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Effect of an Anionic Soil Conditioner on Water Stable Aggregation of Three Hawaiian Soils

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ABSTRACT

The primary purpose of soil conditioner application is to enhance a soil's resistance to erosion processes by increasing the water stability of aggregates. In this study, a wrist-action shaker was used to assess the aggregate stability of three Hawaiian soils treated with an anionic surfactant soil conditioner (AGRI-SC). Aggregates of 2.00 to 4.00 mm in size were treated with Agri-SC at rates of 1 to 100,000 times the manufacturer-recommended rate of 0.30 L ha^{-1}. The manufacturer-recommended application rate of Agri-SC was effective for only the most stable soil tested (Kaneloa Oxisol), ineffective for the Lualualei Vertisol, and adversely effective for the Molokai Oxisol. For higher application rates ranging from 10 to 10,000 times recommended, stability of large aggregate fractions increased for the Kaneloa Oxisol. In sharp contrast, the same application rates decreased aggregate stability of the Molokai Oxisol. For the third, least stable soil (Lualualei Vertisol), Agri-SC was relatively ineffective, except at very high application rates (1,000 and 10,000 times recommend). Finally, at the extremely high application rate of 100,000 times recommended, aggregates for all soils were peptized. These results suggest that careful attention should be given to the application of soil conditioners with anionic surfactants as active ingredients, for aggregate response to various application rates appears to be soil dependent.

INTRODUCTION

Interest in soil conditioners (stabilizers and amendments) in the last 40 years has been influenced by the development of new classes of stabilizers and the identification of new uses for them (Sojka and Lentz, 1994). Chemical soil conditioners have been shown to aggregate and/or stabilize soils, improve hydraulic conductivity, impart friability, increase crop yields, and reduce interrill and rill erosion (Azzam, 1980). Commonly, soil conditioners increase the degree of aggregation of upper soil layers, thereby reducing the formation of surface seals. The result is a soil with increased resistance to splash detachment and entrainment, i.e., a soil of lower erodibility.

Aggregate stability is the resistance of soil aggregates to collapse when subjected to disruptive forces (Nadler et al., 1996). Numerous studies have been conducted to determine the change in the percentage of water stable aggregates (WSAs) after treatment with soil conditioners. The majority of studies have found significant increases in WSA after applying a variety of products (Table 1). Some studies, however, have found no change in size of WSA (Fitch et al., 1989) or only minor ones (Wallace and Wallace, 1986; Mukhopadhyay et al., 1994; Nadler et al., 1996). The results from studies on the soil conditioner Agri-SC (brand name) are contradictory. Fullen et al. (1993, 1995), using the drop test method, found aggregates treated with Agri-SC to be more resistant to breakdown. Fitch et al. (1989), however, using a wet-sieving procedure, found no significant changes in the arithmetic mean of aggregate mass diameter (MAMD), and thus no change in water stable aggregation. Because Agri-SC is advertised widely in erosion control trade magazines and is relatively inexpensive at manufacturer-recommended rates (c.f., Sutherland and Ziegler, 1997), it is important to fully characterize the influence of Agri-SC on processes that influence interrill and rill erosion. Thus, the objectives of this study are, for a range of soils: (1) determine the influence of Agri-SC on selected indices of water stable aggregation; and (2) characterize the influence of various application rates of Agri-SC on the stability.

MATERIALS AND METHODS

Soil Conditioner

Agri-SC is manufactured by Four Star Services, Inc., Bluffton, IN. At the recommended application rate (0.30 L ha^{-1}) for agricultural soils, this soil conditioner is relatively inexpensive at approximately $7.94 to $10.42 (excluding shipping and application costs). The main ingredient in Agri-SC is ammonium laureth sulfate (48%), an anionic surface active agent (surfactant)—widely used in shampoos because of its excellent cleansing and foaming properties (Nikitakis, 1988).

The mechanisms by which Agri-SC may increase aggregate stability are not clearly understood. It may function like anionic polyacrylamides by adsorbing to

TABLE 1. Influence of soil conditioners on water stable aggregate (WSA) percent.

Author(s)	Soil Conditioner / Application Rate	Technique†	Aggregate Size (mm)	WSA Before (%)	WSA After (%)
Bernas et al. (1995)	Latex [2 g kg^{-1}] Poly(DADMAC) [2 g kg^{-1}]	WS & IW WS & IW	> 2.0 > 2.0	8 - 25 8 - 25	80 - 95 15 - 45
Bryan (1992)	Separan AP30, Anionic PAM [0.05%]	WS & IW	> 2.8 > 0.5	2 - 40 2 - 57	20 - 78 48 - 91
Fitch et al. (1989)	Agri-SC, Anionic surfactant [0.15 - 0.60 L ha^{-1}]	WS & IW WS & IW	MAMD‡ 1986 MAMD‡ 1987	0.25 mm 0.08 mm	0.24-0.28 mm 0.07-0.16 mm
Fox and Bryan (1992)	Separan AP30 [0.01%]	WS & IW	1.0 - 2.0 2.0 - 4.0	0.08 - 1.15 0.18 - 0.53	11.4 - 11.5 3.8 - 4.9
Fullen et al. (1993)	Agri-SC [0.3 - 5.0 L ha^{-1}]	WDT	4.0 - 5.6	29 drops	52 - 71 drops
Fullen et al. (1995)	Agri-SC [0.3 - 1.2 L ha^{-1}]	WDT	4.0 - 5.6	4.7 drops	5.8 - 8.5 drops
Le Souder et al. (1991)	WAC Al Polychlorosulphate [250 - 1000 L ha^{-1}]	WS & IE	> 1.0	3	22 - 66
Martin (1953)	VAMA (Vinyl acetate-maleic acid) [0.05 - 0.15 %]	WS	> 0.25 > 2.0	44 10	85 - 94 63 - 90
Mukhopadhyay et al. (1994)	Copolymer (85% acrylo-nitrile & 15% vinyl acetate) [0.01 - 0.50 %]	WS & IW	> 2.0	0	0 - 94.9
Nadler et al. (1996)	PAM-2J (Anionic) PAM-21J (Anionic) [25 - 75 mg kg^{-1}]	WS, PW WS, PW	> 0.25 >0.25	10 - 40 10 - 40	15 - 65 45 - 85
Terry and Nelson (1986)	Polyacrylamide (PAM) [650 kg ha^{-1}]	WS & IW	> 0.25	11.4 - 17.6	47.7 - 82.0
Wallace and Wallace (1986)	PAM (Anionic) [0.0004 - 0.0016%]	WS & IW	> 0.30	17.6	33.4 - 79.4

†WS=wet-sieving, IW=immersion in water, IE=immersion in ethanol, WDT=water drop test, PW=pre-wet.

‡MAMD represents the arithmetic mean aggregate mass diameter; 1986 was the first year of application; 1987, the second year.

positively charged sites on clay minerals. Letey (1994) notes that electrostatic interaction between polymers and clays greatly affects adsorption of charged polymers, with the general order of adsorption being: cationic > nonionic > anionic. Nadler and Letey (1989) found that treatment of soils with negatively charged polymers affected soil aggregation positively, negatively, or neutrally, depending on specific experimental variables.

Soils Selected

The three Hawaiian soils used in this study include: (1) the Ap-horizon from the clay Molokai Oxisol (Typic Eutrotorrox); (2) the A-horizon from the clay Lualualei Vertisol (Typic Chromustert); and (3) the Bw-horizon from the silty clay loam Kaneloa Oxisol. The properties of each soil are summarized in a companion paper (Sutherland and Ziegler, 1997). The order of aggregate stability for these three soils is Kaneloa Oxisol > Molokai Oxisol > Lualualei Vertisol.

Wrist-Action Shaker and Agri-SC Application Rates

The methodology described in detail in the companion paper was used in this study (Sutherland and Ziegler, 1997). Briefly, sieving of air-dry aggregates is used to isolate the 2.00-4.00 mm fraction. A sample of 10 g of 2.00-4.00 mm aggregates was then treated with 7.5 mL of solution. Solution application rates of Agri-SC were equivalent to 0 L ha^{-1} (untreated control), 0.3 L ha^{-1} (1x, the manufacturer-recommend rate), 3 L ha^{-1} (10x), 30 L ha^{-1} (100x), 300 L ha^{-1} (1,000x), 3,000 L ha^{-1} (10,000x), and 30,000 L ha^{-1} (100,000x). A wide range of application rates were tested to identify the optimal concentration for these Hawaiian soils. Very high rates were used to identify the threshold where product performance breaks down, or becomes detrimental. Application rates $\geq$1x were replicated eight times, while the untreated controls were replicated between 16 and 24 times. After 48 h of incubation, samples were immersed in 100 mL of tap water, then shaken for a period of 10 min. Shaking was followed by gently washing the sample through a series of screens with mesh diameters of 2.00, 1.00, 0.25, and 0.063 mm. The samples were then oven-dried at 105°C for 24 h, then massed. Seven indices for WSA were then derived. Based on previous research and data from the literature (Sutherland and Ziegler, 1997), two WSA indices were examined in detail, the geometric mean aggregate diameter (GMAD) and the percent of water stable aggregates remaining on the 0.25 mm screen (% WSA >0.25 mm). The GMAD is defined by Kemper et al. (1985) as:

$$\mathbf{GMAD} = \exp\left[\frac{\sum_{i=1}^{n} m_i \log \mathbf{X}_i}{\sum_{i=1}^{n} m_i}\right]$$

where $\mathbf{X}_i$ (mm) is the mean inter-sieve size and m_i is the aggregate mass (g) retained on each sieve.

Statistical Analysis

The influence of various rates of Agri-SC on seven indices of water stable aggregation, for each of the three soils, was assessed using one-way analysis of variance (ANOVA). This was followed by multiple comparison testing (Fisher's Protected Least Significant Difference test) when the F-values were significant at α=0.05 (Gagnon et al., 1989).

RESULTS AND DISCUSSION

Effectiveness at Manufacturer Recommended Rates

Effectiveness of Agri-SC in increasing aggregate stability at manufacturer recommended rates (1x) varied between the three soils. Agri-SC (1x) worked best for the Kaneloa Oxisol. For example, compared to the untreated control, GMAD and % WSA >0.25 mm were significantly greater at this application rate (Table 2). In addition, this treatment produced a significant decrease in the most erodible fraction (<0.063 mm) and was successful in preserving a larger percentage of the initial 2.00-4.00 mm aggregates than the control. In contrast, Agri-SC (1x) was ineffective on the Lualualei soil (Table 3). The data indicate a significant breakdown in 2.00-4.00 mm aggregates contributed to a significant increase in the smaller 0.25-1.0 mm fractions; no other aggregate fractions were significantly different from the untreated control. Treatment of the Molokai Oxisol with this application rate of Agri-SC appears to be detrimental (Table 4). The WSA data show significant decreases in GMAD, % WSA >0.25 mm, % WSA 2.00-4.00 mm, % WSA 1.00-2.00 mm, and % WSA 0.25-1.0 mm; these decreases in the larger fractions were accompanied by significant increases in the small erodible fractions, 0.063-0.25 mm, and <0.063 mm. In summary, the manufacturer-recommended application rate of Agri-SC was (i) effective for only the most stable soil tested, the Kaneloa Oxisol; (ii) ineffective for the least stable soil, the Lualualei Vertisol; and (iii) adversely effective for the Molokai Oxisol. The reasons for performance differences between the three soils is presently unclear. Additional analyses are required for all test soils, especially on the Kaneloa Oxisol because its chemistry and mineralogy are poorly understood. Differences in anionic exchange capacities of the test soils, however, may explain success or failure following application of an anionic surfactant (Agri-SC).

Higher than Recommended Application Rates

As shown by the response of Agri-SC (1x) on the Kaneloa Oxisol, higher than recommended application rates were very effective in increasing aggregate stability (Table 2). Rates of 10x, 100x, and 1,000x produced significant decreases in the highly erodible fraction (<0.063 mm) and showed increases in the GMAD and % WSA >0.25 mm. The other WSA indices indicate a mixed performance at higher application rates. The general tendencies, however, were decreases in the smaller, erodible fractions and preservation of the larger ones.

TABLE 2. Mean values of water stable aggregate fractions and indices for the Kaneloa Oxisol for various application rates of Agri-SC.

Variable	0x†	1x	10x	100x	1 000x	10 000x	100 000x
GMAD (mm)	0.903^{b}‡	0.956^{cd}	0.934^{bc}	0.999^{de}	1.020^{e}	0.930^{bc}	0.349^{a}
WSA > 0.25 mm (%)	80.8^{b}	83.6^{cd}	84.5^{cde}	86.7^{e}	85.3^{de}	82.6^{bc}	5.2^{a}
WSA 2.0-4.0 mm (%)	28.6^{bc}	32.2^{cd}	26.2^{b}	31.5^{cd}	35.1^{d}	28.8^{bc}	3.5^{a}
WSA 1.0-2.0 mm (%)	22.4^{b}	23.6^{bc}	26.5^{cd}	26.3^{cd}	23.8^{bc}	27.9^{d}	0.3^{a}
WSA 0.25-1.0 mm (%)	29.8^{cd}	27.8^{bc}	31.8^{d}	29.0^{bcd}	26.3^{b}	26.0^{b}	1.5^{a}
WSA 0.063-0.25 mm (%)	10.1^{a}	8.8^{a}	8.2^{a}	8.6^{a}	12.3^{a}	8.0^{a}	51.3^{b}
WSA < 0.063 mm (%)	9.1^{c}	7.6^{bc}	7.3^{bc}	4.7^{ab}	2.5^{a}	9.5^{c}	43.5^{d}

†Application rates are: 0x=0 L ha^{-1} (Bare), 1x=0.3 L ha^{-1}, 10x=3.0 L ha^{-1}, 100x=30 L ha^{-1}, 1,000x=300 L ha^{-1}, 10,000x=3,000 L ha^{-1}, 100,000x=30,000 L ha^{-1}.

‡Mean values in a given row (row-wise comparison) with the same letter are not significantly different at α=0.05.

TABLE 3. Mean values of water stable aggregate fractions and indices for the Lualualei Vertisol for various application rates of Agri-SC.

Variable	0x†	1x	10x	100x	1 000x	10 000x	100 000x
GMAD (mm)	$0.479^{b\ddagger}$	0.494^{bc}	0.491^{b}	0.490^{b}	0.514^{cd}	0.527^{d}	0.264^{a}
WSA > 0.25 mm (%)	33.8^{b}	36.9^{bc}	37.1^{bc}	35.7^{b}	41.2^{cd}	43.9^{d}	2.8^{a}
WSA 2.0-4.0 mm (%)	1.5^{d}	1.0^{abc}	0.9^{ab}	1.1^{abcd}	1.3^{bcd}	1.5^{cd}	0.6^{a}
WSA 1.0-2.0 mm (%)	1.5^{b}	1.7^{b}	1.7^{b}	1.4^{b}	1.8^{b}	2.5^{c}	0.3^{a}
WSA 0.25-1.0 mm (%)	30.7^{b}	34.2^{cd}	35.5^{cd}	33.2^{bc}	38.1^{de}	39.9^{e}	1.9^{a}
WSA 0.063-0.25 mm (%)	44.9^{d}	43.7^{bcd}	42.9^{bcd}	44.9^{cd}	40.7^{bc}	39.3^{b}	18.9^{a}
WSA < 0.063 mm (%)	21.3^{b}	19.4^{ab}	20.1^{ab}	19.4^{ab}	18.1^{ab}	16.9^{a}	78.4^{c}

†Application rates are: 0x=0 L ha^{-1} (Bare), 1x=0.3 L ha^{-1}, 10x=3.0 L ha^{-1}, 100x=30 L ha^{-1}, 1,000x=300 L ha^{-1}, 10,000x=3,000 L ha^{-1}, 100,000x=30,000 L ha^{-1}.

‡Mean values in a given row (row-wise comparison) with the same letter are not significantly different at α=0.05.

TABLE 4. Mean values of water stable aggregate fractions and indices for the Molokai Oxisol for various application rates of Agri-SC.

Variable	0x[†]	1x	10x	100x	1 000x	10 000x	100 000x
GMAD (mm)	0.849[d‡]	0.713[b]	0.692[b]	0.772[c]	0.794[c]	0.705[b]	0.343[a]
WSA > 0.25 mm (%)	75.6[e]	67.1[c]	64.8[b]	70.6[d]	72.0[d]	64.9[b]	4.4[a]
WSA 2.0-4.0 mm (%)	24.7[d]	14.4[b]	12.2[b]	14.4[b]	18.4[c]	18.2[c]	1.0[a]
WSA 1.0-2.0 mm (%)	27.5[e]	23.9[bc]	22.2[b]	25.2[cd]	26.1[de]	23.4[bc]	0.6[a]
WSA 0.25-1.0 mm (%)	23.4[b]	28.8[cd]	30.4[d]	30.9[d]	27.5[c]	23.3[b]	2.7[a]
WSA 0.063-0.25 mm (%)	12.2[a]	15.0[b]	18.0[cd]	19.0[d]	16.1[bc]	14.1[ab]	52.9[e]
WSA < 0.063 mm (%)	12.3[a]	17.9[b]	17.2[b]	10.4[a]	11.9[a]	21.0[c]	42.7[d]

[†]Application rates are: 0x=0 L ha^{-1} (Bare), 1x=0.3 L ha^{-1}, 10x=3.0 L ha^{-1}, 100x=30 L ha^{-1}, 1,000x=300 L ha^{-1}, 10,000x=3,000 L ha^{-1}, 100,000x=30,000 L ha^{-1}.

[‡]Mean values in a given row (row-wise comparison) with the same letter are not significantly different at α=0.05.

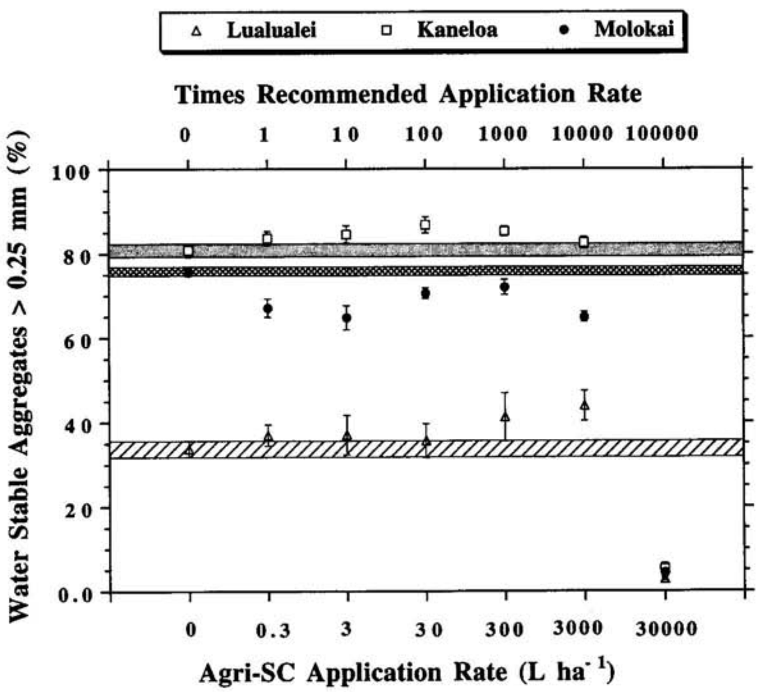

FIGURE 1. Variation in geometric mean aggregate diameter for seven application rates of Agri-SC applied to three Hawaiian soils. Shaded regions represent the 95% confidence band about the mean of the untreated aggregates.

Only very high application rates of Agri-SC increased aggregate stability of the Lualualei Vertisol (Table 3). For example, significant increases in GMAD and % WSA >0.25 mm were found at rates of 1,000x and 10,000x. Accompanying these increases were decreases in % WSA 0.063-0.25 mm (significant at both rates) and % WSA <0.063 mm (significant at 10,000x). Also of interest is that 2.00-4.00 mm aggregates were not preserved until application rates were 100 to 10,000 times recommended.

Nearly all Agri-SC treatments between 10x and 10,000x on the Molokai Oxisol ranged from ineffective to detrimental, as indicated by significant decreases in GMAD, % WSA >0.25 mm, % WSA 2.00-4.00 mm, and % WSA 1.00-2.00 mm. The decreases in the larger fractions were accompanied by significant increases in several of the small fraction indices, especially % WSA 0.25-1.0 (10x - 1,000x) mm, % WSA 0.063-0.25 mm (10x-1,000x), and WSA <0.063 (10x, 10,000x).

At application rates of 100,000 times recommended aggregates from all test soils were peptized (destroyed). The GMAD, % WSA >0.25 mm, and % WSA 2.00-4.00 mm aggregates for all soils were greatly reduced (Figure 1-2, Tables 2-

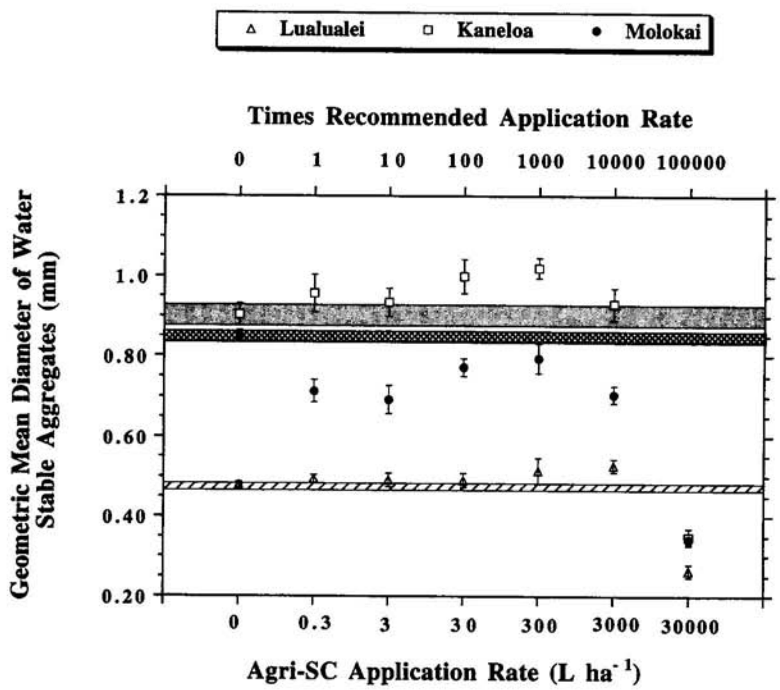

FIGURE 2. Variation in percent of water stable aggregates greater than 0.25 mm for seven application rates of Agri-SC applied to three Hawaiian soils. Shaded regions represent the 95% confidence band about the mean of the untreated aggregates.

4). In addition, % WSA 0.063-0.25 mm and % WSA <0.063 mm increased significantly. The disruption of aggregates at this extremely high application rate indicates that the critical micelle concentration (CMC) for this surfactant was exceeded. As Professor A. Jacobson (Carnegie Mellon University, personal communication, 1996) suggests, above the CMC, the micellar "aggregates" of the surfactant may start to solubilize the soil.

SUMMARY AND CONCLUSIONS

Response of aggregate stability to the application of the soil conditioner Agri-SC was soil dependent. At low application rates of 0.3 and 3.0 L ha^{-1} (1 and 10 times manufacturer-recommended rates, respectively) significant increases of aggregate stability were found for only the Kaneloa Oxisol, which was the most stable soil tested. All application rates of Agri-SC (1x-10,000x) on the Molokai Oxisol decreased aggregate stability, thereby increasing the presence of highly erodible aggregate fractions after testing. Only at very high application rates (i.e., 1,000x and 10,000x), did Agri-SC increase aggregate stability on the Lualualei Vertisol, the least stable soil tested.

The generally poor performance of this anionic surfactant on the Lualualei Vertisol and the Molokai Oxisol probably relates to their low anionic exchange capacities at their prevailing pH levels. The results of Agri-SC on these two soils support the earlier work of Fitch et al. (1989), in that Agri-SC at low application rates (<10 times recommended) may have no significant influence on mean WSA diameter. The agricultural soil (Alfisol) examined by Fitch et al. (1989) differed mineralogically from the Hawaiian soils examined in this study. To date, only the Kaneloa Oxisol tested in this work, and the Entisol from England examined by Fullen et al. (1993, 1995), have shown increased aggregate stability when treated with Agri-SC. These contradictory results indicate that further work is required to isolate soils most suited to the application of Agri-SC, and to explain its effect. Additionally, studies are also needed to investigate the relationship between indices of water stable aggregation and process measurements of interrill and rill erosion.

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