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Effects of Adjuvants on Wetting and Water Infiltration of Soils

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Surface runoff and soil erosion, in some cases, have been attributed to low water infiltration rates due to water repellency of soils (Miller et al. 1975). A low infiltration rate can also be caused by soil compaction resulting from operations with machinery (Morgan et al. 1966). Adjuvants are potential solutions to poor wetting and infiltration problems and have been tested in water management and erosion control (Miyamoto 1978, Pelishek et al. 1962). For example, nonionic surfactants significantly increased yield of soybeans grown in a crusting soil with a low water infiltration rate (McCauley 1993).

Pelishek et al. (1962) found that surfactants increased infiltration rates of water into hydrophobic soils but had no or adverse effect on soils which were not particularly hydrophobic. Similar findings were reported on penetrability and diffusivity of soils (Mustafa and Letey 1971). In contrast, Miyamoto (1985) observed that surfactants enhanced water infiltration into both poorly-wettable and wettable soils. Mustafa and Letey (1970) reported that increased penetrability of water by surfactants into soils was dependent on type of surfactants. Miyamoto also observed that effects of wetting agents on water infiltration into both poorly-wettable and wettable soils varied with wetting agent (Miyamoto 1978, 1985). In a study of adjuvant effects on soil wettability for pesticide controlling ameliorate fairy rings of turfgrass, Nadeau et al. (1993) found that Silwet L-77, the only organosilicone surfactant among the 13 adjuvants tested, was the most effective in increasing solution uptake by both infested and uninfected soils.

Organosilicone surfactants are a group of relatively new adjuvants with extreme spreading of their aqueous solutions (Stevens 1993). Extensive studies have been reported on their effects of enhancing stomata infiltration of spray solutions and other foliar applications; however, its potential in soil application has not been well explored (Stevens 1993). The objective of this study was to compare the effect of organosilicone adjuvants on soil wetting and water infiltration with that of nonorganosilicone adjuvants.

MATERIALS AND METHODS

Soil collected from the field between 0 and 30 cm depth was screened through a

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sieve (meshes size of 2 mm) after air drying. The soil, a Candler fine sand (Typic Quartzipsamment), had 1.2% organic matter, 96% sand, and a pH of 6.3. Leaching columns were used to study the effect of adjuvants on soil wetting and water infiltration. The columns were 8 cm tall with an inner diameter of 7 cm and a bottom lined with a thin nylon mesh above the perforated plate. The mesh allowed free water movement while maintaining soil column integrity. The column was packed (bulk density of 1.5 g cm^{-3}) by adding small amounts of soil to the column while the column was shaken on a vortex shaker. A piece of filter paper was placed at the bottom and on the top of the soil.

Both organosilicone and non-organosilicone adjuvants were tested for their effect on soil wetting and water infiltration. The organosilicone adjuvants were Break-Thru, DyneAmic, Herbex, Kinetic, Silkin, and Sylgard 309, and the non-organosilicone adjuvants included AD-Spray 80™, Agri-Dex, Induce, Meth oil, Pen-A-Trate II™, and X-77 (Table 1). The adjuvant concentrations of all treatments were 0.5% (v/v). Tap water alone was the control.

The column packed with air-dried soil was placed on top of a beaker for leachate collection, and 200 mL of each adjuvant solution or water was poured to the column gradually. The solution level was kept at 0.5 cm above the soil surface until the disappearance of the 200 mL solution on the soil surface. Time needed for the first drop of solution to drip into the beaker and time needed for the standing water on the soil surface to completely disappear were recorded to represent wetting and infiltration rates of the solution. Leachate resulting from the addition of 200 mL water or adjuvant solutions in the column was collected by the beaker and was measured when the dripping stopped. A portion of the 200 mL solution was held by the soil column and the rest dripped into the beaker. After 24 h, the procedures were repeated with the above-used columns which had been saturated with water or adjuvant solutions, but 200 mL water instead of adjuvant solution was poured into a column. All wet columns except the one treated with water alone contained adjuvant residues in the soil left by previous treatment of adjuvant solutions.

A randomized block design was used with four replications. Analysis of variance was performed separately for the dry columns (newly-packed) and the wet columns (columns after the adjuvant treatment). Means of treatments were separated by Duncan's Multiple Range Test; Orthogonal Contrast Test was used to separate group (organosilicone vs. non-organosilicone surfactants) means.

RESULTS AND DISCUSSION

Time needed for the first drop of water to drip into the beaker was significantly longer for the water alone treatment as compared with that for adjuvant solutions, except for Break-Thru and Induce (Table 2). This shows that some of the adjuvants improved soil wetting, leading to a faster moving front of adjuvant solutions in the soil than water alone. However, no significant difference was found between organosilicone and non-organosilicone adjuvants (Table 2).

Table 1. Adjuvants tested.

Trade name	Active ingredients	Manufacture
Organosilicone adjuvant		
Break-Thru	Polyether-polymethylsiloxane-copolymer	Goldschmidt Corp
DyneAmic	Blend of polyalkeneoxide modified polydimethysiloxane, nonionic emulsifiers, methylated vegetable oils	Helena Chemical Co
Herbex	Polycarboxylic acids, polyether-polymethysiloxane-copolymer	American Colloid Co
Kinetic	Blend of polyakyloneoxide modified polydimethysiloxane and nonionic surfactants	Helena Chemical Co
Silkin	Polyalkyleneoxcide modified heptamethyltrisiloxane, nonionic surfactants	Riverside/Terra Corp
Sylgard 309	2-(3-hydoxypropyl)-heptamethyltrisiloxane, ethoxlated, acetate, allyloxy polyethylene glycol monoallyl acetate, polyethylene glycol diacetate	Dow Conning Corp
Non-organosilicone adjuvant		
AD-Spray 80™	Alkyl aryl polyalkoxylated alcohols, propanol	Helena Chemical Co
Agri-Dex	Heavy range paraffin base petroleum oil, polyol fatty acids esters, polyethoxylated derivatives	Helena Chemical Co
Induce	Blend of alkyl aryl polyoxylkane ether, free fatty acids	Helena Chemical Co
Meth oil	Methylated seed oil	Riverside/Terra Corp
Pen-A-Trate II	Alkyl polyethoxy ethers and other ethoxylated derivatives	Precision Laboratories, Inc
Ortho X-77	Alkylarypolyoxyethylene, free fatty acids, glycols, isopropanol	Loveland Industries

Time needed for 200 mL of 0.5% (v/v) Kinetic and Induce solutions to infiltrate into the soil column was 16.7 and 17.6 min, respectively (Table 2). They were significantly longer than that of water alone treatment (7.9 min), indicating that these two adjuvants reduced water infiltration or unsaturated flow rates of water in the soil. None of the remaining adjuvants had any effect on the infiltration, and no difference was observed between organosilicone and non-organosilicone adjuvants (Table 2).

Pelishek et al. (1962) explained that the infiltration rate of a solution was positively related to its surface tension but was negatively related to its contact angle with soil particles. Addition of surfactants to water results in lower surface tension and reduced liquid-solid contact angle (Miller et al. 1975). The net effect of surfactants

Table 2. Effects of adjuvants at a concentration of 0.5% (v/v) on wetting and water infiltration of dry soil

Adjuvant	Time needed for the first drop of water to drip into the beaker (min)	Time needed for 200 mL solution to infiltrate into a soil column (min)	Volume of leachate (mL)
Break-Thru	1.4 abc†	12.2 abc	113 a
DyneAmic	1.1 cd	11.2 abc	104 a
Herbex	1.3 bcd	11.5 abc	103 a
Kinetic	1.3 bcd	16.7 ab	103 a
Silkin	1.2 bcd	9.0 c	101 a
Sylgard 309	1.1 cd	11.5 abc	98 a
AD-Spray 80™	1.0 d	10.1 be	103 a
Agri-Dex	1.2 bcd	8.3 c	111 a
Induce	1.5 ab	17.6 a	97 a
Meth oil	1.0 d	6.7 c	95 a
Pen-A-Trate II™	1.0 d	7.7 c	95 a
X-77	1.2 bcd	9.2 c	95 a
Check	1.7 a	7.9 c	100 a
Average of organosilicone	1.3 a	12.0 a	104 a
Average of other adjuvant	1.2 a	9.9 a	99 a

†Separation of treatment means for both organosilicone and non-organosilicone adjuvants in the column by Duncan's Multiple Range Test at 5%; different letter indicates significant difference. Separation of group means by orthogonal contrast test at 5%.

on the infiltration rate, therefore, depends on the balance between changes of surface tension and contact angle caused by surfactants. In our experiment, the reduced contact angle between liquid and soil particles caused by adjuvants might have been counteracted or surpassed by the reduced surface tension caused by the same adjuvant. The unchanged or decreased infiltration rate by adjuvants may be a result of the balance between changes of surface tension and contact angle. Data from this experiment are consistent with the results of Pelishek et al. (1962) who reported that surfactants had no effect or adverse effects on infiltration rates into soils which were not particularly hydrophobic. They believed that only hydrophobic soils could make it possible for a surfactant to create enough reduction in contact angle to counteract the effect of surface tension reduction by the same surfactant.

Mustafa and Letey (1971) found that addition of two surfactants in water either slightly decreased or had no effect on penetrability and diffusivity of wettable soils but increased the penetrability and diffusivity of water-repellent soils. They attributed the slight decrease in penetrability and diffusivity of the wettable soil to decrease in aggregate stability of the soil (Mustafa and Letey 1969, 1971). Miller et al. (1975) believed that general decrease of flow rates at high surfactant concentrations could be the result of soil particle migration, surfactant micelle "clogging" of soil pores, and the breakdown of soil aggregates (Miller et al. 1975).

Table 3. Effects of adjuvant residues on water infiltration and flow in wet soil columns

Adjuvant residue in the soil columns	Time needed for the first drop of water to drip into the beaker (min)	Time needed for 200 mL water to infiltrate into a soil column (min)	Volume of leachate (mL)
Break-Thru	0.20 b†	15.7 bc	190 a
DyneAmic	0.20 b	14.1 bc	181 abc
Herbex	0.18 bc	16.5 bc	187 ab
Kinetic	0.15 bcd	19.7 b	190 a
Silkin	0.13 cd	11.1 bc	189 a
Sylgard 309	0.68 a	33.5 a	175 c
AD-Spray 80'	0.16 bcd	11.0 bc	174 c
Agri-Dex	0.21 b	8.6 c	175 c
Induce	0.12 cd	12.4 bc	190 a
Meth oil	0.17 bcd	7.6 c	178 bc
Pen-A-Trate II™	0.13 cd	7.7 c	186 ab
X-77	0.10 d	8.5 c	190 a
Check	0.21 b	6.8 c	181 abc
Average of organosilicone	0.26 a	18.4 a	185 a
Average of other adjuvant	0.15 b	9.3 b	182 a

†Separation of treatment means for both organosilicone and non-organosilicone adjuvants in the column by Duncan's Multiple Range Test at 5%; different letter indicates significant difference. Separation of group means by orthogonal contrast test at 5%.

About half of the added water or adjuvant solutions penetrated the column and was collected in the beaker; the other half was held by the soil column (Table 2). No significant difference was observed between water and adjuvant treatments in leachate volume, neither between organosilicone and non-organosilicone adjuvants. This implies that adjuvants had no influence on water holding capacity or drainage of the soil.

The soil column after infiltrated by 200 mL of water or adjuvant solutions had a water content of field capacity, and the columns infiltrated by the adjuvants solutions also contained residues of the adjuvants. These wet soil columns were ideal for further testing of adjuvant residue effect on water infiltration and saturated flow.

Time needed for the first drop of water in the wet soil column, containing Sylgard 309 residue, to drip into the beaker was longer in comparison with the column without any adjuvant residue (Table 3). In contrast, the time needed for the first drop of water to drip into the beaker for the wet soil columns with residues of Silkin, Induce, Pen-A-Trate II™, or X-77 was significantly shorter than that of the column without any adjuvant residue. More time was needed for the first drop of water to drip into the beaker for the wet soil columns containing residues of organosilicone adjuvants compared to non-organosilicone adjuvants.

It took more time for 200 mL of water to infiltrate into the wet soil columns containing residues of Kinetic or Sylgard 309 than the columns without any adjuvant (Table 3). Both Kinetic and Sylgard 309 are organosilicone adjuvants. None of the remaining adjuvant residues had any impact on water infiltration time of the wet soil columns. These results were similar to the infiltration pattern of adjuvant solutions in dry soil (Table 2). Pelishek et al. (1962) also observed similar residue effects of surfactants on water infiltration into soils. The average infiltration time for the wet soil columns with residues of organosilicone adjuvants was significantly longer than that of non-organosilicone adjuvants. Leachate volumes were different between some adjuvant residue treatments, but there was no difference between wet soil columns with and without adjuvant residues or between columns with residues of organosilicone and non-organosilicone adjuvants as groups (Table 3).

In summary, adjuvants improved wetting of dry soil, but some of them reduced water infiltration rates into the dry soil. The adjuvants and their residues in the soil had no effect on water-holding capacity of the soil. Adjuvant residues in wet soil had various effects on the moving speed of water fronts in the soil. The residue reduced or had no effect on water infiltration rates into the wet soil. Organosilicone adjuvants as a group were similar to non-organosilicone adjuvants in affecting wetting, water infiltration, and drainage of dry soil. However, the residues of organosilicone adjuvants as a group reduced water infiltration rates of wet soil in a greater extent than non-organosilicone adjuvants. This study demonstrated that experimental adjuvants improved soil wetting but had no effect on or decreased water infiltration rates.

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