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Effectiveness of halophyte species in the remediation of saline/sodic soils

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ABSTRACT

The generation of large quantities of waste including brine is part of the production process in the petroleum industry. In the early days of the petroleum industry, the environmental guidelines for the disposal of such waste were non-existent or inadequate based on present day standards. Plants have been used to remove specific ions from soils as a way to remediate the contaminated soil. In nature, there are many plant species available that can help in the remediation of brine-contaminated soils. Natural properties of these plants (Halophytes) can help in the extraction of salts form the soil. Halophytes are species that can tolerate or accumulate salinity levels present in the form of sodium, calcium, or magnesium chloride, or as free chlorides ions and, therefore, can remove the excess salts present in the brine-contaminated sites. The main objective of this study was to determine ways and means of using salt tolerant plants to remediate brine spills associated with the petroleum industry.

On the basis of the previously conducted germination trial, four species were selected for pot study. The species selected were *Atriplex patula, Puccinella nuttaliana, Calamagrostis inexpansia,* and *Agropyron trachycaulum*. These species were grown in pots with three different types of soils: potting soil (Control), contaminated soil and contaminated soil mixed with peat moss on a 50:50 weight basis mixture. The pot study was carried out over 150 days. Seeds seeded for each species were 15 in each pot.

The germination of *A. patula, P. nuttaliana*, and *A. trachycaulum* in potting soil and mixed soil started approximately on the same days. The germination of all species in contaminated soil was delayed. Based on the pot study, 44% of *A. Trachycaulum* seeds were found to germinate well in contaminated soil compared to 70% in mixed soil, and

92% in potting soil. The germination of A. Patula and P. Nuttaliana was found to be less than 15% in contaminated soil. However, *P. Nuttaliana* had 100% germination in mixed soil and potting soil. The germination of *C. Inexpansia* was 6% in contaminated soil, 17% in mixed soil, and 23% in potting soil.

The species recommended for the brine-spilled sites are A. Patula, *P. Nuttaliana* and A. Trachycaulum. Of these three species, *A. Patula* will be very effective in removing Chloride and Sodium, and also helpful in reducing Calcium, and Total Sulfur. *P. Nuttaliana* and A. Trachycaulum, having the ability to tolerate high concentrations of salts, were suitable plants for revegetation of the contaminated site. It is also evident that the number of plants growing in an area did not affect the dry matter yield. A large number of seeds germinating within area will lead to tall plants with fewer branches

Keywords: brine spills, halophytes, and contamination**.**

INTRODUCTION

The generation of large quantities of waste including brine is part of the production process in the petroleum industry. In the early days of the petroleum industry, the environmental guidelines for the disposal of such waste were non-existent or inadequate based on present day standards. As a result, the brine separated from the crude oil during pumping was inappropriately disposed in open land or in natural water bodies leading to land degradation. In addition, accidental spills are also another source of contamination. When the area of degraded land is very large, excavation and replacement of brine-contaminated soil is not economically viable.

Brine contamination of soil directly or indirectly leads to environmental degradation. Ecosystem sensitivity to brine contamination and the ability to recover depends on the flora, fauna, soil properties, geology, slope, hydrology and climate of the spill site (Milan et al 1997). Salinity of brine may range from 1,000 to 400,000mg L^{-1} (USGS 1997). Brine-contaminated soils have excess soluble salts and high electrical conductivity. Many of the brine-affected soils are classified as saline-sodic soils (Lindsay, 1998). The Sodium Absorption Ratio (SAR) is defined as ratio of the quantity of sodium ions occupying the cation absorption sites to the quantity of magnesium and calcium ions. High values of SAR are an indication of the high sodicity of the soil which leads to higher rates of clay dispersion, soil swelling, and pore plugging. Sodic soils usually lose their structure and have extremely low infiltration rates (Sandoval and Gould, 1978).

Plants have been used to remove specific ions from soils as a way to remediate the contaminated soil. In nature, there are many plant species available that can help in the remediation of brine-contaminated soils. Natural properties of these plants (Halophytes) can help in the extraction of salts form the soil. The subsurface environment in the vicinity of vegetation is highly bioactive. Plants and soil microbes have evolved highly complex symbiotic and synergistic relationships that provide the plant with protection, nutrition, and enhanced water uptake capacities

There are several processes acting together to remove or stabilize contaminants in soils. These processes include biodegradation of contaminants in the root zone, plant uptake followed by transformation or volatilization, and contaminant stabilization / immobilization. Some organic contaminants may be taken up by the plants by a passive process related to the ability of the chemical to move through cell membranes (Briggs et al. 1982). Once taken up, certain organic compounds can be metabolized by plant enzymes into less toxic forms (Newman et al. 1997; Trapp and McFarlane 1995). When volatile organic compounds (VOCs) are translocated to plant leaves, they may volatilize through the stomata, the tiny openings in the plant leaves where gas exchange occurs (Vroblesky et al. 1999).

In each region of soil-plant atmosphere continuum, various processes play a role in the clean up depending on the type of contaminant present. The ability of a contaminant to pass through the various regions of this continuum depends on its physical characteristics such as solubility, vapour pressure, Henry's Law constant, and phase distribution (Dragun 1998). Depending on the scenario, the cost of phytoremediation is around one tenth that of conventional soil cleaning procedures (David 2002).

This study was initiated to find a phytoremediation strategy to clean-up a brine contaminated soil located within a Provincial park. Being a park, there were restrictions in the type of clean-up methods that can be used in this area. The existing vegetation, the level of contamination, and the topography were taken into account in deciding the remediation strategy for this site. The main objective of this study was to determine ways and means of using salt tolerant plants to remediate brine spills associated with an de-commissioned petroleum production operation.

METHODS AND MATERIALS

Site Description

There are two discreet brine contamination sites located within 200 meters of each other in the cattail-bullrush riparian zone of a shallow lake or large slough near

Lulu Lake, located within the Turtle Mountain Provincial Park in south western Manitoba. The sites were contaminated by an oil well that deposited or spilled brine from the well site over the course of approximately fifty years. One of the site has also been contaminated by hydrocarbons and drilling mud (bentonite clay). At both sites, the vegetation is very sparse with a high percentage of the area being bare ground. The sites are extensively used by large wild animals; moose, elk and deer, as a ‘salt lick.” Animal tracks are numerous and there was some evidence that some of the denuded blackened appearance of the sites was actually caused by heavy hoofed animal trampling. The extent of salt contamination on Site A, located immediately down hill from the actual well site was approximately 75 X 25 meters while Site B measured 130 X 40 meters.

Water analysis of the brine documented in December 1955 indicated that water overflowing into the flare pit had 145,000 to150,000 ppm of Total Dissolved Solids (TDS). The Lulu Lake was contaminated to chloride levels exceeding 70,000 ppm by a salt water tank leaking in July 1970. An electromagnetic (EM) survey of the contaminated sites was conducted in November 1997, which provided the level of contamination in different locations of the contaminated site (Figure 1). Table 1 shows the variation in the values of different contaminants at different locations sampled during the EM survey.

Laboratory Experiments

Growth chamber studies were carried in two stages. In first stage, a germination trial was conducted to identify plant species that can germinate and grow well in the contaminated soil. The results of the germination trials were used to identify viable species that can be used in phytoremediation. Based on this, four plant species were identified for further investigation of their ability to remediate the contaminate soil in a pot study.

Set-up of the Pot Study

Plants for this study was selected based on the pervious germination trials conducted on ten halophytic species i.e. *Scirpus validus, Atriplex patula, Trigloclim maritima, Calamgrostis inexpansia, Scirpus raludosus, Typha latifolia, Hordeum jubatuns, Agropyron trachycaulum, Puccinella nuttaliana,* and *Chenopodium glaucum*. The four species that had shown promise as viable species capable of germinating in saline conditions were selected for a growth chamber study herein after referred to as "pot study". The species selected were *A. patula, P. nuttaliana*, *A. trachycaulum* and *C. inexpansia*.

A large quantity of contaminated soil from the contaminated site was transported to the laboratory for use in the pot studies. The contaminated soil was collected from different locations and up to 50 cm down into the contaminated soil. The collected soil was sieved through a 2-mm sieve (Canadian standard sieve series) and were well mixed.

Three types of soils were used in the pot studies, contaminated soil, soil amended with peat moss 50:50 by weight (Mixed soil) and potting soil. Potting soil was used as control. No fertilizers were added into all three types of the soils at any stage of the study. After mixing, a soil analysis was carried out on sub-samples. Fifteen seeds of each species were planted in the pot under controlled environment. The temperature in the growth chamber varied from 15°C to 30°C with a mean temperature of 22 °C.

The growth chamber was equipped with 215 W/m^2 of light in the growth area. The numbers of seeds germinating were recorded daily. The heights of the plant were recorded every week. The pot study period lasted for 150 days. During the first 50 days, 100 ml of water was applied daily and after that 150 ml of water was applied every second day. After harvesting, the plants were dried and weighed to obtain the dry matter gain. A plant tissue analysis was also carried out to determine the uptake of different ions present in the soil.

RESULTS AND DISCUSSION

The soil analyses of the different soil treatments (Contaminated, mixed and potting soil) used in study are presented in **Table 2**. The mixing of contaminated soil with peat moss (50:50 by weight) helped reduce the contamination level and improved the soil structure. The Electrical Conductivity (EC) of the mixed soil was reduced from 144.5 dS/m to a 47.8 dS/m. Mixing of peat moss with contaminated soil reduced Sodium Absorption Ratio (SAR) and Chloride and Sodium contaminants to half. It was also observed from the soil analysis that the contaminant levels were increased since 1997 EM survey. Particularly Chloride and Sodium had increased ten times than that of the 1997 levels. The mixing of peat moss improved soil texture, increased water-holding capacity and provided organic matter to the contaminated soil. The improved conditions certainly helped in the higher germination of seeds in these amended soils.

Germination of Seeds

The germination of *A. patula, P. nuttaliana*, and *A. trachycaulum* in potting soil and mixed soil started approximately on the same days. The germination of all species in contaminated soil was delayed. Based on the pot study, 44% of *A. Trachycaulum* seeds were found to germinate well in contaminated soil compared to 70% in mixed soil, and 92% in potting soil. The germination of A. Patula and P. Nuttaliana was found to be less than 15% in contaminated soil. However, *P. Nuttaliana* had 100% germination in mixed soil and potting soil. C. Inexpansia had shown very poor germination in all three kinds of soils. The germination of *C. Inexpansia* was 6% in contaminated soil, 17% in mixed soil, and 23% in potting soil. Percent germination of these species is shown in Figure 2**.**

Biomass Analysis

The average dry matter yield of each species is shown in Figure 3. The dry matter yield by *C. Inexpansia* in all the soil treatments was not enough to carry further analysis. Moreover, dry matter produced by *A. Patula, P. Nuttaliana and A. Trachycaulum* in contaminated soil was also not enough to carry the further analysis. The dry matter yield produced by *A. patula* did not depend on the number of plants germinated. The number of plants grown in each pot was fifteen. The A. Patula among all four species grown produced the highest dry matter yield. The dry matter yield produced by A. Patula is shown in Figure 4. The dry matter yield produced by *P. Nuttaliana* was higher than *A. Trachycaulum* in mixed soil but *A. Trachycaulum* produced more dry matter than *P. Nuttaliana* in contaminated soil.

Plant Height

The plant height of the *P. Nuttaliana* and *A. Trachycaulum* was approximately similar. *P. Nuttaliana* and *A. Trachycaulum* are grasses, and therefore, there was no correlation between the height and number of plants. Plant height of the *A. Patual* was higher with the higher number of germination. Lower number of plant germination allowed the plants to develop the branches. The average plants height attained during the pot study by *A. Patula* is shown in the Figure 5.

Removal of Contaminants

The contaminants removed form the mixed soil and potting soil are shown in Figure 6.

A. Patula It was found that *A. Patula* was very effective in removing Chloride, Sodium and Calcium. It had also shown some ability to remove total Sulfer. A. Patula had removed 75, 36 and 12 g/m^2 of Chloride, Sodium and Calcium, respectively form mixed soil and 43, 12 and 9 g/m^2 of Chloride, Sodium and Calcium, respectively from potting soil. Physiologically the *A. Patula* is a salt accumulator plant and it was evident from these results. Plant tissue analysis indicated that A. Patula is very capable of removing Chloride and Sodium from the brine contaminated soils.

P. Nuttaliana and A. Trachycaulum *P. Nuttaliana* and *A. Trachycaulum* were able to survive in the mixed soil having Chloride and Sodium in the range of 17.0 and 8.4 g/kg, respectively. Plant tissue analysis indicated that both of the species showed no promise in their capability to remove salts from the soil. It was evident from the study that *P. Nuttalian* and A. Trachycaulum are salt tolerant species.

CONCLUSIONS

The species recommended for the brine-spilled sites are A. Patula, *P. Nuttaliana* and A. Trachycaulum. Of these three species, *A. Patula* will be very effective in removing Chloride and Sodium, and also helpful in reducing Calcium, and Total Sulfur. *P. Nuttaliana* and A. Trachycaulum, having the ability to tolerate high concentrations of salts, were suitable plants for revegetation of the contaminated site. It is also evident that the number of plants growing in an area did not affect the dry matter yield. A large number of seeds germinating within area will lead to tall plants with fewer branches. On the contrary, smaller plant densities resulted in plants having more branches and foliage.

The Halophyte species are capable of removing a broad range of ions from the soil and therefore are more suitable for sites that are not readily remediated by other methods. The reclamation of brine-contaminated soils will be cost-effective with phytoremediation using halophytes. The low-cost is due to the simplicity in using plants to remove the contaminants over a longer period of time. In some cases, the harvestable portion of the plant material can be utilised to recover the cost of the operation, or even turn a profit. Another advantage of using halophytes is that it leaves the soil fertile and has less adverse environmental effects compared to conventional clean-up methods.

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Table No. 1 Soils and sediments analysis (1997)

Description	EM Survey Colour area					
	Green	Yellow	Dark Yellow	Brown	Dark Brown	Dark Brown pit Area
pH	7.5	7.9	7.9	8.0	7.8	8.1
Electrical Cond. (dS/m)	0.8	2.4	4.0	5.1	9.1	11.6
Saturation (%)	52	79	89	75	84	90
SAR	4.5	25.1	46.6	54.7	53.2	62
Chloride (mg/Kg)	16.7	450	1130	1240	2650	3770
Calcium (mg/Kg)	29.1	21.2	19.4	22.2	59.6	62.0
Sodium (mg/Kg)	71.7	422	812	821	1700	2320
Potassium (mg/Kg)	4.5	4.1	6.9	8.5	25.7	37.4
Magnesium (mg/Kg)	4.6	3.6	3.9	3.9	20.0	34.6
Sulphate-S (MG/Kg)	7.8	39.8	31.2	69.9	251	393

Source: Manitoba Energy and Mine, tests done by Norwest Labs on November 21, 1997

Table No. 2 Soils and sediments analysis (2004)

Description	Contaminated Soil	Mixed Soil	Potting Soil
pH	7.2	6.9	4.8
Electrical Conductivity (dS/m)	145	47.8	1.9
SAR	74.3	34.4	0.6
Chloride (mg/Kg)	37350	17400	136.5
Calcium (mg/Kg)	3335	2550	469
Sodium (mg/Kg)	17950	8470	73
Potassium (mg/Kg)	175	135	107
Magnesium (mg/Kg)	1580	903	144.5
Sulphate-S (MG/Kg)	670	695	141.5

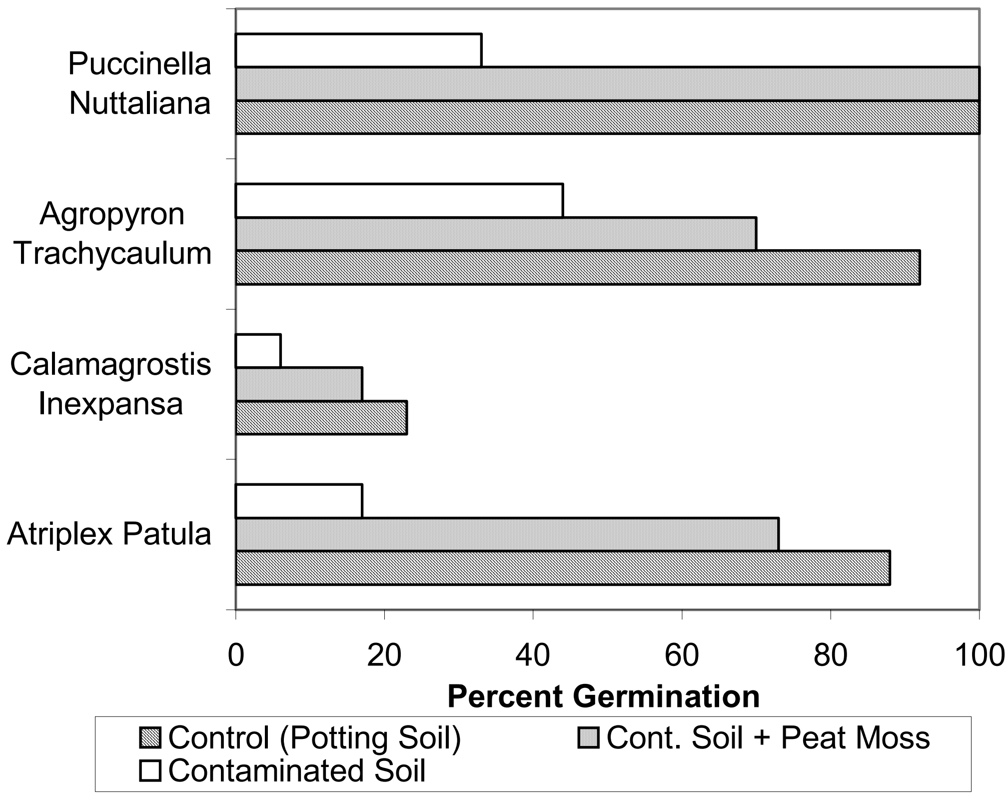

Figure 1 Percent Germination of the plants

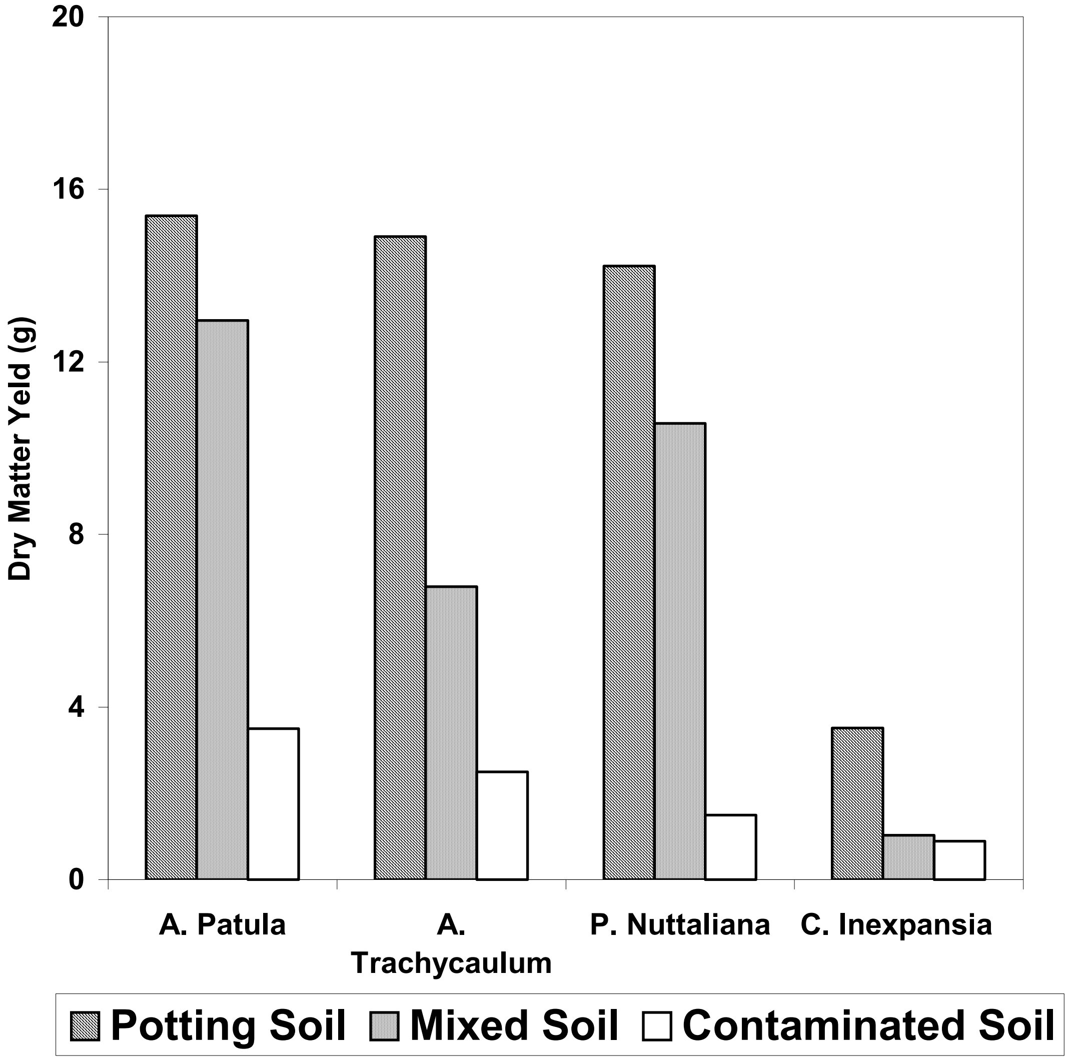

Figure 2 Dry Matter yield produced by different species in different soils

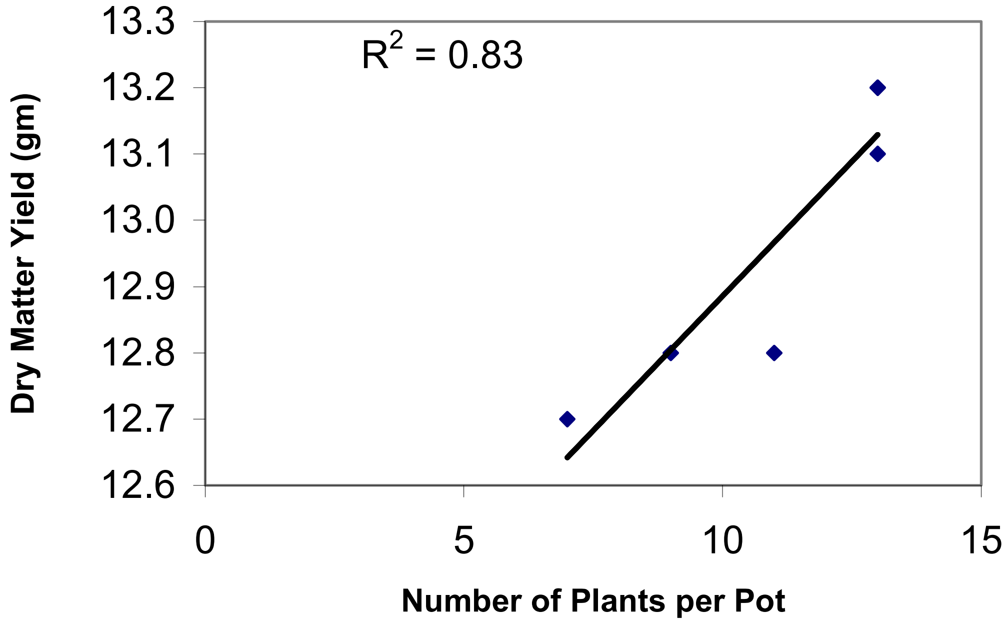

Figure 3 **Dry Matter yields produced by A. Patula in mixed soil and number of plants germinated.**

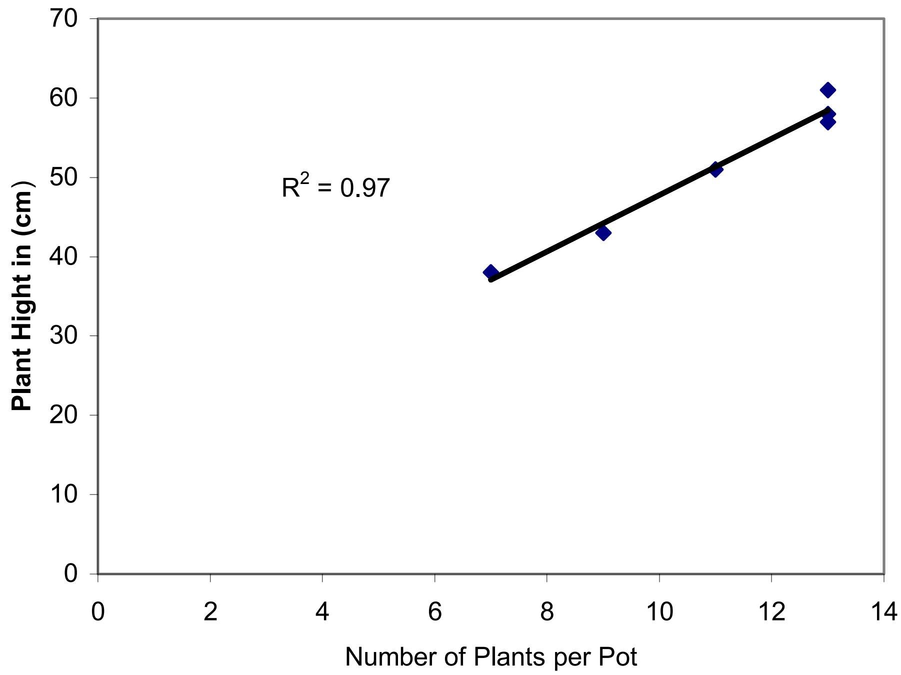

Figure 4 Average height of the A. Patula plant and number of plant germinated

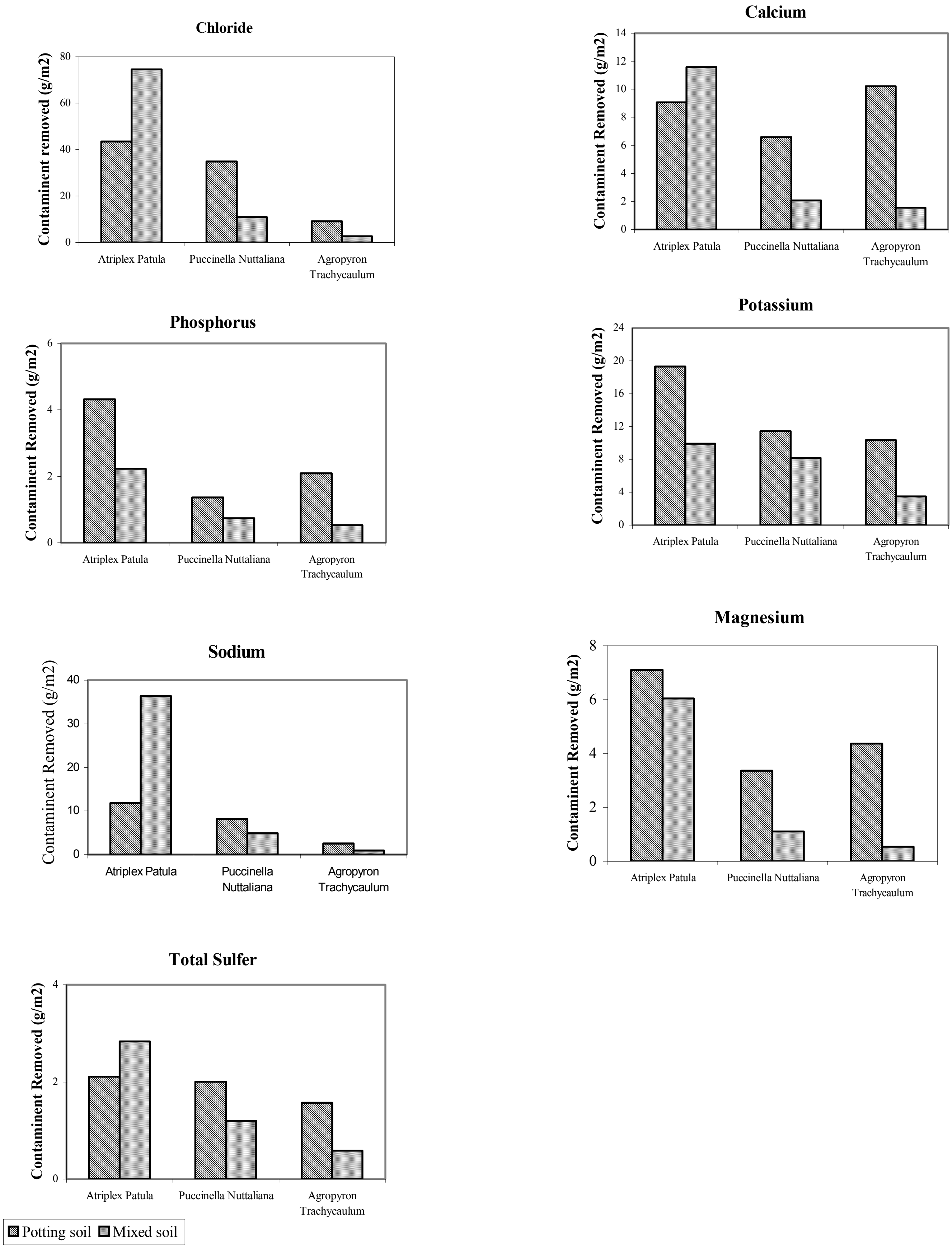

Figure 5 Contaminants removed from the soil in grams per meter square