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Five years of straw incorporation and its effect on growth, yield and nitrogen nutrition of sugarbeet (*Beta vulgaris*)

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SUMMARY

In 1990–92, field experiments were performed at Broom's Barn Experimental Station to study the effect of 5 years' repeated straw incorporation on sugarbeet. Straw incorporation had no effect on plant population density. Processing quality was reduced by incorporated straw but N had a much larger effect. The effect of incorporated straw on the mineral N content of the soils and N uptake by beet was inconsistent, and this may be related to the amount of soil mineral N present when the straw was incorporated. The efficiency of fertilizer use was unaffected by straw incorporation. On Broom's Barn soils when straw was incorporated, the optimal economic N dressing was *c.* 120 kg N/ha, and in unincorporated plots it was *c.* 100 kg N/ha. At the optimal economic N rate, incorporated straw increased beet yields.

INTRODUCTION

Currently 90% of the UK's sugarbeet crop follows a cereal crop. In 1993 the British Sugar Crop Survey showed that, by area, 6% of the straw from this cereal was burnt in the field, 33% incorporated and 54% removed from the field. Therefore following the imposition of a straw-burning ban in late autumn 1992, *c.* 40% of the national beet crop will now be sown into land where the previous cereal straw has been incorporated. A previous paper (Allison *et al.* 1992) considered the effect over three seasons of 1 year's straw incorporation on the subsequent beet crop. This work showed that at the recommended rate of N fertilizer application for Broom's Barn (120 kg N/ha), straw incorporation had no effect on sugar yield, and at the lowest N fertilizer rate tested (40 kg N/ha), straw incorporation decreased sugar yield and N uptake in just one season.

The longer term effects of repeated straw incorporation on beet sugar yield have been studied previously (Rayns & Culpin 1948; Harvey 1959; Patterson 1960; Short 1973). However since these studies were performed, the agronomy of both cereal and sugarbeet crops has changed substantially. In particular, the yield of cereals has increased due, in part, to a change from spring-sown to winter-sown cereals and an increased use of N fertilizer. As a result straw yields have also increased. In contrast, the beet crop now receives less N; in 1976 the average application was 155 kg N/ha, whilst in 1992 it was 115 kg N/ha.

As stated in a previous paper (Allison *et al.* 1992) the longer-term effect of incorporated straw on sugarbeet nutrition remains unknown, especially the influence of changes in the size of the organic matter pool and its activity. This paper investigates the effect of 5 years' repeated straw incorporation on N supply to the beet crop, its yield and N fertilizer requirement.

MATERIALS AND METHODS

This second series of experiments was performed in 1990 (Expt 1), 1991 (Expt 2) and 1992 (Expt 3) on three different fields at Broom's Barn.

In the first series of experiments, Allison *et al.* (1992) reported the effects of a single incorporation of winter-barley straw on the growth and yield of sugarbeet. The experiments were then continued on the same experimental areas, for one full rotation with crops of spring barley, winter oats, winter wheat, winter barley and finally sugarbeet. Straw from the cereal crops was either incorporated or baled and removed from the plots as appropriate. The second series of experiments therefore tested the effects of a total of 5 years of straw incorporation.

Each experiment consisted of four blocks, each with two main plots where the straw was either removed (except for the stubble which was *c.* 15 cm high) or incorporated. In Expts 1 and 3, the amount of straw dry matter (DM) incorporated each year from cereal crops was 8 t/ha, whilst in Expt 2, 10 t DM/ha was incorporated each year. After sowing the sugarbeet, the main plots were subdivided into six subplots. These were randomized and received 0, 40, 80, 120 and 200 kg N/ha as ammonium nitrate. Where appropriate the N was applied as a split dressing of 40 kg N/ha at drilling with the remainder applied when the crop was at the 2–4 true leaf stage. These plots also received 0·78 kg a.i./ha of the granular pesticide, Temik (aldicarb). The sixth subplot received 120 kg N/ha without pesticide. Within each main plot, the subplots given 120 kg N/ha (with or without pesticide) were always adjacent. In each experiment, no discard area was left between blocks, main plots or subplots. In Expt 1, the subplots were 2·5 m (five rows) wide × 12·5 m long; in Expts 2 and 3 the subplots were 3 m (six rows) wide × 12 m long. In all experiments, the subplots receiving 120 kg N/ha were double width to reduce the risk of pest migration between pesticide-treated and untreated plots.

Each cereal crop was uniformly fertilized according to current recommendations (MAFF 1985). At each harvest, the cereal straw was baled and removed, the weight of a subsample dried at 85 °C was determined and the required amount of straw was returned to the appropriate plots. The straw was chopped in the field to *c.* 5 cm length, and then incorporated down to *c.* 12 cm depth with one pass of a power harrow. In the November preceding the beet crop, nutrients (50 kg P/ha, 123 kg K/ha, 158 kg Na/ha and 53 kg Mg/ha) were applied to the entire experimental area, which was then ploughed (to 25 cm depth) and consolidated by a furrow press (Jaggard *et al.* 1989). In the spring, the seedbed was prepared by one pass of a powered rotary harrow and crumbler. Beet seed (cv. Amethyst) was sown at an average spacing of 18 cm in rows 50 cm apart. All sugarbeet crops were irrigated so that limiting soil moisture deficits were not exceeded (Jaggard *et al.* 1989).

The area used for measuring plant establishment and yield was three rows × 10 m (Expt 1) or four rows × 8 m (Expts 2 and 3). The number of established beet seedlings was recorded 4–5 weeks after sowing, when most seedlings had four true leaves. At harvest, the plants were manually lifted, topped and counted. The tops were weighed and subsamples were dried to constant weight at 85 °C to determine shoot dry matter yields. The cleaned beet from each plot were weighed and the sugar percentage and juice impurities were determined using standard methods (Carruthers & Oldfield 1961). Macerated root (brei) samples were dried to constant weight at 85 °C. The dried top and root samples were then milled to < 1 mm and their N contents determined by Kjeldahl digestion using standard methodology (MAFF/ADAS 1986).

Soil nitrate and ammonium (N_{min}) was measured in those plots receiving no N on four occasions; close to the time of incorporation, at drilling of the beet crop, mid-season when the crop canopy first closed, and at final harvest. In Expts 1 and 2, N_{min} was measured *c.* 1 month after incorporation. In Expt 3, however, due to the lateness of the incorporation, N_{min} contents were measured *c.* 1 month before incorporation. N_{min} was measured for the 120 kg N/ha plots once each season when the crop canopy first closed. In all cases, samples were augered (0–30, 30–60 and 60–90 cm) from near the centre of the plots. After sampling, the soils were immediately extracted with 0·5 M KCl. The soil extracts were then analysed for nitrate and ammonium content using an automated, colorimetric method. The results were expressed on an oven dry weight basis, with standard bulk density values for each depth being used for all years and treatments.

The effect of straw incorporation, nitrogen fertilizer and pesticide usage on processing quality was assessed by calculating juice purities. Juice purity is an index of the likely efficiency of sucrose extraction and was calculated using the formula of Carruthers *et al.* (1962):

$$\text{Juice Purity} = 97{\cdot}0 - 0{\cdot}0008\,(2{\cdot}5\,\text{K} + 3{\cdot}5\,\text{Na} + 10\,\alpha\text{-amino N})$$

where the K, Na and α-amino N impurities are expressed as mg/100 g sugar.

Within the UK, beet farmers are paid by the processor for clean root yield adjusted to 16% sugar; the adjusted tonnage of clean beet (ACB). Each grower is allocated a quota of ACB by the processor. This is the 'A+B' quota, the value of which is supported by the EC's Common Agricultural Policy. In 1992, the 'A+B' quota had a value of £37.32/ACBt. Beet produced in excess of the 'A+B' quota is designated 'C' quota, the price of which is unsupported, and which in 1992 had a value of £14.48/ACBt. N was assumed to cost £0.29/kg N. To determine the optimal economic N application rate, for both price structures, a linear plus exponential model of the form $y = a + br^x + cx$, where x is N fertilizer (kg N/ha) and y is the yield (t/ha), was used (George 1984). Previous work (M. F. Allison, unpublished) has shown that fitting ACB directly to fertilizer N, and estimating the economic optima from the gradient of the response curve, results in estimates of yield and N application rate with large S.E.S. A better method was to correct the ACBs for the cost of the N used to produce them, resulting in corrected ACBs (CACBs).

The CACBs were then fitted against applied N. The maximum of the curve therefore represents the maximum economic yield and, by interpolation, the N application rate needed to achieve it can be estimated. The data from all the experiments were fitted simultaneously, using common best fit values for the r and c parameters. Different a and b parameters were calculated for each individual year/straw treatment. This results in curves of similar shape, displaced horizontally and vertically according to the effects of year and straw treatment.

Analyses of variance were produced for all plant and soil variates. For simplicity, variates comprising a data-value for each subplot were analysed by split-plot analyses of variance, disregarding the randomization restriction which required subplots for the two treatments with 120 kg N/ha to be adjacent. These analyses of variance are therefore not strictly valid, and the S.E.s produced should be treated with caution. Interactions between straw and pesticide applications were tested by restricting the analysis of variance to the 120 kg N/ha plots. No interactions were found and, for simplicity, only the unrestricted analyses are shown in the tables. Differences are quoted as being significant only if their probability of occurrence by chance was < 5% ($P < 0.05$). The residuals in the straw stratum of the analysis of variance were usually smaller than the residuals from the pesticide/N strata. Consequently the S.E.s for comparing the same level of straw are often larger than S.E.s comparing different levels of straw. Where this occurs in Tables 1, 2 and 4, the larger S.E. is presented. The standard errors for the straw incorporation treatments based upon 3 D.F. are not strictly valid, and have been included for guidance only.

RESULTS AND DISCUSSION

Plant population densities

Plant population densities were not significantly affected by straw incorporation, N fertilizer or granular pesticide application. Plant population per hectare averaged 95000 in 1990, 80000 in 1991 and 100000 in 1992. Since maximal sugar yields are attained when plant populations are > 75000 plants/ha at the end of the season (Draycott *et al.* 1974; Jaggard *et al.* 1989), the populations in these experiments were more than adequate. There was no indication that straw incorporation increased the damage caused by seedling pests, as there was no effect of aldicarb application on plant population densities.

Beet and sugar yield

Straw incorporation significantly increased clean beet yield in Expt 1, reduced it in Expt 2, but had no effect in Expt 3 (Table 1). Nitrogen fertilizer significantly increased yield in each experiment. Pesticide at drilling had no significant effect in any year.

Incorporated straw tended to increase root-sugar concentration, but this effect was not significant (data not shown). N fertilizer significantly decreased root-sugar concentration. Averaged over all years, and straw and pesticide treatments, root-sugar concentration when no N was applied was 18·47%, compared to 18·05% at 200 kg N/ha. Sugar yield, the product of clean beet yield and sugar concentration, was affected in a similar way to beet yield with respect to straw incorporation and N (Table 2).

Nitrogen in the soil and crop

Generally, straw incorporation had little effect on N_{min}, except in Expt 2 where it significantly reduced the soil mineral N content when measured a few

Table 1. *Effect of 5 years of straw incorporation, N fertilizer and pesticide on clean beet yield (t/ha) in three experiments at Broom's Barn. Standard errors based upon 3 D.F. are for guidance only**

Experiment	Incorporated straw (t/ha)	N fertilizer (kg N/ha) 0	40	80	120	120†	200	Mean
1	0	61	66	75	71	70	70	69
	8	66	70	73	74	68	73	71
S.E.				1·97 (30 D.F.)				0·42 (3 D.F.)
2	0	56	59	65	63	63	63	61
	10	44	54	58	58	58	61	55
S.E.				2·14 (30 D.F.)				0·77 (3 D.F.)
3	0	59	68	72	72	72	74	70
	8	58	65	72	74	72	75	70
S.E.				1·18 (30 D.F.)				0·28 (3 D.F.)
Mean	−straw	59	64	70	69	68	69	67
	+straw	56	63	67	69	66	70	65
S.E.				1·05 (90 D.F.)				0·31 (9 D.F.)

* See text for explanation.
† Plots that did not receive pesticide at drilling.

Table 2. *Effect of 5 years of straw incorporation, N fertilizer and pesticide on sugar yield (t/ha) in three experiments at Broom's Barn. Standard errors based upon 3 D.F. are for guidance only**

Experiment	Incorporated straw (t/ha)	N fertilizer (kg N/ha) 0	40	80	120	120†	200	Mean
1	0	11·2	12·2	13·9	13·1	12·6	13·5	12·6
	8	12·0	13·0	13·7	13·7	12·3	13·2	13·0
S.E.				0·35 (30 D.F.)				0·05 (3 D.F.)
2	0	10·7	11·4	12·5	12·1	11·9	11·7	11·7
	10	8·5	10·4	11·0	11·4	11·4	11·4	10·7
S.E.				0·41 (30 D.F.)				0·16 (3 D.F.)
3	0	10·6	12·1	12·7	12·8	12·7	12·8	12·3
	8	10·4	11·9	13·1	13·3	13·5	12·9	12·5
S.E.				0·25 (30 D.F.)				0·10 (3 D.F.)
Mean	−straw	10·8	11·9	13·1	12·6	12·4	12·3	12·2
	+straw	10·3	11·8	12·6	12·8	12·2	12·7	12·1
S.E.				0·20 (90 D.F.)				0·05 (9 D.F.)

* See text for explanation.
† Plots that did not receive pesticide at drilling.

weeks after incorporation (Table 3). There was an indication (not significant) that straw incorporation tended to reduce mineral N at drilling and mid-season, whilst increasing it at harvest. The amount of N mineralized from soil organic matter was unaffected by straw.

Root impurities

In all experiments, N fertilizer significantly decreased juice purity (Table 4). Over the range of N rates tested, the decrease in juice purity with increasing N was similar to that quoted by Draycott (1972). The effect of straw was only significant in Expt 3. Pesticide application had no significant effect on juice purity in any year. Over the three experiments, the year variance ratio was 7·10, the straw variance ratio was 15·77, whilst the pesticide/N variance ratio was 69·87. The results show that whilst incorporated straw may decrease juice purity, N fertilization has a much larger effect and care is needed in this aspect of crop management. The mechanism by which straw incorporation affects juice purity is not known but it may be due to the increased availability of K in straw-incorporated soils.

Allison *et al.* (1992) suggested that straw incorporation might help to reduce the leaching of nitrate over winter. In these current experiments, detailed measurements of soil N_{min} content were not made during the autumn/winter period so this cannot be proved. However, measurements made before incorporation in Expt 3 would suggest that straw incorporation had no effect on the amount of residual N_{min} after cereal harvest, also the N_{min} contents at drilling were not significantly affected by straw treatment in all three experiments (Table 3). Therefore in Expt 1, where the incorporated straw had no effect on soil N_{min} one month after incorporation, the extent to which the incorporated straw helped to reduce leaching was negligible. Conversely, in Expt 2, substantial immobilization occurred, with a likely reduction in the risk of nitrate leaching. Other workers (Powlson *et al.* 1985; Jarvis *et al.* 1989; Machet & Mary 1989) have shown that incorporated straw may reduce nitrate leaching. Ocio *et al.* (1991) monitored changes in biomass N when soils were incubated with ^{15}N-labelled cereal straw. These workers showed that about two thirds of the increase in biomass N, resulting from straw incorporation, was derived from the decomposing straw. When inorganic N was added to the incubations, the proportion of biomass N derived from the straw fell to about one third. It is possible therefore that when soil N_{min} contents are small, much of the demand for N by the straw-decomposing microflora may be met from within the straw itself. The degree to which incorporated straw reduces nitrate leaching may therefore be highly dependent on the N_{min} content of the soil into which it is incorporated. This may also help explain the inconsistent effects of incorporated straw between the first and second rotations of the experiment.

In the first series of experiments, incorporated straw reduced sugar yield at the lowest N rate in Expt 1, but in the second series of experiments, the yield reduction resulting from incorporated straw was seen in Expt 2. This response of sugarbeet crops cannot be attributed to factors specific to individual

Table 3. *Effect of 5 years of straw incorporation on soil N_{min} (0–90 cm) at about the time of incorporation, at drilling, at mid-season and at harvest and net N mineralized in unfertilized plots (net mineralization = (2+3)−1). Standard errors based upon 3 D.F. are for guidance only**

Experiment	Incorporated straw (t/ha)	N_{min} at incorporation (kg N/ha)	N_{min} at drilling (kg N/ha) '1'	N_{min} at mid-season (kg N/ha) N Fertilizer (kg N/ha) 0	120	N_{min} at harvest (kg N/ha) '2'	N uptake of unfertilized beet crop (kg N/ha) '3'	Net mineralization (kg N/ha) (2+3)−1
1	0	105	51	106	135	19	161	128
	8	108	54	88	125	21	165	132
S.E. (different rate of straw)		15·0 (3 D.F.)	6·1 (3 D.F.)	27·4 (6 D.F.)		3·8 (3 D.F.)	15·6 (3 D.F.)	13·6 (3 D.F.)
(same rate of straw)				7·4 (6 D.F.)				
2	0	181	44	146	48	38	109	103
	10	102	33	131	73	46	94	107
S.E. (different rate of straw)		12·7 (3 D.F.)	3·1 (3 D.F.)	18·0 (6 D.F.)		6·5 (3 D.F.)	5·2 (3 D.F.)	5·2 (3 D.F.)
(same rate of straw)				9·4 (6 D.F.)				
3	0	40	38	116	188	41	147	150
	8	40	35	110	135	45	145	154
S.E. (different rate of straw)		3·6 (3 D.F.)	3·7 (3 D.F.)	15·8 (6 D.F.)		1·6 (3 D.F.)	4·3 (3 D.F.)	4·7 (3 D.F.)
(same rate of straw)				15·1 (6 D.F.)				
Mean	−straw	109	44	122	124	33	139	127
	+straw	83	40	110	111	37	135	131
S.E. (different rate of straw)		11·6 (9 D.F.)	2·6 (9 D.F.)	12·1 (18 D.F.)		2·6 (9 D.F.)	9·8 (9 D.F.)	8·9 (9 D.F.)
(same rate of straw)				6·4 (18 D.F.)				

* See text for explanation.

fields (i.e. soil texture or organic matter content). It is possible that the response of sugarbeet crops to incorporated straw may depend on how much N_{min} is left behind at cereal harvest, as well as the C:N ratio of the incorporated straw and the extent to which the weather permits mineralization of soil organic matter. With this complex picture, it is unlikely that the measurement of one or two simple variables (i.e. straw yield, straw C:N ratio or N_{min} at harvest) would allow a prediction to be made of the likely response of the following sugarbeet crop.

In Expt 2, the unfertilized plots had a larger N_{min} content mid-season than did those plots receiving 120 kg N/ha (Table 3). Averaged over straw treatments, the unfertilized plots contained 20 kg N/ha in the 0–30 cm layer, 85 kg N/ha in the 30–60 cm layer and 22 kg N/ha in the 60–90 cm layer. The corresponding values for the fertilized plots were 12, 22 and 15 kg N/ha. The fertilized crop thus appeared to have exploited the subsoil N better. This may be because the fertilized crop had a better fibrous root system. Also, heavy rain at the end of April may have moved nitrate beyond the reach of the slowly advancing root system of the unfertilized crop, further reducing crop vigour and N uptake.

Within the range of N application rates tested (0–200 kg N/ha), the uptake of N was related linearly to application rate (Table 5). A simple linear regression explained 74–99% of the variation. The slope of the line is an estimate of the apparent efficiency of fertilizer use. The values calculated by this method are typical for beet (Anon. 1990). They are also similar to estimates of fertilizer efficiency as measured with ^{15}N-labelled fertilizers (Abshahi *et al.* 1984; Anon. 1987). The apparent efficiency of fertilizer uptake in Expt 1 was poor and this may be partly due to the large uptake of N by the unfertilized crop, because in this year the apparent efficiency of use of soil-derived N (calculated as N uptake by the unfertilized crop/net mineralization $+N_{min}$ at drilling) was 90% in Expt 1 compared to *c.* 75% in Expts 2 and 3.

Scott & Jaggard (1993) described a positive correlation between total leaf area index and N uptake. To maximize yields it is important to establish a full canopy as early as possible, therefore a crop with a high efficiency of N uptake early in the season is likely to yield well. Ignoring the effects of straw (which were not significant), the N uptake at optimal yield was 205 kg N/ha in Expt 1, 149 kg N/ha in Expt 2 and 200 kg N/ha in Expt 3. Last *et al.* (1983) and Armstrong & Milford (1985) showed that N uptakes

Table 4. *Effect of 5 years of straw incorporation, N fertilizer and pesticide on juice purity* (%), *in three experiments at Broom's Barn. Standard errors based upon 3 D.F. are for guidance only**

Experiment	Incorporated straw (t/ha)	N fertilizer (kg N/ha) 0	40	80	120	120†	200	Mean
1	0	94·97	94·98	94·82	94·62	94·59	94·17	94·69
	8	94·67	94·82	94·65	94·39	94·36	94·09	94·50
S.E.				0·100 (30 D.F.)				0·043 (3 D.F.)
2	0	95·10	95·03	95·00	94·81	94·94	94·50	94·90
	10	94·96	95·02	94·92	94·82	94·88	94·45	94·84
S.E.				0·052 (30 D.F.)				0·025 (3 D.F.)
3	0	94·89	94·87	94·86	94·69	94·84	94·29	94·74
	8	94·82	94·77	94·78	94·58	94·63	94·49	94·68
S.E.				0·057 (30 D.F.)				0·024 (3 D.F.)
Mean	−straw	94·99	94·96	94·89	94·71	94·79	94·32	94·78
	+straw	94·82	94·87	94·78	94·60	94·62	94·34	94·67
S.E.				0·042 (90 D.F.)				0·018 (9 D.F.)

* See text for explanation.
† Plots that did not receive pesticide at drilling.

Table 5. *Effect of 5 years of straw incorporation on the N uptake of unfertilized crops, and the apparent efficiency of fertilizer use. Parameters were estimated from simple linear regression analysis of measured N uptake on applied N*

Experiment	Incorporated straw (t/ha)	Nitrogen uptake by unfertilized crop (kg N/ha)	Efficiency of nitrogen fertilizer uptake (%)	Variation accounted for by regression (%)
1	0	161	34	92
	8	178	34	74
S.E. (6 D.F.)		10·2	9·4	
2	0	108	46	99
	10	89	47	95
S.E. (6 D.F.)		5·5	5·0	
3	0	143	47	99
	8	143	48	93
S.E. (6 D.F.)		6·7	6·0	

of 220 kg N/ha were sufficient to attain maximum yield for most sites/years tested but subsequent studies (Anon. 1990) showed that N uptake at optimal economic yield may be substantially smaller (*c*. 175 kg N/ha). In all experiments, the yield per kg N uptake varies widely. Last *et al*. (1983) obtained values ranging from 30 to 55 kg sugar/kg N. Other experiments (Anon. 1990) gave values from 33 to 95 with a mean of 63 kg sugar/kg N. In the current series, Expts 1 and 3 yielded 70 kg sugar/kg N, whilst Expt 2 gave 86 kg sugar/kg N. This variation in sugar yield per unit N is to be expected. Sugarbeet partitions only 30–50% of its N to the roots. Conversely, cereals may partition 75% of their N to the grain, and there are often good correlations between N uptake and grain yield (Vaidyanathan 1984). Also, the N content of beet tops and roots at the optimal N dressing are variable. Data from 34 field experiments (Broom's Barn, Rothamsted and British Sugar plc, unpublished) showed that, at the optimum N application rate, the mean N concentration of the roots was 0·53% and that of the tops 1·97%. Both these values had relative standard deviations of *c*. 12%. Sugarbeet therefore has the capacity to produce optimal sugar yields under a wide range of internal N concentrations.

A further complication is that nearly all the data relating optimal yield, N fertilization rate and N uptake are based upon variables measured at final

Table 6. *Effect of 5 years of straw incorporation on the optimal N fertilizer rate on the adjusted clean beet ACB yield for two pricing structures*

		'A+B' price regime		'C' price regime	
Experiment	Incorporated straw (t/ha)	Optimal N application rate (kg N/ha)	ACB yield at optimal N (t/ha)	Optimal N application rate (kg N/ha)	ACB yield at optimal N (t/ha)
1	0	106	87	98	87
	8	104	91	96	91
S.E. (16 D.F.)		9·9	1·2	10·1	1·2
2	0	102	82	94	82
	10	133	78	124	78
S.E. (16 D.F.)		10·4	1·3	10·7	1·2
3	0	118	85	110	85
	8	136	89	129	89
S.E. (16 D.F.)		10·5	1·3	10·7	1·2

For the 'A+B' pricing regime clean beet at 16% sugar has a value of £37.32/t, whilst in the 'C' pricing regime it has a value of £14.48/t. Nitrogen was assumed to cost £0.29/kg N. The S.E.s are asymmetric about the optima.

harvest. The N uptake by the beet crop at final harvest is often less than the maximum N uptake, due to loss of foliage in the autumn and winter. Beet also has the capacity to remobilize substantial amounts of N from top to root late in the season (Armstrong *et al.* 1986). Therefore, final harvest data cannot accurately represent N dynamics within the growing crop. A more accurate way of estimating fertilizer requirements may need to be based on measurements made during the period of fastest growth and N uptake. Recommendations could then be given to ensure rapid and complete canopy development.

The economic cost of straw incorporation in the UK

There was a tendency for straw incorporation to increase the N fertilizer requirement by *c.* 15 kg N/ha; however, yields were generally larger when straw was incorporated (Table 6). Using the 'C' price regime reduced the optimal N application by *c.* 8 kg N/ha, but had no effect on yield because the response curve is very flat about the optima. This is also why small errors in estimating the economically optimal yield cause rather large errors in the recommended fertilizer application rate.

To determine the optimum N dressing for commercial practice, the 'C' price regime was used. This is because, to achieve their allocated quota, growers will plant an area of beet which on the basis of previous experience will produce their A+B quota and an 'insurance' of *c.* 10–20% surplus 'C' beet. Within this system, N is not used as a tool to fine-tune production of quota but to maximize the economic return per unit area. The soils and cropping practices at Broom's Barn are representative of *c.* 40% of the national beet area (i.e. a beet/cereal rotation on loamy soils that have not received organic manures within the past 5–10 years). On this basis, at Broom's Barn the optimal N dressing for unincorporated soils was *c.* 100 kg N/ha. For incorporated soils it was *c.* 120 kg N/ha. These results suggest that for beet grown on the loam soils where straw is incorporated, the current recommendation of 125 kg N/ha is perfectly adequate. Where the straw is removed, a reduction of input to *c.* 100 kg N/ha could be made without any adverse effect on yield.

The effects of straw incorporation in the long term cannot be reliably assessed by experiments where only 5 years of straw incorporation has taken place. As stated in the initial paper (Allison *et al.* 1992), it will take many years for carbon and N inputs and outputs to return to equilibrium within soils that have only recently received annual inputs of straw. These experiments would suggest that, for many soils, the currently recommended N fertilizer inputs are sufficient. It would be advisable, however, to monitor straw disposal methods, fertilizer input, yield and processing quality to ensure that changes in soil fertility resulting from straw incorporation are matched by changes in crop management.

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