Corrigendum

Volume 42, issue 1, pp. 107–114.

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p. 110, Fig. 2. The *y*-axis caption should read 'Dung wet weight (kg)' for the top graph, and 'Dung dry weight (kg)' for the bottom graph.

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Dung decomposition in temperate dairy pastures I. Changes in soil chemical properties

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Abstract. The effect of dung from cows grazing low and high input systems (2 cows/ha, 35 kg P/ha; 4 cows/ha, 140 kg P/ha) on soil chemical properties in temperate dairy pastures was investigated. Dung was used to create pads, and their effect on soil at 2 depths compared with control areas to which nothing was applied. Most dung had decomposed after 40 days in autumn, and was completely degraded by Day 60 in this temperate environment. Large quantities of the nutrients P, K, Ca, Na, Mg, and S were applied to the soil in these dung pads. The mechanism of movement of these nutrients from the pads into soil appeared to be based on their solubility in water. Phosphorus did not leach from the pads but was incorporated into the soil with the decomposing pad. Calcium, Mg, and S concentrations declined slowly in the decomposing pads. On the other hand, K and Na appeared to leach from the pads, as significant decreases in concentrations occurred during decomposition. Soil pH (1 : 20 soil : water) decreased under dung pads, although the effect did not last beyond 60 days and was linked to the observed increase in soil EC with depth. Extractable P and K increased considerably in soil under dung pads, but only in the upper 0–5 cm layer. Soil exchangeable aluminium and total organic P were not affected by the presence of dung pads. These results are discussed in relation to nutrient cycling in temperate Australian dairy pasture soils.

Additional keywords: manure, degradation, phosphorus, potassium, electrical conductivity, pH.

Introduction

Dairy cows contribute significantly to nutrient cycling in grazed pastures by returning large amounts of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and sulfur (S) in dung (Blair *et al*. 1976; Haynes and Williams 1993). As a percentage of the cow's total intake, approximately 65, 11, 78, 80, and 29% of P, K, Ca, Mg, and Na, respectively, is returned in faeces. The process of dung decomposition leads to the release of these nutrients into soil, with the mechanism of return of each nutrient dependent on its solubility and hence mobility (Underhay and Dickinson 1978; Dickinson and Craig 1990; Haynes and Williams 1993).

Almost all of the P consumed by dairy cows is deposited on pastures in dung (Blair *et al*. 1976; Haynes and Williams 1993), with as much as 80% of the plant organic P mineralised to inorganic P in dung. Soil P increases under dung are due to either leaching losses from the pad or the physical incorporation of the decomposing pad (Haynes and Williams 1993). However, dung-induced reductions in P sorption observed on a high P-sorbing soil (During and Weeda 1973) may also contribute to increased availability of P under dung pads.

A significant increase in Truog soil P under dung was observed within 10 days (MacDiarmid and Watkin 1972*a*) and within 1 month (Weeda 1977) of the application of pads. Williams and Haynes (1995) reported a significant increase in bicarbonate-extractable P in soil 12 months after the application of cattle dung. In contrast, Dickinson and Craig (1990) observed a sharp decline in total soil P levels under dung in the first 12 days after pads were placed in the field, which never subsequently recovered.

Most of the K and Na in dung occurs as water-soluble cations, contributing to the ready leaching of these nutrients into the soil below pads. Rapid increases in soil K and Na under dung were observed (MacDiarmid and Watkin 1972*a*; Weeda 1977; Dickinson and Craig 1990), although where pads were covered and thus not exposed to water, K movement from the pad was restricted (Dickinson and Craig 1990).

Calcium and Mg in dung are primarily insoluble, being present as the carbonate salt, and hence are only slowly leached. Exchangeable Mg increased under pads (During *et al*. 1973; Williams and Haynes 1995), as did Ca (During *et al*. 1973; Weeda 1977; Williams and Haynes 1995). The high calcium carbonate content gives dung an alkaline pH,

 10.1071/SR03008_CO 0004-9573/04/010107

which was thought to explain the increased soil pH observed under dung pads (During and Weeda 1973; During *et al*. 1973). However, this increase in soil pH was not always observed (Williams and Haynes 1995).

Nutrient cycling in grazed pastures depends on the rate of movement of nutrients into soil from the decomposing pad, as well as the nutrient content of the pad. In general, as nutrient intakes of dairy cows increase so does the nutrient content of the dung returned (Haynes and Williams 1993). Thus, in high input systems, nutrient return and, hence, cycling are likely to increase. This experiment investigated the effect of dung on changes in soil chemical properties in low- and high-input dairy production systems and the contribution to nutrient cycling in these temperate grazed pasture systems.

Materials and methods

Site

This experiment was undertaken at the Ellinbank Research Institute, Victoria (38°15′S, 145°93′E), in autumn 1996. The site is located on undulating topography and receives an average annual rainfall of 1100 mm. The soils are high P-sorbing Ferrosols (Babare *et al*. 1997) of moderate fertility. The pastures consisted predominantly of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), with some cocksfoot (*Dactylis glomerat*a L.), wintergrass (*Poa annua* L.), and broadleaf weeds such as plantain (*Plantago lanceolata* L.).

Plot establishment

Low (L) and high (H) input systems were compared, consisting of rotationally grazed paddocks receiving 35 kg P/ha and stocked at 2 cows/ha (L) or 140 kg P/ha and stocked at 4 cows/ha (H), respectively. These treatments had been applied since April 1995 as part of an extensive P rate × stocking rate farmlet trial laid out spatially as an incomplete block design with 10 treatments (farmlets) in 26 blocks of 5 paddocks (Gourley 2001). Each P rate × stocking rate farmlet consisted of 13 paddocks grazed in a rotation. For this study, 5 of the 13 paddocks were selected for each of the 2 input systems based on their pH, extractable P (Olsen *et al*. 1954), and Skene K (Rayment and Higginson 1992). Within each input system, the paddocks selected had fertility levels similar to the mean for all 13 paddocks. Both sets of paddocks were uniformly distributed across the farmlet trial site.

Within each paddock, 3 caged plots (1.4 by 2.0 m) were established. The caged areas were mowed to 4 cm prior to plot establishment. Each plot contained a column of 6 dung pads and a column of 6 control 'pads', laid out in a 6 row by 2 column array. One row, containing 1 dung pad and 1 control 'pad', was destructively sampled on each of 6 days over a 60-day period starting in April 1996.

Dung pads were created by pouring 1 L of dung into a 21-cm-diameter PVC ring placed on the surface of the soil. The ring was briefly left in place to confine the dung to a defined area, then removed so as not to restrict naturally occurring decomposition processes. Control 'pad' areas had nothing applied to them, and were located beside and uphill from the corresponding dung pad.

Dung

Preparation

Dung was collected from each herd grazing the L and H paddocks for 2 weeks prior to the establishment of the pads. The cows from each herd were kept in separate yards after the morning and afternoon milking. The dung voided was placed in clean bins, weighed, and stored at 4°C until sufficient was collected for the experiment. Each herd's dung was thoroughly combined just prior to creating the 21-cm-diameter pads in either the L or H paddocks.

Sampling

Dung samples remaining in the plots were collected prior to soil sampling on each sample day and returned to the laboratory for analysis. Dung left on the grass of the soil core was washed into a container, dried (105°C), and weighed to determine the recovery of dung.

Analysis

Dung samples were dried at 75°C for 3–5 days, ground (<0.5 mm), and analysed by X-ray analysis for total nutrient content. Pasture and soil incorporated in the decaying dung sample was carefully removed before drying and grinding.

Soil

Sampling

Soil cores (21 cm diam. by 10 cm) were collected on each of 6 sample days (Day 0, 5, 10, 20, 40, and 60) beginning 24 April, beneath the dung and control 'pads'. The cores were returned to the laboratory, sectioned into 0–5 and 5–10 cm depths, dried (40°C) for 72 h, ground, and sieved (<2 mm) before analysis.

Analysis

Soils were analysed for pH [1:5 in 0.01 M $CaCl_2$ (pH_c) or H_2O (pH_w)], exchangeable aluminium (Rayment and Higginson 1992), total organic P (TOP) by the ignition method (Olsen and Sommers 1982), EC (1:5 in H_2O), Olsen P (Olsen *et al*. 1954), and Colwell K (Colwell 1963). The P in the bicarbonate extracts was measured colourimetrically (Murphy and Riley 1962), while K was measured by atomic absorption spectroscopy.

Statistical analyses

Analysis of variance of the data was performed using GENSTAT 5 where the treatment and blocking structures are given below (Rothamsted). Within these structures, '∗' represents a crossed factorial structure and '/' indicates a nested structure. The dung data had a factorial treatment structure of 'system ∗ time' and a blocking structure of 'paddock/cage/row', or 'paddock/row' where data were averaged over cages within paddocks prior to statistical analysis.

Statistical analysis of 720 soil data points was based on the factorial treatment structure 'system ∗ depth ∗ time ∗ treatment', and blocking structure 'paddock/depth + (paddock/cage(row ∗ column ∗ depth))'. The paddock/depth term was necessary to allow for effects that, if ignored, gave rise to a distinct 'V' pattern in graphs of residuals *v.* fitted values.

Only soil samples from the low (L) input system were analysed for Colwell K, where a factorial treatment structure of 'depth ∗ time ∗ treatment' was used with the same blocking structure given above.

Results

The rainfall and temperature for the duration of the experiment are given in Fig. 1. Rainfall events were small and continuous for the duration of the experiment, with daily totals of ≤5 mm for most events. The largest rainfall event occurred just prior to the sample collections on Day 40 and Day 60. Both air and soil temperatures declined slowly, with maximum temperatures (22.5 and 12.8°C, respectively) occurring in the first 20 days of the experiment.

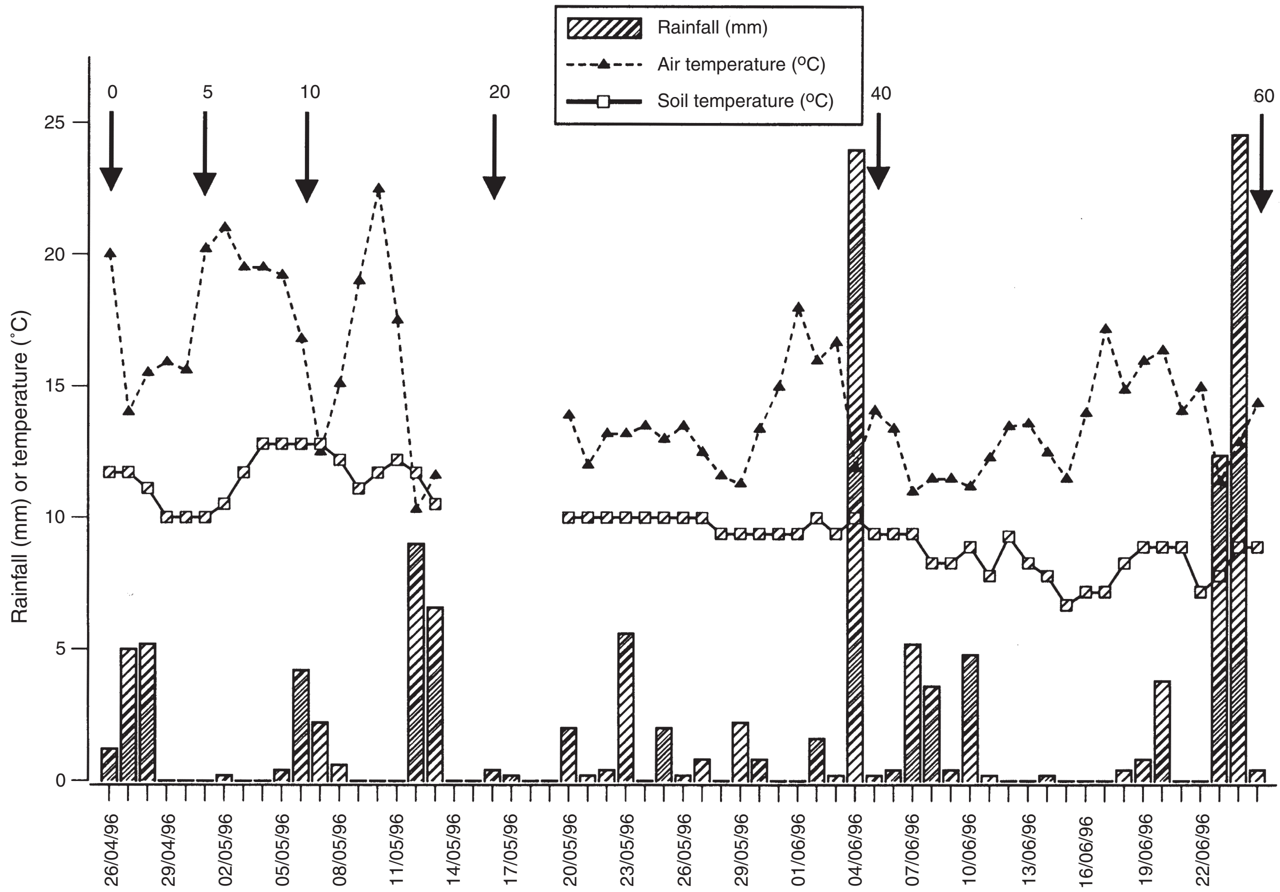

Fig. 1. Rainfall, air, and soil temperatures in autumn 1996 for the duration of the dung decomposition experiment. Sample times are indicated by arrows.

Recovery of dung pads on each sample day was high, as very small amounts of dung remained attached to pasture after the pads were removed. Only averages ranging from 1.0883 g (left adhering to the pasture on Day 5) to 0.2059 g (left on Day 40) were recovered. This amounted to 0.72% to 0.39%, respectively, of the dry weight harvested, indicating that this method of collecting pads resulted in high recovery of the dung present.

Dung decomposition

Both dung wet and dry weights declined by the end of the experiment (Fig. 2) The initial rate of decline in dung wet weights was greater than that occurring over the subsequent 35 days. About one-third of the pads (11 of 30) were completely degraded by Day 40 with no visible evidence of dung in any of the plots at Day 60. At Day 40 most of the remaining pads had associated material that appeared to be partially decomposed dung. This material, called dung detritus (DD), was neither dung nor soil, but consisted of undigested grass remains and some barley grains, presumably fractions more resistant to decomposition. The wet weight data were analysed with and without the DD component and the data are presented without the DD. The dry weight of the dung increased from Day 0 to Day 5, then the pads degraded slowly thereafter until Day 40, after which no pads were present.

Input system had no effect on dung wet weight (Fig. 2) but there were highly significant time ($P < 0.001$) and time × system interaction ($P = 0.002$) effects. In contrast, when the DD was considered, an input system effect was observed ($P = 0.017$). Both time and time × system interaction effects were highly significant ($P < 0.001$). Dung dry weight was influenced by the input system ($P = 0.002$) and varied significantly ($P < 0.001$) with time. There was no system × time interaction, however.

Dung nutrient content

The concentrations of P, K, Ca, Mg, Na, and S applied to the soil in the dung pads (Table 1) ranged from an average of 1.94% for K to 0.24% for Na on a dry weight basis. Input system significantly affected the changes in K ($P < 0.001$), Mg ($P = 0.007$), and S ($P = 0.012$), but had no effect on

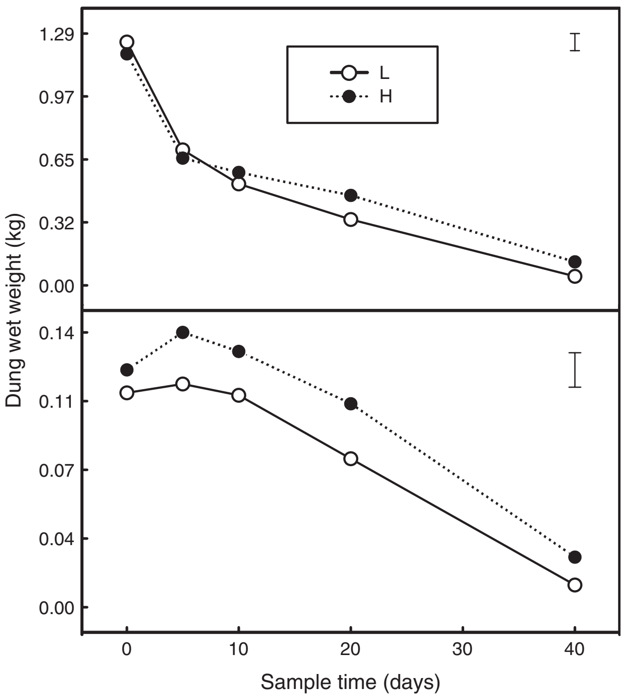

Fig. 2. Changes in wet and dry weights of dung from cows grazing low (L) and high (H) input systems. The error bar is the l.s.d. ($P = 0.05$) for comparing systems at a given time.

changes in P, Ca, or Na. Significant ($P < 0.001$) changes with time were observed in the concentrations in dung of all nutrients except P. Neither P nor Na showed any system × time interaction, whereas these interactions were highly significant ($P < 0.006$) for the other nutrients.

The P concentration of the dung pads decreased slightly (by ~26%) over the duration of the experiment (Fig. 3), as did Ca (25%), Mg (31%), and S (20%). The K and Na concentrations on the other hand declined considerably and were at least 68% less at the end of the experiment.

Soil nutrient content

In general, no significant system effects on the soil properties were measured (Table 2). Only TOP showed a slightly significant ($P = 0.046$) system effect. As expected, depth was highly significant ($P < 0.002$), but only Olsen P showed a significant depth × system interaction. Neither soil aluminium (Al) nor TOP was significantly affected by the dung treatment, in contrast to all other soil chemical properties measured. However, there was a significant ($P = 0.003$) treatment × system interaction for TOP only. All soil chemical properties changed significantly with time, and were not affected by system × time, depth × system × time, or system × time × treatment interactions. Neither pH_w nor pH_c showed a significant depth × treatment interaction, unlike all other chemical properties measured. Significant depth × time interactions were observed for all analyses except pH_c, and only TOP and Olsen P showed significant depth × system × time interactions. Olsen P, EC, K, and pH_w were significantly affected by time × treatment interactions. All nutrients showed significant depth × time × treatment effects, except Al.

Soil pH_w decreased under dung to 5 cm immediately followed by an increase after 20 days (Fig. 4). The pH_w in the 5–10 cm depth subsequently decreased at this time. This response to dung was reflected in the changes in soil EC. Soil EC increased in the upper layer from Day 5 to Day 20, after which there was a decline. This was followed by an increase lower in the profile as the movement of the front of salts from the pad extended into the 5–10 cm layer. The pH_c was not affected to the same extent as the pH_w due to the extraction in 0.01 M $CaCl_2$. Dung had no effect on soil Al in the upper soil layer. Exchangeable Al was always greater under dung pads in the 5–10 cm layer, but this was not significant until Day 60 (l.s.d. = 23.7). Olsen P increased in the upper 5 cm of soil after 20 days, whereas Colwell K increased almost immediately. Neither Olsen P nor Colwell K declined in the upper layer over the duration of the experiment, and there was no significant increase with depth, although there was a trend for Olsen P.

Discussion

The dung pads created in this experiment were not protected from the environment and, excluding trampling, simulated the mechanisms operating in the field when grazing dairy cows defecate. The greatest rate of decline in wet weight occurred within the first 5 days after the pads were laid out in the field, amounting to a 51% and 58% moisture loss for the L and H dung, respectively. This decrease in wet weight suggests that most of the loss of water and potentially nutrients occurred soon after the pads were placed in the field. Moderate temperatures and rainfall, resulting in soil moisture contents under the pad of >0.5 g/g (Aarons *et al.* 2004), would have contributed to the decomposition of the pads as well as leaching losses of nutrients. Dickinson *et al.* (1981) suggested that leaching losses from dung were strongly correlated with decomposition rates. The decomposition of the fresh pads from the L or H systems in this experiment was similar. The highly significant time ×

Table 1. Nutrients (%wt/dry wt, kg/ha) applied in dung from cows grazing low (L) and high (H) input systems

System	P		K		Ca		Mg		Na		S	
	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)
Low	0.61	236	1.86	782	1.46	614	0.59	248	0.19	80	0.37	156
High	0.59	248	2.02	780	1.72	664	0.57	220	0.29	112	0.39	151

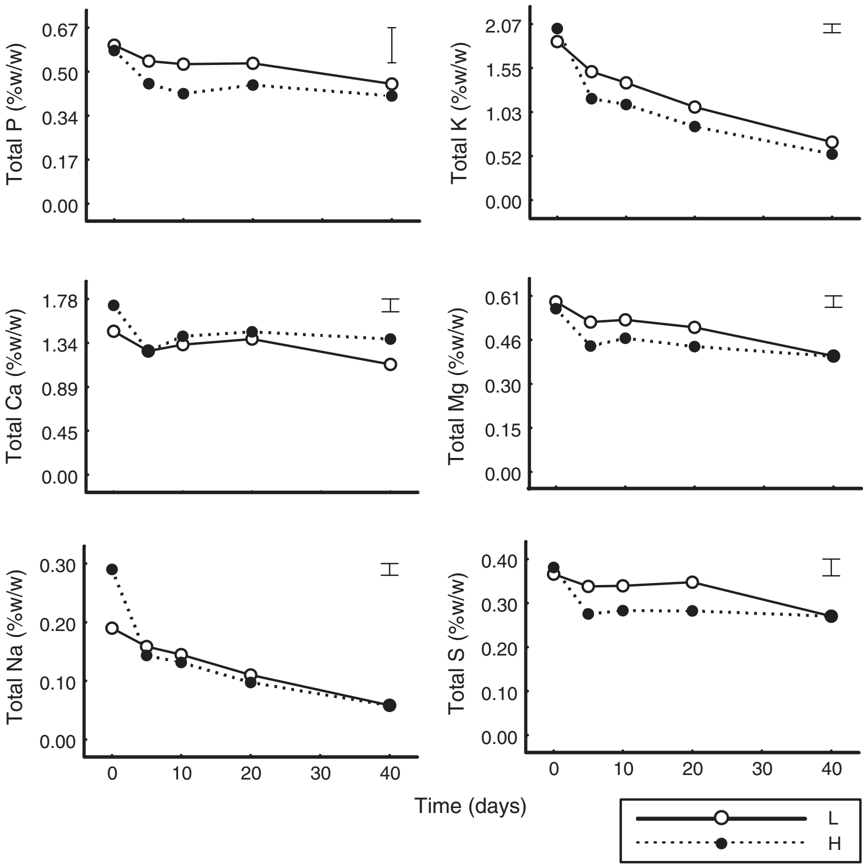

Fig. 3. Changes in the P, K, Ca, Mg, Na, and S concentrations of decomposing dung pads from cows grazing low (L) and high (H) input systems. The error bar is the l.s.d. (P = 0.05) for comparing systems at a given time.

Table 2. Results of statistical analysis (*P* values) of soil chemical properties under dung or control (treatment) pads at two soil depths over six sampling times and from two input systems

Effects	pH_w	pH_c	Al	TOP	EC	OlsP	ColK
System	n.s.	n.s.	n.s.	0.046	n.s.	n.s.	n.d.
Depth	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Depth × system	n.s.	n.s.	n.s.	n.s.	n.s.	0.022	
Treat	<0.001	0.016	n.s.	n.s.	<0.001	<0.001	<0.001
Treat × system	n.s.	n.s.	n.s.	0.003	n.s.	n.s.	
Time	<0.001	<0.001	0.022	0.019	<0.001	<0.001	<0.001
System × time	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Depth × treat	n.s.	n.s.	0.001	0.002	<0.001	<0.001	<0.001
Depth × system × treat	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Depth × time	0.003	n.s.	0.038	0.001	<0.001	<0.001	<0.001
Depth × system × time	n.s.	n.s.	n.s.	0.01	n.s.	0.017	
Time × treat	<0.001	n.s.	n.s.	n.s.	<0.001	<0.001	<0.001
System × time × treat	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Depth × time × treat	<0.001	<0.001	n.s.	0.066	<0.001	<0.001	<0.001

n.d., Not determined; n.s., not significant.

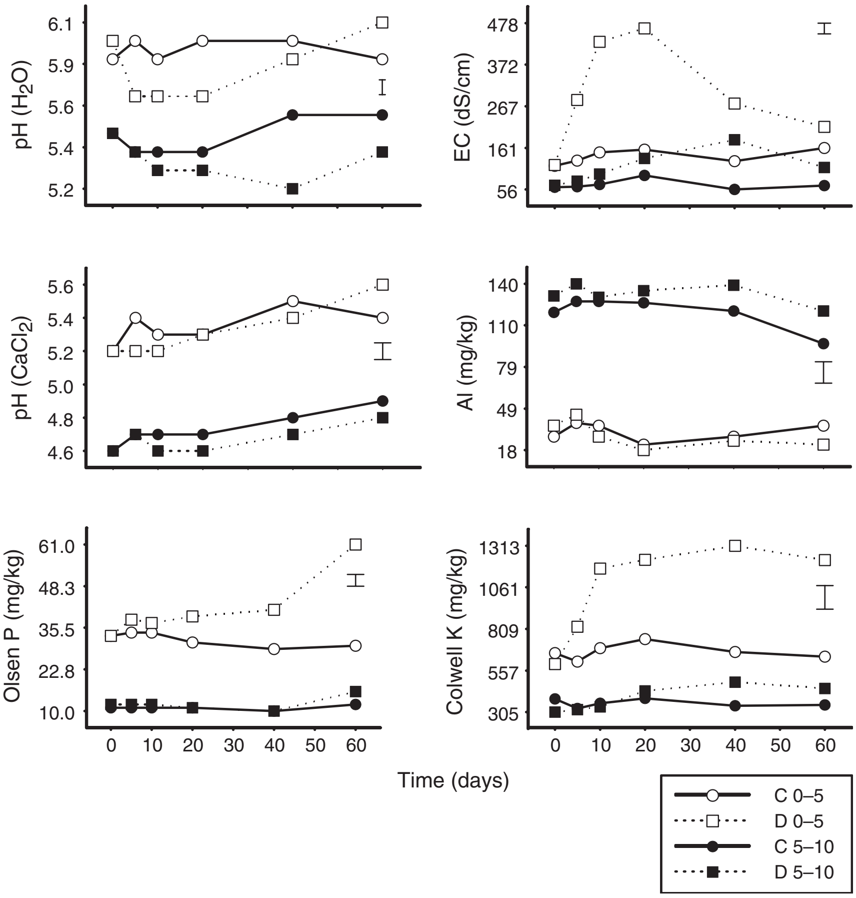

Fig. 4. Changes in soil chemical properties under dung (D) and control (C) pads at 0–5 and 5–10 cm depths. The error bar is the l.s.d. (P = 0.05) for comparing treatments at a given depth and time.

system interaction was probably due the crossover of the L and H weights between Day 5 and 10.

The dry weight increase observed in the first 5 days is most likely due to the action of earthworms and dung beetles. Small mounds of soil, presumably brought to the surface by soil fauna, were observed at the edges and within the pads on Day 5. Dickinson and Craig (1990) reported dry weight increases of 3.8–5.1% 5 days after their pads were created. The dry weight of dung from cows grazing the H system increased by 13%, whereas the L dung only changed by 3%. System effects evident in the dry weight and wet weight DD data may be a reflection of the greater grain and hay intake of the H herd (27.7 *v.* 6.5 t) in the farmlet trial (CJP Gourley, unpublished data). This increased hay and grain was required, as pasture dry matter produced in this farmlet was insufficient to maintain the H herd milk production. As a consequence, dry weights of the H herd dung were likely to be greater, while the decomposing dung would most probably contain larger amounts of more resistant DD.

Dung pads were completely degraded by Day 60, with almost half of the pads completely degraded by Day 40. The rate of decomposition of pads depended on the season in which the dung was voided (Dickinson *et al*. 1981) as well as the impact of watering regime (Dickinson and Craig 1990). Based on the calculation of 75% loss of dry weight, the dung in this experiment disappeared in 18–23 days, much less than that reported for several other countries in autumn (Dickinson *et al*. 1981). This may be a function of the frequent rainfall events and mild temperatures of autumn in this region.

The large quantities of nutrients returned in dung pads have implications for nutrient cycling in grazed pastures. The rates of nutrients (kg/ha) applied in our experiment were in the range of those given in previous experiments (During and Weeda 1973; Weeda 1977; Dickinson *et al*. 1981; Williams and Haynes 1995). The published nutrient contents of the applied dung appeared to vary depending on the fertility of the site (During and Weeda 1973) and the year in which the samples were collected (Dickinson *et al*. 1981). In general dung P levels for both L and H systems in this experiment were lower than in the previous studies, but were higher than for Dickinson *et al*. (1981) and the low P dung of During and Weeda (1973). On the other hand, the K applied in this experiment was always greater than that for the published data. Differences in dung nutrient contents of this and previous experiments are likely to be due to the fertiliser and stock management history of the site (Gourley 2001).

Although the rate of decline in nutrients was generally greatest in the first 5 days after pads were created, sporadic rainfall over the duration of the experiment could have contributed to the continued leaching of nutrients from the pads. The rate of decline in Ca, Mg, and S from the L dung increased after Day 20, probably due to the rainfall that occurred between Day 10 and 20. Underhay and Dickinson (1978) reported increased leaching losses of K and Ca after heavy rainfall. Dung K and Na concentrations decreased considerably due to leaching losses. However, the overall decline in P, Ca, Mg, and S concentrations were too small to suggest that leaching was the sole mechanism of entry of these nutrients into the soil. Complexes formed by Ca and Mg (Underhay and Dickinson 1978; Haynes and Williams 1993) in dung may retard leaching losses of these nutrients.

Dung increased the nutrient content of the soil below the pads (MacDiarmid and Watkin 1972*a*; During and Weeda 1973; During *et al*. 1973; Weeda 1977; Dickinson and Craig 1990; Williams and Haynes 1995), with Olsen extractable P and Colwell K almost doubled in the upper soil layers in this experiment. Nutrient movement from the pads into the soil varied depending on mobility of the nutrient. Phosphorus increases only occurred after Day 20, whereas mobile cations like K and Na moved readily into the soil. Rapid and sustained increases in extractable soil K were observed under the pad. It is evident that changes in EC observed were largely due to the leaching of Na (68–79% decrease in pad concentrations) from the pad. The highly mobile Na would have contributed to the changes in EC observed in the lower soil layers. Neither extractable P nor K increased with depth, suggesting that the K was chemically immobilised in the top 5 cm of the soil. No change in soil pH_c was observed and pHw decreased, despite reports of increases in soil pH under pads due to the alkaline nature of dung (During and Weeda 1973; Weeda 1977). The rate of Ca applied in the pads in this experiment (equivalent to 1.6 t/ha of lime) was insufficient to increase soil pH. As this rate was similar to the rates applied previously in other experiments, it appears that this Ferrosol must have a greater pH buffering capacity than those other soils. (During and Weeda 1973; Weeda 1977).

The mechanism of entry of dung nutrients into soil can be determined from changes in nutrient concentration while the pad is decomposing, as well as observed increases in soil nutrient contents. The minor change in dung P concentration, in contrast to the large decreases observed for K and Na, indicates a different mechanism of P movement into soil. Physical incorporation (Haynes and Williams 1993) rather than leaching was the likely means of P entry, based on the marginal decline in dung P concentration for the duration of the experiment and the slower rate of increase in soil Olsen P. This incorporation was most likely mediated by soil fauna such as earthworms and dung beetles, as evidenced by the presence of casts and burrows.

Changes in soil nutrient content under dung have implications for the cycling of nutrients by grazing cows. Nutrients consumed in pasture (such as P and K) are returned in dung and subsequently become available for plant uptake. These plant-available soil nutrients remained elevated even after the pads had completely disappeared and thus may contribute to plant uptake in the longer term. With the disappearance of the pad, the pasture becomes more palatable (MacDiarmid and Watkin 1972*b*) to the cows and these nutrients are recycled through the animal again. During and Weeda (1973) reported that up to 40% of pasture could be affected by dung deposited by a grazing herd, although Williams and Haynes (1995) predicted only 6%. The latter did not consider the area of influence outside the dung pad, which may be as much as 6 times the area covered (Haynes and Williams 1993). As stocking rates double, dung distribution within a paddock will increase at least 2-fold, due mainly to differences in the mean excretal densities (Petersen *et al*. 1956) of the different systems. From the results presented, greater dung deposition at higher stocking rates will increase the area of pasture with greater plant-available soil nutrient contents.

The high K rates applied in dung far exceed average K fertiliser rates on most dairy farms, with the difference in dung K between the 2 systems likely to be due to the greater supplement intake of the H herd. With average K contents of the hay and grain supplements in the 1995–96 lactation of 2.41% and 0.56%, respectively, the H herd intake of K is 4.6 times greater than the L herd. Assuming 11% of the K intake is excreted in dung (Haynes and Williams 1993), the H herd will return 47.6 kg K over the lactation, compared with 10.3 kg from the L herd. In addition, the soil K levels measured under pads were considerably greater than recommended rates of <500 mg/kg. During *et al*. (1973) observed luxury uptake by pasture of K from soil below dung pads, which has consequences for luxury consumption of K by dairy animals especially as stocking rates increase. Grazing management practices resulting in stock camps, or using night paddocks for holding cattle between night and morning milking, could put the animals at risk of grass tetany due to greater deposition of dung and higher soil and pasture K levels.

Likewise, the rates of P applied in dung could result in areas of the farm (stock camps, night paddocks) with high soil P levels. On this high P-sorbing soil, extractable P almost doubled under dung pads. This potentially has consequences for fertiliser use on farm as well as P loss to the environment at higher stocking rates.

Stocking rate differences were not observed here, as the system differences (rates of P fertiliser applied and stocking rate) had only been implemented for 1 year. The stocking rate effects at this early stage of the farmlet trial are driven primarily by differences in nutrient intakes (i.e. supplementary hay and grain) of the L and H herds. These effects are likely to increase as the farmlet trial continues and will be compounded by the greater return of dung to the H pastures. As a consequence, soil fertility is expected to increase more rapidly in the higher input system due to the increased rate of P fertiliser as well as stocking rate. Soil K levels are also likely to increase markedly in the high input system, driven primarily by the greater supplement intake at higher stocking rates.

While the primary form of P in dung is inorganic (Haynes and Williams 1993), both organic and inorganic P are returned to grazed pastures. The amounts of these dung P pools returned and changes in soil pools may affect plant uptake and nutrient use, as extractable soil organic P pools are available for plant uptake (Bowman and Cole 1978). The proportion of organic and inorganic extractable P in dung, the changes in these levels during dung decomposition, and the relative contribution to soil organic and inorganic P pools are examined in the subsequent paper (Aarons *et al*. 2004).

In this experiment, dung applied to temperate dairy pasture soils decayed rapidly. Differences in decomposition of dung from the L and H herds are most likely due to the increased supplements (hay and grain) consumed by the latter herd. Dung decay resulted in the addition of large amounts of P, K, Ca, Mg, Na and S to the soil. Movement of these nutrients out of the pad depended on their solubility in water and was reflected in the rate of increase in soil nutrient levels. Whereas most P was physically incorporated, K leached into the soil. The high soil P and K levels under dung pads have consequences for P losses to the environment and increased likelihood of grass tetany in cows, especially in stock camp areas and night paddocks. These results indicate that fertiliser use on dairy farms needs to take into account areas of high dung return, which are likely to be exacerbated in high input systems.

Acknowledgments

We thank Mr Murray Hannah for statistical advice. This research was supported by the Dairy Research and Development Corporation and the Victorian Department of Primary Industries.

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Manuscript received 9 January 2003, accepted 14 October 2003