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Integration of nitrate cover crops into sugarbeet (*Beta vulgaris*) rotations. II. Effect of cover crops on growth, yield and N requirement of sugarbeet

M. F. ALLISON[1]*, M. J. ARMSTRONG[2], K. W. JAGGARD[1] AND A. D. TODD[3]

[1] *IACR Broom's Barn, Higham, Bury St Edmunds, Suffolk IP28 6NP, UK*
[2] *British Sugar plc, Holmewood Hall, Holme, Cambridgeshire PE7 3PG, UK*
[3] *IACR Rothamsted, Harpenden, Hertfordshire AL5 2JQ, UK*

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SUMMARY

Between 1989 and 1993, 17 experiments tested the effects of autumn-sown cover crops on the yield, processing quality and N nutrition of subsequent sugarbeet crops. Cover crops had no effect on sugarbeet plant population density or pesticide requirement. In nitrogen response experiments, the mean beet yield at the economic optimum was 83 t/ha. The mean N fertilizer requirement was 96 kg N/ha and the N uptake at maximum yield averaged 180 kg N/ha. Cover crops had no effect on yield, fertilizer requirement or N uptake. In addition, cover crops generally had no effect on the efficiency of N fertilizer use, the mineralization of N from the soil organic matter nor the amount of soil mineral nitrogen at sowing or at harvest of the beet crop. Processing quality was also not affected by cover crops. The cost of growing a cover crop ranged from 0 to 50 £/ha. Since these costs cannot be offset against increases in yields or reduced fertilizer application rates, cover crops need to be low cost, i.e. cheap seed and minimal cultivation. Cover crops using volunteer cereals and weeds or farm-saved grain that are established with a single stubble-cultivation should fulfil these criteria.

INTRODUCTION

An earlier paper (Allison *et al.* 1998) reports the effects of cover species, sowing and destruction date on cover crop dry matter (DM) yield, N uptake, soil mineral nitrogen (SMN) and soil water. This paper investigates the effect of cover crops on sugarbeet yield, processing quality and N nutrition. Earlier studies on peas (Knott 1996) and spring barley (Richards *et al.* 1996) have shown that cover crops have relatively little effect on yield or N nutrition. To date, there has been little reported work on the effects of autumn-sown cover crops on subsequent beet crops. Effects of green manure (Dyke 1965; Draycott & Last 1970; Last *et al.* 1981) on beet yield were variable, with the greatest benefit occurring at low N fertilizer rates. Last *et al.* (1981) also showed that green manures caused an increase in N uptake by beet and also increased α-amino N impurities within the roots. Large amounts of α-amino N impurities in the root reduce the extraction efficiency of sugar during processing. Autumn-sown cover crops might similarly be expected to affect N supply to the beet crop and thus alter yield or processing quality. This paper investigates the effects of cover crops on the growth, yield, processing quality, N and pesticide requirements of a subsequent beet crop.

* Present address: Cambridge University Farm, Huntingdon Rd, Girton, Cambridge CB3 0LH, UK. Email: mfa22@cam.ac.uk

MATERIALS AND METHODS

Between 1989 and 1993, 17 experiments tested the effects of nitrate cover crops on the growth, yield, N and pesticide requirement of sugarbeet. Details about the growth of the cover crops, soil types, experiment locations and design are given by Allison *et al.* (1998). Details about the management and analysis of the sugarbeet crop are given here.

Basal (P, K and Mg) fertilizers for each sugarbeet crop were applied before the cover crop was destroyed by ploughing, at rates determined by soil analysis. All crops were sown in April to a stand, using monogerm pelleted seed. The N treatments were applied as ammonium nitrate as a split dressing, 30 kg N/ha at the time of drilling, the remainder when most of the crop had 2–4 true leaves.

At harvest in the autumn, plants were lifted by hand from the centre 8×2 m (four rows) of each plot.

The plants were topped at the height of the first leaf scar and the roots counted. Twenty tops (i.e. crown plus petioles and leaves) from each plot were weighed in the field and a subsample of five tops was dried at 85 °C for 48 h and weighed. All the beet from each plot was washed and weighed (clean beet weight), and subsampled by passing the beet over high-speed circular saws. One subsample of this brei was extracted with basic lead acetate, for measurement of the sucrose, α-amino N, Na and K contents by standard methods (Last *et al*. 1976). The combined effects of α-amino N, Na and K on the amount of sugar lost to molasses in the factory process was assessed using the 'New Braunschweig formula' (Märländer *et al*. 1996):

$$\text{Sugar loss} = 0{\cdot}12\,(\text{Na}+\text{K}) + 0{\cdot}24\,(\alpha\text{-amino N}) + 1{\cdot}08 \quad (1)$$

where α-amino N, Na and K are expressed as mmol/100 g beet.

Another subsample of brei was dried at 85 °C. The dried samples of tops and brei were milled (< 1 mm), and their total N contents were measured by Kjeldahl digestion, modified to include nitrate (AOAC 1955), or by an automated Dumas combustion method (LECO Corporation, St Joseph, Michigan, USA).

The amounts of inorganic N mineralized from the soil organic matter during the growing season were indirectly estimated by subtracting the amount of mineral N present in the soil in spring from that contained in the crop and soil at harvest.

Yields were converted to adjusted tonnages of clean beet (ACB) by standardizing their sugar concentrations to 16%. These tonnages were further corrected by subtracting a weight of beet equivalent in value to the cost of the N fertilizer. In calculating these corrected and adjusted yields of clean beet (CACB), the clean beet was valued at the 1992 'C quota' price of £14.48/tonne, and the N fertilizer at £0.29/kg. The CACB yields (y) were related to rates of applied N (x) using the exponential plus linear model as used by Allison *et al*. (1996):

$$y = a + br^x + cx \quad (2)$$

Best fit values were obtained for the parameters r and c by using all the data, but different values were calculated for parameters a and b for each site in each year. This produced curves of similar shape in which the asymptotes were displaced horizontally and vertically in accordance with the effects of site and season. The intersect of the asymptote with the ordinate gave the optimum economic yield and its intersect with the abscissa, the optimum amount of N fertilizer required to achieve the optimum economic yield (N_{opt}). The efficiency of use of fertilizer N was estimated as the slope of the linear regression relating the total N content of the crop at harvest to the amount of N fertilizer applied. The N content of the crops at optimum economic yield were calculated by substituting values of N_{opt}, obtained from the response curve, into the linear regressions.

The effects of N rate and season, and their interaction with site, on the actual and maximum economic yields, quality attributes, N_{opt} and N uptake at maximum economic yield were tested by analysis of variance. For simplicity, only the seven N response experiments will be discussed in detail. These included the two largest cover crops (North Duffield 1991, phacelia (*Phacelia tanacetifolia* Benth.), 5·2 t/ha; Coney Weston 1993, fodder radish 6·8 t/ha) and should, therefore, demonstrate what effects cover crops have on subsequent beet crops. Where appropriate, reference will also be made to the 'time of cover crop destruction' experiments and to the cover crop 'species and sowing date' experiments.

RESULTS AND DISCUSSION

Plant population densities

The production of cover crops, and their sowing and destruction dates, had no significant effects on plant population density at any year/site. In two experiments (Broom's Barn 1991 and 1992), the effect of cover crops on plant population density was tested in factorial combination with the pesticide Temik (Aldicarb). These two experiments showed that Temik at 7·5 kg active ingredient/ha had no effect on plant population density, and that damage due to soil pests was not increased when cover crops were used. These results agree with those of Last *et al*. (1981), who found that green manure residues had no effect on plant establishment, and those of Allison & Hetschkun (1995), who found that cereal straw residues also had no effect on establishment. In some circumstances, returning cover crop residues to the soil may help to reduce pest damage to the beet crop by providing an alternative food source for soil pests (Cooke 1993). In all experiments, plant population densities were > 75000 plants/ha, which is the minimum needed to attain maximum yield potential (Jaggard *et al*. 1995).

Yield, N fertilizer requirement and N uptake

In the seven N-response experiments, the economic maximum beet yield ranged from 47 t/ha at North Duffield in 1991 to 97 t/ha at Coney Weston in 1993 (Table 1). Average yields for the experiments at Broom's Barn were 90 t/ha. In all seven N-response experiments, the use of a cover crop had no significant effect on beet yield. The effect of cover crop destruction date was tested at two sites; Pakenham in 1991 and Barningham in 1992. Changing the destruction date from November to February had no significant effect on adjusted beet yield, although at Barningham the fodder radish cover crop was associated with a 5 t/ha increase in beet yield.

Table 1. *Effect of cover crops on economic optimum yield, economic optimum fertilizer rate* (N_{opt}) *and N uptake at the economic optimum* (N_{opt}) *of seven sugarbeet crops. The letters E and L refer to early* (*July*) *or late* (*September*) *sowing of the cover crop. All* S.E.*s are based upon 69* D.F.

Site and year	Cover crop	Yield S.E. (t/ha)	N_{opt} S.E. (kg N/ha)	N_{opt} S.E. (kg N/ha)
North Duffield 1990	Control	73·6 ± 0·91	111 ± 7·9	171 ± 3·6
	Phacelia-E	73·1 ± 0·84	93 ± 8·7	177 ± 3·4
North Duffield 1991	Control	47·6 ± 0·88	103 ± 8·2	103 ± 3·5
	Phacelia-E	46·5 ± 0·96	124 ± 7·8	109 ± 3·9
Broom's Barn 1991	Control	89·1 ± 0·89	107 ± 8·0	166 ± 3·5
	Phacelia-E	88·4 ± 0·91	113 ± 7·9	167 ± 3·6
Heighington 1992	Control	79·4 ± 0·93	117 ± 7·8	194 ± 3·7
	Fodder radish-E	79·1 ± 0·93	118 ± 7·8	185 ± 3·8
Broom's Barn 1992	Control	88·0 ± 0·91	112 ± 7·9	197 ± 3·6
	Buckwheat-E	88·9 ± 0·99	131 ± 8·0	199 ± 4·1
Coney Weston 1993	Control	93·3 ± 1·07	17 ± 23·6	214 ± 5·8
	Volunteers-E	96·5 ± 0·95	67 ± 12·4	243 ± 4·2
	Fodder radish-E	93·7 ± 0·93	55 ± 14·1	230 ± 4·5
	Fodder radish-L	96·7 ± 0·97	30 ± 19·6	222 ± 5·3
Broom's Barn 1993	Control	91·1 ± 1·18	129 ± 8·4	176 ± 4·7
	Barley-E	91·7 ± 1·14	119 ± 8·4	163 ± 4·4
	Barley-L	88·5 ± 1·10	111 ± 8·6	160 ± 4·3

Table 2. *Effect of cover crops on the uptake of N in crops receiving no fertilizer and the efficiency of fertilizer usage in fertilized crops. The letters E and L refer to early* (*July*) *or late* (*September*) *sowing of the cover crop. All* S.E.*s are based upon 10* D.F. *except for Coney Weston 1993* (*12* D.F.) *and Broom's Barn 1993* (*9* D.F.)

Site and year	Cover crop	N uptake S.E. (kg N/ha)	Efficiency S.E. (%)
North Duffield 1990	Control	130 ± 5·2	51 ± 4·8
	Phacelia-E	104 ± 5·2	61 ± 4·8
North Duffield 1991	Control	67 ± 3·9	34 ± 3·6
	Phacelia-E	72 ± 3·9	30 ± 3·6
Broom's Barn 1991	Control	112 ± 5·7	49 ± 5·3
	Phacelia-E	114 ± 5·7	49 ± 5·3
Heighington 1992	Control	123 ± 5·9	61 ± 5·4
	Fodder radish-E	121 ± 5·9	54 ± 5·4
Broom's Barn 1992	Control	134 ± 6·6	50 ± 6·1
	Buckwheat-E	139 ± 6·6	51 ± 6.1
Coney Weston 1993	Control	207 ± 10·1	44 ± 9·0
	Volunteers-E	206 ± 10·1	55 ± 9·0
	Fodder radish-E	208 ± 10·1	40 ± 9·0
	Fodder radish-L	208 ± 10·1	46 ± 9·0
Broom's Barn 1993	Control	118 ± 3·2	44 ± 2·8
	Barley-E	113 ± 3·2	42 ± 2·8
	Barley-L	110 ± 3·2	45 ± 2·8

The economic optimum N application rate varied from 17 kg N/ha at Coney Weston in 1993 to 130 kg N/ha at Broom's Barn in 1992. With the exception of Coney Weston, the N fertilizer requirement for all sites was similar to that currently recommended for those soil types and previous cropping histories (Jaggard *et al*. 1995). The average N fertilizer requirement for Broom's Barn was 120 kg N/ha – very similar to that found in previous studies (Allison *et al*. 1996). The small fertilizer requirement for Coney Weston in 1993 suggests that organic manures or previous crops leaving large N residues had been used. Cover crops had no effect on the N fertilizer requirement of the beet crops and therefore current recommendations do not need to be modified when cover crops are grown.

Earlier work (Allison *et al.* 1996) has shown that, at the economic maximum yield, the total N uptake of the beet crop needs to be *c*. 200 kg N/ha. In these current N-response experiments, the overall mean N uptake was 180 kg N/ha, ranging from 100 kg N/ha at North Duffield (1991) to 230 kg N/ha at Coney Weston (1993). In common with yield and N requirement, cover crops had no effect on N uptake at the maximum economic yield at any site or year.

Uptake of N by unfertilized crops and efficiency of N fertilizer use

The uptake of N by crops receiving no fertilizer and the efficiency with which N fertilizer was used was estimated from the intercepts and slopes of regressions of N uptake against N applied (Table 2). The average N uptake was 130 kg N/ha and ranged from 70 (at North Duffield) to 210 kg N/ha (at Coney Weston). The average efficiency of N fertilizer use was 47%, and ranged from 30 to 61%. In earlier studies (Allison *et al.* 1996), an average efficiency of 60% was measured. The smaller average efficiency in these experiments is mainly due to low efficiency of N use at North Duffield in 1991 and at Coney Weston in 1993. The North Duffield site also had a small economic optimal yield and a small N uptake at optimal yield. The small efficiency at Coney Weston probably resulted from the large amount of inorganic N in the soil. Generally, cover crops had no effect on either N uptake of unfertilized crops or on the efficiency of N fertilizer use. The sole exception was at North Duffield in 1990, where N uptake was 26 kg N/ha less when a cover crop was grown.

Quantity of N in soil at sowing, harvest and amount of N mineralized

In the unfertilized plots, the amount of N in the soil at sowing of the beet crop averaged 66 kg N/ha (Table 3) which is a typical value for these soil types and cropping histories. There were large amounts of SMN at Coney Weston, again suggesting the prior use of organic manures or the use of crops that left large N residues. The use of cover crops had no effect of the amount of SMN in the soil at sowing.

The quantity of SMN in the soil at harvest of unfertilized beet crops was also typical and averaged 22 kg N/ha. At Heighington in 1992, cover crops significantly increased SMN by 3 kg N/ha; however, this small amount is not agronomically or environmentally important. Apart from this example, cover crops had no effect on SMN at harvest.

The amount of N mineralized from the soil organic matter averaged 93 kg N/ha, a value which is typical for these soil types. Cover crops had no significant effect on N mineralization, with one exception; N mineralized at North Duffield in 1990 was reduced by 21 kg N/ha.

The lack of effect of cover crops on beet yield is not surprising, as previous work (Allison & Armstrong 1995; Allison *et al.* 1996) has shown that, close to the economic optimum, beet yields are relatively insensitive to N supply. For instance, compared to the yield at the optimum N rate, changing the N input by 60 kg N/ha will change the beet yield by *c*. 3 t/ha. Our experiments have shown that cover crops have little or no effect on N supply to the beet crop (i.e. SMN at drilling or N mineralized are unaffected). Both Knott (1996) and Richards *et al.* (1996) have shown that cover crops had little effect on the yield of peas or spring barley, respectively. Richards *et al.* (1996) attributed the lack of effect of cover crops on yield and N nutrition to be due to the relatively large C:N ratio of the cover crop residues (mean 11·2). This meant that the small amount of N released from the cover crop residues was negligible compared with N inputs from mineralization of soil organic matter or precipitation. In our experiments, the mean C:N ratio of the cover crop residues was 20, resulting in even less N being released to the sugarbeet crop. The use of C:N ratios to predict N transfer release from crop residues to the beet crop assumes negligible losses of N from the soil/crop system. Cover crop destruction by ploughing in late autumn or winter should minimize losses of N by ammonia volatilization. Denitrification losses, however, may be much larger, depending on soil conditions.

Effect of cover crops on root sugar concentrations and beet processing quality

The effects of N on root sugar concentrations and on α-amino N, K and Na impurities are well known (i.e. Pocock *et al.* 1990; Allison *et al.* 1996). Therefore, for simplicity, the effects of cover crops on sugar and impurities were analysed at the N application rate closest to the economic optima.

Cover crops had small and inconsistent effects on sugar concentration and on root impurities (Table 4). Sugar contents in the seven N-response experiments averaged 18·8% and cover crops had no significant effect on root sugar concentration. Large amounts of α-amino N in the root reduce the efficiency with which sugar is extracted in the factory. The average α-amino N concentration was 75 mg N/100 g sugar. At one site (Heighington 1992) the use of a fodder radish cover crop significantly increased the amount of amino N in the root. An increase in α-amino N generally corresponds with an increased availability of inorganic nitrogen to the beet crop, particularly if this occurs towards the end of the season. The fodder radish cover crop at Heighington yielded 1·7 t DM/ha

Table 3. *Effect of cover crops on soil mineral nitrogen at sowing and harvest, N uptake by crops receiving no N and the amount of N mineralized from the soil organic matter. The letters E and L refer to early (July) or late (September) sowing of the cover crop*

Site and year	Cover crop	N in soil at sowing	N in soil at harvest	N uptake N_0 crop	N mineralized
		(kg N/ha)			
North Duffield 1990	Control	35	18	128	111
	Phacelia-E	28	18	100	90
	S.E. (5 D.F.)	4·7	0·7	5·2	2·7
North Duffield 1991	Control	60	39	62	41
	Phacelia-E	51	33	68	50
	S.E. (3 D.F.)	8·3	10·3	7·4	16·6
Broom's Barn 1991	Control	61	49	121	109
	Phacelia-E	54	51	107	104
	S.E. (4 D.F.)	3·8	2·1	5·6	3·9
Heighington 1992	Control	64	27	125	88
	Fodder radish-E	68	30	128	90
	S.E. (3 D.F.)	5·4	0·3	8·6	9·5
Broom's Barn 1992	Control	31	25	142	137
	Buckwheat-E	39	25	140	126
	S.E. (4 D.F.)	5·8	1·3	12·7	14·4
Coney Weston 1993	Control	102	19	217	134
	Volunteers-E	93	10	226	145
	Fodder radish-E	87	11	211	135
	Fodder radish-L	90	12	198	120
	S.E. (16 D.F.)	8·6	3·0	16·1	20·9
Broom's Barn 1993	Control	90	4	120	34
	Barley-E	96	4	120	42
	Barley-L	78	3	116	28
	S.E. (12 D.F.)	8·5	0·6	7·5	9·6

and had an N uptake of 27 kg/ha; however, there was no evidence that the cover crop increased the amount of SMN in the soil at sowing or the amount of N mineralized. Generally, cover crops had no effect on the concentration of Na impurities in the roots. At North Duffield, the phacelia cover crop significantly reduced Na impurities by 25%.

The overall effect of cover crops on the three main root impurities was assessed using the 'New Braunschweig formula'. In the N response experiments, the average amount of large-value sugar lost to small-value molasses was 1·78%. The effect of the cover crops on sugar loss was small and inconsistent. At Heighington (1992), the fodder radish cover crop increased sugar losses, whereas at Broom's Barn (1993) an early-sown barley cover crop reduced sugar losses compared to the later-sown barley crop.

The economics of using cover crops in beet rotations

The experiments reported here have shown that cover crops do not result in increased yields, reduced N fertilizer requirement or improved processing quality. Consequently there are no benefits that will help to offset the extra costs incurred by using cover crops. The main extra costs are the cost of drilling or broadcasting cover crop seed, and the cost of the seed itself. Seed costs may range from nothing, if natural regeneration of volunteers and weeds is used, or £10/ha if farm-saved grain is used, to £30–40/ha if mustard, radish or phacelia is used. Studies by Shepherd & May (1993) showed that there was little difference between the minimal cultivation methods used to establish cover crops. Consequently, a range of techniques may be used. Broadcasting seed onto the stubble will cost *c.* £11.00/ha, whilst drilling will cost *c.* £15.00/ha (Nix 1996). A shallow cultivation may also be required to encourage germination, but this will not always be an extra cost since it is often done whether a cover crop is grown or not. The direct costs of establishing a cover crop will therefore range from £0/ha (volunteers and weeds and a stubble cultivation) to *c.* £50/ha ('specialist' seed, drilling and stubble cultivation).

Nematode-resistant, cruciferous cover crops (i.e. white mustard and oil radish) can be used to help reduce populations of beet cyst nematode (Cooke 1991). These cover crops stimulate hatching of the

Table 4. *Effect of cover crops on sugar content, α-amino N and Na impurities within the root and an estimate of the amount of sugar lost to molasses in the factory process. The letters E and L refer to early (July) or late (September) sowing of the cover crop*

Site and year	Cover crop	Sugar content (%)	α-amino N in roots (mg/100 g)	Na in roots (mg/100 g)	Sugar lost to molasses (%)
North Duffield 1990	Control	18·7	73	45	1·85
	Phacelia-E	18·8	60	42	1·82
	S.E. (5 D.F.)	0·183	4·0	1·9	0·012
North Duffield 1991	Control	19·0	53	56	1·76
	Phacelia-E	19·3	59	42	1·77
	S.E. (5 D.F.)	0·11	8·0	3·1	0·037
Broom's Barn 1991	Control	20·3	92	51	1·89
	Phacelia-E	20·0	95	58	0·87
	S.E. (4 D.F.)	0·08	5·9	5·5	0·031
Heighington 1992	Control	18·9	76	40	1·74
	Fodder radish-E	19·0	99	41	1·84
	S.E. (5 D.F.)	0·06	3·7	2·6	0·014
Broom's Barn 1992	Control	18·9	61	51	1·66
	Buckwheat-E	18·8	67	52	1·67
	S.E. (4 D.F.)	0·09	4·0	2·3	0·015
Coney Weston 1993	Control	18·2	89	53	1·83
	Volunteers-E	18·1	82	54	1·80
	Fodder radish-E	18·0	82	51	1·80
	Fodder radish-L	18·0	85	53	1·81
	S.E. (12 D.F.)	0·10	12·7	4·1	0·044
Broom's Barn 1993	Control	18·7	74	59	1·74
	Barley-E	19·0	69	51	1·71
	Barley-L	18·7	80	60	1·76
	S.E. (8 D.F.)	0·13	3·8	3·5	0·010

nematode eggs but are destroyed before the nematode can complete its life cycle. The use of these cover crops may therefore provide a biological control method for a potentially serious pest, as well as a sink for SMN, which will help to offset initial seed costs. However, whilst these cover crops are used successfully in continental Europe, their use in the UK is limited due to cool autumn weather, which limits their effectiveness (Cooke 1991).

Survey data by British Sugar plc show that, after the harvest of beet, *c*. 15% of beet tops are fed to livestock either directly in the field or after ensiling, and that tops are fed predominantly on sandy-textured soils where cover crops are most likely to be grown. In this type of farming system, cover crops such as fodder radish could also be fed to livestock as a means of recouping some of the expenditure used to produce the cover crop. There are two main disadvantages for such a system. First, fodder crops normally receive *c*. 100 kg N/ha and will produce relatively large yields of good quality forage. Cover crops receive no nitrogen, and will tend to produce smaller yields of lower quality. Second, much of the N taken up by the cover crop will then be returned to the soil as urine or faeces. Consequently, whilst the cover crop may reduce N leaching, feeding the cover crop to animals is likely to result in increased N losses to the atmosphere.

There are two main recommendations from this work. First, cover crops in beet rotations will need to be established as cheaply as possible, since there are few opportunities to recoup costs. Generally this means establishing cover crops of cereal volunteers mixed with weeds or of farm-saved cereals with minimal cultivation. Second, beet crop management, in particular N and pesticide inputs, will not need to be modified when cover crops are introduced into the rotation.

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