DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS **CSG 15**

Research and Development

Final Project Report

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Executive summary (maximum 2 sides A4)

The aim of this experiment (1999-2001) was to investigate the agronomic effects of applying treated and untreated farmyard manure and slurry to an organically managed, upland clover/ryegrass pasture. Seven main treatments were imposed in a split plot, randomised complete block design, simulating inputs from organic and conventional systems at ADAS Redesdale. The main treatments were; composted (Treatment A) and uncomposted (B) FYM; aerated (C) and unaerated (D) cattle slurry; ammonium nitrate (E); and a zero nitrogen control (F). A further control treatment (G), to which slurry was applied only in 1996, was added to provide a common control treatment during an earlier phase of the experiment. Target application rates were 150 kg total N/ha for untreated slurry and FYM treatments. Following aeration, the same volume of slurry as for the unaerated slurry treatments was applied. Allowing for losses, composted FYM was applied at a rate calculated to supply 80% (120 kg/ha) of total N compared to the untreated FYM treatment. Ammonium nitrate was used as a conventional control treatment, applied at an annual rate of 240 kg/N/ha.

To determine the effect of phosphate and potash, one half of the plots were supplemented when soil levels of these nutrients fell below theoretically optimum levels. Highland Slag and Seagreen K were used as organic sources of P and K, while muriate of potash and superphosphate were used on the conventionally managed plots. Application rates were based on the results of soil analysis, according to standard recommendations for organic (Glenside Organics, Ltd) and conventional (Anon. 2000) production.

Nitrogen application rates achieved for FYM and slurry treatments were 109%, 125%, 93% and 97% of target for treatments A to D, respectively. Although chemical composition was highly variable between batches, aeration of the slurry tended to reduce BOD and COD values, and increase nitrate-N content. The chemical composition of FYM was also variable. Compared with uncomposted material, composted FYM had higher dry matter, nitrate-N, potassium and phosphate concentrations.

Across all treatments, mean dry matter yields (kg/ha) were 9,827, 10,028 and 9,412, for each of the three years respectively. Expressed as a percentage of the zero nitrogen control treatment, the use of ammonium nitrate increased dry matter yield by 5% - 31%. Slurry and FYM increased yields by 11% - 32%. In terms of total dry matter yield, there were no significant benefits from composting FYM or aerating slurry. However, composted FYM produced a considerably better response per kg N applied compared to the untreated material. Although supplementing the conventionally managed plots did increase dry matter yield, overall there was no statistically significant effect on herbage yield from supplying additional P and K.

Soluble nitrogen fertiliser significantly reduced ($P < 0.001$) the proportion of clover in the sward. Conventionally managed plots tended to have the lowest weed content, possibly due to greater competition from a heavily fertilised grass sward. On the zero nitrogen control plots, the contribution of clover to total nitrogen supply was estimated to be approximately 150 kg N/ha/annum.

Plots receiving high levels of ammonium nitrate had the highest concentration (mean 2.85% by dry matter) of herbage nitrogen. Herbage phosphorous levels were adequate across all treatments, with the highest concentrations occurring where FYM/slurry had been applied. Livestock manures also maintained acceptable levels of herbage potassium (mean 2.56%). Herbage potassium was lowest on the zero nitrogen control treatments (mean 1.54%), and on the conventional treatment which had not been supplemented with 290 kg/annum K_2O (2.66% Vs 2.21% in 2000; 2.07% Vs 1.84% in 2001).

Ammonium nitrate resulted in the greatest nitrogen uptake ($p < 0.001$). Uptake was consistently greater for composted FYM, compared with untreated FYM. Phosphorous uptake was reduced by lower yields on the zero nitrogen control treatments ($p < 0.001$). Application of super phosphate, increased uptake on the conventionally managed plots, restoring comparability with FYM/slurry treatments. Low herbage potassium content on the conventionally managed plots significantly reduced total potassium uptake, which improved following the application of muriate of potash.

Addition of livestock manures produced a significantly better balance of soil nutrients, and significantly increased soil organic matter ($P < 0.05$). Soil pH declined more rapidly where ammonium nitrate had been used ($P < 0.05$). Phosphate levels (Index 1/2) were adequate across all treatments. Even without supplementary phosphate, calculated phosphorous inputs ranged from 81% - 119% of offtake following the use of FYM/slurry. A cutting and carting system of management resulted in a depletion of soil potassium to an Index 0/1 across all treatments.Without additional potassium fertiliser the proportion of K supplied in manure, relative to that removed by the crop, was 63%. Potassium input, as a percentage of total offtake, was 81% where muriate of potash had been applied to conventionally managed plots.

As an indicator of microbial activity, there were no significant treatment differences in soil respiration, measured *in situ* as CO_2 emission, during the last year of the experiment. However, soil biomass N was significantly lower ($P < 0.05$) on the conventionally managed plots.

Overall, the results indicate that high clover swards and the return of major nutrients in slurry and FYM can support a high level of productivity from an organically managed pasture, without the requirement for exogenous fertiliser inputs. Under a conservation system of management, it was clear that soil potassium could be a major limiting factor to herbage yield. However, FYM/slurry maintained an acceptable concentration of herbage K, despite a Soil Index of 0/1. The information generated on nutrient cycling, on output and other measures of productivity raises questions as to the optimum level of soil nutrients required for organic production, the role of soil microbial activity and the potential to better exploit composted FYM. The balance of crop offtake from more modest yields, with nutrients released from the soil, may dictate that high levels of extractable nutrients in the soil may not be a prerequisite for good performance from an organic system.

Scientific report (maximum 20 sides A4)

1.0 Introduction

Organic systems of livestock production emphasise the interaction between soil, plant and animal. Efficient cycling of nutrients is essential to maintaining grassland productivity, if the need for supplementary fertiliser inputs is to be avoided.

Livestock output on many hill and upland farms is underpinned by the productivity of a small area of better quality land which, conventionally, would receive high levels of fertiliser input. Under organic management, soluble nitrogen fertilisers are prohibited, and clover is expected to make a significant contribution to the nitrogen (N) requirements of an organically managed sward. Conventional research indicates clover N fixation rates equivalent to 150-200 kg N/ha from a clover-based system (Wood, 1996). Phosphorus (P) and potassium (K) may also become limiting, if nutrient offtake in the harvested crop exceeds that provided from soil reserves, or recycled through livestock manures (Younie, 2001).

Efficient use of plant nutrients, recycled in the form of livestock manures, is therefore critically important to the performance and sustainability of organic grassland systems. Composting of solid manure and aeration of slurry are frequently advocated for organic farms. European research has demonstrated the potential of both processes to reduce nutrient losses at spreading, to limit disruption to soil processes and to reduce the viability of weed seeds and pathogens (Vogtmann & Besson, 1978). However, little practical information is available in the UK on the agronomic effects of these treatments.

2.0 Objectives

An experiment had been established at ADAS Redesdale in 1996 to investigate the effects of treated and untreated farmyard manure and slurry on crop yield, botanical composition, forage nutrient value and soil nutrient status. To determine the longer-term implications of these treatments, assessments were completed during the current reporting period (1999/00 – 2001/02), with the additional objective to assess the effects of supplementary P and K, where soil levels of these nutrients had fallen below theoretically optimum levels.

Specific objectives were

1. To assess the long-term effect of N source on herbage yield and composition

2. To determine the requirements for additional P and K above those supplied from livestock manures

3. To determine the effect of treatment on soil nutrient parameters

The work supports DEFRA's policy objective to promote sustainable, organic food production systems, and the efficient use of livestock wastes.

3.0 Materials and Methods

The experiment was sited on inbye land within the organic unit at ADAS Redesdale, at an elevation of approximately 160 m. Soil texture was clay loam. Mean annual rainfall over the duration of the experiment was 937 mm.

3.1 Manure treatments

Seven main treatments were imposed in a split plot, randomised complete block design, simulating inputs from organic and conventional systems. There were 4 replications of each main treatment (8 x 8 m plots). The treatments were; composted (Treatment A) and uncomposted (B) FYM; aerated (C) and unaerated (D) cattle slurry; ammonium nitrate (E); and a zero N control (F). A further control treatment (G), to which slurry was applied only in 1996, was originally included to provide a common control treatment at the start of the experiment.

For the organic unit as a whole, it was calculated that 150 kg total N, would be available from livestock manures per hectare of inbye land. This target rate of total N was used for the untreated slurry and untreated (stacked) FYM treatments. For the aerated slurry (Treatment C), the same volume of slurry as for Treatment A was applied. Slurry was applied in three applications – February (60 kg N/ha), March (60 kg N/ha) and July (30 kg N/ha). Aeration was achieved for the 10 days prior to application, using a system of Dunlop diffusers connected to a compressor.

FYM from cattle and sheep enterprises was mixed mechanically using a second-hand Armix feeder wagon, turned three times, and composted over a seven-month period in a covered yard. This was applied at a rate calculated to supply 80% (120 kg/ha) of total N compared to the untreated FYM treatment, based on the assumption that about 20% of the starting N content would be lost during the composting process. Uncomposted FYM was obtained from comparable raw material, based on cattle/sheep straw bedding, stockpiled outside without cover for 12-18 months. FYM was applied as a single dressing in January/February.

Derogation was obtained from UKROFS to include conventionally managed plots as a control treatment. Ammonium nitrate was applied three times during the growing season - March (60 kg/N/ha), May (100 kg/N/ha) and July (80 kg/N/ha), at a rate equivalent to 240 kg/N/ha (representing normal commercial practice).

3.2 Phosphate and potash treatments

From autumn 1999, a split plot design was superimposed by splitting each main plot, and randomly allocating one half to receive supplementary P, K and lime, at a rate determined for each main treatment by the results of soil and herbage analysis.

On the organically managed plots, Highland Slag (15% P_2O_5; 3% K_2O) and Seagreen K (6% K_2O) were applied as a single dressing in Spring 2000, at rates recommended by Glenside Organics Ltd (Throsk, Stirlingshire).

Given the relatively low concentration of P and K in these materials, calculated application rates of K_2O were 44, 46, 84, 84, 97 and 91 kg/ha for organic treatments A, B, C, D, F and G, respectively. Application rates of P_2O_5 were equivalent to 0, 0, 114 ,106,131,and 121 kg/ha, respectively.

Reflecting low soil K levels, conventionally managed plots (E) were given 287 kg /ha K_2O annually as Muriate of Potash, in three applications over the season. Phosphate was applied as SuperPhosphate, providing the equivalent of 85 kg/ha P_2O_5 per annum.

Based on soil analyses and recommendations Glenside Organics Ltd, calcium limestone was applied to organically managed half-plots in 2000 to restore soil pH to 6.5. Consistent with previous practice, magnesium limestone was applied to the conventionally managed half-plots plots in Spring 2000 and 2002.

3.3 Assessments

Herbage yield

Simulating typical grazing and cutting management on inbye fields, herbage yield was assessed by mowing four or five times depending on the growing season. Mown herbage was removed from the entire plot at each assessment. A sub-sample of each mown strip was taken for dry matter determination, and total dry matter yield per hectare calculated. Total organic dry matter yield was calculated taking into account herbage ash content.

Botanical composition

At each harvest date, botanical composition was assessed on each sub-plot by pre-cutting a strip within the area to be mown, and hand sorting into grass, clover and weeds. The percentage of each component present was calculated on a dry matter basis following oven drying.

Chemical composition of forage

A sample of dried herbage, bulked for each main and sub-treatment, was sent for laboratory analysis. For each harvest date, data was obtained for crude protein (CP), digestibility (NCDG), total ash, total P, and total K content.

Soil nutrient status

At the end of each grazing season, 5 samples of soil were taken to a depth of 0-7.5 cm from all 56 sub-plots, and analysed for extractable P, extractable K, extractable Mg, pH, organic matter, total nitrogen, nitrate-N, ammonium-N.

Soil microbiological activity

In early June 2001, the experimental plots were assessed in situ for CO_2 emission, using a hand-held Infrared Gas Analyser. A week later, soil samples were taken and sent for laboratory analysis of microbial biomass nitrogen, using a chloroform fumication and solvent extraction technique.

4.0 Results

4.1 Effect of manure treatment

Slurry aeration

Results for chemical composition are based on a total of 22 samples for each slurry type. Data from a further 8 samples have not been included, due to prolonged storage resulting from the Foot and Mouth Disease outbreak in 2001. Differences in composition (Table 1) between aerated and unaerated slurry varied considerably between batches. However, gross changes following aeration were broadly predictable, notably a reduction in BOD and COD values, an increase in nitrate-N, and a reduction in ammonium-N.

Table 1. Effect of aerating cattle slurry on the mean change in chemical composition.

Parameter measured	Aerated	Unaerated	Effect of aeration (% change)
BOD - ATU 5 day (mg/l)	2289.5	3106.3	-26.3
Total solids (g/kg/DM)	57.6	56.1	2.8
Nitrate-N (mg/kg/DM)	25.4	22.8	11.8
Total N (g/kg/DM)	28.7	29.8	-3.7
P (mg/kg/DM)	4739.2	5053.3	-6.2
K (mg/kg/DM)	35399.5	37694.7	-6.1
COD (mg/l)	54171.9	59210.4	-8.5
Ammonium-N (mg/kg/DM)	11091.4	12987.9	-14.6

Composted Vs uncomposted FYM

At each application, chemical composition (Table 2) was determined from 4 samples taken from each manure type.

Table 2. Effect of composting cattle/sheep FYM on the mean change in chemical composition.

Parameter measured	Composted	Uncomposted	Effect of composting (% change)
Dry matter (%)	26.7	20.9	27.8
Nitrate N (mg/kg/DM)	233.2	42.3	451.9
Total N (g/kg/DM)	26.0	25.7	1.3
Total P (mg/kg/DM)	5737.5	4571.7	25.5
Total K (mg/kg/DM)	60816.7	22250.0	173.3
Organic C (%m/m)	21.8	24.1	-9.8
Ammonium N (mg/kg/DM)	1839.5	1838.8	0.0
C:N ratio	12.6	12.4	1.8

Although variable between batches, differences in chemical composition were broadly as expected. Composting FYM tended to increase dry matter, total nitrogen and nitrate-N content. Organic carbon content decreased. These changes have previously been noted by Shepherd *et al.* (1999).

Concentration of P and K could be due to composting, however all changes (including differences in nitrate) could be due the fact that comparison is made with a stacked manure left outside, uncovered for over a year, with significant potential for leaching losses.

4.2 Herbage yield

Across all treatments, mean dry matter yields (kg/ha) were 9,827, 10,028 and 9,412, for each of the three years respectively.

In terms of total dry matter, yield differences between the main manurial treatments were statistically significant (Table 3). However, there was no overall yield advantage from composting FYM or aerating slurry. However, composted FYM resulted in a better yield response per kg/total N applied (see section 4.7 – Nutrient input and output relationships)

As a sub-treatment, the effect of providing additional P and K from spring 2000 onwards, is also presented below. Overall, there was no statistically significant effect of additional P and K, although the interaction term *(p= 0.074)* approached statistical significance in 2001.

Table 3 Herbage total dry matter yield (kg/DM/ha)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	10205	10617	10448	10801	10437	9782	11113
B)	Untreated FYM	10300	10101	8966	9797	10405	9153	8780
C)	Aerated cattle slurry	10327	10706	9677	10166	11246	9660	9694
D)	Untreated cattle slurry	10460	11035	9677	10986	11085	9903	9451
E)	Conventional N	10435	9569	10425	9975	9164	10916	9935
F)	Zero control 1996-2000	8901	9079	8753	9545	8613	8885	8622
G)	Zero control 1997-2000	8158	9087	7941	9062	9111	8007	7875
	Sign: Main treatment	P<0.01	P<0.01	P<0.01		P < 0.01		P < 0.01
	Sub-treatment					P = 0.847		P = 0.511
	Interraction					P = 0.123		P= 0.074

Expressed as a percentage of the control treatment (Table 4), the use of ammonium nitrate increased organic dry matter yield by 5% - 31%. Slurry and FYM increased yields by 11% - 32%. Although plots treated with slurry and FYM tended to have higher herbage ash contents (see below), yield differences were consistent both for total dry matter, and total organic dry matter yield (i.e. excluding the potential contribution of ash to total yield).

Table 4. Dry matter yield, relative to the unfertilised control (% of control yield)

Treatment		Total dry matter			Total organic dry matter		
		1999	2000	2001	1999	2000	2001
A)	Composted FYM	125	117	132	123	115	130
B)	Untreated FYM	126	111	113	124	111	111
C)	Aerated cattle slurry	127	118	122	124	115	120
D)	Untreated cattle slurry	128	121	122	126	120	120
E)	Conventional N	128	105	131	130	106	132
F)	Zero control 1996/97/98/99;	109	100	110	107	99	110
G)	Zero control 1997/98/99;	100	100	100	100	100	100

4.3 Botanical composition

Clover content in the sward varied, both within and between seasons. As expected, the mean proportion of clover in the sward was significantly reduced by the application of soluble nitrogen fertiliser (Table 5).

Table 5. Mean clover and weed content (as a % of total dry matter)

Treatment		Mean clover %			Mean weed %		
		1999	2000	2001	1999	2000	2001
A)	Composted FYM	14.0	21.6	32.2	18.3	16.5	22.6
B)	Untreated FYM	9.0	8.5	16.5	17.8	21.7	26.3
C)	Aerated cattle slurry	10.8	12.5	20.7	16.4	22.9	25.5
D)	Untreated cattle slurry	13.5	16.3	26.5	11.4	15.0	21.9
E)	Conventional N	2.5	3.8	3.8	11.9	9.8	18.7
F)	Zero control 1996/97/98;	16.6	16.1	22.9	13.5	15.4	18.8
G)	Zero control 1997/98;	17.7	19.1	20.6	12.1	20.1	18.6
	Overall mean	12.0	14.0	20.5	14.5	17.3	21.8
	Statistical significance	P<0.01	P<0.001	P<0.001	N/S	P<0.01	N/S

Weed content (predominately buttercup and chickweed) increased progressively across all treatments, to a mean of approximately 22%. Weed content tended to be lowest where ammonium nitrate had been applied (reaching statistical significance in 2000), possibly due to greater competition from a heavily fertilised grass sward. There was no significant effect of supplementary P and K on sward clover or weed content.

4.4 Chemical composition of forage

Analyses of herbage for nutrient content were carried out on a bulked sample basis for main and sub-treatments. The data is therefore not suitable for statistical analysis, but has been used to calculate total offtake and nutrient balance data.

Nitrogen

Herbage N concentration tended to be highest following application of ammonium nitrate (Table 6). When cut at the same date, herbage digestability was generally lower than on the other main treatments, presumably due to a faster rate of herbage growth. Although differences were not always consistent, there was a tendency towards higher ash contents where FYM and slurry had been applied.

Table 6. Mean herbage N concentration, digestibility and ash content (%)

Treatment		N %			Digestibility (%)			Ash %		
		1999	2000	2001	1999	2000	2001	1999	2000	2001
A)	Composted FYM	2.40	2.52	2.98	71.5	74.7	72.0	13.7	10.6	12.7
B)	Untreated FYM	2.50	2.24	2.84	73.0	73.4	73.3	12.6	10.0	13.0
C)	Aerated cattle slurry	2.30	2.35	2.83	69.5	71.2	72.1	13.9	12.1	14.6
D)	Untreated cattle slurry	2.40	2.35	2.93	72.2	74.4	72.2	13.5	10.2	13.7
E)	Conventional N	2.40	2.83	3.33	69.2	72.5	69.5	11.7	8.7	13.3
F)	Zero control 1996-2000	2.30	2.56	2.88	71.1	73.6	72.7	13.5	9.0	12.4
G)	Zero control 1997-2000	2.50	2.56	2.95	74.8	75.2	73.4	10.8	8.2	12.2

Phosphorous

Herbage P levels were generally adequate. Treatment differences were small (Table 7). Little improvement in herbage P concentration was apparent, following the use of phosphate fertiliser.

Table 7. Herbage phosphorous content (%)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	0.40	0.39	0.40	0.39	0.38	0.40	0.41
B)	Untreated FYM	0.40	0.39	0.42	0.39	0.39	0.42	0.42
C)	Aerated cattle slurry	0.40	0.38	0.39	0.39	0.38	0.39	0.40
D)	Untreated cattle slurry	0.30	0.35	0.38	0.35	0.35	0.37	0.39
E)	Conventional N	0.30	0.38	0.36	0.39	0.37	0.36	0.35
F)	Zero control 1996-2000	0.30	0.36	0.36	0.36	0.36	0.36	0.36
G)	Zero control 1997-2000	0.40	0.37	0.38	0.36	0.38	0.37	0.39

<u>Potassium</u>

The use of slurry and FYM alone maintained herbage K at acceptable levels (Table 8). Furthermore, there was little apparent response to the additional rock-based potash fertiliser applied to these treatments in 2000.

The conventionally managed plots initially had very low herbage K levels, which responded to the addition of muriate of potash in 2000 and 2001. However, herbage K levels in 2001, at just over 2% by dry matter, were still marginal by conventional standards.

On the zero N control plots (treatments F and G), herbage K was consistently below optimum levels. No benefit was seen in herbage K content from the single application of Highland Slag and Seagreen K fertiliser made in spring 2000.

Table 8. Herbage potassium content (%)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	2.60	2.45	2.64	2.40	2.51	2.66	2.62
B)	Untreated FYM	2.60	2.71	2.61	2.71	2.71	2.61	2.61
C)	Aerated cattle slurry	2.50	2.71	2.57	2.74	2.69	2.57	2.58
D)	Untreated cattle slurry	2.50	2.46	2.40	2.48	2.43	2.38	2.43
E)	Conventional N	1.40	2.43	1.96	2.66	2.21	2.07	1.84
F)	Zero control 1996-2000	1.70	1.62	1.45	1.62	1.62	1.45	1.45
G)	Zero control 1997-2000	1.80	1.65	1.48	1.48	1.81	1.49	1.46

4.5 Nutrient uptake

Nutrient offtake was calculated from dry matter yield of individual plots and nutrient concentrations from bulked samples.

<u>Nitrogen</u>

Through a combination of higher yield and higher N concentration in the harvested material, greatest uptake of N in the crop occurred in the conventional treatment (Table 9). Uptake by the growing crop was consistently higher following the use composted FYM relative to stacked FYM. There was no consistent effect of applying additional P and K on herbage N uptake.

Table 9. Nitrogen uptake in herbage (kg/ha)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	208	231	281	247	215	257	304
B)	Untreated FYM	195	193	228	188	197	232	225
C)	Aerated cattle slurry	203	226	254	218	235	257	251
D)	Untreated cattle slurry	202	218	256	211	225	255	257
E)	Conventional N	227	229	326	236	221	340	312
F)	Zero control 1996-2000	168	203	238	216	190	242	234
G)	Zero control 1997-2000	172	203	210	203	203	208	212
	Sign: Main treatment	P<0.001	P<0.001	P<0.001	P < 0.05		P < 0.001	
	Sub-treatment	N/A	N/A	N/A	P = 0.202		P = 0.920	
	Interraction	N/A	N/A	N/A	P < 0.01		P= 0.077	

Phosphorous

Lower yields reduced P uptake on the zero N treatments (Table 10). Uptakes were generally higher on the slurry and FYM treatments, than where ammonium nitrate was applied.

Table 10. Phosphorous uptake in herbage (kg/ha)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	36	37	40	39	36	37	43
B)	Untreated FYM	37	34	35	33	34	36	35
C)	Aerated cattle slurry	36	37	38	36	39	37	38
D)	Untreated cattle slurry	33	35	36	34	35	36	35
E)	Conventional N	29	31	36	33	30	39	34
F)	Zero control 1996-2000	26	29	31	31	27	32	31
G)	Zero control 1997-2000	28	30	29	29	32	28	29
	Sign: Main treatment	P<0.001	P<0.001	P<0.001		P < 0.001		P < 0.001
	Sub-treatment	N/A	N/A	N/A		P = 0.964		P = 0.921
	Interraction	N/A	N/A	N/A		P < 0.05		P= 0.051

Although the overall effect of supplying additional P and K was not statistically significant, there were significant interactions, notably an improvement in uptake here additional nutrients had been added to the conventionally managed plots.

Potassium

Treatment differences in K uptake were more striking (Table 11). Uptakes were lower on the conventional treatment, and particularly on the zero N control plots, due to a combination of lower yield and lower herbage concentration. Potassium uptake on the conventional plots showed marked improvement when muriate of potash was applied.

Table 11 Potassium uptake in herbage (kg/ha)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	274	264	281	263	266	263	299
B)	Untreated FYM	278	247	241	240	253	246	237
C)	Aerated cattle slurry	268	295	265	282	307	268	261
D)	Untreated cattle slurry	264	264	237	263	265	244	230
E)	Conventional N	136	201	206	222	179	232	180
F)	Zero control 1996-2000	153	140	131	146	134	133	129
G)	Zero control 1997-2000	141	155	115	133	178	120	111
	Sign: Main treatment	P<0.001	P<0.001	P<0.001		P < 0.001		P < 0.001
	Sub-treatment					P = 0.565		P = 0.145
	Interraction					P = 0.158		P < 0.05

4.6 Soil nutrient status

Soil organic matter

As expected, soil organic matter content was higher on plots receiving slurry and FYM (Table 12). However, there was considerable between-year variation in soil organic matter content, as determined by the results of laboratory analysis.

Table 12 Soil organic matter (%)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	4.53	4.49	5.82	4.46	4.52	5.59	6.06
B)	Untreated FYM	4.60	4.33	5.73	4.32	4.35	5.98	5.48
C)	Aerated cattle slurry	4.65	4.23	5.03	4.24	4.22	5.28	4.79
D)	Untreated cattle slurry	4.35	4.02	5.20	3.99	4.05	5.26	5.14
E)	Conventional N	4.15	4.03	4.61	4.02	4.05	4.68	4.55
F)	Zero control 1996-2000	4.35	3.94	4.68	3.84	4.04	4.73	4.63
G)	Zero control 1997-2000	4.38	4.04	4.96	3.98	4.10	5.33	4.58
	Sign: Main treatment	P<0.05	P<0.05	P<0.001		P<0.05		P<0.001
	Sub-treatment					P=0.363		P=0.129
	Interraction					P=0.990		P=0.429

Soil pH

On a mineral soil, a pH of 6.0 is considered adequate for grass production. In this experiment, the use of ammonium nitrate significantly increased soil acidity (Table 13). Although the addition of lime in 2000 increased soil pH to acceptable levels, the effect was relatively short lived. On the organic treatments given Ca lime in 2000, soil pH increased further in 2001. Without additional lime, pH on the organically managed plots declined gradually towards a pH of 6.

Table 13 Soil pH

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	6.6	6.5	6.4	6.6	6.4	6.7	6.2
B)	Untreated FYM	6.6	6.5	6.4	6.6	6.4	6.8	6.1
C)	Aerated cattle slurry	6.5	6.5	6.5	6.7	6.3	6.8	6.2
D)	Untreated cattle slurry	6.7	6.5	6.4	6.6	6.5	6.7	6.2
E)	Conventional N	6.2	5.8	5.6	6.0	5.6	5.6	5.6
F)	Zero control 1996-2000	6.5	6.5	6.4	6.5	6.5	6.6	6.2
G)	Zero control 1997-2000	6.5	6.5	6.5	6.5	6.5	6.8	6.1
	Sign: Main treatment	P<0.001	P<0.001	P<0.001		P<0.001		P<0.001
	Sub-treatment					P < 0.01		P<0.001
	Interraction					P = 0.35		P < 0.05

Soil phosphorous

The levels of soil P obtained (Soil Index 1-2), would not be considered limiting for grass growth (Table 14). Although soil P had fallen on the conventionally managed area, levels were restored by the addition of Super Phosphate fertiliser.

Table 14 Soil extractable phosphorous (mg/l)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	17	20	19	20	20	20	18
B)	Untreated FYM	21	21	19	21	22	21	18
C)	Aerated cattle slurry	16	16	16	15	17	16	17
D)	Untreated cattle slurry	15	16	15	16	16	15	14
E)	Conventional N	10	14	14	13	14	17	12
F)	Zero control 1996-2000	13	13	12	14	13	12	11
G)	Zero control 1997-2000	13	12	11	12	12	12	11
	Sign: Main treatment	P<0.001	P<0.001	P<0.001		P < 0.001		P < 0.001
	Sub-treatment					P = 0.611		P< 0.01
	Interraction					P= 0.957		P< 0.05

Soil potassium

Soil levels of extractable K, generally at soil Index 0, were below optimum levels for grass growth. Soil K was significantly reduced on the conventional and zero N treatments (Table 14).

Despite annual inputs of muriate of potash, and an improvement in herbage K content, soil K status on the conventionally managed plots had not increased by the end of the grazing season.

Organically managed plots showed no improvement in soil potassium levels following the application of Highland Slag and Seagreen K in spring 2000.

Table 15. Soil extractable potassium (mg/l)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	92	67	79	73	61	82	76
B)	Untreated FYM	105	86	83	79	94	90	76
C)	Aerated cattle slurry	94	78	82	83	74	82	82
D)	Untreated cattle slurry	71	63	70	57	69	81	60
E)	Conventional N	52	61	58	54	69	69	46
F)	Zero control 1996-2000	60	50	49	48	52	48	50
G)	Zero control 1997-2000	61	49	53	45	53	42	63
	Sign: Main treatment	P<0.001	P<0.01	P<0.001		P = 0.01		P < 0.001
	Sub-treatment	N/A	N/A	N/A		P = 0.257		P = 0.121
	Interraction	N/A	N/A	N/A		P= 0.516		P= 0.06

<u>Other soil parameters</u>

Conventionally managed plots had significantly lower soil magnesium levels (Table 16).

Table 16. Soil extractable magnesium (mg/l)

Treatment		Overall			2000		2001	
		1999	2000	2001	+ P & K	- P & K	+ P & K	- P & K
A)	Composted FYM	230	225	233	206	245	211	255
B)	Untreated FYM	210	234	238	229	239	235	240
C)	Aerated cattle slurry	222	228	219	241	215	218	220
D)	Untreated cattle slurry	229	233	223	238	228	223	224
E)	Conventional N	181	163	164	183	143	160	168
F)	Zero control 1996-2000	225	214	213	213	215	196	231
G)	Zero control 1997-2000	225	222	213	211	233	191	236
	Sign: Main treatment	P= 0.05	P=0.001	P<0.001		P < 0.001		P < 0.001
	Sub-treatment					P = 0.948		P = 0.007
	Interraction					P= 0.05		P= 0.278

There were no consistent treatment differences in soil NO_3-N , NH_4-N, or N% contents.

4.7 Nutrient input and output relationships

<u>Nitrogen</u>

Within the experiment, N will be available for grass growth from short and medium term manure/fertiliser application, clover fixation, and atmospheric deposition. Approximately 30% of total nitrogen applied as FYM may be readily available for plant growth.

Calculated total N application rates from samples taken at application were 109%, 125%, 93% and 97% of target for treatments A to D respectively. Based on these application rates, a calculation of N inputs from manures/fertiliser versus outputs in herbage was made over the three years of the experiment (Table 15).

Table 17. Calculated nitrogen balance (crop offtake, less manure and fertilser inputs) for each treatment over three years, and input as a percentage of crop offtake.

Treatment	Supplementary P and K				No additional P and K			
	Input	Offtake	Balance	%	Input	Offtake	Balance	%
A) Composted FYM	394	712	-318	55	394	727	-333	54
B) Untreated FYM	564	615	-51	92	564	617	-83	91
C) Aerated cattle slurry	420	678	-259	62	420	689	-269	61
D) Untreated cattle slurry	435	668	-233	65	435	684	-249	64
E) Conventional N	720	803	-83	90	720	760	-40	95
F) Zero control 1996-2000	0	626	-626	0	0	592	-592	0
G) Zero control 1997-2000	0	583	-583	0	0	587	-587	0

If it is assumed that atmospheric deposition is equivalent to approximately 50 kg/N/ha, clover N fixation per hectare on the control plots can be estimated to be approximately 144 kg – 159 kg.

Where slurry and FYM were applied, the total N contribution from manures varied from 54% to 92% of offtake. However at the levels of sward clover content recorded on these treatments, significant additional N could also have been made available through fixation (Kristensen *et al*, 1995).

On the conventionally managed plots, mean clover content was less than 5%, and fixation could be expected to be less than 20 kg/N/ha (Kopke, 1995). The total amount of N removed as harvested crop was almost exactly equivalent to that applied in soluble form as ammonium nitrate. Presumably there was a further trade off between net atmospheric input, and leaching losses to groundwater.

<u>Phosphorous</u>

Where FYM and slurry only had been used, total supplies of P were reasonably balanced at 67% - 90% of offtake (Table 18). This ratio improved further following the use of Highland Slag. However, for organically approved rock sources of P and K, the levels of readily available nutrients are a relatively small proportion of total nutrient content. Super phosphate supplied 75% of the P removed in the conventional treatment.

Table 18. Total phosphorous input as a percentage of total offtake (kg/ha equiv.)

Treatment	Supplementary P and K				No additional P and K			
	Input	Offtake	Balance	%	Input	Offtake	Balance	%
A) Composted FYM	90	112	-22	81	90	116	-26	78
B) Untreated FYM	95	105	-10	90	95	106	-11	90
C) Aerated cattle slurry	126	109	17	115	76	113	-37	67
D) Untreated cattle slurry	122	102	20	119	76	103	-27	74
E) Conventional N	75	100	-25	75	0	92	-92	0
F) Zero control 1996-2000	57	89	-32	64	0	84	-84	0
G) Zero control 1997-2000	53	84	-31	63	0	89	-89	0

Potassium

Where livestock manures were used only, the proportion of K supplied relative to that removed in the crop was very consistent at 60% to 67% (Table 19).

Table 19 Total potassium input as a percentage of total offtake (kg/ha equiv.)

Treatment	Supplementary P and K				No additional P and K			
	Input	Offtake	Balance	%	Input	Offtake	Balance	%
A) Composted FYM	588	800	-212	74	551	839	-288	66
B) Untreated FYM	499	764	-265	65	461	768	-307	60
C) Aerated cattle slurry	572	818	-246	70	502	836	-334	60
D) Untreated cattle slurry	578	771	-193	75	509	759	-250	67
E) Conventional N	477	590	-113	81	0	495	-495	0
F) Zero control 1996-2000	81	432	-351	19	0	416	-416	0
G) Zero control 1997-2000	75	394	-319	19	0	430	-430	0

When additional potash was applied, the proportion improved marginally, but there was still a shortfall of 25% - 30% above that supplied from slurry and FYM.

Despite heavy applications of muriate of potash, inputs to the conventional treatment were still only 81% of the potassium removed, which confirms the lack of any improvement in soil potassium levels.

A figure of 19% K supplied relative to offtake on the zero control treatments, underlines the relatively low amount of total nutrient supplied by these rock sources of P and K, at the rates of application recommended. Furthermore, the balances above calculate absolute amounts, and do not take any account of the availability of these nutrients for plant growth.

4.8 Soil microbiological activity

An estimate was made of soil microbiological activity from spot measurements of CO_2 respiration measured in the field in June 01, and from soil samples taken for laboratory analysis, to determine soil biomass nitrogen (Table 20).

Table 20 Soil biological activity – CO_2 respiration, and soil biomass N.

Treatment	CO_2 Respiration g/m^2/ha	Biomass N (µg/g/DM)
A) Composted FYM	1.195	121.2
B) Untreated FYM	1.242	127.7
C) Aerated cattle slurry	1.170	133.8
D) Untreated cattle slurry	0.985	133.3
E) Conventional N	1.042	100.0
F) Zero control 1996-2000	1.130	116.0
G) Zero control 1997-2000	1.202	116.7
Sign.	P= 0.538	P < 0.05

It is recognised that the CO_2 technique is subject to greater variation in a grass sward, even when closely cropped before measurements are taken, relative to bare soil.

Treatment differences in CO_2 respiration were not statistically different. However, it may be worth noting that the lowest readings were obtained from the soluble N and untreated slurry treatments. In addition, the soil reaction to organic amendments is generally one of a flush of activity in the immediate post-application period rather than a sustained increase in activity over the longer term. The soil was assessed 3 months after the last application of organic material. Therefore any increase may have subsided to background levels by the time the measurements were taken.

Soil biomass nitrogen was significantly reduced ($P < 0.05$) on the conventional nitrogen treatments, which may reflect greater microbial activity on the organically managed plots.

5.0 Summary and Conclusions

Overall, the results indicate that high clover swards and the return of major nutrients in slurry and FYM can support a high level of productivity from an organically managed pasture, without the requirement for exogenous fertiliser inputs.

Where plots were managed without any N input, the contribution of clover to N fixation was approximately 150 kg N/ha/annum, which is consistent with previous data from conventional experiments with grass/clover swards. However, in the current experiment, this level of output was achieved at theoretically sub-optimal levels of soil potassium.

A concern often expressed about organic farming is that the system will mine nutrients such as P and K so that productivity is maintained in the short-term, but will ultimately be unsustainable without additional fertiliser inputs.

Through an exacting regime of harvest and crop removal, the current experiment has deliberately depleted the originally very high levels of potash existing on the site at the time of conversion. The experiment has therefore been able to test at the limits of what is conventionally considered acceptable, notably for soil potash levels. Data collected under this challenging system of management indicates how difficult it is to maintain production and soil nutrient status even with high levels of soluble fertilisers.

Reliance on clover and FYM or slurry, enabled good levels of output to be achieved while maintaining a better balance of soil nutrients, soil pH and soil organic matter content. The application of high levels of soluble fertiliser increased organic dry matter yield by an average of only 19% (range 6% – 32%). FYM and slurry increased yield by 11% - 30%, narrowing the gap in output between a highly fertilised conventional sward and an organic system relying on the return of animal manures.

A key question is whether the organically managed plots performed particularly well, or the conventional treatment was compromised by low potash levels and declining soil pH.

The results raise interesting questions regarding the progressive changes in nutrient dynamics in organic soils over time. Evidence was provided to suggest that soil microbial activity was reduced by soluble fertiliser treatments, or enhanced where additional organic matter was provided from livestock manures. Furthermore, no analyses of trace elements or other micro-nutrients were undertaken in this experiment, inputs of which would not occur solely through the use of conventional, soluble, N, P and K fertilisers.

There was little to indicate any agronomic advantage from aerating slurry. Composted FYM, gave a better yield reponse per kg of total N applied than stacked material. However, an improved mean response from the composted compared to untreated FYM, may simply be a reflection of relative points on the response curve to total added N.

The information generated on nutrient cycling, on output and other measures of productivity raises questions as to the optimum level of soil nutrients required for organic production. Recommendations need to be refined for organic systems, taking account of nutrient losses to the environment, offtake as crop or animal products, and appropriate systems of measuring nutrient availability. The balance of crop offtake from more modest yields, with nutrients released from the soil, may dictate that high levels of extractable nutrients in the soil may not be a prerequisite for good performance from an organic system.

6.0 Policy relevance

This work confirms the value of replicated medium to long-term studies, involving organic and conventional management systems, in order to compare long-term effects on nutrient cycling and overall sustainability.

The data supports the development of integrated decision support tools such as MANNER to improve the utilisation of livestock wastes on organic farms.

7.0 Future work

Additional, longer-term research work is required in organic systems to test the role of soil processes in nutrient dynamics. Research to clarify the optimum level of soil fertility, to be maintained by appropriate manuring and husbandry strategies, would be valuable to increase efficiency, reduce pollution and improve the sustainability of organic farming. The interactive effect of organic farming and soil microbiology may be considered appropriate for further research.

From the results of this experiment, aerating slurry appears to have little to commend it’s use on UK organic farms. However, further work should be considered on-farm composting to develop practical composting techniques, quantify energy input, cost, environmental impact and potential benefits at soil level.

Further information is required on the most appropriate laboratory analyses and indicators of soil fertility for use in organic farming systems.

A significant amount of data has already been generated within the experiment which could be used to verify existing, and new, nutrient flow models. Although funding for the experiment ceased on 31 March 02, it is intended to maintain the plots and manurial treatments in the short-term, as a potential resource for further studies by ADAS or other contractors. This is consistent with DEFRA’s aim to encourage greater use of existing organic systems studies by a wider range of contractors and research consortia.

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