LABORATORY EVALUATION OF WATER-REPELLENT SOILS FOR WATER HARVESTING

by

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INTRODUCTION

No matter the stage of development of our arid West, water seems always to be a limiting factor. Water shortage occurs in spite of a continuous progression of water development systems, both in numbers and complexity. Ironically, most arid areas receive a substantial quantity of precipitation; for example, our two driest states, Nevada and Arizona, receive an annual average of 50 and 78 gallons of precipitation, respectively, for every square yard of surface area.

Unfortunately, most of the precipitation in these areas is lost, primarily by direct evaporation from the soil, or by transpiration through desert plants with no agricultural value. Much of the little water that reaches stream channels is lost by flash flooding, phreatophytes, or to ground water, which can not always be locally recovered. Little of the precipitation is directly useable by man. For most of the water we use we must improve on Nature's way by constructing wells, storage facilities, and elaborate transport systems.

Water harvesting is one such way of increasing our useable water supply. Water harvesting essentially is preventing water from infiltrating the soil, thus forcing it to run off so it can be collected. Several means are used for water harvesting, including vegetation alteration, land smoothing, covering the soil with various types of impermeable barriers, and making the soils water repellent by treating them with thin coatings of organic chemicals.

This study reports laboratory evaluations to screen water-repellent materials and treatments before testing them in the field. Although information is needed on erodibility, durability, cost, and toxicity, an *a priori* starting test normally is whether the treated soil is water repellent. The study's three objectives were: (1) to determine the relative effectiveness of six methods for measuring water repellency of soils, (2) to search for materials and treatments worth field testing, and (3) to evaluate effects of soil type and properties on initial water repellency.

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METHODS

All five soils selected (Table 1) are being used or contemplated for use as water harvesting sites. Four are from Arizona; the high clay Pullman soil is from the High Plains of Texas. Texture analysis shows that all the Arizona soils are sandy loams. Experience, however, has taught us that these soils behave quite differently when used for water harvesting. The soils for our test were screened to < 2 mm, mixed with 10 percent water, packed into petri dishes, and air dried. After drying, some were treated with stabilizers (Table 2) by flooding the material on with a pipette. Again after drying, all the soils were treated with potential water repellents (Table 2). The paraffin wax was applied as a powder, then melted into the soil by using a heat lamp. The wax emulsion and silicone were flooded onto the soil with a pipette. The lard was melted and flooded onto the soil. The liquid dust suppressant was brushed on.

The six water repellency tests were: (a) the aqueous-alcohol drop test for determination of the "90°-surface tension" for a porous solid (γ_n) (Watson and Letey, 1970), (b) the water drop penetration time test (WDPT) (Adams et al., 1968; Savage et al., 1969), (c) the relative height of a large sessile water drop resting on the smoothed, treated soil surface, (ℓ/ℓ_n) (Fink, 1970), (d and e) the presence and persistence of air bubbles trapped between the soil-water interface. The entrapped air test was observed for both the WDPT drops (test d) and the large sessile drops (test e). Test (f) was made simply to note whether the large sessile water drop from test (c) would infiltrate into the soil or eventually evaporate after 3 to 4 hours.

For the γ_n test, a series of methyl alcohol-water mixtures were prepared with a range of liquid surface tensions from 22.6 to 72.8 dynes/cm. Small drops of these mixtures were placed on the treated soils, and the times required for complete infiltration recorded. Then, the liquid surface tensions vs infiltration times were plotted, and the data extrapolated to zero time. This intercept is the 90°-surface tension value (γ_n). The greater the repellency, the lower the γ_n value.

For the WDPT test, four water drops were placed on the treated soil, and the times required for complete infiltration recorded. Times of the four drops were averaged. For the ℓ/ℓ_n test, a water drop large enough to have attained maximum height was placed on the treated soil. The height of the drop relative to the soil (ℓ) was measured with a point gage. This height value was normalized by dividing it by the theoretical height (ℓ_n = 0.3855 cm) of a water drop with a 90°-contact angle, when resting on a smooth, nonporous solid surface.

The entrapped air test is strictly a qualitative observation, in which the presence and persistence of air bubbles trapped between the soil-water interface are noted. The test resulted from the observation that several samples rapidly lost the air trapped between the soil and water interfaces. We could see the air bubbles dissipate and disappear from samples that were not water repellent, and we noted a marked darkening of the soil under the drop. This loss of air undoubtedly was caused by the capillary action of the water moving down into the pores of the soil, driving the air ahead of it. The loss of air and darkening of the soil could be observed about as well for large as for small water drops.

The values that we accepted or rejected for delineating water repellency in all these tests were somewhat arbitrary. For the γ_n test, values of 30 or higher were rejected. For the WDPT test, only treatments for which all four drops eventually evaporated were accepted. For the ℓ/ℓ_n test, treatments with values less than 1.35 were rejected. For the entrapped-air test, we rejected those treatments which developed isolated dark patches under the drop, or those where air loss could be seen.

RESULTS

The results of the water repellency tests are summarized in Table 3. If a soil-treatment combination passed all six water repellency tests, it is marked with an exclamation mark. If a soil-treatment combination failed some of the tests and passed others, the failures are denoted by the respective test letter, and the passes by asterisks instead of the test letters.

WATER REPELLENCY TESTS

All six of the tests readily and consistently adjudged those treatments which produced highly water-repellent soil surfaces (Table 3). These treatments were the high rates of paraffin wax and all rates of the dust suppressant.

As repellency decreased, variation and apparent inconsistency developed among the tests. No test, for example, proved consistently best suited for detecting the inadequate surface coverage of the low rate of paraffin wax (treatment Nos. 5, 8 and 11). These three low-rate treatments developed mottled soil surfaces; the light areas undoubtedly had received little or no wax. However, even the light-colored areas were generally found water repellent by the WDPT and the two entrapped air tests. Undoubtedly, while the soil was under the heat lamp, wax vapors had distilled over from the treated areas. Even the ultimate, final test (f) of infiltration of the large sessile drops into the soil failed to detect this low coverage except in two samples. Previous work (Fink, 1970) also had shown that contact angle techniques were not particularly well suited for establishing minimum or monolayer coverage. This study suggests, however, that running several types of tests will indicate an approximate minimum coverage.

Treatments that did not produce water repellency were most consistently detected by using tests c, d and e, i.e., the ℓ/ℓ_n or drop height test, and the two entrapped air tests. These three tests detected nonrepellency for all soils treated with either the wax emulsions or the lard. Used in combination, tests c and e also indicated that all but one of the silicone-treated soils were nonrepellent.

Of the six tests, the drop height (ℓ/ℓ_n) test was the most quantitative. Values ranged from 1.36 to 1.51 for all the dust suppressant treatments and for the higher rates of paraffin wax. These ℓ/ℓ_n values decreased as repellency decreased, finally reaching an assigned low value of $\ell/\ell_n < 1$ for those samples on which water spread laterally across the soil surface.

Although the entrapped air tests were fast, they were only qualitative as used in this study. Efforts are being made to quantitatively evaluate the proportion of entrapped air to soil-water interface as a function of time. Currently, the laboratory procedure followed for evaluating water-repellent soil treatments is to measure the relative drop height (ℓ/ℓ_n), note the presence and persistence of entrapped air under this drop, and then note whether this drop eventually evaporates or infiltrates. Thus, the one large sessile water drop can readily be used for three tests.

WATER REPELLENTS

Table 3 shows 12 treatments were water repellent for all six tests and all five soils. These consisted of the solid paraffin wax, with or without stabilizers, and the dust suppressant, with or without stabilizers. The low rate of wax (0.27 kg/m^2) failed some tests for some soils in treatments 5 and 11, but proved acceptable for all tests and all soils in treatment 8. About 0.5 kg wax per square meter of surface area seems to be the optimum rate to assure maximum water repellency. All except one dust suppressant treatment passed all six water repellency tests for all soils. These tests could not show whether a separate soil stabilizer was needed with the wax or the dust suppressant; they only showed that the stabilizer did not adversely affect water repellency.

The paraffin wax and the dust suppressant are being field tested at the laboratory's Granite Reef Test Site. Table 4 summarizes the runoff data through March 1974. Procedural details on the wax plots have already been published (Fink and Cooley, 1973; Fink et al., 1973). Briefly, the two wax plots were treated with approximately 0.5 kg wax/m^2 in the summer of 1972. After nearly 2 years, the plots continue to yield about 90 percent runoff, which compares favorably with solid soil covers such as butyl. This runoff is three to six times the runoff obtained from adjacent smoothed-only plots.

The dust suppressant has been under field test for less than 6 months. Thus, results reported are strictly preliminary. The 80- to 85-percent runoff yields (Table 4) strongly support laboratory findings that the material does produce a water-repellent soil surface.

Table 3 shows that, in general, treatments Nos. 12 through 16, 22 and 23 did not produce water-repellent soils. Most of these treated soils failed three or more of the tests. However, only treatment No. 22 failed all six tests on three soils. Wax emulsions have been tested earlier (Hillel, 1967), without success, for creating water-repellent soils for harvesting precipitation. Alone, they are not stable against erosion; with or without a separate soil stabilizer, they are not even water repellent. The lard consistently passed the water repellency tests based on infiltration (a, b, f), but failed the other three tests (c, d, e). Apparently, the lard waterproofed the soil, but did not make it water repellent, i.e., the lard completely plugged the soil pores at the surface, but the contact angle of water resting on the treated surface was less than 90°.

SOIL TYPE

No patterns of acceptance or rejection of the five soil types with respect to water repellency treatments or water repellency tests, as measured in the laboratory, could be observed. Previous work (Fink, 1970) had shown that the contact angle (θ) of water resting on organic-coated soils was not significantly influenced by soil type. Once the soil was covered with a monolayer of the organic coating, the contact angle remained relatively constant with increased coverage, with the value of θ depending primarily on the type of exposed organic functional groups at the organic-water interface. For this study, multilayer coverages were assumed to be obtained for all treatments on all soils.

Soil type, however, does affect other factors that determine suitability for water harvesting, for example, erodibility and persistence of water repellency with time under different climatic conditions, amount of material needed to obtain monolayer coverage, and ability to withstand a water pressure head. None of these factors was tested in this study.

CONCLUSIONS

1. Laboratory tests can be used to evaluate water-repellent-treated soils as a precursor to the more expensive and time-consuming field testing of potential organic coatings for water harvesting.

2. The large sessile drop height test and a newly proposed entrapped air method proved the most useful of the six methods tested for measuring water repellency.

3. Two organics found suitable as water repellents by the laboratory tests are undergoing preliminary field testing. Both paraffin wax and a dust suppressant are yielding approximately 90 percent precipitation runoff.

4. Soil type *per se* had no significant influence on degree of water repellency as measured in the laboratory by the six tests used in this study.

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Table 1 - Soils and associated texture analysis

Soil	Texture (μ)				Classification
	Sand	Silt	Silt	Clay	
	> 50	50-20	< 20	< 2	
	%				
Granite Reef	66	18	9	7	sandy loam
Seneca	59	14	17	10	sandy loam
Monument Tank (1-3)	55	16	17	12	sandy loam
Monument Tank (2-3)	62	12	12	14	sandy loam
Pullman	13	29	23	35	silty clay loam

Table 2 – Water-repellent treatments

Treat. No.	Treatment
	Paraffin wax (143-150 F MP)
1.	Wax at 0.68 kg/m^2
2.	Wax at 0.68 kg/m^2 + stabilizer (Dow 620); 3% at 1.5 l/m^2
	Paraffin wax (143-150 F MP) + stabilizer (PVA, Elvanol 72-60); 3% at 1.5 l/m^2
3.	Wax at 0.81 kg/m^2
4.	Wax at 0.54 kg/m^2
5.	Wax at 0.27 kg/m^2
	Paraffin wax (143-150 F MP) + stabilizer (Dow 209); 3% at 1.5 l/m^2
6.	Wax at 0.81 kg/m^2
7.	Wax at 0.54 kg/m^2
8.	Wax at 0.27 kg/m^2
	Paraffin wax (143-150 F MP) + stabilizer (Dow 233); 3% at 1.5 l/m^2
9.	Wax at 0.81 kg/m^2
10.	Wax at 0.54 kg/m^2
11.	Wax at 0.27 kg/m^2
	Paraffin wax emulsion (128-130 F MP); 47.5% wax by weight.
12.	Wax at 0.68 kg/m^2
13.	Wax at 0.68 kg/m^2 + stabilizer (Dow 209); 3% at 1.5 l/m^2
14.	Wax at 0.68 kg/m^2 + stabilizer (Dow 233); 3% at 1.5 l/m^2
	Lard
15.	Lard at 0.81 kg/m^2
16.	Lard at 0.81 kg/m^2 + stabilizer (Dow 233); 3% at 1.5 l/m^2
	Dust suppressant (DS), (Chevron Oil Co.), 70% resinous solids, 30% volatiles
17.	DS at 2.26 l/m^2
18.	DS at 1.13 l/m^2
19.	DS at 0.56 l/m^2
20.	DS at 1.13 l/m^2 + stabilizer (Dow 209); 3% at 1.5 l/m^2
21.	DS at 0.56 l/m^2 + stabilizer (Dow 209); 3% at 1.5 l/m^2
	Silicone (Dow XZ - 8 - 5079)
22.	Silicone, 3% at 1.5 l/m^2
23.	Silicone, 6% at 1.5 l/m^2

Table 3. Water repellency of organic coated soils as determined by six different methods.

Treat. No.	Soil: Granite Reef	Seneca	Monument Tank (1-3)	Monument Tank (2-3)	Pullman
1 - Wax	(!)	(!)	(!)	(!)	(!)
2 -	(!)	(!)	(!)	(!)	(!)
3 -	(!)	(!)	(!)	(!)	(!)
4 -	(!)	(!)	(!)	(!)	(!)
5 -	a*c**f	(!)	**c***	**c***	(!)
6 -	(!)	(!)	(!)	(!)	(!)
7 -	(!)	(!)	(!)	(!)	(!)
8 -	(!)	(!)	(!)	(!)	(!)
9 -	(!)	(!)	(!)	(!)	(!)
10 -	(!)	(!)	(!)	a*****	(!)
11 -	ab****	(!)	ab****	*****f	*b****
12 - Wax em.	abcde*	*bcde*	**cde*	**cde*	*bcde*
13 -	*bcde*	abcde*	**cde*	**cde*	*bcde*
14 -	*bcde*	**cde*	*bcde*	abcde*	**cde*
15 - Lard	**cde*	a*cde*	**cde*	**cde*	**cde*
16 -	**cde*	**cde*	**cde*	**cde*	**cde*
17 - DS	(!)	(!)	(!)	(!)	(!)
18 -	(!)	(!)	(!)	(!)	(!)
19 -	(!)	(!)	(!)	(!)	(!)
20 -	(!)	(!)	(!)	(!)	(!)
21 -	(!)	(!)	(!)	(!)	*b****
22 - Si	a*cdef	abcdef	abcdef	a*c*ef	abcdef
23 -	a*c*e*	a**def	a*****	a*c*ef	ab*def

Water repellency tests: a = γ_n; b = WDPT; c = ℓ/ℓ_n; d = entrapped air for WDPT drops; e = entrapped air for ℓ/ℓ_n drops; f = infiltration of ℓ/ℓ_n drops.

Table notation: Presence of a letter denotes nonrepellency for that test; an asterisk instead of a letter denotes repellency for that test; an exclamation mark denotes repellency for all six tests.

Table 4 - Precipitation runoff from water-repellent soil catchments compared to smoothed only and to butyl-covered catchments

Year	Precip.	Percent runoff					
		10 m^2 plots				200 m^2 plots	
		Smoothed	Butyl	Wax	Dust Suppressant	Smoothed	Wax
	mm	%					
1972	244	28	100	92 1/	--	31	90 1/
1973	208	17	94	88	87 2/	14	87
1974 3/	79	20	97	98	80	25	91

1/ Approximately 6 months data in 1972.

2/ Approximately 2 months data in 1973.

3/ January through March in 1974.