Consideration of the supply of beet for biofuel production

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Executive summary

- If the outcome of the EU sugar regime is such that the UK continues to produce beet sugar to a quota of about 1.2Mt, then the only prospect of a large biofuel-from-beet industry comes from an increased throughput for the existing slice and juice extraction capacity. This means extending the campaign.

- The current start time (mid September) cannot move forward because the soil is likely to be too hard for efficient harvesting and the yield and quality are far from optimal.

- To finish later with conventional agronomy means increased rates of storage loss and increased storage losses for beet delivered in March. The loss rate would rise to 0.21% per day on an adjusted tonnage basis. This may not be attractive without an increased late delivery payment.

- The alternative is not to store the beet in insulated clamps but to leave them in the field and harvest them just in time for delivery to the factory. This avoids storage losses and leads to a yield per hectare increase of 4% across the whole campaign. However, the risk of severe frosts and catastrophic losses is too large for this to be the plan. Much beet was exposed and damaged in 2001, and this was not an extraordinarily cold winter.

- Instead it may be possible to provide enough frost protection to the tops of beet roots by covering them with a ridge of soil in November and December.

- The ridging process is too slow to be commercially attractive in 50cm rows, but it may be possible in rows 60cm apart. Rows this far apart have not been tested recently, but they probably represent a yield loss of about 4%, partly counterbalanced by a seed cost saving of about £22/ha. Nevertheless there is a large net gain over the alternative which is long term storage.

- Some 6 row beet harvesters can be modified to take 5 rows at 60cm.

- This ridging technique could only be applied to the easily worked sandy and sandy loam soils. The minimum proportion of these soils in any one factory area is 38% (Wissington).

- Disease control in the beet crop means that the whole of the old crop should be harvested before the new crop emerges. Thus, with in-field frost protection it would be possible to extend the campaign to late March. To extend the campaign still further with clamp storage seems impractical, the predicted rates of yield loss in store become too great (0.3% per day in April and 0.4% per day in May).

- Extending the campaign to the end of March could provide a total slice of about 200 days, of which 135 days will be required for quota sugar and about 65 days for ethanol, although both would be concurrent. In this scheme most post-Christmas beet would be delivered from specialist late-lift growers on sandy soils. This represents about 45% of the total beet requirement, and a 24% increase over the supply today. Nevertheless, this still represents a smaller beet area than was grown in the early 1990's, so it can be accommodated within today's factory areas.

- Will farmers want to grow this extra beet and will they grow it in this way? Any proposed extension of the campaign in the past has been resisted, mostly for two reasons: the beet in the extended period was of low value (surplus), and any extension interfered with the potential to grow the next crop profitably.

- Clearly the relative values of 'early versus late delivered beet' and 'beet for sugar versus biofuel' are matters of commercial negotiation and will not be discussed here.

- The situation re the profitability of the next crop has changed drastically with CAP reform. Government support for agriculture is no longer production driven, and the value of produce is determined by the market. Cropping will struggle to be profitable on many farms, so the consequences of having a fallow period following one profitable crop are much less acute than in the past. Therefore farmers are today much more likely to be receptive to beet being in the ground in March. Nevertheless there are still crops which can be grown profitably after March-harvested beet.

- The next stage in the development of this approach must be to grow some beet in 60cm rows and to test its

  yield potential
  our ability to protect it from frost
  the commercial feasibility and cost of applying protection
  our ability to harvest it commercially

The first three of these are being examined on a small scale during the winter of 2005, but harvestability remains to be investigated.

1 Introduction

The EU proposes that a significant proportion of transport fuel shall come from renewable resources. In the medium term this means biodiesel and ethanol. The eventual extent of production in the UK will depend upon the mineral oil price and excise duty exemptions to make renewables competitive with mineral oil sources. The mineral oil price has risen sharply in recent months (Brent Crude high was $67/barrel) and pundits consider that it is unlikely to return to $40 per barrel, the price pre December 2004 (www.bbc.co.uk/market data/commodities). A high mineral oil price makes biofuel more competitive. The Treasury has made a concession of 20p/l in favour of biofuel.

The technology for bioethanol production by fermentation is well proven and is the method used throughout the world. Beet is a good feed-stock because it stores sugar which is directly used as the yeast substrate: starchy materials like wheat or maize have to be pre-treated to convert starch to a simple fermentable sugar, and this adds a cost.

Beet is being used for ethanol production in many EU countries (eg. Netherlands, France, Spain), and for use as a fuel source in France and Spain. The other common feedstocks for bioethanol are sugar cane (Brazil), wheat and maize (US and France) (Berg, 2004). In the UK the likely competitor crop will be wheat. UK growers can produce large yields of winter wheat (8-9 t/ha) cheaply, and the grain can be stored for use in all 12 months of the year. However, in the UK wheat has the disadvantage that it already dominates the countryside, limiting the range of arable habitats that are available for exploitation by many wild flowers, arthropods and birds. Any reduction in the area of sugar beet will reduce the area of spring sown crops, which are already at a premium because they provide winter and spring feeding grounds for many herbivorous bird species.

If beet is to be used for biofuel production, it must first be washed, sliced and the sugar diffused out into solution in exactly the same way as beet is prepared for sugar production. After diffusion, the raw juice is partially purified and concentrated to produce thick juice (65% dry matter content). This juice can either be stored or used to produce crystalline sugar. The liquor left after some sugar has been crystallized will probably be material that is used for ethanol production by fermentation. In this scenario, ethanol and sugar have a common initial production stream.

At present, this stream works at full capacity to produce sugar. The ability to produce ethanol will have to come from one or a mixture of three sources (a) capital invested in increased slicing and diffusion capacity (b) a reduction in the production of sugar or (c) an increase in the operating period of today's equipment. Reform of the EU Sugar Regime may force a reduction in UK sugar production, but we anticipate that this reduction will be small. Thus the most cost effective method to accommodate ethanol production will be to expand total capacity by expanding the working period of the factories. This analysis considers how it might be possible to supply beet for a sufficiently long campaign for it to be a major biofuel source.

2 Beet supply for a longer campaign.

The current slice capacity of the beet sugar factories in England is approximately 57000 t/day, with a white sugar production capacity of about 8500 t/day. Following reform of the EU Sugar Regime in 2006, the industry hopes to have a sugar quota of 1.221 Mt. If British Sugar slices beet solely to satisfy this quota, and if beet quality is stable at its average November level (about 93% sugar extractability) then it would take approximately 135 days to complete the task. British Sugar can currently slice for about 160 days, so the equivalent of 25 days' capacity could be devoted to biofuel production. This is a relatively small proportion of the total. How can capacity be increased?

One possibility is to open the factories earlier. This has obvious attractions but three major disadvantages.

1. The beet are still growing rapidly during September, so an advance in sowing date sacrifices yield per hectare.

2. During late summer beet quality is still increasing, so earlier harvest almost always means poorer beet quality and smaller white sugar extraction.

3. On average in England rainfall in late summer does not exceed evapotranspiration until mid September, so the soil does not begin to wet up until then (Jaggard & Werker, 1997). Until wetting up begins, the soil on all except the Fen peats is too hard for harvesting to proceed efficiently. Therefore, it is not appropriate to plan for harvesting to begin before the last third of September.

Another possibility is to close the factories later. At present the end date of the campaign is limited by two important agricultural considerations:

1. During late February and early March beet that have been stored have been respiring for at least 70 days. Their sugar concentration and yield have fallen and the white sugar extraction rate has declined slightly (Jaggard *et al.*, 1997).

2. Beet clamps on farms in spring are a potential source of diseases if they are not cleared away before the new crop emerges (Hull, 1974).

Can these problems be overcome efficiently?

3 Crop storage for a longer campaign

During storage beet lose sugar, almost entirely as a loss of sugar concentration, and this drop in concentration is often quite dramatic. Jaggard *et al* (1997) measured an average loss of 0.02% per day over 60 days in January and February (Fig. 1).

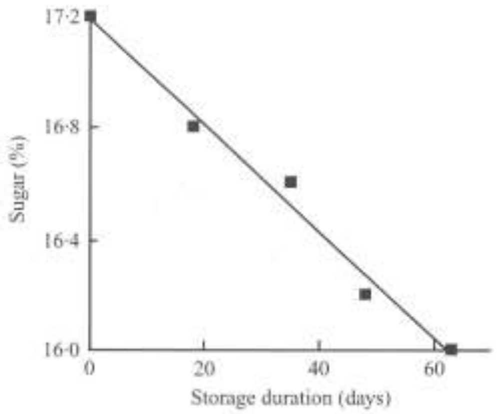


Fig. 1. The average effect of storage duration on sugar percentage in 18 clamps on farms in England: 1992–95. The linear regression equation is:
Sugar (%) = 17·19 (±0·039) − 0·02 (±0·0010) × days.

Due to the reduction in sugar percentage and to an increase in the concentrations of glucose and fructose in stored beet, Jaggard *et al*. (1997) also measured a small fall in sugar extractability (from 91.0% to 90.2%). They showed, as expected, that loss of sugar was directly related to the heat experienced inside the storage clamp: the longer and warmer the storage, the greater the loss of sugar. A BBRO sponsored study (BBRO 02/06) extended the storage period from late February to late March or early April (up to 120 days). During this period the weather usually gets warmer and, in consequence the rate of sugar loss increases too. However, this loss rate was not catastrophic, it increased to about 0.21% per day throughout March. Nevertheless, any increase in storage time increases the amount of sugar lost. Predictions of white sugar extractability declined too, but slowly. The overall impact of this storage was that estimated white sugar yield declined by 14.6% after storage for 115 days.

The changes in adjusted tonnage yield on an area basis can be estimated from a combination of data from regular harvests throughout the autumn and from storage experiments. Morley Research Station studied changes in yield from August until late December, 1997-2002 (Jaggard & Lainsbury, 2001; Lainsbury pers.com.). Averaging the data from each year, and expressing the yield changes as a percentage of the maximum yield (achieved in late November), produces the yield profile for the first 103 days illustrated in Fig. 2. The profile thereafter is derived from the losses measured in the most recent series of BBRO-sponsored storage experiments. Thus Fig 2 illustrates the pattern of yield changes that could be anticipated if all beet prior to late December were delivered 'just-in-time'; beet delivered later were all stored in late December.

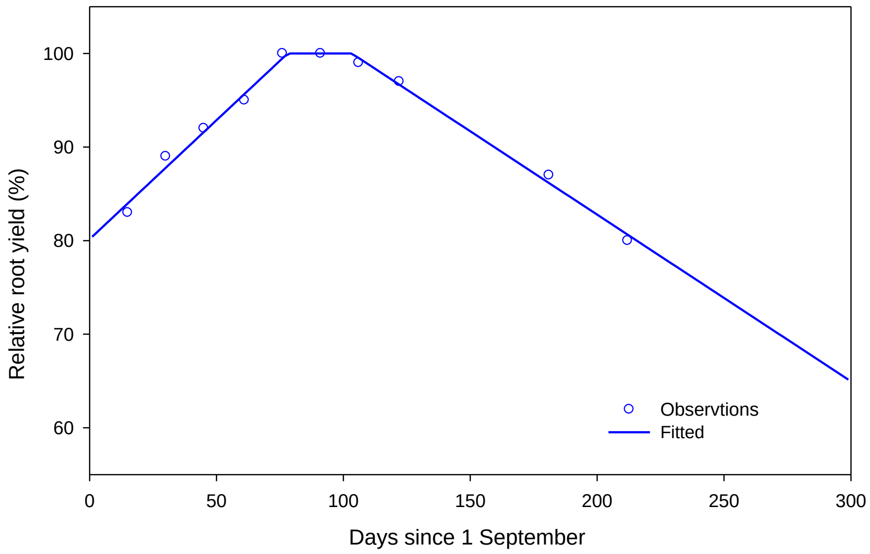


Fig. 2. *The pattern of changes in relative root yield (adjusted) of freshly lifted (September-December) and then stored beet (January-March). For simplicity a series of straight lines have been fitted to the data.*

At what price might growers be prepared to grow and deliver beet under this extended (to late March) campaign period? Beet for delivery from store in March would probably be harvested during the first 20 days of December and frost protection would be applied before Christmas. On average, beet for the campaign extension would be delivered on 15 March. Thus the average storage period would be from 10 December to 15 March, 95 days. The average loss rate is likely to be 0.113% per day (BBRO 02/06), so the sugar yield loss in store would be 10.7%. Crop yield and production costs have been published for 2002 (Bee and Limb, 2003; Lang, 2004). Both analyses found similar variable costs and average yields, while Bee and Limb identified operational costs at £555/ha. Total variable plus operational costs for the average beet enterprise was £905/ha. With an average yield at 55 adjusted tonnes per hectare, the operational and variable costs per tonne were approximately £17. An extension to the campaign achieved through on-farm storage would suffer a yield penalty of approximately 10%, so costs for this portion of the crop would rise to approximately £18.5 per tonne. Thus, aside from any extra variable and operational expenses and apart from crop rotation considerations, farmers are unlikely to consider deliveries throughout March unless these beet are worth at least an extra £1.5/t. Could biofuel production sustain this additional cost?

4. Keeping the beet in the field

A recent BBRO funded project (02/24) has shown that beet kept in the field throughout January and February do not suffer any significant loss of sugar yield or quality provided that they do not suffer frost damage (Table 1).

Table 1. *Yield and quality of beet harvested throughout the winter from sandy soil: 2002-2004.*

	Oct	Dec	Jan	Feb	SED
Adjusted yield (t/ha)	91.0	97.8	99.1	96.2	1.93
Sugar %	18.91	18.39	18.27	18.05	0.086
Sugar yield (t/ha)	13.83	14.90	15.12	14.68	0.293
Juice purity (%)	94.90	94.94	94.73	94.81	0.053

This project was set up to determine the scale of possible improvements to beet production for white sugar extraction, where the maintenance of quality was of similar importance to the maintenance of yield. Unfortunately, the experiments did not continue throughout March and April, which would have been especially valuable for a consideration of extending the campaign to accommodate biofuel production. In the absence of this information, we have assumed a worst case, that beet in the field from late February until late March or early April would suffer a yield loss at the same daily rate as beet clamped throughout this period. By 10 May observations at Broom's Barn showed that beet were extending their stems in preparation for flowering and their sugar concentration fell from a January high of 18.3% to 13.9%. At best, this represents a yield loss of 25%. These values have been used to produce the yield profile shown in Fig. 3.

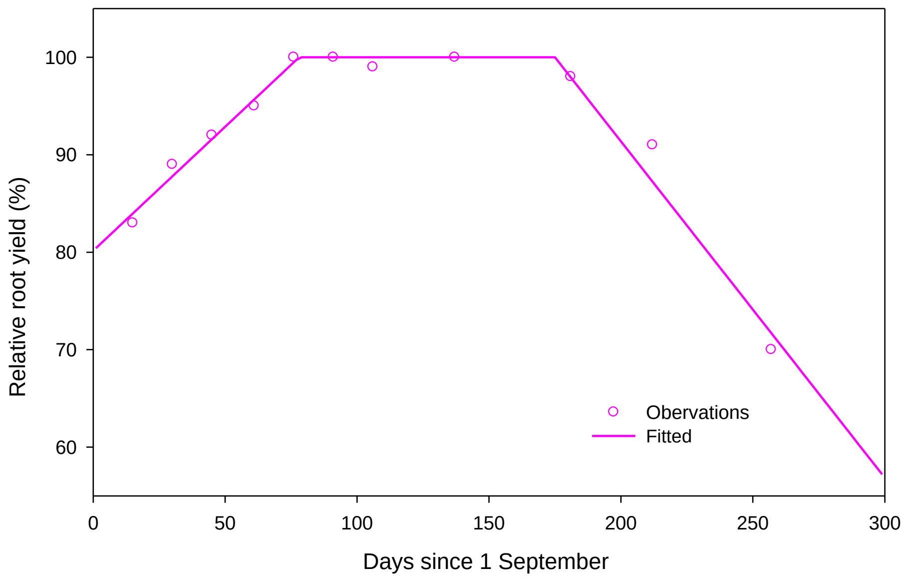


Fig 3. *Composite pattern of development of adjusted root yield from mid September until May. All beet are delivered fresh from the field.*

If it was possible to use beet delivered straight from the field throughout the campaign (until late March, day 212) and thereby to eliminate the yield losses in store, average beet yields would rise by 4%.

To leave the beet in the ground after Christmas runs the risk of frost damage which makes the beet difficult to process. The first problem is that, once thawed, bacteria in the beet begin to produce dextran gum which can block the filters immediately after the carbonatation stage of the juice clarification process (Harvey & Dutton, 1993). This stage precedes the production of thick juice, the product that can be stored for subsequent sugar or bioethanol production. Therefore freeze damaged beet would be as unsuitable for bioethanol as they are for sugar production.

What risk is there that beet in the ground will be damaged by freezing weather? Except for the very recent past, the practice has been to have all beet, except game cover strips, harvested and clamped by Christmas. Therefore little beet was at risk of post-Christmas freezing. Nevertheless, Factory Agricultural Managers' weekly reports during the period 1990 to 1995 (when they ceased to be produced) show that some beet in, for example, the Bury St Edmunds area was damaged by frost and had to be topped severely in 91/92, 92/93 and 94/95 (3 years out of 6). Also beet was severely damaged in 2001, to the extent that thousands of tonnes delivered after late January had to be severely topped to ground level to be acceptable for processing. The late January and early February weather was unprecedentedly warm (8.6°C compared to the long-term average of 3.8°C), making damaged beet deteriorate rapidly and 30,000 tonnes became unfit for processing (Bee, 2002). To put these winters in context, we have examined the last 30 years' weather records for Broom's Barn and estimated the duration and intensity of cold hours from the measured maximum and minimum air temperatures. These values are shown as cooling hour degrees below -3°C for each day in Figure 4. The ticks below the x axis show the position of 1 January in every second year. The wider the trace above the axis, the longer the cold period; the taller any individual trace, the colder the day. This figure clearly shows that these cold periods usually occur at the beginning of the year, in January. It also shows that the amount of freezing damage experienced in 2001 was associated, not with the intensity of the cold, but instead with the length of the cold period and the area of beet that was exposed: that cold period was not a rare event. So far there is little evidence that global climate change has warmed the winter in eastern England so much that we can leave beet in the field without protection and with impunity.

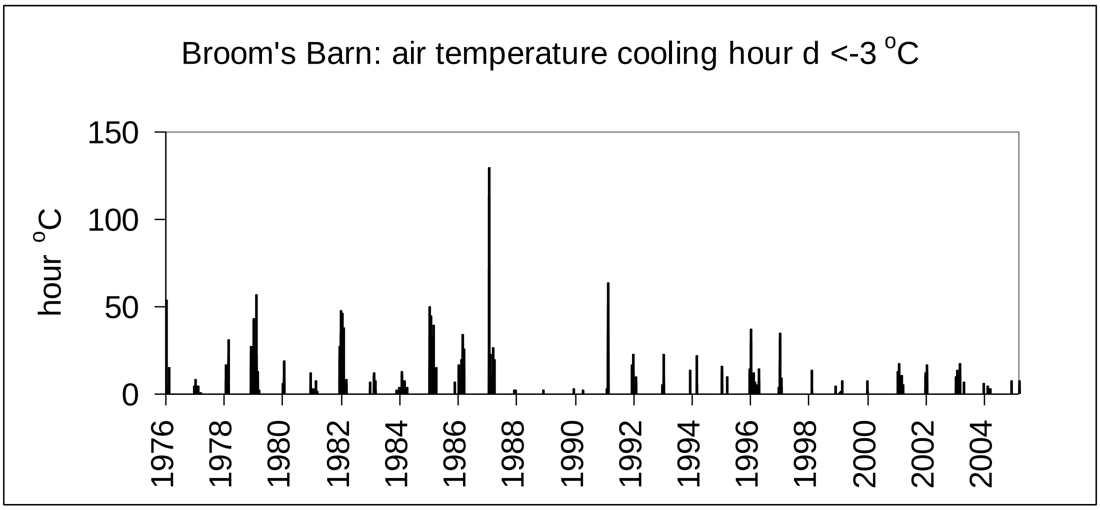


Fig 4. *Cooling hour degrees C below -3°C for each day at Broom's Barn since 1976*

5 Protection of beet in the field from freezing damage

Research by Milford et al. (2002) showed the extent to which the beet crown and the root just below the soil surface is buffered from the extremes of the cold air and how the soil provided insulation against freezing. After 5 consecutive days when the temperature varied each day between 0° and -10°C, the beet roots were no colder than -3°C. For every °C hour below 0°C in the air, the root experienced 0.28°C hours, measured at a depth of 5cm (Fig 5). The storage of beet that has been damaged by freezing has always been considered very risky, because any rots in the beet induced by frost damage could spread rapidly. This problem is avoided if the post freeze beet are harvested for immediate delivery and processing, as is the case in the beet industry today. Therefore, it has become appropriate to top beet severely to remove any damaged tissue immediately before delivery.

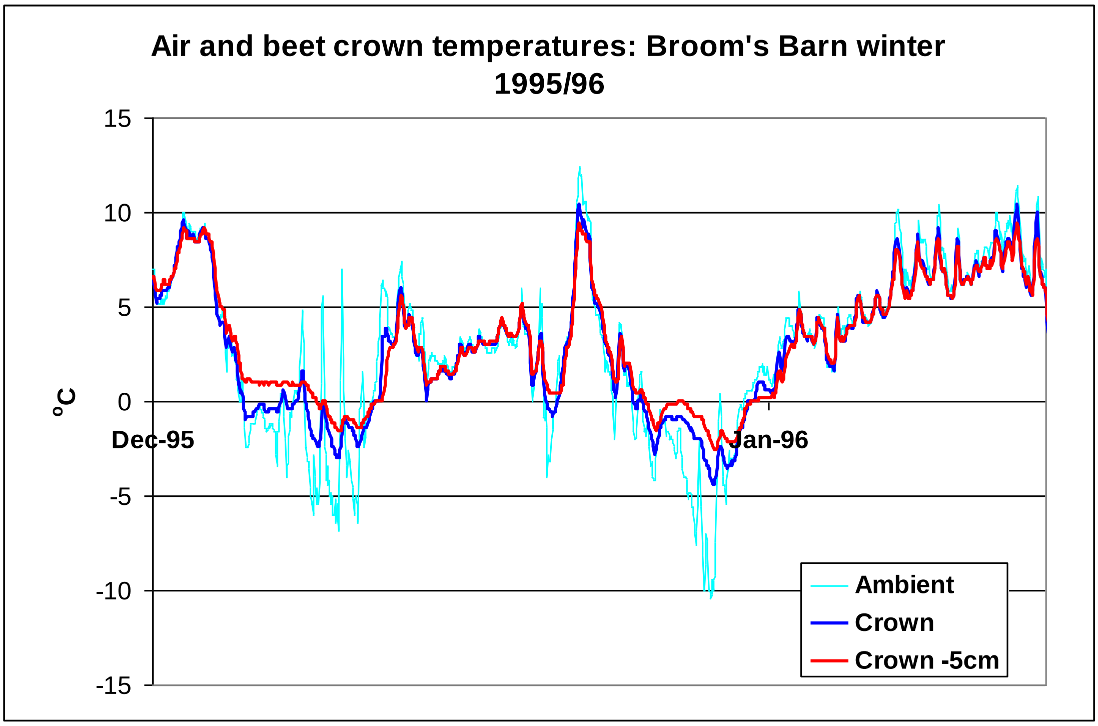


Figure 5. *Temperatures measured in the field at Broom's Barn during winter 1995/96, showing the extent to which the crowns of beet are buffered against the extremes of cold measured in the air.*

A recent BBRO sponsored project (02/24) has studied the protection of the top of the beet root by covering it with a ridge of soil in November or December, before the frost. Covering with soil produces good quality beet in the absence of freezing but we still do not know if it provides enough protection from the cold. Also the covering process is too slow for commercial adoption in crops grown in rows 50cm apart.

Covering beet with soil in rows separated by 60cm may be practical, but has not been tested yet. Wider rows will mean a smaller yield: the most recent evidence comes from experiments testing 55cm rows (Bee & Jaggard, 1996), which showed a yield reduction of 3%. Studies including rows as far apart as 60cm have not been made since the 1960's, when yield was reduced by 4% (Jaggard, 1979). In part, this loss of yield would be counteracted by a saving in seed (*c.* £22/ha) and an improvement in weed beet control where this involves mechanical hoeing; these would compensate for about half of the cost of the yield loss. The topping and lifting mechanisms of some of today's harvesting machines can be modified to work with 5 rows at 60cm instead of 6 rows at 50cm. However, this is more complex than making a few simple adjustments. If covering beet with soil in 60cm rows becomes a practical alternative to clamp storage then it means that some of the harvester ownership costs can be spread over a larger beet area because the working period (and hence the area per machine) can increase from about 110 days per campaign to 190 days.

6 Crops to follow late-lifted beet

Conventionally, beet that is lifted late is harvested during November and December, and most of it is followed by one of the following:

- late-sown wheat
- spring barley
- potatoes
- root vegetables
- peas
- set-aside

If beet is left in the ground until late February or even late March, what will be the next crop? Possibilities include main crop and late season early potatoes, carrots, onions and peas. Because farm income support is no longer linked to whether a crop is produced, on many farms a new contender for this slot will be fallow. Fallow will provide a good entry for the next crop, although this is unlikely to be wheat on the sandy soils that will be suitable for late lift beet.

7 Implications for pest and disease epidemiology

Many potentially serious air-bourne pests and diseases of sugar beet are partially or completely controlled because their host plant (beet) is not present in the landscape all the time. For example, this effectively controls Downey Mildew (Byford, 1967) and Beet Yellows Virus (Smith, 1986), and partially controls Beet Mild Yellowing Viruses and Powdery Mildew. If the beet harvest period is to be extended in order to accommodate biofuel production, then it will remain essential, for crop hygine purposes, to have all beet out of the field and their debris incorporated into the soil before the new crop emerges. Effectively, this means that harvest should be complete by the end of March.

8 Beet storage during April

If beet harvest has to be completed by the end of March, why not store beet in clamps on farms throughout April and beyond? Storage studies have not been made during April and May in England. However, recent BBRO-funded studies (02/06) showed that beet lost adjusted tonnage at 0.21% per day during March, when the average temperature at Broom's Barn was 7.1°C. The long term average temperatures at Broom's Barn are 6.0° in March, 8.0° in April and 11.5°C in May, but have been getting warmer. Data in Jaggard *et* *al*. (1997) can be used to make a crude prediction of the losses in each of these months, on the basis that very well ventilated clamps maintain a temperature of about 5°C above daily ambient air temperature and that beet in store lose 0.025% of their adjusted tonnage per °Cday (Jaggard *et al*., 1997). Thus predicted loss rates for April and May are 0.32 and 0.41 % per day. Beet harvested and clamped in early March and delivered at the end of April would have lost 16% of their adjusted weight. This represents an average change in production costs from about £17/t to £19.7/t. In addition to the problems posed by the storage losses, these beet clamps also represent a disease threat, as did mangels clamped for animal feed in the past (Hull, 1974).

Apart from storage problems causing difficulties for any long term plan to operate factories throughout April, there is also the issue of how to process beet in years when yields are larger than expected. This inevitably leads to an extension of the campaign period: it would be a grave mistake if this extension (which might occur one year in three) had to take place during a time when the new crop was emerging. To jeopardize the new crop by processing the old would cause terrific rancour within the industry.

9 Beet supply capacity

The current beet processing campaign in England runs from mid September until late February, for about 160 days. If, for ethanol production purposes, the campaign can be extended until the end of March, then it will run for an extra 39 days, making 199 days in all. At full capacity this will require about 24% more beet, and the extra will all have to come from sandy or sandy loam soil that can be worked in late autumn to produce ridges and which can be harvested when the soil is near to field capacity. About 4% of the extra could come simply from the saving in storage losses by switching to just in time harvest after Christmas. However, as already discussed, this crop would probably have to be grown on wider rows than today's crop and this would reduce yield on this area a little, perhaps the equivalent of 1% overall. Thus about 21% more beet will need to be produced and it will come from extra area, all other things being equal. This equates to an area of about 180,000 ha, a smaller beet crop than was grown in the mid 1990's.

Does the distribution of soil types allow this production? Ninety of the total 199 days' worth of supply would ideally come from specialist late season beet producers having sandy or sandy loam soil. Table 2 shows that there is a large enough proportion of light soil to supply this beet in all factory areas except Wissington, where disproportionate expansion by the sandy soil growers would be needed. The sandy and sandy loam soils are distributed throughout each factory's area (Figs 6 & 7).

Table 2. *Proportion of sandy and sandy loam soils sown with beet in 2005*

Factory	Sandy (%)	Sandy loam (%)	Total (%)
Allscott	9.4	66.7	76.2
Bury	9.9	44.1	54.0
Cantley	5.6	73.3	79.0
Newark	17.8	48.0	65.8
Wissington	7.0	31.1	38.1
York	15.5	54.2	69.7

Fig. 6 Distribution of sandy soils sown to beet crops in 2005

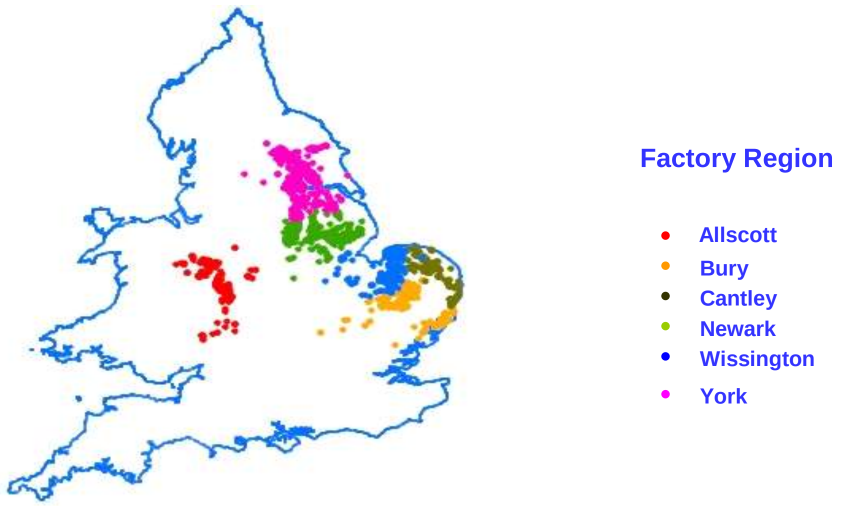
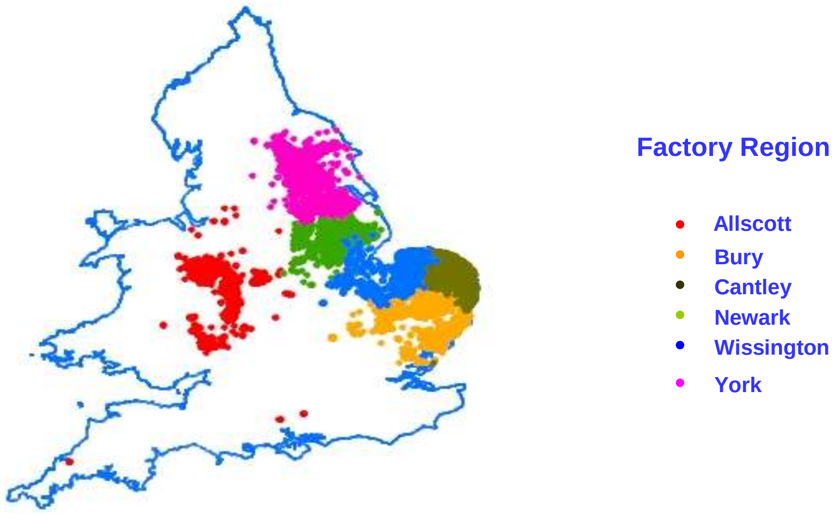


Fig. 7 Distribution of sandy and sandy loam soils sown to beet crops in 2005



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