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Nitrogen value of poultry litter applications to root crops and following cereal crops

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SUMMARY

The efficiency of poultry litter nitrogen (N) utilization was studied in seven field experiments in eastern England during harvest years 1991 to 1994. Poultry litter was applied at different application rates in winter or spring, prior to sugar beet or potatoes. The mean manure N efficiency based on crop yields was 33% (range 25–43%) for sugar beet and 36% (range 13–66%) for potatoes. For potatoes, the manure N efficiency was greater from spring (mean 43%) than from winter application timings (mean 30%). The manure readily available N applied (i.e. ammonium-N + uric acid-N) and fertilizer N replacement values were well related ($P < 0{\cdot}05$) for both sugar beet and potatoes. Similarly, there was a good relationship ($P < 0{\cdot}001$) between the amounts of readily available N applied in the poultry litter dressings and measured elevations in spring soil mineral N supply. Where the poultry litter dressings supplied > 600 kg/ha total N to sugar beet, root sugar concentrations were depressed ($P < 0{\cdot}05$) and amino-N concentrations increased ($P < 0{\cdot}01$). The soil mineral N supply following harvest of the sugar beet and potato crops was also increased where application rates supplied > 600 kg/ha total N. Yield increases were also recorded in cereal crops grown the following season, but only where high rates of manure N (> 600 kg/ha) had been applied. The current work has shown that the fertilizer N replacement value of poultry litter can be predicted based on the amounts of total and readily available N applied, providing guidance to farmers on appropriate reductions in inorganic fertilizer N applications to make allowance for poultry litter N supply.

INTRODUCTION

Organic manures have traditionally been applied to improve the fertility of soils. However, in more recent decades readily available and relatively cheap inorganic fertilizers have come to dominate farm nutrient management practices in the UK. This change, coupled with the increased intensification of livestock production, has encouraged many farmers to regard the land application of organic manures as a 'waste' disposal practice, rather than as a method of recycling valuable crop nutrients. Moreover, it is difficult for farmers to assess the crop available nitrogen (N) supply from organic manures and their perception of its value is poor (Smith & Chambers 1995). Data from the Survey of Fertiliser Practice (Chalmers *et al.* 2000) suggest that only small and inconsistent reductions in inorganic fertilizer N applications are made following the application of organic manures, despite the fact that discounting or ignoring the manure N contribution to crop requirements can have negative effects on crop yields and quality (Hayward *et al.* 1993). Even modest improvements in the allowance made for N availability from organic manures could result in major cost savings for the farmer, by reducing the requirement for inorganic fertilizer N and also reduce the risks of environmental pollution.

Around 4·4 million tonnes of poultry manure are produced annually in the UK, of which *c.* 2·5 million tonnes are from broiler and turkey units (Chambers & Smith 1998). Broiler and turkey litter is normally in the form of excreta mixed with bedding material (generally wood shavings or straw) and has a dry matter content of *c.* 60%. The typical nitrogen content (MAFF 2000) of poultry litter is about twice as high (30 kg/t fresh weight) as laying hen manure (16 kg/t fresh weight), with an estimated 100 000 tonnes of N applied in poultry manure to agricultural land annually.

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Table 1. *Location, soil type and cropping at each experimental site*

	Brandon 1991	Brandon 1992	Freckenham	Ripon	Asenby	Crowle	Elveden
Site location (county)	Suffolk	Suffolk	Suffolk	Yorkshire	Yorkshire	Yorkshire	Suffolk
Soil texture							
Top soil	Sandy loam	Sandy loam	Loamy sand	Sandy loam	Sandy loam	Loamy sand	Loamy sand
Subsoil	Clay loam	Clay loam	Sand	Sandy clay loam	Sandy loam	Loamy sand	Sand
Soil Association*	Methwold	Methwold	Newport	Escrick 2	Wick	Newport	Worlington
Root crop							
Season	1990–91	1991–92	1992–93	1990–91	1991–92	1992–93	1993–94
Crop	Sugar beet	Sugar beet	Sugar beet	Potatoes	Potatoes	Potatoes	Potatoes
Cereal crop (residual effects)							
Season	1991–92	1992–93	ND	1991–92	1992–93	1993–94	ND
Crop	Spring wheat	Spring wheat	ND	Winter wheat	Spring wheat	Winter barley	ND

* Soil Survey of England and Wales (SSEW 1983).
ND, residual effects of poultry litter applications not studied.

Previous studies in England (Chambers *et al.* 1994) showed that the efficiency of N utilization from poultry manures (broiler litter and laying hen manure) applied as a topdressing to growing cereal crops in spring was 34 % (range 21–55 %) relative to inorganic fertilizer N. The fertilizer N replacement value of the poultry manures was closely related to the quantities of readily available N (i.e. ammonium-N + uric acid-N) applied. N efficiency for the autumn – early winter applications ranged from 20 to 46 %, with the lower efficiencies associated with higher over-winter rainfall volumes and hence greater N losses through nitrate leaching.

Root crops are also an important outlet for poultry manure applications to land. Between 1992 and 1995 in England and Wales, an estimated 7·6 % of the sugar beet cropping area (*c.* 15 000 ha) and 6·6 % of main-crop potatoes (*c.* 6000 ha) received poultry manure applications (A. Chalmers, *pers. comm.*). However, little is known about the efficiency of N utilization from poultry manures applied to root crops, how this is affected by application timing and residual N effects on following cereal crops.

The objective of the present study was to evaluate the efficiency of N utilization from poultry manure (broiler and turkey litter) applications in winter and spring, prior to sugar beet and potatoes. As nitrogen release from a single manure application can extend over several years, residual effects on cereal yields were examined in the second cropping season following manure application.

MATERIALS AND METHODS

Seven experiments (three on sugar beet and four on potatoes) were undertaken in eastern England during harvest years 1991 to 1994. Details of the experimental sites and their cropping management are given in Table 1.

Experiment design

Poultry litter was applied at three rates in either winter (November–early January) or spring (late January–March) prior to drilling sugar beet or planting potatoes (Table 2). At each site, inorganic fertilizer N was also applied in spring at a range of rates to separate plots, to create a fertilizer N response curve (0–210 kg N/ha on sugar beet and 0–360 kg N/ha on potatoes). All the manure and inorganic fertilizer N treatments were applied by hand. Following application, the manures were incorporated into the soil using a plough or cultivator, usually within 48 h (Table 2).

The plot sizes were 5 × 18 m for the sugar beet experiments and 3·7 × 12 m for the potato experiments. In all the experiments, there were three replicates of each manure, inorganic fertilizer N and nil N control treatments, arranged in a randomized block design.

At five of the seven sites (excluding Freckenham and Elveden), the residual effects of the poultry litter treatments on following cereal crop grain yields and N uptake were studied. Details of the cereal crops grown are given in Table 1. In these years, inorganic fertilizer N was not applied to any of the manure or previous inorganic fertilizer N treatments, but was applied to one of the two nil N control treatments at the optimum recommended rate (MAFF 2000).

Sampling and analysis

At each site a local source of poultry litter was used. Between winter and spring applications, the litter was

Table 2. *Poultry litter application dates, speed of litter incorporation, effective rainfall and application rates*

	Autumn/winter application						Spring application					
Experiment site	Application date	Speed of incorporation	Effective rainfall* (mm)	Application rate (t/ha)	Total N (kg/ha)	Readily available N† (kg/ha)	Application date	Speed of incorporation	Effective rainfall (mm)	Application rate (t/ha)	Total N (kg/ha)	Readily available N (kg/ha)
Brandon 1991 (sugar beet)	12 Dec 90	10 days	86	3·9	123	54	6 Mar 91	14 days	32	3·3	100	58
				7·9	246	109				6·6	201	117
				19·7	615	272				16·7	502	293
Brandon 1992 (sugar beet)	7 Jan 92	6 h	92	4·4	150	59	3 Mar 92	6 h	56	4·4	158	55
				8·8	301	119				8·8	317	109
				21·9	753	298				21·9	793	274
Freckenham (sugar beet)	12 Nov 92	6 h	157	1·6	59	25	25 Jan 93	6 h	31	1·6	51	20
				3·3	118	50				3·3	101	40
				6·5	237	100				6·5	202	79
Ripon (potatoes)	18 Oct 90	<48 h	274	8·5	200	76‡	9 Apr 91	<48 h	0	16·7	174	32
				17·0	400	152‡				33·4	348	63
				42·6	1000	380‡				83·5	871	159
Asenby (potatoes)	27 Nov 91	<48 h	144	9·5	219	102	19 Mar 92	<48 h	40	8·5	273	118
				19·0	438	203				16·6	546	234
				47·5	1096	508				41·5	1332	572
Crowle (potatoes)	19 Jan 92	<48 h	111	8·3	177	41	11 Mar 93	<48 h	0	8·5	170	25
				16·7	355	81				16·9	338	49
				41·6	887	205				42·3	846	123
Elveden (potatoes)	28 Feb 93	<3 h	81	4·2	135	61	30 Mar 94	<3 h	47	4·2	160	69
				8·4	271	123				8·4	320	139
				20·9	679	307				20·9	800	346

* Effective rainfall = rainfall − evapotranspiration between manure application and end of drainage.

† Readily available N = ammonium-N + uric acid-N.

‡ Uric acid-N was not measured at Ripon. Readily available N was estimated at 38 % of total N applied (see Table 3).

stored under polythene sheeting in order to minimize differences in manure composition, and to restrict nitrogen losses through ammonia volatilization and leaching during storage. Representative samples of manure were taken immediately prior to spreading and analysed for dry matter (DM), pH, organic carbon (OC), total N, ammonium-N and uric acid-N.

Soil from selected treatments was sampled at four depths (0–15, 15–30, 30–60 and 60–90 cm) in the spring prior to drilling sugar beet or planting potatoes, and in the autumn following harvest. The soil samples were analysed for nitrate-N and ammonium-N, and the results used to calculate the soil mineral nitrogen (SMN) content to a depth of 90 cm, assuming a soil bulk density of 1·33 g/cm^3.

At sugar beet harvest, samples of roots and tops were weighed to determine the total fresh weight yield, and analysed for dry matter and total N, and samples of the roots for amino-N and sugar content. At potato harvest, total and ware yields (40–85 mm size fraction) were determined, and samples of the tubers analysed for dry matter and total N.

All analyses were undertaken using standard analytical techniques (MAFF 1986).

Crop husbandry and harvesting

All sites had satisfactory soil pH and nutrient (phosphorus, potassium and magnesium) levels. Where required to ensure unrestricted crop growth, recommended rates of nutrients (except nitrogen) and other crop management inputs (herbicides, fungicides, insecticides) were applied uniformly to all treatments.

Sugar beet and potato harvesting was carried out by hand (12·6 m^2 harvest area for sugar beet; 15·2 m^2 harvest area for potatoes using three central beds with a discard bed at each side of each plot), and cereal harvesting using a small plot combine (31 m^2).

Calculation of effective rainfall

The effective rainfall (rainfall minus evapotranspiration) between manure application and the end of drainage was calculated for each site. All calculations were undertaken using the Meteorological Office Rainfall and Evaporation Calculation System (MORECS 1991).

Calculation of the efficiency of poultry manure N utilization and optimum inorganic fertilizer N rates

The nitrogen efficiency of the poultry litter applications prior to sugar beet and potatoes was calculated by interpolation from 'fitted' inorganic fertilizer N response curves (Sylvester-Bradley *et al.* 1984) using a linear plus exponential model in the absence of manure, using the yield produced on the manure-only treatment. This is the standard method used to calculate the fertilizer N replacement value of manures (Pain *et al.* 1986; Chambers *et al.* 1994; Nicholson *et al.* 1999). Fitted inorganic fertilizer N response curves were produced using crop yield (clean beet yield adjusted to 16% sugar for sugar beet; ware yield at 85% dry matter for potatoes) and N offtake data at harvest. N efficiencies could not be calculated where crop yields or N offtake on the poultry manure treatments were close to the levels recorded with the highest inorganic fertilizer N rate.

Optimum economic N application rates were calculated based on adjusted clean beet yields (16% sugar) and potato ware yields (Sylvester-Bradley *et al.* 1984), using a break-even price ratio for sugar beet of 30 kg roots per kg fertilizer N and 3·5 kg ware potatoes per kg fertilizer N. Apparent N recoveries were calculated on each poultry litter treatment by subtracting crop N uptake on the untreated control from the manure treatment, divided by the total N applied.

RESULTS

Poultry litter composition

The composition of the poultry litters used in the experiments was broadly similar at all sites. Mean values were 590 g DM/kg, 29 kg total N/t fresh weight, 7·6 kg ammonium-N/t fresh weight, 4·2 kg uric acid-N/t fresh weight and a C:N ratio of 7:1 (Table 3). The readily available N (ammonium-N + uric acid-N) content of the litters was on average 38% of the total N content.

Yield response to inorganic fertilizer nitrogen

The sugar beet crops at Brandon (1991) and Brandon (1992) only responded to low rates of inorganic fertilizer N. Optimum economic rates of inorganic fertilizer N were 65 kg/ha at Brandon in 1991 and 79 kg/ha N at Brandon in 1992, compared with 140 kg/ha at Freckenham in 1993 (Table 4). For potatoes at Ripon and Elveden, the optimum rate of N was above the maximum rate tested during the experiments (360 kg N/ha), whilst at Crowle, the rate was much lower at 158 kg/ha (Table 4).

Soil mineral N

Where the manures were rapidly incorporated into the soil within 48 h (all sites except Brandon in 1991), increases in spring SMN following the poultry litter applications were related (slope = 1·20, $r^2 = 0·53$, $P < 0·001$) to the quantity of readily available N applied in the poultry litters (Fig. 1).

Efficiency of poultry litter N utilization

Manure N efficiencies calculated on the basis of sugar beet crop yield could not be made for Brandon in 1991

Table 3. *Analysis of poultry litter samples used in the experiments and comparison with typical values*

Experimental site	Dry matter (g/kg)	pH	Total N	NH$_4$-N	Uric-acid N	Readily available N (% of total N)	C:N ratio
			(kg/t fresh weight)				
Brandon 1991							
Winter	543	6·5	31·2	9·0	4·8	44	6
Spring	555	8·9	30·7	6·9	11·0	58	6
Brandon 1992							
Winter	573	7·0	34·4	9·4	4·2	39	5
Spring	577	8·8	36·2	8·7	3·8	34	5
Freckenham							
Winter	606	7·1	36·3	9·4	5·9	42	4
Spring	580	7·8	31·2	9·1	3·1	39	5
Ripon							
Winter*	583	8·3	23·5	7·1	ND	38†	ND
Spring*	338	8·3	10·4	1·6	0·1	16	12
Asenby							
Winter	537	8·4	23·1	6·4	4·3	46	9
Spring	603	8·2	32·1	8·8	5·0	13	7
Crowle							
Winter	736	8·4	21·3	4·4	0·4	23	11
Spring	759	8·8	20·0	2·6	0·3	15	10
Elveden							
Winter	623	7·8	32·5	10·4	4·3	45	7
Spring	676	8·4	38·3	10·6	6·0	43	6
Mean	590	8·0	29·3	7·6	4·2	38	7
Broiler litter†	642	8·2	33	6	4	30	6
Turkey litter†	523	8·2	27	7	2	33	6

* Different sources of poultry litter were used for winter and spring applications.
† Estimated to be 38 % of total N (mean value).
ND, not determined.

and 1992, because the yields were close to or above the levels recorded at the highest rate of N fertilizer. However, N efficiency calculations based on N offtake at Brandon in 1991 varied between the treatments (mean value of 59 %; range 19–109 %), with N efficiency decreasing in relation to increasing N application rate (Table 5). At Freckenham, where the poultry litters were rapidly incorporated, the mean N efficiency based on yield was 33 % (range 25–43 %) and on the basis of N offtake 62 % (range 45–88 %). The mean N efficiency of poultry litter dressings to potatoes based on yields measured was 36 % (range 13–66 %; Table 5). There was no relationship ($P > 0·05$) between N efficiency and litter application rate.

Where potatoes were grown, there was an indication ($P > 0·05$) of greater N efficiencies from the spring applications (mean 43 %) than the autumn/winter applications (mean 30 %). At the sugar beet sites, there were no differences in N efficiencies based on crop N offtake ($P > 0·05$) between the winter (mean 62 %) and spring (mean 64 %) application timings.

Fertilizer N replacement value of poultry litter

There was a positive relationship (Fig. 2) between the readily available N applied in the poultry litters and the fertilizer N replacement values ($r^2 = 0·44$, $P < 0·05$).

Crop recovery of poultry litter N

The mean apparent recovery of poultry litter N by the sugar beet crop was 16 % at Brandon in 1991, 37 % at Brandon in 1992 and 53 % at Freckenham (Table 6). For potatoes, the mean apparent recovery of poultry litter N was lower at Crowle (mean 13 %) and Ripon (mean 16 %) than at Asenby (mean 22 %) and Elveden (mean 25 %) (Table 6). There were no differences ($P > 0·05$) in apparent N recovery between the winter and spring poultry litter applications at any of the sites.

Crop quality

At Brandon in 1991 and 1992, where > 600 kg/ha total N was applied in the poultry litter dressings, root sugar

Table 4. *Sugar beet and potato (ware) yield response to inorganic fertilizer nitrogen applications*

Site	Optimum N rate (kg/ha)	Yield at nil N rate (t/ha)	Yield at optimum N rate (t/ha)	Yield response to optimum N rate (t/ha)
Brandon 1991 (sugar beet)	65	79·7	86·0	6·3
Brandon 1992 (sugar beet)	79	78·0	87·4	9·4
Freckenham (sugar beet)	140	67·4	107·4	40·0
Ripon (potatoes)	>300	43·4	65·7	22·3
Asenby (potatoes)	253	51·3	68·6	17·3
Crowle (potatoes)	158	40·6	46·2	5·6
Elveden (potatoes)	>360	35·4	78·0	42·6

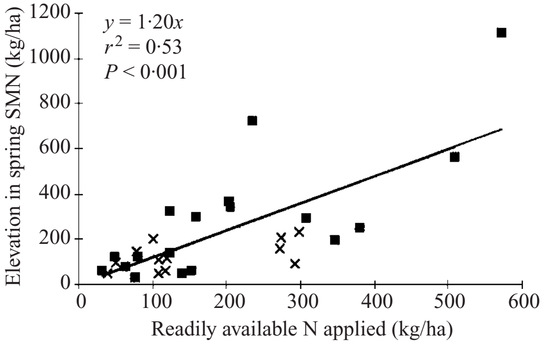

Fig. 1. Relationship between spring soil mineral nitrogen (SMN) and readily available N applied in poultry litters. ■ potatoes, × sugar beet.

concentrations were decreased ($P<0·05$) by *c.* 0·6 and *c.* 1·0%, respectively, compared with the application rates supplying 246 kg N/ha in 1991 and *c.* 310 kg N/ha in 1992 (Table 7). Similarly, root amino-N concentrations were elevated ($P<0·01$) by 97–127 mg/100 g sugar, compared with application rates close to that recommended in the MAFF Water Code (250 kg total N/ha). At Freckenham, the amount of N applied in the poultry litter was up to 237 kg N/ha and no differences ($P>0·05$) were measured in sugar or amino-N concentrations between the poultry litter treatments.

Potato tuber dry matter contents were often depressed ($P<0·05$) where poultry litter applications supplied >500 kg/ha total N (Table 7). The proportion of tubers in different size ranges (<45 mm, 45–65 mm, >85 mm) was generally not affected by the poultry manure applications (data not shown).

Response of following cereal crops

There was a good yield response to inorganic fertilizer N additions in the cereal crops grown following harvest of the sugar beet (data not presented). At Brandon in 1992, inorganic fertilizer N (200 kg/ha) applied to one of the previous nil N control treatments increased grain yields from 5·32 to 9·00 t/ha, and at Brandon in 1993 from 3·48 to 7·66 t/ha. At harvest at Brandon in 1992, grain yields were also increased ($P<0·001$) above the nil N control following the previous winter (7·30 t/ha) and spring (6·39 t/ha) poultry litter applications which supplied 615 and 502 kg/ha total N, respectively. Similarly, grain yields at Brandon in 1993 were also increased ($P<0·001$) above the control treatment following the previous winter (4·97 and 6·11 t/ha) and spring (5·68 t/ha) poultry litter applications supplying 301, 753 and 793 kg/ha total N, respectively. The amount of N recovered by the cereal crops ranged from 3 to 12% of the total N originally applied in the poultry litters (Table 6). This was consistent with the low levels of SMN following sugar beet harvest where <600 kg/ha total N was applied (SMN levels in the range 20–61 kg/ha), and the high efficiency of manure N recovery by the sugar beet crop.

Cereal yield responses to inorganic fertilizer N additions were lower after the potato crops (range 0–1·5 t/ha) than after sugar beet (range 3·7–4·2 t/ha). At Ripon, inorganic fertilizer N (200 kg/ha) applications to one of the previous nil N control treatments increased grain yields from 7·44 to 8·21 t/ha and at Asenby from 4·10 to 5·60 t/ha. The reason for the poor yield response was probably due to late drilling of the cereal crops after potato harvest. At Ripon, grain yields in 1992 were also increased ($P<0·05$) above the nil N control following the previous winter

Table 5. *Nitrogen efficiency of winter and spring poultry litter dressings based on crop yield and N offtake**

	Winter							Spring						
Site	Application rate (t/ha)	Adjusted clean beet yield/total ware yield (t/ha)	Total crop N offtake (kg/ha)	N efficiency based on yield (%)	Fertilizer N replacement based on yield (kg/ha)	N efficiency based on crop N offtake (%)	Fertilizer N replacement based on crop N offtake (kg/ha)	Application rate (t/ha)	Adjusted clean beet yield/total ware yield (t/ha)	Total crop N offtake (kg/ha)	N efficiency based on yield (%)	Fertilizer N replacement based on yield (kg/ha)	N efficiency based on crop N offtake (%)	Fertilizer N replacement based on crop N offtake (kg/ha)
Brandon 91 (sugar beet)	3·9	88	271	ND	ND	79	97	3·3	85	283	ND	ND	109	109
	7·9	86	281	ND	ND	44	107	6·6	89	262	ND	ND	44	89
	19·7	81	354	ND	ND	ND	ND	16·7	89	271	ND	ND	19	98
Brandon 92 (sugar beet)	4·4	89	231	ND	ND	71	106	4·4	99	253	ND	ND	82	130
	8·8	96	363	ND	ND	ND	ND	8·8	90	310	ND	ND	59	189
	21·9	86	418	ND	ND	ND	ND	21·9	86	399	ND	ND	ND	ND
Freckenham (sugar beet)	1·6	74	154	32	19	50	30	1·6	76	45	25	13	45	23
	3·3	93	183	43	51	51	61	3·3	104	88	ND	ND	88	89
	6·5	116	326	ND	ND	77	182	6·5	111	62	ND	ND	62	125
Ripon (potatoes)	8·5	48	133	22	44	18	36	16·7	48	140	24	42	25	44
	17·0	49	139	13	52	10	40	33·4	53	161	22	77	20	70
	42·6	60	208	21	210	14	140	83·5	62	232	ND	ND	20	174
Asenby (potatoes)	9·5	65	194	57	125	38	83	8·5	68	217	51	139	58	158
	19·0	68	219	39	171	26	114	16·6	65	234	27	147	37	202
	47·5	60	225	ND	ND	16	175	41·5	54	214	ND	ND	15	200
Crowle (potatoes)	8·3	42	134	23	41	8	14	8·5	44	159	54	92	14	24
	16·7	44	147	20	71	13	46	16·9	49	168	ND	ND	49	166
	41·6	45	172	ND	ND	ND	ND	42·3	48	176	ND	ND	ND	ND
Elveden (potatoes)	4·2	51	125	37	50	31	42	4·2	56	132	60	96	33	53
	8·4	59	144	41	111	25	68	8·4	67	187	66	211	44	141
	20·9	76	230	ND	ND	39	265	20·9	75	224	ND	ND	31	248

* Includes N uptake by roots and tops for sugar beet, and by roots only for potatoes.
ND, N efficiency could not be determined where the crop yields or N offtake were close to or above the level recorded with the highest rate of fertilizer N.

Table 6. *Apparent N recovery from the different poultry litter application rates by the root crops and following cereal crops*

	N recovery (%)							
	Winter application				Spring application			
Site and harvest year	Low	Medium	High	Mean	Low	Medium	High	Mean
Brandon 1991								
Sugar beet 1991	19	13	17	16	35	7	5	16
Spring wheat 1992	8	3	8	6	5	7	3	5
Total	27	16	25	22	40	14	8	31
Brandon 1992								
Sugar beet 1992	28	58	30	39	40	38	26	35
Spring wheat 1993	6	12	9	9	7	3	8	6
Total	34	70	39	48	47	41	34	41
Freckenham								
Sugar beet 1993	44	47	83	42	42	84	62	63
Ripon								
Potatoes 1991	17	10	11	13	23	18	15	19
Winter wheat 1992	10	8	8	9	2	0	4	2
Total	27	18	19	21	25	18	19	21
Asenby								
Potatoes 1992	34	23	10	22	36	21	7	21
Spring wheat 1993	6	9	5	7	9	7	3	6
Total	40	31	15	29	45	28	10	28
Crowle								
Potatoes 1993	6	6	5	6	29	18	9	19
Winter barley 1994	5	7	2	5	12	2	2	5
Total	11	13	7	10	41	20	11	24
Elveden								
Potatoes 1994	30	22	21	24	29	32	17	26

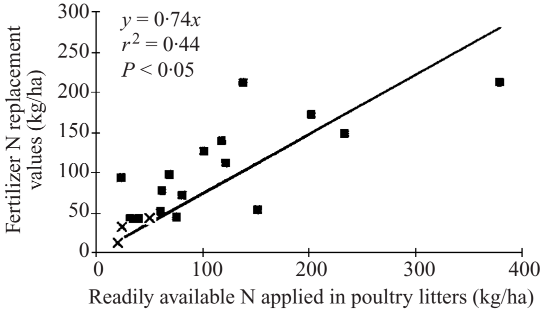

Fig. 2. Relationship between fertilizer N replacement values and readily available N applied in poultry litter applications. ■ potatoes, × sugar beet.

(8·39, 8·52, 9·55 t/ha) and spring (8·96 t/ha) poultry litter applications, which supplied 200, 400, 1000 and 871 kg/ha total N, respectively. Similarly at Asenby, grain yields in 1993 were increased above the control treatment ($P < 0{\cdot}05$) following previous winter (5·99 and 6·57 t/ha) and spring (5·92 and 6·03 t/ha) poultry litter applications supplying 438, 1096, 546 and 1332 kg/ha total N, respectively. At Crowle, there was no grain yield response ($P > 0{\cdot}05$) at harvest in 1994 to the previously applied poultry litter N. The amount of N recovered by the cereal crops ranged from 0 to 12% of the total N originally applied in the poultry litters (Table 6).

DISCUSSION

Poultry litter composition

The nitrogen composition of the poultry litters used in these experiments (Table 3) was comparable with both published 'typical' values for broiler/turkey litter (MAFF 2000) and to the mean analysis of broiler and turkey litter samples from a survey of poultry manures in England and Wales (Nicholson *et al.* 1996).

Poultry litters are a concentrated N source compared with most other organic manures and relatively low application rates are required to comply with the maximum recommended annual application rate of 250 kg/ha total N in the MAFF Code of Good Agricultural Practice for the Protection of Water (MAFF 1998). Based on a typical poultry litter analysis of 29 kg total N/t fresh weight, the annual application rate

Table 7. *Sugar beet sugar and root amino-N concentrations, and potato tuber dry matter and N concentrations*

	N application rate (kg/ha)	Sugar beet sugar (g/kg)	Amino-N (mg/100 g sugar)		N application rate (kg/ha)	Potato dry matter (g/kg)	Tuber N (g/kg)
Brandon 1991				Ripon			
Control	0	174	141	Control	0	193	116
Winter	123	173	139	Winter	200	198	127
	246	173	167		400	199	129
	615	167	294		1000	205	159
Spring	100	171	155	Spring	174	197	136
	201	175	157		348	199	141
	502	173	189		871	194	173
	P	<0·05	<0·001		*P*	NS	<0·001
	s.e. (d.f.)	1·8 (32)	21 (32)		s.e. (d.f.)	4·9 (28)	0·7 (28)
Brandon 1992				Asenby			
Control	0	177	88	Control	0	166	117
Winter	150	180	94	Winter	219	157	159
	301	174	159		438	159	181
	753	162	259		1096	159	213
Spring	158	176	87	Spring	273	152	180
	317	174	152		546	151	197
	793	165	249		1332	150	220
	P	<0·001	<0·001		*P*	<0·05	<0·001
	s.e. (d.f.)	3·4 (32)	22 (32)		s.e. (d.f.)	7·4 (32)	1·4 (32)
Freckenham				Crowle			
Control	0	187	49	Control	0	215	133
Winter	59	187	48	Winter	177	215	133
	118	188	53		355	205	151
	237	188	90		887	203	171
Spring	51	184	44	Spring	170	213	132
	101	190	57		338	207	156
	202	187	82		846	209	162
	P	NS	<0·001		*P*	NS	<0·001
	s.e. (d.f.)	3·3 (36)	8·09 (36)		s.e. (d.f.)	6·7 (34)	1·1 (34)
				Elveden			
				Control	0	185	110
				Winter	135	176	126
					271	175	126
					679	168	164
				Spring	160	175	118
					320	182	138
					800	154	179
					P	<0·001	<0·001
					s.e. (d.f.)	5·4 (44)	1·0 (44)

Note: Not all treatments included in the statistical analysis are reported in this table. NS, non-significant.

should not exceed 9 t/ha. However, in the present experiments the recommended rate was exceeded in order to evaluate the effects on root crop yields and quality.

Yield response to fertilizer N

There were large differences in optimum inorganic fertilizer N rates for sugar beet and potatoes at the different sites (Table 4). For the sugar beet crops, these differences largely reflected the lower spring SMN status of the Freckenham site (38 kg/ha N on the nil N control plot), compared with 133 kg N/ha at Brandon in 1991 and 56 kg N/ha at Brandon in 1992 on the nil N control plots (data not presented). The poor potato yield response to inorganic fertilizer N at Crowle (Table 4) was most probably due to severe drought stress.

Soil mineral N

There was a good relationship between increases in spring SMN following poultry litter applications (which were rapidly incorporated into the soil) and the quantity of readily available N applied (Fig. 1). This

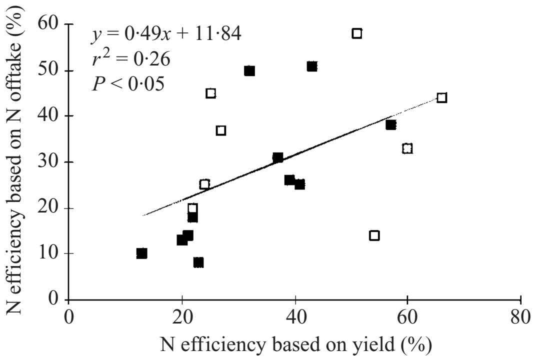

Fig. 3. Relationship between fertilizer N efficiencies calculated using yield and N offtake methods. ■ autumn/winter applications, □ spring applications.

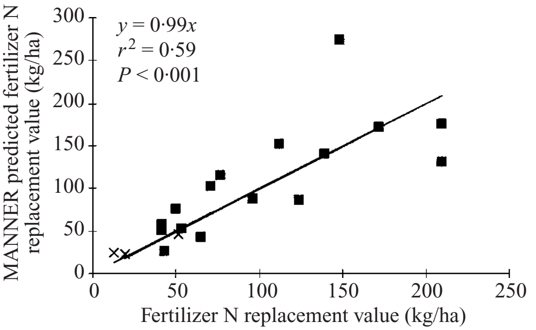

Fig. 4. Relationship between MANNER predicted and measured fertilizer N replacement values for poultry litter applications to sugar beet and potatoes. ■ potatoes, × sugar beet.

supports previous work by Chambers & Smith (1992) who reported a significant ($P < 0.001$) relationship between measured elevations in SMN and readily available N applied in poultry manures.

Efficiency of poultry litter N utilization

Calculations of manure N efficiencies are generally based on crop yield data. However, where these data are not available (e.g. because the yields were close to or above the level recorded with the highest rate of N fertilizer), results based on crop N offtakes can also be used to estimate manure N efficiencies. In the present study, the poultry litter N efficiencies calculated using the two methods were in reasonable agreement ($r^2 = 0.26$, $P < 0.05$), as shown in Fig. 3. The calculated N efficiencies based on crop yields were similar to those reported by Chambers *et al.* (1994) following the spring topdressing of poultry manures to growing cereal crops (mean 34%).

Where potatoes were grown, the relatively small N efficiency differences between spring and winter applications were most probably due to the low effective rainfall volumes (81–274 mm) following the winter timings (Table 2), which would have limited the amount of manure N lost through nitrate leaching. Previous work has shown that more than 100 mm of effective rainfall is needed on deep sandy soils to cause significant nitrate leaching below crop rooting depths (Chambers & Smith 1995) and, under wetter conditions, nitrate leaching losses following the winter timings would probably have been greater.

Fertilizer N replacement value of poultry litter

The slope of the positive relationship between the readily available N applied in the poultry litters and the fertilizer N replacement values (0·74) indicated that there had been a net loss of N, either through ammonia volatilization or nitrate leaching between application and crop uptake (Fig. 2). Chambers *et al.* (1997) reported that ammonia volatilization losses following surface applications of poultry manure can result in 35% of the readily available N content being lost by volatilization over a 20-day period, although the actual amount of ammonia lost depends on a range of environmental factors including wind speed, temperature and rainfall (Jarvis & Pain 1990).

Previous workers have also found good relationships between the available N supplied by poultry manures and fertilizer N replacement values. Bitzer & Sims (1988) showed that the available N supplied by poultry manures was equivalent to 80% of the inorganic N (ammonium and nitrate N) content, plus 60% of the organic N. Beauchamp (1986) reported that the fertilizer N value of poultry slurries was equivalent to 75–80% of the ammonium-N content. Payne & Donald (1990) recommended that the ammonium-N content of poultry manures could be regarded as equivalent to fertilizer N in the absence of losses by volatilization or leaching, and that 50% of the organic N content would be plant available in the first season following application. Similarly, the ready availability of uric acid to plants is supported by the work of Kirchmann (1991) who showed that uric acid-N was completely decomposed within 10 days following soil incorporation.

The fertilizer N replacement values measured in these experiments were compared with predictions generated by inputting the data on manure composition and application into the ADAS MANNER decision support system (Chambers *et al.* 1999). The fertilizer N replacement values measured in these experiments were reliably predicted by MANNER ($r^2 = 0.59$, $P < 0.001$), with the slope of the regression line close to unity (0·99, Fig. 4). These results support the practical approach of analysing individual poultry manures for total, ammonium and uric acid-N, and incorporating the results into MANNER to predict crop-available N supply.

Crop recovery of poultry litter N

The low apparent N recovery by the sugar beet crop at Brandon in 1991 (16 %) was most probably related to the delayed incorporation of the manure, which resulted in N losses via ammonia volatilization, and the higher initial soil mineral nitrogen levels (133 kg/ha) compared with 56 and 38 kg/ha at Brandon in 1992 and Freckenham in 1993, respectively (data not reported). The low recovery by the potato crop at Ripon (16 %) was most probably associated with greater N losses through nitrate leaching.

Crop quality

In the present study, where the poultry litter dressings supplied > 600 kg/ha total N to sugar beet, root sugar concentrations were depressed and amino-N concentrations increased. The sugar content of sugar beet is important as this determines the effective yield of the crop and growers are paid on the basis of sugar yields. The amino-N concentration is an important quality criteria for sugar beet, as sugar extractability is decreased at high impurity levels of amino-N. Concentrations above 150 mg/100 g sugar are generally considered to indicate situations where N supply is in excess of crop requirements.

Tuber dry matter content influences the potential use of a potato crop, such that the crop can only be used for processing into high value products such as chips and crisps if the dry matter content is greater than around 210 g/kg. However, if the dry matter content reaches 230–250 g/kg, then problems with bruising can occur.

Response of following cereal crops

The present study showed that at normal agronomic rates of manure application (up to 250 kg N/ha), cereal crops grown after sugar beet or potato crops that have received poultry litter applications will receive small residual N benefits (range 0–12 % of the N applied). Also, the poultry litter will supply valuable quantities of other plant nutrients (e.g. phosphorus) which will be available to the following cereal crops. Increases in residual soil N supply and soil organic matter status are most likely where elevated application rates are used or repeated applications are made.

Summary and conclusions

The efficiency of poultry litter N utilization was studied in seven field experiments in eastern England, where poultry litter was applied at different application rates in winter or spring, prior to sugar beet or potatoes. The mean measure N efficiency based on crop yield was 33 % (range 25–43 %) for sugar beet and 35 % (range 13–66 %) for potatoes, similar to results reported by other workers. For potatoes, the manure N efficiency was greater from spring (mean 43 %) than from winter application timings (mean 30 %), although the amount of N lost through nitrate leaching following the winter timings was probably limited by low effective rainfall and under wetter conditions this difference would have been more pronounced.

The manure readily available N applied (i.e. ammonium-N + uric acid-N) and fertilizer N replacement values were well related for both sugar beet and potatoes. Similarly, there was a good relationship between the amounts of readily available N applied in the poultry litter dressings and measured elevations in spring soil mineral N supply.

The study highlighted some potentially adverse effects of applying poultry litter at greater than recommended agronomic rates. Where the poultry litter dressings supplied > 600 kg/ha total N to sugar beet, root sugar concentrations were depressed and amino-N concentrations increased, adversely affecting the quality of the harvested crop. The soil mineral N supply following harvest of the sugar beet and potato crops was also increased where application rates supplied > 600 kg/ha total N, increasing the potential for over-winter nitrate leaching losses.

At recommended agronomic rates of application (up to 250 kg N/ha), cereal crops grown after the sugar beet or potato crops received a small residual N benefit (range 0–12 % of the N applied) from the poultry litter applications. Significant yield increases were recorded in the following cereal crops, but only where high rates of manure N (> 600 kg/ha) had been applied.

In summary, the current work has shown that the fertilizer N replacement value of poultry litter can be predicted based on the amounts of total and readily available N applied. This provides guidance to farmers on appropriate reductions in inorganic fertilizer N applications, reducing both their costs of production and the risk of environmental pollution through nitrate leaching.

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