WAX WATER-HARVESTING TREATMENT IMPROVED WITH ANTISTRIPPING AGENT AND SOIL STABILIZER

by

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INTRODUCTION

Presently, with wax-treated water-harvesting catchments, the wax serves both as the water repellent and the soil stabilizer (Fink et al., 1973; and Cooley et al., 1978). This works adequately for most sandy loam soils because they already have considerable structural stability in the dry, compacted state. The wax preserves that structural stability primarily by keeping the soil dry.

However, other textural-type soils are more difficult to treat: sandy soils erode easily, whereas clay loam or finer textured soils are subject to shrink-swell and freeze-thaw cycling damage. These structural problems can be partially overcome by increasing the wax application rate from 1 to 2 kg/m^2 or more, (Frasier et al., 1980). However, this increase may not be the best solution: (1) these petroleum derivatives are becoming increasingly expensive; (2) waxes are not good soil stabilizers, bonding only weakly to soil surfaces; and (3) theoretically at least, only small amounts of wax are required to obtain adequate water repellency. A logical solution would seem to be to stabilize the soil by some other means, and use only enough wax to create the water-repellent surface.

Soils are stabilized to stop water and wind erosion and/or convert the soil to a load-bearing surface; they are conditioned to improve their physical agronomic properties, such as aggregate stability, tilth, water-holding capacity, and aeration. These two (stabilization and conditioning) are related since both imply manipulation of soil physical properties. Stabilization, however, usually requires greater alteration.

Many techniques and materials have been tested to alter soil-physical properties. Many involve some organic or inorganic additive mixed with or sprayed on the soil (Ingles, 1968; Lyles et al., 1969; and Sultan, 1974). For example, various carbohydrates have been used, but mainly as soil conditioners (Lynch et al., 1956; and Parfitt and Greenland, 1970). One of the most promising carbohydrate soil conditioners is cellulose that has been xanthated to make it water-soluble for application ease (Smith et al., 1958). Menefee and Hautala (1978) found that this cellulose xanthate also could be used for the more rigorous demands of soil stabilization.

Since waxes form only weak bonds with the soil surfaces, water can easily interpose itself at this interface and "strip" off the wax. This same phenomenon operates to destroy asphalt roads--especially in cold, wet climates. Many "antistripping" agents have been developed that, when added to asphalt, selectively and strongly bind to the rock aggregate, preventing this water intrusion at the interfaces (Majidzadeh and Brovald, 1968).

In this study, soil from a potential runoff-farming site was evaluated in the laboratory to determine if cellulose-xanthate soil-stabilizer and an anti-stripping agent would make wax-treated soil more resistant to the physically destructive forces of water erosion and freeze-thaw cycling. Furthermore, these treatments were also evaluated to determine whether wax-treatment cost could be reduced by using a surplus, residual-grade wax applied at a low application rate. The experiment was designed to determine optimal field application rates of these three materials for treating the water-catchment area of the runoff-farming site.

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METHODS

The runoff-farming site is located on Prescott National Forest land near Camp Verde, Arizona. The red-colored, well-graded, fine-sandy-textured soil apparently is depositional material that eroded from weathered sandstones and shales of the nearby Colorado plateau. Soil for the laboratory analyses was sieved (<2 mm) to remove trash and stones. Textural analyses of the <2-mm fraction showed the soil was 79, 13, and 8% sand, silt and clay, respectively.

Sample preparation procedures were similar to those already described (Fink, 1976). Ninety samples were prepared: 150 g of the soil was placed into each 9-cm-diameter petri dish, smoothed, uniformly wetted, packed, and air dried. The experimental design for treatments is shown in Table 1, and involved three levels of soil stabilization, with two waxes applied at three rates, each amended with five levels of antistripping agent.

The soil stabilizer was cellulose xanthate, prepared from used computer cards according to the method of Menefee and Hautala (1978). Xanthate was applied at three levels for stabilization: controls which received no xanthate, and samples sprayed with 1.5 ℓ/m^2 of water solutions of the xanthate, containing 0.2 and 0.5% by weight of cellulose. Samples were air dried for several days prior to treating with wax.

The two waxes tested were refined paraffin (128-131 AMP) and Chevron Unrefined (slack) Wax 140. The slack wax is a residual product of the refining process and contains a mixture of long-chain, branched paraffins, and other complex hydrocarbons. It congeals at 61 C and contains 18% oil. The antistripping agent was Trymeen 6639, a cationic, nitrogen-containing formulation developed primarily for the asphalt industry. Antistrip-wax mixtures of 0, 0.5, 1, 2 and 4% by weight of antistripping agent were prepared. These mixtures were brushed onto the soil samples as hot melts and further melted-in, using heat lamps. Application rates of the wax-antistrip mixtures were 0.25, 0.5 and 1.0 kg/m^2. The peripheral edges of the soil samples were sealed to the glass dishes with a ring of high melting paraffin to prevent water wicking.

The treated samples were subjected to the weathering-testing sequence shown in Figure 1. Samples were tested initially for water repellency and structural stability using the 4-hour-hydration test (Fink, 1976). In this test, a large (about 3-cm-diameter) water drop was placed atop the center of the treated sample surface. By definition, if the drop completely infiltrated the soil within 4 hours, or if the soil beneath the drop swelled and subsequently cracked upon drying, the sample was judged to have failed and was not tested further.

Samples that passed the initial 4-hour-hydration test were next evaluated for structural stability against water erosion using the dripolator test (Fink, 1976). For this test, 1000 5-mm-diameter water drops were dropped onto the center of the treated soil surface from a 2-m height in 5 minutes. Again, by definition, samples were judged to have failed if resultant pitting punctured the treated surface layer.

Samples surviving the initial tests were subjected to a cyclic weathering-testing sequence that included accelerated weathering in a freeze-thaw chamber, another 5-minute dripolator test, air drying, and another 4-hour-hydration test. A 3-cm diameter water drop was centrally placed on top of the soil of samples in the freeze-thaw chamber, and the chamber was cycled between $\pm$ 20 C at 7 to 9 cycles/day. After a day, the samples were taken out, given the dripolator test and the 4-hour-hydration test, and then placed back into the freeze-thaw chamber. This sequence of weathering and testing was repeated until the sample either failed one of the two tests (loss of structural stability or water repellency) or attained a total of 200 minutes under the dripolator (40 dripolator events and a total of 340 freeze-thaw cycles). Samples that cracked were noted, but were continued in the normal testing sequence.

RESULTS

All samples passed the initial 4-hour-hydration test, i.e., all had liquid water remaining on the soil surface after 4 hours, and none of the samples swelled and cracked upon drying. The area under the large drop remained relatively constant during the 4 hours for most samples; i.e., evaporation reduced only the height of the drop. However, some water spreading occurred on some samples treated with the combination of slack wax and the two highest rates of the antistripping agent. Presumably, if antistripping agent is present in excess of that needed to coat the soil, it reacts with compounds in the slack wax and becomes concentrated at the planar surface in an orientation exposing enough polar or other high surface energy groups to the water interface to permit spreading. No spreading was observed on any sample during the second 4-hour-hydration test. Two intervening 5-minute washes under the dripolator must have effectively removed these high energy molecules from sample surfaces.

All samples also passed the initial 5-minute dripolator test. Untreated soil samples will erode to the bottom of a petri dish in only a matter of a few seconds, indicating the severity of the test.

Samples were then subjected to 9 freeze-thaw cycles, and given another dripolator test. All three paraffin-only treatments and the 0.25-kg/m^2 slack wax treatment failed this test by eroding through the treated soil zone (top row of data of Table 1). The two higher slack wax treatments lasted only slightly longer (22 and 30 minutes). This quick failure was not surprising; previous laboratory studies had shown that most wax treatments were rather vulnerable to the destructive forces of freeze-thaw cycling, provided that water was present on top of the soil (Fink and Mitchell, 1975). Generally, more than 1.0 kg/m^2 wax was necessary under freeze-thaw weathering conditions for the wax to serve both as a water repellent and as a soil stabilizer. Undoubtedly, at such large application rates, the wax acts more as a water barrier than as a water repellent.

Complete results of the time the samples survived under the dripolator are listed in Table 1. I did not distinguish whether the samples finally failed by the dripolator or by the 4-hour-hydration test, because in either case the gradual erosion of the treated zone was responsible for failure.

The top three rows of data in Table 1 show the combined effects of the cellulose xanthate soil stabilizer and the two waxes--without benefit of antistripping agent. Increasing the application rate of xanthate increased weatherability in all but one instance. Increasing the wax application rate also generally improved weatherability.

What constitutes an adequate treatment based on these results is somewhat arbitrary. Data from several weather stations near the runoff-farming site indicated that the area of the site naturally undergoes between 50 to 100 freeze-thaw cycles each year. Of course, only a small fraction of these cycles are associated with the wet conditions necessary for treatment degradation. Based on this information, I selected 100 minutes under the dripolator as being the minimal necessary survival time to constitute an adequate treatment for this soil. This represented 180 freeze-thaw cycles.

Based on this survival time criterion, the 1 kg/m^2 of paraffin and the 0.5% xanthate in combination, survived 90 minutes under the dripolator and was almost adequate; and the 0.5 kg/m^2 slack wax-0.5% xanthate combination treatment survived 100 minutes. However, the 1 kg/m^2 slack wax-0.5% xanthate combination treatment survived only 65 minutes. This inconsistency suggested that something more was needed.

The antistripping agent appears to meet that need. A preliminary study (Fink, 1978) had shown that adding 5% antistripping agent to wax could markedly improve wax-treated soil's resistance to freeze-thaw cycling. Table 1 shows that most samples treated with the antistripping agent survived the 100-minute minimum survival time under the dripolator, and most samples even survived the 200-minute maximum testing limit. One hundred minutes under the dripolator represents 20 5-minute erosion cycles and 180 freeze-thaw cycles. Two hundred minutes represent 40 5-minute erosion cycles, and 340 freeze-thaw cycles.

However, if this soil was not stabilized with xanthate, one could only be assured of adequate weatherability (100 minutes under the dripolator) by applying a high rate of wax (1 kg/m^2) plus antistripping agent. With the paraffin treatment, 2% antistripping agent was required (180 min); with the slack-wax treatment, 0.5% antistripping agent was adequate (200 minutes). None of the 0.25- and 0.5-kg/m^2 unstabilized paraffin-antistrip treatments survived the 100-minute survival time; nor did any of the unstabilized, 0.25 kg/m^2 slack wax antistrip treatments. Two of the unstabilized, 0.5-kg/m^2 slack wax-1 or 2% antistrip treatments survived 200 minutes, but the unstabilized, 0.5 kg/m^2 slack wax-4% antistrip treatment survived only 40 minutes. Thus, for both wax treatments, the 1 kg/m^2 rate-antistrip treatment seems necessary to treat this soil if it has not previously been stabilized with xanthate. There is no ready explanation as to why the unstabilized, paraffin treatment required four times as much antistrip as the unstabilized slack wax treatment (2 vs 0.5%, respectively).

Only by combining all three treatments: xanthate, wax, and antistrip, could high freeze-thaw weatherability be achieved with really low chemical application rates. Table 1 shows that adequate freeze-thaw weatherability was attained for this soil with only 0.25 kg/m^2 of wax provided that the soil had been first stabilized with the cellulose xanthate and provided an adequate amount of antistrip was present.

Results using the low rate (0.25 kg/m^2) were slightly different for the two waxes. For the paraffin, adequate weatherability was attained with the high xanthate concentration (0.5%) and 2% antistrip in the paraffin. For the slack wax, adequate weatherability was attained with either the 0.2 or 0.5% xanthate solution and only 0.5% antistrip in the wax. The 0.5% xanthate concentration provided slightly better weatherability than the 0.2% concentration, so the higher xanthate rate is preferred for either wax. Again, the slack wax required only one-fourth as much antistrip as did the paraffin (0.5 vs 2%).

Since the antistripping agent is the most costly of the three soil additives, it is prudent to use as little as possible. If the antistrip serves no other useful function than to prevent infusion of water between the soil-wax interface, then only enough antistrip is needed to coat this interfacial surface. In Figure 2, the resistance to weathering is plotted vs the accumulated amount of antistripping agent added to unit planar area of the sample for the paraffin wax treatments. Weatherability is clearly maximized at about 5 g/m^2 antistrip, and practically nothing is gained by adding more antistrip. The slack wax treatment required only 1.25 g/m^2 of antistrip for maximum benefit. Possibly the slack wax naturally contains molecules that bond tightly to the soil and compete successfully for adsorption sites with the antistripping agent.

Cracking of wax-treated catchments could constitute a serious problem because of enhanced potential for water infiltration and channeling. Table 2 summarizes the data shown in Table 1. None of the 45 slack wax-treated samples cracked, whereas 20 of the 45 paraffin samples did. Incongruously, stabilization intensified cracking. Cracking was greatest for the treatment combination of stabilizer (either rate) and lowest rate of paraffin, but was unrelated to the amount of antistripping agent present. These results, combined with economic considerations, essentially rule out paraffin as a potential treatment for this runoff-farming site.

The recommended treatment for this site, then, will be to compact the soil when wet, stabilize it when dry with a 0.5% concentration of cellulose xanthate applied at 1.5 ℓ/m^2, and then make it water repellent with 0.25 kg/m^2 slack wax, containing 0.5% of the 6639 antistripping agent.

Chemical costs (1979) for this treatment would be less than 10 cents/m^2 ($1000/ha or $400/A). If runoff (treated) and runon (untreated) areas are equally divided, treatment costs for the combined areas would be half those listed above ($500/ha or $200/A). Corresponding water costs attributable to the chemicals would be $160/thousand cubic meters ($200/acre-foot) in this 300-mm (12-inch) rainfall zone (assuming 100% runoff from treated areas), if principal costs are amortized the first year. Actually, there would be 600 mm (2 ft) of water available to the crop; half from direct precipitation and half from runoff. By amortizing costs over 10 years (estimated treatment life expectancy), this water cost due to chemicals is reduced to only $16/thousand cubic meters ($20/acre-foot). These costs must be correspondingly altered as the ratio of runoff to runon area is adjusted to meet the crop's water requirement. Accordingly, selecting crops with low water requirements, and sites with high precipitation would reduce the water-harvesting treatment costs.

These low water costs make this runoff-farming treatment attractive for a number of applications, including growing certain high value crops, landscaping, and vegetation establishment of disturbed lands.

CONCLUSIONS

1. Laboratory studies showed that an antistripping agent-wax additive markedly improved the structural stability of a wax-treated soil against the destructive weathering forces of freeze-thaw cycling.
2. Treating soil with cellulose-xanthate (a soil stabilizer made from waste paper) before coating with wax also improved performance.
3. Combining the three treatments, i.e., stabilizing the soil with cellulose xanthate (0.5% solution applied at 1.5 ℓ/m^2) and adding 0.5% antistripping agent to the wax provided adequate structural stability and water repellency, using only 0.25 kg/m^2 of an inexpensive residual-grade slack wax.
4. Cost of chemicals for this treatment (1979 prices) on this soil was less than 10 cents/m^2, making the treatment attractive for certain high value runoff-farming crops.
5. Water costs (based on initial cost of the chemicals only) were estimated at $16/thousand cubic meters ($20/acre-foot), based on a crop requiring only 2 acre-feet of water per year, grown in a 300-mm (12-inch) rainfall zone, and assuming a 10-year treatment life.

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Table 1. Structural stability (minutes under dripolator) of a variously amended wax-treated soil as affected by freeze-thaw cycling.

		Structural stability					
		Paraffin (kg/m^2)			Slack wax (kg/m^2)		
Antistrip	Xanthate	0.25	0.5	1.0	0.25	0.5	1.0
%	%	min					
0	0	10	10	10	8	22	30
	0.2	23 1/	22 1/	35	30	30	100
	0.5	30 1/	30	90	80	100	65
0.5	0	17	21	70	45	35	200 3/
	0.2	23 1/	60	160 1/	95	135	200
	0.5	80	30 1/	200	200	200	200
1.0	0	23	23	65	35	200	200
	0.2	55 1/	135	200 1/	90	200	200
	0.5	35 1/	22 1,2/	200	200	200	200
2.0	0	40	65	180	40	200	200
	0.2	75	188 1/	200 1/	178	200	200
	0.5	100 1/	200 1/	200 1/	95	200	200
4.0	0	40 1/	50 1/	200	90	40	200
	0.2	75 1/	200 1/	200	200	200	200
	0.5	200 1/	200	200	200	200	200

1/ Surface cracks developed during weathering.
2/ Sample inadvertently destroyed.
3/ Testing was terminated after 200 minutes under the dripolator.

Table 2. Number of samples which cracked during testing.

Xanthate	Slack wax (all 3 rates)	Paraffin (kg/m^2) 0.25	0.5	1.0	Total
%		no.			
0	0	1	1	0	2
0.2	0	4	3	3	10
0.5	0	4	3	1	8
Total	0	9	7	4	20

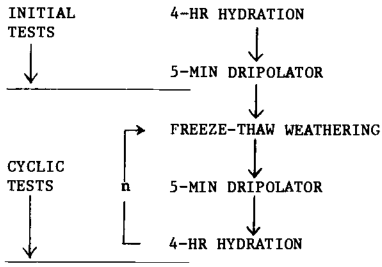

Figure 1. Laboratory testing-weathering sequence for evaluating water-repellent soil treatments.

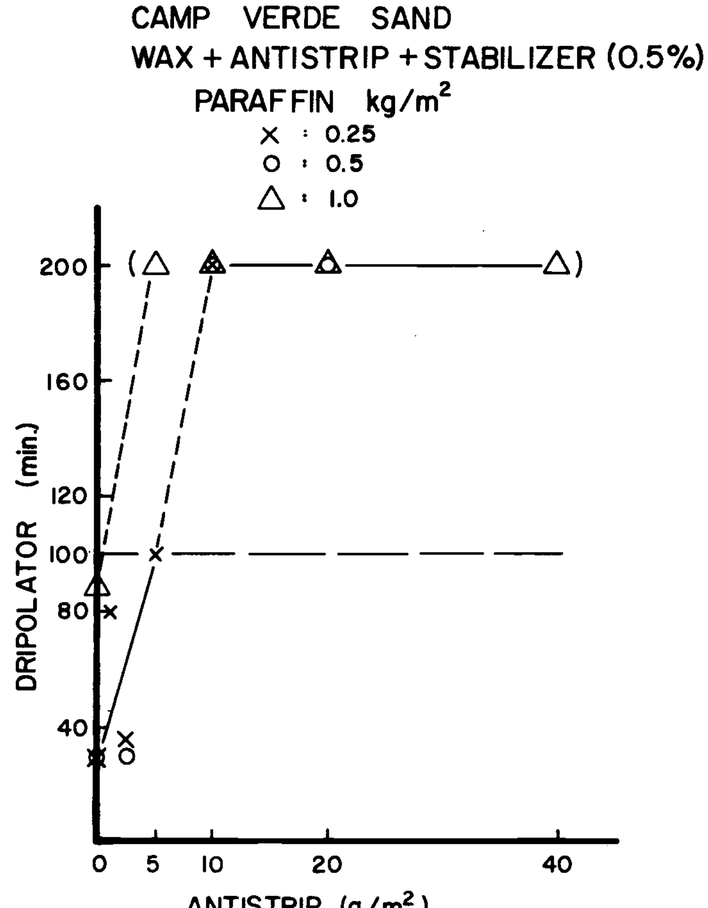

Figure 2. Structural stability (minutes under dripolator) of stabilized, paraffin-treated soil as a function of amount of antistripping agent applied per unit planar soil area.