REMEDIATION OF BORON CONTAMINATED WATER AND SOIL WITH VETIVER PHYTOREMEDIATION TECHNOLOGY IN NORTHERN CHILE

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Abstract

The valleys of Arica Parinacota Province in Northern Chile present outstanding climatic conditions that allow crop production all year long, the province is the supplier of fresh vegetables for both central and southern Chile during winter, placing Arica´s valleys as one of the key factors in food security of the country.

However, the valleys are inserted in a desert region where salinity, boron and arsenic are in high concentrations in rivers, as well as in soil, restricting the development of most plant species. The purpose of this study was to evaluate an unconventional strategy for boron remediation in irrigation water and agricultural soil of the Lluta valley.

To implement this, several trials were carried out to test the remediation effectiveness of Vetiver Phytoremediation Technology. The trials were conducted in water and soil. The first experiment was conducted in two stages:

1) A test was done in pools of 3000L and different biomass (5 kg, 10 kg, 15 kg, 20 kg, 25 kg of Vetiver). The efficiency remediation was 20-23% for the 5, 10, 20 and 25 biomass and 36% for the 15 biomass treatment. The efficiency removal was 98.4% for lead, 40% for arsenic and 76% for manganese.

2) A field experiment was established to introduce 4 new crops and irrigated them with Vetiver treated water, where the boron level decreased by 2 mg/L. Crop yields in the Azapa valley were used as control since this valley has no problems with boron and salinity.

Crop Yield Results Yields for corn were high, 1 corn cob per plant of extra quality. All corn was 100% extra quality. This is a very significant result since previously sweet corn cannot be grown in this valley. Lettuce had a yield of 4 boxes (12-14 lettuces) every 10 lineal meters. For melon the average was 3 melons per plant of 2nd class. For Cristal chili pepper, yield reached 70-80 fruits per plant of first class.

Soil Results A test was established in pots with 6 replications that were irrigated with different boron concentrations. The treatments consisted in T1; 1 mg/L, T2; 20 mg/L, T3; 50 mg/L; T4; 100 mg/L. The pots were irrigated for 3 months and samples were taken every 4 weeks for soil and leaves analyses. Efficiency percentage at 3rd month were: T1; 66.3%, T2; 91%, T3; 95%, T4; 96.5%. We conclude that Vetiver Phytoremediation Technology is a technology capable of remediating boron toxicity, allowing the introduction of new crops and improvement of crop yields.

Keywords Phytoremediation, Boron, Soil and Water remediation, Agronomic practice, *Chrysopogon zizanioides*

INTRODUCTION

The development of agriculture depends on several factors, among them, one of the most important is the quantity and quality of water available for irrigation. The quality varies widely according to the amount and types of salt concentration, some saline compounds are toxic to plants; the most important ones for agriculture are chlorides, sodium and boron (Ayers & Westcot, 1994).

In Chile, one of the most important natural sources of boron is Ulexite, which is in important salt flats located at high altitude and sometimes in surface waters, as in Surire Lake at Parinacota Province (Figueroa *et al.*, 1998). These phenomena created several places in northern region of the country where agriculture is practiced in" borated" valleys, particularly in the Province of Arica Parinacota.

The agricultural industry of the Province is developed in small canyons and coastal valleys under a desert climate; mainly in Lluta and Azapa valleys. The climatic conditions allow high productivity under irrigation, so water resource is very valuable. However, the high content of boron, arsenic, and salts in Lluta and Camarones Rivers, strongly limit the agricultural potential of these valleys due to the toxicity of these elements for the majority of crops.

According to the annual report (2012) of the General Water Bureau, boron content goes from 10 to 23 mg/L in Lluta River and from 16 to 29 mg/L in Camarones River. The presence of boron and arsenic (0.30-0.60 mg/L) has diminished the development of the valleys in comparison with other basins with similar climatic conditions but with good water quality, as in Azapa Valley which has developed a highly competitive and profitable agricultural industry.

Possible solutions

Traditionally, the common practice to deal with salinity or excess of unwanted elements in soils has been washing or leaching. According to Ayers and Westcot (1994) and Havlin *et al*. (1999), in order to wash boron from soil requires three times the amount of water needed to wash the same amount of sodium or chloride. Besides, boron requires greater washing time because it moves slowly in soil solution since it is easily adsorbed by clay minerals (Ayers and Westcot, 1994; Havlin, *et al.*, 1999).

Trials to remove boron in the Province from water sources include technologies such as reverse osmosis and the use of column resins have been conducted. Reverse osmosis is able to remove up to 50% of boron content in water. Although water with 50% boron reduction could be useful to improve existing crop yields and probably introduction of new crops, but the cost of implementation and maintenance makes it a non-viable technology for medium size farmer. In addition, disposal of rejected water generates additional economic and environmental costs that should be considered.

Research at the Chemistry Department of Tarapacá University has developed a column resin system to reduce boron concentration in water up to 97%. This technology is expensive for medium and large irrigation areas, for example, the cost to clean 350 m^3day for 1 ha irrigation is estimated to be US$ 41,600. This system requires periodical cleaning of the resin with sulphuric acid and sodium hydroxide which generates large amount of residues plus the rejected water. These possible disadvantages and its cost make it little affordable to small and medium size farmers. Nevertheless could be useful in high-yield crops.

Vetiver Phytoremediation Technology as a possible solution

Poor quality water and poor soils in the Lluta and Camarones valleys represent an under-development of 3,000 ha of agricultural land. The improvement of the water and soils through a phytoremediation technology will allow the production of diverse crops with greater yields.

There are many technological alternatives that address water and soil remediation, however few are cost effective and limit their use in areas of widespread contamination. The remediation of conventional technologies is fast and relatively insensitive to the heterogeneity of the contaminated matrix, can act on a wide range of Oxygen, pH, pressure, temperature, and osmotic potential (Cunningham et al., 1997). In addition they also tend to be less effective, costly and harmful to the environment (Cunningham and Ay, 1996) and are subjected to the texture and soil permeability.

Within the emerging sustainable technologies, proven and with an appropriate cost effective relationship is phytoremediation in its various forms. This innovative technology has many advantages over conventional methods of contaminated sites treatment since it is economic and ecologically friendly.

Specifically in the past decades Vetiver grass, *Chrysopogon zizanioides L.* has proven to be the most effective for decontamination and remediation of water and soil, due to their unique features such as: non-invasive, adaptable to extreme edaphic and climatic conditions and high phytoremediating capacity including a large number of heavy metals, rapid growth, very deep root mass, does not harbor pests or diseases, Truong (2010) and does not require major agronomic management after establishment. Many researchers reported the potential of utilizing Vetiver to decontaminate heavy metals from soil (Truong and Baker, 1998; Roongtanakiat and Chairoj, 2001a; Roongtanakiat and Chairoj, 2001b).

In this regard the objective of the project was to validate the Vetiver Phytoremediation Technology in remediating boron, arsenic, and heavy metals from irrigation water and agricultural land in the Lluta valley. The 18 month project (U$ 177,000) was sponsored by the Foundation for Agricultural Innovation from the Ministry of Agriculture and was developed through the Agronomy Department of the Tarapacá University, Arica, Chile.

METHOD

Part I. Water Tests

The first stage included different indoor tests in a multi factorial experiment and a complete randomized design were established in order to measure the effect of different pollutant concentrations, water volume, retention time and biomass. Vetiver plants were first grown on floating flat forms before introducing to the containers or pools. (More details in Appendix}

Figure 1. **Vetiver plantation in borated and saline soils (Arica Parinacota Province)**

Figure 2. **Vetiver plants on floating flat forms**

Test 1: Manganese and Lead

60 L containers, filled with irrigation water, and 6 replications and 4 treatments (T1; day 0, T2; day 5, T3; day 10, T4; day 15) were established. Water was spiked with 2 mg/L as a tritisol 1000 ppm from lead nitrate ($Pb(NO_3)_2$) and 1 mg/L manganese as a tritisol 1000 ppm from ($Mn(NO_3)_2$. Plants of similar weight were place in each container, approximately 600 g each with 40 cm root. Sampling was taken every 5 days for 15 days. Aerial part and root samples were taken at the beginning and at 15th day.

Test 2: Arsenic

Two tests were done in order to evaluate arsenic remediation in water. First test was a factorial design 4x2 (2 treatments and 4 retention times; T1 600 g and T2 1000 g biomass) contained in 60 L containers with 6 replications. Natural river arsenic concentration in water was 0.5 mg/L. Vetiver plants had 40 cm root and samples were taken every 5 days for 15 days. Aerial part and root samples were taken at the beginning and at 15th day.

The second test was done outdoors in a 3,000 L pool filled with underground water from a well in Lluta valley. The biomass was 5 kg of Vetiver, all Vetiver plants were same size with 40cm root. Arsenic concentration was 0.3 mg/L. Three samples were taken in the 5th and 10th day. The arsenic concentration was determined *in situ* with Merckoquant© test for arsenic (0.005 mg/L-0.5 mg/L).

Test 3: Boron
Two indoors tests were done in order to evaluate the phytoremediation capacity of Vetiver on boron. The tests were done in 60 L containers with 3 and 4 replicates each and with 1000g Vetiver biomass. Containers were filled with water from the Lluta River, one set with 18 mg/L B and the second set with 12 mg/L B). Samples were taken every 5 days for 15 days. Aerial part and root samples were taken at the beginning and at 15th day.

The third test was done outdoor in pools of 3,000 L and different biomass (5, 10, 15, 20, 25 kg) with an initial natural concentration of 7 mg/L. All Vetiver plants were similar size and weight; roots were 50-60cm long. Three samples were taken every day for 10 days at medium depth of 3 replications.

For all tests the pH and EC levels were controlled daily. For all indoor tests water was homogenized before taking samples. Tests were established under semi shade condition at room temperature and were done during winter season (May to September). Medium temperature was registered between 10-18C° and daily medium evaporation (Type A tray) was registered at 4mm/ day.

Removal efficiency is calculated as: $[\text{element in soil or water}]_{\text{final}}*100/[\text{element in soil or water}]_{\text{initial.}}$
Translocation Factor (TF) is: $[\text{element}]_{\text{aerial part}} / [\text{element}]_{\text{root}}$

Part II. Soil Tests

Test 1: Indoor
A trial in soil was established in indoor conditions in pots with 6 replicates. Pots were irrigated with different boron concentrations and soil was from the Agronomy Department at Tarapacá University, Arica. Soil was thoroughly mixed and a sample was taken for initial analysis, the soil was then placed in 10 kg polyethylene pots and one Vetiver plant was placed in each pot; plants had an average weight of 600g and 30cm roots. The treatments consisted of T1; 1 mg/L (natural concentration), T2; 20 mg/L, T3; 50 mg/L; T4; 100 mg/L boron concentration. Irrigation water was prepared monthly with boric acid and kept in sealed containers to avoid any evaporation.

The pots were irrigated 1,000 ml weekly during 3 months, after irrigation all percolating water was collected in plates and reapplied again into the pots in order to have an exact amount of water used. Samples were taken every 4 weeks in soil, every 2 weeks for aerial parts and at the beginning and end of the experiment for roots.

Test 2: Field experiment

The main objective of the Project was to introduce new crops in the valley that are not able to grow under natural boron conditions. Sweet corn, lettuce, melon and chili pepper were grown as seedlings under indoor conditions at the Agronomy Department at Tarapacá University, Arica.

Two irrigations pools of $30m^3$ were established; in pool 1, 100 kg of Vetiver were floated on it, this water was allowed to stay for 5 days for remediation and after that was pumped to a second pool from where it was used for crops irrigation.

Crops were irrigated every day, 500 ml humic acid was added into irrigation water twice a week in order to improved organic matter. The fertilization consisted in 4 kg/m^2 of manure, no chemical fertilizers were used except for Phosphate that was added before planting.

Analytical Methods

Parameter	**Water analysis**	**Soil analysis**	**Foliar analysis**
Boron	Azomethine-H procedure Métodos para anális d agua de riego- INIA*, pp229 www2.**inia**.cl/medios/biblioteca/serieactas/NR33999.pdf	Saturated soil paste Azomethine-H procedure in: Métodos recomendados para los **suelos** de Chile- INIA*, pp117 http://www2.inia.cl/medios/biblioteca/serieactas/NR33998.pdf	Method INIA* 9.9.1 in Métodos de análisis de tejidos vegetales - Inia www2.**inia**.cl/medios/biblioteca/serieactas/NR34664.pdf Azomethine-H procedure
Arsenic	Standard Method for examination of water and waste water, Ed 21 3114 C		Based on PT 13 pretreatment of sampling and analysis by AAS of soils, sediments and leachates
Lead	Standard Method for examination of water and waste water, 1995		Method INIA 8-8.1 in Métodos de análisis de tejidos vegetales - Inia www2.**inia**.cl/medios/biblioteca/serieactas/NR34664.pdf
Manganese	Standard Method for examination of water and waste water, 1995		Method INIA 8-8.1 in Métodos de análisis de tejidos vegetales - Inia www2.**inia**.cl/medios/biblioteca/serieactas/NR34664.pdf
pH	Potenciometric	Saturated soil paste (Maff 1:2,5)	

EC	Conductimeter	Saturated soil paste (Maff 1:2,5)	

*INIA: National Institute for Agricultural Research

Boron analyses were done using MAS PYT 810 and AAS Varian 220 for lead and manganese. Arsenic reading was done in a Perkin Elmer MSH-10 connected to a Perkin Elmer 2380 Spectrophotometer. Statistical comparison of means was examined using the general analysis of variance procedure of Statgraphics Plus 5.1. Dunnet *t* test was analyzed by SPSS 18. Significance was reported at 5% probability level.

RESULTS

Part I. Tests in Water

According to the General Water Bureau in 2011-2012 the Lluta River presented 0.38-0.90 mg/L of manganese and 0.26-0.49 mg/L of arsenic, all these values are above the Chilean norm for irrigation water (N.Ch. 1333)[1]. Lead was included in the tests because of the historical lead problem present in the city of Arica with multi heavy metals contamination.

Test 1: Manganese and Lead

In the test for lead and manganese the analysis of variance (Dunnett *t* test) revealed significant variations ($p<0.05$) in the removal of these metals (Table 1). The removal efficiency for lead was 98.4% after 10 days treatment; lead was not detected at the 15th day treatment while manganese had 76 % efficiency in 15 days (Table 3). Vetiver did not show any toxic symptom during this period. Water pH was reported 6.3 at day one and 7.3 at day 15th, while EC was 2.7 at day one and 3.2 at day 15th, probably due to root exudates. This change in pH did not seem to interfere in lead and manganese absorption as is indicated by the high removal efficiency.

The aerial part and root analysis revealed that Vetiver accumulates Pb and Mn in root as is shown in the translocation factor (Table 2), indicating that Vetiver is not a hyper-accumulator. This result is similar to the results reported by Roongtanakiat (2009) that low translocation factor for Pb and Mn in different wastewater treatments ranging from 0.07 to 0.67 respectively. Truong (1999) reported that a moderate proportion of copper, lead, nickel and selenium were translocated (16-33%). However, numerous investigators (Yang *et al.*, 2003, Roongtanakiat *et al.*, 2007 and Singh *et al.*, 2007) found that Vetiver root accumulated higher heavy metal concentrations than aerial part.

[1] NCh1333. O f1978 MOD.1987. Water Quality Standard for different uses.

Table 1.
Concentration of lead and manganese in water (mg/L) in different sampling periods (n=6)

Metal	Treatments (Residence Time in days)				Dunnett+
	0	5	10	15	(p< 0,05)
Lead	2	1.43	0.03	ND	
0-5 days					0.5750*
0-10					1.9683*
0-15					
Manganese	1	0.69	0.34	0.24	
0-5 days					0.100*
+0-10					0.6633*
M0-15					0.7567*
e					

Mean values denoted by different letters are significantly different ($P < 0.05$) according to Dunnett *t* test. ** $P < 0.01$; * $P < 0.05$; ND: not detectable

Table 2. Translocation factor for lead and manganese

	Roots mg/k	Aerial parts mg/k	Translocation factor
Pb	211.8	7.4	0.03
Mn	191.5	12.1	0.06

Table 3. Removal efficiency

	Lead			Manganese		
	Initial (mg/L)	Final (mg/L)	Efficiency %	Initial (mg/L)	Final (mg/L)	Efficiency %
Vetiver	2	0.03	98.5	1	0.24	76

Test 2 Arsenic

The test for arsenic phytoremediation presented a 40% removal efficiency and no difference between biomass (Table 4). The concentration dropped from 0.5 mg/L to 0.3 mg/L in both treatments (Table 4) with significant differences ($P < 0.05$).

The second test done in a 3.000 L pool revealed a substantial dropped from 0.3 mg/L to 0.06 mg/L in the 5th day and was not detectable on the 10th day, this may be attributed to the pH level in the water, as test 1 pH was 6.5 and test 2 pH was 8.5. pH plays an important role in metal bioavailability, under neutral to weakly alkaline conditions bioavailability of some heavy metals, except As, V, Mo, Co and Cr decrease (Mathur *et* al.. 1991; Dermatas & Meng 2003). This reduces the possibility of their translocation from roots into the plant itself (Bolan *et* al., 2003).

As in lead and manganese, Vetiver showed a low translocation factor for As, indicating that accumulates arsenic in roots (Table 5). Truong (1999) has reported that very little As was translocated from root to aerial part (1-5%). In general, plant species growing in metal contaminated water have restricted translocation of metals to the aerial parts (Zaranyika and Ndapwadza 1995). Lower accumulation of metals in leaves can be associated with protection of photosynthesis from levels of trace elements (Landberg and Greger 1996).

Table 4. Residual As concentration in water (mg/L) at different sampling periods (n=6). T1 (600 g biomass). T2 (1000 g biomass).

Treatments	Residence time in days				Days+	As+
	0	5	10	15		
T1	0.5	0.47	0.37	0.3	0	0.5a
					5	0.48a
T2	0.5	0.5	0.4	0.32	10	0.39b
					15	0.31c
ANOVA $_{0.05}$						
(Days) *						
(Treatments) NS						
(Weeks x Treatments) NS						

+Mean values denoted by different letters are significantly different ($P < 0.05$) according to Duncan´s range test. **. $P < 0.01$; *. $P < 0.05$; NS. not significant.

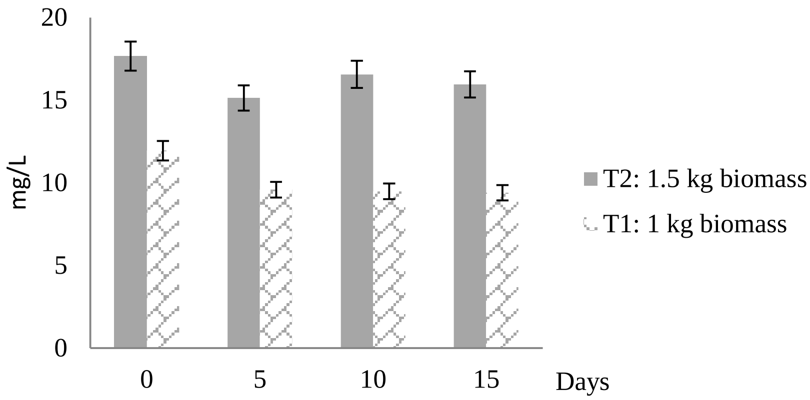
Table 5. Translocation factor for Arsenic

	Root mg/kg	Aerial part mg/kg	Translocation factor
As	41.6	0.45	0.011

Test 3: Boron

There are few researches in boron phytoremediation and fewer with Vetiver as a phytoremediating plant for boron. Due to this, the first approach was to start with a small pretest in order to evaluate its behavior. Several small pretests with 60 L containers and 500 g biomass showed that Vetiver exuded boron from roots back to water after few days so its concentration increased again. Because of this the biomass was increased and 2 new tests were done. The first 2 pretest showed a decrease in boron concentration. Test 1 (1 kg biomass) found a drop from 11.9 mg/L to 9.5 mg/L while Test 2 (1.5 kg biomass) from 17.7 mg/L to 15.1 mg/L (Figure 3). Water pH was reported at 7.5 in both tests.

Figure 3

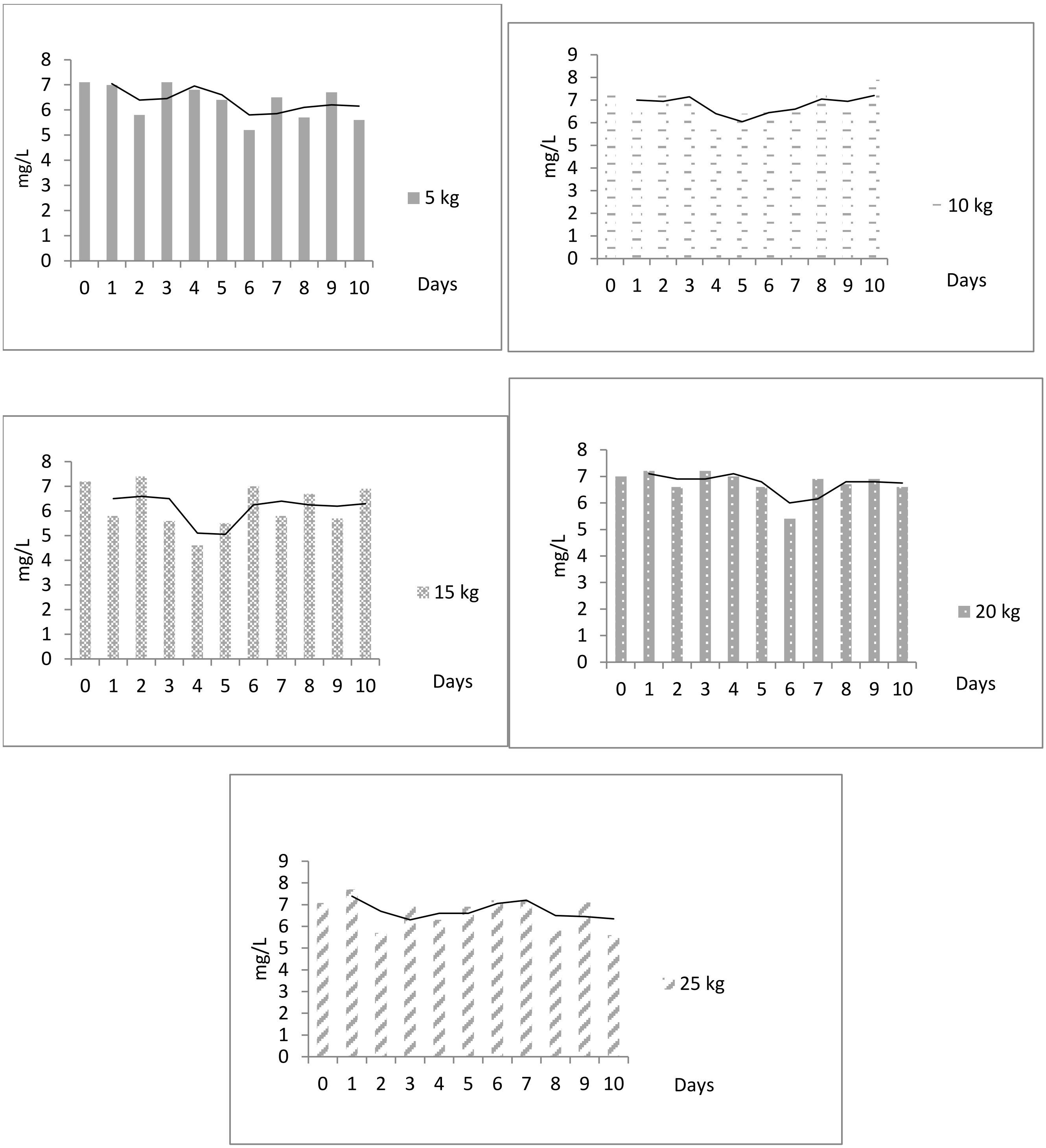


Boron Phytoremediation in Water for test 1. Error bars represent the standard error at 5% (n=3 in T1, n=4 in T2).

In the 3,000 L pool test, it was also observed that remediation was not stable (Figure 4). It was found that boron is exuded from roots almost constantly, so it is not possible to determine a fixed retention time. One cause of exudation is associated to plant decay when plants gets intoxicated, Wenzl *et al*. (2001), but Vetiver did not showed evidence of decay even several months after the test. The efficiency percentage for this test was 25% for the 5, 10, 20 and 25 kg and 35% for the 15 kg test. 2.5 mg/L less boron was registered for the 15 kg treatment. Best retention time for remediation varied from treatment to treatment (Fig 4).

The 15 kg treatment showed the highest drop in all treatments, 4.6 mg/L in day 4th, but concentration increased up to 6.9 mg/L in day 10th (Figure 4). In general, it was found that independent of Vetiver biomass, water volume and boron concentration, ***Vetiver could reduce the initial concentration between 2 mg/L to 2.5 mg/L*** though this decrease was not maintained because of exudation. Treatments with 5, 10, 20 and 25 kg did not drop below 5 mg/L. Even though the reduction was not high it allowed the cultivation of new crops that presently are not able to be grown in Lluta valley (Test 5). Aerial parts and roots analysis for this test showed that Vetiver acts as a hyper-accumulator plant which is indicated by the high Translocation Factor, from 4.6 to 22.2, although it should be considered that exudation rate is very high and constant as seen in Figure 4.

Figure 4. Trend of Boron Phytoremediation in Water with Different Biomass



Part II. Tests in Soil

Test 1: Boron

Analysis of variance (Duncan test) revealed significant variations ($p<0.05$) in the removal of boron (Table 6) among all treatments, being T4 the treatment with better performance. The peak of removal was observed at week 8 in all treatments with no significant differences between week 8 (13.04 mg/L) and 12 (12.11 mg/L) (Table 6), which suggest that Vetiver could perform a stable removal during 3 months. Nevertheless it is necessary to do a longer period trial in order to determine if Vetiver could withstand high concentration removal for longer periods and with same efficiency.

Table 6. Residual B concentration in soil (mg/L)* at different sampling times. Mean soil dry weight per pot (n=5) irrigated with different B concentration. T1, 1 mg/L. T2, 20 mg/L. T3, 50 mg/L and T4, 100 mg/L.

Treatments	Weeks after planting			Treatments+		Week+	
	4	8	12				
T1	4.266	6.38	5.78	T1	5.47d	4	9.27b
T2	7.978	12.12	11.76	T2	10.62c	8	13.04a
T3	10.424	16.4	15.58	T3	14.13b	12	12.11a
T4	14.426	17.28	15.3	T4	15.67a		

$ANOVA_{0.05}$ (Weeks) *
(Treatments) *
(Weeks x Treatments) NS

***** Results are given in mg/L according to the Azomethine-H method in saturated soil paste (refer to Analytical Methods above). Saturation % of soil: 27%.
+Mean values within the same column denoted by different letters are significantly different ($P < 0.05$) according to Duncan´s range test. * $P < 0.05$; **$P < 0.01$; NS; not significant.

The translocation factor for all treatments was above 1 indicating that Vetiver is hyper-accumulator (Table 8) accumulating boron in leaves. Regarding the efficiency removal Vetiver had a high performance with significant differences ($P < 0.05$) for treatments and length of time, showing up to 96.2% of efficiency in T4 and 93.34% in T3. The peak efficiency was reached at 4^{th} week (87.18%) with significant differences compare to week 8 and 12 as seen in Table 7.

This result shows the efficiency of removal declines with time when Vetiver is exposed to a constant concentration of boron. It should be noted that during the 3 months experimental period Vetiver did not show boron toxic symptoms, such as chlorosis, necrosis or growth reduction. This can be related to an internal mechanism for detoxification of B as it has been found in some halophytes and members of the *Rosaceae* family which are able to inactivate excess B by binding it to sugar alcohols like sorbitol (Rozema *et* al.. 1992; Brown et al.. 1997).

Table 7. Removal Efficiency Percentage at different sampling times after planting. T1, 1 mg/L; T2, 20 mg/L; T3, 50 mg/L and T4, 100 mg/L.

Treatments	Weeks after planting			Treatments+		Weeks+	
	4	8	12				
T1	66.3	22.7	44.6	T1	44.53c	4	87.18a
T2	91.0	86.2	87.2	T2	88.16b	8	80.24b
T3	95.0	92.2	92.8	T3	93.34a	12	74.25c
T4	96.5	95.8	96.3	T4	96.21a		
$ANOVA_{0.05}$	(Weeks) *						
	(Treatments) *						
	(Weeks x Treatments) NS						

+Mean values within the same column denoted by different letters are significantly different ($P < 0.05$) according to Duncan´s range test. * $P < 0.05$, **$P < 0.01$. NS; not significant. Values used to calculate removal efficiency are based on initial soil concentration which is equal to total boron applied through irrigation per month (4000 ml per pot) and residual boron in soil at the end of each month. Removal efficiency is calculated as: $[\text{boron in soil}]_{final}*100/[\text{boron in soil}]_{initial.}$

Table 8. Translocation Factor (TF) for Boron (mg/kg)

	T1	T2	T3	T4
Leave	187.4	267.7	312.9	350.3
Root	19.8	81.7	117.3	175.5
TF	9.48	3.28	2.67	2.00

In foliar analysis the analysis of variance (Duncan test) revealed significant variations (P <0.05) for treatments and length of time. Treatment T3 and T4 had no significant differences accumulating more than 300 mg B/kg (Table 9). While the highest accumulation was found in week 8 with significant differences compare to all weeks.

The foliar concentrations found in this test was much lower than concentrations found in several pretests done one year before where it was found that Vetiver could accumulate 1279 mg/kg when kept hydroponically in water with 16 mg B/L.

Robinson et al. (2007) found that leaf B concentrations also varied considerably with time over a growing season. These findings are consistent with the notion that boron uptake into plants is mainly passive and primarily driven by convection with the stream of transpiration water when soil B concentrations are adequate (Schulin *et* al,. 2010) thus, accumulation in the leaves is primarily associated with the transpiration water flow and there is little or no relocation of B in the phloem.

Table 9. Foliar analysis at different sampling times. (Boron in mg/kg). T1, 1 mg/L; T2, 20 mg/L; T3, 50 mg/L and T4, 100 mg/L.

Treatments	Weeks after planting					Treatments+		Weeks+	
	4	6	8	10	12				
T1	191.4	199.1	304.1	158.8	187.4	T1	203.02c	4	285.90b
T2	281.8	297.4	345.5	298.1	267.7	T2	297.33b	6	268.96b
T3	345.3	268.5	364.7	315.4	312.9	T3	317.96ab	8	337.08a
T4	331.7	310.8	365.1	300.2	350.3	T4	333.42a	10	268.13b
								12	279.60b

$ANOVA_{0.05}$ (Weeks)*
(Treatments) *
(Weeks x Treatments) NS

+Mean values within the same column denoted by different letters are significantly different ($P < 0.05$) according to Duncan´s range test. * $P < 0.05$, **$P < 0.01$, NS; not significant.

Test 2. Field experiment

All crops were irrigated with Vetiver treated water. Results showed that:

Hibrid corn cv. prays: Yields for corn were high. 1 corn per plant of extra quality, all the crops were 100% extra quality. This is a very significant result since sweet corn cannot be grown in this valley. Some farmers report to have tried it and obtained 3th and 2nd class quality. In this valley the Lluta ecotype only attained 1st class quality, never extra. In the Azapa valley this corn yields 1st and 2nd class quality. This is a good option for farmers in summer season when the Lluta ecotype does not grow well. Also because of the shorter fenology (60 days) as compare to Lluta ecotype (90 days).

Figure 5. Irrigation pool with Vetiver floats, left. Extra quality sweet corn, right

Lettuce c.v. Batavia: Lettuce had a yield of 4 boxes (12-14 lettuces) every 10 linear meters. The average yield in Azapa valley is 3 boxes (12 lettuces) for every 10 linear meters. The lettuce presented burn borders at the time of harvest, although 1 week before there was no symptoms of saline toxicity.

Figure 6. **Lettuce 2 weeks after planting**

Melon: This crop was planted out of season, so the lower temperatures of autumn affected the fruit growth. Also the low population of pollinating agents, as bees, affected its growth. Despite all this set back the melon yield was acceptable. The average was 3 melons per plant of 2^{nd} class. Whereas in the Azapa valley yields are 3-4 melons per plant; 30% extra, 30% first and 40% second class.

Figure 7. **Second class melon**

Figure 8. **Chilean crystal chili pepper**

Chili pepper var. cristal: This cultivar is very delicate and not be grown in the valleys of Arica Parinacota Province. There is one farmer in the Azapa valley that has yield of average 80 fruits first class per plant. In this experiment yield reached 70-80 fruits per plant of first class. The crop did not show any salinity symptom.

The production cost projected for one hectare was U$ 5,300 in compost, compost tea and manure tea plus U$ 400 for biopesticides. The cost of organic fertilization can be lower down to 50% using 2 kilos compost per m^2 instead of 4 kilos and replacing it for compost tea.

The cost for phyto-remediation of water is around U$ 1,600 for one season and U$ 10,000 for soil remediation. The cost to clean 350 m^3 /day of water needed to irrigate 1 hectare in one season is estimated in US$ 41,600 with column resin system.

RECOMENDATIONS AND CONCLUSION

The trial results allowed us to conclude that Vetiver Phytoremediation Technology is a suitable technology to remediate boron, arsenic and heavy metals in the Arica Parinacota Region. In addition, the trial studied the phytoremediation of boron, which is an element not widely studied in phytoremediation and has none with Vetiver. A pool of scientific data has been generated in this regard for the world of phytoremediation.

The test in boron showed that Vetiver can decrease boron in water only by a small percentage; however, this reduction of 2 mg/L is enough for introducing new high yielding crops to the Lluta Valley. As for the phytoremediation of boron in soil the decrease was highly significant (96%). This fact is very significant to the valley as lower boron in soil will allow introduction of new crops and higher yields of existing crops in the 3,000 ha land area, which was not possible in untreated soil. In addition, it has proven that Vetiver Phytoremediation Technology is highly efficient in remediating lead and manganese, while water remediation in arsenic is moderate.

The results show that Vetiver Phytoremediation Technology is a proven, ecologically friendly and low cost technology for remediation and a promising technology for the agricultural development of this province and other desert areas in the world.

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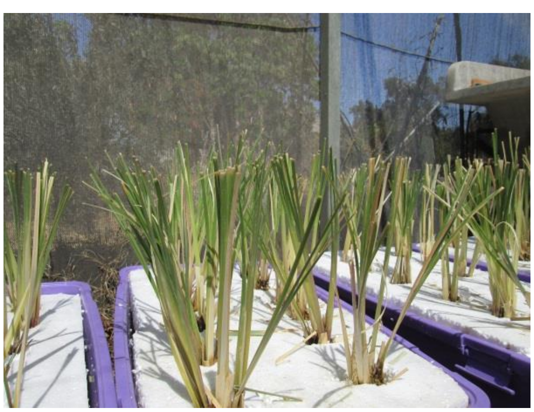
APPENDIX

Preparation of Vetiver floating platforms



First days in water

Same plants after 1 month in water

Vetiver roots ready for treatment (L) **and in treatment pool later (R)**

Vetiver treatment in above ground pool (L) and in ground pool (R)

Nursery in Camarones Valley (4 month old)

Workshop for the Forestry National Corporation Staff


Workshop for farmers and students from Azapa Agricultural High school

Workshop for students from Azapa Agricultural High school


Workshop for farmers. Lluta Valley

Workshop for Agronomy students. Lluta valley


Irrigation tank with vetiver. Field experiment in LLuta valley (L) and Field preparation (R)

First day after planting **Lettuce one week after planting**

Corn one week after planting **Melon one week after planting**

Crops 2 months after planting **Ripe corn**

Ripe melon