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Relation Between Soil Properties and Effectiveness of Low-cost Water-harvesting Treatments[1]

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ABSTRACT

Knowledge of the relationship between soil properties and treatment performance is important to obtain maximum benefit from low-cost water-harvesting treatments. Six low-cost water-harvesting treatments were field tested on small plots by determining runoff percentages and threshold values at eight sites for 164 weeks. Effectiveness of all treatments decreased over time, with the order of effectiveness being: waxes > silicones ≥ control (smoothed soil). Regression equations were developed to predict runoff percentages and threshold values based on soil properties. These equations can be used in determining which water-harvesting treatment would be most appropriate for a specific soil. All soil properties evaluated influenced the effectiveness of the water-harvesting treatments. Therefore, relationships between specific soil properties and the effectiveness of the treatments could not be established. A set of important soil properties were identified for each treatment in the regression equations, but more research is needed to determine the absolute importance of the individual soil properties in the effectiveness of the treatments.

Additional Index Words: **wax, paraffin, slack, silicone, antistripping agent.**

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WATER HARVESTING IS NOT A NEW DEVELOPMENT (Myers, 1975). Evenari et al. (1961) documented that water harvesting was used for growing crops in the Negev Desert over 4 000 yr ago. Modern day water-harvesting systems supply water for livestock, wildlife, domestic, and agricultural uses (Frasier, 1980). Systems which provide drinking water for livestock and wildlife are valuable aids in rangeland management (Cooley et al., 1978; Frasier, 1981). There is also the potential for increasing rangeland forage production, providing water to trees in arid climates, and producing commercial Christmas trees for market by runoff-farming techniques (Schreiber and Frasier, 1978; Kowsar, 1982; Fink and Ehrler, 1983).

In early water-harvesting systems, the runoff water was collected from cleared and smoothed hillside areas, soil crusts, and rock surfaces. In the past 50 yr, barrier-type materials have been employed to increase precipitation runoff: examples include concrete, soil cement, sheet metal, asphalt-fabric membranes, and gravel-covered sheetings. These types of treatments are effective, but are too expensive for most purposes.

More recently, chemical treatments that create hydrophobic soils have been investigated as potential low-cost methods for increasing runoff (Michaels, 1963; Myers and Frasier, 1969; Fink et al., 1973). Chemicals examined include waxes and silicones, which interact with the soils to which they are applied (Fink et al., 1980). An evaluation of the cost of the chemicals, site preparation, and water produced, has been completed (Frasier and Myers, 1983; Frasier, 1984). Paraffin wax treatments can be effective for 10 yr or longer if conditions are favorable (Fink, 1982). It has been speculated that reported failures of the wax and silicone treatments may have been caused by freezing and thawing, and unknown soil properties (Fink and Frasier, 1975; Fink and Mitchell, 1975; Fink et al., 1980). Laboratory testing has shown that soil stabilizers and antistripping agents improve the effectiveness of the water repellent treatments (Fink, 1976a, b, 1984). Cooley et al. (1975) stated that a comprehensive study of the importance of soil properties, in relation to treatment performance, is needed to obtain maximum benefit from low-cost water-harvesting. The objectives of this study were to: (i) determine runoff percentages and threshold runoff values for wax and silicone water-harvesting treatments on four different soils, (ii) develop relationships between specific soil properties and effectiveness of the treatments, and (iii) develop equations based on soil properties to predict runoff percentages and threshold runoff values for a specific soil.

MATERIALS AND METHODS

Field test plots were constructed at the Walnut Gulch Experimental Watershed (WG) and Santa Rita Experimental Range (SR) in southern Arizona. Four soil series were selected at each location. They were Bernardino (Berd) (fine, mixed, thermic Ustollic Haplargid), Cave (loamy, thermic shallow Typic Paleorthid), Comoro (Como) (coarse-loamy, mixed, thermic Typic Torrifluvent), and Sonoita (Sono) (coarse-loamy, mixed, thermic Typic Haplargid). Experimental sites were selected with slopes of 2 to 5%, graded smooth with minimal soil surface disturbance, and fenced. Eighteen 3-by-3 m test plots, 0.5 m apart, were staked at each of the eight sites.

Eight soil-surface (0–2.54 cm) subsamples were collected on each plot and composited for analysis of soil properties. The range of selected soil properties from the plots is given in Table 1. The sand, silt, and clay fractions were determined by the hydrometer method (Day, 1965). The fractions 12.7 mm through < 0.5 mm were obtained by sieving a 1000-g sample through the sequence of sieves given in Table 1, and presented as the mass retained on each sieve. Exchangeable Na, K, Ca, and Mg were extracted with ammonium acetate and reported as NaEX, KEX, CaEX, and MgEX, respectively (Thomas, 1982). Values for pH through HCO_3, given in Table 1, were determined from saturation extracts (U.S. Salinity Laboratory Staff, 1954) by standard laboratory procedures. Calcium carbonate was determined by the pressure-calcimeter method (Nelson, 1982). Organic C was determined using the Walkley-Black procedure (Nelson and Sommers, 1982).

Six treatments were evaluated: (i) control (Cont), bare soil with no chemical treatment; (ii) refined paraffin wax (PW)

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[3] Trade names and company names are included for the benefit of the reader, and do not imply any endorsement or preferential treatment of the product listed by the USDA.

Table 1. Range of selected soil properties from test plots.

Property	Units	Range Smallest	Range Largest	Property	Units	Range Smallest	Range Largest
Sand	%†	62.	87.	pH	¶	5.75	8.32
Silt	%†	7.	29.	EC	dS/m¶	0.62	11.9
Clay	%†	5.	17.	Na	mg/L¶	4.2	30.8
12.7 mm	g‡	0	194.	K	mg/L¶	11.9	53.4
9.4 mm	g‡	0	72.	Ca	mg/L¶	12.	557.
4.76 mm	g‡	11.	137.	Mg	mg/L¶	2.4	52.8
2.0 mm	g‡	35.	175.	NO_3-N	mg/L¶	0.5	350.
1.0 mm	g‡	58.	214.	NH_4-N	mg/L¶	0.0	5.1
0.5 mm	g‡	77.	211.	PO_4-P	mg/L¶	0.01	1.34
<0.5 mm	g‡	319.	809.	SO_4	mg/L¶	17.	627.
NaEX	$cmol_c$/kg§	0.02	0.14	Cl	mg/L¶	3.0	31.3
KEX	$cmol_c$/kg§	0.24	0.76	HCO_3	mg/L¶	10.	461.
CaEX	$cmol_c$/kg§	1.41	27.60	$CaCO_3$	%†	0.0	21.0
MgEX	$cmol_c$/kg§	0.46	1.76	C (organic)	%†	0.0	1.62

† Percent <2 mm, g/g.

‡ Grams retained on each sieve after passing 1000 g of soil through the sieve sequence.

§ NH_4OAc extractable. ¶ In saturation extract.

(125-128 AMP) applied in a molten form at a rate of 1.1 kg/m^2; (iii) the paraffin wax plus 0.03 kg/m^2 antistripping agent (PW + A) (Frymeen 6639 by Emery Industries, Inc.[3]); (iv) slack wax (SW) (Chevron unrefined wax 140) applied at a rate of 1.1 kg/m^2, plus the antistripping agent at 0.03 kg/m^2; (v) silicone (Sil) (Dow Corning® 772 Water Repellent, sodium methyl siliconate) as a 3% water solution applied at a rate of 0.22 kg/m^2; and (6) the silicone plus latex (Sil + L), a soil stabilizer (National Starch and Chemical Co., Resyn 2813) applied at a rate of 0.22 kg/m^2. All treatments were spray applied to three randomly selected plots at each site in the spring of 1981.

A 1-m^2 portable sprinkler, developed by Frasier et al. (1979), was used to evaluate the treatments for runoff efficiency (%) and threshold rainfall values (rainfall required to produce runoff, mm) for 4 yr after the summer rains, and for 2 yr in the spring. The sprinkler sprayed water down onto the plot surface at a rate of 45 to 50 mm/h for 10 to 15 min. The runoff collected at the lower edge of the plot was pumped into a graduated cylinder. Cumulative runoff was plotted vs. the cumulative water applied for each evaluation. The x-axis intercept (called the threshold value) and the slope of the line (referred to as the runoff efficiency of the treatment) were estimated by linear regression using data points after runoff started. The overall variability of the simulator test for runoff efficiency and threshold values is ± 10%, which includes: pump speed changes, wind effects, runoff measurement errors, and other errors expressed in the regression analysis.

Runoff percentages and threshold values for the treatments were statistically analyzed using the Statistical Package for the Social Sciences (SPSS) (Nie et al., 1975). The assumption of normality and homogeneity of error variance could not be accurately tested for, because of the small sample size. A violation of normality was considered likely due to the physical bounding of runoff percentage between 0 to 100%. The Kolmogorov-Smirnov Test was used to test for significant differences ($P = 0.10$) from a normal distribution and none were found for the treatments. Due to the possible violation of normality and homogeneity of error variance, small sample size, plot and rainfall sprinkler variability, a 1% level of significance was chosen for the treatment separation. The significance of the interaction between location and/or soil with the treatments determined how the analysis for treatment separation was performed. No interaction allowed pooling of locations and soils. A location by treatment and soil by treatment interaction required separation by location and soil, respectively. A three-way interaction required that location and soil be separated for analysis. Tukey's HSD Test (Daniel, 1983) was used to separate the mean differences in the treatments using the mean squared error term calculated by SPSS.

Regression equations were developed between the soil properties and runoff percentages and threshold values for each treatment using the BMDP Statistical Software Program. The all possible subsets regression program of BMDP was utilized (Frane, 1983). There were more soil properties (independent variables) determined than measurements of runoff and threshold values (dependent variables) for each evaluation time; therefore, the soil properties were split into two groups and analyzed separately. The two groups consisted of clay through MgEX and pH through C in Table 1. Sand and silt were eliminated because of their colinear dependence with clay. The BMDP program calculates a correlation matrix, and linearly dependent independent variables are removed from consideration before the regression equations are developed. All soil properties that produced the five lowest Mallow's *Cp* values (Daniel and Wood, 1971, p. 86) were combined and analyzed as a third group. The regression equation with five soil properties was selected, and a new set of transformed variables was introduced composed of the original five properties plus their products and squares. The regression equation, from the transformed variable set that had the highest adjusted R^2 (Theil, 1971, p. 179) was selected. Five soil properties were also selected that were readily available in soil survey reports or easily determinable in the laboratory, and regression equations were developed using the same procedure of products and squares for each treatment.

RESULTS AND DISCUSSION

Runoff percentages and threshold rainfall values were plotted against time for each plot. Typical results are shown by the Bernardino soil at the SR location (Fig. 1). With the exception of the control, there was a gradual decreasing trend in runoff percentage and an increasing trend in threshold values with time. The control treatment displayed only minor departures from an overall constant runoff of 55% and a threshold value of 3.1 mm. The control treatment could be a feasible water-harvesting treatment under conditions where low runoff percentages can be utilized. The dip at 48 weeks to 30% for the SR Bernardino control treatment plots was attributed to soil freezing, which opened soil pores and increased infiltration. A similar decrease in runoff efficiency was observed at some of the other sites and treatments. For the wax treatments, it was thought the wax may have crystalized and cracked, or separated from the soil particles during winter freeze/thaw cycles, then remelted in the summer to restore the water repellency. The lower runoff efficiencies on wax treatments in the spring, as opposed to the fall, have been observed on operational water-harvesting catchments (Frasier et al., 1979). On the silicone treatments, the dips in efficiency were also thought to be attributed to freezing and thawing causing the opening of the soil pores and/or crack formation, which was then filled in by eroding hydrophobic soil particles from the intense summer thunderstorms.

The wax treatments generally had the smallest decrease in runoff percentages and increase in threshold values with time (Fig. 1). The wax treatments with antistripping agents were generally higher in runoff percentage at most sites after 164 weeks, but the dif-

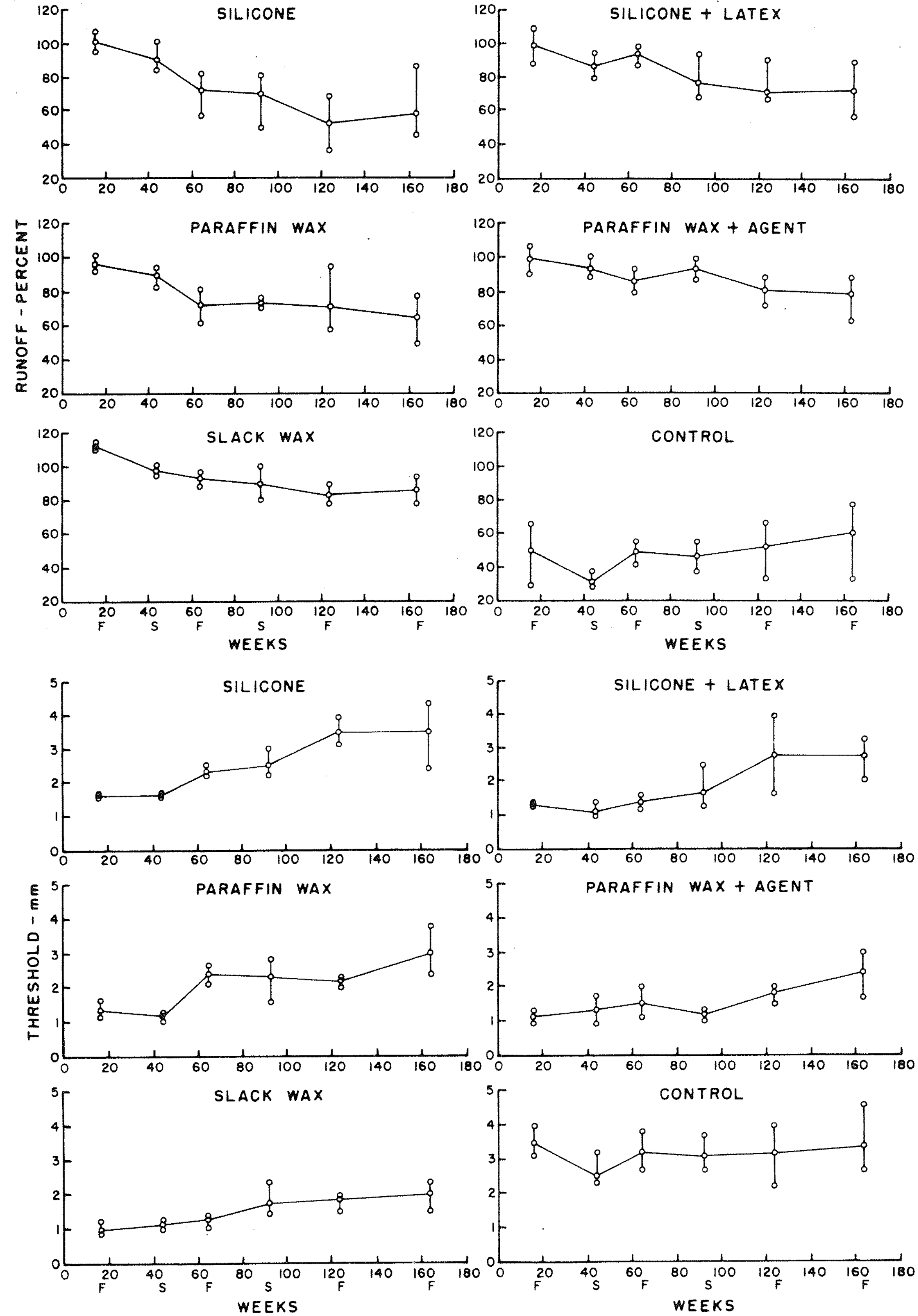

Fig. 1. Mean and range values for runoff and threshold vs. time for the Bernardino soil at the Santa Rita location. S and F are spring and fall measurements, respectively.

Table 2. Mean runoff percentages and threshold values of treatments after 16 weeks.

Soil	Treatment					
	Cont	PW	PW + A	SW	Sil	Sil + L
	runoff, %					
	Walnut Gulch location					
Berd	66a*	92ab	93ab	99b	92ab	95b
Cave	41a	68ab	93c	90bc	94c	95c
Como	64a	87ab	95b	95b	85ab	97b
Sono	64a	104b	106b	105b	95b	98b
	Santa Rita location					
Berd	50a	97b	99b	112b	101b	99b
Cave	54a	108b	102b	111b	97b	94b
Como	47a	108b	103b	92b	89b	99b
Sono	64a	92ab	100b	88ab	90ab	102b
	threshold, mm					
	Walnut Gulch location					
Berd	2.8a	1.3b	1.4b	1.5b	2.1ab	1.7ab
Cave	3.4a	2.7b	1.7b	1.6b	2.2b	2.1b
Como	3.0a	2.4ab	1.8ab	1.5b	2.7ab	1.9ab
Sono	3.4a	1.4b	1.2b	1.3b	1.4b	1.9b
	Santa Rita location					
Berd	3.5a	1.3b	1.2b	1.0b	1.7b	1.3b
Cave	2.6a	1.4b	1.0b	1.4ab	1.2b	1.2b
Como	3.1a	1.1b	0.9b	1.0b	1.5b	1.2b
Sono	2.7a	1.3b	1.2b	1.4b	1.4b	1.3b

* Means across rows followed by the same letter are not significantly different at the 1% level using Tukey's HSD test.

Table 3. Mean runoff percentages and threshold values of treatments after 164 weeks.

Location	Treatment					
	Cont	PW	PW + A	SW	Sil	Sil + L
	runoff, %					
WG & SR	57a*	83cd	87d	87d	61ab	72bc
	threshold, mm					
WG	3.9a	2.0c	2.0c	2.3bc	3.1ab	3.4a
SR	3.5a	2.0b	2.1b	1.8b	3.4a	2.3b

* Means across rows followed by the same letter are not significantly different at the 1% level using Tukey's HSD test.

ferences in wax treatments were not statistically significant. Although the wax treatments were not statistically different, the use of antistripping agents may be advisable for longer term efficiency of the wax treatments as the decrease in runoff efficiency was smaller for the antistripping agent treatments. The lower-cost slack wax, when used with the antistripping agent, produced the same runoff efficiency as the paraffin, and hence would be the most economical.

Over time, the silicone treatment showed the greatest decrease in runoff percentage and increase in threshold value (Fig. 1). After 164 weeks at the SR Bernardino site and others, the silicone treatment had lower runoff percentages than the control treatments, although not statistically different. Silicone plus latex treatment performed efficiently for 64 weeks, then started to decline. By 164 weeks, the differences in silicone treatments were not significant but the silicone plus latex was significantly different from the control.

Treatment effects on mean runoff percentages and threshold runoff values were determined using data obtained 16 and 164 weeks after treatment (Tables 2 and 3). The 16- and 164-week data sets were used because they represented initial conditions and differences after time. The degree of interaction between the location, soil, and treatment played a role in determining significant differences between treatments. A three-way interaction required that the locations and soils be separated for analysis and, with only three replications at each time, there had to be a large difference in the means before it was statistically significant. As the degree of interaction decreased, smaller differences were generally needed for significance. There was a significant three-way interaction between the location, soil, and treatment after 16 weeks; therefore, each location and soil was analyzed separately (Table 2). Runoff efficiency for 78% of the wax and silicone treatments was significantly higher than the control treatment. With the exception of the control plots, runoff percentages were generally >90%, indicating the treatments were effective. Approximately 80% of the wax and silicone treatments had significantly lower threshold values than the control treatment.

Analysis of the data 164 weeks after treatment showed no interaction between treatments and location or soil for runoff percentages; hence, locations and soils were pooled for analysis of treatment differences (Table 3). For threshold values, there was a significant interaction between location and treatment; therefore, each location was analyzed separately. There were no significant differences between the control treatment and silicone treatment for the runoff percentages, indicating that this treatment was no longer effective. The silicone plus latex treatment was not significantly different from the silicone treatment, but was different than the control treatment. This would indicate that the silicone latex treatment was close to losing its effectiveness. The wax treatments had the highest runoff percentages, with two of the three significantly different than the other treatments. The wax treatments averaged 85% runoff. This was only a reduction of about 10% from the first determination. Threshold data indicated the same trends among treatments.

The runoff percentage and threshold values collected after 164 weeks were utilized to develop the regression equations using soil properties as the independent variables. This time period allowed time for the soil properties to influence treatment effectiveness. At 16 weeks, all treatments were effective (except the control), and the soil properties had not influenced the treatments. A test of the soil properties showed a significant two-way interaction between location and soil for all properties. This interaction indicated there was sufficient variability in the site soil properties to allow their use in the regression equations.

The results of the all possible subsets regression part of the BMDP program are presented in Tables 4 and 5 for runoff percentages and threshold values. The runoff regression equations generally had higher R^2 values than the threshold equations. This was thought to be due to the micro-relief at the soil surface. A small amount of micro-relief on some plot surfaces caused a substantial water retention on the soil surface. This

Table 4. Runoff percentage regression equations and coefficients of determination for the treatments.

Equation	R^2	Adjusted R^2	Standard error of estimate
Control			
$Y^{\dagger} = -184 + 14.6(\text{Clay}^{\ddagger}) + 38.8(\text{Cl}) - 1.29(\text{Clay} \cdot \text{Na}) + 21.0(\text{Clay} \cdot \text{PO}_4\text{-P}) + 4.33(\text{pH} \cdot \text{Na}) - 20.3(\text{pH} \cdot \text{PO}_4\text{-P}) - 6.26(\text{pH} \cdot \text{Cl}) - 0.451[(\text{Na})^2]$	0.77	0.61	9.76
Paraffin wax			
$Y = 557 - 0.986(<0.5\ \text{mm}) - 623.(\text{C}) - 0.0123[(4.76\ \text{mm})^2] + 3.27(4.76\ \text{mm} \cdot \text{KEX}) + 0.000537[(<0.5\ \text{mm})^2] + 0.592(<0.5\ \text{mm} \cdot \text{C}) - 240.[(\text{KEX})^2] - 1.43\ [(\text{Cl})^2] + 38.6(\text{Cl} \cdot \text{C})$	0.93	0.88	4.53
Paraffin wax + agent			
$Y = 167 - 0.790(9.4\ \text{mm}) + 380.(\text{C}) + 0.0219(1.0\ \text{mm} \cdot 0.5\ \text{mm}) - 0.00146[1.0\ \text{mm}(<0.5\ \text{mm})] - 5.09(1.0\ \text{mm} \cdot \text{C}) - 0.0131[(0.5\ \text{mm})^2] + 2.06\ (0.5\ \text{mm} \cdot \text{C}) - 0.368[(<0.5\ \text{mm} \cdot \text{C})]$	0.82	0.73	7.27
Slack wax			
$Y = -150 + 17.5(\text{Clay}) + 53.4(\text{Cl}) - 0.573(\text{Clay} \cdot \text{CaEX}) - 1.83(\text{Clay} \cdot \text{Cl}) + 0.0700[(\text{CaEX})^2] + 0.484(\text{CaEX} \cdot \text{Cl}) - 0.322[(\text{Na})^2] - 2.562[(\text{Cl})^2]$	0.88	0.82	5.17
Silicone			
$Y = -123 + 1296.(\text{KEX}) - 138.(\text{KEX} \cdot \text{pH}) - 18.3(\text{KEX} \cdot \text{Mg}) + 1.42(\text{pH} \cdot \text{Mg}) + 0.642(\text{pH} \cdot \text{SO}_4) - 0.347[(\text{Mg})^2] + 0.530(\text{Mg} \cdot \text{Cl}) - 0.964(\text{SO}_4 \cdot \text{Cl}) + 2.46\ [(\text{Cl})^2]$	0.95	0.91	4.62
Silicone + latex			
$Y = -560 + 7.84(0.5\ \text{mm}) + 3.86(\text{Ca}) - 0.0108[(0.5\ \text{mm})^2] - 0.711(0.5\ \text{mm} \cdot \text{pH}) + 0.0134(0.5\ \text{mm} \cdot \text{Ca}) + 7.24[(\text{pH})^2] - 0.340(\text{pH} \cdot \text{Ca}) - 0.00644[(\text{Ca})^2] - 4.36(\text{Ca} \cdot \text{C}) + 267.[(\text{C})^2]$	0.81	0.66	11.47

† Predicted runoff percent based on soil properties. ‡ Units for each variable are the same as given in Table 1.

caused the threshold values to be higher than they would have been without the micro-relief. The regression equations were able to predict the runoff percentages with R^2 values >0.77 for all treatments, and adjusted R^2 values >0.61. The R^2 and adjusted R^2 values for the threshold values were lower than the runoff percentages for most treatments, and ranged from 0.45 to 0.91. Many regression equations for both runoff and threshold prediction were found that had other subsets of soil properties with R^2 values slightly lower than reported in Tables 4 and 5. This indicated that the soil properties could be used to predict how effective a treatment would be on a specific soil. The use of these equations in selecting a treatment should be restricted to soils that have properties that fall within the ranges from which they were developed (Table 1). The more a soil deviates from the soil property values listed in Table 1, the less likely the equation will hold, as even a single soil property may substantially influence the predicted runoff percentages and threshold values.

In many areas where a water-harvesting system

Table 5. Threshold regression equations and coefficients of determination for the treatments.

Equation	R^2	Adjusted R^2	Standard error of estimate
Control			
$Y^{\dagger} = 2.72 + 3.51(\text{MgEX}^{\ddagger}) + 0.0682(\text{NO}_3\text{-N}) - 0.0109(\text{Clay} \cdot \text{Mg}) - 0.0144[(\text{Clay})^2] - 0.0000780[(1.0\ \text{mm})^2]$	0.94	0.91	0.18
Paraffin wax			
$Y = 3.08 - 0.0938(12.7\ \text{mm}) - 27.5\ (\text{NaEX}) + 1.05\ (12.7\ \text{mm} \cdot \text{NaEX}) + 0.0698(12.7\ \text{mm} \cdot \text{KEX}) - 0.000683(12.7\ \text{mm} \cdot \text{Mg}) + 0.0000970(12.7\ \text{mm} \cdot \text{HCO}_3)$	0.86	0.81	0.38
Paraffin wax + agent			
$Y = -0.0628 - 0.0963(4.76\ \text{mm}) + 1.12(\text{Na}) + 0.0149(\text{Clay} \cdot 4.76\ \text{mm}) - 0.00379(\text{Clay} \cdot 2.0\ \text{mm}) - 0.0667(\text{Clay} \cdot \text{Na}) + 0.00782(9.4\ \text{mm} \cdot \text{Na}) - 0.00131[(9.4\ \text{mm})^2] - 0.0331[(\text{Na})^2]$	0.79	0.68	0.34
Slack wax			
$Y = -12.9 + 2.22(\text{pH}) + 8.43(\text{EC}) - 0.0363(\text{NO}_3\text{-N}) - 1.21(\text{pH} \cdot \text{EC}) + 0.0139(\text{pH} \cdot \text{CaCO}_3) + 0.000306[(\text{NO}_3\text{-N})^2]$	0.74	0.64	0.47
Silicone			
$Y = 5.02 - 0.0258(1.0\ \text{mm}) + 0.000755(1.0\ \text{mm} \cdot \text{Mg}) + 0.00640(1.0\ \text{mm} \cdot \text{PO}_4\text{-P})$	0.52	0.45	0.56
Silicone + latex			
$Y = 4.35 - 0.241\ (\text{K}) + 0.00308(\text{Clay} \cdot \text{Ca}) + 0.000317(12.7\ \text{mm} \cdot \text{K}) - 0.252(\text{NaEX} \cdot \text{Ca}) + 341\ [(\text{NaEX})^2] + 0.00328[(\text{K})^2]$	0.91	0.88	0.39

† Predicted threshold value based on soil properties. ‡ Units for each variable are the same as given in Table 1.

Table 6. Selected variable runoff percentage regression equations and coefficients of determination for the treatments.

Equation	R^2	Adjusted R^2	Standard error of estimate
Control			
Y† = 44.4 + 15.7(9.4 mm‡) − 29.0(pH) − 0.0203(9.4 mm • 4.76 mm) − 1.58(9.4 mm • pH) − 0.381(9.4 mm • Clay) + 0.925(4.76 mm • pH) − 2.10(4.76 mm • EC) − 0.246(4.76 mm • Clay) + 15.0(Clay • EC)	0.92	0.86	5.92
Paraffin wax			
Y = −396 + 139.(pH) + 0.0386(4.76 mm • pH) − 1.79(Clay • EC) −9.78[(pH)^2] + 1.14[(EC)^2]	0.53	0.41	10.27
Paraffin wax + agent			
Y = −1749 + 120.(Clay) + 376.(pH) − 0.0133 [(4.76 mm)^2) + 0.191(4.76 mm • pH) − 2.33[(Clay)^2] − 11.0(Clay • pH) − 20.5[(pH)^2]	0.64	0.50	10.00
Slack wax			
Y = 163 − 17.9(pH) + 0.00409[(9.4 mm)^2] − 0.257(9.4 mm • EC) − 0.0161[(4.76 mm)^2] + 0.255(4.76 mm • pH) + 1.32(Clay • EC)	0.71	0.60	7.66
Silicone			
Y = −197 + 7.85(4.76 mm) + 44.0(Clay) − 0.0686(4.76 mm • 9.4 mm) + 1.65(9.4 mm • EC) + 0.0318[(4.76 mm)^2] − 0.534(4.76 mm • pH) − 2.13 (4.76 mm • EC) − 3.48[(Clay)^2] + 6.43(Clay • EC)	0.62	0.36	12.26
Silicone + latex			
Y = −238 + 5.62(4.76 mm) + 36.5(Clay) + 129.(EC) − 0.149[(9.4 mm)^2] + 0.119(4.76 mm • 9.4 mm) + 1.40(9.4 mm • pH) − 1.13(9.4 mm • Clay) − 0.0517[(4.76 mm)^2] − 1.12(4.76 mm • pH) + 0.657(4.76 mm • Clay) − 18.4(Clay • EC)	0.84	0.69	10.92

† Predicted runoff percent based on soil properties.

‡ Units for each variable are the same as given in Table 1.

would be employed, the complete soil property information presented in Table 1 would not be available. To address this problem, five variables were selected that are readily available from soil survey reports, or are easily obtained. The selected variables were 9.4- and 4.76-mm size fractions, clay percentage, pH, and EC. The results of using these variables to develop regression equations are given in Tables 6 and 7. As expected, most of the R^2 values were lower than before because the variables used were not selected as an optimum set by the BMDP program. Even though some of the equations had lower R^2 values and higher stan-

Table 7. Selected variable threshold regression equations and coefficients of determination for the treatments.

Equation	R^2	Adjusted R^2	Standard error of estimate
Control			
Y† = −61.2 + 2.65(Clay‡) − 0.878(9.4 mm) + 17.7(pH) − 1.31(EC) −0.000790[(9.4 mm)^2] + 0.0863(9.4 mm • pH) + 0.0327(9.4 mm • Clay) − 0.536(Clay • pH) + 0.193(Clay • EC) − 1.03[(pH)^2]	0.90	0.78	0.29
Paraffin wax			
Y = 57.5 − 11.0(Clay) + 0.0654(4.76 mm) − 6.01(pH) + 0.00471(9.4 mm • Clay) − 0.0397(9.4 mm • EC) + 0.205[(Clay)^2] + 1.00(Clay • pH) + 0.146(pH • EC) + 0.121 [(EC)^2]	0.84	0.73	0.45
Paraffin wax + agent			
Y = 1.55 + 0.0701(9.4 mm) − 0.0448(4.76 mm) − 0.00111[(9.4 mm)^2] + 0.000464[(4.76 mm)^2] + 0.0129[(pH)^2]	0.45	0.30	0.51
Slack wax			
Y = −7.13 + 1.62(pH) + 0.00101(9.4 mm • 4.76 mm) − 0.0132(9.4 mm • pH) + 0.0293(9.4 mm • EC) − 0.0901(Clay • EC) − 0.144(pH • EC)	0.69	0.58	0.51
Silicone			
Y = 95.7 − 3.60(Clay) − 23.9(pH) + 14.9(EC) + 0.00918(9.4 mm • 4.76 mm) −0.0599(9.4 mm • pH) − 0.00365[(4.76 mm)^2] + 0.152(4.76 mm • EC) − 0.0241(4.76 mm • Clay) + 0.823(Clay • pH) − 0.656(Clay • EC) + 1.17[(pH)^2] − 3.79[(EC)^2]	0.97	0.93	0.18
Silicone + latex			
Y = 5.99 − 0.487(4.76 mm) + 0.00914[(9.4 mm)^2] − 0.00801(9.4 mm • 4.76 mm) − 0.0341(9.4 mm • pH) + 0.0177(9.4 mm • Clay) + 0.00186[(4.76 mm)^2] + 0.0674(4.76 mm • pH) − 0.0613[(pH)^2] + 0.0840[(EC)^2]	0.87	0.78	0.53

† Predicted threshold value based on soil properties.

‡ Units for each variable are the same as given in Table 1.

dard error of estimate values, they are useful as a guide in selecting a treatment for a specific soil if only limited soils data are available. Consideration should be given to the differences in the R^2 values of the predictive equations when using them to compare treatments for a specific soil.

SUMMARY AND CONCLUSIONS

All soil properties influenced the effectiveness of the water-harvesting treatments to some extent. Hence, definitive relationships between specific soil properties and the effectiveness of the water-harvesting treatments could not be established. Tables 4 and 6 illustrated the diversity of soil properties that were influencing the runoff percentages of the silicone plus latex treatment where completely different sets of soil properties produced similar R^2 values for the regression equations. More research is needed to determine the absolute importance of each soil property to the effectiveness of the treatments. The soil properties selected for the regression equations in Tables 4 and 5 were important ones related to the effectiveness of the individual treatments. The regression equations in Tables 4 to 7 can be used to predict the effectiveness of a treatment on a specific soil based on soil properties, and to aid in the selection of a treatment for a specific soil.

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