Comparing Effects of Granular and Oil-Emulsion PAM on Soil Erosion, Water Infiltration, and Yields of Furrow Irrigated Crops

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INTRODUCTION

Two formulations of water-soluble anionic polyacrylamide (WSPAM) are used in agriculture to reduce erosion and manage infiltration in furrow irrigations: 1) the granular or solid form and 2) the inverse emulsion or oil-based liquid form, in which polymer occurs as aqueous droplets stabilized by surfactants in a continuous phase of a petroleum distillate.

Few if any published studies have directly compared the two major types of WSPAM products for furrow irrigation. Furthermore, WSPAM research published to date reports primarily short-term observations and rarely evaluates agronomic impacts. For example, only a few studies continued WSPAM application and monitoring of treated furrows into a second irrigation season.

OBJECTIVE

The objective of this research was to compare the efficacy of granular and emulsion WSPAM applications for managing infiltration and erosion in irrigated furrows, and to determine WSPAM effects on crop yields over a seven-year period of continual treatment.

MATERIALS AND METHODS

SITE AND CROPS

The 7-year-long experiment was initiated in 1993 on furrow irrigated Portneuf silt loam soils (coarse-silty, mixed superactive, mesic Durinodic Xeric Haplocalcids) with 1.5% slopes near Kimberly, Idaho, USA. Each experimental unit was 4-m wide by 180-m long, and was separated from adjacent plots by a 1.3-m wide buffer strip. Each plot included 5 planted rows (0.76-m spacing) in years when the field was planted to silage corn (*Zea mays* L.) and 7 planted rows (0.55-m spacing) in years the field was planted to bean ('Viva Pink' *Phaseolus vulgaris* L.).

EXPERIMENTAL DESIGN

The experimental design was a randomized complete block with three replicates. The three treatments included: 1) control (no WSPAM); 2) WSPAM applied as a solution made up from solid PAM (A110) and injected into the irrigation inflows at a concentration of 10 mg L^{-1} only during irrigation advance (while water first advances down the furrow); and 3) WSPAM applied as a solution made up from inverse emulsion WSPAM and injected identically to that of the A110 treatment. The same treatment was applied in the same plot for each irrigation and for each year during the 7-y study.

WSPAM EMPLOYED

The two WSPAM formulations (Kemira Water Solutions, 1937 West Main Street, Stamford, CT) were linear anionic copolymers with 15 to 20 Mg mol^{-1} molecular weight.

A110: A solid acrylamide/sodium acrylate copolymer with 18% charge density

A1883: A liquid inverse emulsion acrylamide/acrylic acid-ammonium salt copolymer with 30% charge density.

IRRIGATIONS

Five to seven irrigations were applied to plots each year, except in the fallow year, when two were scheduled (Table 1). Irrigation inflow rates and set duration employed in the first four years differed from those used in subsequent years.

1993 to 1996:

Inflow Rates: 23 L min^{-1} until furrow streams had advanced to the end of the furrow, then 15 L min^{-1}.

Irrigation Durations: Identical for all treatments, typically 12 h.

1997 to 1999:

Inflow Rates: 15 L min^{-1} for controls; 45 L min^{-1} for WSPAM furrows; all reduced to 15 L min^{-1} once furrow streams had advanced. WSPAM furrow inflows were set higher to overcome WSPAM's tendency to slow furrow advance and thus reduce irrigation uniformity. WSPAM prevented erosion that would ordinarily occur at these higher inflow rates.

Irrigation Durations: Adjusted in real time so that all treatments received similar net furrow infiltration amounts. Irrigation set times for irrigations ranged from 8 to 30 h.

IRRIGATION TYPE

Each irrigation was classified as being one of three irrigation types (*Irr. Type*) based on the number of irrigations applied to the furrow before it was reformed:

Irr. Type 1 1st irrigation on freshly formed furrows;
Irr. Type 2 2nd irrigation on an otherwise undisturbed furrow;
Irr. Type 3 furrows having 2 or more repeat irrigations on an otherwise undisturbed furrow.

Table 2. Crop, planting and irrigation characteristics for years included in the study.

Year	Crop	Planting Date	Harvest Date	Irrigation #	Date of 1st Irrigation	Date of Last Irrigation	Irrigation Water Inputs
							mm
1993 †	Corn	17 May	21 Sept.	7	26 May	18 Aug.	181
1994	Beans	2 June	1 Sept.	5	8 June	3 Aug.	217
1995	Beans	1 June	7 Sept.	7	15 June	16 Aug.	226
1996	Fallow ‡	n/a	n/a	2	5 Sept.	19 Sept.	73
1997	Corn	8 July §	21 Sept.	5	16 July	10 Sept.	186
1998	Corn	1 June §	21 Sept.	5	8 July	2 Sept.	239
1999	Corn	18 May	28 Sept.	7	23 June	8 Sept.	347

† Yield measurements were not determined for this crop.
‡ In 1996, soil water percolation samplers were installed below the soil surface in the field, so a crop was not grown.
§ In 1997, the planting date was delayed to allow completion of the above-ground soil water collection equipment. A corn hybrid with 75-day maturity was planted to match the brief season. In 1998, the planting date was delayed due to heavy spring rains.

MEASUREMENTS

Furrow inflows rates, *stream outflow rates*, and *sediment concentrations* were measured during each irrigation.

Net infiltration volume for individual furrows was calculated by subtracting the total outflow volume from the total inflow volume, where inflow and outflow volumes were computed by integrating the inflow- and outflow-rate curves over time. Net infiltration was reported on an area basis (mm depth).

Standardized parameters for soil loss, infiltration, and crop yield were computed to permit comparisons among years. The average control value was used in order that all soil loss and yield responses could be established relative to a single, field-wide control standard in each year.

Soil-loss reduction — 100 times the ratio of soil loss difference (WSPAM treatment minus average control value) to average control soil loss.

Yield gain — Ratio of the WSPAM yield gain to the average control value, where yield gain was calculated as the yield difference, WSPAM minus the average control value.

Infiltration fraction — 100 times the ratio of net furrow infiltration divided by net inflow.

RESULTS AND DISCUSSION

The A1883 and A110 treatments reduced erosion equivalently, and over the 7-y study, prevented the loss of an average 47.8 Mg soil ha^{-1}, in comparison with soil losses in control furrows (Fig. 1).

Relative to controls in each irrigation, WSPAM treatments as a class significantly decreased runoff sediment losses (84%), decreased runoff sediment concentrations (82%), and increased net infiltration (1.08 times).

A significant interaction between treatment and year (P < 0.05) influenced runoff sediment concentration and sediment losses, outflow rate, and net infiltration in each irrigation (Fig. 2).

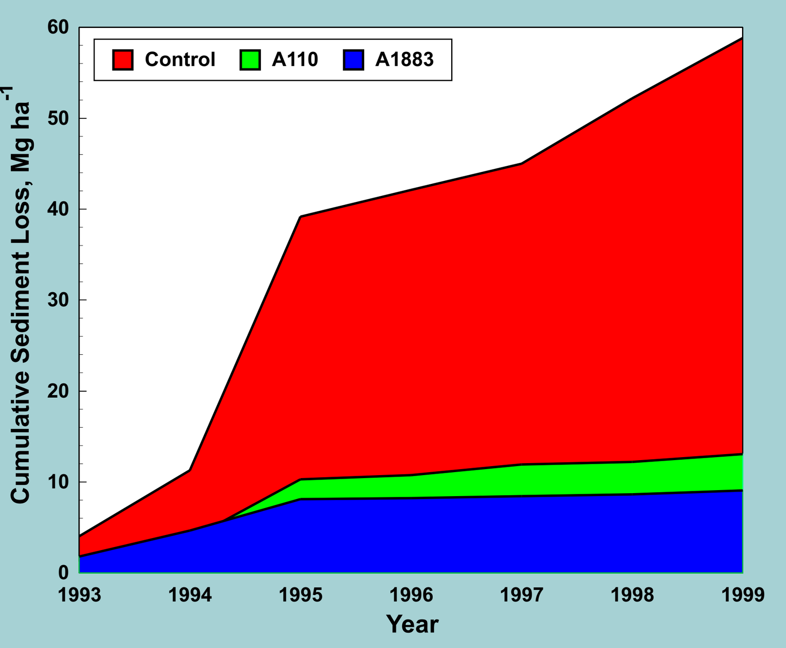

Fig. 1. Yearly cumulative runoff soil losses for the three furrow treatments.

Table 2. The effect of control and WSPAM treatments as a class on Irrigation mean values for furrow runoff sediment, outflow, infiltration and advance parameters.

Treatment	Sediment Loss	Sediment Conc.	Sediment Loss Reduction †	Mean Outflow Rate	Net Infiltration	Advance time	Infiltration Fraction
	Mg ha^{-1}	g L^{-1}	%	L min^{-1}	mm	min	%
Control	1.463 a ‡	4.6 a	0 a	8.10 a	36 a	87 a	54 b
WSPAM	0.242 b	0.85 b	84 b	7.97 a	39 a	56 b	56 b

† Soil loss reduction was computed relative to control values.
‡ If followed by the same letter, parameter values within a given column group (between rows) are not significantly different (P = 0.05).

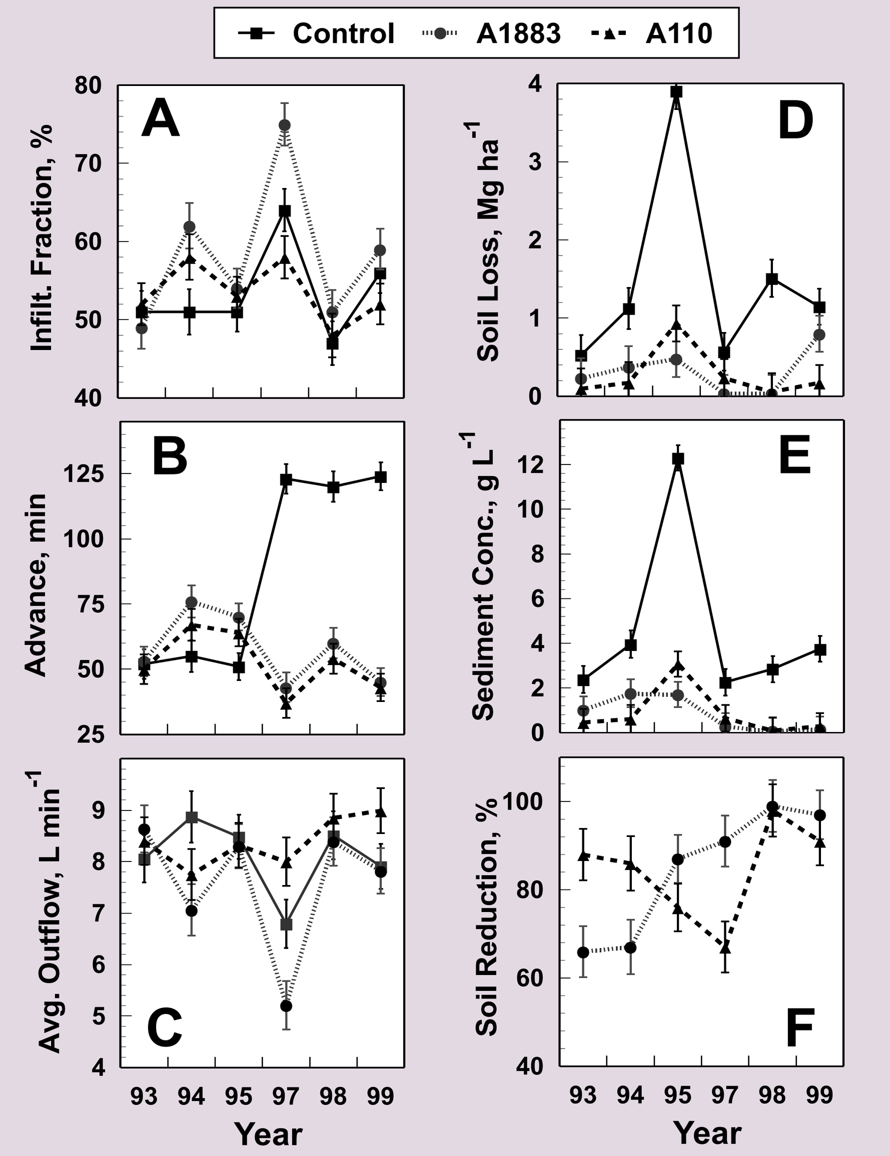

Fig. 2. Interaction effects of year and treatment on infiltration fraction (A), furrow advance period (B), Mean furrow outflow (C), runoff sediment loss (D), mean runoff sediment concentration (E), and soil loss reduction relative to controls (F). Values are derived from irrigation means. Each leg of an error bar equals one standard error (n=9).

Treatment By Year Interactions

Mean soil losses per year are shown for each treatment and year in Fig. 2d. These data suggest a trend in the response pattern, i.e., in 1993-94, mean soil losses for A110 were smaller than that of A1883, while the reverse was indicated for later years. We observed this relationship more clearly when examining the year-by-treatment interaction on soil-loss reduction (Fig. 2f). A similar response pattern occurred when soil loss reduction was computed from yearly cumulative total soil loss values (Fig. 3), except that differences between years 1993 and 1994 were not significant.

In Fig. 4 the yearly cumulative soil loss reductions for WSPAM treatments (from Fig. 3) were plotted as a function of the mean electrical conductivity (EC) of supplied irrigation water. The erosion control efficacy for A110 peaked at a water EC of 0.0365 S m^{-1} and declined when EC dipped below, or rose above this value. The erosion control efficacy of A1883 also declined when water EC fell below 0.0365 S m^{-1}, but unlike A110, was strong at lower ECs. The data imply that an optimal water EC may exist in this soil-water system with regard to erosion control. In contrast to A110, A1883 may have retained its erosion control efficacy at low EC values because it has a higher charge density and greater solvated coil diameter than A110.

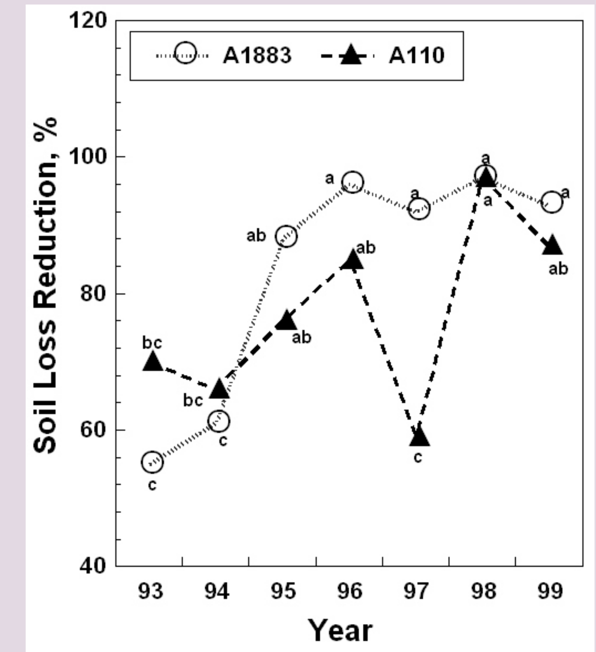

Fig. 3. The influence of inverse emulsion (A1883) and granular (A110) WSPAM treatments on yearly soil loss reduction (relative to controls). Values are derived from mean cumulative yearly soil losses. Quantities for symbols followed by similar letters are not significantly different.

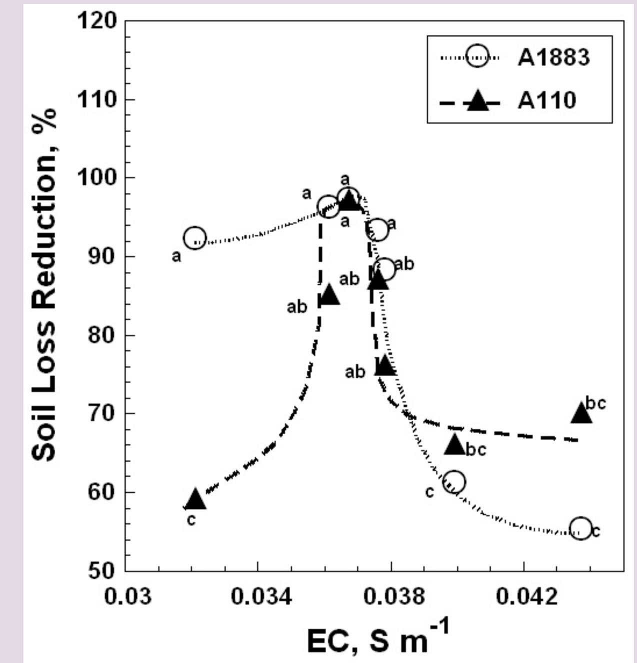

Fig. 4 The relationship between the mean electrical conductivity (EC) of supplied irrigation water and the reduction in cumulative yearly soil losses attained by inverse emulsion (A1883) and granular (A110) WSPAM treatments (relative to controls).

Treatment By Irrigation-Type Interactions

A significant interaction between treatment and irrigation-type (P < 0.05) influenced infiltration fraction and soil loss reduction.

In fresh furrows (*Irr. Type* 1), WSPAM treatments significantly increased infiltration fraction relative to control furrows (Fig. 5a). However, this infiltration benefit declined with repeated irrigations. The decline resulted from an increase in control furrow infiltration and not to a decrease in WSPAM furrow infiltration (with repeated irrigations). The infiltration fraction of controls increased from 47% in fresh furrows to 59% in multiple-repeat furrows, while WSPAM values were relatively unchanged (Fig. 5a). The increase in control furrow infiltration with repeated irrigations was attributed to decreasing furrow stream sediment concentrations.

In general, mean runoff sediment concentrations and runoff soil losses decreased, and WSPAM-induced soil-loss reduction increased, with irrigation type, i.e. as the number of irrigations conducted on an otherwise undisturbed furrow increased (Fig. 5d,e,f). The decrease in soil losses was partly due to the decreasing availability of loose, easily entrained soil present in freshly formed furrows that is systematically removed during each subsequent irrigation; and also due to the general decrease in furrow stream outflow rate that occurred with increasing irrigation number (Fig. 5c).

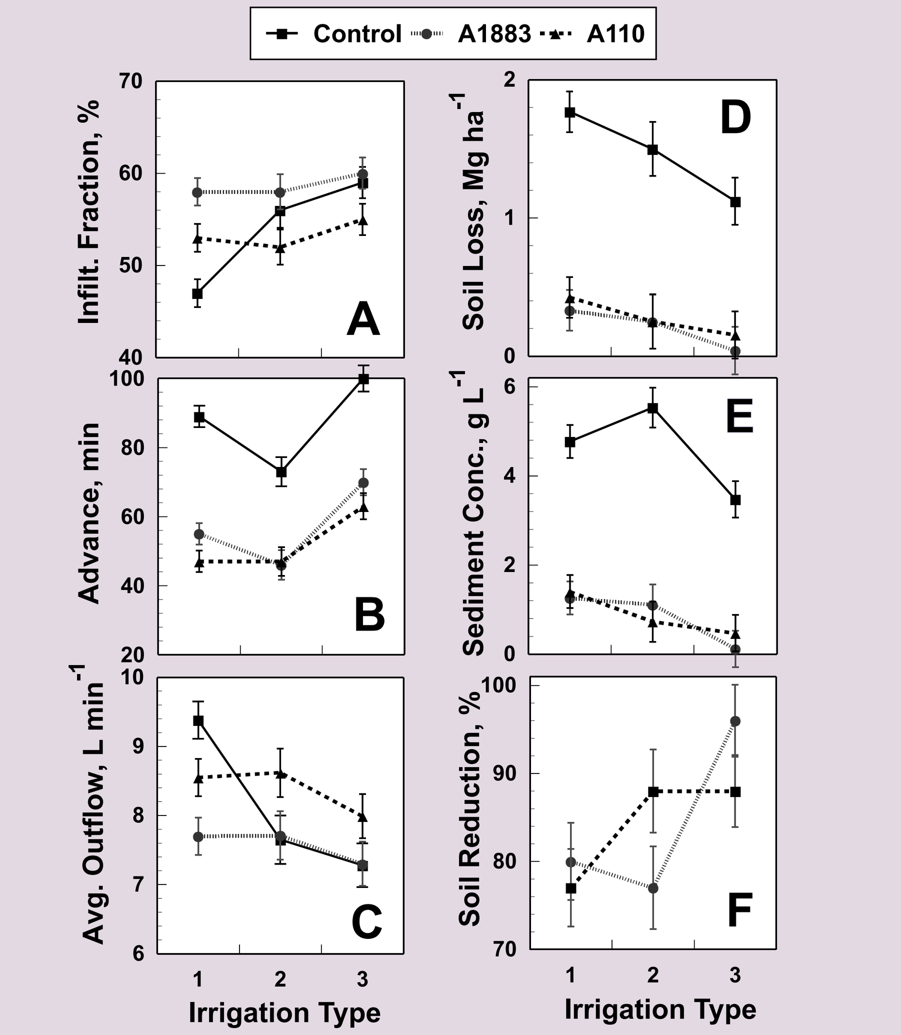

Fig. 5. The effect of treatment and irrigation-type on infiltration fraction (A), furrow advance period (B), Mean furrow outflow (C), runoff sediment loss (D), mean runoff sediment concentration (E), and soil loss reduction relative to controls (F). Values are derived from irrigation means. Each leg of an error bar equals one standard error (n=18).

Table 3. The effect of control and WSPAM treatments as a class on crop yield and yield gain†.

Variable	Treatment	Bean ‡	Corn ‡
Yield, Mg ha^{1}	Control	2.7 b§	20.5 a
	WSPAM	3.1 a	21.4 a
Yield Gain †, %	Control	0 b	0 b
	WSPAM	14.3 a	4.5 a

† Yield gain values were derived as the ratio of the treatment yield gain to the average control value, where yield gain was calculated as the yield difference, treatment minus the average control value.
‡ Mean crop stand counts were unaffected by treatment or field location: 41.5 plants $plot^{-1}$ for Bean and for 46.3 plants $plot^{-1}$ for Corn.
§ If followed by the same lower case letter, treatment values for a given variable and crop are not significantly different (P = 0.05).

WSPAM Effects on Crop Yield

When analyzed as a class in comparison to controls, the WSPAM treatments produced small but significant yield gains for both bean (14.3%) and corn (4.5%) crops (Table 3). Absolute bean yield values also significantly increased with WSPAM treatment (Table 3). While an increase in mean absolute corn yield for WSPAM treatments relative to controls was observed, the difference was not significant (P=0.06), possibly due to greater variability in corn yield values in comparison to that of beans.

Yield-gains observed for individual crops indicate that the cost of the WSPAM application may be reimbursed by an ensuing gain in crop yields. In this study the mean WSPAM application was 11.5 kg ha^{-1} y^{--1}, whereas, if the 23-L-min^{-1} water inflows used in the first few years were employed in all six cropped years, the total WSPAM used would have been 7.2 kg ha^{-1} y^{-1}. At the current price of \$8.80 kg^{-1} for A110 (solid WSPAM), this represents a cost of \$101 ha^{-1} y^{-1} for this study or as little as \$63 ha^{-1} y^{-1} had the low inflow rate been used in all years. This cost would double if A1883 (inverse emulsion WSPAM) was employed instead of A110. A 14.3% yield increase would produce an extra 0.43 Mg ha^{-1} y^{-1} in beans and a 4.5% yield increase would produce an extra 0.95 Mg ha^{-1} y^{-1} in standing corn. Local market prices realized over the last two years have ranged from \$360 to \$725 Mg^{-1} (\$20 to \$40 cwt^{-1}) for dry beans and from \$36 to \$50 Mg-1 (\$40 to \$55 ton^{-1}) for standing corn. Therefore, the additional yields could generate an additional \$155 to \$311 ha^{-1} y^{-1} for the bean and \$34 to \$48 ha^{-1} y^{-1} for the standing corn crops. Hence, the use of WSPAM in furrow irrigation not only generates benefits related to the conservation of sediment, water, and soil nutrients, but potentially provides yield enhancement and monetary reimbursement.