Water Properties of Caliche

J.T. HENNESSY, R.P. GIBBENS, J.M. TROMBLE, AND M. CARDENAS

Abstract

Water absorption and retention by hard caliche nodules (rocks) collected from soils in southern New Mexico were determined. The rate of water uptake by the caliche rocks was rapid and water content at saturation was 13.0% by weight (24.7% by volume). At a matrix potential of -0.7 MPa, the rocks retained 10.6% water by weight, an 18% loss from saturation. Water loss from saturated rocks to a dry atmosphere was slow, but most of the absorbed water was released. The rocks contained only 0.6% water by weight (1.1% by volume) after 34 days in a desiccator. Both laboratory and field trials indicated that, although indurated caliche layers will absorb large amounts of water, the water does not pass through the layers to the soil below.

Caliche is commonly found in soils in the arid and semiarid southwestern United States. Although the chemical composition of caliche varies spatially, calcium carbonate ($CaCO_3$) is always the major constituent. Deposits of caliche often limit the downward extension of plant roots and the volume of soil from which plants can extract water. Thus, an understanding of plant distributions on arid rangelands is often dependent upon a knowledge of how caliche deposits influence the availability of soil water.

The dissolving and leaching of $CaCO_3$ by rainwater, followed by the evaporation and rapid removal of soil water by plants, leads to precipitation of $CaCO_3$ and the development of caliche deposits in soils (Gile et al. 1966, Shreve and Mallery 1932, Stuart and Dixon 1973, Stuart et al. 1961). Deposits of caliche often form along and below contacts between coarse-textured soil layers or between coarse- and fine-textured interfaces (Stuart and Dixon 1973). These carbonate deposits may be in the form of indurated or "hard" caliche—which does not slake when an air-dried portion is placed in water—or in the form of nonindurated "soft" caliche—which does slake when an air-dried portion is placed in water (Gile 1961). Both types of caliche often exist together. Caliche deposits may be in the form of either nodules or layers. In either form, the material is usually parallel to the soil surface in either continuous or discontinuous layers. Depth of the deposits varies from near the surface to a depth of a meter or more. With maturity, whole deposits may become hardened and strongly indurated, especially if they contain high amounts of calcium or aluminum silicates (Stuart et al. 1961). Where soil horizons are so strongly impregnated with carbonate that their morphology is determined by the carbonate, a petrocalcic or Bkm horizon may be designated (USDA Soil Conserv. Serv. 1981). Since hardened deposits are not easily weathered, the layer, upon exposure, can form a caprock (Lattman 1977). The development of carbonate horizons is a useful indicator in determining soil age (Gile 1970).

In calcareous soils, those with caliche layers and those with enough $CaCO_3$ to potentially form caliche, water penetrability and soil sorptivity decrease as the $CaCO_3$ content in the sand fraction increases. Precipitates in such soils can block pore spaces and increase the length of passages available for soil water movement. As a result, both the water storage-capacity and the rate of water advancement (hydraulic conductivity) in the soil are decreased (Tayel 1975, Verplancke et al. 1976). Removal of $CaCO_3$ from a soil increased soil porosity and soil water retention at all suction levels tested by Stakman and Bishay (1976). Calcareous soils were also found to be more susceptible to compaction damage and clogging of micropores by cementation (Talha et al. 1978). Gile (1961) found that infiltration rates of carbonate horizons ranged from 0.13 to 14.99 cm per hour and that infiltration rates decreased exponentially as carbonate content increased.

Caliche is highly insoluble in soil water except when the soil water contains abundant CO_2 (Shreve and Mallery 1932). The insolubility of caliche in water has lead to the assumption that most caliche is highly impermeable to water (Lattman 1977). However, Shreve and Mallery (1932) found that "hard" caliche would absorb small amounts of water (3-6% by dry weight) whereas "soft" caliche absorbed up to 17% water. Shreve and Mallory (1932) also found that water transferred slowly through thin (1-cm thick) caliche layers. They concluded that caliche was a deterrent to the penetration of water from the surface to lower depths, and that, once water reached lower depths, caliche effectively retained it.

Caliche often occurs within the rooting zone of plants on arid rangelands (Gile and Grossman 1979). Thus, water properties of caliche may influence the amount of soil water available to plants. The objective of this study was to determine the water absorption, retention, and transfer characteristics of indurated caliche.

Materials and Methods

Caliche samples were obtained from a mesquite (*Prosopis glandulosa* Torr.) duneland site on the Jornada Experimental Range (administered by the U.S. Department of Agriculture, Agricultural Research Service) in Dona Ana County, N. Mex. On-site examination was made by Soil Conservation Service personnel. Interdunal soils were identified as coarse-loamy, mixed, thermic Typic Haplargids of the Onite series and as coarse-loamy, mixed, thermic Typic Calciorthids of the Wink series. Dunes tall enough to qualify as pedons were classified as mixed Typic Torripsamments of the Pintura series. All of the soils contain petrocalcic layers, generally horizontally discontinuous and ranging from the surface to a meter or more in depth. These soils are in an arid area where mean annual rainfall is 230 mm. Mean annual temperature is 15°C. The average temperatures are maximum in June (36°C) and lowest in January (13.3°C).

Hard caliche nodules (rocks) were gathered from the field site. A layer of caliche rocks is typically found just above the solidly indurated caliche layers. Four weight classes, with 5 rocks in each class, were chosen, based on oven-dry weight as follows: (1) 40-70 g; (2) 70-100 g; (3) 100-150 g; and (4) 150-300 g.

Water Absorption

To determine rate of water uptake and water content at saturation, we oven-dried (105°C) the caliche rocks to a constant weight (48 hr) and submerged them in distilled water. The rocks were removed from the water and excess water removed with towels, then immediately weighed and replaced in water. This procedure was performed after 1, 5, and 15 min; 1 hr; 5 hr; and 24 hr of submergence. Weight determinations at 36 hr showed that a constant weight had been reached at 24 hr. Water content (percentage of dry weight) was calculated for each rock at each time interval.

Authors are former graduate student, Animal and Range Science Department, New Mexico State University, Las Cruces, now range research officer, Gaborone, Botswana, Africa; range scientist and hydrologist, U.S. Department of Agriculture, Agricultural Research Service, Las Cruces, N. Mex. 88003; and associate professor, Department of Experimental Statistics, New Mexico State University, Las Cruces, respectively.

This article is published as journal article 960, Agricultural Experiment Station, New Mexico State Univ., Las Cruces.

Manuscript received November 1, 1982.

An analysis of covariance (rock-size classes treatments-time covariate) was used to determine whether differences existed among the absorption curves of the rock-weight classes.

To determine water retention and release, we first saturated the 20 caliche rocks to a constant weight by submerging them in distilled water for about 24 hours. Then we placed them in a pressure plate apparatus on a bed of soil and, using the procedure described by Richards (1965), equilibrated the rocks with matrix potential values of -0.03, -0.1, -0.7 and -1.5 MPa. After each such application, the rocks were weighed, oven-dried, and then resaturated. Water release curves were plotted for each weight class. An analysis of covariance procedure (weight size classes treatments-matrix potential covariate) was used to determine whether differences existed among the water release curves.

Desorption to a Dry Atmosphere

Water release to dry air was determined by saturating the rocks and placing them in desiccating jars with silica gel crystals for 34 days. Periodically, the rocks were removed, weighed, and replaced as quickly as possible. An analysis of covariance (rock-weight classes treatments-time covariate) was used to test for differences among water release curves for the rock-size classes. After the above experiments were completed, densities of the caliche rocks were determined by oven-drying, weighing, and coating each rock with a thin layer of varnish. After the varnish was dry, each rock was placed in a graduated cylinder or beaker, and volume was determined by water displacement.

Water Flow Through Caliche

To determine whether water would flow through a solid caliche layer, we sealed 3 caliche rocks, which appeared to have no cracks through them, in clear, plastic cylinders with silicone caulking. The sides of the rocks were coated with caulking and rolled up in 30 cm squares of flexible sheet plastic. The overlapping edges of the plastic sheets were sealed with caulking to form a water-tight cylinder. The top of each cylinder was filled with distilled water to a depth of 10 cm. The bottom surfaces of the rocks were exposed to air. The rocks were observed periodically for 3 days to determine whether water had passed through them.

A field test for water flow through caliche was made in conjunction with soil hydraulic conductivity measurements (Hennessy 1982). On an interdune area, a 1-m^2 area was cleared of about 15 cm of soil to expose the indurated caliche layers. A neutron probe access tube was passed through the center of the plot to a depth of approximately 1.22 m. A soil water content was determined with a neutron thermilization unit before water was applied. A metal frame 1 m^2 was placed on the plot. Water was ponded within the frame to a height of 15 cm. That water level was maintained for 15 min, and then the level was allowed to drop. Beginning 2 min after the introduction of water, soil water determinations were made at 15–30 min intervals for the first 5 hr and thereafter once a day for 6 consecutive days. The caliche layer at this location was approximately 30.5 cm thick as observed when the access hole was drilled and as confirmed by probe data. At a nearby plot an access tube was placed in an area where about 45 cm of soil existed above the caliche layer. The plot was flooded and measurements were taken as described above, but the soil above the caliche was not removed. The access tubes fit tightly in the holes. If water seepage occurred between the tubes and surrounding caliche it was not in quantities large enough to influence neutron probe readings which remained fairly constant below the caliche layers.

Results and Discussion

The mean density of the 20 caliche rocks was 1.9 g/cm^3. The range of means among size classes was 1.8 to 2.0 g/cm^3. Examination of rocks under a microscope revealed that density may vary considerably among rocks as both coarse and finely packed layers were usually present. The bulk density of the caliche (1.9 g/cm^3) was much greater than the bulk density of soils on the site. (1.4 g/cm^3).

Water Absorption

The laboratory measurement indicated that all of the caliche rocks had become saturated 24 hr after submersion, and several rocks were at or near saturation after 5 hr of submergence. The absorption curves of the rock-weight classes did not differ significantly ($P>0.05$), so the overall mean (all weight classes combined) was used to illustrate water absorption (Fig. 1). The rate of water uptake was rapid; after 1 min, the mean water content was 3.3% by weight (6.3% by volume); after 5 min, 6.1% by weight (11.6% by volume); after 1 hr, 11.5% by weight (21.9% by volume). The mean of percentage of water content for all the rocks at saturation was 13.0% by weight (24.7% by volume).

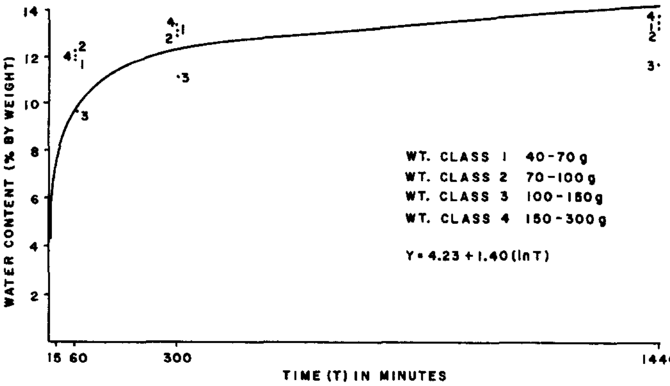

Fig. 1. *Absorption curve of mean water content (% by weight) over time of 20 caliche rocks (all weight classes combined) submersed in water. Observed values at 60, 300, and 1440 minutes are shown for each weight class. The absorption curves of the different weight classes did not differ significantly (P>0.05).*

Desorption at Various Matrix Potentials

The caliche examined appeared to retain water very well. The water lost at various matrix potentials was influenced to some degree by the weight or size (more specifically, no doubt, the surface to pore volume ratios) of the caliche rocks (Fig. 2). The desorption curves for the various rock-weight classes differed significantly ($P<0.05$). The desorption curve for weight-class 3 was somewhat anomalous (Fig. 2), largely because one rock absorbed much less water than the others. The water retention values at -1.5 MPa were erratic, perhaps because the increased pressure disrupted the continuity of water films at the rock-soil interface. Also, the repeated saturation, pressurization, and oven-drying may have

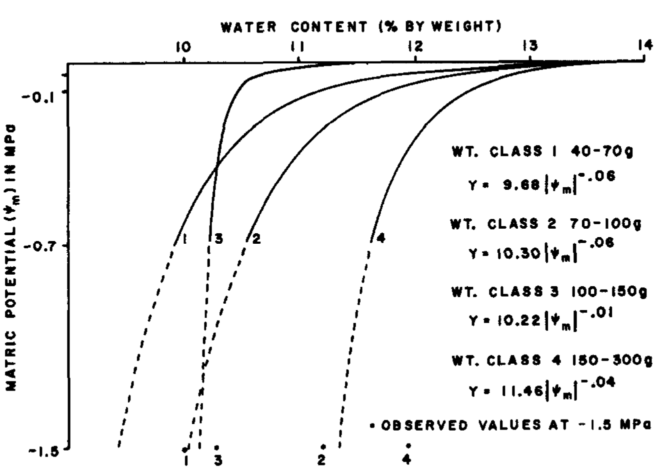

Fig. 2. *Desorption curves for caliche rocks subjected to various levels of maxtrix potential. The curves are based on -0.03, -0.1, and -0.7 MPa values and extrapolated (dashed portion) to -1.5 MPa. Observed values at -1.5 MPa are shown. The curves for the different weight classes differed significantly (P<0.05).*

influenced results.

The largest rocks (weight-class 4), which would be expected to have the smallest surface to pore volume ratios, retained the most water at all matric potentials (Fig. 2). The amount of water retained appeared to be correlated with rock weight, except for weight-class 3 (Fig. 2). Probably the internal pore structure of individual rocks, as well as their surface to pore volume ratios, is an important factor in water retention.

For all size classes combined, the mean (% by weight) of water retained at -0.03 MPa matric potential was 12%, a 6% loss from saturation. At -0.1 MPa matric potential, 11.4% water by weight was retained, a 12% loss from saturation. At -0.7 MPa matric potential, 10.6% water by weight remained, an 18% loss from saturation. Both calculated and observed values indicate that little additional water was lost between -0.7 and -1.5 MPa.

Desorption in Dry Atmosphere

When the 20 caliche rocks were placed in desiccators, weight loss continued for 34 days. The desorption curves for the rock-weight classes did not differ significantly ($P>0.05$), so the overall mean (all weight classes combined) was used to portray water loss (Fig. 3). The mass of the rocks apparently has little influence on the rate of water loss to a dry atmosphere, at least over the time intervals used. The rate of water loss was relatively slow, but most of the water contained in the rocks was released. Only 0.6% by weight (1.1% by volume) remained after 34 days.

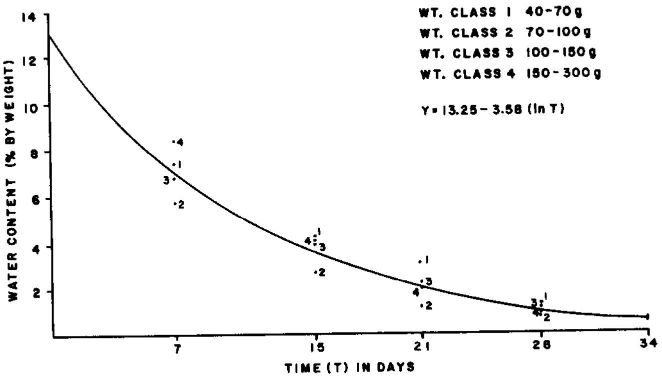

Fig. 3. *Water loss, over time, for 20 caliche rocks (all weight classes combined) after the saturated rocks were placed in a dry environment. Observed values at 7, 15, 21, and 28 days are shown for each weight class. At 34 days the water content ranged from 0.6 to 0.7% among the weight classes. The desorption curves for the various weight classes did not differ significantly (P>0.05).*

Water Flow Through Caliche

In the laboratory tests for determining whether water would flow through caliche, none passed through, although water was absorbed by the rocks. Flooding of the 1-m^2 field plots confirmed that finding. In the field tests, considerable water was absorbed by the caliche on the plot where caliche was exposed before flooding, but no water passed through to underlying soil layers. Measurements of water content in the caliche layer indicated that it increased during the first 2.15 hr (Table 1). Thereafter, water content remained fairly constant until 72.52 hr. At the end of 6 days, water content in the caliche layer had decreased, perhaps due to lateral flow within the caliche layer. The probe sampling zone at a depth of 30.5 cm was at the lower extreme of the caliche layer, and the reduced amount of caliche at that depth probably accounted for the smaller increase in water content at that depth that at the 15-cm depth (Table 1). At a depth of 45 cm, water content did not change.

On the plot where soil was left in place over the caliche layer, results similar to those shown in Table 1 were found after flooding. On that plot the caliche layer extended from about 45 cm to 61 cm below the soil surface. After the plot was flooded, water content of the soil at depths of 15 and 30.5 cm increased for 3 hr, and then declined. Water content at depths of 45 and 61 cm, where caliche was present, increased steadily for 6 days, indicating that water was accumulating in the caliche layer. Below the caliche layer, at a depth of 76 cm, water content did not change during the 6 days of measurement.

Table 1. Volumetric water content (as a decimal fraction) at 3 depths over time after flooding of a 1 m² plot where the caliche layer was at the surface and extended to a depth of 30.5 cm.

Time (hours)	Volumetric water content at depths of: 15 cm	30.5 cm	45 cm
	Before flooding		
	0.19	0.18	0.18
	After flooding		
.32	0.27	0.18	
.48	0.28	0.18	
.90	0.32	0.18	
1.15	0.32	0.19	0.18
1.40	0.34	0.19	
1.65	0.35	0.20	
2.15	0.36	0.20	
2.40	0.36	0.20	
2.65	0.36	0.20	0.18
2.90	0.36	0.21	
3.40	0.36	0.20	
3.83	0.35	0.20	
4.40	0.36	0.20	
4.90	0.36	0.21	0.18
29.03	0.34	0.22	
72.52	0.36	0.22	
[1]144.23	0.33	0.22	0.18

[1]6 days

Conclusions

Results of both the laboratory and field experiments indicated that caliche can absorb appreciable quantities of water at a rapid rate. It also retains water for extended periods. Hence, in field soils where a caliche layer is present near the surface, a potential exists for a fairly high percentage of rainfall to be absorbed in the caliche layer and rendered unavailable to plants. Although a solid caliche layer prevents water passage to soil below the caliche, some water does reach that soil, probably passing through discontinuities in the caliche layer. That water is generally unavailable to plants unless the discontinuities in the layer are large enough for roots to pass through.

This study has raised a question that needs further investigation. Will the caliche, through vapor transfer and condensation, release absorbed water in sufficient quantities to be beneficial to plants? In view of the large amounts of water (25% by volume) that caliche can absorb, the ultimate fate of the absorbed water is of prime importance in arid regions. Studies of grass cover on the Jornada Experimental Range have indicated that survival of grasses during droughts is better on soils underlain by caliche at shallow depths than on deeper soils (Herbel et al. 1972). That finding indicates that, when caliche is within the rooting zone of plants, it does influence soil water relationships in some manner. The morphological development of caliche layers indicates that thin zones of free water are present, at times, on top of caliche layers (Gile et al. 1966). The longevity of such films and their influence on plant survival in drought periods is not known.

Literature Cited

Gile, L.H. 1961. A classification of ca horizons in soils of a desert region, Dona Ana County, New Mexico. Soil Sci. Soc. Amer. Proc. 25:52-61.

Gile, L.H. 1970. Soils of the Rio Grande Valley border in southern New Mexico. Soil Sci. Soc. Amer. Proc. 34:465-472.

Gile, L.H., and R.B. Grossman. 1979. The desert project soil monograph. USDA, Soil Cons. Serv. Washington, D.C.

Gile, L.H., F.F. Peterson, and R.B. Grossman. 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Sci. 101:347-360.

Hennessy, J.T. 1982. Mesquite (*Prosopis glandulosa* Torr.) dunes and interdunes in southern New Mexico: A study of water relations and plant production. Ph.D. Diss., New Mexico State Univ. Las Cruces.

Herbel, C.H., F.N. Ares, and R.A. Wright. 1972. Drought effects on a semidesert grassland range. Ecology 53:1084-1093.

Lattman, L.H. 1977. Weathering of caliche in Southern Nevada, p. 221-231. *In:* D.O. Doehring (ed.). Geomorphology in Arid Regions. Allen and Unwin Ltd., London.

Richards, L.A. 1965. Physical condition of water in soil. p. 128-151. *In:* C.A. Black (ed.). Methods of Soil Analysis, Part 1. Amer. Soc. of Agron., Inc. Madison, Wisc.

Shreve, F., and T.D. Mallery. 1932. The relation of caliche to desert plants. Soil Sci. 35:99-113.

Stakman, W.P., and B. Bishay. 1976. Moisture retention and plasticity of highly calcareous soils. Neth. J. Agr. Sci. 24:43-57.

Stuart, D.M., and R. Dixon. 1973. Water movement and caliche formation in layered arid and semiarid soils. Soil Sci. Soc. Amer. Proc. 37:323-324.

Stuart, D.M., M. Fosberg, and G. Lewis. 1961. Caliche in southwestern Idaho. Soil Sci. Soc. Amer. Proc. 25:132-135.

Talha, M.S. Metwally, and E. Abu-Gabal. 1978. The effect of compaction on some physical properties of alluvial and calcareous soil. Egypt. J. Soil Sci. 18:29-38.

Tayel, M. 1975. Penetrability and sorptivity in calcareous soils. Egypt. J. Soil Sci. 15:141-150.

USDA Soil Conserv. Ser. 1981. Chap. 4. Examination and description of soils in the field. p. 4-1-4-107. Soil Survey Manual, Title 430-V, Issue 1. Washington, D.C.

Verplancke, H., R. Hartmann, and M. DeBoodt. 1976. The water transmission characteristics of highly calcareous soils as related to swelling and shrinking, p. 47-59. *In:* M. Kutilek and J. Sutor (ed.). Water in Heavy Soils, Vol. III. The Czech. Sci. Tech. Soc. Praha, Czech.