NUTRIENT CYCLING IN EFFLUENT-IRRIGATED SOIL (MOLLISOL) PLANTED TO TROPICAL GRASSES IN A TROPICAL ISLAND ENVIRONMENT

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ABSTRACT

Dairy producers accumulate large quantities of effluent in lagoons. Lagoons occasionally overflow causing the nutrients and other contaminants in effluent to pollute the land and water bodies. Alternative uses of effluent are, therefore, urgently needed for a sustainable and environment-friendly dairy production. This study determined the sustainable effluent application rate and assessed the effects of effluent irrigation on plant and soil (Cumulic Haplustoll) properties. Five tropical grasses—bana (*Pennisetum purpureum* K.), signal (*Brachiaria decumbens* S.), California (*Brachiaria mutica*), star (*Cynodon nlemfuensis* V.), and suerte (*Paspalum atratum* S.)—were subsurface drip irrigated with dairy effluent at two rates based on potential evapotranspiration (ET_p) at the site (Waianae, Hawai‘i)—2.0 ET_p (7 to 44 mm d^{-1}) and 0.5 ET_p (2 to 11 mm d^{-1}). Treatments were arranged in an augmented completely randomized design.

Brachiaria mutica and *P. purpureum* yielded the highest dry matter (57 and 51 Mg ha^{-1} y^{-1}, respectively). Nutrient removal of grasses was 30 to 187%, 13 to 86% and 2 to 14% of applied effluent N, P and K, respectively. Extractable soil P (with means of 141 mg kg-1 in July 2003 and 166 in Aug 2006 at the 0-15 cm depth; 91 mg kg^{-1} and 145 mg kg^{-1}, respectively, at the 15-30 cm depth) and soil solution total P (6.2 mg L^{-1} in June 2004 and 4.7 mg L^{-1} in Aug 2006) did not significantly increase after two years of effluent irrigation. Soil pH increased from an average of 7.5 (July 2003) to 8.5 (Aug 2006) possibly due to the high pH and carbonate/bicarbonate content of the effluent. Electrical conductivity (1.3 in Aug 2004 to 0.9 dS m^{-1} in Aug 2006) remained below 4.0 dS m^{-1} (U.S. Salinity Laboratory’s critical level for classifying saline soils). Soil exchangeable sodium percentage (ESP) remained below 15% (critical ESP for classifying soils as sodic), which may be related to the low SAR of both effluent and soil solution throughout the duration of the study. Results suggest that irrigating high yielding tropical grasses with effluent at 2.0 ET_p may be acceptable as indicated by the lack of excessive nutrient and salt accumulation. Additional monitoring is needed to determine the longer-term impacts of effluent application on soil and plant properties. Information generated will allow dairy producers to reduce feed costs while minimizing pollution associated with effluent application—thus, creating a win-win option.

INTRODUCTION

Imported feeds supply a tremendous amount of nutrients to Hawai‘i and island nations, but dairy producers are not exporting or using the manure and liquid wastes. This situation created an open nutrient cycle in the milk production system in island environments. Most of these nutrients end up accumulating in lagoons where liquid wastes from dairy production are collected. However, lagoons occasionally overflow leading to the transfer of nutrients and other contaminants in the effluent to pollute the land and associated surface, coastal, and even shallow ground waters (Plate 1). Dairy producers, thus, urgently need management options by which wastewaters can be utilized for a more sustainable and environment-friendly dairy production.

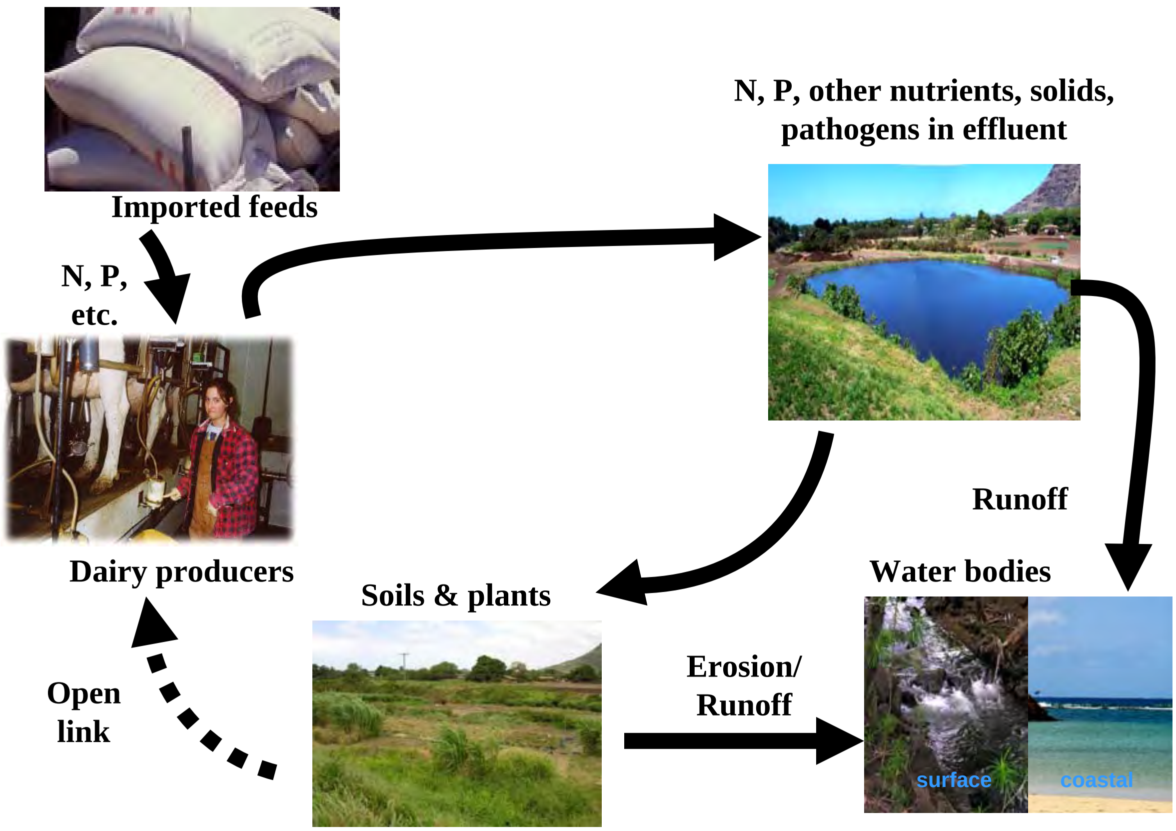

Plate 1. Environmental problems associated with dairy waste management.

OBJECTIVES AND METHODOLOGY

This study determined the sustainable effluent application rate and assessed the effects of effluent irrigation on plant and soil (Cumulic Haplustoll) properties. Five tropical grasses—bana (*Pennisetum purpureum* K.), California (*Brachiaria mutica* S.), signal (*Brachiaria decumbens* S.), star (*Cynodon nlemfuensis* V.), and suerte (*Paspalum atratum* S.)—were planted in an augmented completely randomized design. Two rates of dairy effluent were supplied daily through a subsurface (20-25 cm depth) drip irrigation system based on the potential evapotranspiration (ET_p)—2.0 ET_p (7 to 44 mm d^{-1}) and 0.5 ET_p (2 to 11 mm d^{-1})—at the site (Waianae, Hawai‘i.). Forages were harvested, and soils and soil solutions were collected every 28 to 42 d during the first year and 30 to 52 d during the second year.

RESULTS AND DISCUSSION

Most of these grasses produced very high dry matter with effluent irrigation (Fig. 1) that compared well or were higher than those commonly reported in the literature for these species

(Vicente-Chandler et al., 1959a & b; Vicente-Chandler and Pearson, 1960). Among the grasses, *P. purpureum* and *B. mutica* had consistently the highest N, P, K uptake (Fig. 2). At the 2.0 ET_p irrigation rate, *P. purpureum* removed 1190 kg N ha^{-1} y^{-1}, 153 kg P ha^{-1} y^{-1} and 2008 kg K ha^{-1} y^{-1}, while *B. mutica* removed 1262 kg N ha^{-1} y^{-1}, 157 kg P ha^{-1} y^{-1} and 1922 kg Kha^{-1} y^{-1}. At the 0.5 ET_p irrigation rate, *P. purpureum* removed 934 kg N ha^{-1} y^{-1}, 158 kg P ha^{-1} y^{-1} and 1730 kg K ha^{-1} y^{-1} while *B. mutica* removed 743 kg N ha^{-1} y^{-1}, 116 kg P ha^{-1} y^{-1} and 1267 kg K ha^{-1} y^{-1}. Nutrient removal of grasses was 30 to 187% N, 13 to 86% P and 2 to14% K of the applied effluent. When bahia grass (*Paspalum notatum*) forage critical levels were used as the reference, average annual N concentration was in the deficient range (1.51 to 2.39%), P was nearly at adequate levels (0.20 to 0.42%), and K was above the sufficient level (2.5 to 4.2%).

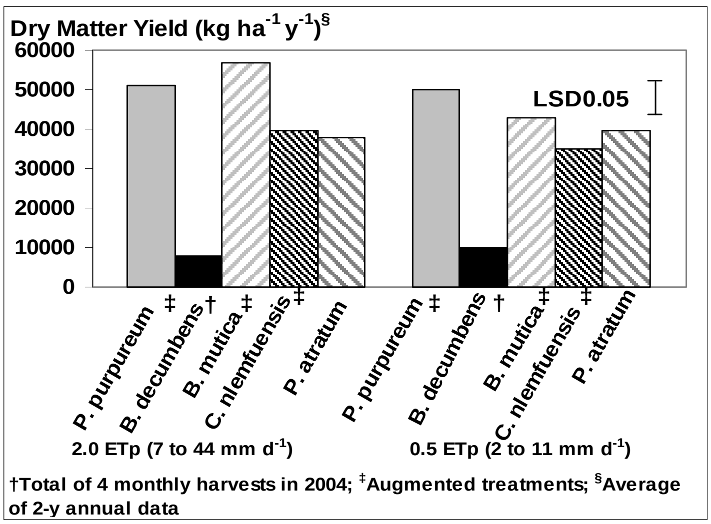

Fig. 1. Dry matter yield of tropical grasses irrigated with dairy effluent, Oahu, Hawai‘i.

Daily irrigation with effluent for a year, even at the 2.0 ET_p rate did not result in significant increases in Olsen extractable soil P and soil solution total P, which may be ascribed to the relatively high levels of soil and soil solution P at the beginning of the experiment (means of 141 mg kg^{-1} in July 2003 and 6.2 mg L^{-1} in July 2004, respectively) (Fig. 3). The formation of various calcium-phosphate compounds in this soil amended with dairy effluent (Wang et al., 1995) may explain the steady or no increases in Olsen extractable soil P. Calcium phosphate precipitation may be occurring due to the very high amounts of Ca added to the soil from the effluent and the already high Ca content of the soil in the site. Evidence of calcium-phosphate precipitation was indicated by calculated phosphate potentials for dicalcium phosphate dihydrate, octacalcium phosphate, tricalcium phosphate and hydroxyapatite. Acid extractable soil P was also much higher than Olsen soil P, suggesting an insoluble P precipitate. Extractable soil Ca also declined with time, further supporting the hypothesis of calcium phosphate formation.

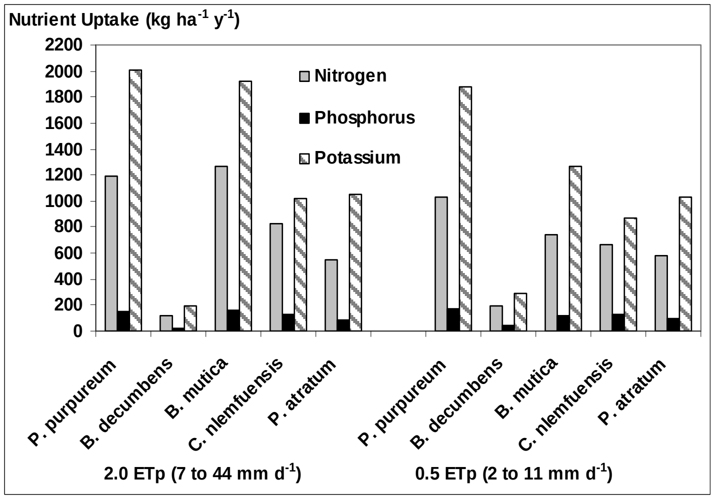

Fig. 2. Nutrient uptake of tropical grasses irrigated with dairy effluent, Oahu, Hawai‘i.

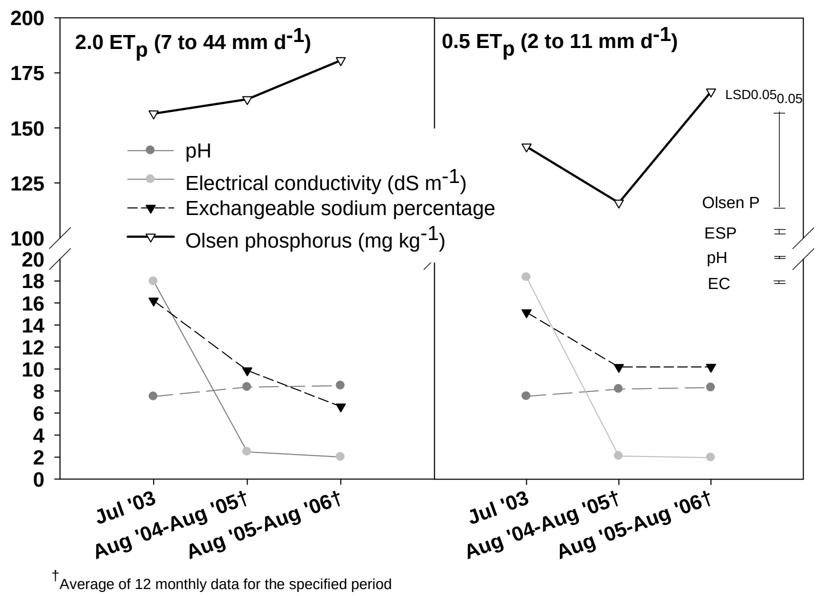

Fig. 3. Selected soil properties of dairy effluent-irrigated soil, Oahu, Hawaii.

Soil and soil solution pH generally increased with time, which could be explained by the high pH (7.9 to 8.9) and carbonate (111 to 113 mg $CaCO_3$ L^{-1}) and bicarbonate (1350 to 2000 mg $CaCO_3$ L^{-1}) content of the effluent used for irrigation. Soil pH increased from 7.4-7.8 in July 2003 to 7.8-8.4 in Aug 2004, after which it did not change significantly with time (Fig. 3). Soil solution pH also remained stable with time. These results indicate that this effluent-irrigated soil system has a high pH buffering capacity.

Soil electrical conductivity measured from saturated paste extract (EC_{spe}) dropped from a mean of 18.0 dS m^{-1} in July 2003 to a mean of 2.7 dS m^{-1} in Aug 2006 (Fig. 3). The soil EC_{spe} and soil solution EC values between Aug 2004 and Aug 2006 were below the US Salinity Laboratory's (1954) critical level for soils classified as saline (4.0 dS m^{-1}). No significant differences in the EC values of soils receiving 0.5 ET_p and 2.0 ET_p were observed which may be due to the high buffering capacity of the soil. Soil ESP decreased despite repeated effluent application. The mean ESP values between Aug 2004 and Aug 2006 (ranging from 6.4 to 10.2%) remained below the 15% critical ESP value for classifying soils as sodic (US Salinity Laboratory, 1954). The SAR (1.3 to 2.2) of the dairy effluent used for irrigation remained at low levels for the duration of the study which explains the lack of increases in soil ESP. The SAR of the soil solution (5 to 9) also remained low during the 2-y period of irrigation. The LF for the plots irrigated at 0.5 ET_p ranged from 0.34 to 0.41 compared to 0.28 to 0.31 for plots irrigated at 2.0 ET_p. This trend is logical because the plots receiving 0.5 ET_p has much less water passing through the profile and possibly, some of the water was moving upward instead of downward during the hot summer periods when evapotranspiration is high. Results suggest that effluent irrigation did not result in excessive salinity increases, sodicity and associated soil dispersion.

CONCLUSIONS

In general, effluent irrigation to produce the forage is an effective means of closing the open nutrient cycle in the milk production system. *Brachiaria mutica* and *P. purpureum* appeared to be the best choices for forage production, especially if the prime objective was to effectively remove nutrients from the soil in order to maximize the application of liquid effluent without serious nutrient and salt accumulation in the soil. The resulting high pH with effluent irrigation necessitates the application of micronutrients to sustain grass productivity. Results of this study suggest that high yielding tropical grasses grown in this type of soil can be irrigated with dairy effluent at 2.0 ET_p (7 to 44 mm d^{-1})—a rate that is substantially higher than that designed for most irrigation objectives. This is necessary to meet the leaching requirement that is important when irrigating with salt-rich wastewaters. Additional monitoring is needed to determine the longer-term impacts of dairy effluent application on plant and soil properties in these conditions, especially on P accumulation, salinity and sodicity.

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