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Effects of repeated straw incorporation on crop fertilizer nitrogen requirements, soil mineral nitrogen and nitrate leaching losses

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Abstract. The effects of straw disposal by burning and incorporation on soil and crop nitrogen (N) supply, were investigated on two light textured soils in central (ADAS Gleadthorpe) and eastern England (Morley Research Centre) over the period 1984 to 1995. Nitrogen balance calculations showed that after 11 years of contrasting straw incorporation versus burn treatments, the cumulative N returns in straw were *c.* 570 kg/ha at Gleadthorpe and *c.* 330 kg/ha at Morley. However, these N returns via straw incorporation were not reflected in increased total soil N levels in autumn 1994. There were no differences ($P > 0.05$) between straw disposal treatments in autumn soil mineral N supply, readily mineralizable N or organic carbon. Similarly, there were no consistent differences between the treatments in terms of crop yield, crop N uptake or optimum fertilizer N rates. Fertilizer N applications of 200 kg N/ha/y increased topsoil organic carbon from 1.18 to 1.28% and total N content from 0.091 to 0.102% on the loamy sand textured soil at ADAS Gleadthorpe, but not at Morley. Previous fertilizer N applications increased the quantity of nitrate-N leached in drainage water by *c.* 20 kg/ha at Gleadthorpe and *c.* 60 kg/ha at Morley overwinter 1994/95, and by 10–20 kg/ha at both sites overwinter 1995/96. There was some indication overwinter 1994/95 that straw incorporation reduced nitrate-N leaching by 10–25 kg/ha, but there were no differences between treatments overwinter 1995/96.

Keywords: Straw incorporation, nitrogen fertilizers, nitrogen, soil, nitrates, leaching, organic carbon

INTRODUCTION

At its peak in the early 1980s, straw burning was used to dispose of *c.* 35% of the cereal straw production in England and Wales (Ministry of Agriculture, Fisheries and Food, 1982). However, following the ban on straw and stubble burning in 1993, all straw is now either incorporated into the soil, or baled and removed. Results of the 1992 and 1994 straw disposal surveys (Ministry of Agriculture, Fisheries and Food, 1992; Ministry of Agriculture, Fisheries and Food, 1994a) show that fewer farmers are now incorporating straw (28% of holdings in 1994, compared to 37% in 1992), with an increasing amount being baled (72% in 1994, compared to 52% in 1992). However, even after baling, Addiscott & Dexter (1994) estimated that 22% of straw remained on the soil surface as stubble.

Although straw contains less N than grain (*c.* 0.6% in straw, compared with *c.* 2% in grain), N returned to the soil via straw incorporation for cereal crops yielding 7–12 t/ha straw can amount to 40–70 kg N/ha/y. However, the wide C : N ratio of straw can result in additional soil mineral N (SMN) being used by soil microbes during decomposition, immobilizing about 10 kg N/ha/y per tonne of straw incorporated (Addiscott & Dexter, 1994). This demand for N mainly occurs within the first 2–3 months after straw incorporation. If there are large quantities of SMN at the time of incorporation, then more immobilization is likely to occur than when there is less SMN (Recous *et al.*, 1995). If there is insufficient SMN in the soil, decomposition will be slowed, although after about a year, two thirds of the C originally in the straw will have been lost as CO_2, regardless of the amount of mineral N the soil originally contained (Jenkinson, 1985). It has been suggested that straw incorporation may help to reduce overwinter nitrate leaching losses as a result of N immobilization during decomposition (Powlson *et al.*, 1985). However, in two experiments where this hypothesis was tested, the effect of straw incorporation on nitrate leaching was found to be negligible (Catt *et al.*, 1992, Davies *et al.*, 1996).

Powlson *et al.* (1985) found that when straw containing 0.5% N was incorporated into a soil that was subsequently sown with winter wheat, 78% of the added N remained in the soil a year after incorporation. Powlson *et al.* (1987) also showed that long-term straw incorporation increased the quantity of mineralizable N in the soil by 40–50%. Thus, soil organic N reserves are likely to increase gradually as a result of straw incorporation and this N may subsequently be released through mineralization over a period of many years. If this occurs in synchrony with crop uptake (spring/summer) crop N requirements will be reduced, but if the mineralization occurs in the autumn or winter, the risk of nitrate leaching may be increased.

This study was established to determine what effects contrasting straw disposal and cultivation techniques have on crop yields and N uptake, soil N supply and nitrate-N leach-

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ing losses. The results of experiments on two light textured soils in central and eastern England are presented.

MATERIALS AND METHODS

Site descriptions

The experiments were located at ADAS Gleadthorpe (Nottinghamshire), on a loamy sand of the Newport Association; and at Morley Research Centre (Norfolk), on a sandy loam of the Ashley Association (Soil Survey of England and Wales, 1993). The average annual rainfall and selected soil characteristics for each site are given in Table 1.

Table 1. Average annual rainfall and selected soil properties at the two experimental sites (soil samples taken in autumn 1992)

	Gleadthorpe	Morley
Average annual rainfall (mm)	630	620
Soil association	Newport	Ashley
Soil texture	Loamy sand over sand	Sandy loam over chalky boulder clay
% clay	7	11
pH	6.9	7.1
Organic carbon (%)†	1.2	1.0

† Measured in autumn 1994

Experiment design

The experimental sites were established in 1984, and were initially designed to investigate the effects of timing and depth of straw incorporation on the establishment and yield of subsequent crops. The design was a randomized block with split plots, with five straw cultivation treatments on the main plots and five nitrogen fertilizer regimes on the subplots. However, following the 1989 harvest, the objectives of the experiment changed to evaluate the effects of the contrasting straw disposal techniques on crop N requirements, SMN and potential for nitrate leaching losses. As a result, the number of cultivation treatments was reduced and fertilizer regimes were modified to give six incremental rates of N application.

The re-designed experiment was a randomized block with split plots, and four replicates of each treatment. There were three straw disposal/cultivation treatments :

(1) Burn straw, tine to incorporate ash, autumn plough (burn).
(2) Chop straw, tine to incorporate straw, autumn plough (incorporate).
(3) Chop straw, autumn plough (plough).

Straw was chopped at harvest and either incorporated into the soil or burnt. The burn and incorporate treatments were both cultivated on the same date to a depth of 0.15 m. All three cultivation treatments were ploughed to a depth of 0.30 m on the same date using a mouldboard plough with a heavy, broad-ringed furrow press.

The crop rotations at both sites are given in Table 4. Where oilseed rape was grown, the straw was treated in the same way as the cereal straw. Where sugarbeet was grown, the leaves and crowns were ploughed into the soil on all cultivation treatments. The spring wheat crop grown in 1990 at Morley was drilled in autumn 1989 following harvest of the preceeding sugarbeet crop; in all other cases, crop drilling was timed in accordance with standard farm practice.

Table 2. Effect of straw incorporation and nitrogen fertilizer rate on soil organic carbon (%) 0–0.15 m measured in autumn 1994

Cultivation treatment	Previous fertilizer N rate (kg/ha) 0	100	150	200	Mean
Gleadthorpe					
Burn	1.17	1.21	1.20	1.24	1.21
Incorporate	1.21	1.21	1.33	1.28	1.26
Plough	1.14	1.25	1.27	1.32	1.24
Mean	1.18	1.22	1.27	1.28	1.24
Cultivation means		N rate means			
P	>0.05	*P*	<0.001		
S.E.D.	0.174	S.E.D.	0.126		
df	6	df	45		
Morley					
Burn	1.00	1.06	1.00	0.99	1.01
Incorporate	0.99	0.94	0.99	0.99	0.98
Mean	0.99	1.00	0.99	0.99	1.00
Cultivation means		N rate means			
P	>0.05	*P*	>0.05		
S.E.D.	0.042	S.E.D.	0.039		
df	3	df	18		

Six rates of fertilizer N were superimposed on the cultivation treatments as subplots. These ranged from 0 to 250 kg N/ha/y in 50 kg increments for winter cereals, 0 to 150 kg N/ha/y in 30 kg increments for spring cereals and sugarbeet, and from 0 to 300 kg N/ha/y in 60 kg increments for winter oilseed rape. The area of each subplot was 64 m^2 at Gleadthorpe and 69 m^2 at Morley. Nitrogen was applied to the subplots by hand as 34.5% ammonium nitrate prills in two applications. Phosphate and potash were applied at rates consistent with current fertilizer recommendations (Ministry of Agriculture, Fisheries and Food, 1994b). In all other respects crops were managed according to standard farm husbandry.

Table 3. Effect of straw incorporation and nitrogen fertilizer rate on readily mineralizable nitrogen (kg/ha) 0–0.15 m measured in autumn 1994

Cultivation treatment	Previous fertilizer N rate (kg/ha) 0	100	150	200	Mean
Gleadthorpe					
Burn	26	23	25	25	25
Incorporate	23	22	27	21	23
Plough	19	24	29	23	24
Mean	23	23	27	23	24
Cultivation means		N rate means			
P	>0.05	*P*	>0.05		
S.E.D.	3.6	S.E.D.	1.7		
df	6	df	27		
Morley					
Burn	62	58	55	60	59
Incorporate	55	54	51	56	54
Mean	59	56	53	58	57
Cultivation means		N rate means			
P	>0.05	*P*	>0.05		
S.E.D.	4.41	S.E.D.	4.49		
df	3	df	18		

Sample collection and analysis

Combinable crops were harvested using a small plot combine, with grain yields adjusted to 85% dry matter. Nitrogen harvest index was assessed by hand threshing whole crop samples taken to ground level immediately prior to combine harvesting. Grain and straw samples taken at harvest from selected plots were analysed to determine their total N content (Ministry of Agriculture, Fisheries and Food, 1986). Optimum fertilizer N rates were calculated using the linear plus exponential model (Sylvester-Bradley *et al.*, 1984) with a break-even grain to fertilizer N ratio of 3:1.

Soil mineral N samples were taken from selected plots in autumns 1990 to 1995 at Gleadthorpe, and autumns 1991 and 1994 at Morley. SMN samples were taken before the soil returned to field capacity, in four depth increments; 0–0.15 m, 0.15–0.3 m, 0.3–0.6 m and 0.6–0.9 m. The soil samples were frozen and analysed for mineral N (nitrate and ammonium N) by extraction with 2M KCl (Ministry of Agriculture, Fisheries and Food, 1986). Additionally, in autumn 1994, topsoil samples (0–0.15 m) were analysed for readily mineralizable N (RMN) using 'hot' KCl following an adaptation of the method described by Gianello & Bremner (1986), in which 40 g of fresh soil was boiled for 4 hours with 200 ml of 2M KCl, and the extract analysed for nitrate and ammonium N. RMN was calculated by difference between the 'hot' KCl and normal 'cold' KCl mineral N determinations. These topsoil samples were also analysed for total N (TN) and organic carbon (OC), using standard methods (Ministry of Agriculture, Fisheries and Food, 1986).

In autumn 1994, porous ceramic cups were installed in two N rates (control and 150 kg N/ha at Gleadthorpe; control and 200 kg N/ha at Morley) of the burn and incorporate treatments, to measure the effect of these treatments on nitrate leaching losses. Five cups were installed in each plot at a depth of 0.9 m at Gleadthorpe and 0.6 m at Morley (Lord & Shepherd, 1993). The cups were shallower at Morley due to the presence of a layer of chalky clay at depths greater than 0.6 m which it was felt would influence drainage patterns. Porous cup water samples were collected at approximately two week intervals during the drainage season and analysed for nitrate-N using standard methods (Ministry of Agriculture, Fisheries and Food, 1986). Drainage volumes were estimated using the ADAS Irriguide model (Bailey & Spackman, 1996).

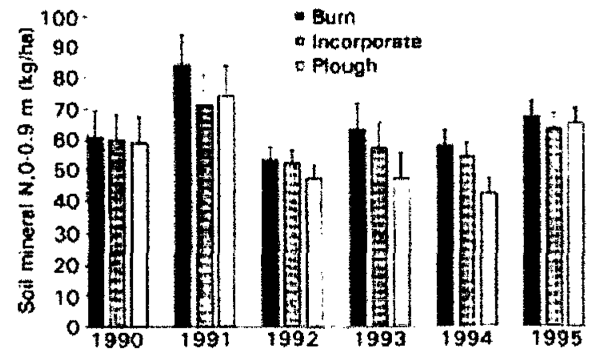

Fig. 1. Autumn soil mineral nitrogen at ADAS Gleadthorpe, 1990–1995, bars denote S.E.s.

RESULTS AND DISCUSSION

Effect of straw disposal treatments on soil properties

Straw disposal technique had no consistent effect ($P > 0.05$) on SMN levels at either site. Measurements reported in the literature on the effects of straw incorporation on SMN are variable. For example, Allison *et al.* (1992) found that incorporated straw reduced SMN levels by a third in one experiment and had no effect in two similar experiments. In a second study (Allison & Hetschkun, 1995), there was an indication, albeit not statistically significant, that previous cereal straw incorporation reduced SMN at drilling and mid-season, but increased levels at harvest.

At Gleadthorpe, there was a trend towards greater autumn SMN levels (0–90 cm) on the burn and incorporate treatments over several years (1990–1995) compared with the plough treatment, indicating that early cultivation had promoted nitrogen mineralization (Fig. 1), although the differences could not always be confirmed statistically. Data for 1992–1995 for SMN at 0–0.15 m, 0.15–0.30 m, 0.30–0.60 m, 0.60–0.90 m and 0–0.90 m were analysed to ascertain whether any treatment differences could be found when results for the whole 4 year time period were considered together. Results of this statistical analysis showed that the only significant ($P < 0.05$) difference in autumn SMN was for the 0.15–0.30 soil layer where the burn and incorporate treatments had more SMN than the plough treatment. At Morley, there were no differences in SMN levels between the straw disposal/cultivation techniques.

The effect of early cultivation in stimulating N mineralization is well established (Shepherd *et al.*, 1993). For example, Dowdell *et al.* (1983) found that soil which had been ploughed contained more nitrate during autumn and early winter, than soil left unploughed and direct drilled.

Soil OC contents were not affected ($P > 0.05$) by straw disposal technique at either site (Table 2). This supports the results of a Danish study (Powlson *et al.*, 1987), which showed

Table 4. Effect of straw incorporation and nitrogen fertilizer rate on soil total nitrogen (%) 0–0.15 m measured in autumn 1994

Cultivation treatment	Previous fertilizer N rate (kg/ha) 0	50	100	150	200	250	Mean
Gleadthorpe							
Burn	0.088	ND	0.095	0.095	0.100	ND	0.094
Incorporate	0.095	ND	0.098	0.103	0.103	ND	0.099
Plough	0.090	ND	0.100	0.110	0.103	ND	0.101
Mean	0.091		0.098	0.103	0.102		0.098
Cultivation means		N rate means					
P	> 0.05	*P*	< 0.05				
S.E.D.	0.0063	S.E.D.	0.0042				
df	6	df	27				
Morley							
Burn	0.177	0.127	0.115	0.117	0.115	0.127	0.120
Incorporate	0.122	0.115	0.125	0.125	0.120	0.130	0.123
Plough	0.132	0.127	0.127	0.125	0.132	0.137	0.130
Mean	0.124	0.123	0.122	0.122	0.122	0.132	0.124
Cultivation means		N rate means					
P	> 0.05	*P*	> 0.05				
S.E.D.	0.006	S.E.D.	0.005				
df	6	df	45				

ND = not determined.

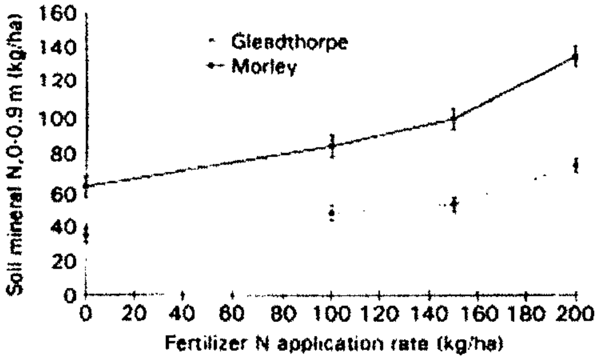

Fig. 2. The effect of fertilizer N rate on autumn 1994 soil mineral nitrogen levels (mean of three straw treatments), bars denote S.E.s.

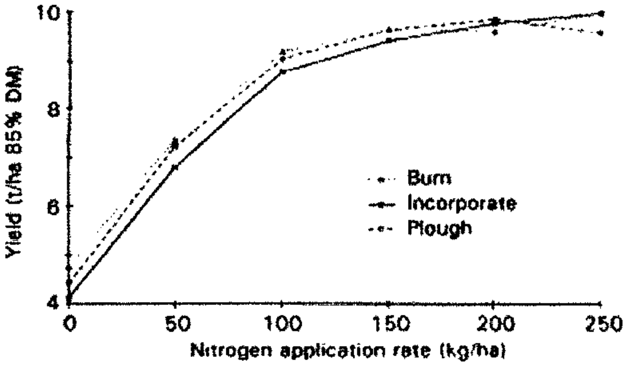

Fig. 3. Effect of straw treatment on winter wheat yield at Morley (harvest 1995).

that after 18 years of annual straw incorporation, total soil OC levels had only been increased by 5%. Nyborg *et al.* (1995a) reported that in Alberta, Canada, the OC content in the surface 0.15 m of two soils after 11 years of straw incorporation increased by 0–18%. It would therefore appear that changes in soil OC due to straw incorporation are likely to take many years to reach significance, with the magnitude of the change being dependent on both soil type and climatic conditions.

Straw disposal had no effect ($P > 0.05$) on RMN (Table 3) or TN (Table 4) at either site. This contrasts with results of a study by Powlson *et al.* (1987) where a 60 day laboratory incubation of soils from plots where straw had been either burned or incorporated indicated that long-term (18 year) incorporation of straw had increased the quantity of mineralizable N in the soil by 40–50%. The same study also showed an increase in soil total N of *c.* 10%.

Effect of annual fertilizer N additions on selected soil properties

By harvest 1994, the experimental plots had received annual applications of inorganic fertilizer N for 10 years. Topsoil samples, taken at both sites in autumn 1994, were analysed for SMN, RMN, TN and OC, to determine whether the fertilizer additions had affected any of these soil properties.

At Gleadthorpe, annual fertilizer N applications increased ($P < 0.05$) the soil OC from 1.18% on the nil N treatment to 1.28% on the treatment which previously received 200 kg N/ha/y (Table 2). Similarly, there was an increase ($P < 0.05$) in soil TN from 0.091% on the nil N treatment to 0.102% on the treatment which previously received 200 kg N/ha/y (Table 4). Thus, on this loamy sand soil, the larger quantities of organic residues returned when crops were grown with fertilizer N additions averaging *c.* 190 kg/ha/y resulted in an increase in soil OC content of *c.* 8% and TN content of *c.* 12%. This supports previous work by Nyborg *et al.* (1995a) on soils in Alberta, Canada, where 11 annual fertilizer N additions resulted in net increases in soil OC and TN. Recently, work reported from the Broadbalk Experiment at Rothamsted Experimental Station showed increases in soil TN of up to 21% on plots where 144 kg N/ha/y had been applied for 135 years; differences in TN between fertilized and unfertilized plots in this experiment were established within the first 30 years (Glendining *et al.*, 1996). Similarly, Bhogal *et al.* (1997), found a 6% increase in soil TN on plots at Ropsley (Lincolnshire) where, on average, 255 kg N/ha had been applied for 14 years.

By contrast at Morley, fertilizer N additions had no effect ($P > 0.05$) on soil OC or TN contents. There were no differences ($P > 0.05$) in RMN between the different N treatments at either site (Table 3).

Fertilizer N additions increased ($P < 0.001$) the amount of autumn SMN (0–90 cm) at both sites (Fig. 2). These increases were most marked where more than 150 kg N/ha/y had been applied, as the optimum N rate for the crops had been exceeded (Table 5). Chaney (1990) and Sylvester-Bradley & Chambers (1992) reported similar increases in autumn SMN supply where optimum fertilizer N rates had been exceeded.

Table 5. Optimum N rates and estimated grain or seed yields at optimum N

	1990		1991		1992		1993		1994		1995	
	Optimum N rate (kg/ha)	Yield (t/ha)	Optimum N rate (kg/ha)	Yield (t/ha)	Optimum N rate (kg/ha)	Yield (t/ha)	Optimum N rate (kg/ha)	Yield (t/ha)	Optimum N rate (kg/ha)	Yield (t/ha)	Optimum N rate (kg/ha)	Yield (t/ha)
Gleadthorpe												
Crop	Spring barley		Winter barley		Oilseed rape		Winter wheat		Winter barley		Winter barley	
Treatment:												
Burn	101	3.40	188	5.56	122	1.65	179	8.07	156	4.42	139	3.70
Incorporate	81	2.95	179	5.48	130	1.39	166	7.64	117	4.40	131	3.70
Plough	82	3.08	171	5.40	127	1.49	181	7.57	124	4.64	152	3.64
Morley												
Crop	Spring wheat		Winter oats		Winter barley		Sugarbeet		Spring wheat		Winter wheat	
Treatment												
Burn	> 250*	> 9.09*	78	7.16	156	8.19	ND	ND	122	4.02	186	9.84
Incorporate	189	8.66	93	7.09	177	7.95	ND	ND	141	4.14	215	9.88
Plough	> 250*	> 8.85*	89	7.28	163	7.91	ND	ND	89	4.25	175	9.76

ND = Not determined. * = Highest N rate/yield taken as optimum

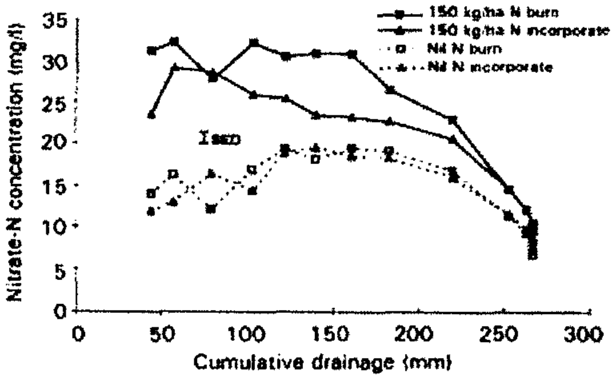

Fig. 4. Nitrate-N concentrations of drainage water at ADAS Gleadthorpe (winter 1994/5).

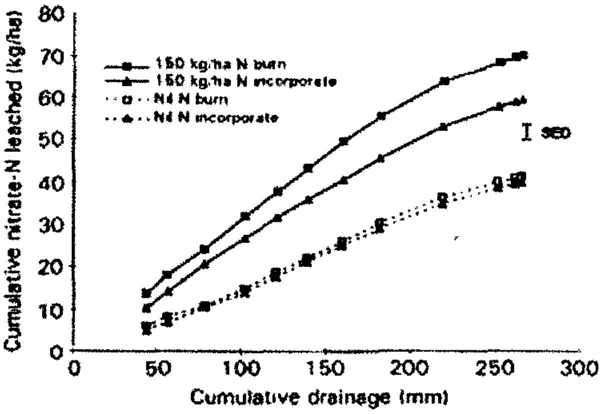

Fig. 5. Nitrate-N leaching losses at ADAS Gleadthorpe (winter 1994/5).

Crop yield and N uptake

Results from the first phase of the experiments (harvest 1985–1989) showed no differences in grain yield ($P > 0.05$) between the incorporate and burn treatments at either site. This contrasts with a number of previous studies (e.g. Tomar & Soper, 1981; Nyborg *et al.*, 1995b) where it was found that returning rather than removing cereal straw tended to decrease following crop yields, possibly because N immobilization by soil microbes had decreased crop N supply during early plant growth (Christian & Bacon, 1991). However, recent work reported by Johnson & Smith (1996), also failed to find any cultivation/straw disposal effects on winter barley yield during a five year period (1990 to 1994).

After implementation of the new experiment design following the 1989 harvest, grain yields (1990–1995) continued to be similar ($P > 0.05$) on the straw disposal treatments. In every year there was a response ($P < 0.001$) to fertilizer nitrogen, with grain yields generally doubling at the optimum rate of fertilizer N addition (Fig. 3). The optimum N application rate differred between years, depending on the season and crop grown, although straw disposal technique had no consistent effect on the optimum N rate (Table 2).

Although crop N uptake (straw and grain) was significantly affected by N application ($P < 0.001$) at both sites, the straw disposal treatments generally had no effect ($P > 0.05$) on N uptake at either site (Table 6).

Calculation of straw N returns

Measurements of straw N uptake were used to estimate the amount of N returned to the soil after 11 years of straw incorporation on the treatments receiving 150 kg/ha/y fertilizer N (Table 7). Typical straw N uptake values were used for crops where measurements were not available (Sylvester-Bradley, 1993). Note that in the years where sugarbeet was grown in the rotation, residues were incorporated on all treatments, and hence were not included in calculations of N returns.

Nitrogen returns via straw incorporation following 10 years of comparative treatments at Gleadthorpe and 8 years at Morley (Table 7) were estimated to be 572 kg N/ha and 329 kg N/ha, respectively. The N returned via straw incorporation at Gleadthorpe was equivalent to *c.* 15% of the total topsoil N content of the 150 kg N/ha burn treatment in autumn 1994, and at Morley to *c.* 7% of total topsoil N, assuming a topsoil

Table 6. Crop N offtake and grain N content at harvest 1990 to 1995 (mean of fertilizer N treatments)

	1990		1991		1992		1993		1994		1995	
	Crop N uptake (kg/ha)	Grain N content (%)	Crop N uptake (kg/ha)	Grain N content (%)	Crop N uptake (kg/ha)	Grain N content (%)	Crop N uptake (kg/ha)	Grain N content (%)	Crop N uptake (kg/ha)	Grain N content (%)	Crop N uptake (kg/ha)	Grain N content (%)
Gleadthorpe												
Crop	Spring barley		Winter barley		Oilseed rape		Winter wheat		Winter barley		Winter barley	
Treatment:												
Burn	ND	2.12	100	1.85	ND	ND	140	1.87	83	1.98	69	2.15
Incorporate	ND	2.18	106	1.91	ND	ND	132	1.89	79	2.03	68	2.10
Plough	ND	2.15	101	1.93	ND	ND	137	1.92	89	2.04	71	2.15
P	ND	> 0.05	> 0.05	> 0.05	ND	ND	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05
S.E.D.	ND	0.036	5.6	0.047	ND	ND	7.6	0.034	5.2	0.043	3.7	0.048
df	ND	45	26†	45	ND	ND	27	44†	27	45	27	45
Morley												
Crop	Spring wheat		Winter oats		Winter barley		Sugarbeet		Spring wheat		Winter wheat	
Treatment.												
Burn	162	1.97	123	1.73	157	1.65	ND	ND	95	2.28	183	1.91
Incorporate	170	1.99	116	1.70	140	1.65	ND	ND	98	2.28	173	1.92
Plough	166	1.98	115	1.67	145	1.68	ND	ND	104	2.28	175	1.90
P	> 0.05	> 0.05	< 0.001	> 0.05	> 0.05	> 0.05	ND	ND	> 0.05	> 0.05	> 0.05	> 0.05
S.E.D.	5.2	0.064	1.9	0.049	6.5	0.029	ND	ND	3.7	0.044	5.45	0.050
df	27	27	27	45	27	45	ND	ND	44†	45	45	45

ND = Not determined. † = missing plot.

Table 7. Estimated extra amounts of N returned as a result of straw incorporation on treatments receiving 150 kg N/ha/y

	Gleadthorpe		Morley	
Year	Crop	N returned (kg/ha)	Crop	N returned (kg/ha)
1985	Winter barley	35[a]	Winter barley	35[a]
1986	Winter oilseed rape	155[a]	Sugarbeet	0[b]
1987	Winter wheat	50[a]	Winter wheat	50[a]
1988	Winter barley	35[a]	Winter wheat	50[a]
1989	Sugarbeet	0[b]	Sugarbeet	0[b]
1990	Spring barley	30[a]	Spring wheat	32
1991	Winter barley	36	Winter oats	32
1992	Winter oilseed rape	155[a]	Winter barley	56
1993	Winter wheat	38	Sugarbeet	0[b]
1994	Winter barley	20	Spring wheat	30
1995	Winter barley	18	Winter wheat	44
	Total N returned in straw	572	Total N returned in straw	329

[a] Estimated values from Sylvester-Bradley (1993)

[b] Sugarbeet residues were incorporated on all cultivation treatments.

depth of 0.3 m and a soil density of 1.3 g/cm^3. However, these increased N returns were not reflected in the topsoil total N measurements made in autumn 1994 on the treatments where straw was incorporated. This was not unexpected as these N returns are relatively small in comparison to the total topsoil N content and would be difficult to detect within the range of experimental and analytical errors.

Nitrate-N leaching

Nitrate-N concentrations (mg/l) in drainage water and nitrate-N leaching losses (kg/ha) overwinter 1994/5 are shown for Gleadthorpe in Figures 4 and 5, and for Morley in Figures 6 and 7.

As expected, nitrate-N losses were greater from the previous fertilizer N application treatments compared with the nil N treatments overwinter 1994/95 (*c.* 60 kg/ha *cf.* *c.* 40 kg/ha at Gleadthorpe, and *c.* 100 kg/ha *cf.* to 40 kg/ha at Morley). At Morley, straw incorporation reduced ($P < 0.05$) nitrate-N leaching losses by *c.* 30 kg/ha on the 200 kg N/ha treatment and by *c.* 20 kg/ha on the nil N treatment as a result of N immobilization during straw decomposition. There was an indication at Gleadthorpe that straw incorporation had reduced ($P > 0.05$) nitrate-N leaching by *c.* 10 kg/ha where fertilizer N had been applied (Fig. 5). Nitrate-N concentrations in drainage water were generally higher at the Morley site (Fig. 6), which reflected the greater SMN contents in autumn 1994 at Morley (mean 95 kg N/ha) than at Gleadthorpe (mean 51 kg N/ha). These results support those of Jarvis *et al.* (1989) who, using monolith lysimeters with a test crop of winter cereals, identified reduced nitrate leaching losses on loamy sand and clay textured soils where straw had been incorporated compared to burned. In contrast, Catt *et al.* (1992) and Davies *et al.* (1996) reported that the effect of straw incorporation on nitrate leaching was negligible.

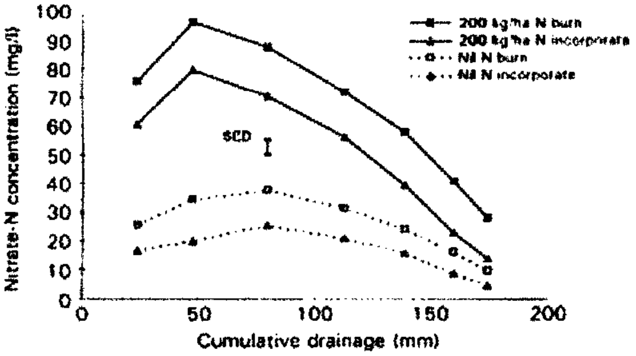

Fig. 6. Nitrate-N concentrations of drainage water at Morley (winter 1994/5).

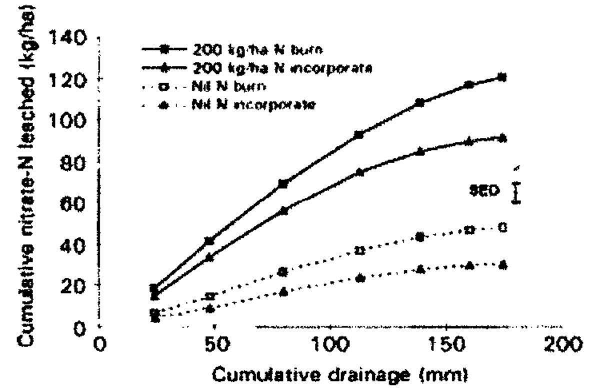

Fig. 7. Nitrate-N leaching losses at Morley (winter 1994/5).

These measurements were repeated overwinter 1995/6. Nitrate-N concentrations in drainage water at both sites were less than the previous year and because of the dry winter, the volume of drainage was smaller. As a consequence, the cumulative amount of nitrate-N leached from both sites was low, with no differences ($P > 0.05$) between the straw disposal treatments at either site. As in the previous winter, more nitrate-N was leached where fertilizer N had been applied (*c.* 30 kg/ha at Gleadthorpe and *c.* 12 kg/ha at Morley) compared with the nil N treatments (*c.* 12 kg/ha at Gleadthorpe and *c.* 2 kg/ha at Morley).

CONCLUSIONS

(1) Following 8–10 years comparing straw incorporation with burn treatments, there were no detectable differences ($P > 0.05$) in topsoil organic carbon or total N contents, or consistent effects on autumn SMN.

(2) Fertilizer nitrogen significantly increased the amount of topsoil organic carbon and total N at Gleadthorpe, probably because of larger crop residue returns where fertilizer N was applied.

(3) There was no difference in crop yield or crop N uptake between the different straw disposal treatments.

(4) Fertilizer N increased the quantity of nitrate-N leached in drainage water overwinters 1994/95 and 1995/96 at both sites.

(5) There was an indication overwinter 1994/95 that straw incorporation reduced nitrate-N leaching compared with straw burning, by *c.* 10 kg/ha at Gleadthorpe and *c.* 25 kg/ha at Morley.

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