Effect of long-term irrigation with dairy factory wastewater on soil properties

Yen-Yiu Liu and Richard Haynes

School of Land, Crop and Food Sciences/CRC CARE, The University of Queensland, St Lucia, QLD, Australia, Email yenyiuliu@gmail.com and r.haynes1@uq.edu.au

Abstract

The effects of irrigation with dairy factory wastewater on soil properties were investigated at two sites that had received irrigation for > 60 years. In comparison with paired sites that had not received effluent, long-term wastewater irrigation resulted in an increase in pH, EC, extractable P, exchangeable Na and K and ESP. These changes were related to the use of phosphoric acid, NaOH and KOH as cleaning agents in the factory. Despite these clear changes in soil chemical properties, there were no increases in soil organic matter content (organic C and total N) and the size (microbial biomass C and N) and activity (basal respiration) of the soil microbial community were, in fact, increased by wastewater irrigation. These increases were attributed to regular inputs of soluble C (e.g. lactose) present as milk residues in the wastewater.

Key Words

Dairy factory; wastewater; effluent; irrigation; soil quality.

Introduction

The dairy industry is a major source of food processing wastewater (Britz *et al.* 2006). Dairy factory wastewater (DFW) generally contains a high organic load, due to the presence of diluted milk/milk products, and contains significant quantities of cleaning and sanitizing compounds (e.g. NaOH, H_3PO_4/HNO_3, NaOCl). There are three methods of disposal of such wastewater: (i) point source discharge to surface waters, (ii) discharge to the municipal sewer system and (iii) irrigation onto land surrounding the factory (land disposal). In Australasia, and other parts of the world, dairy factories in rural areas (often those manufacturing longer self-life products such as butter, cheese, long-life milk and milk powders) commonly irrigate effluent onto surrounding pastoral land. This is not only a waste disposal strategy for the factory but also it increases productivity of surrounding land since it is a supply of irrigation water (often a scarce resource) and nutrients (e.g. N and P) to farmers without cost.

Environmental concerns surrounding DFW irrigation include the possibilities of leaching of nutrients to groundwater and accumulation of Na in the soil (Britz *et al.* 2006). Nevertheless, a limited amount of research has shown that effluent irrigation has positive effects on soil properties including a liming effect, sometimes modest increases in soil organic matter status and substantial increases in the size and activity of the soil microbial community (Degens *et al.* 2000; Sparling *et al.* 2001). Such research has been carried out on a very small number of sites in New Zealand on soils mainly derived from volcanic ash and the wider applicability of the findings is, as yet, unknown. The purpose of this study is to investigate how irrigation of grazed dairy pastures with dairy factory effluent influences soil chemical and microbial properties.

Materials and methods

The experimental site is in the Bega Valley (NSW). Soils in the study area are light textured, alluvial soils and are classified as granitic Chromasols and Tenosols (Isbell 2002). Experimental monitoring transects were laid down by the Victoria Department of Agriculture in 32 fields surrounding the factory in 2001 (Gourley *et al.* 2007). Typical factory effluent content is $BOD_5 = 3438$, P = 46, N = 161, Ca = 71, Mg = 16, K = 536, Na = 340 mg/L. For this study, initially two sites close to the factory were chosen that had a known history of long-term (i.e. > 60 years) DFE irrigation [long-term DFE (1) and (2)]. Two fields close-by, which had not received

DFE, were chosen as control sites (one irrigated and one dryland) [control (1) and irrigated control]. The transect lines were split into three equal lengths. Twenty soil samples (0-10 cm) were taken from the three areas (within a distance of 3 m out either side of the line within each of the three lengths). Samples from each area were bulked to give three replicate samples per field. Bulked samples were thoroughly mixed and sieved (< 2 mm). A portion of each sample was stored at 4ºC for microbial analysis and the rest was air-dried and stored for chemical analysis.

Table 1. Some chemical properties of soils under long-term irrigation with dairy factory effluent (DFE) compared to control sites.

Treatment	pH	EC	Extractable P	Ca	Mg	K	Na	ESP
				Exchangeable Cations				
	($CaCl_2$)	(dS/m)	mg P/ g soil	$mmol_c$/kg				(%)
Control (1)	4.2a	0.04a	61.8b	58a	22b	2.7a	2.7a	1.7a
Irrigated control	5.5b	0.06a	7.8a	54a	23b	2.3a	1.3a	3.2a
Long-term DFE (1)	6.5c	0.31c	629d	64a	13a	11.2b	11.5b	11.2b
Long-term DFE (2)	6.3c	0.20b	439c	95b	16ab	13.9b	12.2b	8.9b

Means followed by the same letter are not significantly different $P<0.05$.

Electrical conductivity and pH were analysed in a 1:5 (v/v) water extract using glass electrodes. Exchangeable bases were extracted with 1 M ammonium acetate (pH 7) and Ca, Mg, K, and Na in the extracts were analysed by ICP-AES (Rayment and Higginson 1992). Available P was extracted with 0.5 M $NaHCO_3$ (pH 8.5) (1:100 w/v for 16 h) (Rayment and Higginson 1992) and measured colorimetrically by the molybdenum blue method. Organic C and total N content were measured by automated dry combustion using a Carlo Erba C, H, N analyser.

Microbial biomass C and N were estimated based on the difference between organic C and N extracted with 0.5 M K_2SO_4 from chloroform-fumigated and unfumigated soil samples using a K_C factor of 0.38 and a K_N factor of 0.54. Basal respiration was determined by placing 30 g oven dry equivalent of moist soil in a 50-ml beaker and incubating the sample in the dark for 10 days at 25ºC in a 1-l air-tight jar along with 10 ml 1M NaOH. The CO_2 evolved was determined by titration. The metabolic quotient was calculated as basal respiration (µg CO_2-C/h) expressed per mg of microbial biomass C.

The statistical significance of experimental treatments was determined by Analysis of Variance Analysis using the Minitab Statistical Software Package and differences were calculated at the 5% level using Tukey's test.

Results and discussion

Long-term irrigation of effluent with a high Na content will, as shown in Table 1, inevitably result in accumulation of exchangeable Na in the soil. Although, in general, monovalent cations are held less strongly on cation exchange sites than divalent ones, by mass action the added Na displaces other cations (e.g. Ca and Mg) into soil solution and they can then be leached down the soil profile. A decrease in exchangeable Ca and Mg is therefore commonly reported where Na-enriched effluents have been repeatedly applied. At these sites, a decrease in exchangeable Mg was evident (Table 1) but exchangeable Ca levels were not greatly changed. This is presumably attributable to the application of about 3 t/ha of gypsum ($CaSO_4.2H_20$) in early 2007 which was applied to counteract previous accumulation of exchangeable Na that had occurred at the long-term irrigated sites (Gourley *et al.* 2007). The elevated exchangeable Na noted here will be the result of residual Na remaining after the gypsum application plus that which has accumulated since the application. Effluent irrigation also, as expected, increased soluble salt levels and, because of its significant K content, exchangeable K levels were also elevated (Table 1). The increase in pH is attributable to the high pH of DFW (7-8). This increase in pH will need to be monitored since values are 6.3-6.5 in 0.01 M $CaCl_2$ (about 7 in water) and further increases could induce micronutrient cation deficiencies (e.g. Fe, Mn, Zn and Cu).

Table 2. Microbial biomass C and N, basal respiration and metabolic quotient in soils under long-term irrigation with dairy factory effluent (DFE) compared to control sites.

Treatment	Microbial biomass C	Microbial biomass N	Basal respiration	Metabolic quotient
	mg/kg	mg/kg	µg C/g/day	µg C/g/day
Control (1)	164b	30.3a	25.8a	0.16ns
Irrigated control	126a	50.7b	22.3a	0.12
Long-term DFE (1)	261c	70.4c	36.5b	0.14
Long-term DFE (2)	282c	72.8c	34.8b	0.12

Means followed by the same letter are not significantly different $P<0.05$.

Although EC values were moderate in long-term DFW-irrigated irrigated soils, ESP values of 9-11% reflect sodic conditions (Isbell 1995). Nonetheless, dispersive behaviour has not been noted in these soils in the field and subsequent aggregate stability measurements (by wet sieving) have revealed stable aggregation under both control and DFW irrigation. The reason for the stable structure is probably related to the fact that these soils are under permanent pasture. Under pasture, the extremely ramified root system of grasses explores a large proportion of the surface soil and carbohydrate exudates from the roots themselves, and from the extensive rhizosphere microflora have an aggregating and stabilizing effect on soil aggregates (Haynes and Beare 1996). In addition, organic materials in the DFW (e.g. lactose) may also have a stabilizing effect (Cameron *et al.* 2003).

Extractable P levels are very high under long-term irrigated sites (i.e. 439 and 629 mg/kg) (Table 1) reflecting the high P content of dairy factory effluent (due principally to the use of H_3PO_4 as a cleaning agent). Degens *et al.* (2000) also noted a large accumulation of extractable and total P in soils under long-term DFW irrigation. Accumulation of P in the surface soil could result in increased losses of P via runoff. Nonetheless, under permanent pasture, where the surface soil is protected by vegetation, such losses are likely to be small. Due to strong adsorption onto inorganic soil colloids, it is usually considered there is a low risk of P leaching down the soil profile. Some studies have, however, suggested that at high soil test P levels measureable movement of P down the profile can occur (Hesketh and Brookes 2000). It will, therefore, be important to monitor for any possible downward movement of P in these long-term DFW-irrigated soils.

Long-term DFW irrigation did not result in significant increases in organic C or total N in the soil profile (data not shown). The lack of any increase in organic C following long-term effluent irrigation suggests that the additional inputs of organic C in effluent are balanced by losses of C of the same magnitude. Similar results were recorded by Degens *et al.* (2000) and Sparling *et al.* (2001) on long-term DFE-irrigated soils in New Zealand. Under any particular management system, soil organic matter characteristically equilibrates to a level where inputs and losses balance (Haynes and Beare 1996). Losses of C are likely to be principally as CO_2 evolution due to the increased microbial activity (Table 2) but leaching of soluble organic matter could also play a part (Menneer *et al.* 2001). The lack of any accumulation of total N in the soil under DFE irrigation may well be at least partially related to similar N loads being applied to the “control” and DFE-irrigated fields. That is, control sites typically received substantial inorganic fertilizer N inputs (i.e. 100-200 kg/ha/yr) while fertilizer rates were much reduced on effluent-irrigated fields (to take account of N inputs from the effluent).

The increase in the size (microbial biomass C and N) and activity (basal respiration) of the soil microbial community under DFW irrigation (Table 2) is likely to be the result of regular inputs of soluble C (e.g. lactose), along with additional N and P, in the effluent. This occurred despite there being no increase in total soil organic C content. Such an increase in microbial biomass, despite no increase or even a decrease in organic C, was also noted by Sparling *et al.* (2001) in long-term DFE irrigated pastures. There was no increase in metabolic quotient due to DFE irrigation (Table 2) indicating that the increase in basal respiration was proportional to the increase in microbial biomass C. An increase in metabolic quotient is considered a response of the microbial community to adverse conditions (either stress or disturbance) (Wardle and Ghani 1995). Thus, the accumulation of soluble salts, P and Na in the effluent-treated soil did not appear to cause undue stress to the soil microbial community.

Conclusions

Under DFW irrigation there is a characteristic increase in EC, ESP, extractable soil Na, K and particularly P, and an increase in the size and activity of the soil microbial community. Further work will investigate the effects of DFW irrigation on the catabolic diversity and structural composition and diversity of the microbial community.

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