Australian Journal of Crop Science AJCS
AJCS 6(6):963-969 (2012) ISSN:1835-2707

Investigation of polyacrylamide application under different tillage intensity on sediment and nitrogen losses in irrigated corn field

Majid Roozbeh[*1], Hooshang[1] Bahrami, Morteza Almassi[1], M.J. Sheikhdavoodi[1], Fariborz Abbasi[2], Mahdi Gheysari[3]

[1]Department of Agricultural Machinery Engineering and Mechanization, Faculty of Agriculture, Shahid Chamran University, Ahwaz, Iran
[2]Water Engineering Department, Agricultural Engineering Research Institute, Karaj, Iran
[3]Water Engineering Department, College of Agriculture, Isfahan University of Technology, Isfahan, Iran

[*]Corresponding author: roozbeh.majid@gmail.com

Abstract

Degradation of agricultural soils and nutrient losses affected by intensive agriculture and tillage are some of the environmental and agricultural concerns. These concerns lead to emergence and development of conservative technologies such as conservation tillage systems [(RT),(NT)] and anionic polyacrylamide (PAM). A study was conducted to determine the consequences of three tillage systems and anionic polyacrylamide on sediment loss, runoff nitrate concentration, nitrogen losses from the soil-plant system and nitrogen recovery. The experimental design was a randomized complete block with split-plot arranged in three replications. The anionic polyacrylamide (PAM) were in three levels of zero (P0), 10 (P10) and 20 (P20) mg L^{-1} as the main plot and different tillage intensities as the subplot including moldboard plowing plus two disk harrow passes (CT1), one stubble cultivator pass (RT) and moldboard plowing plus one power harrow pass (CT2). PAM was applied only in the first irrigation and during the advance water flow before runoff began. The results showed that tillage treatments and PAM had a significant effect on reduction of sediment transfer and soil loss. The RT treatment relative to CT2 led to soil loss reduction by 52.7% during the first irrigation. The P10 and P20 treatments compared to P0, caused sediment concentration reduction by 94.6 and 95.2% and soil loss reduction by 96.4 and 96.7%, respectively. The RT × P20 treatment had a greater impact in reduction of runoff nitrate losses than CT1 × P20 and CT2 × P20 treatments. Losses of nitrogen in the fertilized plots and RAN were influenced by both tillage system and PAM application.

Keywords: tillage, polyacrylamide, PAM, soil losses, nitrate
Abbreviations: CT1- moldboard plowing plus two disk harrow passes; CT2- moldboard plowing plus one power harrow pass; NT- no-till; PAM- polyacrylamide; RAN- recovery of applied nitrogen; RT- reduced tillage; N- nitrogen; V3-V4- third and forth-leaf stages of corn; V5-V6- fifth and sixth-leaf stages of corn

Introduction

Traditional farming systems for the intensive production of agricultural land can degrade the quality of soil and water resources. Continuous farming under these systems can accelerate the depletion of soil organic matter, soil erosion and lead to the deterioration of soil structure in surface-irrigated agriculture (Lal et al.,1994; Hussain et al., 1999). These concerns lead to emergence and development of conservative technologies such as conservation tillage systems [reduced tillage (RT) and no-till (NT)] and residue management. Despite these technologies can decrease nutrient and sediment losses in runoff (Shock et al., 1997), such practices due to excessive residue, may interfere with water flow during furrow irrigation and sometimes with planting operation. In the other hand in some areas, like Iran, the high residue from crops such as wheat and barley is utilized by animal feed or other uses and, therefore, it is not available to protect soil surface from erosion (Sepaskhah and Bazrafshan-jahromi, 2006), increase infiltration rates (Lentz and Bjorneberg, 2003) and decrease nutrient losses in runoff (Shock et al., 1997). An alternative to conservative practices is integrated application of conservative technologies such as conservation tillage and anionic polyacrylamide (PAM) in arid and semi-arid Agro-ecosystems. Polyacrylamide is a water-soluble polymer with the ability to flocculate suspended clay and silt particles dispersed and transported by the flowing water (Sojka and Lentz, 1997) . PAM greatly reduced detachment, transport and redistribution of residue in furrow, which helped to prevent furrow blockage and attendant overflow problems, allowing farmers to use conservation tillage instead of clean-till in furrow irrigated(Lentz and Bjorneberg, 2003). Soil aggregate is influenced by a large number of factors such as changes in soil organic matter, crop type, moisture content, root development and tillage implementation (Alvaro-

Fuentes et al., 2008a). Tillage mechanically disrupts soil aggregates leading to break down and decrease in aggregate size (Yang and Wander, 1998; Alvaro-Fuentes et al., 2008b). During furrow irrigation, the shear stress associated with running water detaches soil particles and deposits them farther down the furrow. These processes simultaneously promote surface seal formation, which decreases furrow infiltration (Segeren and Trout, 1991) and increases runoff and sediment loss. Application of small amount of moderate to high molecular weight anionic polyacrylamide (PAM) has effectively controlled aggregate disintegration and seal formation in soils from arid and semiarid regions (Helalia and Letey, 1988; Shainberg et al., 1990; Fox and Bryan,1992). Combining plant residue and PAM in furrows produced greater erosion control and larger infiltration enhancements than with straw alone (Lentz and Bjorneberg,2003). Bjorneberg et al. (2000) reported that applying PAM with crop residue was most effective in reduction of runoff, erosion and total phosphorus loss. Lentz and Bjorneberg (2003) demonstrated that adding PAM to low and high straw treatments increased average sediment loss reduction from 80 to 100% in the first two irrigations, and from 94 to 99.8% in subsequent irrigations. Phosphorus and nitrogen losses are associated with runoff sediment, and can be minimized by eliminating irrigation induced erosion (Lentz et al., 2001). Paul and Clark (1989) suggested that good soil conservation practices, such as NT , reduce NO_3^--N losses in surface runoff , but result in increased NO_3^--N drainage losses through leaching. In a 3-yr study, Weed and Kanwar (1996) found that average NO_3^--N concentration of the tile water of no- tillage was lower (21.9 mg L^{-1}) than that of moldboard plowing (36.9 mg L^{-1}). Tillage systems have a significant effect on N dynamics by affecting N pools in the soil system. Soil disturbance during the tillage process and the incorporation of surface residue increases soil aeration, which can increase the rate of residue decomposition (Mc Carthy et al., 1995). This process impacts soil organic N mineralization whereby readily available N for plant use is increased (Dinnes et al., 2002). Therefore, the type of tillage system can influence the amount of N available for loss in the soil profile. Deep accumulation of NO_3^--N in the soil profile represents a potential for NO_3^--N leaching into shallow water table (Keeney and Follett, 1991). Caldron and Jackson (2002) found that after irrigation, nitrate concentration increased by 42% in the disked soil and 29% in the rototilled soil relative to the control. Halvorson et al. (2001) reported that conventional and conservation tillage systems accumulated more soil NO_3^--N down to 150 cm compared with a no-tillage system. However, some reports have shown that conservation tillage systems may increase NH_3 and N_2O emissions as well as NO_3^--N leaching, while others have reported the opposite or no difference. Boddy and Baker (1990) and Schreiber and Cullum (1992) reported higher NO_3^--N losses under NT, while Elmi et al. (2003) found tillage system had no effect on NO_3^--N losses. However, little published information is available in worldwide- particularly there are not any information in Iran that describes the combined influence of different tillage systems and PAM applications for furrow irrigation. The objectives of this study were to evaluate the interactive effects of three tillage systems and three PAM concentrations (0, 10, 20 ppm) on sediment loss, nitrate concentration in runoff and N losses from the soil plant system.

Results and discussion

Tillage and PAM effects on soil loss and sediment concentration

Different tillage intensities had **si**gnificant effects on sediment concentration and soil loss (Table1). The RT treatment relative to CT2 treatment led to a significant soil loss reduction by 52.7% during the first irrigation (Fig.1). The rototilled soil in CT2 treatment had a greater soil loss than the disked soil in CT1 in the first, second and third irrigations (Fig.1). There were also significant differences in soil loss within the tillage systems in subsequent irrigations. Larney and Bullock (1994) reported that the rototiller power blades cause to disrupt aggregate intensely, whereas Non-powered disk mechanisms may be effective at inverting the soil profile but cause less aggregate breakdown. The increase in soil loss in CT2 can be probably attributed to more aggregate disintegration and soil disturbance. The previous studies indicated that breakdown of surface aggregates can affect soil detachment and soil erosion (Calderon and Jackson, 2002; Kayisoglu et al., 2007). PAM applications reduced soil loss and sediment concentration in furrow runoff (Table1). Regardless of tillage systems, P10 and P20 reduced sediment concentration by 94.6 and 95.2% and soil loss by 96.4 and 96.7% , respectively" compared to P0" (Table 2). The decrease in sediment concentration and soil loss in PAM treatments can be attributed to aggregate stability and flocculating dispersed sediment in the furrow stream (Brown et al.,1988 ; Trout et al., 1995; Lentz and Bjorneberg., 2003). It has been shown that when PAM concentration was increased from 10 to 20 mg L^{-1} it only reduced soil loss by 12.5% ,whereas replacing RT treatment with CT1 and CT2 led to the soil loss reduction by 37.1 and 52% respectively (Figure 1,Table 2). Tillage x PAM interaction had a significant effect on soil loss and sediment concentration (Table3). The minimum soil loss and sediment concentration were observed for RT x P20 treatment and the maximum occurred for the CT2 x P0 treatment during the first to third irrigations (Table3). Soil loss in RT x P0 increased by 96.09% as compared to RT x P20 (Table3). On the other hand, despite higher disturbance of the soil in CT1 and CT2 treatments, PAM significantly reduced soil loss in both treatments (Table3). Therefore, it can be concluded that RT x PAM or CT x PAM relative to RT or CT alone, were the most appropriate for reduction of soil and sediment losses. However, with on-farm cost of PAM ranging from about $7 to 13 ha^{-1} (Sojka and Entry, 2000), the RT or CT treatment in combination with PAM are an economic soil and water conservation practice.

Tillage and PAM effects on runoff nitrate concentration

Runoff nitrate concentration in RT treatment was significantly less than CT2 treatment in the first (15%) and second irrigation (26.4%), but not in the third irrigation (Fig. 2). There were two reasons for this. First, CT2 treatment increased outflow rate and second, CT2 increased the load of sediment mixed into the furrow stream. Nitrate losses from furrows were 14.9 and 9.6% lower in RT than CT1 during the first and second irrigations, respectively. Relative to CT2, CT1 treatment was more effective in reduction of runoff nitrate losses, although there were no significant difference between them in the first and third irrigations (Fig.2). PAM-treated furrows runoff exhibited

Table 1. Analysis of variance for soil loss, sediment concentration, runoff nitrate concentration, N loss and recovery of applied nitrogen.

Source	P>F				
	Soil loss	Sed. conc.	Nit. conc	N loss	RAN
PAM	< 0.0001	< 0.0001	0.0162	0.1918	0.0520
Tillage	< 0.0001	< 0.0001	0.0737	0.0039	0.1443
PAM× Tillage	< 0.0001	< 0.0001	0.1677	0.1911	0.4365

PAM: Polyacrylamide; Sed. Conc: sediment concentration; Nit. conc: nitrate concentration; N loss: nitrogen loss; RAN: recovery of applied nitrogen; Significant level ($p \leq 0.05$)

Table 2. Sediment concentration and soil loss as affected by polyacrylamide (PAM).

PAM	Soil loss (kg ha^{-1})	Sediment concentration (mg L^{-1})
P0[+]	4998.3 (859.9)[a*]	2518.7 (242.2)[a]
P10	144.8 (29.2)[b]	127.8 (15.4)[b]
P20	126.7 (23.9)[b]	110.2 (13.4)[b]

+P0: Without PAM, P10: 10 mg PAM L^{-1}, P20: 20 mg PAM L^{-1}. *Values with the same letter in each column are not significantly different (P<0.05, Duncan). Values between brackets indicate standard deviation.

significantly lower levels of nitrate as compared with non-treated furrows (Table 1). In the first irrigation, P10 and P20 treatments reduced runoff nitrate losses by 16.7% and 25.6% compared to untreated furrows (P0), respectively (Table 4). Relative to P10, P20 application was more effective in reduction of runoff nitrate losses during 1st irrigation (10.7%) and 2nd and 3rd irrigation (20.05%, 12.7%), respectively (Table 4). This can be attributed to PAM effect on reduction runoff rate and sediment concentration into the furrow stream. Previous studies have reported similar results (Lentz and Sojka, 1994; Lentz et al., 1998; Meral et al., 2004). The results also showed that tillage systems can increase PAM effectiveness in reducing runoff nitrate. The RT x P20 treatment had a greater impact in reduction of runoff nitrate losses than CT1 x P20 and CT2 x P20 treatments (Table 3). The RT x P10 interaction reduced nitrate losses in furrows by 23.9 and 18.1%, respectively" compared to CT1 x P10 and CT2 x P10 interactions"(Table 3). The results also revealed that outflow rate and subsequent runoff nitrate losses increased as PAM concentration decreased and tillage frequency increased during the first to third irrigations (Table 3). The minimum outflow rate for the three irrigations were observed for the RT x P20 (4.8 L min^{-1}) and the maximum occurred for the CT2 (11.1 L min^{-1}) (Table 3). Adding PAM (10 or 20 mg PAM L^{-1}) to the RT treatment provided extra protection against seal formation by preventing aggregate from breaking down, flocculating dispersed sediment and virtually eliminating stream sediment load. Thus**,** infiltration rate may have been higher in the RT x PAM treatments. Our results are similar to the results of previous studies that have reported that runoff nitrate losses can be decreased through the runoff sediment reduction and outflow rate in PAM-treated furrows (Lentz et al., 1998; Lentz et al., 2001; Meral et al., 2004). These results indicated that tillage x PAM interaction had a greater impact on reduction of runoff nitrate concentration than when the PAM was used alone.

Nitrogen losses from soil-plant system and recovery of applied N (RAN)

Different tillage intensities had a significant effect on nitrogen losses from the soil-plant system (Table 1). The minimum losses of N was observed for the CT1 treatment (118.9 kg ha^{-1}) and the maximum nitrogen losses occurred for the RT treatment (152.4 kg ha^{-1}) (Table 5). In RT treatment, losses were probably due to volatilization of ammonium from the soil during the application of the fertilizer, by tissue of the plant or to residues left on the surface that hinder the penetration of the fertilizer into the soil (Angas et al., 2006). The results indicated that the CT1 treatment on average was able to reduce N losses by 10.3% as compared to CT2 treatment (Table 5). The few losses of nitrogen in CT1 treatment can be attributed to lower N immobilization and greater N availability to the plant (Aulakh et al. , 1991; Knowles et al., 1993). PAM application reduced nitrogen losses from the soil-plant system, although difference in N loss was not significant among PAM-treated furrows and non-treated (Tables 1 and 5). Relative to P0, the P20 application reduced N losses by 5.6% v.s 10.1% for the P10 (Table 5). High PAM concentration decreases the solution flow rate in the soil pores allowing PAM molecules to interact with soil particles, which decreases infiltration rates. The lower N losses associated with PAM concentration can be attributed to reduction in infiltration rate and NO_3^--N leaching to lower depths in the soil profile (Malik and Letey, 1992; Ajwa and Trout, 2006). The recovery of applied N (RAN) was influenced by both tillage system and PAM application. RAN was 32.9, 29.1 and 27.05% for CT1, CT2 and RT treatments, respectively (Table 5). The maximum N recovery was obtained at the P20 treatment (34.9%) and the minimum was obtained at the P0 (22.4%) (Table 5). However, the P20 treatment had greater impact on N recovery than P10 treatment (Table 5). The PAM x tillage interaction had no significant effect on N recovery (Table 1). The highest RAN was observed in the CT1

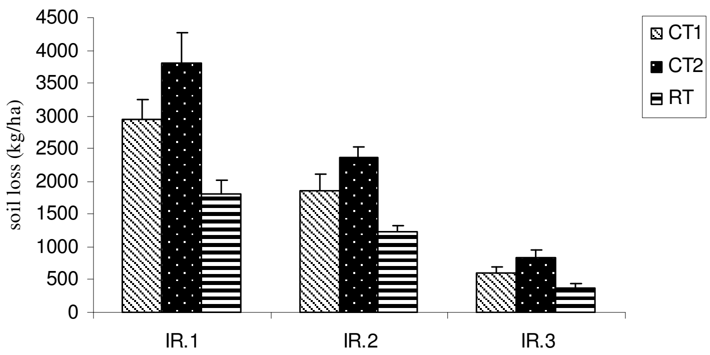

Fig 1. soil losses under different tillage intensities during 1st, 2nd, and 3rd irrigation.
CT1: Moldboard plow+2disk, CT2: Moldboard plow + power harrow, RT: Cultivator only
IR: 1st, 2nd, and 3rd irrigation. The error bars indicate standard deviation.

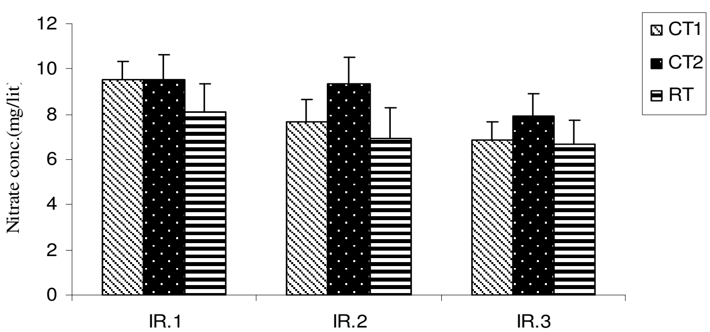

Fig 2. Nitrate concentration in runoff as affected by different tillage intensities during 1st, 2nd, and 3rd irrigation.
CT1: Moldboard plow+2disk, CT2: Moldboard plow + power harrow, RT: Cultivator only
IR: 1st, 2nd, and 3rd irrigation. The error bars indicate standard deviation.

x P20 treatment. N fertilizer recovery under RT x P20 was 24.5% lower than in CT1 x P20 (Table 5). This can be attributed to N immobilization from incorporation of residue and the lack of synchrony of N release with crop demand during crop growth.

Materials and methods

Site description and experimental design

This study was conducted in 2009 at the Darab Agricultural Research Station in Fars province, located in the south-western of Iran (28° 47′ N, 57° 17′ E; 1120 m above sea level). The region has a semi-arid climate, total amount of annual rainfall is about 265 mm, most of which occur during winter. During the 2009 growing season, the minimum and maximum air temperature were 13.9 and 43.1°c respectively, and the minimum and maximum average humidity were 18.3 and 60.1% respectively. The soil texture was loam (17.95% clay, 41.75% silt, 40.3% sand) up to a depth of 120 cm. Soil organic matter was 6.5 g kg^{-1} . Saturated paste extract electrical conductivity (EC) and soil initial NO_3^-N were 0.62 dS m^{-1} and 37.3 mg Kg^{-1}, respectively ; pH was 7.91 with calcium carbonate equivalent of 4.5% . The slope was 0.5% . The experimental design used in this study was a randomized complete block with split plot arranged in three replications. Three PAM application of 0 (P0); 10 (P10) and 20 (P20) mg L^{-1} were allocated as the main plots and the three tillage systems were allocated as the subplots. The tillage treatments consisted of moldboard plowing (25-30 cm depth) plus two disk harrow passes (CT1), one stubble cultivator pass (14-16 cm depth) as RT and moldboard plowing (25-30 cm depth) plus one power harrow pass (CT2).

Crop management

Corn was planted because it is the most dominant crop in the region grown during the summer and fall in rotation with winter cereals. Corn hybrid 704 was planted on 11 July 2009 with seeding rate of 75 550 plants ha^{-1}, using a four-row planter at 4-cm planting depth and 75-cm row spacing. P and N fertilizer demand were determined based on soil test results. Triple superphosphate was broadcasted to the entire plot area before planting at 90 kg P_2O_5 ha^{-1}. The nitrogen source was urea (46% N), and was applied at 250 kg N ha^{-1}. One-third of the fertilizer was applied before planting and two-thirds at the V3-V4 and at V5-V6 developing stages (Ritchie and Hanway, 1982). Sowing was performed using a bed-planting system with furrow irrigation between the beds. Irrigation water had an electrical conductivity (EC) of 0.6 dS m^{-1} and a sodium adsorption ratio (SAR) of 0.49. Irrigation was carried out at 50% depletion of available water determined gravimetrically in the top 60 cm of soil. A continuous irrigation strategy was employed. Inflow rate was 24 L min^{-1} during furrow advance. A gated pipe conveyed water to the each furrow, and adjustable spigots controlled inflow rates. Polyacrylamide copolymer was a dry granular material with 20% charge density and molecular weight of 12 to 15 Mg $mole^{-1}$. PAM was applied at 10 and 20 mg L^{-1} during the advance phase.

Measurements and data analysis

Furrow inflows and outflows were monitored, and runoff sediment concentrations were measured throughout irrigation. Inflows were measured by timing the filling rate of a known volume, and outflows were measured with W.S.C flumes installed at the end of the furrows. Measurements were made at 15 min intervals early in the irrigation, and then every hour in the later half of the irrigation, after outflows and sediment loads had stabilized. The samples were collected from the end of flumes placed in the furrows. The samples were filtered the captured sediment oven-dried at 105°C. The outflow rate at the time of sampling and the sediment content of the sample were combined to calculate an instantaneous rate of sediment discharge. Three runoff samples were collected from each furrow during an irrigation. Three runoff samples were taken from outflow monitoring flumes. Samples were analyzed for NO_3^--N. Runoff samples were stored in a refrigerator for <8 days before being analyzed. A sample of plants were harvested from two rows with a length of 12 m in the center of each plot and weighed to determine biomass at physiological maturity.

Table 3. Irrigation parameter comparisons as affected by tillage and polyacrylamide.

	P0 $^{+}$			P10			P20		
	CT1 $^{+}$	CT2	RT	CT1	CT2	RT	CT1	CT2	RT
Irrigation 1									
Sediment conc. (mg L^{-1})	3912 (138.6) ^{b*}	4143 (140.8) ^{a}	2885 (125.4) ^{c}	215.2 (22.04) ^{d}	237 (10.07) ^{d}	142.6 (18.2) ^{d}	178.2 (5.9) ^{d}	197 (13.2) ^{d}	124.1 (11.8) ^{d}
Soil loss (kg ha^{-1})	8450 (263.8) ^{b}	10940(206.4) ^{a}	5192 (37.1) ^{c}	201.4 (8.7) ^{d}	258.8 (18.3) ^{d}	102.7 (11.2) ^{d}	157.5 (20.1) ^{d}	210.4 (27.1) ^{d}	99.2 (8.5) ^{d}
Nitrate conc. (mg L^{-1})	10.8 (0.6) ^{a}	10.5 (0.1) ^{ab}	10.2 (0.6) ^{ab}	9.8 (0.5) ^{ab}	9.1 (0.5) ^{abc}	7.4 (0.3) ^{bc}	7.9 (0.4) ^{abc}	8.9 (0.4) ^{abc}	6.5 (0.5) ^{c}
Outflow (L min $^{-1}$)	10.8 (0.4) ^{b}	13.2 (0.2) ^{a}	8.9 (0.9) ^{c}	4.6 (0.2) ^{de}	5.4 (0.4) ^{d}	3.6 (0.3) ^{e}	4.3 (0.4) ^{de}	5.3 (0.6) ^{d}	4 (0.2) ^{de}
Irrigation 2									
Sediment conc. (mg L^{-1})	3154 (27.6) ^{a}	3283 (83.1) ^{a}	2435 (165.9) ^{b}	133.8 (5.1) ^{c}	140.5 (7.1) ^{c}	95.3 (4.3) ^{c}	114.9 (12.7) ^{c}	119.2 (5) ^{c}	81.9 (10.6) ^{c}
Soil loss (kg ha^{-1})	5298 (78.2) ^{b}	6697 (25.8) ^{a}	3507 (46.2) ^{c}	159.3 (7.4) ^{de}	230.9 (14.5) ^{d}	97.2 (5.3) ^{e}	137.9 (9.9) ^{de}	186.3 (18.4) ^{de}	89.4 (16.6) ^{e}
Nitrate conc. (mg L^{-1})	9.9 (0.4) ^{ab}	10.2 (0.6) ^{a}	9.5 (0.5) ^{ab}	7.2 (0.3) ^{cd}	9.7 (0.4) ^{ab}	6.3 (0.4) ^{cde}	5.7 (0.1) ^{de}	8.1 (0.6) ^{bc}	4.8 (0.4) ^{e}
Outflow (L min $^{-1}$)	8.3 (0.5) ^{ab}	10.2 (0.5) ^{a}	8.2 (0.7) ^{b}	5.9 (0.2) ^{cde}	7.8 (0.5) ^{bc}	5.4 (0.3) ^{de}	5.9 (0.5) ^{cde}	7.2 (0.9) ^{bcd}	5.1 (0.2)^{e}
Irrigation 3									
Sediment conc. (mg L^{-1})	1024 (74.6) ^{b}	1142 (34.3) ^{a}	690.2 (23.2) ^{c}	62.7 (2.3) ^{d}	67.5 (5.2) ^{d}	56 (1.7) ^{d}	62.3 (3.2) ^{d}	65.8 (4.5) ^{d}	48.6 (3.1) ^{d}
Soil loss (kg ha^{-1})	1659 (63.7) ^{b}	2275 (68.6) ^{a}	969 (71.9) ^{c}	73.8 (12.4) ^{d}	105.3 (7) ^{d}	73.9 (5.1) ^{d}	82.3 (4.6) ^{d}	107.5 (9) ^{d}	70 (6.7) ^{d}
Nitrate conc. (mg L^{-1})	8.4 (0.5) ^{ab}	8.9 (0.4) ^{a}	8.4 (0.5) ^{ab}	6 (0.2) ^{bc}	7.8 (0.2) ^{ab}	6.7 (0.3) ^{abc}	6.2 (0.5) ^{abc}	7 (0.4) ^{abc}	4.7 (0.2) ^{c}
Outflow (L min $^{-1}$)	8.1 (0.05) ^{ab}	9.9 (0.2) ^{a}	8.1 (0.2) ^{ab}	7 (0.3) ^{b}	7.8 (0.9) ^{ab}	6.5 (0.3) ^{b}	6.5 (0.1) ^{b}	7.2 (1.1) ^{b}	5.8 (0.9) ^{b}

+ CT1: Moldboard plow + 2disk, CT2: Moldboard plow + power harrow, RT: Cultivator only.+P0: Without PAM, P10: 10 mg PAM L^{-1}, P20: 20 mg PAM L^{-1}.*Values with the same letter for each irrigation within a row are not significantly different for PAM and tillage interactions ($P<0.05$). Values between brackets indicate standard deviation.

Table 4. Nitrate concentration in runoff as affected by polyacrylamide during 1st, 2nd, and 3rd irrigation.

Irrigation	PAM	No_3 – N (mg L^{-1})
	P0^{+}	10.54 (0.7) ^{a*}
1	P10	8.78 (0.9) ^{b}
	P20	7.84 (0.9) ^{b}
	P0	9.91 (0.8) ^{a}
2	P10	7.78 (1.1) ^{ab}
	P20	6.22 (1) ^{b}
	P0	8.61 (0.7) ^{a}
3	P10	6.86 (0.6) ^{b}
	P20	5.99 (0.8) ^{b}

+P0: Without PAM, P10: 10 mg PAM L^{-1}, P20: 20 mg PAM L^{-1}.*Values with the same letter for each irrigation within a column are not significantly different ($P<0.05$). Values between brackets indicate standard deviation.

Table 5. N losses and recovery of applied nitrogen (RAN) as affected by tillage and polyacrylamide.

PAM	Tillage system	N losses (kg ha $^{-1}$)	RAN (%)
	CT1^{+}	133.2 (24)^{abcd*}	24 (6.7)^{bc}
P0^{+}	CT2	145.8 (30.6)^{abc}	23.59 (1.7)^{bc}
	RT	147.4 (31.9)^{ab}	19.86 (1.6)^{c}
Mean		142.1 (15.7)^{A**}	22.48 (3.7)^{B}
	CT1	118 (14.2)^{bcd}	32.51(4.4)^{ab}
P10	CT2	114.4 (9.06)^{cd}	33.25 (3.07)^{ab}
	RT	150.6 (3.3)^{ab}	29.30 (6.2)^{bc}
Mean		127.7 (13.1)^{A}	31.69 (4.2)^{AB}
	CT1	105.6 (1.8)^{d}	42.37 (6.8)^{a}
P20	CT2	137.5 (7.2)^{abcd}	30.60 (7.4)^{bc}
	RT	159.3 (2.3)^{a}	31.97 (5.4)^{ab}
Mean		134.1 (14.05)^{A}	34.98 (6.5)^{A}

+P0: Without PAM, P10: 10 mg PAM L^{-1}, P20: 20 mg PAM L^{-1}.+ CT1: Moldboard plow + 2 disk, CT2: Moldboard plow + power harrow, RT: Cultivator only. *Values with the same lowercase letter in each column are not significantly different for PAM and tillage interactions (P<0.05). Values between brackets indicate standard deviation. ** PAM means with the same uppercase letter in each column are not significantly different (P<0.05).

Total plant N concentration was determined using the micro Kjeldahl method (Nelson and Sommers, 1980), and total plant N uptake was calculated by multiplying plant N concentration by biomass. Soil NO_3^--N was determined before planting and fertilizing (N_{ini}) and after harvest (N_{final}). Samples were taken at a depth of 0-120 cm from three consecutive layers (30 cm per layer). Soil nitrate was measured with a spectrophotometer (Jenway- 6400) using a cadmium reduction method (APHA, 1992). N mineralization (N_{min}) was estimated for the no fertilized plots, applying the equation $N_{min} = N_{final} + N_{plant} - N_{ini}$ (Sexton et al., 1996). Plant N content (N_{plant}) was the above ground plant N uptake at maturity. N losses (N lost) were estimated from the N budget for the fertilized plots (Angas et al., 2006), using the following expression: $N\ lost = N_{final} - N_{ini} + N_{plant} - N_{fert} - N_{min}$. N_{fert} was N applied by fertilization. A negative value of N lost could be interpreted as a N loss from the soil-plant system. Recovery of applied N (RAN) was calculated by the method described by Echeverria and Videla (1998), representing apparent recovery.

$RAN = [\ (N_{plant}$ in fertilized plots $- N_{plant}$ in no fertilized plots) $/ N_{fert}\ ] \times 100$

Data thus recorded were statistically analyzed using standard analysis of variance techniques with M Stat-C (Freed and Eisen-smith, 1986). Means were compared for significance using Duncan test at $P \leq 0.05$.

Conclusions

It was found that, conventional tillage (CT) and reduced tillage (RT) in combination with PAM treatments substantially reduced field-losses of sediment, soil and runoff nitrate concentration compared to CT and RT alone. The most effective treatment for reducing sediment and runoff nitrate losses was PAM-20, where 20 mg L^{-1} PAM was metered into furrow irrigation inflows during the furrow advance. In average, interaction CT1x P20 showed a highest RAN and lowest N losses from soil-plant system.

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