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Sea salmon sludge as fertilizer: effects on a volcanic soil and annual ryegrass yield and quality

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Abstract. To evaluate the effect of sea salmon sludge on soil and ryegrass yield and quality, five treatments were tested (30, 60 and 90 t ha^{-1} of sludge, inorganic fertilizer and control). The sludge contained 16% dry matter (DM), 0.13% total N and 1.6% P. The sludge increased ryegrass DM yield, P and Na content, but decreased K concentrations in soil and plants. Sludge can be applied successfully on to land, but its addition should be complemented with inorganic nutrients (N, K). The high Na content of the sludge may limit repeated application, but the main benefit is its P content.

Keywords: Phosphorus, sodium, sea salmon sludge, fertilizer equivalent

INTRODUCTION

Chile is the main salmon producer in the world with an annual production of about 490 000 tonnes. Aquaculture generates large quantities of organic waste, mainly faeces and uneaten feed. Waste accumulation results in water pollution which, in turn, reduces fish production (Naylor *et al.* 1999; Mazzarino *et al.* 1998).

Fish sludge contains organic matter and many nutrients (Salazar & Saldaña 2004) and therefore could be used as fertilizer in agriculture, but it has low available-nutrient concentrations, so that the interaction between sludge and soil can be important to obtain adequate mineralization rates.

The volcanic soils of southern Chile are deficient in phosphorus (P). The recycling of fish sludge as a fertilizer can reduce the risk of water pollution and increase soil fertility. However, sludge may also contain heavy metals, pathogens and high quantities of Na, which could limit its use.

The objective of this study was to compare the effects of sea salmon sludge with those of inorganic fertilizers on soil and annual ryegrass dry matter (DM) yield and quality.

MATERIALS AND METHODS

Experimental site

The experiment was set up on a deep volcanic soil (Typic Distrandept; USDA-SCS 1975; 40°35′S, 73°8′W, 73 m a.s.l.), with less than 5% slope, 24% organic matter (0–10 cm) and 0.6 g cm^{-3} bulk density (0–20 cm).

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Sea salmon sludge

Sludge was collected from the sea (*c.* 35 m depth) and pumped to floating containers where it was flocculated with zeolite and thoroughly mixed for analysis (Table 1), before application.

Experiment set-up

Sludge was incorporated into the bare soil (17/10/2002), using a rotavator (0–12 cm depth). Annual ryegrass (*Lolium multiflorum* L. cv. Sabalan) was sown (21/10/2002) at 35 kg seed ha^{-1}. A randomized design with four replicates (3 × 3 m) was used to compare sludge at 0 (control), 30, 60 and 90 t ha^{-1} (fresh weight) and inorganic fertilizer (37 kg N, 72 kg P and 66 kg K ha^{-1}) applied as urea, triple superphosphate and potassium chloride.

Initial soil samples were taken (0–20 cm depth) from each replicate and at the end of the experiment from each treatment. Samples were analysed for Olsen P (mg kg^{-1}), pH (water), Ca, Mg, Na, K, cation exchange capacity (CEC) and Al (cmol(+) kg^{-1}) (Sadzawka 1990).

The ryegrass was cut six times during the experimental period of 12 months (5 cm residual height). Samples were weighed fresh and a subsample (200 g) was oven dried at 65 °C for 48 hours, to determine DM content (%) and yield (kg DM ha^{-1}). The dry subsample was ground and analysed for N, P, Na and K concentrations (Sadzawka *et al.* 2004).

Soil nutrient budgets were calculated (N, P, Na, K). Nutrients incorporated in fertilizers were the input and plant uptake was the output. Budgets were the difference between inputs and outputs.

Statistical analysis

Analysis of variance (ANOVA) was used to determine statistical differences between treatments. Sludge rates were regressed against ryegrass DM yield using GENSTAT 7.0.

Table 1. Characteristics and contribution of sea salmon sludge used in the experiment, on dry matter basis, except for N which is on fresh matter basis ($n = 4$, $\pm$ s.e.m.).

Characteristic	Value	Contribution (kg t^{-1})
Dry matter (%)	15.8 ± 0.65	158
Total N (%)	0.13 ± 0.005	1.3
NH_4-N	0.008 ± 0.0003	0.08
P (%)	1.6 ± 0.04	2.5
K (%)	0.4 ± 0.02	0.6
Ca (%)	4.3 ± 0.09	6.8
Mg (%)	1.2 ± 0.03	1.9
Na (%)	5.0 ± 0.21	7.9
Mn (mg kg^{-1})	172 ± 3.9	0.03
Zn (mg kg^{-1})	280 ± 2.9	0.04
Fe (mg kg^{-1})	16,662 ± 282.3	2.6
Cu (mg kg^{-1})	106 ± 10.0	0.02
Al (mg kg^{-1})	27,437 ± 865.3	4.3
Ash (%)	85 ± 0.2	
Organic matter (%)	14.7 ± 0.16	
Carbon (%)	8.2 ± 0.09	
Ratio C : N	9.8 ± 0.15	
pH (Water)	7.8 ± 0.02	
Density (g cm^{-3})	1.06 ± 0.005	

RESULTS

Sea salmon sludge and soil

The sludge contained high P, Na, Al and Fe, and low N concentrations (Table 1). Initial soil data indicated low P, Ca and Na concentrations (Table 2). Sludge application resulted in significant increases in Olsen P, Na and CEC, as well as a significant decrease of Al and K in soil solution ($P \leq 0.05$; Table 2).

Ryegrass yield and quality

All treatments produced significantly higher DM yields than the control ($P \leq 0.05$; Table 3). The higher sludge rate caused greater P and Na concentration in plants ($P \leq 0.05$). Average N and K concentration did not differ between treatments ($P > 0.05$; Table 3).

Nutrient budgets

Soil N budgets did not differ between treatments (-46 kg N ha^{-1} yr^{-1}, $P > 0.05$). Phosphorus and Na budgets increased with increasing sludge rates ($P \leq 0.05$), varying between 69 and 219 kg P ha^{-1} yr^{-1} and between 223 and 690 kg Na ha^{-1} yr^{-1}. Sodium budget in the inorganic fertilizer treatment was similar to the control. Increasing sludge rates increased K budget from -42 to -4 kg K ha^{-1} yr^{-1}.

DISCUSSION

Sea salmon sludge

Salmon sludge had low N and K concentrations (Table 1), in agreement with Salazar & Saldaña (2004) but in contrast with Mazzarino *et al.* (1998), probably because Chilean sludge came from underneath cages of sea bays and not from ponds or raceways.

Naylor *et al.* (1999) showed in the feed that 78% of P is in the solid fraction and 80% of N is in a soluble form, in agreement with P concentration results for this study. This would also explain the low N content in the sludge collected, in agreement with Salazar & Saldaña (2004), because the soluble N was probably lost in sea water.

Calcium and Na concentrations were high, because of high sodium chloride concentration of sea water and the decomposing marine organisms (Naylor *et al.* 1999). High Al and Fe concentrations could be related to silica and sand contamination (Table 1).

Soil

Soil concentrations of Mg and Na increased with increasing sludge rate ($P \leq 0.05$; Table 2). The control suffered P, Mg and Na depletion, with negative nutrient budgets. Inorganic fertilizer had similar effects to the application of 30 t sludge ha^{-1} apart from Na. Calcium concentration did not vary between sludge treatments ($P > 0.05$), probably because of its low solubility (Naylor *et al.* 1999).

Ryegrass yield and quality

Sludge did not affect ryegrass establishment. Total DM yield was small, probably because of the lack of N. Fertilized treatments produced greater yield than the control ($P \leq 0.05$; Table 3), but there were no significant differences between any of the other treatments, probably because of the small N inputs.

Yield results suggest that the application of 30 t ha^{-1} of sludge was equivalent to the inorganic fertilizer treatment,

Table 2. Chemical soil analysis before the sludge application (02/10/2002) and at the end of the experimental period (02/10/2003) (0–20 cm) ($n = 4$, $\pm$ s.e.m).

Analyses	Initial concentration	Final concentration				
		Control	30 t ha^{-1}	60 t ha^{-1}	90 t ha^{-1}	Inorganic fertilizer[a]
pH (H_2O)	5.8 ± 0.02	5.8 ± 0.02 c	5.9 ± 0.01b	6.0 ± 0.02 a	6.0 ± 0.02 a	5.8 ± 0.02 c
P Olsen (mg kg^{-1})	4 ± 0.2	4 ± 0.2 c	5 ± 0.4 b	6 ± 0.3 b	7 ± 0.4 a	5 ± 0.5 b
Ca (cmol(+) kg^{-1})	3.1 ± 0.20	3.3 ± 0.14 a	3.4 ± 0.21 a	3.7 ± 0.31 a	4.0 ± 0.35 a	3.5 ± 0.08 a
Mg (cmol(+) kg^{-1})	0.7 ± 0.04	0.8 ± 0.03 b	0.9 ± 0.06 b	1.1 ± 0.09 a	1.2 ± 0.11 a	0.9 ± 0.04 b
K (cmol(+) kg^{-1})	0.4 ± 0.01	0.3 ± 0.02 a	0.3 ± 0.01 a	0.3 ± 0.02 a	0.3 ± 0.02 a	0.3 ± 0.01 a
Na (cmol(+) kg^{-1})	0.2 ± 0.01	0.2 ± 0.02 d	0.4 ± 0.01 c	0.6 ± 0.03 b	0.6 ± 0.03 a	0.2 ± 0.01 d
CEC (cmol(+) kg^{-1})	4.5 ± 0.23	4.6 ± 0.16 b	5.0 ± 0.28 b	5.7 ± 0.44 ab	6.1 ± 0.45 a	4.9 ± 0.12 b
Al (cmol(+) kg^{-1})	0.2 ± 0.01	0.2 ± 0.02 a	0.2 ± 0.01 a	0.2 ± 0.02 a	0.1 ± 0.01 b	0.2 ± 0.01 a

Different letters in rows indicate significant differences between treatments ($P \leq 0.05$). [a] Inorganic fertilizer: 37 kg N ha^{-1}, 72 kg P ha^{-1}, 66 kg K ha^{-1}.

Table 3. Annual ryegrass yield and quality in different treatments. October 2002–October 2003 ($n = 4$, ± sem).

Treatment	Yield[a] (kg DM ha^{-1})	DM[b] (%)	N[b]	P[b]	Na[b]	K[b]
Control	2791 ± 366 b	22 ± 0.8 a	2.7 ± 0.19 a	0.16 ± 0.006 e	0.26 ± 0.043 c	2.3 ± 0.18 a
30 t ha^{-1}	5553 ± 696 a	19 ± 0.5 b	2.4 ± 0.17 a	0.22 ± 0.004 c	0.44 ± 0.056 b	2.5 ± 0.19 a
60 t ha^{-1}	5860 ± 567 a	19 ± 0.5 b	2.2 ± 0.13 a	0.26 ± 0.005 b	0.61 ± 0.052 a	2.4 ± 0.28 a
90 t ha^{-1}	6825 ± 904 a	18 ± 0.5 b	2.3 ± 0.15 a	0.27 ± 0.009 a	0.63 ± 0.069 a	2.4 ± 0.24 a
Inorganic fertilizer[c]	5349 ± 276 a	20 ± 0.4 b	2.4 ± 0.16 a	0.19 ± 0.007 d	0.28 ± 0.038 c	2.6 ± 0.16 a

Different letters in columns indicate significant differences between treatments ($P \leq 0.05^a$, $P \leq 0.01^b$). [c] Inorganic fertilizer application: 37 kg N ha^{-1}, 72 kg P ha^{-1}, 66 kg K ha^{-1}.

but supplementary application of N and K would be needed to increase pasture yield. The regression equation for dry matter yield and sludge rates was $Y = 2.801 + 91.64X - 0.54X^2$ ($r^2 = 0.62$; $P \leq 0.05$).

Nutrient budgets

Nitrogen budgets showed soil depletion in all treatments. Phosphorus budgets increased with increasing sludge rates ($P \leq 0.05$), so that the large P content of the sludge is its main benefit. Despite the large P input in the 90 t ha^{-1} application (229 kg ha^{-1}), P fixation, a characteristic of volcanic soils, may have limited the increase in Olsen P. Repeated sludge applications on land could have negative effects on surface water pollution once P deficiency has been corrected.

Potassium budgets were negative in all sludge treatments, because of the low K concentration in the sludge and the high plant uptake.

Sodium budgets were positive in all sludge treatments (between 238 and 713 kg ha^{-1}), because of the high Na concentration. Continuous sludge applications could have negative effects on soil physical properties because of the high Na inputs.

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