The effect of field margins on the yield of sugar beet and cereal crops

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Summary

The effect of field margins on the yield of sugar beet, wheat and barley was studied on commercial farms and in a series of field experiments from 1992-1997. There was always a trend of increasing yield from the edge of the field to the centre, with a marked reduction around the 'tramlines' and the area where machinery turns. In the studies on commercial farms, headland yield loss varied widely. In sugar beet the headlands yielded 19-41% less than the centre, with a mean reduction of 26%. In cereals the range was 3-19%, with a mean loss of 7%. Headland yield reductions were generally smaller in the field experiments than those found on commercial farms. These headland effects did not move towards the centre of the field when grass margins were planted at the edge of the field; there was no significant effect on the yield of the adjacent crop. The presence of boundary trees had the greatest effect on yield: in the outer 9 m of the field, the area shaded by trees produced 4.4 t ha⁻¹ of wheat, and the area that was not shaded 8.1 t ha⁻¹. Turning of machinery also significantly reduced yield, while grazing by rabbits and hares surprisingly had no effect.

Following the reform of the Common Agricultural Policy in 1992, the main effect of which was to change from a price support policy to direct payments to producers, farmers in the European Union who produce more than a specified tonnage of 'eligible crops' per year, are required to fallow a given percentage of their land (currently 5%), to qualify for Arable Area Payments. Growers can elect to fallow fields on a rotational basis, or permanently. Headland set-aside is a term used to describe strips of set-aside, a minimum of 20 m wide around the edges of fields. In these experiments, the headland effect did not extend beyond 20 m from the field edge. Therefore, particularly in fields with boundary hedges or trees, headland set-aside could effectively remove the poor-yielding area at the field margin.

Key words: Wheat, barley, sugar beet, headland, field margin

Introduction

In an arable field the land adjacent to a boundary is often called the 'headland'. Headlands can be classified into two groups: 'turning headlands' are areas where turning of machinery occurs, causing significant soil compaction and crop damage. On these headlands the crop...
rows are drilled at a different angle to the rest of the crop, but parallel to the boundary. ‘Non-turning headlands’ are those areas adjacent to a field boundary, usually drilled parallel to the rest of the crop and where machinery does not turn. Headlands have been reported to yield significantly less than the rest of the field in cereals (Boatman & Sotherton, 1988; Fisher, Davies & Richards, 1988; Speller, Cleal & Runham, 1992) and root crops (Jaggard, Gummerson & Clark, 1987). They can also be difficult areas to manage, especially when working with large machinery. For example, where a turning headland meets the crop at an angle other than 90° there may be large areas which receive either no inputs or double doses.

The studies reported here were designed to quantify the effects of headlands with particular characteristics on the performance of the whole crop, in order to guide decision-making about headland set-aside. The studies were of two types. First, yields of the headlands and centres of representative commercial fields were measured. Second, field experiments were designed to investigate the yield transect from the edge of the field to the centre and to determine whether the poor yielding headland area would be removed by a set-aside margin or if it would move towards the field centre. In one experiment a further objective was to identify and rank those factors which cause poor headland yields with a view to providing guidance on which headlands should be set-aside.

**Materials and Methods**

*Studies on commercial farms*

Yields from 18 m wide headlands were recorded separately from the centre for five cereal fields, using the Datavision yield monitoring system, at Moat House Farm and Fens Farm, Combs, Suffolk in 1993 and 1994. Datavision is a system fitted to some models of Massey Ferguson combine harvester, that consists of a yield meter located in the grain elevator which produces a weak gamma ray signal. Grain flowing through the elevator interrupts this signal, and measurements of this interruption can be calibrated as grain weight per unit time (Swindell, 1995). The Datavision system can be used with a Global Positioning System (GPS) to produce yield contour maps. Yield maps of Coates Field, Royal Agricultural College, Cirencester, for two consecutive winter barley crops were studied. The yield of one field at Bedfordia Farms, Bedford, was recorded by harvesting the headland area and the centre of the field separately, and measuring the yields on the farm weighbridge.

During 1992, 1993, 1994 and 1997, the headland yield was recorded separately for 13 sugar beet fields in East Anglia. The headland was consistently 36 rows wide, from around the entire perimeter of the field. Actual width of the headland was determined using the between row spacing. Growers whose normal practice is to record the yield of each of their beet fields were asked to harvest the beet off the headlands from one field and to clamp and deliver it to the factory separately from the beet in the rest of the field. Thus yields for the headlands and field centres were obtained independently.

*Field experiments*

Experiments were conducted within winter barley and sugar beet crops on turning headlands in 1992/3 and 1993/4 at the University of Nottingham Farm, Sutton Bonington, Loughborough, Leicestershire (52° 50'N, 1° 15'W at 45 m altitude). The objectives of the three experiments were a) to describe the changes in yield of the two crops from the edge of the field to the centre, b) to investigate whether the poor yielding area at the edge of a field is removed when a grass margin is planted or whether it moves towards the field centre, c) to determine the width of margin required to eliminate this poor yielding area.
Field margins and the yield of beet and cereals

Fig. 1. Schematic layout of the plots within the wheat fields (not to scale).
Grass margins of different widths were established at the edge of commercially managed fields to simulate headland set-aside. The grass was mown approximately every 6 wk to a height of about 7 cm.

**Winter barley**

Barley seed (cv. Pastoral) was drilled on 13 and 14 October 1992 at a rate of 150 kg ha\(^{-1}\), at Bunny Park Farm, Nottinghamshire: the crop was managed according to normal farm practice. Four widths of grass margin (0 m, 3 m, 9 m, 18 m) were drilled into the crop at the field margin on 16 March 1993. The experiment had four blocks but the design was systematic for ease of management: in one block the margin widths were progressively larger, and in the adjacent block the widths were progressively smaller, creating a 'castellated' effect. The plots were 18 m long, to fit with the farm machinery. No sprays or fertilisers were applied to the grass margin area: this was achieved by switching off sections of the applicator boom. The plots were harvested mechanically, using a Wintersteiger plot combine, on 27 and 28 July; swathes 1.75 m wide by approximately 16 m long (exact dimensions of individual plots were measured) were harvested from the centre of strips, each 3 m wide, and parallel to the field margin, extending 36 m into the crop. The grain was weighed and a sample of 200 g was collected, weighed and dried to constant weight at 80°C to determine moisture content. All yields were corrected to 85% dry matter. The experiment was repeated in 1993/4 using the same design and assessment procedures, except that a 2 m swathe was cut from each 3 m strip using a Sampo plot combine.

The data was analysed using a factorial analysis of variance with two factors: width of grass margin and distance from the field edge.

**Sugar beet**

Sugar beet seed (cv. Saxon) was drilled on 19 April 1993, at a spacing of 19 cm, in rows 45 cm apart. This crop was managed according to normal farm practice. Using the same basic design as for the barley experiment, the grass margins were drilled on the following day in plots 5.4 m, 10.8 m or 18 m wide and managed as described in the previous section. The beet plots (6 rows by 3 m) were harvested between 1 and 4 October. The roots were pulled and 'topped' by hand, counted in the field, and sent to IACR-Broom’s Barn for analysis. Clean weight and sugar concentrations were determined. Sugar content was measured polarimetrically in a lead acetate extract using standard methods employed in the sugar industry (Carruthers & Oldfield, 1962). The experiment was repeated, using the same design and management procedures, in 1994.

The data was analysed using a factorial analysis of variance with two factors: width of grass margin and distance from the field edge.

**Wheat**

An experiment was set up in 1993/4 within two adjacent winter wheat crops. In addition to the objectives for the barley and beet experiments, this experiment was designed to identify and rank the factors that cause poor headland yields. The factors investigated were: shading by boundary trees, turning of machinery, grazing by wild mammals and birds, and the presence of a grass margin. The two adjacent fields (Field Nos 4 and 6) had the same cropping history for the previous 4 yr. A factorial experiment was superimposed on these fields, incorporating turning/non-turning, trees/no trees and the presence or absence of an 18 m grass margin (Fig. 1). The turning/non-turning comparison was achieved by drilling Field 6 from north to south and Field 4 from east to west. The trees were approximately 15 m tall and caused intense shade on the east side of the fields.
**Table 1. Yields from the centre and headlands of seven cereal fields**

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Soil texture</th>
<th>Area (ha)</th>
<th>Centre yield (t ha⁻¹)</th>
<th>Headland yield (t ha⁻¹)</th>
<th>Headland yield reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>WW</td>
<td>Clay loam</td>
<td>7.73</td>
<td>8.3</td>
<td>7.3</td>
<td>11.6</td>
</tr>
<tr>
<td>1993</td>
<td>WW</td>
<td>Clay loam</td>
<td>8.85</td>
<td>9.7</td>
<td>9.3</td>
<td>3.5</td>
</tr>
<tr>
<td>1993</td>
<td>WW</td>
<td>Clay loam</td>
<td>3.71</td>
<td>8.8</td>
<td>8.6</td>
<td>2.3</td>
</tr>
<tr>
<td>1993</td>
<td>WW</td>
<td>Clay loam</td>
<td>4.30</td>
<td>9.5</td>
<td>9.2</td>
<td>3.3</td>
</tr>
<tr>
<td>1994</td>
<td>WW</td>
<td>Clay loam</td>
<td>10.25</td>
<td>10.2</td>
<td>8.3</td>
<td>18.6</td>
</tr>
<tr>
<td>1994</td>
<td>WW</td>
<td>Clay loam-clay</td>
<td>23.97</td>
<td>8.3</td>
<td>7.6</td>
<td>8.6</td>
</tr>
<tr>
<td>1993</td>
<td>WB</td>
<td>Clay loam-clay</td>
<td>10.89</td>
<td>6.5</td>
<td>6.4</td>
<td>2.6</td>
</tr>
<tr>
<td>1994</td>
<td>WB</td>
<td>Clay loam-clay</td>
<td>10.89</td>
<td>5.7</td>
<td>5.3</td>
<td>7.6</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>10.07</td>
<td>8.4</td>
<td>7.7</td>
<td>7.3</td>
</tr>
<tr>
<td>SE</td>
<td></td>
<td></td>
<td>2.37</td>
<td>0.59</td>
<td>0.53</td>
<td>2.14</td>
</tr>
</tbody>
</table>

Winter wheat (cv. Riband) was drilled at a rate of 180 kg ha⁻¹ on 20 October 1993 in a north-south orientation in Field 6 and 21 October 1993 (east-west orientation) in Field 4. On 28 October the grass margins were drilled into the wheat and managed as described for the barley. These margin plots were 36 m long by 18 m wide, interspersed by 36 m sections of crop drilled to the field edge. There were two replicates on each margin, arranged in blocks, except for the western boundary of Field 6 which was only long enough to accommodate one replicate.

On 25 November electrified rabbit netting, 45 cm high, was used to enclose strips of crop, 8 m wide, extending from the field edge for 36 m into each plot. This was established in Field 6, where non-turning headlands were monitored: only in this field could the netting be left undisturbed for several months. On 28 February 1994 the number of plants damaged by grazing was counted in two randomly selected rows, 1 m long, in each plot. On the damaged plants, the number of leaves which had been grazed was also counted. Crop cover was...
measured using a spectral ratio meter (Steven, Biscoe & Jaggard, 1983; Haggar, Stent & Rose, 1984) on 9 March, 29 March, 29 April and 31 May. The plots were harvested on the 11 and 12 August following the method described for the barley crop. In Field 4 the plots were 34 m long. In Field 6 the plots were necessarily smaller.
due to the enclosed areas. The enclosed plots were 7 m long and the open plots 12 m; all sample areas were 2 m wide. Subsamples were taken to determine moisture content (method described above). Approximately 100 g of dried grain was accurately weighed and counted to determine thousand grain weight using a Decca Mastercount.

Multi-factorial analysis of variance was carried out on the data. The factors were: the presence or absence of trees on the field boundary (trees/no trees), whether the headland was used by farm machinery for turning (turning/non-turning headland), presence or absence of an 18 m grass margin (margin/cropped to field edge) and whether the area was protected from grazing (open/enclosed).

Results

Studies on commercial farms

The yield data collected from commercial farms for cereal field headlands and centres are presented in Table 1. The crops were winter wheat in all except ‘Coates’ field, which was winter barley in both years. The mean headland yield reduction in winter wheat was 8%. Over two consecutive winter barley crops the mean reduction was 5%.

The range of headland yield reductions in sugar beet was 19–41%, with a mean of 26% (Table 2). On another field, just the turning headlands were recorded separately from the rest of the crop. This was a square field of 6.24 ha, with two turning headlands. The field centre yielded 63.41 t ha$^{-1}$, and the turning headlands 35.63 t ha$^{-1}$, a yield reduction of 44%.
**Winter barley experiments**

In 1993 there was a pronounced reduction in winter barley yields near the tramlines (9–10 m from the field edge) then the yield was approximately stable from 15 m towards the centre of the field (Fig. 2a). For analysis, the transect was divided into two parts, the edge (0–
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Fig. 5. Foliage cover (%) of wheat on two dates 29 April (squares) and 31 May (circles): open, grazed plots (□, ○) or enclosed plots (■, ●); bars indicate SEDs for respective dates (16 df).

18 m) and the centre (19–36 m). In 1993 there was no significant difference between the two areas, but there was a significant difference within the areas. This was due to the poor yields near the tramlines.

In 1994 there was a trend of progressively increasing yield from field edge to centre and the reduction in yield around the tramlines (Fig. 2b) was much less pronounced than in 1993. The probability that the difference in yield between the edge and the centre was due to chance was 0.07 — slightly larger than the conventional significance level ($P = 0.05$). The presence of the grass margins had no significant effect on yield in either year ($P = 0.349$).

Sugar beet experiments

In 1993 there was a trend for an increase in sugar yield from the field edge toward the centre, peaking at about 20 m (Fig. 3). The transect was divided into the edge (0–16 m) and the centre (16–24 m) and there was a significant difference in sugar yield between the two areas ($P = 0.01$). The headland was 16 m wide, at which point the row direction changed. The average sugar yield for the edge was 9.01 t ha$^{-1}$, compared to 9.41 t ha$^{-1}$ for the centre. In 1994, there was again a significant difference in sugar yield between the edge and centre plots ($P = 0.05$), the edge averaged 8.55 t ha$^{-1}$ and the centre 9.28 t ha$^{-1}$. In both years, yield was poor 10 m from the edge, coinciding with the position of the tramlines in the headland. Soil compaction would be expected to be greatest in this area due to repeated wheeling. There were no significant differences in plant population density, sugar, sodium, potassium or amino
N concentration in the beet between the edge and centre areas in either year. The presence of grass margins had no significant influence on sugar yield in either year (data not shown).

Wheat experiment

On 29 April the crop adjacent to the trees in Field 4 had significantly less foliage than the edge of the crop that was not shaded, a difference as great as 20% (Fig. 4a). By 31 May, there was no longer a significant difference between the two ends of the field. This pattern was reversed in Field 6 (Fig. 4b). The plant population density at the open end of the field, away from the trees, was much less than that in the area adjacent to the trees and the effect on crop cover was greater than that of the trees at the opposite side of the field.

Until 29 April the difference in foliage cover between the open and enclosed (protected from grazing) areas was clear (Fig. 5). By 31 May there was no difference. Differences in grazing were only evident in the outermost part of the field: in the open plots the presence of trees increased significantly the number of plants which were grazed (probably by rabbits and hares), but the distance from the edge of the field did not significantly affect the severity of grazing damage.

The presence of grass margins had no significant effect on grain yield. In a similar way to the barley and beet, the transect of the field was divided into the edge (0–18 m) and the centre (19–36 m). Over all plots the edge produced significantly less grain than the centre ($P < 0.001$). The presence of trees at the field boundary increased the difference between the two areas ($P = 0.002$), as did machinery turning ($P = 0.004$) (Fig. 6). Within the area of the field classified as the edge in the analysis, there were significant differences in yield ($P = 0.01$). In
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Fig. 7. The effect of trees on quality of winter wheat in Field 4 (a) thousand grain weight of wheat (b) moisture content; adjacent to trees (●), no trees (○); bar indicates SED (47 df).

all four transects, there was a marked yield reduction between 9 and 12 m from the edge (Fig. 6). This coincides with the position of the tramlines, and is probably associated with soil compaction and mechanical damage to plants. In Field 6 poor establishment at the 'no trees' end of the field, where crop cover was poor, resulted in a smaller yield. There was no
significant difference in yield between the open and enclosed plots (data not shown), despite
the signs of grazing damage and differences in crop cover earlier in the season.

The presence of the trees had significant effects on the quality of the wheat grain. The trees
caused a significant reduction ($P = 0.026$) in thousand grain weight (Fig. 7a) which persisted
for at least 9 m into the field. The trees also caused a significant ($P < 0.001$) increase in grain
moisture content (Fig. 7b) which extended across approximately the outermost 20 m of the
field.

**Discussion**

The Datavision system, used to record the headland and centre field yields of commercial
cereal crops works by measuring forward speed and assuming that the combine is cutting a
complete swathe. From this, yield per unit area can be calculated (Swindell, 1995). In general,
the assumption of a full cutter bar will usually hold true on the headland, but where awkward
field shapes result in short, irregular strips to be cut, and for the last swathe in the main part
of the field this will seldom be the case. This could mean that the difference between headland
and centre field yields is underestimated, but the effect is likely to be small. The yield of five
of the cereal fields was recorded by the Datavision system, but without the use of GPS. The
headlands were cut first and the yield recorded, before harvesting the remainder of the field
and recording the yield from this.

The absolute accuracy of the yield maps produced using the Datavision system together
with GPS, is debatable. The delay between the crop being cut and the threshed grain reaching
the yield meter may be as long as 60 s, in which time the combine harvester will have moved a
considerable distance (Swindell, 1995). However, the purpose of the yield measurement in
this project was not to pinpoint the yield of small areas of the field, but to compare the
headland with the field centre. As the headland is normally cut before the rest of the field, by
taking two or three swathes from around the edge, it is reasonable to assume that the average
yield of this area, and that of the centre is accurate.

In the studies on commercial farms, depression in yield on the headlands varied widely,
with sugar beet always suffering a greater loss than wheat or barley. This was a feature of the
field experiments also, with the area of crop adjacent to the boundary yielding less than the
centre. The boundaries of fields with the sugar beet and barley experiments were open and the
differences were smaller than for the wheat fields which had trees on the boundaries. In the
sugar beet and barley experiments, the nature of the boundaries was such that there was no
shading, and no grazing damage was observed. The yield reduction at the edge of the field
was therefore ascribed to soil compaction and physical damage to plants caused by machinery
turning. Compaction from tractor wheels can be a major cause of yield loss in sugar beet
(Jaggard, 1977), but its effect on cereal crops is not so severe. Assaeed, McGowan, Hellethwaite & Brereton (1990) found that when barley and sugar beet plots were
compacted to the same soil bulk density, yield of barley was reduced by 29% and sugar beet
by 34%. Their crops suffered much greater losses than found in the field experiments reported
here, but unlike these experiments, the whole plot area was compacted. There were no
differences in sugar concentration of the beet between the edge and the centre of the field.
This agrees with previous work in which soil compaction had no effect on percentage sugar

The experimental designs were systematic due to management reasons. The experiments
were imposed on commercial fields and managed by farm staff. This was necessary to ensure
that the plot areas received a realistic amount of soil compaction caused by machinery
turning. Without randomisation, it is still possible to calculate error terms, but care has to be taken in the interpretation of the results.

In the wheat experiment the boundary trees reduced headland yield by more than any other factor although turning of machinery also had a significant effect. Grazing, probably by rabbits and hares, occurred in February, and measurements of foliage cover showed significant differences between protected and open areas of the field in March and April. However, by harvest there were no significant yield differences between the grazed and protected areas. Crawley & Weiner (1991) found that compensatory growth occurred in wheat plants grazed by rabbits.

There was no evidence that the poor-yielding area at the edge of the field moved towards the centre when a grass margin was established. However, each of these experiments only lasted for 1 yr. Over a number of seasons, it could be that weeds would colonise the cropped area from the margin. Certain species, such as Bromus sterilis are known to move into the field from the margin. Rew, Wilson, Froud-Williams & Boatman (1992) found that the main trajectory of seed from Bromus sterilis was into the field. However, 92% of seeds fell within 0.5 m from the source, indicating that any movement into the field would be slow, and therefore simple to prevent through mowing the set-aside margin. Where a field is cropped right to the field edge the weeds in the hedge bottom cannot be managed in this way.

The moisture content of grain from plots adjacent to the trees was as much as 6% greater than that from plots which were not sheltered. This could be important commercially particularly when the weather is unsettled over the harvest period. The cost of reducing the moisture content of 1 t of grain by 6% is approximately £7.00 (Nix, 1996). This problem could be avoided if the headland was set aside.

The headland yield losses in the barley and sugar beet experiments were smaller than those recorded by the farmers. In the case of the beet the difference can be explained by the method of harvesting: in the field experiments the beet was lifted and topped by hand, whereas in the survey the harvest was done by commercial machines. Losses from machines can be particularly large on headland areas, especially if the rows are not straight, making it difficult to keep the machine ‘on line’. Also, the plant population density on the corners of sugar beet fields is usually sparse (sometimes the corners are not seeded deliberately). These sparse areas would be included in the commercial assessments, but were not in the field experiments.

Both in the field experiments and on the farms, wheat headlands tended suffer a bigger percentage yield loss than barley. There are at least two possible reasons for this. First, tractors may move through a wheat field more times than through a barley field with commensurately increased soil compaction and direct damage to plants. Second, wheat may be more susceptible to compaction than barley: Mulholland (1994) found barley shoot growth in the field to be optimal at a soil bulk density of 1.4 g cm$^{-3}$, while Masle & Passioua (1987) showed in the glasshouse that wheat shoot growth was depressed even at 1.29 g cm$^{-3}$.

In wheat, barley and sugar beet there were transects of increasing yield from the field edge, across the headland towards the field centre, with marked reductions in yield around the tramlines and the area where machinery turns. In the wheat crop, the presence of boundary trees had the most detrimental effect on headland yield (35%), followed by turning of machinery (15%). Surprisingly, grazing had no significant effect. The ranking of these factors is likely to vary depending on height and aspect of boundary vegetation, soil texture and grazing pressure. There was no evidence for the movement of the poor-yielding area at the edge of the field towards the centre when headland set-aside was established. The width of the margin that needs to be fallowed to remove the poor-yielding area will partly depend on boundary vegetation; the influence of trees 15 m tall extended approximately 20 m into the field. The influence of shorter boundary vegetation would not extend so far, so it is unlikely that a margin of greater width would be needed, and often a much narrower strip would
suffice. Under the current set-aside regulations (Nix, 1996), the minimum width of 20 m would remove all of the poor-yielding area. This would offer the optimum combination of reduced overall production, increased profitability on the area actually cropped and dispersed permanent set-aside areas which would encourage species diversity.

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References


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