Agricultural potential of salmon wastes used as organic fertilizer on two Chilean degraded soils

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Abstract
The fertilizer potential of farmed salmon sludge was evaluated by a battery of tests carried out with annual ryegrass (*Lolium multiflorum* Lam. cv. Winter Star). Wastes were evaluated on two Chilean degraded soils: a Patagonian soil (Andic cryofluvent) and a granitic soil (Ultic Palexeralf). The treatments were salmon ground-farming waste (PSW) and salmon lake-farming waste (LSW) at different rates: 25, 50, 75, 100 and 150 t/ha. Tests with ryegrass were conducted for above ground biomass yield. For both soils, biomass data indicated that PSW and LSW sludge can be applied at 25 to 150 t/ha on Patagonian soil and only LSW sludge on granitic soil. However, its addition should be complemented with N and K inorganic fertilizer to increase pasture yield. MSS and PSW sludge applied at 150 t/ha was clearly detrimental for crop yield, especially when applied to granitic soil.

Key Words
Fish sludge, soil remediation, organic fertilizer, degraded soil.

Introduction
There is an enormous preoccupation that salmon sludge may contaminate pristine waterways, ruin livelihoods and damage Chile's reputation for quality produce. Besides nutrients and organic matter, sludge also contains pathogens, heavy metals and water, so soil application could be limited (Shober *et al.* 2003). There is little research published on the application of sewage sludge and salmon wastes into eroded soils in South America, and particularly on Chilean Patagonian soils. Previous studies are limited to volcanic soils (Teuber *et al.* 2005) and agricultural soils (Salazar and Saldaña 2007) of southern Chile, and of the Argentinean Patagonian region (Mazzarino *et al.* 1998; Laos *et al.* 2000). In the Chilean Patagonian region, 80% of soils are affected by wind erosion processes, whereas 39% of the soils in the Bío-Bío Region are rain-eroded (Pérez and González 2001). For that reason, there is a great potential to recover degraded soils that could be used for recycling of organic residues as fertilizer. The objectives of this research were to: (i) describe the nutrients of salmon wastes and (ii) evaluate rates of these organic wastes amended to degraded soilsin a greenhouse trial with ryegrass as an indicator plant to determine their potential use in agricultural.

Methods
The experiment was performed using two different degraded soils samples were taken from the surface (0-20 cm) of a deforested site under native pasture. In one case, soil samples of a Patagonian soil (Entisol), Andic cryofluvent, were obtained from a site located 50 km east from Coyhaique (45º30' S; 71º44' W), in the Chilean Patagonian region. Physically, this Patagonian soil is sandy loam textured, with less than 5% slope and 1 g/cm bulk density. Sampling location corresponded to a cold steppe, at the Eastern slope of the Andes Mountains, near to the borderline with Argentine. In the second case, soil samples of a granitic soil (Alfisol), Ultic Palexeralf, were obtained of a site located 10 km west from Quillón (36º40` S; 72º27` W) in the Bío-Bío Region. This granitic soil presents low water infiltration, typical of the rain-eroded coastal region of Chile, clay texture, with more than 15% slope and 1.4 g/cm bulk density (Stolpe, 2005).

Salmon sludge was collected from the settling zones at two commercial salmon farms: i) a land-based salmon pisciculture located 10 km from Puerto Octay (40º58´S; 72º52´W), Los Lagos Region, and ii) a lake-salmon farm located in Lake Tarahuín (42º42´S; 73º45´W), Chiloé. Land-based salmon pisciculture waste (PSW) was collected with shovel from the sediment in accumulation ponds, whereas lake-salmon waste (LSW) was collected with dredges from the sediment (0-20 cm) under cages at 20 m deep. Soil and sludge samples were air-dried to ambient temperature and then ground to pass a 2 mm sieve. Then, different sludge/soil ratios were prepared from mixing 1 kg of soil with sludge at different doses. These sludge/soil ratios were incubated in clean plastic bags by 15 days, using a growing chamber with controlled temperature (25±2 ºC) and humidity (60-70%). After that, chemical analysis was performed to each sludge/soil ratio with no duplicate.

Air-dried soils and sludge ground to pass a 2 mm sieve were employed. Pots with drainage holes were filled with 1.2 kg of soil mixed thoroughly with sludge. Annual ryegrass var. Winter Star was sown at 0.4 g/pot. Soil water content in the pots was maintained at 70-80% of field capacity throughout the experiment. Mean greenhouse temperature ranged between 18 and 24ºC. Days were 17 h long, using artificial light. A completely randomized design with three replicates was used to compare sludge at 0 (control), 25, 50, 75, 100 and 150 t/ha (dry weight) and inorganic fertilizer (140 kg N, 200 kg P and 130 kg K/ha) applied as potassium nitrate and superphosphate. A no-fertilizer control (T), and an inorganic fertilizer (F) were included. Triplicate subsamples were used for chemical analyses in laboratory. The ryegrass was cut two times during the experiment period of two months (5 cm residual height). Samples were weighted fresh and oven dried at 65 ºC for 48 h to determine biomass yield (g/pot) and then transformed to dry matter (kg/ha). The samples were freeze-dried and ground to a fine powder to ensure homogeneity before analysis. Soil samples were analyzed according to Sadzawka *et al.* (2006). Municipal sludge and fish waste was analyzed for macronutrients, micronutrients and heavy metals. Samples of wastes were analyzed according to Sadzawka *et al.* (2005).

Data were subjected to analysis of variance (ANOVA) procedures for a randomized complete block design using the SAS Statistical Software Package. Differences among treatment means were compared by means of the Tukey test. Statistical comparison was made with a 5% significance level.

Results

Initial degraded soils data showed low organic matter (OM), N, P, Ca, Na and Al concentrations (Table 1). In comparison, Patagonian soil analysis indicated lower P, Al, Mn, Zn and Cu, and higher pH, OM, N, K, Ca and Na than granitic soil. Both soils presented high K concentrations. Municipal sewage sludge and salmon wastes presented high OM (values >15%) and NH_4-N (values >700 mg/kg). All three sludge showed low C/N ratios with values of <11/1. Even though it is difficult to compare these values with those from other studies because of the differences in conditions under which the wastes were produced, these values are generally similar than previously reported values for salmonid manure content (Teuber *et al.* 2005). MSS had much higher OM, N, P, K, Mg, and Na contents, and lower pH, Al, Fe, and C/N than PSW and LSW. Ca, Fe, and Mn were higher in LSW than in MSS and PSW. LSW had low N and P concentrations, in agreement with Teuber *et al.* (2005), probably because sludge came from underneath cages of lake. Higher K levels in LSW than in PSW were probably the result of lake sediment in the waste than of waste composition since soluble components from fish feces and food are leached by moving water. Calcium and Na concentrations were higher in LSW than in PSW, probably because of the decomposing lacustrine organisms. High Al, Fe and Mn concentrations could be related to silica and sand contamination (Teuber *et al.* 2005).

Table 1. Initial chemical characteristics of Granitic soil, Patagonian soil, land-based salmon pisciculture waste (PSW) and lake-salmon sludge (LSW).

Characteristic	Granitic soil	Patagonian soil	PSW	LSW
pH (water)	5.6	6.8	7.0	6.7
Organic matter, %	2.5	2.9	20.7	18.3
Total N, %	0.15	0.12	1.10	1.35
NH_4-N, mg/kg	3.3	3.8	1687.5	730.0
Olsen-P, mg/kg	5.4	3.2	480.0	19.9
K available, mg/kg	129.8	414.3	30.0	120.8
Ca, cmol/kg	3.73	6.09	0.76	17.9
Mg, cmol/kg	1.37	1.69	0.74	0.43
Na, cmol/kg	0.03	0.08	0.14	0.57
Al, cmol/kg	0.02	0.01	0.03	0.03
Fe, mg/kg	8.3	9.1	6.2	11.0
Mn, mg/kg	7.6	0.3	0.6	2.5
Ratio C/N	9.3	13.4	10.5	7.5

One of the chemical characteristics of interest when livestock manure is used as a soil fertilizer is the concentrations of toxic substances, such as heavy metals (Naylor *et al.* 1999). Salmon wastes did not exceed the heavy metal levels (Table 2), a similar trend observed by Salazar and Saldaña (2007).

Table 2. Heavy metals concentrations (mg/kg) presented in municipal sewage sludge (MSS), land-based salmon pisciculture waste (PSW) and lake-salmon sludge (LSW), used in this study.

Parameter	Sludge			EPA [1]
	MSS	PSW	LSW	
Arsenic (As)	1.33	0.73	0.94	75
Cadmium (Cd)	0.74	0.69	1.77	85
Chromium (Cr)	11.74	8.68	9.7	3,000
Copper (Cu)	239.6	29.0	24.3	4,300
Lead (Pb)	0.89	2.05	29.98	840
Mercury (Hg)	0.63	0.024	0.15	57
Molybdenum (Mo)	< 0.15	< 0.15	< 0.15	75
Nickel (Ni)	12.7	24.5	7.4	420
Selenium (Se)	0.054	0.81	1.16	100
Zinc (Zn)	684.6	390.4	364.8	7,500

[1] Ceiling concentration limits for all sludge applied to land (EPA, 1994).

Dry matter yields of annual ryegrass on Patagonian soil showed that all treatments were similar to the inorganic fertilizer treatment (Table 3), and biomass yield did not differ statistically between salmon wastes treatments. Dry matter yield, especially in the control, was small probably because of the lack of N. There were no significant differences between any other treatments, probably because of the small N inputs, as previously noted by Teuber *et al.* (2005) when using sea salmon sludge on volcanic soil. On the other hand, on a granitic soil, PSW treatment produced a significantly lower biomass yields than the control; treatment PSW at higher rates caused lower biomass yields ($P \leq 0.05$). There was no significant LSW treatment effect on biomass yield compared to control and inorganic fertilizer, even though LSW treatments produced higher yield than PSW treatment. Yield results suggest that the application in the range of 25 to 150 t/ha of salmon wastes was equivalent to the inorganic fertilizer treatment, but supplementary application of N and K would be needed to increase pasture yield.

Table 3. Dry matter yields of annual ryegrass cv. Winter Star expressed as aboveground biomass in different treatments applied in two Chilean degraded soils.

Treatment	Sludge rate						IF [(¥)]	CV
	0	25	50	75	100	150		(%)
Patagonian soil								
PSW	3.27a	5.37a	4.76ab	4.60ab	5.10a	5.10a	5.20a	11.6
LSW	3.27a	4.80a	5.33a	3.77a	4.40a	5.37a	5.20a	17.3
Granitic soil								
PSW	3.59a	1.98b	1.47b	0.22c	0.11c	0.07c	3.45a	19.6
LSW	3.59a	3.37a	3.59a	3.48a	3.57a	3.04a	3.45a	8.2

[(¥)] Inorganic fertilizer (140 kg N, 200 kg P and 130 kg K/ha); PSW: land-based salmon farm waste; LSW: lake-salmon waste; F: inorganic fertilizer. Different letters in same row indicate statistical differences ($P \leq 0.05$).

Conclusion

Salmon wasted presented high macro and micronutrient concentrations. Annual ryegrass yield indicated that either salmon ground-farming waste or lake-salmon waste can be applied successfully on Patagonian soil (Entisol) at 25, 50, 75, 100 or 150 t/ha rates. Only lake-salmon sludge on granitic soil (Alfisol) can be applied successfully at 25, 50, 75, 100 or 150 t/ha rates. High rates of salmon ground-farming waste had a detrimental effect on annual ryegrass yield when added to the degraded Alfisol.

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