75

0.10	0.05	1.97	1.288	0.014	0.018	270818.	5.433	0.399	0.514	0.203	0.261	0.156	0.201	0.074	0.096	0.011	0.047	0.0601
0.20	0.15	5.91	1.536	0.044	0.068	16323.	4.213	0.274	0.421	0.124	0.190	0.095	0.146	0.045	0.070	0.008	0.028	0.0436
0.30	0.25	9.84	1.702	0.079	0.135	2745.	3.438	0.210	0.358	0.147	0.250	0.113	0.193	0.054	0.092	0.010	0.034	0.0575
0.40	0.35	13.78	1.913	0.116	0.222	855.	2.932	0.145	0.278	0.176	0.336	0.135	0.259	0.064	0.123	0.014	0.040	0.0772
0.50	0.45	17.72	2.004	0.132	0.264	759.	2.880	0.122	0.244	0.196	0.392	0.151	0.302	0.072	0.144	0.016	0.045	0.0901
0.60	0.55	21.65	2.041	0.143	0.291	378.	2.578	0.113	0.230	0.192	0.391	0.147	0.301	0.070	0.143	0.016	0.044	0.0899
0.70	0.65	25.59	1.817	0.150	0.273	281.	2.449	0.173	0.314	0.194	0.352	0.149	0.271	0.071	0.129	0.014	0.045	0.0810
0.80	0.75	29.53	1.629	0.156	0.253	281.	2.449	0.236	0.385	0.201	0.327	0.154	0.252	0.073	0.120	0.013	0.046	0.0751
0.90	0.85	33.46	1.473	0.163	0.239	275.	2.439	0.302	0.444	0.209	0.308	0.161	0.237	0.077	0.113	0.012	0.048	0.0707
1.00	0.95	37.40	1.428	0.174	0.248	149.	2.173	0.323	0.461	0.207	0.295	0.159	0.227	0.076	0.108	0.012	0.047	0.0678

Appendix --*Soil-moisture data for six sites at Rosebud Mine, Colstrip, Montana*

COLS SITE NO. 4 DATE OF SAMPLING: 9/12/75

SAMPLE DEPTH INC M	C I M	CI IN	BULK DENSITY G/CC	SOIL WETNESS WT/WT	SOIL WETNESS VL/VL	SOIL WATER STRESS G/SQCM	SOIL WATER STRESS PF	VOID CAPACITY WT/WT	VOID CAPACITY VL/VL	WETNESS PF 1.51 WT/WT	WETNESS PF 1.51 VL/VL	WETNESS PF 2.477 .3 BAR WT/WT	WETNESS PF 2.477 .3 BAR VL/VL	WETNESS MINIMUM PF 4.176 WT/WT	WETNESS MINIMUM PF 4.176 VL/VL	AVAILABLE WATER M	AVAILABLE WATER WT/WT	SLOWLY DRAINABLE WATER VL/VL
NAME COLS SITE 4 SMN NUMBER 1 BEFORE RUN DATE OF SAMPLING: 9/12/75																		
0.10	0.05	1.97	1.219	0.026	0.031	60909.	4.785	0.443	0.540	0.115	0.140	0.089	0.108	0.042	0.051	0.006	0.026	0.0322
0.20	0.15	5.91	1.451	0.060	0.087	12301.	4.090	0.312	0.453	0.156	0.226	0.120	0.174	0.057	0.083	0.009	0.036	0.0519
0.30	0.25	9.84	1.700	0.073	0.124	4732.	3.675	0.211	0.359	0.151	0.256	0.116	0.197	0.055	0.094	0.010	0.035	0.0589
0.40	0.35	13.78	1.435	0.076	0.109	2919.	3.465	0.320	0.459	0.142	0.204	0.110	0.157	0.052	0.075	0.008	0.033	0.0470
0.50	0.45	17.72	1.676	0.062	0.104	2282.	3.358	0.219	0.368	0.111	0.186	0.085	0.143	0.041	0.068	0.007	0.025	0.0427
0.60	0.55	21.65	1.665	0.062	0.104	1716.	3.235	0.223	0.372	0.106	0.177	0.082	0.136	0.039	0.065	0.007	0.024	0.0406
0.70	0.65	25.59	1.847	0.079	0.146	1335.	3.125	0.164	0.303	0.128	0.237	0.099	0.183	0.047	0.087	0.010	0.030	0.0545
0.80	0.75	29.53	1.910	0.096	0.182	1117.	3.048	0.146	0.279	0.151	0.288	0.116	0.222	0.055	0.105	0.012	0.035	0.0662
0.90	0.85	33.46	1.933	0.116	0.223	1306.	3.116	0.140	0.271	0.187	0.362	0.144	0.278	0.069	0.132	0.015	0.043	0.0832
1.00	0.95	37.40	2.004	0.126	0.252	2353.	3.372	0.122	0.244	0.225	0.452	0.174	0.348	0.083	0.166	0.018	0.052	0.1039
NAME COLS SITE 5 SMN NUMBER 1 BEFORE RUN DATE OF SAMPLING: 9/12/75																		
0.10	0.05	1.97	1.164	0.043	0.050	63040.	4.800	0.482	0.561	0.198	0.231	0.153	0.178	0.073	0.085	0.009	0.046	0.0531
0.20	0.15	5.91	1.410	0.047	0.066	30951.	4.491	0.332	0.468	0.161	0.227	0.124	0.175	0.059	0.083	0.009	0.037	0.0523
0.30	0.25	9.84	1.620	0.052	0.085	20438.	4.310	0.240	0.389	0.157	0.254	0.121	0.195	0.057	0.093	0.010	0.036	0.0584
0.40	0.35	13.78	1.702	0.054	0.091	17851.	4.252	0.210	0.358	0.154	0.262	0.118	0.201	0.056	0.096	0.011	0.035	0.0602
0.50	0.45	17.72	1.785	0.053	0.095	14109.	4.149	0.183	0.326	0.143	0.255	0.110	0.196	0.052	0.093	0.010	0.033	0.0585
0.60	0.55	21.65	1.760	0.065	0.114	10771.	4.032	0.191	0.336	0.162	0.285	0.125	0.220	0.059	0.105	0.012	0.037	0.0656
0.70	0.65	25.59	1.751	0.068	0.119	7237.	3.860	0.194	0.339	0.154	0.269	0.118	0.207	0.056	0.099	0.011	0.035	0.0620
0.80	0.75	29.53	1.740	0.080	0.140	5310.	3.725	0.197	0.343	0.170	0.296	0.131	0.228	0.062	0.108	0.012	0.039	0.0681
0.90	0.85	33.46	1.764	0.080	0.141	4002.	3.602	0.190	0.334	0.159	0.281	0.123	0.216	0.058	0.103	0.011	0.037	0.0646
1.00	0.95	37.40	1.682	0.092	0.154	3337.	3.523	0.217	0.365	0.176	0.296	0.136	0.228	0.064	0.108	0.012	0.040	0.0681
1.10	1.05	41.34	1.691	0.094	0.159	2787.	3.445	0.214	0.362	0.175	0.295	0.134	0.227	0.064	0.108	0.012	0.040	0.0679
1.20	1.15	45.28	1.661	0.092	0.153	2260.	3.354	0.225	0.373	0.164	0.273	0.126	0.210	0.060	0.100	0.011	0.038	0.0627
NAME COLS SITE 6 SMN NUMBER 1 BEFORE RUN DATE OF SAMPLING: 9/12/75																		
0.10	0.05	1.97	1.344	0.018	0.024	65522.	4.816	0.367	0.493	0.082	0.111	0.063	0.085	0.030	0.041	0.004	0.019	0.0254
0.20	0.15	5.91	1.556	0.037	0.058	34115.	4.533	0.266	0.413	0.132	0.205	0.102	0.158	0.048	0.075	0.008	0.030	0.0473
0.30	0.25	9.84	1.749	0.047	0.081	22823.	4.358	0.194	0.340	0.144	0.252	0.111	0.194	0.053	0.092	0.010	0.033	0.0581
0.40	0.35	13.78	1.759	0.045	0.080	18678.	4.271	0.191	0.336	0.132	0.233	0.102	0.179	0.049	0.085	0.009	0.030	0.0536
0.50	0.45	17.72	1.832	0.056	0.103	14878.	4.173	0.169	0.309	0.154	0.281	0.118	0.217	0.056	0.103	0.011	0.035	0.0647
0.60	0.55	21.65	1.772	0.062	0.110	10539.	4.023	0.187	0.332	0.155	0.274	0.119	0.211	0.057	0.100	0.011	0.036	0.0631
0.70	0.65	25.59	1.769	0.073	0.129	7668.	3.885	0.188	0.333	0.168	0.298	0.130	0.229	0.062	0.109	0.012	0.039	0.0684
0.80	0.75	29.53	1.705	0.062	0.105	6040.	3.781	0.209	0.357	0.134	0.228	0.103	0.176	0.049	0.084	0.009	0.031	0.0525
0.90	0.85	33.46	1.703	0.060	0.102	4668.	3.669	0.210	0.357	0.123	0.210	0.095	0.162	0.045	0.077	0.008	0.028	0.0483
1.00	0.95	37.40	1.655	0.059	0.098	4086.	3.611	0.227	0.376	0.118	0.196	0.091	0.151	0.043	0.072	0.008	0.027	0.0450
1.10	1.05	41.34	1.734	0.070	0.122	3483.	3.542	0.199	0.346	0.136	0.236	0.105	0.182	0.050	0.086	0.010	0.031	0.0542
1.20	1.15	45.28	1.831	0.076	0.139	3704.	3.569	0.169	0.309	0.148	0.272	0.114	0.209	0.054	0.100	0.011	0.034	0.0625