On-Farm Comparison of Polyacrylamide and Straw Mulch on Dry Bean Yield, Irrigation Performance and Erosion

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Quantity and quality of water resources are a major concern in Idaho, which is ranked fourth in the nation in terms of irrigated area. Approximately 690,000 ha. in Idaho is irrigated by some form of surface irrigation. Soil erosion due to surface irrigation significantly contributes to surface water quality degradation and threatens the sustainability of irrigated agriculture. The predominately silt loams soils of southern Idaho are highly erosive and typically have thin A horizons. Carter (1993) showed that the yield potential of these soils is significantly reduced if the A horizon is removed. Many fields in southern Idaho have little or no topsoil remaining on their upper reaches resulting from years of surface irrigation-induced soil erosion.

Surface irrigation in southern Idaho is common on slopes ranging from 0.5 to 4% which often vary within a field. As a result of erosion, furrows develop into narrow deep channels on slopes greater than 1-1.5%. This change in furrow shape decreases the wetted perimeter of the furrow and infiltration rate. Producers often consider crops such as dry beans and sugar beets adequately irrigated when the wetting front moves 5-10 cm beyond the plant row. Reduced infiltration rates resulting from furrow erosion lead to irrigation set times of 24 hrs or longer. These long irrigation set times exacerbate furrow erosion, increase the volume of sediment laden runoff and reduce irrigation efficiency. Producers often view adequate irrigation for maximum crop production more important than sediment losses in runoff and associated long-term productivity reductions. Surface irrigation management practices are needed to reduce surface irrigation-induced erosion, maintain or increase infiltration rates so that irrigation efficiency can be increased while sustaining crop yields and soil productivity and reducing offsite water quality degradation and associated societal costs.

Use of plant residues such as straw selectively placed in furrows, sometimes referred to as straw mulching, greatly reduces erosion and increases infiltration. Several research studies *(Aarstad and Miller, 1981; Brown, 1985; and Brown and Kemper, 1987)* have shown 52-90% reductions in furrow sediment loss and 30-110% increase in infiltration by straw mulching. Placement of residue in furrows greatly increases advance times as a result of increased infiltration rates. This increases the characteristic nonuniform infiltration along the furrow length resulting in increased deep percolation and reduced irrigation efficiency.

Surge irrigation, which employs multiple on/off periods of increased flow rates during the advance phase of irrigation, has been shown to provide advance times equivalent or slightly longer with straw mulching than conventional continuous flow irrigation with clean furrows *(Miller et al., 1987; Evans et al., 1987)*. The use of surge irrigation combined with straw mulching has been shown to maintain or improve irrigation uniformity while greatly reducing erosion and increasing infiltration rates. The increased infiltration caused by straw mulching is partially compensated by the decrease in infiltration resulting from surge flow application. Adoption of this irrigation management practice will require a significant modification to many existing surface irrigations systems in southern Idaho. Additionally, straw mulching can occur at inconvenient times for the producer, cause problems during cultivation and straw can move in the furrow, damming them and causing them to overflow into adjacent furrows.

The treatment of furrow irrigation water with 10 g m^{-3} of PAM during the advance phase of irrigation greatly reduces furrow erosion and increases infiltration. Recent research studies *(Lentz et al., 1992; Lentz and Sojka, 1994)* have shown 80-99% reductions in furrow sediment loss and -8-57% increases in infiltration. The low concentration of PAM required, which is used only in the advance phase of irrigation, results in a minimum amount of material being required which minimizes cost. Additionally, minimal equipment and little modification of existing irrigation systems is required depending upon the method used to apply the material.

Irrigation management techniques such as straw mulching and PAM for erosion control and infiltration modification are not widely practiced or recognized in many surface irrigated areas of the state. The objective of this study was to obtain site-specific information on the effect of straw mulching under surge flow irrigation and PAM with continuous flow furrow irrigation on irrigation performance, erosion control and crop yield to be used as a basis for dissemination of information on the potential advantages and disadvantages of these practices in the study area.

Study methods

The study site near Paul, ID, was on a Portneuf silt loam on a field conventionally planted to dry beans. Two experimental sites within the field were established. Site 1 has a slope of 1.6% and furrow length of 198 m (650 ft). Site 2 has a slope of 0.8% and furrow length of 213 m (700 ft). The small furrows were 15 cm deep (approximately) and parabolic in shape with a spacing of 112 cm (44 ins). The water source was groundwater and sediment free.

Each experimental site was established using a block of 18 furrows constituting a complete randomized block with six replicates and three treatments. The treatments consisted of the control, PAM and straw mulching combined with surge irrigation. Trafficked and non-trafficked furrows were not differentiated as field scale results were of primary interest. Both experimental sites were irrigated by individually regulated siphon tubes. Site 1 was irrigated from an earthen ditch and site 2 from a cement-lined ditch. The irrigation duration for all treatments was equal and approximately 12 h, half the 24-h duration employed by the producer on the remainder of the field. The control treatment consisted of continuous inflow over the 12-h period at a rate of 15.1 L min^{-1} (4 gpm).

The PAM treatment consisted of polymer addition to furrow inflow throughout the advance phase of irrigation. Water inflow to the furrow was continuous over the 12-h irrigation period at the same rate as the control. The polymer used was Superfloc A-836 (Cytec Industries Inc., West Paterson, NJ), a commercially available PAM formulation for soil erosion control. The PAM was injected at the turbulent point of water inflow at the furrow head from the siphon tube. The PAM injection system consisted of a portable constant head supply tank of stock PAM solution, 2250 g m^{-3}, connected to a fixed 3.8 cm (1.5 in.) diameter PVC manifold laid adjacent to the water supply ditch. The manifold was equipped with individually regulated outlets along the length. Clear plastic tubing was used to pipe the PAM stock solution from the manifold outlet to the appropriate furrow in each experimental block. The predetermined PAM injection flow rate was set prior to the start of water inflow to each furrow. The injection flow rate was predetermined to provide a PAM concentration of 10 g m^{-3} in the furrow. The duration of PAM injection was constant for all furrows and determined by the time for the last PAM-treated furrow to advance across the field.

The straw mulch treatment consisted of 931 kg ha^{-1} (832 lb ac^{-1}) straw hand-placed in each furrow prior to the first irrigation. Site 2 received a second equivalent straw application following a single cultivation between irrigation 1 and 2. Site 1 was not cultivated after planting, but did receive additional straw application following straw movement problems in the furrows during the first irrigation as a result of initially using too large of flow rate during advance. Water inflow to the straw-treated furrows was manually surged with an inflow rate of 22.7 L min-1 (6 gpm) (except first irrigation at site 1) during irrigation advance using 1 hr on/off cycles until most furrows advanced across the field (2 or 3 cycles). Thereafter, a continuous inflow of 18.9 L min^{-1} (5 gpm) was used throughout the remainder of the 12-h irrigation.

Site 1 received seven irrigations and site 2 received six irrigations during the season. Irrigations 1, 2, 4 and 5 at site 1 and 1, 2,3 and 4 at site 2 were monitored for inflow, outflow and sediment loss. Furrow inflow was monitored periodically during irrigation. Furrow outflow was continuously recorded throughout the irrigation using a data logger and instrumented, individually calibrated V-notch flumes (Honkers Supreme, Twin Falls, ID)*(Trout, 1986)*. Sediment loss was monitored by collecting one-liter runoff samples from the free-flowing flume discharge every 15 min during the first hour, every 30 min for the next 2 to 3 h and every 60 min thereafter. The weight of sediment per liter of runoff was determined from the settled volume in Imhoff cones, by calibrating the volume of settled sediment and sediment weight per unit volume of runoff (R^2 = 0.90). Irrigations where furrow outflow was not monitored, the same inflows (periodically measured during irrigation), PAM injection rates and surge times as described for each treatment were employed to maintain consisted treatments effects throughout the season. One exception was irrigation number seven at site 1 which the producer performed unexpectedly.

Dry bean yield was measured at three locations in each furrow in the experimental sites. Two-meter of bean row was sampled on each side of the furrow at distances of 30.5, 122 and 182.9 m (100, 400 and 600 ft) from the furrow head. Yield samples were also taken adjacent to each experimental site under the producers irrigation regime for comparison.

Net furrow infiltration depth was determined by dividing the difference between cumulative furrow inflow and outflow volumes by furrow spacing and measured furrow length. Net

Table 1. Inflow, outflow, net infiltration, sediment loss, percent sediment reduction and percent increase in net infiltration at site 1.

Treatment	Cumulative inflow mm	Cumulative outflow mm	Net infiltration mm	Net infiltration %	Sediment loss kg ha^{-1}	Sediment reduction % of control
Irrigation 1						
control	51.4^{A†}	22.5^{A}	28.9^{A}	56.2	7382^{A}	0
PAM	52.3^{A}	17.4^{A}	35.0^{A}	66.9	2150^{B}	70.9
straw	51.6^{A}	16.6^{A}	35.0^{A}	67.8	376^{B}	94.9
Irrigation 2						
control	51.3^{A}	21.1^{A}	30.3^{A}	59.1	3033^{A}	0
PAM	51.0^{A}	14.5^{A}	36.5^{A}	71.6	397^{B}	86.9
straw	49.9^{A}	3.0^{B}	47.0^{B}	94.2	15^{B}	99.5
Irrigation 4						
control	53.9^{A}	15.8^{A}	37.1^{A}	68.8	1995^{A}	0
PAM	53.3^{A}	12.3^{A}	41.7^{A}	78.2	390^{B}	80.5
straw	50.8^{B}	3.4^{B}	47.4^{B}	93.3	11^{B}	99.5
Irrigation 5						
control	54.0^{A}	16.0^{A}	38.2^{A}	70.7	1935^{A}	0
PAM	54.1^{A}	14.6^{A}	39.6^{A}	73.2	143^{B}	92.6
straw	48.4^{B}	7.2^{B}	41.2^{A}	85.1	6^{B}	99.7

[†]Similar uppercase letters indicate nonsignificance (P=0.10) between treatments in each irrigation

infiltration percentage was computed as the ratio of net infiltration depth to cumulative inflow depth. Sediment reduction was computed as the ratio of sediment loss difference (control minus treatment) to sediment loss of the control. Analysis of variance was employed to test for significance of treatment effects within each irrigation. The Tukey multiple comparison procedure was employed to examine mean separations of cumulative inflow, cumulative outflow, net infiltration and sediment loss for each irrigation and yield.

Results and discussion

Irrigation and sediment loss data for the four monitored irrigations at experimental site 1 (1.6% slope) are presented in Table 1. For the first and second irrigations cumulative inflow for the 12-hr irrigations were not significantly different between the treatments. Cumulative inflow for the fourth and fifth irrigations were less for the straw treatment due to less irrigation on time as a result of employing three surge irrigation cycles rather than two. Cumulative outflow from the control and PAM treatment were not significantly different for any of the four monitored irrigations. Cumulative outflow for the straw treatment was significantly less than the control or PAM treatment for irrigations two, four and five. In the first irrigation we initially started with too large of surge flow which washed most of the straw from the furrows and resulted in rapid advance and cumulative outflow nearly equivalent to the clean furrow treatments.

Net infiltration for the straw treatment was significantly greater that the control or PAM treatment for irrigations two and four. Net infiltration for the straw treatment in irrigations two and three is significantly increased despite less cumulative inflow. Less cumulative inflow in irrigation five is partially responsible for the nonsignificant increase in net infiltration in the straw treatment. Net infiltration percentage for the PAM treatment was consistently greater than the control for all monitored irrigations.

Sediment loss was significantly reduced by both treatments for all four monitored irrigations. The straw treatment consistently resulted in less sediment loss than the PAM treatment. Despite the modest difference in sediment loss between the two treatments, it is not statistically significant. Furrow infiltration and erosion processes are often inherently variable making it difficult to detect small treatment differences. For the field conditions encountered in this study, more than the six replicates employed are necessary to differentiate small treatment differences as they are obscured by the occurrence of one or two anomalous extreme values in each irrigation. Sediment reduction relative to the control for site 1 was 70 to 93% for the PAM treatment and 94 to 99% for the straw mulch treatment.

Table 2. Inflow, outflow, net infiltration, sediment loss, percent sediment reduction and percent increase in net infiltration at site 2.

Treatment	Cumulative inflow mm	Cumulative outflow mm	Net infiltration mm	Net infiltration %	Sediment Loss kg ha^{-1}	Sediment Reduction % of control
Irrigation 1						
control	48.2^{A}	16.4^{A}	31.7^{A}	65.7	382^{A}	0
PAM	48.3^{A}	15.5^{A}	32.8^{A}	67.9	78^{A}	79.6
straw	49.5^{A}	7.7^{A}	41.8^{A}	84.4	45^{A}	88.2
Irrigation 2						
control	51.7^{A}	18.5^{A}	33.2^{A}	64.2	1298^{A}	0
PAM	48.6^{A}	14.2^{A}	34.4^{A}	70.3	87^{B}	93.3
straw	65.5^{B}	10.0^{A}	55.5^{B}	84.7	41^{B}	96.8
Irrigation 3						
control	52.6^{A}	10.7^{AB}	39.8^{A}	75.6	628^{A}	0
PAM	52.1^{A}	16.5^{A}	35.6^{A}	68.3	143^{B}	77.2
straw	46.4^{B}	8.0^{B}	38.4^{A}	82.8	25^{B}	96.0
Irrigation 4						
control	52.4^{A}	22.5^{A}	29.6^{A}	56.5	847^{A}	0
PAM	51.1^{A}	19.4^{A}	31.5^{A}	61.6	117^{B}	86.2
straw	50.4^{A}	7.3^{A}	43.2^{A}	85.7	21^{B}	97.5

[1]Similar uppercase letters indicate nonsignificance (P=0.10) between treatments in each irrigation

Irrigation and sediment loss data for the four monitored irrigations at experimental site 2 (0.8% slope) are presented in Table 2. Cumulative outflow for the control and PAM treatment were not significantly different for any of the four irrigations. Net infiltration for the straw treatment was significantly greater than the control or PAM treatment for irrigation two which is partially due to the greater cumulative inflow. The nonsignificant difference in cumulative outflow for the straw treatment in irrigation two is also partially due to the greater cumulative inflow. Net infiltration percentage was consistently greater for the straw treatment in all monitored irrigations compared to the control and PAM treatment. Sediment loss was significantly reduced by both treatments for all but the first irrigation. The straw treatment consistency resulted in less sediment loss than the PAM treatment, but the modest difference was not significant. Sediment reduction relative to the control at site 2 was 77 to 93% for the PAM treatment and 88 to 97% for the straw treatment.

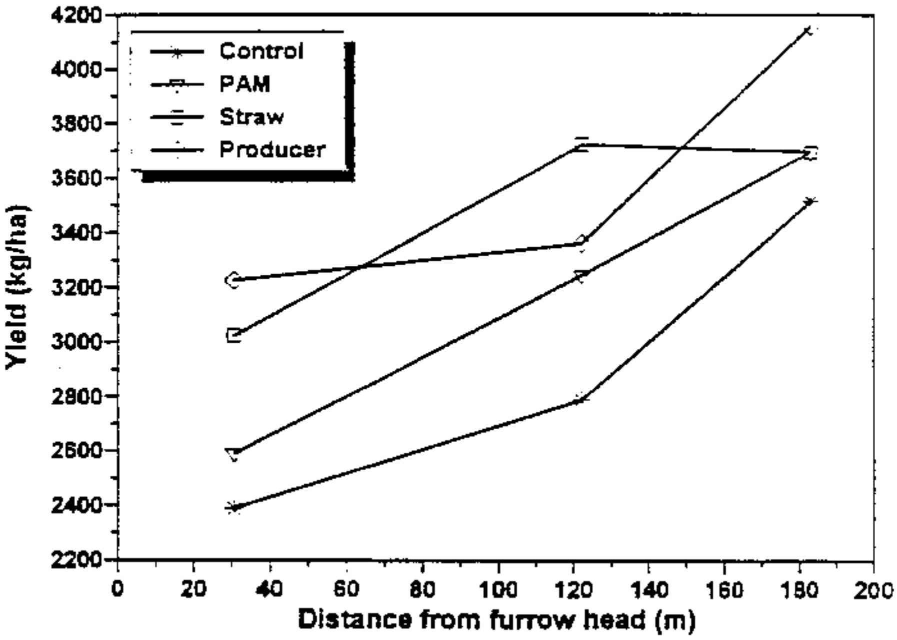
Dry bean yield at three furrow locations within each experimental site are presented in Table 3 (next page). The PAM treatment did not significantly increase yield at any furrow location at either site compared to the control though it generally produced increased yields. The straw treatment significantly increased yield at 20.5 and 122 m from the furrow head compared to the control at site 1 and nearly always resulted in the largest yields at both sites. Yield increases in both treatments over the control is

Table 3. Dry bean yield (kg ha^{-1}) for the two experimental sites for each treatment.

Treatment	Distance from furrow head (m)		
	30.5	122	182.9
Site 1			
control	2389^{a†}	2790^{a}	3516^{A}
PAM	2591^{ab}	3248^{ab}	3695^{A}
straw	3025^{b}	3721^{b}	3695^{A}
Site 2			
control	3486^{A}	3291^{A}	2470^{A}
PAM	3465^{A}	3256^{A}	3057^{A}
straw	3674^{A}	3711^{A}	3040^{A}

†Similar uppercase letters (P=0.10) or similar lower case letters (P=0.05) indicate nonsignificance between treatments in each irrigation.

Figure 1



Dry bean yield for each treatment and producer's irrigation regime at experimental site 1.

attributed to increased total infiltration and lateral wetting resulting in higher soil moisture levels during water sensitive growth stages of the crop.

Dry bean yields from Table 3 along with yields from the producer's irrigation regime which were taken adjacent to each experimental site are shown in Figure 1 for site 1 and Figure 2 for site 2. Yields at site 1 increased with distance from the furrow head which is attributed to loss of yield potential in the upper portions of the field due to years of sustained irrigation-induced soil erosion. The producer's irrigation regime resulted in greater yields than the control for all furrow locations at site 1. Yield under the producer's irrigation regime along the upper portions of the furrows were similar or less than that of the straw treatment. Yields at site 2 (Figure 2) decreased with distance from the furrow head which is attributed to nutrient deficiencies or disease. The producer's irrigation regime resulted in reduced yields compared to the PAM or straw treatments. Nearly equivalent or greater yields were obtained using PAM or straw mulch at both experimental sites under the 12-h irrigations compared to the producer's 24-h irrigation which used twice as much water and certainly resulted in greater soil erosion and sediment laden runoff than was observed under the study conditions.

Summary

Our on-farm study showed that PAM injected during the advance phase of irrigation and straw mulch both significantly and effectively reduced soil erosion. No significant difference in sediment loss was found between the PAM and straw treatments used in this study, however the straw treatment consistently resulted in lower sediment losses. On the 1.6% slope, dry bean yield was significantly increased along the upper reaches of the furrow by the straw mulch treatment while the PAM treatment did not significantly increase yield. On the 0.8% slope, dry bean yield was not significantly increased by either treatment. Comparison of dry bean yield under the 12-hr irrigation duration employed in this study with the 24-hr irrigation duration employed by the producer revealed that nearly equivalent or greater yields can be obtained by using PAM or straw mulch to increase infiltration with approximately half as much water as currently used by the producer. Based on our results, straw mulch will likely provide greater infiltration, erosion control and yield on slopes greater than approximately 1.5% compared to PAM but at a greater expense to the producer.

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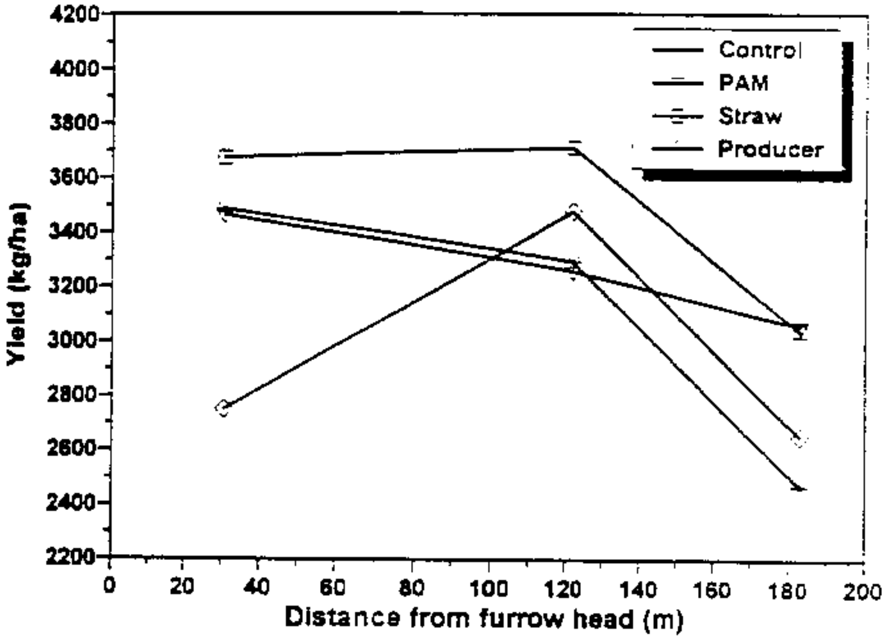
Figure 2



Dry bean yield for each treatment and producer's irrigation regime at experimental site 2.

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