Effect of treated piggery effluent on pasture botanical composition, mineral content, and yield

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Abstract

Preliminary investigations into the implications for long term application of treated piggery effluent to pasture were conducted at two sites in the Manawatu. Potassium was calculated to be the element most limiting the ability of the soil/plant system to sustain continued effluent application. Effluent was applied at a rate delivering the estimated maximum sustainable loading of potassium (218 kg/ha/yr) and double this rate (436 kg/ha/yr). Equivalent hydraulic loading rates were 120 mm/yr and 240 mm/yr respectively. Applications were made to small trial plots and herbage accumulation and composition monitored over a 12 month period. Changes in soil mineral levels and in herbage nutrient concentration were also studied. Application of the low (120 mm/year) and high (240 mm/year) rate of treated piggery effluent resulted in an increase in herbage accumulation of 12.4% and 19.7% respectively over a 12 month period. Effluent application as above increased the percentage of ryegrass in the sward and levels of soil and herbage P and K. By contrast, levels of Ca and Mg in the herbage decreased. This could be expected to result in a greater predisposition to animal disorders such as hypomagnesaemia. The land area required to ensure minimal adverse effects on plant and animal production could be underestimated if only a limited number of design factors (e.g., hydraulic loading and nitrogen application) are considered in the process design of a land treatment scheme. In determining sustainable application rates other factors, including potassium, phosphorus, and heavy metal application rates, soil assimilation rates and crop removal factors, should also be considered. Sustainable effluent disposal may require larger land areas than those currently being used.

Additional key words: *Effluent application, herbage accumulation, land disposal, phosphorus, potassium*

Introduction

Land disposal of effluent has been standard farm practice in many countries for decades (Witty and Flach, 1977). Effluent disposal on land can offer benefits by increasing crop yields and enhancing soil properties (Phillips, 1973; Yeates, 1978; Goold, 1980; Duthion, 1980; Giffney, 1984). In New Zealand, this method of waste disposal is becoming increasingly popular. In the past, land application of wastes was often viewed as simply a disposal method with little consideration given to the soil/plant/animal environment. Even where such information is available, results are somewhat inconsistent, due to seasonal variation in effluent composition, differences in the timing of applications, and different weather and soil conditions at the time of application (Hall and Medmenham, 1992). Quantitative information regarding effects on pasture following effluent applications is scarce, particularly under New Zealand conditions.

This study deals with the land disposal of treated piggery wastes. Many New Zealand piggeries have anaerobic/aerobic lagoon treatment systems installed. Due to increasing restrictions being placed on waterway discharge, piggery managers are looking to dispose of this treated effluent by other means of which land disposal can be an option. Information on the fate of piggery wastes applied to pastoral land in New Zealand was collected by Cameron and Rate (1992), but this study used untreated effluent and placed more emphasis on potential ground water problems associated with excess nitrogen application. Thus, the primary aim of this experiment was to provide additional information on pasture responses and to make a preliminary assessment of other issues that may arise from the disposal of treated piggery effluent to pastoral land.

Materials and Methods

Two pastoral sites close to Massey University were used. The soil type at site 1 was a Tokomaru Silt Loam while site 2 was located on a Manawatu Fine Sandy Loam. Initial soil tests at sites 1 and 2 yielded Olsen P values of 15 and 32, respectively, and exchangeable K values of 0.18 and 0.31 meq/100 g, respectively.

After considering the effluent nutrient concentrations (Table 1) two rates of effluent application were calculated, Treatments 4 and 5 (see below). These were designed to be equal to and higher than the maximum desirable applications of K and N for these soil types. In order to differentiate between nutrient responses and irrigation responses, identical amounts of water were applied to other plots (Treatments 2 and 3). Control plots (Treatment 1) received no applications of water or effluent. The experiment thus comprised 5 treatments as follows:

1. Control (no irrigation)
2. Low water rate irrigation (120 mm/year, water)
3. High water rate irrigation (240 mm/year, water)
4. Low effluent rate irrigation (120 mm/year, effluent)
5. High effluent rate irrigation (240 mm/year, effluent)

To avoid transporting large volumes of effluent and water small plots were irrigated. Each plot consisted of two galvanised steel frames, 0.8 m x 0.63 m, giving a total area of 1 m^2 per plot. The volume of effluent to be applied annually was divided into four equal irrigations applied over a four month period. These were carried out using a garden watering can, with the exact amount of liquid being applied to areas defined by the two galvanised steel frames. The total amounts of nutrients applied over the four irrigations are given in Table 2. There were two replicates of the five treatments at each site, 20 plots in total. Data were analyzed using a "combined experiments design" (I.L. Gordon, pers. comm.; Le Clerg *et al.*, 1962).

In order to simulate typical pasture grazing management under an effluent disposal scheme, each irrigation was applied in instalments within one week of each defoliation, and was then followed by a 3 week with-holding period to allow pathogen die-off. Defoliations comprised a simulated grazing with a modified shearing handpiece, described by Lowe (1992). Four 0.1 m^2 quadrats per plot were harvested at each simulated grazing, monthly for the first 6 months and then less frequently, in order to determine pasture growth rates. Sampling commenced on the 21/1/92 and continued to 23/1/93. Also, herbage sub-samples were dissected, and botanical composition of each plot determined on a percentage dry weight basis at each harvest. The sub-samples were classified into ryegrass (*Lolium* sp.), other grasses (lower fertility grasses), clover (*Trifolium* sp.), weed, and dead material.

Table 1. Average composition of aerobicly treated piggery effluent over a 12 month sampling period.

Component	Concentration (g/m^3)	s.e.m.
Suspended Solids		
Total	358	32.4
Volatile	324	29.9
COD	886	46.6
BOD	176	31.0
Nitrogen		
TKN	213	24.7
Ammonia	170	24.1
Nitrate	17	6.4
Phosphorus		
Total	65	3.2
Soluble	54	2.7
Potassium	162	6.0
Sodium	112	3.2
Magnesium	9.7	0.48
Calcium	43	1.9
Copper	0.26	0.031
Zinc	0.58	0.077
pH	7.8	0.07

COD - Chemical Oxygen Demand
BOD - Biological Oxygen Demand
TKN - Total Kjeldahl Nitrogen

Table 2. Total effluent volumes and nutrient rates (kg/ha) applied over the four irrigations.

	High Application (240mm/yr)	Low Application (120mm/yr)
Volume applied	2400 m^3/ha	1200 m^3/ha
Nitrogen		
Total	330	165
Ammonia	240	120
Phosphorus		
Total	132	66
Soluble	112	56
Potassium	436	218
Sodium	296	148
Magnesium	21	10
Calcium	113	56
Zinc	1.0	0.5
Copper	0.6	0.3

Herbage samples and soil cores (six 25 mm diameter cores per plot to a depth of 75 mm) were collected from each plot during the fourth herbage cut and were retained for nutrient analysis. A random sample of bulk herbage was analyzed for levels of N (total Kjeldahl nitrogen), phosphorus, potassium, calcium, magnesium, copper, and zinc. Soil analyses carried out were Olsen P, exchangeable potassium, exchangeable calcium, exchangeable magnesium, exchangeable sodium, cation exchange capacity and pH. Analyses, except soil copper and zinc, were carried out by the Fertiliser and Lime Research Centre, Massey University, Palmerston North. Herbage total kjeldahl N was determined using a Technicon autoanalyser, and P by colorimetric autoanalysis of the kjeldahl digest (Twine and Williams, 1971). Herbage potassium was determined by atomic emission and herbage calcium and magnesium by atomic absorption spectroscopy, following digestion in nitric acid. Soil P was determined by the Olsen method and exchangeable K, Ca and Mg by a procedure involving leaching with 1 M ammonium acetate at pH 7. Soil copper and zinc testing was carried out at the AgResearch soil testing laboratory at Ruakura, Hamilton.

Results and Discussion

Herbage accumulation and botanical composition

Over the initial four months of the trial, water alone did not significantly increase pasture productivity (Fig. 1) but the application of 120 mm and 240 mm of treated piggery effluent increased pasture production, compared to control plots, by 1424 kg DM/ha (27.2%; $P<0.05\%$) and 2113 kg DM/ha (40.3%; $P<0.05\%$), respectively (Fig. 1). Herbage accumulation response to effluent did not continue after application stopped. Corresponding values for the full 12 month measurement period were 1462 kg DM/ha (12.4 %) and 2319 kg DM/ha (19.7 %), indicating little or no residual response over the 8 month period following effluent application. The fact that irrigation alone had no effect on herbage production (Fig. 1) was attributed to a higher than normal January - April rainfall during 1992. It is therefore concluded that the observed response in Treatments 4 and 5 (Fig. 1) was entirely due to the nutrients contained in the effluent.

For successive pasture harvests over the first four months, seasonal effects were evident in that herbage accumulation progressively decreased in all treatments. (Mean accumulation was 3105, 1490, 666 and 755 kg DM/ha for harvests made on 20 February, 20 March, 20 April and 21 May, respectively). However, despite this seasonal effect, effluent treated plots produced significantly more herbage than the control at all harvests. For example monthly pasture accumulation for Treatment 5 was 934, 691, 218, and 270 kg DM/ha greater than for control plots over the same four harvests.

In this trial, nitrogen response efficiency was 8.6 kg DM/kg N and 6.4 kg DM/kg N for the low (165 kg N/ha) and high (330 kg N/ha) effluent rates, respectively. These values are high when compared to responses of N applied in autumn, as summarised by O'Connor (1982), but similar to values of 9.6 kg DM/kg N and 5.6 kg DM/kg N obtained by Cameron and Rate (1991) after applications of 200 and 600 kg N/ha of raw piggery effluent.

In May, one month after the fourth and final irrigation, the ryegrass composition of Treatments 1 - 3 averaged 38.5%, while in Treatments 4 and 5 it had increased to 51.2% and 55.1% ryegrass, respectively ($P<0.05$). Corresponding percentages for clover were 4.2% averaged over Treatments 1-3 and 1.7% and 2% for Treatments 4 and 5, respectively ($P<0.05$). Grasses other than ryegrass also decreased from 54.4 % (Treatments 1 - 3) to 46.1 and 40.9%, Treatments 4 and 5, respectively, but this trend was not statistically significant. Weed and dead components comprised the balance of the sward. An increased percentage of ryegrass and decreased percentage of clover in the sward is a well known response to nitrogen fertiliser (O'Connor, 1982; Grant *et al.*, 1981), and is therefore consistent with the expected response to application of nitrogen. However eight months later, at the end of the experimental period, there were no statistically significant differences in pasture botanical composition for any of the five treatments.

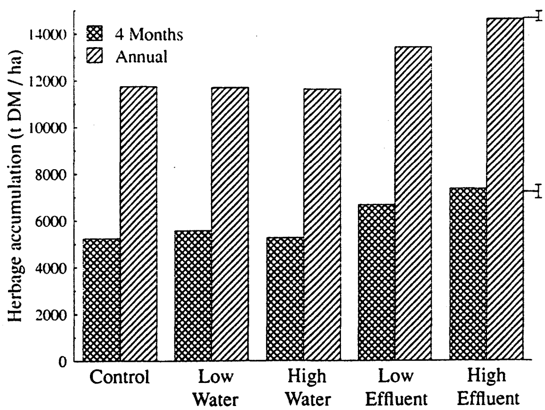

Figure 1. Herbage accumulation after 4 and 12 months.

Soil nutrient status

Olsen P levels were increased considerably from 23.5 on control plots to 32.8 and 42.5 at low and high rates of effluent application, respectively ($P<0.001$). Soil potassium levels also increased substantially from 0.24 m eq/100 g on control plots to 0.67 m eq/100 g at the high rate of effluent application ($P<0.01$; Table 3). Care should be exercised in interpreting these results, however, in view of the rather short time interval of 1 month between the final effluent application and soil testing.

Soil concentration of Ca, Mg and Na showed no significant increase with the addition of effluent. Given that the Sodium Adsorption Ratio[1] (SAR) is reasonably low (SAR = 3.40) any potential build up of Na should not present a problem to drainage (Tchobanoglous and Franklin, 1991).

Herbage nutrient concentration

Herbage N levels measured at the fourth harvest in May were high on control plots (4.1%), and were slightly increased (4.2% and 4.5% for Treatments 4 and 5, respectively, $P<0.01$) after effluent application. Herbage levels of Zn were unchanged on treated plots compared to control plots, while levels of Cu tended to decrease, but not to an extent that was statistically significant. By contrast, herbage levels of P and K were increased ($P<0.001$), and levels of Ca and Mg decreased ($P<0.001$, $P<0.01$, respectively) by effluent application (Fig. 2).

Normally N levels in herbage increase to around 5% soon after application of N fertiliser (Ball and Field, 1982). The rather small increase in this trial was possibly due to the high background levels observed in the control plots (4.1% herbage N). Given these high background levels of herbage N and the time of year and rates of N applied, the apparent nitrogen response efficiency of up to 9.6 kg DM/kg N is unexpectedly high, and may indicate an additive response to other nutrients in the effluent. Nitrogen yield was 215 kg N/ha for control plots and 281 and 312 kg N/ha for low and high effluent application rates, respectively. This represents a recovery in herbage of 40.2% and 29.6% of the N applied in the low and high applications respectively. Such recoveries are typical for pasture as summarized by Whitehead (1970). The unaccounted N may have been lost by volatilisation or denitrification, or immobilisation (i.e., incorporation into the soil biomass; Barton, 1991).

Increases in herbage %K of 39% and 46% for low and high rates of effluent were observed (Fig. 2) and are consistent with results from other studies (Lecomte, 1980; Smilde, 1980). There were also decreases in herbage concentrations of Ca and Mg in the effluent treated plots (Fig. 2). This was expected given the known antagonism between K and Ca and Mg (McNaught, 1959; During, 1972; Metson, 1974; Giffney, 1984). Pasture Mg concentration was 0.25% at the end of the fourth month, for the plots treated with 240 mm effluent. This level exceeds the value normally regarded as adequate for animal health (During, 1972; Wilkinson and Lowery, 1973). During (1972) gives the critical level for plant Mg at less than 0.15% and Grace (1983) cites a value of 0.19% Mg as a minimum requirement for grazing cattle. However it should be noted that high K levels in herbage also suppress uptake of Mg in the rumen (Grace, 1983). The observed decreases in herbage mineral composition therefore indicate that there may be the potential to cause an increased predisposition to hypomagnesaemia and/or hypocalcaemia if effluent were applied to pastures already low in Mg, or if the duration of effluent application was extended.

Table 3. Soil concentration of P, K, Ca, Mg and Ca after the application of 120mm and 240mm of treated piggery effluent. (Standard errors are in brackets).

	Olsen P	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)
Control	23.5	0.24	8.18	1.57	0.60
	(4.73)	(0.041)	(0.845)	(0.195)	(0.178)
120 mm effluent	32.75	0.43	8.23	1.59	1.07
	(3.07)	(0.104)	(0.475)	(0.134)	(0.389)
240 mm effluent	42.5	0.67	8.35	1.64	0.60
	(4.98)	(0.198)	(0.570)	(0.185)	(0.142)

[1] Sodium Adsorption Ratio is the ratio of Na to Ca and Mg ions. A high ratio (high proportion of Na) can indicate a large potential for clay deflocculation resulting in poor soil drainage.

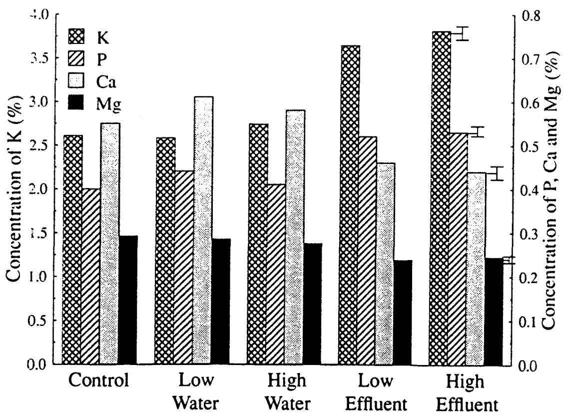

Figure 2. Herbage nutrient levels at the end of four months effluent application.

Variation in effluent composition

In this trial effluent was collected from the outlet of the second aerobic oxidation pond of the National Pig Breeding Centre's Piggery near Palmerston North. A monthly monitoring program by the piggery supplied data on the seasonal variation in composition of the effluent (I G Mason, unpublished data) and mean values for the period of effluent application to plots are given in Table 1.

There was a large seasonal variation in the organic and volatile components of the effluent, especially N. Total Kjeldahl Nitrogen (TKN) concentration ranged from 118g/m^3 in January to 351g/m^3 in August (Table 4), presumably as a result of better performance of the oxidation ponds in summer. Potassium levels also varied and tended to peak at times when nitrogen levels were lower (Table 4). This variation in composition highlights a potential problem for design of disposal systems. Calculation of sustainable application rates based on consideration of nitrogen loadings only, and using data from a short term effluent sampling program, or use of effluent composition data from another source, might result in other effluent constituents, such as potassium, being applied at rates greater than anticipated or recommended. For a example, using the effluent concentrations form the National Pig Breeding Centres Piggery's anaerobic oxidation pond, if the design criterion was that 200 kg/ha/yr N be applied, based on the summer concentration of N, 283 kg/ha/yr of K would be applied (Table 4). This contrasts with 70 kg/ha/yr K using the winter concentrations of N. Thus there is a four fold difference in application of K between the summer and winter because of changes in effluent concentration.

Table 4. Seasonal extremes for total Kjeldahl nitrogen (TKN) and potassium levels in effluent .

	Winter	Summer
TKN		
Concentration (g/m^3)	351	118
Amount applied (kg/ha/yr)	200	200
Potassium		
Concentration (g/m^3)	123	167
Amount applied (kg/ha/yr)	70	283
Volume applied (m^3/ha)	570	1695

Application of results

In view of the short time frame over which monitoring occurred, only tentative conclusions may be drawn. However, in determining the potential seriousness of the probable long term build up of soil P and K levels indicated by data in Table 3, both crop uptake ability and soil nutrient retention capacity should be considered. The quantities of nutrients removed from the soil by plants will depend on the type of crop and the stage of growth and soils vary in their affinity for retaining nutrients. For example, the phosphate fixing ability of volcanic soils containing the clay mineral allophone, is a well known example (Loehr, 1979). Other soils retain nutrients with difficulty due to their chemical properties (Overcash and Pal, 1979). Poor chemical retention combined with rapid infiltration, as in young soils such as coastal sands and some alluvial soils, can severely limit permissible effluent application rates. One example is the free draining alluvial soils on the Canterbury plains, where application of N has been restricted to 200 kg/ha/yr for many grazed pasture land disposal schemes (Carnus, 1993).

Conclusions

The application of 120 mm and 240 mm of treated piggery effluent to pasture produced a considerable increase in pasture yield over a four month period. This response was due to nutrients in the effluent as distinct from any irrigation effect. There was little residual effect on pasture growth after the initial four month period.

Soil concentrations of P and K were increased considerably after just one season's effluent application.

An increase in herbage K was accompanied by a decrease in herbage Ca and Mg levels.

Information on longer term trends would be desirable but indications are that P and K would continue to accumulate in the soil/plant system. The extent and effects of such accumulation are not known, but where effluent application is to grazed land there could be negative consequences for both pasture botanical composition and production, and animal health in the longer term.

When establishing a land disposal system, regular effluent and site monitoring would provide early warning of any developing problem, and thus help ensure the longer term sustainability of the project.

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