Pergamon

0038-0717(95)00140-9

Soil Biol. Biochem. Vol. 28, No. 3, pp. 291–299, 1996

0038-0717/96 $15.00 + 0.00

EFFECT OF CATTLE DUNG ON SOIL MICROBIAL BIOMASS C AND N IN A PERMANENT PASTURE SOIL

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(Accepted 20 September 1995)

Summary—The effects of cattle dung on soil microbial biomass (SMB) C and N were examined in grazed grassland. In a field study using artificially placed pats no effects on the SMB could be demonstrated even though concentrations of mineral N increased ($P < 0.001$) in the underlying soil. When dung was mixed with grassland soil under controlled conditions the size of the SMB increased ($P < 0.001$). Respiration rate also increased ($P < 0.001$) and specific respiration (q) was higher ($P < 0.05$) in soil treated with beef cattle dung than in that treated with dairy cow dung. The presence of added inorganic N (NH_4NO_3) had no further effect. The potential effects of dung on the SMB which were demonstrated under controlled conditions may therefore be diluted in field conditions.

INTRODUCTION

The effects of dung patches on pasture ecosystems have been studied extensively with respect to nutrient cycling (MacDiarmid and Watkin, 1972; Dickinson and Craig, 1990; Sakadevan *et al.*, 1993) and sward composition (MacDiarmid and Watkin, 1971; Castle and MacDaid, 1972). Much research has also been carried out into the breakdown of dung-pats by invertebrates and their effects (Holter, 1979; Hendriksen, 1991; Yokoyama *et al.*, 1991). The rate at which dung breaks down in the field is largely dependent on season and weather (MacDiarmid and Watkin, 1971; Underhay and Dickinson, 1978; Dickinson *et al.*, 1981) so that measurements can be difficult to compare quantitatively. Less is known about the effect of dung on the soil microbial biomass (SMB) (Yokoyama *et al.*, 1991; Bristow and Jarvis, 1991) which, because it plays such a key role in nutrient transformations in soil and largely controls the rate at which C, N and other nutrients cycle through the agricultural ecosystem (Jenkinson, 1988) may be of critical importance. The substantial amounts of nutrients that are contained in cattle dung can potentially be recycled back to the soil in an available form. It has been estimated, for example, that in grazed grassland the return of animal excreta contributes 150–300 kg N ha^{-1} y^{-1} (Whitehead, 1986) and in intensive managements may be considerably greater than that. SMB will play the key role in the various transformations involved but how it reacts in the short term to the concentrated inputs of organic matter and nutrients in dung-pats is not known.

The maximum effect of dung on SMB would occur if it were to be completely mixed with soil, a situation which can take place in arable farming systems where it is common practice to plough-in animal waste along with stubble. In grazed grassland where dung is deposited on the surface of the sward, materials can enter the soil either by the activity of invertebrates or transport of mobile materials in rain and ground water. However, nutrients entering the soil by these routes may not necessarily be in an "available" form; for example, Gunary (1968) found that when dung was incorporated into the soil, 70% of the total P was available to plants but this proportion was reduced to only 13–20% when it was applied to the surface.

In grazed grassland the amounts of nutrients from dung that enter various pools in the soil, and the rate at which they do so, are subject to many variables. Previous studies have shown that a wide range of managerial factors, including N inputs, in grazed swards had remarkably little effect on SMB contents (Lovell *et al.*, 1995). Addition of mineral nutrients alone therefore may not have marked effects on SMB, whereas incorporation of mobile organic materials from dung may cause changes by providing readily-available energy sources and substrates for metabolism. We have followed changes in SMB under field conditions after addition of dung. Because it was thought to be important to provide a yardstick against which to compare events in the field, we also conducted an experiment to measure the potential effect of cattle dung on the SMB by mixing dung with grassland soil under controlled conditions.

MATERIALS AND METHODS

Dung-pat field experiment

Site. The experiment was started in June 1993 on a grass sward area on the IGER farm at North Wyke

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Research Station in Devon, S. W. England. This was a permanent pasture (predominantly ryegrass) on a silty clay loam of the Halstow series, similar to that used in previous studies (Lovell *et al.*, 1995). It had been under conventional grazing management for a number of years and prior to treatment the sward had been cut to 3 cm.

Dung. Fresh dung (moisture content 87%) was collected from lactating dairy cows which had been grazing on a grass–clover sward. Aliquots of dung (1.5 kg) were formed into circular pats of 0.045 m^2 on top of 30 cm squares of 7 mm stainless steel wire mesh which had been laid out on the sward. By lifting up the mesh the dung could be weighed and the soil beneath could be sampled. Dung was applied during June 1993. Soil samples were taken from below the pats 1 week after application and periodically for up to 44 weeks.

At sampling times, four soil cores, 2.5 cm dia and 10 cm deep, were taken from beneath each of four replicate pats. A further four cores taken from adjacent areas, 1 m from each of the pats, were used as controls. Each set of four cores was bulked, crumbled and mixed by hand, stones and above-ground plant material and visible roots were removed and the soil was sieved (4 mm) for analysis.

Dung incubation experiment

Soil cores (2.5 cm dia × 10 cm) were taken at random from unfertilized permanent pasture on a silty clay loam of the same series as that in the field experiments, crumbled by hand with above-ground plant material and stones removed, and (4 mm). The bulked, sieved soil (with a moisture content of 31%) was stored at ambient temperature for approximately 10 days. Dung was collected from two sources: (a) lactating dairy cows, grazing grass / clover supplemented with silage (dung moisture 89%); (b) young beef cattle, grazing unfertilized grass (dung moisture 88%).

In order to provide a homogenous material, the dung was placed in trays at ambient temperature and mixed frequently intervals to prevent crust formation and facilitate even drying. After several weeks when the moisture content had been reduced to 45% the dung had a consistency which enabled it to be broken up into small pieces (> 1cm). It was then chopped finely until it would pass a 6 mm sieve.

Aliquots of chopped dung equivalent to 4.5 g dry wt were added to 125 g moist soil and mixed thoroughly to simulate the effect of an average dung-pat being incorporated into the top 10 cm of soil. These mixtures were then placed in glass jars (520 ml^3) with airtight lids fitted with a subaseal sampling port. An additional treatment was prepared where fertilizer N (NH_4NO_3) was mixed with the soil containing beef cattle dung. The amount added was proportional to a fertilizer regime of 400 kg N $ha^{-1}y^{-1}$ applied in 9 equal parts, i.e. 15 mg NH_4NO_3 added to 125 g soil corresponding to 44 kg N ha^{-1}. This was mixed, as a dry powder, with the soil + beef cattle dung before being placed in incubation jars. Each jar therefore contained 125 g moist soil and sufficient jars were prepared to provide all treatments with four replicates on each of the four sampling dates (16 jars per treatment). The treatments were: (i) soil alone; (ii) soil + dairy cow dung (8.2 g wet wt); (iii) soil + beef cattle dung (8.2 g); and (iv) soil + beef cattle dung (8.2 g) + NH_4NO_3 (15 mg).

The jars were kept at 18°C in a controlled temperature room. Periodically, the jars were sealed and 2 ml samples of headspace were removed after 1–3 days incubation and CO_2 measured by gas chromatography (TCD detector) (initial tests showed that the increase in CO_2 concentration was linear up to 3 days). All the jars were flushed with air after each measurement, i.e. at least every 3 days. At 1, 2, 5 and 10 weeks after the start of incubation, four jars from each treatment were removed and the soil used for the analyses described below.

Soil analyses

The soil from both field and laboratory experiments was examined for microbial biomass C and N, mineral N contents and total C and N contents.

Microbial biomass. Soils were extracted on the day of sampling by a fumigation–extraction (FE) method (Brookes *et al.*, 1985; Vance *et al.*, 1987). The extracts were used to determine biomass C and N as described by Lovell *et al.* (1995), which were expressed on an oven dry soil basis.

Mineral N contents. Soil samples (50 g) were shaken with 1 M KCl (100 ml) on an orbital shaker for 2 h and the suspension was filtered through Whatman No. 1 paper, with the first 5 ml discarded. The concentrations of NH_4^+ + NO_3^- in the extracts were determined colorimetrically (Hendricksen and Selmer-Olsen, 1970; Tecator, 1984).

Total C and N. Samples of soil and dung were air-dried and ground (2 mm). Subsamples were used to determine total C and N using an automated Dumas procedure on a Carlo Erba NA 1500 analyser (Erba Science UK Ltd).

Statistical analysis

Data were examined by analysis of variance using Microsoft Excel 5 software.

RESULTS

Soil characteristics measured at the beginning of each experiment (Table 1) showed that there were differences in total C and N in soils used in field and laboratory experiments but that these were small: the mineral N content of the soil in the field experiment was lower than that in the incubation experiment. This may in part be explained by seasonal effects; the

Table 1. Characteristics of soils (0–10 cm) and dungs measured at the begining of the experiments: values expressed on a dry wt basis

Material	Total C (%)	Total N (%)	C-to-N ratio	$NH_4^+ + NO_3^-$ (mg kg^{-1})	Moisture content (%)
Soil					
Field experiment	4.38	0.45	9.7	5.8	32
Incubation experiment	4.29	0.39	11.0	11.0	31
Dung					
Field experiment					
Dairy cows	30.3	2.10	14.4	—	87
Incubation experiment					
Dairy cows	40.4	3.35	12.1	—	89
Beef cattle	36.7	1.91	19.1	—	88

field experiment began in June when N uptake by plants would have been high resulting in reduced soil mineral N contents, whereas soil for the incubation experiment was taken in November when plant uptake would have been much lower.

The composition of the dung varied between the experiments (Table 1). The higher N content of the dairy cow dung for the incubation experiment may have resulted from the fact that the cows were being given a feed supplement at this time (November). C contents also differed so that the C-to-N ratio of the two dairy cow dungs was not substantially different: the C-to-N ratio for the beef cattle dung was higher, i.e. 19.1 compared with 13.2 (on average) for the dairy cow dung.

Dung-pat field experiment

The experiment began in mid-summer and the weather was warm and dry for the first 2 weeks during which there was 0.4 mm rainfall compared with a 30 y average over the same weeks of 25.9 mm. In comparison with the 30 y mean, weeks 2–6 were wetter (by 72 mm), weeks 6–10 were drier (by 56 mm) and weeks 2–10 were cooler by 1°C. Within a few days of the start of the experiment a hard crust had formed over the dung-pats and they dried rapidly, losing 50% of their fresh weight in the first week and 85% of their weight by the 6th week. Wide ranging weather conditions during the experiment may explain the uneven changes observed in dung-pat dry weight. Total C and N contents of the dung were both reduced by approximately 60% (dry wt basis) in 10 weeks (Table 2): C-to-N ratios remained constant.

SMB C and N were measured at 1, 3, 6 and 10 weeks after application and on each occasion there was no significant difference between that in the control soil and that in the soil beneath dung; mean values are shown in Table 3. Whilst total soil C and N remained unchanged, the amount of mineral N in the soil underlying dung-pats was 3 times higher than in control soil ($P < 0.001$) at weeks 1 and 3; this difference had disappeared by week 6 (Table 4). The NH_4^+-to-NO_3^- ratio was decreased by the addition of dung during the early stages (from 3.7 to 0.9 at week 1), but in both soils increased to > 8.5 by week 10. Further measurements of SMB-C and -N and soil mineral N were made at 44 weeks and the values were no different to those at 10 weeks.

Incubation experiment

When dung was mixed with sieved soil the microbial biomass increased in size by, on average, up to 60% (Table 5). Biomass C and N contents were higher ($P < 0.001$) in the dung-amended soil for up to 10 weeks of incubation and the increase was greater ($P < 0.001$) for the dairy cow dung-treated soil than for the beef cattle dung-treated soil. The addition of inorganic N to the beef cattle dung treatment had no significant effect on the biomass. Although the values of biomass N showed more variability than those of biomass C, both were closely linked and showed similar trends with time [Fig. 1(a, b)] so that the C-to-N ratio of the biomass in the different treatments was similar. Over the 10 weeks of incubation biomass the C-to-N ratios in all treatments tended to reduce and then increase, but differences between treatments were not significant.

Trends in soil respiration were similar in all treatments (Fig. 2) with the effect of added dung lasting for at least 58 days. On average, there was a 5-fold increase in soil respiration ($P < 0.001$) caused by the addition of dung

Table 2. Changes in dung-pat weight and composition under field conditions

Week	Wet wt (g)	SE	Dry wt (g)	SE	Total carbon content (g)	SE	Total nitrogen content (g)	SE
0	1569	7.3	252	14.8	73.4	2.62	5.49	0.341
1	678	7.1	247	7.0	70.6	2.14	5.19	0.171
3	408	11.6	179	8.3	49.6	2.47	3.77	0.166
6	198	10.6	171	9.9	46.7	3.09	3.95	0.366
10	151	8.5	140	9.1	33.8	3.96	2.73	0.444

Table 3. SMB C and N in soil beneath dung-pats under field conditions: values are means ($n = 16$) over 10 weeks

	Biomass C		Biomass N		
Soil	mg kg^{-1} dry soil	SE	mg kg^{-1} dry soil	SE	C-to-N ratio
Control	1252	42.6	231	7.2	5.4
Dung-pat	1261	32.3	232	4.9	5.4

(Table 6) and CO_2 concentrations remained significantly ($P < 0.001$) elevated throughout. There was no difference in respiration rate between the two types of dung and the presence of extra inorganic N had no additional effect. However, when respiration was related to the size of the biomass, differences in respiratory activity were revealed with the beef cattle dung inducing a higher ($P < 0.05$) specific respiration rate (q) than the dairy cow dung. Overall, the respiratory quotient was increased by more than 3.5 times by the addition of dung.

Soil mineral N was measured only at the beginning and at the end of the incubation period (Table 7). At both times the amounts of mineral N in the two dung treatments were higher ($P < 0.01$) than in the control but were not different from each other. The addition of inorganic N to the beef dung treatment raised the concentration of soil $NH_4^+ + NO_3^-$ initially to 3 times that of the dung-treated soil ($P < 0.001$). Over the 10 weeks of incubation there was a net increase in soil mineral N ($P < 0.01$) for all the treatments except the inorganic N treatment, where there was a 25% decrease ($P < 0.01$). There were smaller increases in total mineral N where dung alone was added (on average by 46%) than in the control treatment (66%). In all cases NO_3^- contents increased with time, and NH_4^+ contents decreased or remained constant. The NH_4^+-to-NO_3^- ratios decreased with time in each case, but whereas with beef cattle dung the decrease was comparable to that in the control soil, it remained substantially higher where dairy cow dung was used.

DISCUSSION

In the field we found no increase in the size of the SMB and soil C and N pools underneath dung-pats. Soil was sampled to a depth of 10 cm, which in grassland soils has usually been considered as the upper layer for SMB estimations (Brookes *et al.*, 1985). It is possible therefore that if dung had caused localized changes in SMB close to the surface of the soil, e.g. 0–5 cm, these effects could have been masked.

Over 10 weeks the dung-pats had lost approximately 60% of their total C and N but the extent to which these nutrients had entered the soil is uncertain. Dickinson and Craig (1990) observed that loss of nutrients from dung was not matched by an equivalent gain in the underlying soil, they found that there was considerable downward and lateral movement of nutrients from cow dung due to a general stimulation of root growth. MacDiarmid and Watkin (1972) measured lateral movement of dung N to 15 cm from the edge of cow pats. Even if most of the C and N that was lost from the dung had entered the soil this would represent about 6% of the total dung nutrients entering each week; and in terms of soil C and N this was less than the temporal variability and would not have been detected.

However, there was a considerable increase in mineral N in the soil apparently derived from the dung but which, at least in part, could have been generated by indirect effects such as a prevention of losses and by an increase in mineralization. A dung-pat effectively "caps" the soil preventing the leaching of N, it also kills the grass beneath it and consequently stops plant uptake of N (MacDiarmid and Watkin, 1971). Dung also absorbs radiant heat which warms the underlying soil causing an increase in mineralization (Stanford *et al.*, 1973). These effects last until the pat begins to break up, in this experiment at about 6 weeks, which coincided with soil mineral N contents returning to background concentrations. Extractable mineral N (< 22 mg kg^{-1}) was only a small fraction of the total (4.5g kg^{-1}) in the soil and so changes in totals were not likely to have been seen. Internal recycling would also have occurred (mineralization–immobilization–mineralization etc.) possibly with substantial effects. The fact that considerable differences in the NH_4^+-to-NO_3^- ratios developed early on may reflect changes in utilization–immobilization patterns.

Table 4. Mineral N ($NH_4^+ + NO_3^-$) in soil beneath dung-pats under field conditions ($n = 4$)

	Control			Dung-pats		
Time Week	mg kg^{-1} dry soil	SE	NH_4^+-to-NO_3^- ratio	mg kg^{-1} dry soil	SE	NH_4^+-to-NO_3^- ratio
0	5.80	0.265	2.75	—	—	—
1	8.29^a	0.272	3.75	22.13^b	1.294	0.89
3	5.30^a	0.392	9.18	18.08^b	1.734	0.35
6	5.46^a	0.124	5.19	8.72^a	1.448	2.90
10	6.92^a	0.413	8.56	6.48^a	0.375	8.87
44	4.05^a	0.076	9.78	5.03^a	0.553	6.31

Values within rows with different superscripts are significantly different ($P < 0.001$).

Table 5. SMB C and N in soils with dung amendments under incubation conditions: values are means ($n = 16$) over 10 weeks

	Biomass C		Biomass N		
Treatment	mg kg^{-1} dry soil	SE	mg kg^{-1} dry soil	SE	C-to-N ratio
Control	1034^{a}	35.2	153^{a}	4.9	6.8
Dairy cow dung	1734^{b}	66.2	274^{b}	16.1	6.3
Beef cattle dung	1439^{c}	67.6	231^{c}	17.3	6.2
Beef cattle dung + N	1371^{c}	54.7	203^{c}	8.6	6.7

Values within columns with different superscripts are significantly different (biomass C, $P < 0.001$; biomass N, $P < 0.05$).

Soil fauna play a major role in the breakdown of dung and the subsequent incorporation of nutrients (Holter, 1979). Earthworm activity is one of the most important factors in this process and is dependent on a water deficiency in the soil (van Dijk and Bastiman, 1976). There was virtually no rainfall

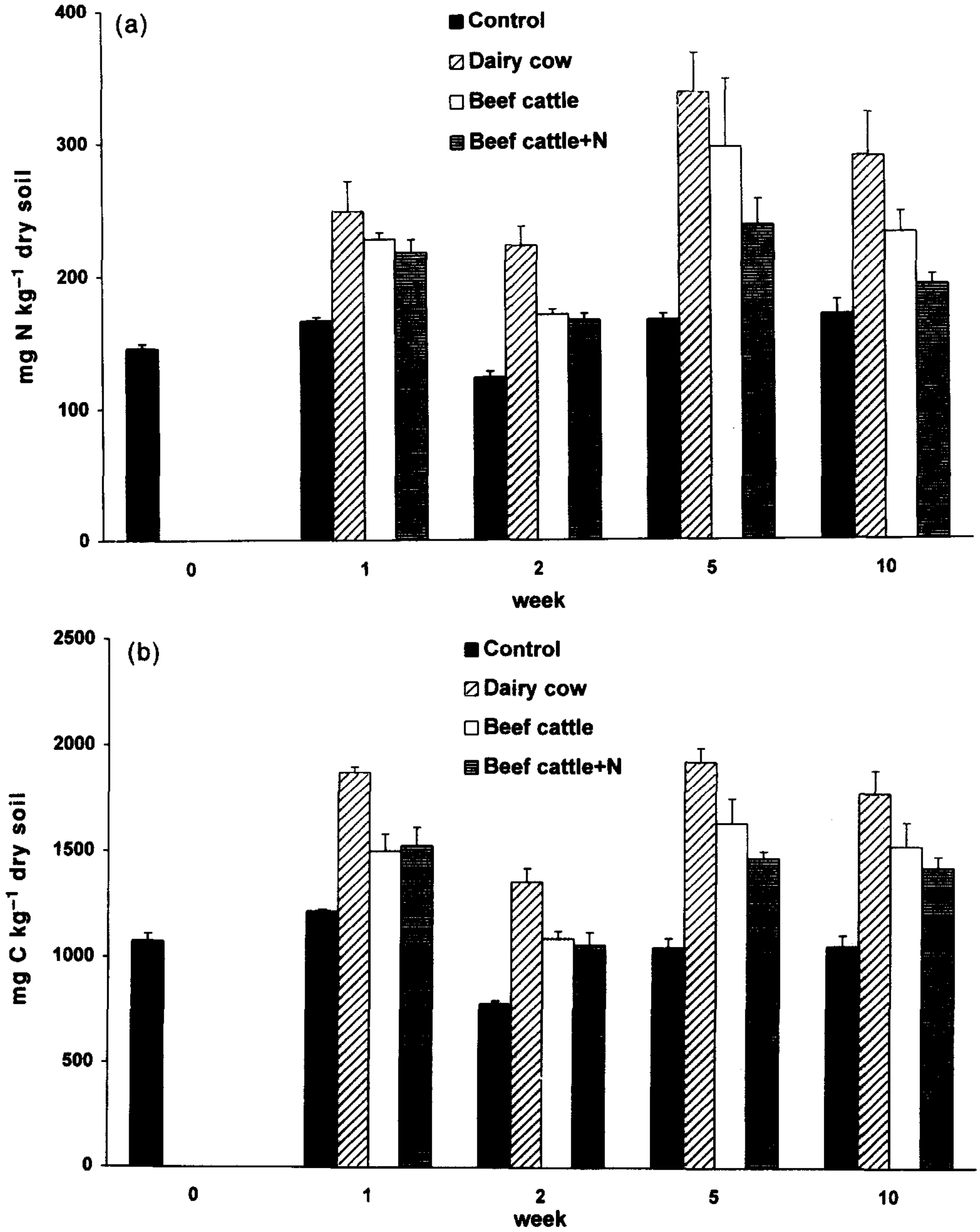

Fig. 1. Changes in SMB N (a) and C (b) after mixing dairy cow or beef cattle (± inorganic N) dung with a silty clay loam soil under controlled conditions over a 10-week period. Mean ($n = 4$) + SE.

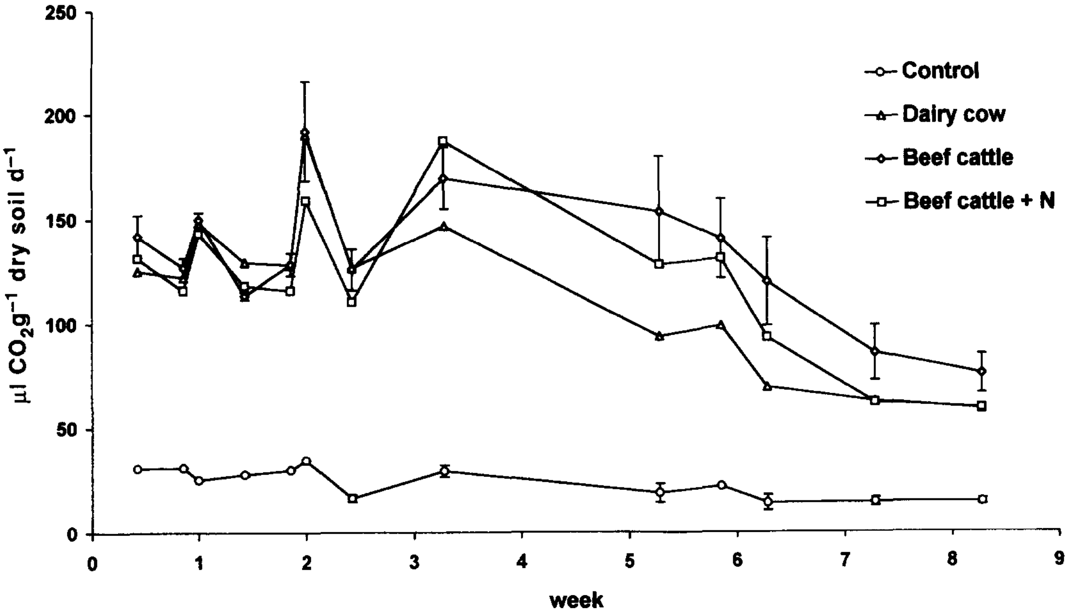

Fig. 2. Changes with time in soil respiration after mixing dairy cow or beef cattle (± inorganic N) dung with a silty clay loam soil under controlled conditions. SE shown for control and one treatment (there were no significant differences between treatments).

during the first 2 weeks of the experiment, the soil was relatively dry and was rarely above 30% moisture content during the 10 weeks involved. Holter (1979) reported very low earthworm activity under dung-pats during a particularly dry summer in Denmark when the rate of dung breakdown was much lower than normal and similar to the rate in our experiment. It is likely therefore that earthworm activity during our experiment would have been low and could have contributed to a slow rate of dung incorporation into the soil; this lack of physical mixing would have slowed the decomposition process.

The breakdown of dung-pats and release of dung nutrients is, however, an extremely variable process. Other workers have reported wide ranging rates of dung breakdown: Dickinson and Craig (1990) measured a 1% loss of dry matter d^{-1} from dung-pats, Castle and MacDaid (1972) found that dung-pats disappeared in about 16 weeks and Holter (1979) reported that pats took 50–65 days to disappear in normal summers but in a dry summer only 35% of the dung had disappeared in 62 days. Since nearly half of the dung C and N still remained in the pats in our study at the end of 10 weeks, further measurements of biomass and mineral N were made in the following spring (after 44 weeks) by which time they had completely disappeared and vegetation had regrown over the area. The results were the same as at 10 weeks, i.e. there were no residual effects on soil mineral-N or SMB-C and -N.

A lack of response in SMB-C and -N pools to excretal returns in grazed grassland soil within a season has been reported before (Bristow and Jarvis, 1991): similar lack of effects have also been noted with a range of N inputs to grassland soils (Lovell *et al.*, 1995). However, there is evidence that in the longer term, the application of animal waste to pasture does lead to an increase (Adams and Laughlin, 1981). In long-term field experiments, Witter *et al.* (1993) found a larger SMB in plots where farmyard manure had been dug in each year than in unfertilized plots, but year-to-year variation was such that the added C was insignificant compared to native soil C on which the stable SMB was sustained. Despite therefore a large input of readily-available substrates, short-term effects of dung on SMB status are minimal under normal field conditions. It seems

Table 6. Effect of dung addition on soil respiration and microbial biomass metabolic quotient: values are means (n = 13) over 60 days

	Respiration rate		Metabolic quotient (q)	
Treatments	µl CO$_2$ g^{-1} dry soil d^{-1}	SE	µg CO$_2$-C µg biomass-C g^{-1} soil h^{-1} × 10^{-3}	SE
Control	23.6^a	2.04	0.51^a	0.044
Dairy cow dung	115.2^b	10.51	1.48^b	0.135
Beef cattle dung	132.5^b	8.72	2.06^c	0.135
Beef cattle dung + N	119.5^b	9.76	1.95^c	0.159

Values within columns with different superscripts are significantly different ($P < 0.001$).

Table 7. Mineral N ($NH_4^+ + NO_3^-$) in soils with dung amendments at the beginning and end of incubation ($n = 4$)

	Week 0			Week 10		
Treatment	Mineral N (mg kg^{-1} dry soil)	SE	NH_4^+-to-NO_3^- ratio	Mineral N (mg kg^{-1} dry soil)	SE	NH_4^+-to-NO_3^- ratio
Control	11.01^a	0.205	0.99	18.31^a	0.118	0.12
Dairy cow dung	17.33^b	0.634	2.36	26.21^b	1.581	1.01
Beef cattle dung	19.72^b	1.063	2.92	27.76^b	1.391	0.29
Beef cattle dung + N	65.23^c	0.452	1.58	49.12^c	2.862	0.24

Values within columns with different superscripts are significantly different ($P < 0.001$).

likely that the way in which nutrients enter the soil from dung-pats in grazed grassland may have the long-term effect of a more general increase in soil nutrients which benefits plant growth and maintains the SMB at a higher level overall.

When dung was mixed with the soil under controlled conditions, effects were substantial. In order to achieve an intimate mixture of dung and sieved soil it was necessary to reduce the moisture content of the dung to a point where its consistency allowed it to be broken up into small fragments, i.e. by storing it at ambient temperatures (10–20°C) for about 6 weeks. This method was of necessity a compromise because of the need to retain as many of the characteristics of fresh dung as possible and although there would have been some compositional changes during this time, these were likely to have been minor. Whitehead and Raistrick (1993) examined the effect of storage on dung N at different temperatures; after 3 weeks at 10°C there were no detectable changes, and at 20°C they found that organic matter had declined by 8% and about 10% of the organic N had been converted to NH_4. Similar changes would have taken place in our materials. An alternative approach would be to allow dung to dry in the field to a defined stage of decay but this would result in the loss of most of the soluble constituents.

When dung was completely mixed with soil there was a considerable increase in respiration and in the size of the SMB indicating that the dung was being used as a substrate by the micro organisms for both metabolism and growth. The larger SMB with dairy cow than with beef cattle dung may have developed as a result of the different resistances of the two dungs to microbial breakdown. The beef cattle had been fed on a relatively poor diet compared to the dairy cows and their dung had a higher C-to-N ratio and would have contained coarse grass residues. Microorganisms utilize substrates of low C-to-N ratio more readily than those of high C-to-N ratio because, in general, the higher the ratio, the more complex the structure and the more resistance there is to microbial breakdown (Ahmad *et al.*, 1969). The presence of added inorganic N to beef cattle dung, which would have compensated to some extent for its lower N content, had no effect on the size or activity of the microbial biomass. This suggests that it was complexity of organic matter structure rather than lack of N that determined the effect of dung on the SMB.

The differences observed in the size of the biomass (measured by FE) in the two dung-treated soils were not paralleled by changes in soil respiration. Ocio and Brookes (1990) observed that when a substrate was added to soil the consequent "substrate induced respiration" was generated by an active part of the biomass which did not necessarily represent the total SMB. They found that FE was a more reliable method of estimating biomass in amended soils. However, respiration did indicate differences in activities in our study. Thus, although the size of the SMB with beef cattle dung was smaller than that with dairy cow dung, it produced a similar amount of CO_2 and therefore had a higher metabolic activity per unit of biomass. Specific respiration provides a means of determining whether dung caused the biomass to become more metabolically active. The metabolic quotient (q) of the biomass was 3–4 times higher in the dung-amended soils than in the control soil and it was higher in the beef dung treatment than in the dairy dung treatment. These values are similar to those obtained by Anderson and Domsch (1985) for maintenance respiration ($q = 0.0018$) in soils using glucose as a substrate to maintain a constant amount of biomass over several weeks incubation. The increase in metabolic activity caused by the addition of dung must reflect a change in the ratio of dormant-to-active components of the biomass. This ratio may also have been modified by the differences in composition between the two dungs (e.g. C-to-N ratio) so that a larger but predominantly dormant population was induced by the dairy cow dung and a smaller but mainly active biomass by the beef cattle dung. On the other hand, qualitative changes within the microbial population might be expected to affect the biomass C-to-N ratio; e.g. a lower microbial C-to-N ratio would suggest an increase in the proportion of bacteria present (Anderson and Domsch, 1980). Although the C-to-N ratio of SMB tended to reduce and then increase during our incubation, which would be consistent with qualitative changes, the effects were not significant.

Over the 10-week incubation there was an increase in mineral N (net mineralization) in the dung-amended soils which was of a similar magnitude to that in the control soil. The addition of inorganic N to the beef cattle dung treatment appeared to cause net immobilization. N was added as NH_4NO_3 and initially produced a higher concentration of NH_4^+ in the soil (40 mg kg^{-1}) than did dung alone (15 mg kg^{-1}). NH_4^+-N is preferentially used by micro-organisms and the presence of such a high amount may have stimulated or induced a functional change in the microbial community which did not affect the overall size or activity of the biomass.

Although the results of our two experiments cannot be directly compared because of the different conditions under which they were performed, they do provide a useful example of the difference between the potential effects and what may occur in practice. Whereas complete mixing of finely-chopped dung with soil had a major impact on both the size and activity of the SMB at least in the short-term, the slow breakdown and release of nutrients from dung-pats under the conditions of the field experiment did not. This slow breakdown coupled with the potential for removal by loss or uptake, may indicate that the dung nutrients becoming available to the SMB were not sufficiently concentrated to cause any measurable localized effect. This is consistent with the idea that the size of the SMB is determined by the input of the stable forms of organic C to soil, with short-term fluctuations being caused by the input of labile C (Anderson and Domsch, 1986). Thus, the increase in biomass observed in the incubation experiment may have been caused by the large, immediate influx of labile dung C, whereas the slower incorporation of dung into the soil in the field failed to stimulate the active component but contributed to the stabilized pool of soil C. Further work is needed to show whether more rapid breakdown of dung in the field would have significant local effects on the SMB, and to determine whether there were other changes in biomass community structure and in the activities of constitute parts.

Acknowledgements—We are grateful to Denise Headon for mineral N analysis and to Andrew Bristow for expert analytical advice. The work was funded by the Ministry of Agriculture, Fisheries and Food, London.

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