Journal of Agricultural Science, Cambridge (1992), **118**, 199–206. *Printed in Great Britain*

Effects of straw incorporation on the yield, nitrogen fertilizer and insecticide requirements of sugarbeet (*Beta vulgaris*)

M. F. ALLISON, K. W. JAGGARD AND P. J. LAST

Broom's Barn Experimental Station, Higham, Bury St Edmunds, Suffolk IP28 6NP, UK

(*Revised MS received 30 October 1991*)

SUMMARY

Incorporation of large amounts of straw (8–15 t/ha dry matter) into the soil had no effect on the incidence of soil pests and diseases or sugarbeet seedling population densities in experiments performed over three seasons (1984/85 to 1986/87) in Suffolk. Straw incorporation had no effect on sugar yield at the recommended rate of nitrogen fertilizer application, but the sugar yield and nitrogen uptake were reduced in one year by the incorporation of straw when the rate of applied nitrogen was low. It is probable that incorporating straw reduced the amount of nitrogen leached over the winter; however, the longer-term implications of straw incorporation remain to be assessed.

INTRODUCTION

At present, 19% of the sugarbeet crop in England follows a cereal, the straw of which is incorporated after harvest. This proportion has increased rapidly and is likely to increase further when in-field burning is banned after 1992. Although sugarbeet has been included in the crop rotation of several straw disposal studies in the past (Rayns & Culpin 1948; Harvey 1959; Patterson 1960; Short 1973), the agronomy of sugarbeet production has since changed substantially. The crop now receives less fertilizer nitrogen, is drilled to a stand and *c.* 50% of the crop is given a granular pesticide at sowing (Dewar & Cooke 1986). Equally important, the agronomy of the other crops in the rotation has also changed, particularly the management of cereals. Therefore, some of the conclusions from past experiments may not be applicable to today's farming practices. Thus a new series of experiments was started to investigate the effect of straw incorporation on plant establishment, incidence of pests and diseases, nitrogen requirement and use, nutrition and sugar yield.

MATERIALS AND METHODS

Each annual experiment was started sequentially, beginning in August 1984, using three fields at Broom's Barn Experimental Station, Suffolk. All fields were in a 5-course rotation of spring barley, winter oats, winter wheat, winter barley and sugarbeet. The experiments were numbered 1, 2 and 3 in chronological order, and only straw from the preceding winter barley crop was incorporated (Table 1).

Each experiment consisted of four blocks, each with two main plots where the straw was either removed (except for the stubble, which was 15 cm high) or incorporated. The amount of straw dry matter (DM) incorporated was 8 t/ha in Experiments 1 and 3; 10 t DM/ha in Experiment 2. In the following spring, sugarbeet seed was sown and the main plots were divided into six subplots. These were given five rates of nitrogen (40, 80, 120, 160 and 200 kg N/ha) allocated randomly, and all received 0·3 kg a.i./ha of granular pesticide at sowing (Table 1); the sixth subplot received 120 kg N/ha but no pesticide. Within each main plot, the subplots given 120 kg N/ha (with or without pesticide) were always adjacent to each other. The effects of incorporating a greater quantity of straw were also studied by including an additional main plot in one block of Expts 2 and 3; the amounts were 15 and 16 t DM/ha respectively. In each experiment, no discard areas were left between blocks, main plots or subplots. In Expt 1 the subplots were 2·5 m wide × 12·5 m long; in later experiments the plots were 3 m wide × 12 m long. However, in all experiments the two subplots receiving 120 kg N/ha were double these widths in order to reduce the risk that pests would rapidly migrate from the subplot without pesticide to the adjacent pest-free, pesticide-treated subplot.

Each winter barley crop was preceded by three other cereal crops, the straw from which was either removed or burnt. After the barley was harvested, the

Table 1. *Soils and management details for Broom's Barn Experimental Station, Suffolk, UK, 1983–87*

	Experiment 1	Experiment 2	Experiment 3
Soil series	Stretham/Dullingham (clay loam/sandy clay to clay loam)	Ashley/Stretham (sandy to sandy clay loam/clay loam)	Barrow (sandy loam)
Farmyard manure last applied and rate (t/ha)	Autumn 1983 15·2	Autumn 1984 17·1	Autumn 1980 27·2
Straw incorporation date prior to sugarbeet	22 Aug 84	18 Aug 85	17 Aug 86
Date sugarbeet sown	10 Apr 85	30 Apr 86	18 Apr 87
Pesticide at sowing	Aldicarb/γ HCH	Aldicarb/γ HCH	Aldicarb
Harvest date	15 Nov 85	24 Nov 86	3 Dec 87

straw was baled and removed, and its moisture content determined by drying a weighed sample at 85 °C to constant weight. The required weight of straw was then chopped to lengths of *c.* 5 cm and spread uniformly on the appropriate plots. The straw was incorporated with one pass of a powered harrow working to a depth of *c.* 12 cm. Nutrients (66 kg/ha P, 166 kg/ha K, 120 kg/ha Mg and 148 kg/ha Na) were then applied to the whole experimental area which, in November, was ploughed (25 cm depth) and the soil consolidated by a furrow press (Jaggard *et al.* 1989). In spring, a seedbed was prepared with one pass of a powered rotary harrow and crumbler. Beet seed was sown with a precision drill at an average spacing of 17·7 cm, in rows 50 cm apart. All three experiments were irrigated during the summer so that the limiting soil moisture deficits for each month 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 between 4 and 5 weeks after sowing, when most seedlings had four true leaves. At harvest, the plants were counted, lifted and topped manually. The tops were weighed and subsamples were dried to constant weight at 85 °C to determine 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 < 1·0 mm and their nitrogen contents determined by Kjeldahl digestion using standard methodology (MAFF/ADAS 1986).

The mineral nitrogen content in the soils in spring was determined in samples augered (0–30 cm and 30–60 cm) from the centre of those plots receiving 40 kg N/ha. The samples were immediately extracted with 0·5 M-K_2SO_4 and analysed. The results have been corrected to allow for variations in soil water content and bulk density.

Analyses of variance were produced for all plant and soil variates. For variates comprising a data-value for each subplot, split-plot analyses of variance were, for simplicity, obtained 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 thus be treated with caution. Differences are quoted as being significant only if their occurrence by chance was < 5% ($P < 0·05$).

RESULTS AND DISCUSSION

Seedling establishment

Neither straw incorporation nor nitrogen fertilizer had any consistent effect on plant population densities (Table 2), and in the first two experiments there was no significant effect of granular pesticide. This is much as expected, the farm is typical of much of the UK beet-growing area, and the soil does not contain large populations of pest species (soil pest numbers were monitored using bait methods as described by Brown (1984), and by analysis of soil cores – data not shown). However, in Expt 3, plant populations increased significantly where aldicarb granules were not used, whether straw was incorporated or not. This was unexpected, as aldicarb is considered safe for use on sugarbeet. However, other beet seedlings from mid-April sowings at Broom's Barn in this year had damaged cotyledons and root systems; these symptoms were attributed to the combined effects of an application of chloridazon herbicide and a residue of chlorsulfuron (Jaggard 1988). It is therefore likely that aldicarb aggravated any such herbicide damage, as similar interactions between pesticides have been found with carbofuran and metamitron (G. H. Winder, personal communication). In any event, plant population densities in aldicarb-treated plots were more than adequate to produce maximum yield (Jaggard *et al.* 1989).

Table 2. *Effects of incorporated straw, fertilizer nitrogen and granular pesticide on seedling population of sugarbeet (1000/ha) 4–5 weeks after sowing in three experiments at Broom's Barn, Suffolk, UK. Except where indicated, means are from four replicate blocks. All fertilizer treatments except one had pesticide at drilling*

Experiment	Incorporated straw (t/ha)	Fertilizer nitrogen (kg/ha) 40	80	120	120*	160	200	Mean
1	0	70·3	70·2	66·0	65·8	67·5	72·8	68·8
	8	71·2	69·3	73·7	69·2	65·0	69·5	69·6
S.E. (same rate of straw)				±2·30				S.E. ±0·91
S.E. (different rate of straw)				±2·29				
2	0	93·6	85·8	88·4	87·0	89·8	84·5	88·2
	10	88·0	80·0	88·6	92·0	82·8	85·9	86·2
S.E. (same rate of straw)				±3·92				S.E. ±2·28
S.E. (different rate of straw)				±4·25				
	15†	81·9	75·6	80·0	85·0	84·4	79·4	81·1
3	0	86·7	90·3	91·6	95·3	88·6	84·4	89·6
	8	87·7	93·6	88·8	94·8	87·0	90·8	90·4
S.E. (same rate of straw)				±1·83				S.E. ±0·42
S.E. (different rate of straw)				±1·73				
	16†	88·1	88·8	94·7	100·0	92·5	89·4	91·4

* No pesticide at drilling.
† Means are from one block only.

Table 3. *Effect of incorporated straw on nitrate plus ammonium nitrogen (kg/ha) in top- and subsoil in spring for three experiments at Broom's Barn, Suffolk, UK. Except where indicated means are from four replicate blocks. Soils in Expt 1 and Expt 2 were sampled* c. *4 weeks after the application of 40 kg N/ha as ammonium nitrate whereas soils in Expt 3 were sampled just before drilling*

Experiment	Incorporated straw (t/ha)	Depth (cm) 0–30	30–60	S.E.
1	0	66	42	±5·2
	8	41	26	
2	0	43	34	±6·7
	10	36	39	
	15*	55	58	
3	0	10	15	±7·3
	8	13	13	
	16*	8	11	

* Means are from one block only.

The effect of straw on nitrogen available for growth

In Expt 1, the presence of incorporated straw reduced the amount of soil mineral nitrogen by one-third, whereas there was a negligible effect in Expts 2 and 3 (Table 3). The effect of straw incorporation on soil mineral N in Expt 1 is difficult to explain. Excessive winter leaching might compound the effect of straw on N availability and hence on yield. Winter drainage (calculated from the August soil moisture deficit accumulated under a cereal crop, and 'effective rainfall' i.e. rainfall adjusted for any evaporation) was 170, 135 and 250 mm in Expts 1, 2 and 3 respectively. Therefore, if winter leaching was a major factor determining inorganic nitrogen in spring, Expts 1 and 2 should have similar quantities of mineral N, with Expt 3 having considerably less. If breakdown of the straw is delayed because of cold, wet conditions, then this might also depress the inorganic nitrogen content of the soil in the spring. However, soil temperatures (10 cm depth) during September to November were higher in 1984 than in the following 2 years, and so it is unlikely that breakdown of the straw was delayed. However, as suggested by Bowen & Harper (1987), the delay in breakdown could perhaps have been caused by a smaller initial inoculum of lignin-decomposing basidiomycetes within the soil of Expt 1 as compared to Expts 2 and 3.

Due to its large C:N ratio, cereal straw immobilizes inorganic nitrogen within the soil when it decomposes. Empirical determinations by Short (1973) at Terrington Experimental Husbandry Farm (EHF) showed that an additional 7·5 kg N was required to offset the immobilization losses caused by incorporating 1 tonne of straw. This is broadly in agreement with the value of 10 kg N/t straw calculated by Johnston & Powlson (1985). Therefore, assuming the mean of these values, incorporation of 8 or 10 t/ha straw might immobilize 70–90 kg N/ha. Expts

Table 4. *Effects of incorporated straw, fertilizer nitrogen and granular pesticide on crop nitrogen uptake (kg N/ha) in three experiments at Broom's Barn, Suffolk, UK. Except where indicated, means are from four replicate blocks. All fertilizer treatments except one had pesticide at drilling*

Experiment	Incorporated straw (t/ha)	Fertilizer nitrogen (kg/ha) 40	80	120	120*	160	200	Mean
1	0	168	173	189	196	212	249	198
	8	135	156	176	192	203	220	180
S.E. (same rate of straw)				±9·3				S.E. ±7·7
S.E. (different rate of straw)				±11·5				
2	0	119	153	190	181	202	251	183
	10	113	136	164	174	190	210	165
S.E. (same rate of straw)				±8·7				S.E. ±9·9
S.E. (different rate of straw)				±12·7				
	15†	106	127	170	129	165	168	
3	0	147	166	193	198	202	214	187
	8	138	158	169	180	205	200	175
S.E. (same rate of straw)				±8·9				S.E. ±3·5
S.E. (different rate of straw)				±8·8				
	16†	128	140	187	186	168	245	

* No pesticide at drilling.
† Means are from one block only.

2 and 3 show that there was no difference in soil mineral N between plots with and without incorporated straw. In these years sufficient nitrogen must have been available to satisfy the demands of the soil biomass. This nitrogen probably originated from the previous crop (e.g. unused fertilizer or, more likely, nitrogen mineralized from soil organic matter late in the growing period) and post-harvest mineralization. Values for residual nitrogen were not determined in this series of experiments. Other data (unpublished) suggest that about 40–60 kg N/ha may remain in the top 60 cm of soil after the harvest of cereals. The shortfall of 10–50 kg N/ha must therefore be fulfilled by post-harvest mineralization. In Expts 2 and 3, the losses of inorganic nitrogen from plots where straw was not incorporated must have been similar to the amounts immobilized where straw was incorporated (i.e. 70–90 kg N/ha). However, the interpretation of these data is complicated by the extra cultivation needed to incorporate the straw. This would stimulate nitrogen mineralization (Dowdell & Cannell 1975; Davies 1985). Recent (unpublished) work at Broom's Barn shows that a rotary cultivation to 6 cm depth stimulated the mineralization of *c.* 40 kg N/ha. The net effect is that the incorporation of 8–10 t/ha of straw may reduce nitrate leaching by 30–50 kg N/ha.

Similar results have been reported by Powlson *et al.* (1985) and Jarvis *et al.* (1989). Powlson showed that the leaching of autumn applied ^{15}N fertilizer was reduced from 30 kg N/ha to 23 kg N/ha by incorporating 3 t/ha of wheat straw. Jarvis demonstrated that the incorporation of 4–6 t/ha of straw could prevent up to 52 kg N/ha from leaching. Similar results were obtained by Machet & Mary (1989). However, the saving would always depend on soil type, nitrogen fertilizer input, crop grown and residue management. The figures from Broom's Barn may be overestimated, since partial anaerobicity might substantially reduce the amount of nitrogen immobilized per tonne of straw decomposed. Similarly, less nitrogen will probably be immobilized by a small biomass with rapid turnover than by a larger biomass with a slower turnover.

Nitrogen uptake and yield

As expected, nitrogen uptake by the tops and roots at harvest was significantly and positively affected by N fertilizer treatments (Table 4). There was a tendency for uptake to be smaller where straw was incorporated although, except in 1985, this effect was too small to be significant. In Expt 1, uptake was significantly reduced by the presence of incorporated straw, where the smallest dose of nitrogen fertilizer was applied: this is consistent with the effects of incorporated straw on soil mineral N (Table 3). Differences in crop nitrogen uptake were due to variations in crop dry matter production, not dry matter N concentration.

Sugar concentration and yield

Sugar concentration (Table 5) was not significantly affected by straw incorporation, but was always reduced (by 0·3 to 0·5%) by large amounts of N (160

Table 5. *Effect of incorporated straw, fertilizer nitrogen and granular pesticide on root sugar percentage, in three experiments at Broom's Barn, Suffolk, UK. Except where indicated, means are from four replicate blocks. All fertilizer treatments except one had pesticide at drilling*

Experiment	Incorporated straw (t/ha)	Fertilizer nitrogen (kg/ha) 40	80	120	120*	160	200	Mean
1	0	20·0	19·8	19·9	19·7	19·7	19·5	19·8
	8	19·8	20·1	20·0	20·0	19·8	19·6	19·9
S.E. (same rate of straw)				±0·16				S.E. ±0·08
S.E. (different rate of straw)				±0·17				
2	0	19·4	19·4	19·3	19·3	19·4	19·0	19·3
	10	19·3	19·4	19·3	19·3	19·2	18·9	19·2
S.E. (same rate of straw)				±0·08				S.E. ±0·04
S.E. (different rate of straw)				±0·08				
	15†	19·6	19·5	19·3	19·6	19·5	19·3	
3	0	18·7	18·7	18·6	18·7	18·5	18·5	18·6
	8	18·7	18·9	18·7	18·9	18·7	18·6	18·8
S.E. (same rate of straw)				±0·07				S.E. ±0·04
S.E. (different rate of straw)				±0·08				
	16†	18·6	18·9	18·7	18·5	18·6	18·3	

* No pesticide at drilling.
† Means are from one block only.

Table 6. *Effects of incorporated straw, fertilizer nitrogen and granular pesticide on sugar yield (t/ha), in three experiments at Broom's Barn, Suffolk, UK. Except where indicated, means are from four replicate blocks. All fertilizer treatments except one had pesticide at drilling*

Experiment	Incorporated straw (t/ha)	Fertilizer nitrogen (kg/ha) 40	80	120	120*	160	200	Mean
1	0	11·1	11·4	11·8	11·5	11·8	11·6	11·5
	8	9·7	10·5	11·8	10·7	11·3	11·8	11·0
S.E. (same rate of straw)				±0·23				S.E. ±0·36
S.E. (different rate of straw)				±0·42				
2	0	8·7	9·1	10·1	9·7	10·3	10·8	9·8
	10	8·1	9·2	10·0	10·0	9·9	10·0	9·5
S.E. (same rate of straw)				±0·24				S.E. ±0·28
S.E. (different rate of straw)				±0·36				
	15†	7·9	8·3	8·9	9·2	9·5	10·5	
3	0	9·6	10·8	11·1	11·3	11·2	11·3	10·9
	8	9·4	10·7	11·4	11·2	11·4	11·5	10·9
S.E. (same rate of straw)				±0·13				S.E. ±0·01
S.E. (different rate of straw)				±0·12				
	16†	8·6	10·4	11·3	11·4	11·4	11·6	

* No pesticide at drilling.
† Means are from one block only.

or 200 kg/ha). However, this effect is well known (Draycott *et al.* 1971) and will not be discussed in detail here.

Sugar yields (the product of root yield and sugar concentration) showed significant, positive responses to nitrogen in all 3 years, and incorporation of straw generally had no significant effect in any one year (Table 6). However, where the amount of applied nitrogen was small, the presence of incorporated straw tended to depress yield; this was particularly marked and significant in Expt 1. Growers with mineral soils like those used for these experiments

Table 7. *Effects of incorporated straw, fertilizer nitrogen and granular pesticide on root amino nitrogen impurities (mg/100 g sugar) in three experiments at Broom's Barn, Suffolk, UK. Except where indicated, means are from four replicate blocks. All fertilizer treatments except one had pesticide at drilling*

Experiment	Incorporated straw (t/ha)	Fertilizer nitrogen (kg/ha) 40	80	120	120*	160	200	Mean
1	0	103	108	134	133	151	179	135
	8	92	95	103	107	133	149	113
S.E. (same rate of straw)				±9·4				S.E. ±3·9
S.E. (different rate of straw)				±9·3				
2	0	40	52	71	71	83	117	72
	10	40	54	65	63	84	115	70
S.E. (same rate of straw)				±5·3				S.E. ±6·1
S.E. (different rate of straw)				±7·8				
	15†	41	51	83	51	67	47	
3	0	35	50	56	53	97	95	64
	8	33	48	56	54	76	95	60
S.E. (same rate of straw)				±4·2				S.E. ±1·7
S.E. (different rate of straw)				±4·0				
	16†	40	42	58	57	80	106	

* No pesticide at drilling.
† Means are from one block only.

would normally be advised to apply 120 kg N/ha for beet (Jaggard *et al.* 1989). In Expts 1 and 3, this rate was justified and adequate on those plots without incorporated straw (Table 6). This pattern was not evident in Expt 2, where the plots given 200 kg N/ha but no straw produced an unexpectedly large yield. Where straw was incorporated at 8 or 10 t/ha the N fertilizer requirement remained at 120 kg N/ha and, at this rate, straw incorporation had no effect on yield. However, there was an indication in both Expts 2 and 3 that the very large amounts of incorporated straw (15 or 16 t DM/ha) did increase the nitrogen requirement of the beet crop. These rates are not unrealistic; uneven spreading of straw across the width of the combine harvester could give these rates. It is also common for farmers to protect carrot crops from frost with 50 t/ha of straw, much of which is disposed of by incorporation in early spring.

Patterson (1960) reported a three-course rotation experiment on straw disposal at Rothamsted which included beet. From 1934 to 1951, average sugar yields were slightly depressed (from 5·41 to 5·13 t/ha) where straw (6·7 t/ha) had been incorporated the previous autumn. These experiments had only small inputs of fertilizer N, to both the beet crop (75 kg/ha) and the preceding cereal (50 kg/ha). When the experiments were revised and a supplementary 25 kg N/ha was applied to the straw in the autumn, the yield penalty was removed. Similar results were obtained in long-term straw disposal experiments performed at the Ministry of Agriculture's EHFs and reported by Short (1973). In the final rotation (1964–68), where no 'supplementary' nitrogen was applied, straw incorporation did not reduce sugar yields, probably because the N application rates were larger than in the Rothamsted experiments. For example, beet received either 75 or 113–126 kg N/ha. The experiments reported by Patterson and by Short were not irrigated, unlike the current experiments. Irrigation may have slightly stimulated N mineralization from organic matter (Last *et al.* 1983) and this might explain the differences between earlier work (particularly Patterson's) and the current experiments.

Alterations to the dynamics of N supply caused by adding straw could affect beet quality. In all 3 years, N fertilizer significantly increased the amounts of α-amino nitrogen, an important class of nitrogenous impurities (Table 7). Straw incorporation tended to reduce impurity concentration, although the effect was seldom significant. The reduction was greatest in Expt 1, again supporting the results found for soil N and crop N uptake. At the recommended N application rate (120 kg N/ha) impurity levels were always within the range acceptable to the processors.

Soil nitrogen supply

With current agricultural practices there seems to be sufficient inorganic N in the soil to supply the biomass decomposing incorporated straw. Mineralization of soil organic matter might also be enhanced under current management. Increased fertilizer use can increase the amounts of roots and stubble being returned to the soil; this will in turn lead to a larger, more active microbial biomass, which mineralizes more nitrogen (Johnston & Powlson 1985). The supply of remineralized nitrogen can have a deleterious effect on sugarbeet quality, particularly on the quantities of amino nitrogen impurities (Draycott *et al.* 1971; Armstrong & Milford 1985). It is possible, therefore, that many years of straw incorporation might reduce beet quality through oversupply of mineralized organic nitrogen unless the supply of fertilizer N was decreased appropriately.

Studies of nitrogen immobilization and remineralization in soils with incorporated straw, using ^{15}N-labelled fertilizer, showed that nitrogen remained immobilized for long periods (Stojanovic & Broadbent 1956; Broadbent & Tyler 1962). Studies by Powlson *et al.* (1985) showed that one year after incorporation, 78% of the immobilized nitrogen still remained in the soil organic matter. Therefore, remineralization of immobilized nitrogen in soils with incorporated straw is unlikely to be an important component of sugarbeet nutrition, unless the amounts of soil organic matter are increased markedly by straw incorporation. Experiments over a 6-year period at Woburn showed that straw incorporation maintained the soil organic matter status at 1·58% – identical to that of a 6-year ley (Johnston 1985). Conversely, studies on a Danish soil reported by Powlson *et al.* (1987) showed that 18 years of straw incorporation did not significantly increase the organic matter content. It seems that the long-term effects of straw incorporation may take several years to manifest themselves and will depend on both soil and climatic conditions.

In conclusion, these annual experiments have demonstrated that incorporation of the previous cereal crop's residue did not increase the fertilizer N requirement of the sugarbeet crop. It is also likely that in the short term, straw incorporation will reduce nitrate leaching. However the longer term effects of straw incorporation remain to be assessed. It is therefore intended that the experiments reported here should continue with straw incorporation treatments for a rotation of four cereal crops before the nitrogen and pesticide responses are tested in beet again, in the fifth year.

The authors thank J. Webb, A. Dewar, the experimental services group and the crop productivity group for initiating and performing these experiments. Thanks are also due to A. E. Johnston for consultation at the outset. This work was funded by the Home Grown Sugar Beet Research and Education Committee.

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