

THE EFFECT OF CHEMICALS ON EVAPORATION OF WATER FROM SOIL

by

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INTRODUCTION

In Kansas as in other Great Plains States and dryland areas, shortage of moisture is the most common limiting factor in crop production. Research studies by Barnes (1938) and Mathews and Army (1960) have shown that as much as 75 to 85 percent of the precipitation that falls on the land in the Great Plains and Canadian Prairies is not stored for plant use, but is lost from the soil as runoff, as deep percolation, or as evaporation.

Runoff losses do not constitute a major source of moisture loss from dryland soils. Runoff from the entire state of Kansas has been estimated at 6.2 percent of annual precipitation (Water in Kansas, 1955). Losses from individual fields may be larger than this figure depending upon conditions such as slope, structure, texture, vegetation cover, and the amount and intensity of rainfall.

Deep percolation losses are not an important source of moisture loss in dryland areas. Except on very sandy soils, deep percolation losses rarely occur, even under summer fallow (Cole and Mathews, 1939).

Estimates of the magnitude of the losses brought about by evaporation (Water in Kansas, 1955; Peters, 1960) range from 50 percent to as much as 75 percent of the annual rainfall. Thus evaporation must be the major avenue of moisture loss from dryland soils. Reduction of evaporation could significantly increase moisture supplies for plant use. If a means of reducing the magnitude of these losses could be found, successful crop production would be possible in the drier regions and total agricultural production could be increased. A number of chemicals have been found to influence soil physical condition. Some of these also affect evaporation losses.

The objective of the present study was to determine the effect of low rates of chemicals applied to soil columns on evaporation losses under laboratory conditions.

REVIEW OF LITERATURE .

The discovery that soil microorganisms synthesized polysaccharides and other compounds which enhanced soil granulation stimulated the search for synthetic compounds which would act in the same way as natural products, but which would persist for longer periods of time in the soil.

Krath and Page (1946) reported that humus, fats, waxes, and resins, resulting from decomposition of fresh organic matter, were effective in aggregating cultivated soils. Quastel and Webley (1947) investigated the effect of sodium alginate upon the physical properties of the soil. Improvements in water holding power and crumb stability were obtained. The incorporation into soil of cellulose acetate, methylcellulose, or of carboxymethyl cellulose also improved the soil's water-air relationship. Further study showed that large amounts (5-10 tons per acre) were required and that these quantities were readily decomposed (Quastel, 1952, 1953). Van Bavel (1950) applied volatile silicones (methyltrichlorosilane and dimethyldichlorosilane) to soils. These materials increased water stability of different soils depending on the rate of treatment and original condition of the soil.

Treatments that will increase the depth to which water penetrates in the soil will help to reduce losses from evaporation, since evaporation losses are greatest from the immediate surface layer. Deeper horizons or layers of soil lose less water due to evaporation. Many investigations of soil conditioners (organic polymers) have been carried out. Martin et al. (1952), working with soil conditioners such as C-1, C-11, C-111, CRD - 186

and CRD - 189, all synthetic polyelectrolytes,¹ found that these materials, without exception, increased soil aggregation, porosity, and permeability. The aggregates, which were produced, proved to be water stable and the conditioning chemicals were highly resistant to decomposition. Structural improvement persisted through the second growing season. The materials were not toxic to crops and in many instances yields were increased appreciably. Qualitative evaluation of polyelectrolytes was carried out by Michaels and Lambe (1953) with soil conditioners such as sodium polyacrylate, the calcium salt of a copolymer of maleic acid and polyvinyl acetate, a copolymer of styrene and N-methyl-2-vinyl pyridine methosulfate. These conditioners were evaluated for their ability to flocculate soils, to produce aggregates resistant to freezing and thawing, and drying and wetting, and to increase water holding capacity and permeability. Polyelectrolytes showed differences in behavior for the different tests in different soils, however, the ability of polyelectrolytes to increase water permeability was very marked. Undoubtedly the concentration required to cause maximum improvement in soil structure depends to a large extent upon the adsorptive selectivity of the soil for the polymer added, and upon the specific surface area of the soil. Some other Krilium related conditioners such as vinyl acetate-maleic acid (VAMA), hydrolyzed polyacrylonitrile² (HPAN), and isobutylene of maleic acid copolymer (IBMA) were extensively studied (Martin 1953). VAMA was found substantially more effective in improving physical conditions of the soil

¹Produced by Monsanto Chemical Company under the trade name of "Krilium".

²Supplied also as sodium polyacrylate.

than HPAN. Rates of 0.1 and 0.2 percent of VAMA were reported to increase yield of potatoes, sweet corn, and other crops in some soils, whereas in other soils yield increases did not occur, even when improvement of aggregation was brought about (Allison 1952). Baldrige, et al. reported that IBMA was a more effective aggregating agent than VAMA under laboratory and field conditions.³ Studies carried out by Taylor and Baldrige (1954) with carboxymethylcellulose (CMC) at 0.5 percent rate increased permeability, aggregation, and plasticity of the soil. However, CMC was found to be less effective than either IBMA or BAMA.³ Resistance of synthetic polymers to microbial decomposition was reported by Hendrick and Mowry (1952) and Martin (1953). HPAN applied to the soil was found to be effective in reducing runoff and in stabilizing erosive, sloping soils against the erosive action of rainfall during the establishment of vegetation, Weeks and Colter (1952).

Jones, et al.⁴ studied the compatibility of fertilizers and soil conditioners. They noted that the aggregate stabilizing ability of HPAN was influenced more by fertilizers than was that of either VAMA or IBMA. In general, phosphates increased aggregation levels with HPAN, whereas KCl and NH_4NO_3 decreased aggregation. They also observed that application of IBMA and HPAN at 0.4 percent decreased yield significantly. The application of

³Baldrige, P. E., M. B. Jones, and J. D. DeMent. 1954. Influence of soil aggregating chemicals on some physical properties of selected Ohio soils. Paper presented at the Northcentral soil conditioner conference. The Palmer House, Chicago, Ill.

⁴Jones, M. B., J. L. Mortensen, and W. C. Barret. 1954. Fertilizer - soil conditioner compatibility tests and response of crops to fertilizer applications in conditioned soils. Paper presented at the Northcentral soil conditioner conference. The Palmer House, Chicago, Ill.

nitrogen and potassium with soil conditioners also decreased the yield. It was also indicated that VAMA was more effective in structural improvement than was HPAN. Grossi and Woolsey (1955) observed the effect of moisture on the aggregating power of 0.1 percent of VAMA and dimethyldioctadecylammonium chloride (DDAC) on a Putnam silt loam. The DDAC treatment produced a large percentage of water stable aggregates, determined by the set sieve analysis. The aggregates proved to be very resistant even after five freezing and thawing cycles. Resistance was affected by high content of inorganic salts. The water stability of the aggregates was attributed to the hydrophobic groups of the colloid cation or to its virtual irreplaceability by a more hydrophilic cation. The presence of ammonium chloride prevented flocculation of the soil treated with DDAC.

Polyelectrolytes are adsorbed on soil from an aqueous solution, so water must be present in sufficient quantity at or near the soil particle surface to provide the medium for adsorption to occur. DDAC, by rendering the soil particle surfaces hydrophobic, displaces a good part of the water necessary for this purpose. The water soluble polyelectrolytes, being hydrophilic, allow a greater opportunity for aggregate breakdown in highly hydrated polyelectrolyte treated soil, than in the necessarily "drier" DDAC treated-soil.

In general it can be said that synthetic polyelectrolytes behave similarly and are effective in changing the structural properties of soils. The water stability of soil aggregates is greatly increased. As a consequence of greater aggregation, changes in porosity, water permeability, apparent density, the lower plastic limit, and workability ensue.

One of the problems with these soil conditioners was that if they became wet prior to incorporation into the soil, a gelatinous mass was formed, making the mixing operation by disc very difficult. Since the conditioners, to be effective, have to be mixed with soils, usually high rates of application have been recommended for positive results, however, rates depend upon the condition of the soil. Sherwood and Engibous (1953) commented that soil conditioners are technically efficient but that they have been used only to a limited extent in agriculture due to their high cost.

Surfactants have been classified by Law and Kunze (1966) into two main classes: ionic and nonionic. The ionic class is further subdivided into anionic and cationic groups. When the linear hydrophobic portion of the molecule forms the anion in aqueous solution, it is said to be anion-active or anionic. If the molecule ionizes so that the linear, hydrophobic portion forms the cation, it is cationic. The nonionic class is characterized by nonionized, hydrophilic end-groups that are usually polar active in nature. Ruehrwein and Ward (1952), working with sodium polymethacrylate (polyanion), poly N-dimethylaminoethylacrylate hydroacetate (polycation), and polyvinylbutylpyridonium bromide (Polycation) observed that polycations, but not polyanions, were adsorbed in the interplanar spacing of the expanding clay lattice. They pointed out that polycations were effective flocculating agents and floc-stabilizing agents for clay. Smith and Bayer (1967) claimed that polyanions were not flocculating agents but effective stabilizing agents for flocculated clay. Studies of adsorption mechanisms conducted by Law and Kunze (1966) showed that anionic surfactants were not adsorbed in appreciable quantity by

kaolinite or by montmorillonite and did not interfere with hydration of clay surfaces. Cationic materials were reported to be strongly adsorbed in amounts equal to or greater than the cation exchange capacity of the clay. This effect was also observed by Ruehrwein and Ward (1952), who claimed that polycations were adsorbed on the clay layers probably by means of cation exchange. Even though it is possible for polyanions to be adsorbed on anion exchange sites, Ruehrwein and Ward (1952) did not observe this sort of bonding in their study, in spite of the fact that the clay they worked with did have anion exchange capacity. Law and Kunze (1966) showed that the presence of cations on clays significantly reduced hydration and water content enough that the clay surface was rendered completely hydrophobic. Nonionic materials were adsorbed by hydrogen bonding of polar active groups to oxygen rich clay-surfaces. Law (1964) reported that the nonionic surfactant, Agua-Gro,⁵ was an effective evaporation reducer when applied at rates of 0.1 percent active chemical. The action of the nonionic surfactant was attributed to a decrease in surface tension at the solid-liquid interface, whereby the capillary flow to the surface layer of the soil was reduced thus causing the formation of a dry diffusion barrier. Cationic and nonionic compounds have been reported by Law and Kunze (1966) to be held in the interlayer spaces of montmorillonite and tended to form double layers if sufficient material was present. More specific studies were carried out by Law et al. (1966) upon the reactions of surfactants with montmorillonitic soils. The effect of anionic surfactants were directly related to the

⁵A mixture of 50 percent polyoxyethylene ester and 50 percent polyoxyethylene ether produced by Aquatrols Corporation of America, Bryn Mawr, Pa.

lowering of surface tension of the liquid phase. The effect of cationic surfactants was related to the degree of hydrophobicity imparted, which increased with alkyl chain length and amount of material added to the soil. The effect of nonionic compounds on soil physical properties was small in proportion to the amount of chemical added. This effect was related to the reduced hydration of surface and to the hydrophilic centers associated with the nonionic compounds.

The mechanism by which polyelectrolytes may bind clay particles together into aggregates has been studied, and a number of possible explanations has been suggested. Packter (1957) claimed there was a clay-polyelectrolyte interaction, the formation of a complex by electrostatic bonding between the negative carboxyl groups of the polyanion and the positively charged edges of the clay plates. Kohl and Taylor (1961) suggested that the mechanism was hydrogen bonding between the carbonyl group of the organic compound and an exposed hydroxyl group on the edge of the clay crystal. Emerson (1963) proposed a link between the carboxyl of the polymer and the external basal surface of the clay. Emerson and Raupach (1964) claimed hydrogen bonding between polymer hydroxyl and clay oxygens as a possible mechanism. Greenland (1965) indicated that van der Waal's forces were responsible for the interaction between organic compounds and the clay surfaces. He also observed that organic compounds with molecular weights of 150 or less were not adsorbed at all or only very weakly while large molecules such as polyvinyl alcohol was very strongly adsorbed. Increase in soil aggregation for a wide range of soils was also accomplished by application of dextrans with high molecular weights (over 1,000,000) and concentrations no larger than 0.6 percent (Novak, et al. 1955).

Clapp, et al. (1962) associated viscosity and carboxyl content with aggregate stability. Geoghegan and Brian (1948) observed that the aggregating effect of the levan decreased with increasing sucrose content and was directly related to the intrinsic viscosities and hence to molecular weight.

Another way by which evaporation has been reduced is by coating the water with a film of material, thus making it more difficult to transform liquid water into vapor.

The application of long-chain alcohols, cetyl alcohol or hexadecanol (HD), stearyl alcohol or octadecanol (OD), has been used effectively to reduce evaporation of water from free water surfaces such as those in reservoirs and lakes. The reduction in evaporation from Petri dishes in laboratory by Deo, et al. (1960) showed that the evaporation decreased with an increase in chain length of alcohols, at temperatures ranging from 20 to 40°C. The efficacy of the C-14 to C-18 alcohols increased steadily with a decrease in temperature.

Appreciable decreases in evaporation were obtained after purification of octadecanol by filtering the solution through a 100 mu millipore filter. LaMer and Aylmore (1962) pointed out that mixtures of (OD) and (HD), purified by molecular distillation, were resistant to evaporation losses as compared to the mixtures of the commercial materials. McArthur and Durham (1957) demonstrated that a commercially available blend of fatty alcohol containing about 45 percent (HD) and 40 percent (OD) exhibited greater evaporation resistance than the film from relatively pure 90 percent (HD) at a water temperature of 20°C.

Attempts to reduce evaporation of water from soil have been made with a long chain alcohol. Abdalla and Flocker (1963) reported that applications of 600 lbs/acre of (HD) to the soil reduced evaporation from bare soil and greatly reduced percolation, but rates of 100 lbs/acre had no effect.

Studies conducted by Roberts (1961) showed that hybrid corn, grown in soils enriched by various amounts of fatty alcohols, such as (HD), required up to 40 percent less water during its growth than control plants. Later work carried out by Olson, et al. (1962), who also grew corn, showed that the amount of water used per unit of dry matter produced did not decrease following the addition of either (HD) or (OD) to the soil. Both alcohols reduced the yield of corn significantly when they were mixed with the soil at rates of 25 g. per 3 kg. of soil. In a band placement only the octadecanol caused a reduction in yield compared with that in the untreated soil. Similar results were obtained by Wooley (1962). In his study evaporation was suppressed but only by causing the plant to grow less. The amount of water used per square centimeter of leaf was unchanged. He also noted that evaporation was reduced more for coarse sand than for fine sand and was not usually reduced at all for clay or loam soil. Aubertin and Gorsline (1964) reported an increase in water required to produce one gram of dry plant material by applications of hexadecanol to the soil. Law (1964) effectively reduced evaporation from sand which was treated with a mixture of (HD) and (OD) at a rate of 400 lbs/acre, although higher rates of these materials applied to the soil didn't reduce evaporation. The mechanism of action attributed to the fatty alcohols was that of reducing capillary flow of moisture to the soil surface. This effect had been proposed previously by Lemon (1956).

The water that is lost by evaporation from a soil must reach the soil-air interface either as a liquid or as a vapor. The volume of water that can be moved as a vapor through a unit volume of soil is much less per unit time than can be moved as a liquid. Thus a method of reducing evaporation has been the use of chemicals that influence the movement of water through the soil. Grossi and Woolsey (1955) noted the decrease in water movement through Putnam silt loam caused by the fatty quaternary ammonium salts. Bowers and Hanks (1961) using Arquod or DDAC⁶ effectively reduced evaporation and infiltration on a sandy loam and on a silty clay loam soil.

Wetting agents can increase water infiltration or retard it, depending on soil conditions and contact angle formed when liquid comes into contact with the soil. Increase in infiltration resulting from applications of wetting agents has been reported on different soils by Pelishek et al. (1962), Krammes and DeBano (1967), and Letey et al. (1961, 1962). Studies of the leachability showed that the wetting agent treatments persisted after 40 cm of water had passed through the soil. Osborn, et al. (1964) reported a significant reduction in erosion as a result of the use of a wetting agent (CS-555).⁷ The mechanism of the action of wetting agents on infiltration in a nonwetable soil has been explained by a decrease in the surface tension, and the creation of a more favorable (decreased) contact angle. The decrease in surface tension brings about a decrease in capillary

⁶Supplied by Armour Chemical Division, Chicago, Illinois, The Mathieson Co., Inc., Joliet, Illinois, and Atlas Power Co., Wilmington, Del.

⁷Active ingredient is alkyl-polyoxyethylene ethanol produced by Emery Industries, Inc., Santa Fe Springs, California.

force. The decrease in the contact angle increases the capillary force. So the final effect of the wetting agent will depend upon which action predominates, the beneficial or the detrimental. Reduction in infiltration can be explained simply by a reduction in surface tension, which was not overcome by a sufficient decrease in contact angle. On a hydrophilic surface the wetting agent will be of little benefit, since the contact angle already is sufficiently small. Thus, the effect of wetting agents will depend on the wettability of the soil, which is different for different soils. This effect is easily appreciated on an hydrophobic soil, in which the effect of increasing infiltration is attributed to a decrease in the liquid-solid contact angle, since other factors influencing infiltration (density, viscosity, aggregate stability, and pore radius) are not modified by the recommended application rates of wetting agents. The property of reduced infiltration has seriously restricted the practical use of these materials in evaporation control.

The use of surface cover has also been suggested for evaporation reduction. Willis (1962) reported a reduction in evaporation from wetted soil by using plastic materials. The efficiency of the film treatment was improved by increasing the size of the individual cover and by increasing the proportion of the area covered by the plastic film. The film appeared to be more effective when the soil was wet. As the soil dried out the effect of selfmulching increased. Benoit and Kirkham (1963) investigated the comparative effectiveness of dust, ground corncobs, and gravel mulch. Gravel showed greatest effectiveness in inhibiting evaporation; the dust mulch proved to be least effective. The mechanism by which mulches reduce evaporation is the disruption of the moisture flux. Essentially any

practice which disrupts the continuity of liquid columns to the soil surface will force moisture to move more slowly as a vapor form through a diffusional barrier. Thus, evaporation is decreased by decreasing capillary continuity in the surface soil layer. Mulches also may decrease the net energy available for evaporation. Zacharov, et al. (1968) studied the thermal efficiency of different mulch covers. It was shown that mulches of oil products and bituminous paints cause a positive thermal effect. Peat and straw cause a negative thermal effect during the daytime. Black polymer film can result in negative or positive thermal effects, depending on the thickness of the air layer between the film and the soil surface. Philip (1957) came to the conclusion that if the process of evaporation develops a dry layer at the surface of the soil, heat flow from the lower layers to the surface intensifies evaporation and heat flow from the surface to lower layers diminishes the evaporation. Rose (1968) pointed out that under field conditions the evaporation pattern would change as the thermal fluxes interact with the moisture flux, this same effect was previously noted by Wiegand and Taylor (1960).

MATERIAL AND METHODS

Top soil of a Geary silty clay loam was taken from the Agronomy farm of Kansas State University. The sample was spread out to air-dry for several days. It was then ground to pass through a 2.38 mm sieve and was mixed thoroughly to insure random distribution of particles and aggregates. Sixteen plastic cylinders, 42 cm in length and 9 cm in inside diameter, were used in the experiment. Eight of these cylinders were distributed on each of two turntables, which were rotated at 2 rpm. Air dry soil was packed

into each column at a density of 1.3 g/cm^3 , the soil columns were wetted from below until free water appeared at the top of the soil. The columns were then allowed to drain for a period of 48 hours. A special protective cover was placed on each turntable. These covers were designed to allow only the top, open ends of the soil cylinders to be exposed to the rays, provided by two cool beam PAR wide angle flood lamps (300 PAR 56/2WFL) which were hung 27 cm above the top surface of the soil in the cylinders. The lamps provided an illumination of 4,500 foot candles as measured by a Weston Illumination Meter, model 756 quartz filter. Temperature recorded at the soil surface was 35.6°C .

After the various soil surfaces were treated with different materials the lamps were turned on and the turntables started in motion. The turntables were run for twenty-day periods during which temperatures 1 cm below the soil surface and evaporated moisture from each cylinder was determined after 0, 24, 48, 72, 144, 240, and 480 hours. Temperatures were determined by means of a thermocouple recorder. Moisture lost by evaporation was determined by weighing each column. At the conclusion of each 480-hour evaporation cycle, the soil moisture content for each treatment was determined gravimetrically for all the columns by two centimeter-depth increments.

Experimental treatments (Table 1) included the application of fatty alcohols, waxes, and plastic materials, sprayed on the soil surface, the application of coated aggregates to the soil surface, as well as applications of straw and gravel.

Where these materials were surface applied they were melted and sprayed on the soil surface after the 48-hour draining period. The

Table 1. Commercial materials used in an attempt to reduce evaporation of water from soil.

Material	Supplier
150/200 penetration asphalt	CRA, Inc. P. O. Box 7305/Kansas City, Mo.
70 solvent intermediate produce wax	CRA, Inc. P. O. Box 7305/Kansas City, Mo.
70 solvent intermediate soft wax	CRA, Inc. P. O. Box 7305/Kansas City, Mo.
120 bright stock product wax	CRA, Inc. P. O. Box 7305/Kansas City, Mo.
120 bright stock soft wax	CRA, Inc. P. O. Box 7305/Kansas City, Mo.
200 M. C. neutral product wax	CRA, Inc. P. O. Box 7305/Kansas City, Mo.
Hexadecanol	K&K Lab. Inc. Plainview, N. Y. Hollywood, California.
Vinyl chloride	Union Carbide Plastics. P. O. Box 471, Texas City, Texas.

aggregate treatment was accomplished by making aggregates of the materials or by coating soil aggregates with the materials. These 4.8 to 7.5 mm aggregates were allowed to dry before placement on the soil surface. Five "runs" were conducted, each including 3 or 4 different treatments in addition to a straw mulch, which was used as a reference standard.

RESULTS AND DISCUSSION

Individual moisture content at the beginning of each run and after 24, 48, 72, 144, 240, and 480 hours on each replication of each treatment was recorded (Tables 8 to 12 in the Appendix). Average soil moisture content of the various treatments after each evaporation period, and the total moisture loss during the entire run were calculated from these data (Table 2).

The various runs were conducted consecutively and therefore there was a chance that evaporation conditions were not the same in each run. It is

Table 2. Averages of the soil moisture content after each evaporation period and the total water lost for all the treatments in the five runs in g per Kg of soil.

Treatment	g of water left after each period							Total water lost
	0	24	48	72	144	240	480	
<u>First run</u>								
Bare	306	281	254	231	191	169	142	164
Gravel	308	301	295	290	271	245	183	125
Hexadecanol	315	295	274	253	205	182	152	163
Straw	315	302	297	293	280	256	203	112
<u>Second run</u>								
70 solvent soft wax	307	284	260	236	189	170	144	163
70 solvent prod. wax	306	285	262	240	193	173	149	157
150/200 penet. asphalt	308	289	268	244	194	173	150	158
Straw	297	293	286	278	257	229	170	127
<u>Third run</u>								
150/200 penet. asphalt*	323	311	297	285	246	202	167	156
120 bright-stock prod. wax	324	305	285	279	205	184	158	166
120 bright-stock soft wax	316	295	271	247	200	179	154	162
200 MC. neutral wax	325	305	283	259	209	184	163	162
Straw	310	305	299	292	275	251	196	114
<u>Fourth run⁺</u>								
Hexadecanol	303	276	249	227	199	182	157	146
White cement	308	285	260	232	192	175	148	160
Vinyl chloride	306	283	261	236	199	180	155	151
Straw	305	299	293	286	272	256	213	92
<u>Fifth run</u>								
120 bright stock soft wax*	315	300	286	273	224	186	158	157
Vinyl chloride*	318	305	293	281	238	199	166	152
White cement*	318	296	282	269	228	191	160	158
Straw	315	307	302	295	272	247	195	120

* Aggregate treatment.

+ In the fourth run, after the 144-hour measurement, only one lamp was used over each turntable.

obvious from the data in Table 2 that evaporation losses from the straw mulched columns in each run were similar, but that in some way conditions were somewhat different in Run 2. The initial moisture content of the straw columns in this run, and the moisture losses during the run were lower than in the other runs. This difference was brought out clearly by statistical analysis (Tables 12 and 13 in Appendix). When data from straw columns in all five runs were analyzed, the "F" value for runs was 19.24 (significant at least at the 0.001 point). When Run 2 data were omitted the "F" value for runs was only 0.54, which is not significant, even at the 25% level. Based on these analyses that conditions during runs 1, 3, 4, and 5 must have been comparable, therefore the various treatments in these runs may be compared.

Straw mulched columns consistently contained more water after each evaporation period than other columns, and after 480 hours had lost the least water. One-centimeter thick straw applications (8,000 pounds per acre) apparently acted as a very efficient diffusional barrier, decreasing the rate of moisture transfer. The gravel mulch was also effective in reducing water losses, but less than the straw. Chemical treatments, in general, were less effective than either straw or gravel.

Average moisture contents in the treated columns are presented in Table 3. From these it is obvious that straw and gravel mulches were the most effective evaporation reducers. It is also obvious from these data that the chemicals used in this study were more effective when applied as aggregated material or when coated on soil aggregates than when applied as a surface film (Table 4).

Table 3. Average moisture content over time for variously treated columns of Geary silty clay loam.

Treatment	Average moisture content (g/Kg dry soil)*
Bare soil	225a
Hexadecanol ⁺	228ab
White cement	228ab
Vinyl chloride	231b
120 bright stock soft wax	237c
Hexadecanol	239c
120 bright stock product wax	246d
200 M. C. neutral wax	247d
120 bright stock soft wax [‡]	249d
White cement [‡]	249d
Vinyl chloride [‡]	257e
150/200 penetration asphalt [‡]	261e
Gravel	270f
Straw	276g

* Values followed by the same letter are not statistically different at the 0.05 point.

‡ Treatments in which the chemical was applied as aggregates on the soil surface, or in which soil aggregates were coated with the material and applied to the surface.

+ Dissolved in benzene prior to application.

One reason for the greater effectiveness of aggregates over surface applied chemicals no doubt is the fact that the water columns were broken by the mulch of aggregates before they contacted the open atmosphere. The aggregates may also have acted as insulation against the heat provided by the lamps. A third reason may have been the cracking of the soil surface in the surface applied, chemically-treated columns. As the surface-treated soil dried out a crack 3 mm in width and about 2 cm deep was formed near the cylinder wall. No doubt these cracks contributed to water losses from the

Table 4. Effect of surface application and of aggregate treatment on water lost from Geary silty clay loam.

Treatment	Water lost, g/Kg dry soil			
	72-hour period		480-hour period	
	Surface	Aggregate	Surface	Aggregate
Bare soil	75		164	
Straw mulch, (av. runs 1, 3, 4, 5)	19		109	
Gravel mulch		18		125
150/200 penetration asphalt	64	38	158	156
120 bright stock soft wax	69	42	162	157
Vinyl chloride	70	37	151	152
White cement	76	49	160	158
Average of chemical and cement	70	42	158	156
L. S. D. ($p = 0.05$) between individual means		12		12
L. S. D. ($p = 0.05$) between averages of surface and aggregate means		6		6

surface several centimeters of soil. Cracks did not develop in the columns to which aggregates had been applied.

The amount of moisture lost (Table 4) was a progressive process in all treatments. For example, the bare column lost constant amounts of water each of the first three days, and water loss continued to the end of the 20-day period.

From the data in Table 4 it is obvious that differences in evaporation losses between treatments are larger after 72 hours than after 480 hours. Actual losses of water by time periods (Table 5) show that the rate of water loss gradually decreased from about 25 g/Kg of dry soil per day initially to about 3 g/Kg of soil for the last 10-day period (10 to 20 days) in the bare

Table 5. Effect of treatment on water lost from soil columns during various periods of time.

Treatment	Water lost (g/Kg of dry soil) in each period in hours.					
	0- 24	24- 48	48- 72	72- 144	144- 240	240- 480
Bare soil	25	24	23	42	21	27
Straw mulch*	8	6	5	16	22	51
Gravel mulch	7	6	5	19	26	62
70 solvent soft wax	23	24	24	47	19	26
70 solvent product wax	21	23	22	47	20	24
150/200 asphalt	19	21	24	50	21	23
150/200 asphalt+	12	14	12	39	44	35
120 bright product wax	19	20	23	57	21	26
120 bright soft wax	21	24	24	47	21	25
120 bright soft wax+	15	14	13	49	38	28
200 M. C. neutral wax	20	22	24	50	25	21
Hexadecanol	20	21	21	48	23	30
Hexadecanol&	27	27	22	28	17	25
White cement‡	23	25	28	40	17	27
White cement+	22	14	13	41	37	31
Vinyl chloride‡	23	22	25	37	19	25
Vinyl chloride+	13	12	12	43	39	33

* Average of runs 1, 3, 4, and 5.

+ Aggregates coated.

‡ Treatments on which one lamp was used on the turntables from 144-hour to 480-hour period.

& Dissolved in benzene.

soil columns and in many of the surface-applied, chemically treated columns. In the straw-covered and the gravel-coated columns the initial rate of water loss was lower than that of the bare column, but this rate remained relatively constant at 6 g/Kg of soil per day to the end of the 20-day period.

Figure 1 shows the differences in evaporation-rate change with time in selected columns. Here again it is evident that initial water losses from

the mulched soil were reduced compared to losses from unmulched columns, but this initial rate of loss continued throughout the 480-hour period on the straw or gravel-mulched columns. In the bare or surface treated columns the initial rate of loss was greater, but as the surface soil dried out the rate of loss declined, and during the 240 to 480-hour period it was lower than in the same time period in the mulched columns. The differential effect of time on evaporation loss on the bare and mulched columns can be explained by the fact that rate of water loss from soils is a function of the water content of the surface soil. When the soil is reasonably wet, capillarity moves water to the surface fast enough to keep the soil surface moist. Thus water lost from the surface is replaced by liquid water flow. As evaporation continues, the surface soil dries out and liquid water no longer moves to the soil surface. Additional water that is lost from the surface then must move to the surface as a vapor. This is a much slower process than is liquid water movement. With time, vapor movement takes place through an ever-thickening layer of dry soil. This still further slows the process of evaporation. In the mulched columns, on the other hand, the mulch layer breaks the contact of liquid filled pores with the atmosphere. Thus from the beginning the rate of water movement from the soil to the atmosphere is reduced. This slower rate of loss, apparently, permits capillary forces to replace the water lost from the soil just below the mulch as fast as it is removed by evaporation. Accordingly, up to the end of the 480-hour period at least, moisture continued to be lost at a rate that is a function of the effectiveness of the mulch as a vapor barrier. The results of this study,

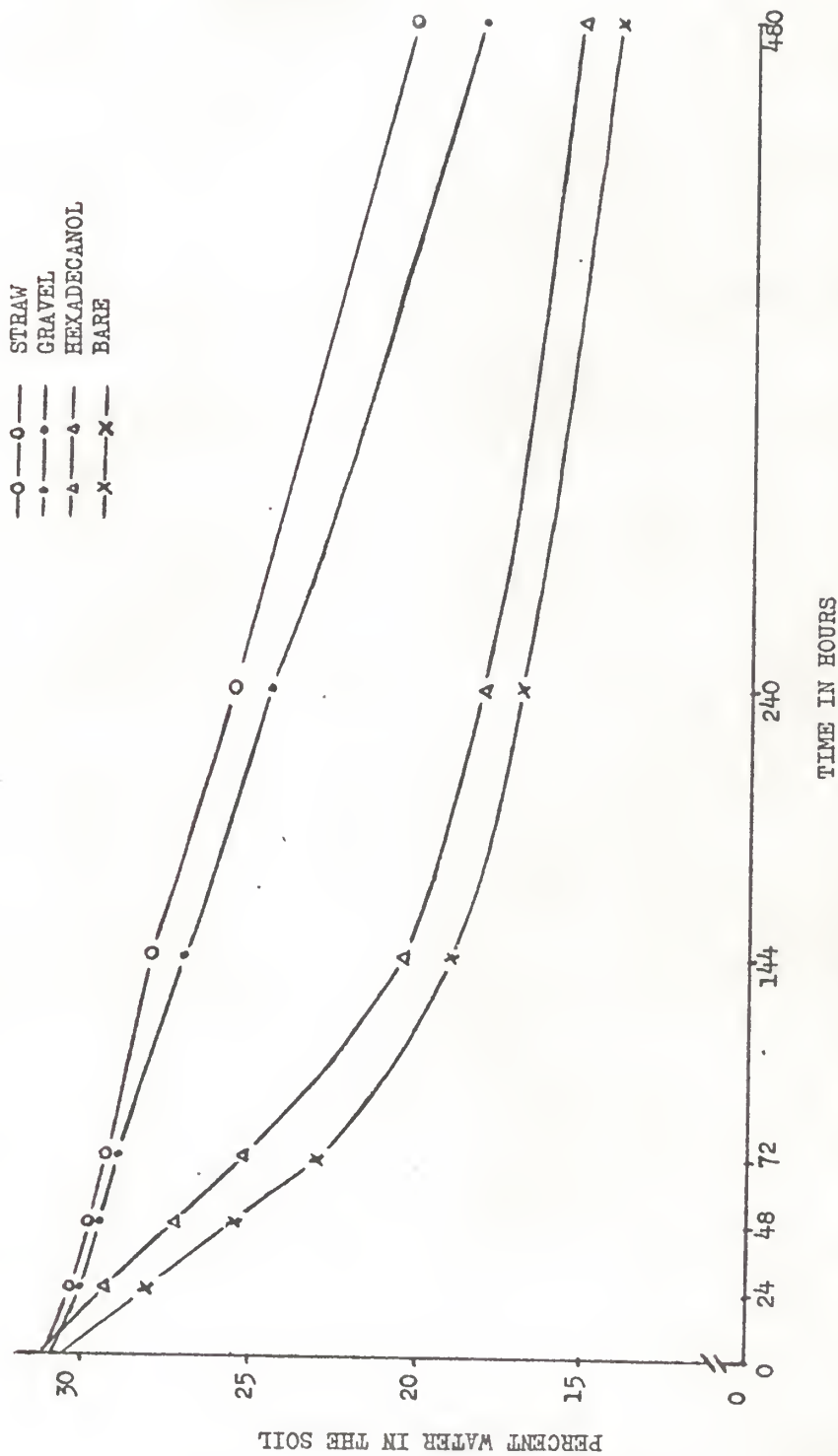


Fig. 1. Water depletion during the 480-hour drying cycle from selected treatments.

(Fig. 1), indicate that if evaporation continued long enough losses from the mulched columns might well have equalled those from the unmulched columns.

The average moisture distribution in the soil columns at the end of 480 hours (Tables 16 to 19 in the Appendix) was recorded for each treatment in the first four runs. While the rates of loss and the final moisture contents under the different treatments were different, there was a similar trend of moisture content in the various treatments (Fig. 2). In all cases the first 4 to 8 cm of soil contained sharply lower amounts of water and the largest variability in moisture content. Below the depth of 4 to 10 cm the amount of moisture increased sharply. Below this point of sharp moisture increase moisture content increased steadily to the bottom of the column. Thus the zone of greatest evaporation loss is close to the surface, but that losses from as deep as 18 cm can occur in a 480-hour period.

Temperatures were recorded at intervals during each run (Table 6). In all cases soil temperatures were lower under the straw mulch than in other treatments. Most of the treatments with coated aggregates had lower soil temperatures after 144 hours than did the surface treated columns. White cement and vinyl chloride coated aggregates lowered the temperatures, while 150/200 penetration asphalt and 120 bright stock soft wax increased the temperature. Black aggregates of asphalt were associated with highest temperature values. This indicates that surface color may have affected the temperature of these columns, with lighter colors reflecting more heat and darker colors absorbing more heat. Temperature under the gravel mulch was higher than under the straw mulch. This may be explained by the relatively high thermal conductivity of the solid gravel particles compared to that of straw.

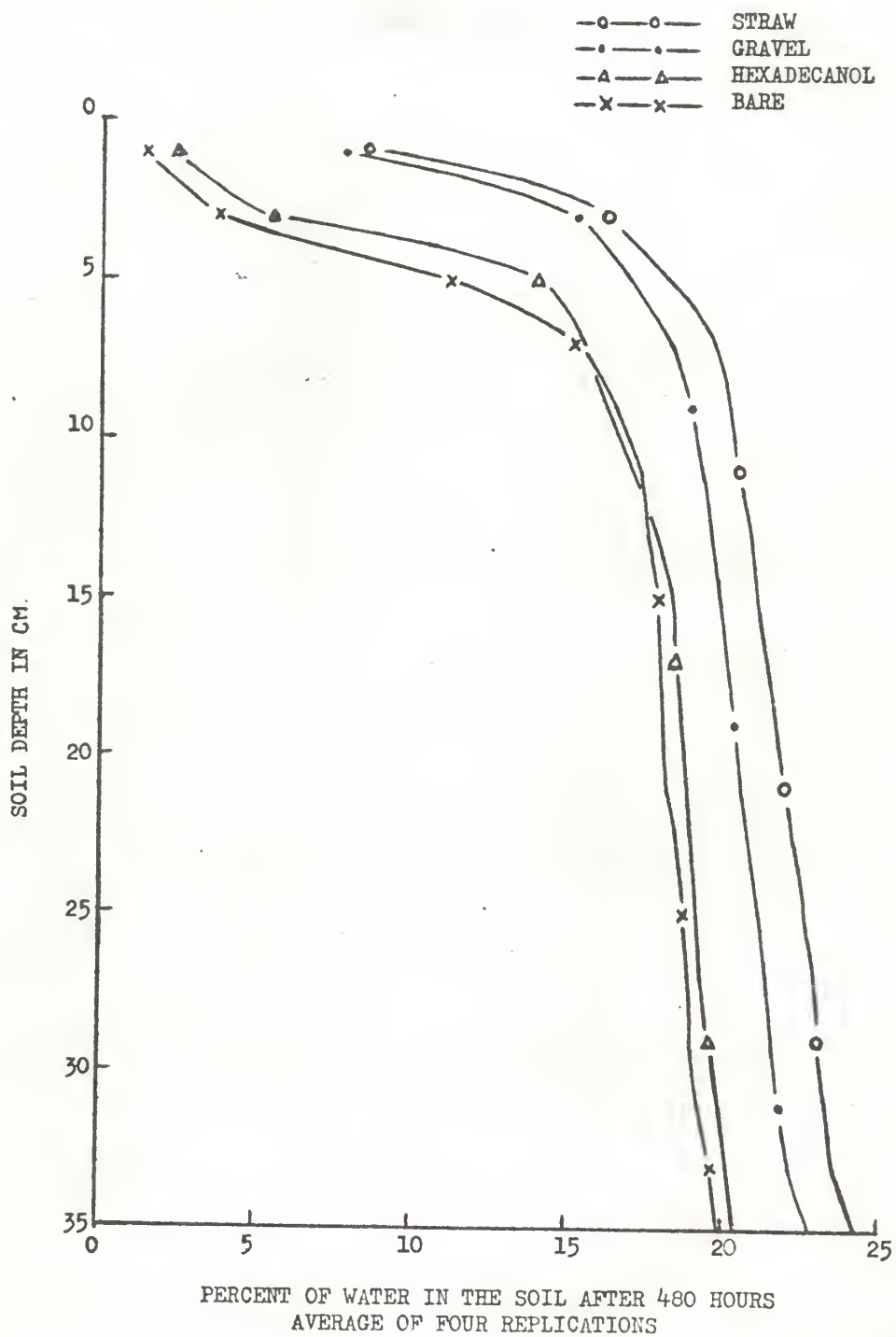


Fig. 2. Moisture distribution through the soil columns in selected treatments, average of four replications.

Table 6. Average temperature 1 cm below soil surface of each treatment after 0, 24, 48, 72, 144, 240 and 480 hours of evaporation.

Treatment	Average temperature °C. at various time periods in hours						
	0	24	48	72	144	240	480
Bare soil	---	---	359	361	386	399	440
Straw mulch*	228	332	342	343	353	357	363
Gravel mulch	---	---	345	375	393	409	428
70 solvent soft wax	226	342	382	382	404	414	431
70 solvent product wax	226	342	376	381	404	409	422
150/200 penetration asphalt	226	346	384	387	407	415	431
150/200 penetration asphalt+	217	381	386	389	410	415	469
120 bright product wax	217	336	342	346	380	397	400
120 bright soft wax	217	346	353	356	397	401	400
120 bright soft wax+	235	337	344	349	365	390	427
200 M. C. neutral wax	217	351	354	356	381	410	417
Hexadecanol	---	---	322	355	358	418	453
Hexadecanol†&	239	359	364	378	411	349	359
White cement‡	239	339	345	357	372	341	340
White cement+	235	333	335	346	352	365	381
Vinyl chloride†	239	332	337	343	379	333	333
Vinyl chloride+	235	334	338	348	351	370	395

* Average of runs 1, 3, 4, and 5.

+ Aggregates coated.

‡ Treatments on which one lamp was used on the turntables from 144-hour to 480-hour period.

& Dissolved in benzene and applied to the soil.

Comparisons of water lost from the soil columns with soil temperatures after 72 and 480 hours were made (Table 7). While there is a tendency for higher evaporation rates to be associated with higher soil temperatures, this relationship is not consistent. This is pointed out by the results of statistical analysis. Correlation coefficients for the data after 72 and 480 hours are $r = 0.128$ and $r = 0.279$ respectively.

Table 7. Average water lost and average temperature for all the treatments after 72 and 480 hours of evaporation.

Treatment	Water lost g/Kg soil		Temperature °C.	
	72 hr.	480 hr.	72 hr.	480 hr.
Bare soil	72	164	361	440
Straw mulch*	19	118	343	357
Gravel mulch	18	125	375	428
70 solvent soft wax	71	163	382	430
70 solvent product wax	66	157	381	422
150/200 penetration asphalt	64	158	387	431
150/200 penetration asphalt†	38	156	389	469
120 bright product wax	62	166	346	400
120 bright soft wax	69	162	356	400
120 bright soft wax†	42	157	349	427
200 M. C. neutral wax	66	162	356	417
Hexadecanol	62	163	355	437
Hexadecanol†&	76	146	378	359
White cement†	76	160	357	340
White cement†	49	158	346	381
Vinyl chloride†	70	151	343	333
Vinyl chloride†	37	152	348	395

* Average of runs 1, 3, 4, and 5.

+ Aggregates coated.

† Treatments on which one lamp was used on the turntables from 144-hour to 480-hour period.

& Dissolved in benzene prior to application.

SUMMARY AND CONCLUSIONS

This study indicates that surface application of several commercial waxes, asphalts, and alcohols, at rates of 600 pounds or less per acre, reduced evaporation of water from soil. Reductions were larger percentage-wise over short periods than over long periods, however, in general these reductions were not statistically significant. Application of these chemicals as aggregates or as coatings for soil aggregates in all cases was

superior to the surface treatment. Reductions of evaporation brought about by aggregate applications over that of surface applied material were statistically significant after 72 hours, but not after 480 hours. This points out that the chemicals tested were apparently quite effective over short dry periods, but that over extended periods of drying conditions they had little effect on evaporation losses.

A gravel mulch was more effective than even aggregates of chemicals or chemically coated soil aggregates were in reducing evaporation, both over short periods (72 hours) and over long periods (480 hours).

Application of straw mulch 1 cm deep was the most effective method tested for reducing evaporation from soils.

While this study showed that chemical treatment could effectively reduce evaporation losses when the chemical was applied as aggregates to the soil surface, the cost of application is too great for field use at the present time. Further investigation is needed with different sizes of aggregates and with combinations of coating agents to determine methods which are more effective and more practical.

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APPENDIX

Table 8. Individual and average moisture contents in the first run.

Treatment	Repli- cation	Moisture content g/Kg soil at the end of hours							Total water lost (g/Kg soil)
		0	24	48	72	144	240	480	
Bare	1	304	279	255	232	190	169	142	164
	2	318	289	261	233	190	168	143	
	3	300	279	256	233	193	173	143	
	4	302	275	245	224	189	167	140	
	Average	306	281	254	231	191	169	142	
Gravel	1	318	310	303	297	280	253	184	125
	2	308	300	294	288	266	236	176	
	3	303	298	293	288	273	249	192	
	4	301	296	289	285	265	240	178	
	Average	308	301	295	290	271	245	183	
Hexadecanol	1	323	299	277	254	203	179	147	163
	2	304	284	263	242	192	168	140	
	3	312	293	273	253	208	187	155	
	4	321	304	283	263	215	193	166	
	Average	315	295	274	253	205	182	152	
Straw	1	316	305	298	292	279	256	203	112
	2	323	310	306	303	286	264	207	
	3	305	297	291	286	278	251	200	
	4	315	296	292	289	276	253	203	
	Average	315	302	297	293	280	256	203	

Table 9. Individual and average moisture contents in the second run.

Treatment	Repli- cation	Moisture content g/kg soil at the end of hours							Total water lost (g/kg soil)
		0	24	48	72	144	240	480	
70 solvent int. soft wax	1	298	277	252	226	184	166	140	163
	2	302	278	253	226	190	172	149	
	3	319	296	272	250	196	177	149	
	4	308	285	264	240	186	164	139	
	Average	307	284	260	236	189	170	144	
70 solvent int. product wax	1	322	299	277	255	198	173	152	157
	2	304	284	258	233	193	176	152	
	3	310	288	265	242	188	169	141	
	4	289	268	248	228	193	175	151	
	Average	306	285	262	240	193	173	149	
150/200 penet. asphalt	1	302	281	262	240	191	166	148	158
	2	314	292	270	245	198	180	155	
	3	311	295	274	248	196	176	152	
	4	306	287	265	243	189	169	145	
	Average	308	289	268	244	194	173	150	
Straw	1	300	297	289	282	259	234	175	127
	2	310	304	299	289	267	236	175	
	3	302	296	290	280	261	232	169	
	4	278	276	266	261	239	212	161	
	Average	297	293	286	278	257	229	170	

Table 10. Individual and average moisture contents in the third run.

Treatment	Repli- cation	Moisture content g/Kg soil at the end of hours							Total water lost (g/Kg soil)
		0	24	48	72	144	240	480	
150/200 penet. asphalt*	1	317	305	292	278	239	197	161	156
	2	333	321	306	297	260	220	184	
	3	319	306	292	279	240	190	155	
	Average	323	311	297	285	246	202	167	
120 bright stock prod. wax	1	320	302	284	270	204	182	155	166
	2	323	301	279	252	199	177	151	
	3	329	311	293	266	213	194	168	
	Average	324	305	285	262	205	184	158	
120 bright stock soft wax	1	328	306	283	259	210	187	162	162
	2	308	288	262	239	197	180	154	
	3	312	291	267	242	192	170	145	
	Average	316	295	271	247	200	179	154	
200 M. C. neutral wax	1	327	305	282	255	213	190	171	162
	2	323	304	283	261	208	181	161	
	3	326	307	285	262	207	181	157	
	Average	325	305	283	259	209	184	163	
Straw	1	299	295	289	282	265	245	190	114
	2	319	313	305	299	280	258	197	
	3	314	310	304	296	281	257	204	
	4	308	303	296	289	274	244	191	
	Average	310	305	299	292	275	251	196	

* Aggregates 4.8 to 7.5 mm made out of asphalt.

Table 11. Individual and average moisture contents in the fourth run.

Treatment	Replication	Moisture content g/Kg soil as the end of hours							Total water lost (g/Kg soil)
		0	24	48	72	144	240	480	
Hexadecanol+	1	303	279	251	228	189	172	149	146
	2	306	281	254	230	206	188	163	
	3	295	269	244	226	202	185	161	
	4	308	276	247	225	198	181	154	
	Average	303	276	249	227	199	182	157	
White cement	1	315	293	268	242	201	183	158	160
	2	314	289	265	236	195	176	147	
	3	295	271	244	219	185	170	144	
	4	308	286	262	230	185	169	142	
	Average	308	285	260	232	192	175	148	
Vinyl chloride	1	304	284	265	236	195	176	152	151
	2	310	290	271	247	202	177	151	
	3	289	263	241	217	190	177	152	
	4	322	294	268	244	209	190	163	
	Average	306	283	261	236	199	180	155	
Straw	1	325	317	311	304	292	276	235	92
	2	310	306	300	292	281	267	232	
	3	281	275	269	263	248	233	187	
	4	305	299	291	286	265	249	196	
	Average	305	299	293	286	272	256	213	

* After the 144 hours measurement, only one lamp was used on each turntable.

+ Hexadecanol dissolved in benzene.

Table 12. Individual and average moisture contents in the fifth run.

Treatment	Repli- cation	Moisture content g/Kg soil at the end of hours							Total water lost (g/Kg soil)
		0	24	48	72	144	240	480	
120 bright stock soft wax*	1	322	307	295	282	239	192	158	157
	2	324	310	298	285	237	191	162	
	3	297	283	268	252	201	178	155	
	4	315	300	282	272	218	182	156	
	Average	315	300	286	273	224	186	158	
Vinyl chloride*	1	323	310	300	287	248	205	165	152
	2	319	307	297	286	247	202	165	
	3	316	304	292	281	241	197	166	
	4	312	297	282	269	217	190	168	
	Average	318	305	293	281	238	199	166	
White cement*	1	330	307	299	287	248	204	165	158
	2	315	292	275	264	222	184	155	
	3	314	296	285	274	233	193	161	
	4	314	287	268	252	207	184	158	
	Average	318	296	282	269	228	191	160	
Straw	1	309	301	297	289	267	243	192	120
	2	320	313	306	300	278	254	199	
	3	318	310	302	296	272	246	196	
	4	314	304	301	294	272	244	194	
	Average	315	307	302	295	272	247	195	

* Aggregate treatment.

Table 13. Analysis of variance summary. Water left in straw mulched columns, all five runs.

Item	Sum of squares	Degrees of freedom	Mean square	F
Treatments	6990.6	4	1747.7	19.24***
Evaporation periods	189580.5	6	31596.8	347.88***
Treat. x periods	2949.9	24	122.9	1.35 ns
Replications	3932.8	3	1310.9	14.43***
Error	<u>9265.2</u>	<u>102</u>	90.8	
	212719.0	139		

Table 14. Analysis of variance summary. Water left in straw mulched columns, runs 1, 3, 4, and 5.

Item	Sum of squares	Degrees of freedom	Mean square	F
Treatments	151.5	3	50.5	0.54 ns
Evaporation periods	140345.5	6	23390.9	256.22***
Treat. x periods	1779.7	18	98.9	1.07***
Replications	2647.3	3	882.4	9.42***
Error	<u>7583.0</u>	<u>81</u>	93.6	
	152507.0	111		

Table 15. Analysis of variance summary. Water left in all treatments in runs 1, 3, 4, and 5, with data for straw averaged.

Item	Sum of squares	Degrees of freedom	Mean square	F
Treatments	90364	13*	6951	99.3***
Evaporation periods	977446	6	162,907	2327.9***
Treat. x periods	36065	78	462	6.7***
Replications	2208	3	736	10.5***
Error	<u>18283</u>	<u>263</u>	70	
	1124366	363*		

* A total of 4 straw treatments and 12 gravel and chemical treatments were included in runs 1, 3, 4, and 5. The straw treatments were averaged by replications making a total of 14 treatments that were included in this analysis.

Table 16. Percent moisture remaining at various depths in soil after 480 hours. Average of four replications, in the first run.

Depth in cm	Bare	Gravel	Hexadecanol	Straw
0-2	1.4	7.7	2.4	8.4
2-4	3.7	15.2	5.5	16.2
4-6	11.2	16.9	13.9	18.3
6-8	15.2	18.3	15.4	19.9
8-10	16.4	18.8	16.2	20.1
10-12	17.3	19.2	17.0	20.4
12-14	17.5	19.5	17.7	20.9
14-16	17.8	19.7	18.3	21.0
16-18	17.8	20.1	18.4	21.4
18-20	17.9	20.2	18.6	21.7
20-22	18.2	20.5	18.7	21.9
22-24	18.6	20.7	18.9	22.3
24-26	18.7	21.1	19.1	22.8
26-28	18.8	21.3	19.2	22.9
28-30	18.9	21.6	19.8	22.9
30-32	19.3	21.8	19.7	23.3
32-34	19.7	22.2	20.2	23.5
34-36	19.8	22.9	20.4	24.3

Table 17. Percent moisture remaining at various depths in soil after 480 hours. Average of four replications, in the second run.

Depth in cm	70 solvent int.	70 solvent int.	150/200 penetra-	Straw
	soft wax	product wax	tion asphalt	
0-2	3.4	3.6	3.2	12.0
2-4	4.5	5.0	4.0	16.5
4-6	12.2	12.4	8.8	17.9
6-8	15.6	15.8	14.9	18.6
8-10	16.9	16.9	15.9	18.9
10-12	17.5	17.6	16.9	19.4
12-14	17.8	17.8	17.5	19.8
14-16	17.9	18.1	17.7	19.9
16-18	18.2	18.3	17.9	20.0
18-20	18.4	18.6	18.3	20.1
20-22	18.6	18.7	18.5	20.2
22-24	18.8	18.9	18.6	20.6
24-26	19.1	19.2	18.8	20.6
26-28	19.2	19.4	19.0	20.9
28-30	19.4	19.6	19.2	21.3
30-32	19.6	19.9	19.4	21.4
32-34	19.9	20.3	19.5	21.5
34-36	19.9	20.6	19.8	21.7

Table 18. Percent moisture remaining at various depths in soil after 480 hours. Average of three replications, in the third run.

Depth	150/200	120 bright	120 bright	200 M. C.	Straw
	penet. asphalt	stock product wax	stock soft wax	neutral product wax	
0-2	3.0	1.2	1.8	1.0	12.3
2-4	9.3	4.0	4.8	2.9	18.0
4-6	14.7	13.0	13.7	9.7	19.7
6-8	16.9	15.9	16.3	14.4	20.2
8-10	17.0	17.0	16.9	18.0	20.5
10-12	17.5	17.6	17.5	18.5	20.8
12-14	18.1	17.8	17.9	18.6	21.0
14-16	18.6	18.0	18.0	18.6	21.5
16-18	19.1	18.5	18.4	18.6	22.0
18-20	19.5	19.0	18.9	18.6	22.2
20-22	19.6	19.2	19.0	18.7	22.4
22-24	19.7	19.4	19.6	19.0	22.5
24-26	19.7	19.7	19.6	19.3	23.0
26-28	20.0	19.9	19.9	19.3	23.0
28-30	20.5	20.0	20.3	19.4	23.3
30-32	20.7	20.1	20.3	19.9	23.5
32-34	20.8	20.2	20.3	19.9	23.9
34-36	21.6	20.2	20.4	19.9	24.2

Table 19. Percent moisture remaining at various depths in soil after 480 hours. Average of four replications, in the fourth run.*

Depth in cm	Hexadecanol	White cement	Vinyl chloride	Straw
0-2	3.6	4.3	4.7	17.8
2-4	7.7	5.6	5.8	19.3
4-6	13.5	13.1	12.9	20.3
6-8	16.8	15.2	15.4	20.7
8-10	17.3	15.9	15.8	21.2
10-12	17.7	16.7	16.8	21.8
12-14	18.1	17.4	17.6	22.3
14-16	18.8	17.9	18.3	22.5
16-18	19.1	18.5	18.6	22.6
18-20	19.6	18.9	18.9	22.9
20-22	19.8	19.3	19.4	23.1
22-24	20.1	19.5	19.9	23.5
24-26	20.4	19.7	20.3	23.7
26-28	20.6	19.7	20.5	23.9
28-30	20.6	19.9	20.6	24.3
30-32	20.7	20.1	20.8	24.8
32-34	20.7	20.3	20.8	25.7
34-36	20.7	20.5	20.9	26.3

* After the 144 hours measurement, only one lamp was used on every turntable.

THE EFFECT OF CHEMICALS ON EVAPORATION OF WATER FROM SOIL

by

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A laboratory experiment was conducted on the influence of chemicals on evaporation of water from soils. Several commercial waxes, asphalts, fatty alcohols, and plastic materials were either sprayed on the soil surface, or were used to make coated aggregates which were applied on the soil surface. The soil was placed in plastic cylinders 42 cm in length and 9 cm in diameter. Air dry soil was packed into each cylinder at a density of 1.3 g/cm³. These soil columns were wet from below until free water appeared at the top of the soil. The columns were then allowed to drain. The soil columns were distributed on two turntables which were rotated at 2 rpm. Two cool beam PAR lamps (300 PAR 56/2WFL) wide flood, which were hung above the surface of the cylinders, were the source of energy for evaporating moisture from the soil columns.

Surface applications of the chemicals at rates of 600 pounds per acre brought about no significant reduction in evaporation of water from soil. Aggregates added on the soil surface were superior to the surface form of application.

Straw at the rate of 8000 pounds per acre, used as a check treatment, provided the greatest reduction in evaporation throughout the study, with an average evaporation reduction of 4 to 5 percent at the end of 480 hours (20 day period) as compared with bare soil. Surface applied aggregates provided a reduction in evaporation of about 2 percent.

Temperature measured by a thermocouple recorder one cm below the soil surface showed the lowest value under the straw treatment at the end of 480 hours and the highest value under the black asphalt aggregates.

None of the treatments employed showed promise for practical field application, but the study did indicate that the most practical line for

further research is likely to be with artificial or natural aggregates applied to the soil surface.