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Lehrsch, G.A., D.C. Kincaid, and R.D. Lentz. 1996. Polyacrylamide sprayed on soil surfaces can stabilize soil aggregates. p. 533-538. In Erosion control technology - bringing it home. Proc. of Conf. 27, Seattle, WA. 27 Feb. - 1 Mar. 1996. Int. Erosion Control Assoc., Steamboat Springs, CO.

POLYACRYLAMIDE SPRAYED ON SOIL SURFACES CAN STABILIZE SOIL AGGREGATES

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ABSTRACT

Vegetative cover protects soil surfaces and aggregates from erosion caused by the impact of raindrops or sprinkler drops. On bare surfaces, drop impact and wetting causes soil aggregates to slake, releasing aggregate fragments and/or primary particles that can obstruct pores at the soil surface and form a depositional seal. The seal reduces infiltration which, in turn, increases runoff and soil erosion. Polyacrylamide (PAM) applications, known to stabilize surface soil in irrigated furrows, may effectively stabilize soil aggregates as well. This field experiment evaluated the effects of spray-applied PAM and sprinkler droplet energy on surface soil aggregate stability, measured before and after 31 mm of irrigation. A moderate charge-density, anionic PAM at two nominal rates, 10 and 25 kg ha^{-1}, was applied as a sprayed solution to replicated plots of a Portneuf silt loam (coarse silty, mixed, mesic *Durixerollic Calciorthid*) near Kimberly, Idaho, on 25 July, 1995. A linear-move irrigation system, designed to deliver water to the soil surface at two droplet energy levels, 5 and 15 J kg^{-1}, applied a total of 31 mm of water to the plots 7 and 10 days after treatment. Soil samples (0 to 5 mm depth) were taken before and 72 hours after this water was applied. Gravimetric water content and aggregate stability by wet sieving were measured on these samples. Initially, PAM-treated aggregates visually appeared to resist breakdown under sprinkler/drop impact better than non-treated aggregates. PAM applications at economic rates increased aggregate stability when droplet energy was 5 J kg^{-1} but had no effect when droplet energy was 15 J kg^{-1}.

INTRODUCTION

Raindrop impact alters soil surfaces on both a large (landscape) scale and also a small scale. Droplet energy-induced modifications on a small scale influence hydrologic processes such as erosion, infiltration, surface sealing, and soil surface depressional storage. Raindrop or sprinkler drop impact upon unprotected soil surfaces decreases depressional storage and leads to the formation of surface crusts. Physical properties of the soil largely determine how a soil responds to external forces such as droplet impact (Truman et al., 1990). Interactions between raindrop or sprinkler drop impact energy and the stability of aggregates at the soil surface warrant further research.

Raindrop impact generally decreases aggregate stability (Glanville and Smith, 1988; Truman et al., 1990). An aggregate's resistance to drop-impact-induced breakdown is positively correlated with the soil's final infiltration rate and negatively correlated with its surface sealing rate. Knowing the response of soil aggregates to droplet energy will enable researchers to better design and manage irrigation systems to minimize surface sealing, maximize infiltration, and control erosion.

When applied to the soil surface, polyacrylamide (PAM) may increase an aggregate's resistance to breakdown by drop impact. All PAM molecules have a backbone structure made by linking the simple organic compound acrylamide, C_3H_5NO, into long chains. The term PAM is used to describe an entire class of compounds, each different in its chemical and physical properties due to different chain lengths and minor alterations in some of the acrylamide subunits (Sojka and Lentz, 1994). Water-soluble PAMs are effective flocculants, used as settling agents in food processing, water treatment, mineral processing, and paper production (Barvenik, 1994).

PAM has been used in agriculture for nearly half a century. Early on, relatively low molecular weight PAMs at high rates (> 500 kg ha^{-1}) were often incorporated into the plow layer, i.e., the uppermost ≈ 15 cm of soil, to improve soil structure (Azzam, 1980; Sojka and Lentz, 1994). More recently, much higher molecular weight, moderately anionic PAMs were added to irrigation water to control erosion, maintain infiltration rates, and strengthen soil structure (Lentz and Sojka, 1994; Trout et al., 1995).

There is no consensus in the literature regarding PAM's effectiveness in stabilizing aggregates, particularly under rain or sprinkler drop impact. Shainberg et al. (1992) found that PAM-treated aggregates were better able to resist breakdown caused by water drop impact than non-treated aggregates. Ben-Hur (1994) attributed decreases in runoff and erosion caused by 20 kg PAM ha^{-1} sprayed on soil surfaces to suspected increases in aggregate stability that prevented surface seal formation. Other studies, however, show less promise for PAM. Levy et al. (1995) found that PAM-treated surface aggregates were not sufficiently stable to withstand drop impact and, as a consequence, allowed a surface seal to form on soils with exchangeable sodium percentages from 13 to 30%. While the application of 20 kg PAM ha^{-1} did reduce runoff and erosion, Ben-Hur (1994) encountered problems with PAM because it dissolved slowly in water and was viscous when in solution.

PAM is effective in apparently stabilizing aggregates along the wetted perimeters of irrigated furrows. PAM may be less effective, however, in controlling surface aggregate breakdown and seal formation from overhead irrigation, due to the much higher energy input, up to 260 times more, from falling water drops than flowing water (Hudson, 1971). This study was part of a larger experiment examining the effects of PAM on sugarbeet (*Beta vulgaris* L.) emergence. The long-term goal of the research project is to increase sugarbeet emergence via the cost-effective application of an appropriate chemical anti-crusting agent and/or manipulation of the soil surface above planted rows of sugarbeet. The objective of the field study we report here was to determine PAM and sprinkler droplet energy effects on soil aggregate stability before and after 31 mm of irrigation.

METHODS AND MATERIALS

Supplies and Plot Details

The polyacrylamide used was Superfloc 836A, manufactured by CYTEC Industries, Wayne, New Jersey. It has a high molecular weight of 12–15 Mg mol^{-1} and moderate anionic charge-density. It was anionic because OH^- replaced 18% of the NH_2^- groups on the acrylamide subunits (i.e., 18% hydrolysis).

The soil was a Portneuf silt loam, a coarse silty, mixed, mesic *Durixerollic Calciorthid.* A representative Portneuf Ap horizon commonly contains 660 g silt kg^{-1} and 200 of clay. Its cation exchange capacity is 18.6 cmol$_c$ kg^{-1}, pH (in a saturated paste) is 7.7, and sodium adsorption ratio is 0.87. Its organic C content is approximately 9.3 g kg^{-1} and its aggregate stability at the soil surface at the start of the study was approximately 84%.

The experiment was performed 2.1 km southwest of Kimberly, Idaho, on a field cropped in 1994 to spring wheat, *Triticum aestivum* L. After being moldboard plowed on 11 April 1995, it was roller-harrowed to a depth of 80 mm, once on 17 April, 16 May and 18 May for an earlier study, and twice on 24 July in preparation for the current study.

The experiment was conducted as a split-split-plot design with main plots arranged in randomized complete blocks, with four replications. The main plots were two droplet energy levels, 5 and 15 J kg^{-1} of water reaching the soil surface. PAM treatments shown in Table 1 were the subplots, and pre- and post-irrigation sampling times were the sub-subplots. Droplet energy levels were randomly assigned to each 19.8 m half

Table 1. Pam Treatments Studied.

Treatment ID	PAM applied to sprayed area: Nominal	PAM applied to sprayed area: Actual	Tap water applied
	-----------kg ha^{-1}-----------		(Y/N)
Control	0	0	N
Water	0	0	Y
10 kg ha^{-1}	10	9.9	Y
25 kg ha^{-1}	25	26.7	Y

span of a linear-move irrigation system. The PAM treatments were randomly assigned to plots under each half span. Plots, each 25 mm wide, were perpendicular to the direction of travel of the irrigation system.

PAM Solutions and Spraying

Table 2 gives operational details of the equipment used to spray the PAM treatments on the soil surface. Tap water, used for the water treatment and to make up the two PAM solutions, had an electrical conductivity of 0.9 dS m^{-1} and a sodium adsorption ratio of 1.5.

Each of the spray solutions was placed in a 19-L tank pressurized with regulated air to maintain the desired nozzle pressures, Table 2. Each solution flowed through approximately 2.3 m of 6 mm (I.D.) hose before entering the fitting of a drop nozzle. Each spray nozzle was fixed in position immediately behind a Milton sugarbeet planter's rubber press wheels. To apply the PAM solutions to the soil surface, a tractor pulled the planter with the spray equipment across the plots at 4.12 km h^{-1}. The spraying of the plots on 25 July 1995 applied about 0.84 mm of tap water only to each of the water plots or 0.84 mm of PAM solution to each of the PAM plots, Table 2.

Irrigations

The linear-move system was used to irrigate the plots, Table 3. During the study, the only natural rainfall received was 0.5 mm on 30 August. We monitored aggregate stability response to only the irrigations on 1 and 4 August, considered a single irrigation for the purposes of this study. This relatively heavy irrigation of 31 mm was selected because it was comparable to one that might occur under a solid-set irrigation system. Such an irrigation was simulated by passing the linear system over the plots twice in a span of 72 h, from 1 to 4 August. Applying more than 21 mm of water at any one time was difficult because the soil's low infiltration rate caused ponding and runoff. Four catch cans, at the soil surface under each 19.8 m wide half span, were used to measure the amount of water applied.

Table 2. Operating Characteristics of the Spray Equipment.

Treatment ID	PAM conc.	Nozzle pressure	Flow rate	Nozzle height above soil surface
	mg L^{-1}	kPa	L h^{-1}	mm
Control	0	-	-	-
Water	0	169	85.4	76
10 kg ha^{-1}	1200	207	86.3	38
25 kg ha^{-1}	3000	476	93.1	76

Table 3. Irrigation Summary.

Irrigation date[†]	Water applied
	mm
27 Jul	12
1 Aug	21
4 Aug	10
10 Aug	10
11 Aug	22

[†] PAM treatments were sprayed on plot surfaces on 25 July 1995

Soil Sampling and Analyses

Soil samples were taken prior to spraying, to establish baseline conditions, and before and after the monitored irrigation. To determine baseline aggregate stability, 10 samples were taken from the uppermost 5 mm of the profile throughout the study area on 25 July. This shallow depth increment was sampled per the recommendation of Lehrsch and Zobeck (1996) and because Mitchell (1986) found that PAM solutions sprayed on soil had no effect at depths greater than 50 mm. About 2 hours prior to the irrigation on 1 August, samples were taken to a depth of 5 mm from each plot. On these so-termed pre-irrigation soil samples, gravimetric water content was measured and aggregate stability was determined using the procedure of Kemper and Rosenau (1986), as modified by Lehrsch and Jolley (1992). The principal modification was that field-moist 1 to 4 mm aggregates, rather than air-dry 1 to 2 mm aggregates, were vapor-wetted using a non-heating vaporizer (Humidifier Model No. 240, Hankscraft, Reedsburg, Wis.) prior to wet sieving. Aggregate stability was reported as the weight percent of aggregates that remained stable after sieving in distilled water for 3 min. A second set of soil samples, the post-irrigation samples, was taken 72 hours after the irrigation on 4 August, and analyzed as were the pre-irrigation samples.

Statistical Analyses

An analysis of variance was used to identify sources of variation that were statistically significant, here defined as those with *F*-ratios significant at probability levels on the order of 0.10 or less. Once a significant source was found, aggregate stability means were separated using paired t-tests and a 0.05 probability level. Additional, pre-planned single degree-of-freedom comparisons were also made.

RESULTS AND DISCUSSION

The PAM solutions, due to their increased viscosity at high PAM concentrations (Ben-Hur, 1994), affected the spray patterns reaching the soil surface (Kincaid et al., 1996). The pattern of the 1200 mg L^{-1}-solution was fan-shaped about 35–40 mm below the nozzle but coalesced into a stream about 65 mm below the nozzle. Thus, to spray a 25 mm wide plot, we lowered the nozzle for this treatment to 38 mm above the soil surface, Table 2. The spray pattern of the 3000 mg L^{-1}-solution was never fan-shaped but resembled a dribbling stream. To apply this solution, we used two nozzles with one offset about 12 mm from the other so that the combination of both streams wet the soil in a 25 mm wide band.

PAM affected aggregate stability differently, depending upon droplet energy. Figure 1 illustrates the effects of this two-way interaction, significant at $P = 0.064$, on aggregate stability, averaged over the pre- and post-irrigation samples. At a droplet energy of 5 J kg^{-1}, aggregate stability increased almost linearly with each treatment. The difference between the highest PAM application and the control was significant at the $P = 0.01$ level.

At a droplet energy of 5 J kg^{-1}, the water treatment was as effective as either of the PAM treatments, Figure 1. As these three treatments were sprayed on the soil surface, they wet surface aggregates, albeit slightly, and may have provided a pathway through which slightly soluble bonding agents could have diffused to contact points between soil particles, there to precipitate as these aggregates subsequently dried (Kemper and Rosenau, 1984).

At this low droplet energy, single degree-of-freedom comparisons indicated that the average aggregate stability of the two PAM treatments, 84.3%, was significantly greater ($P = 0.024$) than the control, 81.7%. Moreover, the aggregate stability of the PAM-treated soil was significantly greater ($P = 0.03$) than the non-PAM-treated soil, 82.3%. These statistical results confirm what was observed earlier, that PAM-treated aggregates initially resisted breakdown by sprinkler-drop impact.

At a droplet energy of 15 J kg^{-1}, in contrast, PAM did not affect aggregate stability, Figure 1. The additional stability imparted by the PAM to the aggregates on the soil surface was not sufficient to prevent them from being broken or, at least, weakened by the greater energy input. Ben-Hur (1994) found PAM to be more effective in reducing runoff and erosion with less

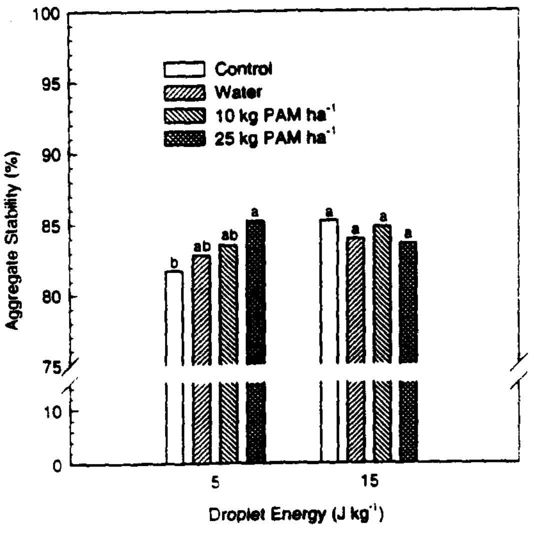

Figure 1. PAM and droplet energy effects on aggregate stability averaged over the pre- and post-irrigation samples. Within each droplet energy, means without a common letter differ at the 0.05 probability level.

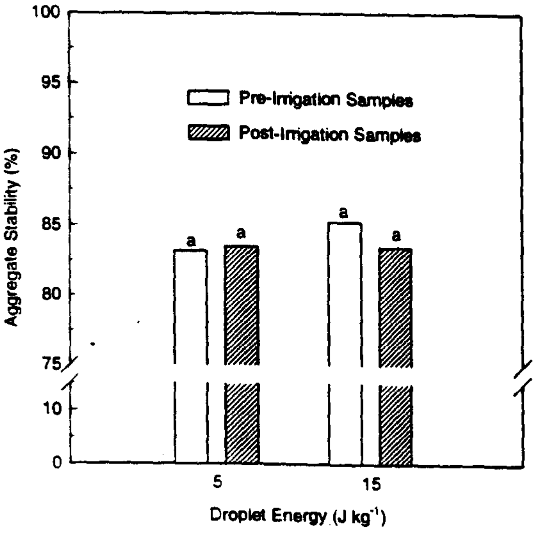

Figure 2. Sampling time and droplet energy effects on aggregate stability averaged over four treatments. Within each droplet energy, means with a common letter do not differ at the 0.05 probability level.

energy input (i.e., early in the irrigation season) than more (late in the season).

The importance of the energy delivered to the soil surface by the sprinkler drops can be seen in Figure 2. It illustrates the significant interaction (P = 0.106) between sampling time and droplet energy on aggregate stability, averaged over the four treatments. At low droplet energy, there was little difference between the aggregate stability of the pre- and post-irrigation samples. At high droplet energy, in contrast, aggregate stability dropped from 85.3% to 83.5%, significant at P = 0.058.

Figure 2 reveals that, for the pre-irrigation soil samples only, their aggregate stability was greater under the high energy level than under the low. In the 15 J kg^{-1}-plots, high energy droplets from the non-monitored irrigation on 27 July (Table 3) may have already broken less stable aggregates to diameters < 1 mm. Thus, when the samples taken on 1 August were sieved prior to aggregate stability analysis, only the remaining, more stable aggregates with diameters from 1 to 4 mm were recovered and, subsequently, analyzed. Glanville and Smith (1988) found that mean weight diameter decreased as rainfall increased on bare soil surfaces, thus revealing a shift in the aggregate size distribution toward the smaller size classes. The apparent, greater pre-irrigation stability with higher energy input in this study may well have been an artifact of the sampling and analysis procedure used. In subsequent studies of droplet energy effects on aggregate stability, more than one size class of aggregates should be studied.

CONCLUSIONS

1. PAM sprayed on soil surfaces increased aggregate stability, provided the energy input from sprinkler drop impact was not too great.

2. The spray application of the PAM used in this study was not effective in preventing the physical deterioration of the soil surface when it was exposed to sprinkler droplet energy of 15 J kg^{-1}.

3. In this study, droplet energy appeared to be a more important factor causing change in aggregate stability than was the PAM we studied.

DISCLAIMER

Trade names are included for the benefit of the reader and do not imply endorsement of the product by the USDA.

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