Assessment of linear anionic polyacrylamide application to irrigation canals for seepage control

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Abstract

South- central area of Chile area has a Mediterranean climate and high crop water requirements. Irrigation water is distributed through long channels which have low water conveyance efficiency (Ec), difficult to improve by conventional techniques. The objective of this study was to quantify Ec and to evaluate the use of Linear Anionic Polyacrylamide (LA-PAM) to reduce seepage losses. The study was carried out in south-central area of Chile, (UTM Coordinate N 5745000; E 725000 m, datum is WGS-84, zone 18S) in 250 km of channels whose flow varied between 0.12 and 24.6 m3 s^{-1}. Water users indicated channel reaches with potential low Ec, which were selected for LA-PAM application. In 11 reaches between 0.51 and 3 km in length, 1 to 3 LA-PAM applications were performed at rates of 10 kg ha^{-1}, considering the wet perimeter area as basis of calculation. Thirty-one LA-PAM applications were performed over a 30.5 km length. Most of the channels were large enough to allow motorboat moving against the current to carry-out LA-PAM application. Water flow was measured (StreamPro ADCP) at both ends of selected reaches before and after granular LA-PAM application. Weekly measurements were made to quantify treatment effect duration. Water turbidity and temperature were measured. Channels showed variable Ec from 87% to 94%. Two reaches showed 6% water gains. In more than 80% cases LA-PAM effect was positive, achieving loss reductions of 15 to 760 L s^{-1}. In other cases LA-PAM had a negative effect since it mainly affected water entry into the channel. It was determined that field conditions referred by users as indicators of Ec are not always correct and vary in time according to climatic conditions. Ec was estimated and it was possible to reduce seepage through LA-PAM applications. This allow increasing irrigation security in critical periods, especially under drought conditions.

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Introduction

Seepage from unlined water delivery canals occurs on a local and regional scale and that losses may be significant in particular areas. According to U.S. Geological Survey (USGS) the loss of water during transport through unlined water delivery and irrigation canals might be significant, with as much as 50 percent lost to seepage through the sides and bottoms of the canals (Carr, 1990). In Chile, as in many parts of the world, agriculture uses large volumes of irrigation water that must be driven through channels. Arumí *et al.* (2009) evaluated the water recharge in lower valley of the Cachapoal River, central Chile, concluding that 52 percent of them come from canals seepage. The Chilean National Irrigation Commission (CNR, 2012) estimates losses of water during transport through canals in more than 30 percent in average.

However, as water resources become further constrained, there is a need for cost-effective seepage reduction technologies that can be used in locations where traditional methods are cost-prohibitive. Traditional seepage-abatement technologies such as compacted earth, reinforced or unreinforced concrete, and buried geomembranes are typically used in situations where seepage rates are elevated and projected water savings offset their high construction and maintenance costs. Polyacrylamide (PAM) has been suggested as a means of sealing unlined water delivery canals to reduce seepage or infiltration losses (Zhu & Young, 2009). In contrast to traditional seepage-abatement technologies, LA-PAM is relatively inexpensive. Polyacrylamide or PAM is a generic term for polymers formed by the union of monomer acrylamide. Polyacrylamide (PAM) is a synthetic organic polymer used globally by a number of important industries. It also has a number of valuable applications in irrigated agriculture, including its use in furrow irrigation to control erosion and sediment loss in runoff, manage infiltration, and a growing use for reducing seepage losses in unlined irrigation canals and reservoirs (Lentz, 2009). Different formulations vary in molecular weight, charges (cationic, anionic or neutral) and if the molecules are linear or branched resulting in a large number of alternatives to be used (Sojka *et al.*, 2007). The granular form of linear anionic polyacrylamide (LA-PAM) has been identified as one such technology capable of cost-effectively reducing seepage rates from unlined water delivery canals (Susfalk *et al.*, 2008).

Granular LA-PAM is one type of a broader family of polyacrylamides that has a variety of uses, including as a flocculant in wastewater treatment, in food packaging, and paper manufacturing. Over the past decade, LA-PAM has been used to reduce erosion and sediment transport from crop fields under furrow irrigation and on construction sites. Water soluble PAM has been tested in reservoir reducing mean seepage rates an average 50% relative (Lentz, 2004).

Granular LA-PAM is easy to apply and can be targeted to specific canal reaches known to have high seepage rates. There is a conflictive empirical evidence of the longevity of a single LA-PAM application, but yearly or more frequent applications do not diminish its cost-effectiveness. This “short-term” seepage reduction of LA-PAM, relative to the more permanent nature of traditional technologies, is a benefit, as it could be applied selectively during drought water years, and allowed to elapse if water savings are no longer needed.

Researches (Smith, 2008; Susfalk *et al.*, 2008) have found that this polymer would reduce water loss by seepage in channels at a cost that would justify their use from an economical point of view, allowing to increase the available flow and controlling the adverse effects of canal seepage. In addition, the polymer can be applied in the watering duration, achieving a reduction of losses of water in a short period of time, making it interesting to use in drought periods, in which an optimization of the transport of water in the channels would translate into a big economic impact for farmers. Research on the use of polymer are complex because there is not possible to compare channels situations which are exactly equal, since variables such as flow, the amount of sediment and the water temperature, that influence the behavior of polymer, are impossible to control.

The results of applications in channels have found that the use of the LA-PAM reduced leaks between 30% and 90% (Smith, 2008) and 28 and 87% in 8 of 11 field experiments. In other three experiments, the application did not reduce channel filtering, so it must study the conditions necessary so that the application of polymers reduce water loss by seepage (Susfalk *et al.*, 2008). The polymers used in agriculture are characterized by molecules anionic with a charge density of 18% and molecular weight between 12-15 Mg mol^{-1}(Sojka et al, 2007).

The Mediterranean climate of the area presents critical periods with peak demand of irrigation and minimum water availability, time in which could be appropriated for LA-PAM applications to have more water in the channels.

The objective of this study was to quantify water losses in channels and to evaluate the use of Linear Anionic Polyacrylamide (LA-PAM) to reduce seepage losses in south-central area of Chile under real water management conditions.

Materials and methods

The study area is shown in Figure 1. A big canal network belonging to South-Bio Bio, Chufquen and Allipen irrigation systems in the south-central area of Chile (UTM Coordinate N 5745000 ; E 725000 m, datum is WGS-84, zone 18S), was considered. The criteria used to select study sites, was the potential losses, according to water user's indication. The study was carried out in 11 reaches selected from 250 km of channels network whose flow varied between 0.12 and 24.6 m^3 s^{-1}. The length of the channels varies between 0.51 km and 3 km. In selected reaches LA-PAM applications and water flow monitoring was carried out.

Seepage rate estimates were focused on short-term and long term to study the effect of LA-PAM applications on water saving at 11 reaches. Water flow measurement and percentage of looses or profits were calculated to compare the pre and post treatment channel performance. The monitoring was just performed before and after LA-PAM application, in next day and weekly until the effect was lost.

From 2011 to 2013, seepage estimates were conducted before and after LA-PAM application. During field applications in 2011 and early 2012, application methods and monitoring protocols were being refined. The most of applications were in 2012 and early 2013.

Seepage was estimated by comparing surface water discharge above and below the reach of interest, avoiding presence of other inflows and outflows along the reach. In channels surface water discharge was measured with a Teledyne-RDI StreamPro (2007) (Poway, CA) acoustic Doppler current profiler (ADCP). Studies recently carried out in the United States has performed the measurements using Acoustic Doppler Profiler (ACDP) (Kinzli *et al.*, 2010) allowing to obtain repeatable results of profiles of speed and therefore acceptable errors in the determination of the flows.In small channels a Teledine Gurley N° 625 current meter was used when it was not possible to use the ADCP. The

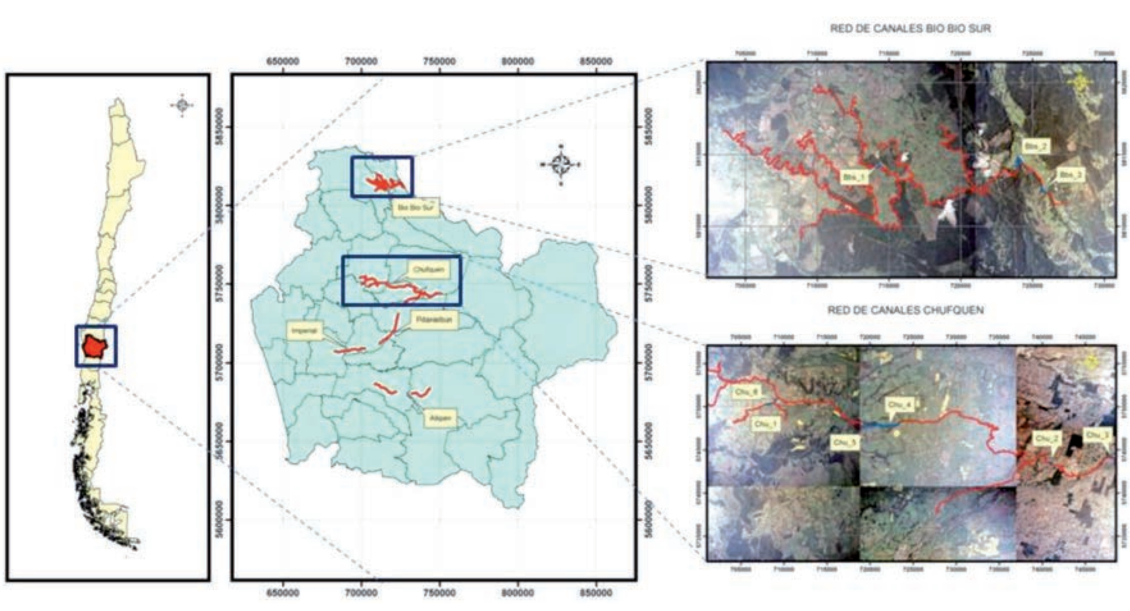

Figure 1. Aerial view of study area showing the location of the canals and reaches that were treated with PAM. UTM Coordinate in m, datum is WGS-84, zone 18S.

ADCP measure across the channel and delivers a flow value. The criteria used to ensure reliable values was four consecutive measurements with variation less than 5% over the average of them. Wrong data values were discarded.

Application rates of 10 kg of LA-PAM per wetted channel were targeted for each of the applications according to recommendation (Susfalk *et al.* 2008) taking into account the low sediment level. The LA-PAM used during these studies conformed specifications for use in irrigation channel. More specifically, the manufacturer certified that the LA-PAM a) complied with the NSF International/American National Standards Institute (ANSI) Health Effect Standard (NSF/ANSI-60); b) was an anionic charge density of 15 to 40 percent plus or minus 5 percent; c) had a molecular weight of at least 12 million g (Mg) mole^{-1}; and d) contained no more than 0.05 percent acrylamide monomer, by weight. The LA-PAM polymer used for field experiments was granulated Clarisol 4015, distributed by Aguasin Aguas Industriales ltda, Chile. This polymer was selected for not present toxicological effect in Daphnia magna after 24 and 48 hour, according to standard Chilean NCh 2083 of 1999 and testing of chronic toxicity at 21 days, according to US EPA, 1995.

In each reach, 1 to 3 LA-PAM applications were conducted by moving the point of LA-PAM application upstream while continuously dispersing granular LA-PAM onto the channel water surface by walking (small channels) or more commonly by boat (Zodiac motorboat 3.5 HP) (Table 1). In both cases a technician with hand sowing machine (Lhaura model 10502) distributed granulated LA-PAM on water surface. Water turbidity and temperature were measured (multi-parameter water quality checker Horiba U-50). In total, thirty-one LA-PAM applications were performed over a 30.5 km length in total.

The Table 1 resumes the principal reach characteristics of experiment. Some experimental reaches were partitioned into two or more subsets.

Analysis was based on comparison of the seepage rates of canal before and after the LA-PAM applications. Thanks to flow measurements at the beginning and end of the studied reaches, it was possible to calculate percentages of water losses with respect to the incoming flow. The average of the losses before LA-PAM applications was compared with the situation post application. Post application average considered a period between the application and the moment that effects of the polymer disappear. On these values average pre and post application was calculated the percentage of seepage-abatement respect to initial seepage rate. When water gains were found in some reaches studied the values of losses had negative sign and the focus was if the polymer produced an effect of increasing gains or reduction of them by sealing of the walls of the channel. The results were also expressed in terms of water saving in liters per second.

Results

Because some experimental reaches were partitioned into two or more subsets, in different measurement length or dates, the results are presented on 31 cases analysis. Water discharge monitoring with ADCP in the beginning and end of the reaches were carried out before and after LA-PAM applications. The Figure 2 shows typical graphics of water

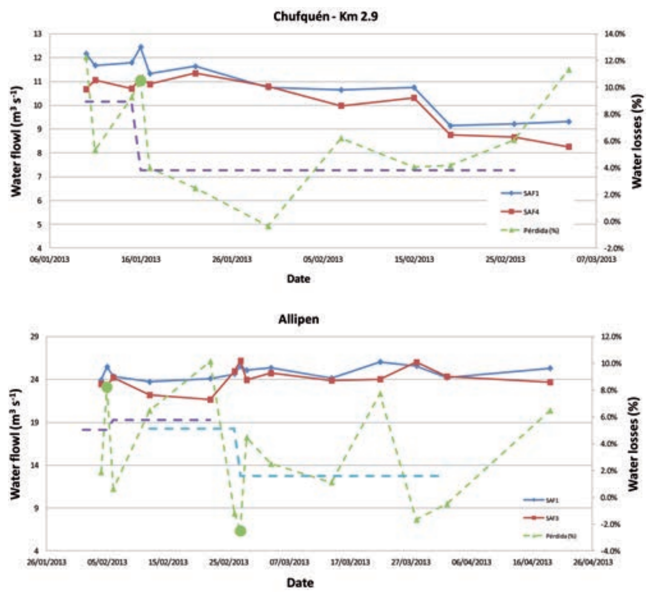

Figure 2. Graphics of water flow at the beginning (blue) and end (red) of reaches. The dots indicate LA-PAM applications. The green dashed lines indicate percentage of losses calculates from eater flow and the purple and ligh blue dashed lines indicate the average percentage of losses changing before and after LA-PAM application. Above: Chufquen canal in km 2.9. Under: Allipen canal.

Table 1. Summary of LA-PAM application locations and characteristics. Code refer to reaches.

Canal Code	Beginning N	Beginning E	End N	End E	Length (m)	Flow (m^3 s^{-1})	Irrigation system	Aplication type
All_1	5682451	742254	5680054	740613	3000	24,602	Allipen	Boat
Bbs_1	5814177	714411	5814046	714162	550	1,071	BioBio Sur	Walking
Bbs_2	5814368	724358	5813989	723933	1860	6,072	BioBio Sur	Boat
Chu_1	5750376	708545	5750234	707850	705	0,82	Chufquen	Walking
All_2	5814049	714161	5814177	714411	1367	0,12	Allipen	Walking
Chu_2	5743295	741049	5743488	740737	629	9,794	Chufquen	Boat
Chu_3	5744004	748164	5744140	747813	844	11,858	Chufquen	Boat
Chu_4	5748173	723390	5747908	721042	2686	6,393	Chufquen	Boat
Chu_5	5747920	721017	5748213	719155	2286	7,657	Chufquen	Boat
Bbs_3	5811533	726759	5812895	725661	513	7,1	BioBio Sur	Boat
Chu_6	5751008	709226	5750589	708909	651	1,721	Chufquen	Boat

UTM Coordinate in m, datum is WGS-84, zone 18S.

flow monitoring and water losses used in the analysis. Water flow monitoring on the time allowed to fallowing the losses of water before and after LA-PAM applications. The averages of losses of water before and after LA-PAM applications were calculated to study the LA-PAM application. The averages post application considered a period until effect of LA-PAM disappear. Negatives values result when water gains occurring instead of losses.

Table 2 resume the results focused to compare the reach condition before and after application in terms of loss by seepage or water gains.

In the analysis were compared to average water loss before and after each LA-PAM application. The average water loss in post application was considered for a period until the LA-PAM effects disappear. The percentage of water loss was calculated as the difference between the flow at the beginning and end of the section, divided by the flow at the beginning, expressed as a percentage.

Measurements pre application shown different cases: 7 reaches always showed losses, 1 reach always presented gains and 3 reaches showed losses or gains depending on the date of measurement. Must be noted that 2012-2013 irrigation season was atypically rainy until January 2013. In December 2012 fall 130 mm in Carillanca weather station, meaning two times monthly average rain.) Other important issue is the topography in the study area. In several cases the canal bordering a slope permitting water inflows through walls of canals, permitting a gain of water.

The results of Table 2 also indicate that in 5 cases, of a 31 in total, the LA-PAM application effects was different to the expected results , expressed as increased loss or reduction of gains post LA-PAM application. This could be explained by the presence of diffuse inputs of water by the walls of the channel, which could have been blocked by the polymer to a greater extent than the water seepage. The diffuse inputs were supported for more water than normal condition associated to abnormal summer rainy period 2012-2013.

The other 26 cases had an expected behavior , *i.e.* losses reduction or gains increased. In 8 cases LA-PAM was applied in reaches gaining water (negative losses), 5 of them were achieved more water gains and only 3 the gain was reduced.

Table 2. Resume of results.

Canal Code	Beginning UTM N*	Beginning UTM E*	End UTM N*	End UTM E*	Application date	**Pre loss	**Post loss	***Effect duration	**Loss variation	****Flow variation
All_1	5682451	742254	5680054	740613	05-02-2013	5,1	5,8	17	-0,70	-172
All_1	5682451	742254	5680054	740613	27-02-2013	4,5	1,6	34	2,90	728
Bbs_1	5814177	714411	5814046	714162	27-11-2012	-1,4	-3,9	37	2,50	27
Bbs_2	5814368	724358	5814321	723933	20-11-2012	-1,5	-5,1	13	3,60	219
Bbs_2	5814368	724358	5814321	723933	14-02-2013	2	-6,6	46	8,60	564
Bbs_2	5814368	724358	5813989	723933	20-11-2012	-6,5	-9,7	13	3,20	194
Bbs_2	5814368	724358	5813989	723933	14-02-2013	-0,7	-11,2	46	10,50	688
Bbs_2	5814321	723933	5813989	723933	20-11-2012	-4,9	-4,3	13	-0,60	-38
Bbs_2	5814321	723933	5813989	723933	14-02-2013	-3,3	-5,2	35	1,90	122
Chu_1	5750376	708545	5750234	707850	15-11-2012	12,9	10,6	7	2,30	19
Chu_1	5750376	708545	5750234	707850	31-01-2013	10,4	8	9	2,40	16
All_2	5814049	714161	5814177	714411	28-03-2012	37,5	22,6	14	14,90	18
Chu_2	5743295	741049	5743488	740737	14-03-2012	6,4	2,8	8	3,60	353
Chu_3	5744004	748164	5744140	747813	16-01-2013	9	3,8	41	5,20	617
Chu_3	5744004	748164	5744140	747813	14-11-2012	4,1	2,21	17	1,89	222
Chu_3	5744004	748164	5744025	747394	16-01-2013	4,2	1,1	41	3,10	368
Chu_3	5744004	748164	5744140	747813	11-04-2012	6,8	1,4	22	5,40	507
Chu_3	5744004	748164	5744140	747813	15-02-2012	5,5	1,8	43	3,70	391
Chu_4	5748173	723390	5747858	723018	29-10-2012	2,6	-0,3	15	2,90	213
Chu_4	5748173	723390	5747858	723018	15-01-2013	1,5	-4,5	15	6,00	454
Chu_4	5748173	723390	5747858	723018	20-02-2013	10,5	1,7	40	8,80	563
Chu_4	5748173	723390	5747908	721042	15-01-2013	3,6	1,3	15	2,30	174
Chu_4	5748173	723390	5747908	721042	20-02-2013	13,5	1,5	40	12,00	767
Chu_5	5747881	720770	5748041	719426	13-11-2012	4,7	0,8	15	3,90	299
Chu_5	5747920	721017	5748213	719155	10-01-2013	6,1	-1,4	25	7,50	541
Chu_5	5747920	721017	5748213	719155	20-02-2013	0,5	-1,2	40	1,70	96
Bbs_3	5811533	726759	5812895	725661	20-11-2012	-1,3	1,7	9	-3,00	-213
Bbs_3	5811533	726759	5812895	725661	14-02-2013	1,6	6,1	27	-4,50	-329
Bbs_3	5811533	726759	5812895	725661	13-04-2012	5	1,4	21	3,60	252
Chu_6	5751008	709226	5750589	708909	14-11-2012	11	9,4	44	1,60	28
Chu_6	5751008	709226	5750589	708909	31-01-2013	-4,2	-2,1	33	-2,10	-36

*, UTM Coordinate in m, datum is WGS-84, zone 18S; **, Losses pre and post LA-PAM Application (%); ***, Days; ****, Flow, liter per second.

The Figure 3 compare percentage water loss before and after 31 cases of LA-PAM applications separated for irrigation system: a) Bio Bio Sur; b) Chuquen and c) Allipen. It is possible to appreciate that most of the points are under red line indicating good result of LA-PAM application.

Discussion

The LA-PAM application is usually recommended for selected channels presenting water seepage, however in this case, on the basis of knowledge of irrigators, reaches where visually selected principally using wet areas as an indicator. In 25% of the cases water gains were presents before LA-PAM applications, indicating that in this area of Chile occurs an inputs and outputs of water thought the wall channels, dominated by the topography, rains and even irrigation recharge. In the main season (2012-2013), when the most of application were performed , atypical rains increased water gains. In normal or dry years would be expected to have water gains until November or December, , except in specific channels located on slopes hills that provide water. However the above, polymer was beneficial even in these conditions, permitting water saving.

The results corroborate that in 84% of cases was an effect of water saving (reduction of losses or profit increase) due to application of polymers. Others studies shown LA-PAM was effective (8 of 11 experiments), seepage rates measured within 24 hours were reduced between 28 and 87 percent. The average duration of effect was 25 days, with minimum of 7 and a maximum 46 days, while other research measured 30% to 100% seepage reduction in long term (more than 100 days) (Susfalk *et al.*, 2008). These results can be explained for low sediment level in water in the area.

Even in channels where there are water gains possible saving it is because the polymer could largely prevent outputs. Also keep in account that usually in channels in slopes losses occur in the walls of the channel slope down. Another important aspect to discuss is that there was no correlation of variables as level of sediment, size of channels , temperature, application dates of with the effect of the polymer, being very specific behaviors for each reach evaluated.

In absolute terms the application of polymer achievement recovers 2.623 m3 s^{-1}. 2.723 m3 s^{-1} were gains (increase gains or loss reduction), while 0.100 m3 s^{-1} were lost. These values are considered an average of saving water among all LA-PAM applications made in each reach. This occurred in 31 LA-PAM applications carried out in 15 kilometers of canal. In terms of irrigated area would mean more than 2500 has additional under drought conditions.

Conclusions

It was possible to quantify water loss in channels and to evaluate the use of Linear Anionic Polyacrylamide (LA-PAM) to reduce seepage losses.

Through water flow monitoring were estimated losses in irrigation channels, achieving a better understanding of the water behaviourn in a temporal and special basis. It was determined that some cases defined by water-users as water loss in channels were not such and also varied according to the rains and topography in the area. However, it was possible to find specifics reaches, not so extensive in length, pre-

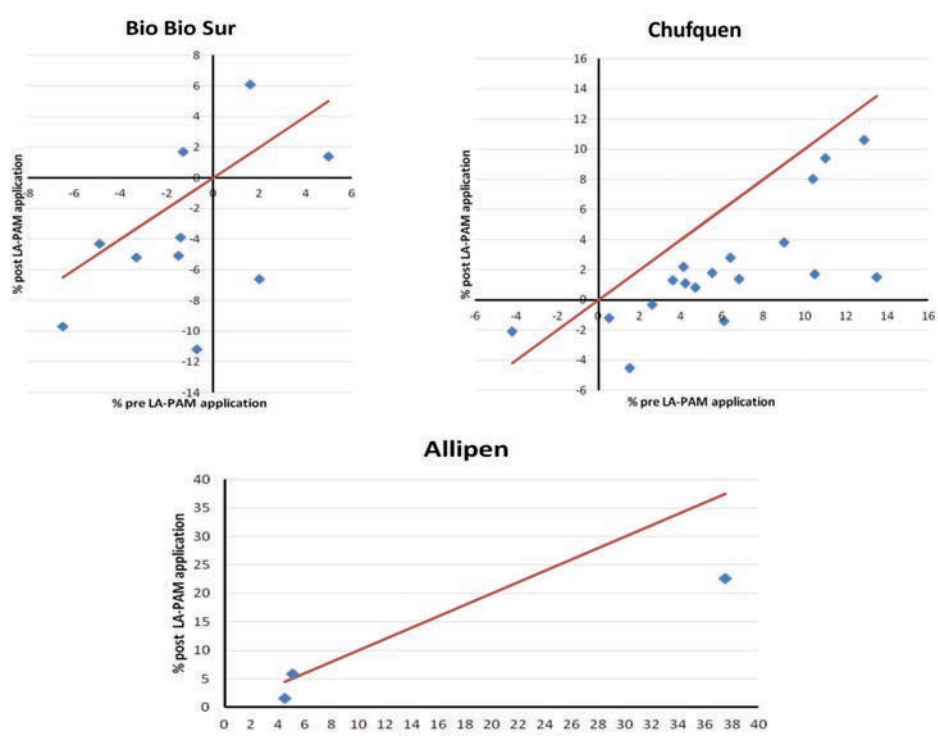

Figure 3. Comparison between percentage water loss (gains in negatives) pre and post LA-PAM applications in each irrigation systems: Bio Bio Sur; Chufquen and Allipen.

senting heavy losses that could be managed through LA- PAM applications. They were able to progress in the knowledge of LA-PAM applications according to local conditions. It was determined that the polymer application was positive since in the majority of cases (84%) it allowed water savings, through specific applications, maximum 3 per season, not affecting the environment and having low cost.

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