Design and Construction of Earthen Embankments for Animal Liquid-Waste Containment

Howard Neibling and Dean Falk

Earthen embankments, which can be used to contain water for a variety of purposes, may also be used to construct animal liquid-waste storage lagoons. A properly designed facility, whether for animal waste or process water, will have adequate storage capacity for the intended use and for any surface water run-off that may be generated from the 25-year, 24-hour design storm, if applicable. It will be constructed in such a manner that the embankment will not fail, and — in the case of animal liquid-waste storage — be constructed using materials and practices that will assure minimal seepage from the sides and bottom of the lagoon. Situations where seepage may occur from a water storage structure are shown in figure 1. Precautions to prevent such seepage are shown in figure 2 and will be discussed later. Procedures for determining the size of an animal-waste containment facility are beyond the scope of this paper. They are adequately discussed in

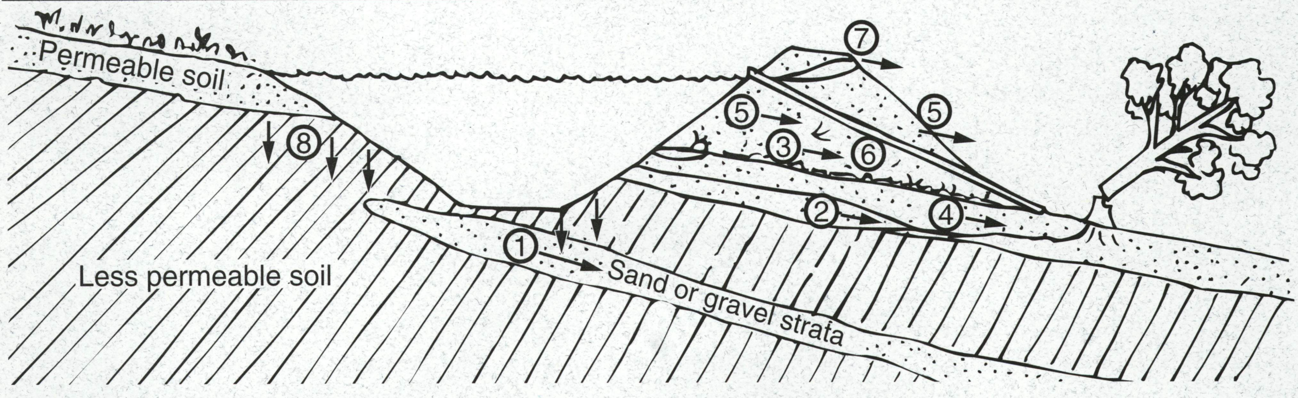

Figure 1. Situations in Which Seepage May Occur from a Water Storage Structure

1. Seepage through strata or pockets of permeable material. These may or may not be exposed during excavation.
2. Seepage along roots and root cavities. If trees in the vicinity of the embankment are cut, the roots will die, leaving cavities through which water will flow.
3. Seepage along the plane between the original ground and the embankment fill material.
4. Seepage under the embankment and through a layer of permeable material.
5. Seepage through the embankment.
6. Seepage along pipes passing through embankment.
7. Flow through muskrat burrows and cavities created by other burrowing animals.
8. Seepage over the entire basin at sites where the soil is permeable throughout the profile.

Source: Adapted from R. P. Beasly, J. M. Gregory, and T. R. McCarty, Erosion and Sediment Pollution Control, 2d ed., (Ames: Iowa State University Press, 1984), 242-43.

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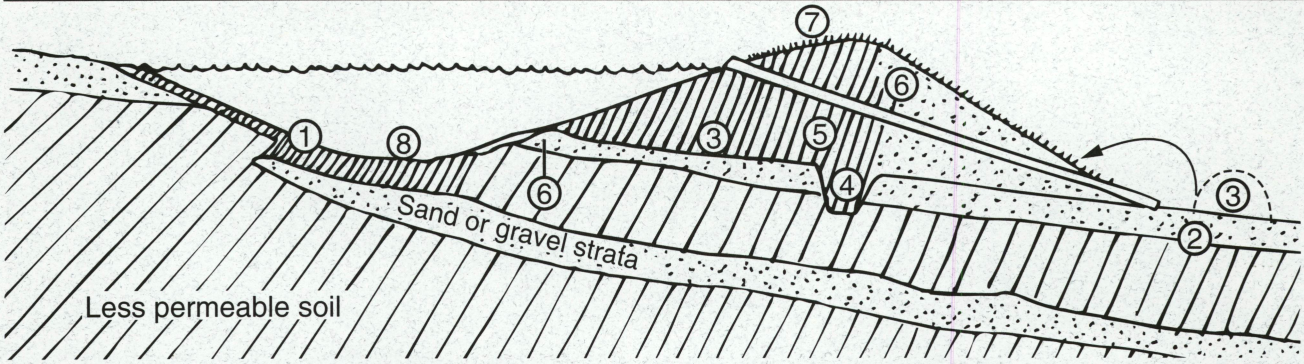

Figure 2. Precautions to Take During Construction of a Water Storage Structure to Prevent Seepage

1. Make a thorough site investigation prior to construction. Either move to another site or give special treatment, such as installation of a compacted blanket of impervious material.
2. Remove all roots from the embankment area prior to construction.
3. Remove all debris and sod and scarify soil surface before adding fill. Possibly construct core trench.
4. Block flow by construction of a core trench.
5. Build the embankment with proper top width and side slopes; remove all brush, roots, and debris from the borrow area so it will not be deposited in the embankment; place the less permeable material on the water side of the embankment and the more permeable material in the downstream part; place fill in thin layers and compact thoroughly.
6. Install anti-seep collars and properly bed the pipe and compact earth around it.
7. Build embankments with proper top width and side slopes; manage the lagoon to minimize water-level fluctuation; keep the embankment clear of brush and debris.
8. Scarify the basin area to a depth of 8-10 inches, compact the loosened soil at optimum moisture content to form a dense layer, and on more permeable soils, install a blanket of compacted low-permeability earth.

Source: Adapted from Beasley et al., 242-43.

Idaho Waste Management Guidelines for Confined Feeding Operations, published by the Division of Environmental Quality, Idaho Department of Health and Welfare.

Facility Design and Construction to Prevent Slope Failure or Excess Seepage

Design and construction of a facility that will function properly begins with selection of a suitable site. Proper site selection, soil evaluation, lagoon sizing, and construction practices are necessary to create a lagoon that meets environmental constraints at the least possible cost.

Site Investigation

Investigate the suitability of the area to hold water and to provide a stable embankment foundation. The highest seasonal water table must be at least 2 feet, but preferably more, below the bottom of the lagoon. A high water table will weaken lagoon embankments and also increase the likelihood of the transfer of nutrients and other chemical constituents from the lagoon to the shallow ground water.

Use of an existing canal bank as one side of the lagoon should be avoided if possible since rapid drawdown of either the lagoon or canal could cause slope failure. In certain cases, however, with an adequate embankment width, low-permeability fill material, relatively low embankment height, and careful management of both lagoon and canal levels, a canal bank may be used. In these cases a professional should evaluate the site to determine its suitability.

To determine the suitability of a soil layer for use as a liner, soil textural analyses should be done for each identifiable layer of soil from the surface to at least 1 foot below the proposed elevation of the lagoon bottom. The soil texture under the lagoon bottom and in the material along the sideslopes will determine whether a soil or synthetic liner is required to limit the seepage rate per square foot to the acceptable level of 1 x 10^{-5} cm/sec. For a hydraulic gradient (water depth/liner thickness) of 8, the corresponding hydraulic conductivity (also called permeability) would be 1.25 x 10^{-6} cm/sec or 0.003 feet/day. Generally, a soil with at least 15 percent clay can be compacted to meet this requirement. For soils with less than 15 percent clay in a 1-foot thickness in the lagoon bottom or sides, a 1-foot layer of acceptable material (>15% clay) may be hauled in and used with proper compaction. If the water depth is greater than 8 feet, the liner thickness will need to be increased to assure that the maximum water depth/liner thickness ratio never exceeds 8.

Synthetic geotextile liners may also be used on the lagoon bottom and sideslope areas below the high water line, although they are subject to tearing or puncture if the lagoon is subsequently cleaned. Soil liners are also subject to damage from cleaning. To prevent such damage, geotextile or soil liners should be covered with at least 1 foot of any soil material or rounded rock.

Design Considerations

Core trench dimensions (#4 in Fig 2.), embankment height, top width, side slopes, freeboard, and slope protection are some of the factors that should be specified by the design. The need for a cutoff wall and its dimensions and the embankment height required to provide sufficient storage are beyond the scope of this paper.

Top width: Embankments must have a minimum top width to provide slope stability and to minimize opportunity for seepage due to burrowing animals or flow through the fill material. Top width should increase as embankment height increases. USDA-Natural Resources Conservation Service (NRCS) minimum top

Class Group Symbol	Description	Proctor Compaction: Maximum Dry Density in Pounds per Cubic Feet	Proctor Compaction: Optimum Water Content, Percent	Permeability K, Feet/Day
GW	Well-graded, clean gravels, gravel-sand mixtures	>119	<13.3	73.97±35.62
GP	poorly graded clean gravels, gravel sand mixtures	>110	<12.4	175.34±93.15
GM	Silty gravels, poorly graded gravel-sand silt	>114	<14.5	>.00082
GC	clayey gravels, poorly graded gravel sand clay	>115	<14.7	>.00082
SW	Well-graded clean sands, gravely sands	119±5[1]	13.3±2.5	(*)[2]
SP	Poorly graded clean sands, sand gravel mix	110±2	12.4±1.0	>.0411
SM	Silty sands, poorly graded sand-silt mix	114±1	14.5±.0.4	.02055±.01315
SM-SC	Sand-silt-clay mix with slightly plastic fines	119±1	12.8±0.5	.00219±.00164
SC	Clayey snads, poorly graded sand-clay mix	115±1	14.7±0.4	.00082±.00055
ML	Inorganic silts and clayey silts	103±1	19.2±0.7	.00162±.00063
ML-CL	Mixture of organic silt and clay	109±2	16.8±0.7	.00036±.00019
CL	inorganic clays of low-to-medium plasticity	108±1	17.3±0.3	.00022±.00008
OL	Organic silts and silt-clays, low plasticity	(*)	(*)	(*)
MH	Inorganic clayey silts, elastic silts	82±4	36.3±3.2	.00043±.00027
CH	Inorganic clays of high plasticity	94±2	25.5±1.2	.00014±.00014
OH	Organic and silty clays	(*)	(*)	(*)

[1] ± indicates 90 percent confidence limits of the average values

[2] * denotes insufficient data

Table 1. Typical Values of Optimum Moisture Content and Maximum (Standard Proctor) Dry Density
Source: US Department of Interior—Bureau of Reclamation, Design of Small Dams, (US Government Printing Office, 1974), 137.

width (T) is determined based on embankment height (H) as:

H<10' = T = 8'
H = 10-20' = T = 10'
H = 21-30' = T = 12'

If the top of the embankment is used as a road, top width must be at least 12 feet.

Side slopes: Side slopes of settled embankments should be at least 2:1 or flatter on the inside of the lagoon (e.g., 2 feet horizontally for every 1 foot vertical change) and 2:1 or flatter on the outside of the lagoon. Flatter slopes may be required on the water side of the embankment relative to the outside slope depending upon lagoon depth and soil characteristics to assure slope stability. Slopes flatter than 2:1 may be required if soil mechanics tests indicate slope stability problems. Flatter slopes may also be desirable if mechanical equipment is used for mowing or other site maintenance. A 4:1 slope is required for machine operations.

Slope protection: On larger ponds or lagoons, or those located in unprotected windy areas, wave action can erode the embankment and compromise facility integrity. Rip-rap (rock blanket), good grass cover, or other soil surface protection can be used to prevent bank erosion. Another alternative is to construct the inner slope at 4:1, although this requires significantly more fill material.

Settlement: Some extra embankment height must be added to assure that the top of the embankment is at the design height after the soil has settled. Some settling will occur regardless of compaction method used. If the material is placed in 6-inch layers with a moisture content acceptable for compaction and compacted with wheel scrapers or rollers, add 5 percent to the design embankment height. If a bulldozer is used for construction and compaction, add 10 percent.

Freeboard: Some height of settled fill above design water level is required to prevent overtopping by waves or to accommodate unanticipated storage needs. For lagoons under 660 feet long, minimum freeboard is 1 foot if all lot runoff requiring storage is considered, or 2 feet if lot runoff is not considered. Larger lagoons require 2 feet of freeboard.

Feel or Appearance of Soil and Moisture Deficiency

Available Soil Moisture Remaining	Loamy Sand	Application of Water in in/ft of Soil	Sandy Loam	Application of in in/ft of S
0 to 25 %	Dry, loose, single grained; flows through fingers	.90 to .70	Dry, loose, flows through fingers	1.3 to 1.0
25 to 50%	Appears to be dry, will not form a ball with pressure[1]	.70 to .45	Appears to be dry, will not form a ball[1]	1.0 to .65
50 to 75%	Appears to be dry, will not form a ball with pressure	.45 to .20	Tends to form a ball under pressure, but seldom holds together	.65 to .30
75 percent to field capacity (100%)	Tends to stick together slightly, sometimes forms a very weak ball under pressure	.20 to .00	Forms weak ball, breaks easily, will not stick	.30 to .00
Field capacity (100%)	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand	.00	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand	.00

Table 2. Soil Feel and Appearance Method for Determining Moisture Content in Loamy Sand, Sandy Loam, Silt Loam, and Clay Loam

Preparation of Site and Borrow Area

All debris (trees, brush, logs, rocks larger than 6 inches, etc.) should be removed from the foundation site and the soil borrow area for embankment or lining material. Strip the top 6 inches of soil to remove grass, weeds, and roots. If the vegetation and roots are not removed from the foundation area, they provide a thin permeable layer between the original soil and the embankment that permits seepage that could cause embankment failure. After removal of surface vegetation, scarify the soil surface within the foundation area to provide a better bond with the fill material. This will prevent further water seepage between the foundation/fill interface.

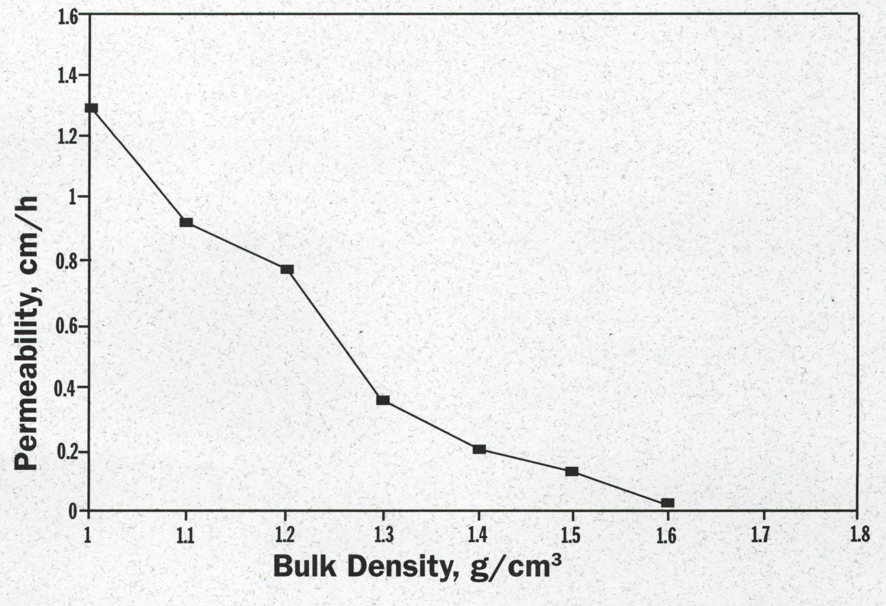

Figure 3. Constant-Head Laboratory Permeability for Soil Cores Compacted to Varying Bulk Densities

Source: W. H. Neibling et al., Underground outlet terrace systems in the deep loess hills—mechanisms of failure and potential solutions, Project no. 482, (Final report to the Missouri Soil and Water Conservation Districts Commission, 1993).

Loam and Silt Loam	Application of Water in in/ft of Soil
Powdery dry, sometimes slightly crusted, but easilybroken down into powdery condition	2.0 to 1.5
Somewhat crumbly, but holds together with pressure	1.5 to 1.0
Forms a ball somewhat plastic; but will sometimes slick slightly with pressure	1.0 to 0.5
Forms a ball; is very pliable; slicks readily; if relatively high in clay	0.5 to .00
Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand	.00

Clay Loam Silty Clay Loam	Application of Water in in/ft of Soil
Hard, baked, cracked; sometimes has loose crumbs on surface	2.2 to 1.65
Somewhat pliable; will ball under pressure[1]	1.65 to 1.10
Forms a ball; ribbons out between thumb and forefinger	1.10 to .55
Easily ribbons out between fingers; has slick feeling	.55 to .00
Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand	.00

[1]Ball is formed by squeezing a handful of soil very firmly.

Source: Idaho Department of Health and Welfare—Division of Environmental Quality, Idaho waste management guidelines for confined feeding operations, (IDHW-DEQ, Twin Falls, Idaho, 1993), 73-74.

Core trench construction: In some cases, depending on embankment height and the foundation and fill materials, a core trench (shown in figure 2) will be required to prevent seepage at the foundation/fill interface. Core trench construction is not usually required for the embankment heights and fill materials used in southern Idaho. If needed, the width and depth should be determined as a part of the embankment design. The trench should be excavated to the width and depth specified, with side slopes of 1:1 or flatter. It should be backfilled with the most impervious material available. Standing water should be avoided in the core trench during backfill, but adequate moisture should be present for proper compaction. (See "Optimum Soil Moisture Content" section for consequences of excess soil water content.)

Installation of compacted, low-permeability blanket: In soils with less than 15 percent clay and a maximum lagoon water depth of 8 feet, a 1-foot-thick blanket of compacted fill material may be used to control seepage from the lagoon sides and bottom. Because the purpose of this layer is to prevent seepage, it must be uniform in characteristics and properly placed and compacted. Therefore, blanket material must contain no brush, roots, sod, or other degradable materials and should contain no cobbles or rock fragments larger than 6 inches in diameter. The material should be at least 15 percent clay or a soil demonstrated by laboratory or field testing to have a permeability that will give seepage per unit area of less than 1×10^{-5} cm/sec with the design lagoon water depth and liner thickness. These factors are all considered in the following equation:

$v = k \times (h/d)$ where:

v = seepage per unit area (1×10^{-5} cm/sec maximum)

k = hydraulic conductivity of the liner as determined by field or laboratory testing, cm/sec

h = maximum lagoon water depth, feet

d = liner thickness, feet

If a blanket is used over the entire pond basin, a core trench is not required.

The blanket material should be placed in uniform-thickness layers in lift thickness depending on the compaction equipment used. Maximum lift thicknesses are 8 inches for a sheepsfoot roller, 6 inches for pneumatic-tired equipment, and 4 inches for tracked equipment, such as bulldozers. If

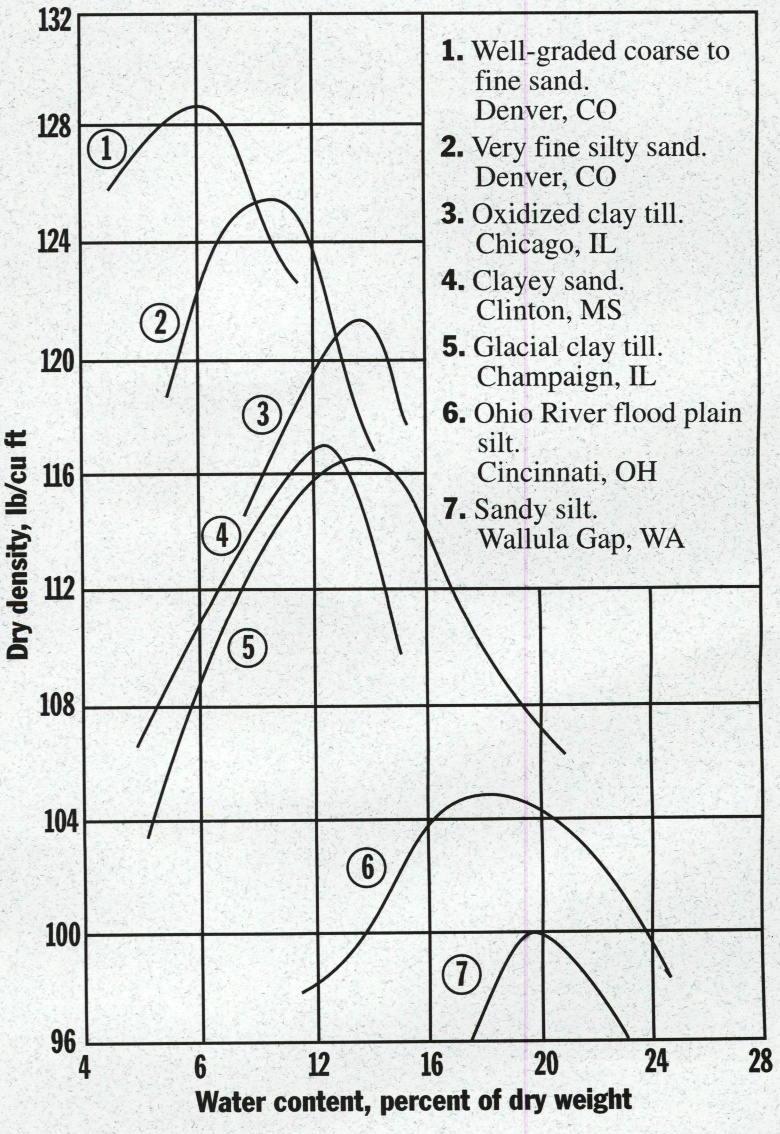

Figure 4. Moisture-Density Relations for Various Types of Soils as Determined by ASTM Method D-698

Source: R. B. Peck, W. E. Hanson, and T. H. Thornburn, Foundation Engineering, (New York: John Wiley and Sons, 1974), 16.

a sheepsfoot roller is used, the entire surface should receive at least 6 passes before more fill is added. Minimum roller weight is 2,500 pounds per foot of roller width, and maximum speed is 3 mph. If either pneumatic or tracked equipment is used, the wheels or tracks should cover the entire fill area before a new lift is placed.

Soil Compaction/ Bentonite Addition Effects on Permeability

For a typical 8-foot-deep lagoon with a 1-foot-thick soil liner, the USDA-NRCS recommended design limit for liner permeability is 0.003 feet per day or less. Representative permeability (hydraulic conductivity) values in table 1 for a number of materials will help place this value in perspective, although density of repacked samples is not given.

Research has shown the sealing effects of organic mats (manure), which are estimated to reduce permeability to about one-tenth of the original permeability. However, cases have been observed where sealing did not take place for some reason. Therefore, USDA-NRCS guidelines require the maximum seepage rate per unit area of 1×10^{-5} cm/sec to be met entirely by a combination of water depth, soil liner thickness, and soil permeability. Any sealing effects of organic mats are an "extra" improvement.

Proper soil compaction can reduce permeability to about one-tenth that of the same soil in a poorly compacted state. A permeability-compaction relationship for a silt loam soil similar in properties to those that might be used to line lagoons in much of southern Idaho is shown in figure 3.

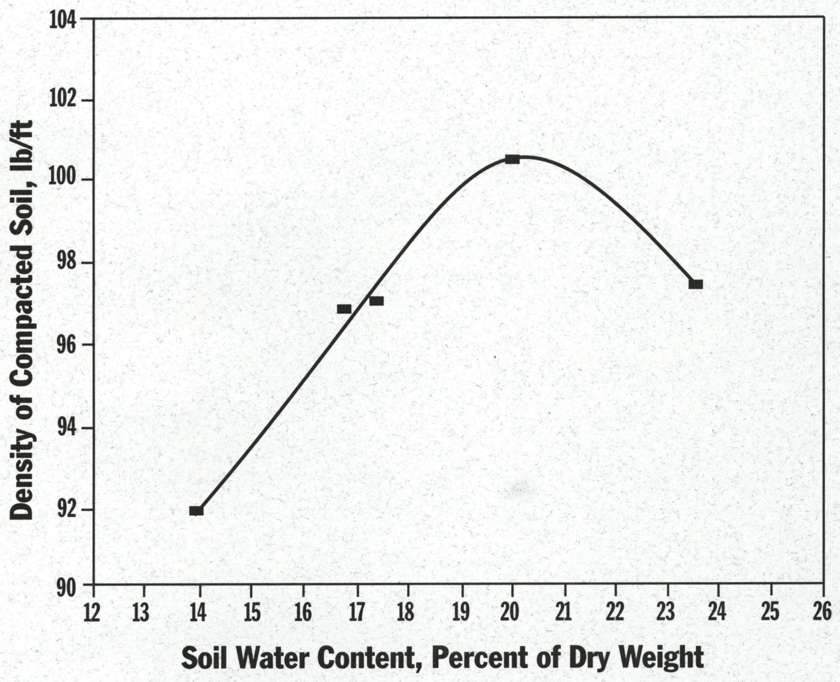

Figure 5. Moisture-Density Relations for Bold Silt Loam, Ray Morris Farm, Holt County, Missouri
Source: Neibling et al.

Optimum Soil Moisture Content

To achieve a highly compacted, low-permeability state, the soil must be compacted at the proper moisture content. The relationship between the degree of soil compaction per unit compactive effort and soil moisture is shown in figure 4 for a variety of soil textures. This relationship is determined by the use of an ASTM test known as the Proctor density test. Moisture content for a sandy soil should be between about 9 and 12 percent by weight to achieve maximum compaction. At moisture contents drier than optimum, insufficient moisture is present to "lubricate" soil particles so they can move into a more dense arrangement. Under soil moisture conditions wetter than optimum, soil particles move against each other too easily. As a result, when compacted, soil moves laterally from under the compacting device rather than being consolidated in place. As shown in figure 4, compaction is poor for very wet soils. The optimum moisture range for finer soils, such as the flood-plain silt shown by curve no. 6 in figure 4, would be in the 16-20 percent range. A moisture-density relationship like that for a silt loam soil similar to many found in southern Idaho is shown in figure 5. Typical values of optimum moisture content and maximum dry densities are summarized in table 1. Rubber-tired farm equipment or bulldozers can achieve about 90 percent of maximum (standard Proctor) density while a sheepsfoot roller can achieve 95 percent.

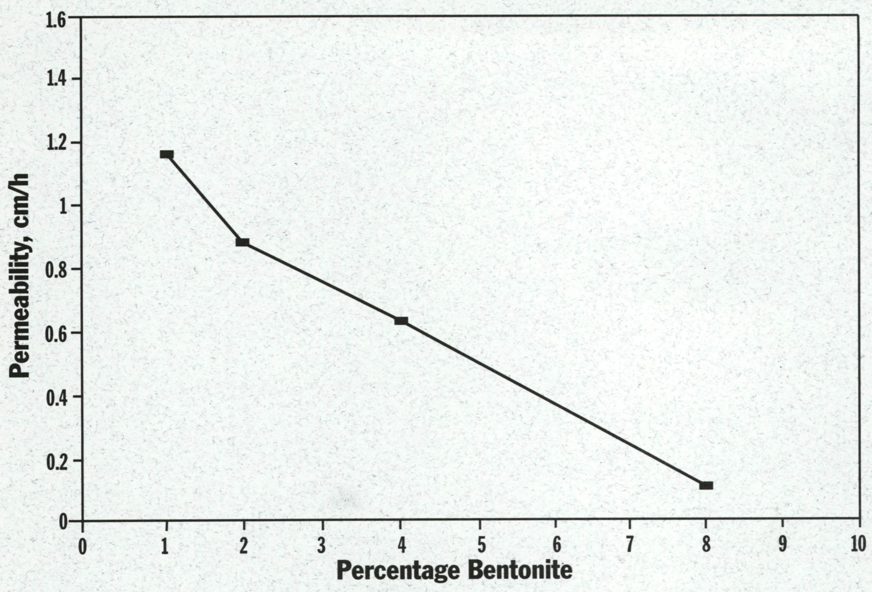

Figure 6. Constant-Head Laboratory Permeability for Soil Cores with Varying Percentage of Bentonite Added to Dry Soil

1) Bulk density is 1.0 (loose pour with no compaction).

Source: Neibling et al.

For most soils, optimum compaction occurs near field capacity, the moisture content one to three days after irrigation or a heavy rainfall. For a sandy soil this occurs about one or two days after irrigation and for a silt loam or heavier soil, about three days after irrigation. A method of determining soil moisture for irrigation purposes, described in table 2, can be adapted as a quick field guide for optimizing soil compaction. Optimum compaction will occur when the soil feel and appearance fall in the 75 percent to field capacity (100%) range.

Soil/Bentonite Mixtures

Bentonite is a clay mineral that expands in volume when wet. When added to a soil, the bentonite expands to fill soil pores and thus reduce soil permeability. Figure 6 shows the reduction in permeability produced by addition of varying percentages of bentonite to a dry soil that was loose-poured (bulk density of 1.0 or 62.4 lb/cubic foot dry density) into the permeability cell. Similar reductions can be expected from higher compaction levels. Figures 3 and 6 show that permeability was about equal for a silt loam compacted to a bulk density of 1.5 (about 94% of standard Proctor in this soil) and the same soil at a bulk density of 1.0 (no compaction) with 8 percent bentonite added. Addition of 8-10 percent bentonite to a soil that was then compacted to 90 or 95 percent of standard Proctor would result in quite low permeability. The exact value must be determined by laboratory testing.

Further Reading

Idaho Department of Health and Welfare—Division of Environmental Quality. 1993. Idaho waste management guidelines for confined feeding operations. IDHW—DEQ, Twin Falls, Idaho. 82 pp.

US Department of Agriculture—Natural Resources Conservation Service. 1993. Design and construction guidelines for considering seepage from agricultural waste storage ponds and treatment lagoons. Technical Note 716 (Revision 1), South National Technical Center, Ft. Worth, Tex. 37 pp.

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