Water Properties of Caliche

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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 semi-arid southwestern United States. Although the chemical composition of caliche varies spatially, calcium carbonate (CaCO₃) 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 CaCO₃ by rainwater, followed by the evaporation and rapid removal of soil water by plants, leads to precipitation of CaCO₃ 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 layers (Stuart and Dixon 1973). These carbonate deposits may be in the form of indurated or "hard" caliche—where does not slake when an air-dried portion is placed in water—or in the form of nonindurated "soft" caliche—where 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 CaCO₃ to potentially form caliche, water penetrability and soil sorptivity decrease as the CaCO₃ 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 CaCO₃ 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. 1976). 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 CO₂ (Shreve and Mallery 1932). The insolubility of caliche in water has led 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 Mallery (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, New Mexico. 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 Calcic horizons of the Wink series. Dunes tall enough to qualify as pedons were classified as mixed Typic Torridissamens 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.
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<sup>2</sup> 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 15 cm. That water level was maintained for 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 1.22 m 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<sup>3</sup>. The range of means among size classes was 1.8 to 2.0 g/cm<sup>3</sup>. 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<sup>3</sup>) was much greater than the bulk density of soils on the site. (1.4 g/cm<sup>3</sup>).
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.

![Graph](attachment:graph.png)

**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-m² 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 7.52 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 43 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.

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Volumetric water content at depths of:</th>
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<tbody>
<tr>
<td></td>
<td>15 cm</td>
</tr>
<tr>
<td>Before flooding</td>
<td>0.19</td>
</tr>
<tr>
<td>After flooding</td>
<td></td>
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<tr>
<td>32</td>
<td>0.27</td>
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<tr>
<td>48</td>
<td>0.28</td>
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<tr>
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<td>144.23</td>
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</table>

*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, it is more likely to absorb and retain water 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


