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Changes in the weight and quality of sugarbeet (*Beta vulgaris*) roots in storage clamps on farms

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SUMMARY

The changes in weight and quality of sugarbeet roots stored in 18 clamps, mostly in eastern England during the winters of 1992/93 to 1994/95, were studied on farms using best commercial practice. Storage usually started in early December, at about the last recommended date of harvesting, and continued until the end of the beet-processing campaign at the local sugar factory (usually in February). Random samples of beet, in open-weave nets, were either analysed at the outset or were buried in a predetermined pattern in the clamp for up to 84 days. Periodically, samples were removed from the clamps for analysis. Beet weight hardly changed but sugar was lost as a reduction in sugar concentration: this declined at *c*. 0·02% per day. The concentration of reducing sugars, which are important impurities, increased fourfold during storage. Most other beet quality parameters remained unchanged. Sugar and adjusted weight was lost at 0·143 and 0·187% per day respectively. This relationship was highly significant, but a relationship between sugar loss and accumulated thermal time (0·0188% per °C day) accounted for more of the variation (73%). Temperature changes within the clamps, and the differences between clamps in accumulated thermal time, were not predictable. Some clamp insulation materials appear to allow more heat to accumulate than is desirable.

INTRODUCTION

Mature storage roots of sugarbeet freeze at *c*. −3 °C (Heijbroek & Huijbregts 1984) and soon after thawing they become unsuitable for processing and sugar extraction (Oldfield *et al*. 1971*a*). Therefore, by the time freezing conditions are likely, beet need to have been harvested and either processed or stored in insulated clamps. In the UK it has sometimes been cold enough to freeze beet in the field in mid-December, and this has become the target date for completion of harvesting. The processing campaign can continue into late February and thus it is not uncommon for beet to be stored for 80 days.

Research in the 1960s and early 1970s showed that beet in insulated clamps during winter lost, on average, 0·1% of their sugar per day, but that the losses could be much greater if the beet became hot, usually because ventilation was poor (Oldfield *et al*. 1980). These authors noted that three types of clamps were the most common cause of problems: clamps built quickly where large capacity harvesters were used; large clamps of *c*. 500 tonnes; and clamps built against walls of straw of *c*. 0·9 m thickness. Today about 55% of the crop is harvested by these large machines, clamps as large as 1000 tonnes are commonplace and they are often built against walls made of big straw bales, 1·2 m thick. These changes came about for sound practical reasons, but without much consideration for their effect on losses and the quality of beet stored on farms. The studies described here were carried out using the range of common commercial clamping practices during three winters. The objective was to assess the changes in beet quality and yield where beet were well-clamped and well-managed, and especially to determine whether clamps built rapidly suffered large losses initially.

EXPERIMENTAL METHODS

Studies of the weight and quality of beet in store were made in six clamps in each of the winters from 1992/93 until 1994/95. The clamps were made on commercial farms from uniformly treated fields of beet in East Anglia, Shropshire, north Lincolnshire and Yorkshire. Each year staff from IACR-Broom's

Barn and Morley were each responsible for two clamps in East Anglia, while staff from NIAB were responsible for two studies, one in Yorkshire and one in Lincolnshire (except in the first year when the clamps were in Yorkshire and Shropshire). The clamps were made by the farmers, usually in early December (near to the latest recommended date of harvest) and using their normal practices. In all cases the tops of the clamps were levelled prior to being covered in order to minimize the number of beet at risk of exposure to freezing conditions. Details of the clamps, their siting and source of beet are given in Appendix 1. Usually the clamps were built within an enclosure made of straw bales; this provided insulated walls 1·2 m thick. Occasionally the clamps were built against walls made from old railway sleepers, or against brick buildings. The open face of the clamp (the face from which beet were taken periodically and delivered to the factory) was commonly covered with a material which could be removed easily, i.e. coarse, woven polypropylene cloth or a plastic coated cloth. Any other sides were covered with straw.

Experimental design, sample selection and retrieval

The changes in beet yield and quality during storage were assessed by difference. Assessments of beet quality were made on representative samples of beet initially, and these were compared with the quality and weight attributes of weighed samples which were buried in the clamps.

In the second and third seasons (Clamps 7–18), the same sampling protocol and layout was used at all sites. At each clamp 100 samples of *c*. 30 kg of beet were selected from one trailer-load of freshly harvested beet. This load was harvested after the headlands of the field had been cleared. The practice of selecting all the samples from one load was adopted to reduce the risk that initially the samples would have large variations in soil tare and internal quality. Each sample was prepared by counting *c*. 30 randomly-selected beet into an open-weave polypropylene net (mesh *c*. 1 cm × 1 cm). The nets of beet were numbered and weighed to the nearest 100 g. At random, they were allocated either to a predetermined burial position within the clamp or for immediate analysis. In each instance, 20 samples were sent for immediate analysis, and the remaining 80 were allocated to one of four faces (inclined at *c*. 60°) within the clamp. On each face the 20 samples were allocated to an array of four rows of five columns. The five columns were equally spaced across the face of the clamps: the four rows were spaced to represent 0·4, 1·0, 1·6 and 2·2 m below the clamp surface.

In the first winter the method of sample preparation was the same, but sample numbers and their positions within the clamps were not standardized. At Clamps 1 and 2, 100 samples were prepared, 20 for immediate analysis and the remainder were split into four replicates of five positions on four faces of the clamp. At Clamps 3 and 4, three groups of 30 samples were prepared. At random, ten of the 30 were immediately analysed and the remaining 20 were allocated at random to an array of four rows of five columns across a face of the clamp; three faces were prepared in each clamp. At Clamp 5, 30 nets were prepared, six for immediate analysis and 24 for burial in four groups, each of six replicates; each group was allocated to a retrieval date. At Clamp 6 there were 36 nets, six for immediate analysis and 30 for burial in five groups of six replicates.

In all clamps except Clamp 8, the freshly harvested samples were buried in the clamp within 48 h. Prior to burial they were protected from frost by covering with either a tarpaulin or straw. At Clamp 8, the harvester broke after one set of 20 samples had been buried. Harvesting resumed on the fifth day but was stopped by heavy rain and waterlogged soil conditions after the second set of 20 samples was buried. Faces 3 and 4 were not buried until 12 days after being harvested. During this period, the samples were kept outside but covered with a tarpaulin to prevent damage by frost and washing by rain, which would have removed soil tare.

The changes in beet quality during storage are likely to be influenced by damage sustained during harvesting and transport. The condition of the loads of beet used to provide the samples in the nets was assessed on a random sample of 100 roots. These were scored for damage by recording the maximum diameter of the broken tip of the beet.

Throughout, the nets of sample beet were buried in the clamps as they were built, and the intention was that these samples should be uncovered, one face at a time, when the surrounding beet were delivered to the factory. As soon as the samples on a face were exposed, beet delivery stopped so that the beet on the next face was not compromised. Thus, the clamps became progressively smaller.

The storage periods for each batch of samples in each clamp are shown in Appendix 2. After these periods, the samples were analysed. There was always an initial analysis, at day zero, immediately after harvest. Four storage periods were planned for each clamp except Clamps 3 and 4 (three periods) and Clamp 6 (five periods). Usually these plans were realized, but in Clamps 14 and 18 the last two sets of samples were retrieved on the same day because the surrounding beet had to be delivered to the local sugar factory, whose processing campaign was almost complete. In Clamp 8, the farmer's delivery schedule dictated that the first two sets of samples had to be uncovered on the same day; thereafter the beet deteriorated and had to be delivered rapidly, therefore the third and fourth faces were retrieved together. In many of the Tables of results the data from the third of the five sets of samples in Clamp 6 have been omitted: this has been done to simplify presentation.

Yield and quality assessments

Whenever a net of beet was moved from a clamp site for analysis, it was placed in a clean, woven polypropylene sack to ensure that loose soil and delicate young shoots were retained. At the laboratory the sacks were weighed, the contents washed and then reweighed to determine the 'dirt' tare. As necessary, the portion of each beet above the level of the lowest leaf scar was sliced off and weighed to determine the tops tare of the sample. As far as possible, and to avoid bias, for each clamp this topping process was performed by one person. The cleaned and topped sample was then weighed and sawn using standard sugar tarehouse procedures to produce a representative sample of brei. These stages were usually completed within 24 h, and were always complete within 48 h. In all cases except Clamps 1 and 2, weighed subsamples of the brei were immediately frozen and stored at −20 °C for subsequent analysis as one batch at the end of each winter. The analyses, for sugar, sodium, potassium and α-amino nitrogen concentrations were made using standard procedures at the NIAB laboratory. For Clamps 1 and 2, samples of the fresh brei were analysed using the same standard procedures but at IACR-Broom's Barn.

For all clamps and sampling dates in 1993/94 and 1994/95, subsamples of the brei from each net in each row were thoroughly mixed to provide a sample to represent that row. Part of this sample was weighed, dried at 85 °C to constant weight, then reweighed to determine water content. Another part (*c.* 2·5 ml) was packed into a 5 ml syringe and immediately frozen in liquid nitrogen for subsequent determination of glucose, fructose and raffinose concentrations using HPLC techniques. The frozen syringes were stored at −20 °C and analysed after thawing at room temperature and being centrifuged at 5500 ***g*** for 20 min. The expressed sap was collected, filtered through a 10 kD membrane and analysed using an Aminex HPX-87N HPLC column (Biorad) with refractive index detection. On the basis that each sap sample contained an unbiased sample of the solute concentration, the analytical results were adjusted according to the water content of the beet. However, the results were first adjusted to take account of the effect of sucrose on the volume of the sample to produce results in terms of mg solute per ml of water.

The presence or absence of bias in the solute concentration was tested after the expressed sap had been collected. The brei pellets from the bottoms of the syringes were allocated to two groups at random. Pellets within one group were weighed, dried at 80 °C to constant weight and then reweighed to estimate the pellet water content. Pellets in the other group were homogenized with a known volume of distilled water, centrifuged again, and the expressed diluted sap was analysed for the same compounds as the original sap. After making an appropriate allowance for the ratio of water within the brei pellet and the added distilled water, there was no significant difference in solute concentrations. It was concluded that the expressed sap was an unbiased sample of the brei sap.

The data, adjusted for (i) the effect of sucrose on the sap volume and (ii) the water content of the beet material, have been tabulated on the basis of per 100 g sugar (analysed polarimetrically with reference to a standard sugar solution).

Clamp temperature

In Clamps 1 and 2 and all clamps studied in the winters of 1993/94 and 1994/95, eight nets in two columns of beet in the first batch to be put into the clamp (the last batch to be retrieved) were fitted with a Type U thermistor probe. The resulting temperatures (two replicates of four depths in the clamp), and ambient temperature (screened and 1·25 m above ground level) were recorded hourly throughout the storage period using SQ8 or 1200 Series Squirrel data loggers (Grant Instruments, Cambridge, Ltd.). In addition, in Clamp 13 a pair of probes was buried to a depth of 1 m. One was pushed 2·5 cm into a beet, the other recorded the temperature around that beet; both temperatures were recorded hourly.

Analysis of weight and quality data

Changes in the concentrations of the various beet quality characteristics (dirt tare, sugar concentration etc) were estimated simply by comparing the concentrations at the outset with those measured on subsequent occasions. Assessment of weight changes was more complex. The dirty, untopped weights of samples at the start and upon retrieval were determined, but any changes in these weights could have been due to changes in the weight of the storage roots, the crown and tops or the adhering soil. Changes in the clean beet weight were calculated on the basis of the following formula:

$$CBL = \left[\frac{(w_1 \times a) - w_2}{w_1 \times a}\right] \times 100$$

where CBL = clean beet loss during storage (%), W_1 = initial weight of stored sample (kg), W_2 = weight of clean, topped beet after storage (kg) and a was a constant for each clamp. This constant was simply:

$$\frac{100 - t}{100}$$

where t was the average total tare of the 20 samples which were analysed at the outset. The calculation to estimate the loss of stored sugar used a similar formula, estimating the initial sugar weight from the estimated initial clean weight and the average sugar concentration of the samples analysed at the outset. In essence, the assumption was made that the sugar concentration and dirt and top tares of the samples as they went into the clamp were equal to the average values for the samples which were analysed when the experiment began.

Throughout Europe, beet for sugar processing are bought and sold on the basis of the tonnage of clean roots, adjusted for their sugar concentration. Here the initial and final tonnages were adjusted to a sugar concentration of 16%, using the correction factors agreed between British Sugar plc and the farmers' representatives. The loss of adjusted tonnage (referred to in this paper as 'adjusted weight') was calculated in a similar way to the loss of clean beet, except that the weights were corrected for the initial and final sugar concentrations.

The beet quality and weight data were analysed using ANOVA procedures in the GENSTAT 5 suite of programs. The data from Clamps 5 and 6 were analysed as randomized block experiments with six replicates. All the other clamps had systematic designs for sample location, and no true replicates. Therefore the effect of, for example, depth of sample below the clamp surface (row) was assessed by considering column and retrieval date as replicates. In order to do this, for each clamp, the 20 samples which were analysed without being buried were, at random, allocated to a row and column position. The variance partitioned to the interaction of rows and/or dates with columns was used as the residual variance to calculate standard errors.

RESULTS AND DISCUSSION

The design of 17 of these experiments was such that period-in-clamp effects were the same as the effect of the position of a face within the clamp. However, the effect of the position of a face was unlikely to be of any significance because, in all the analyses of all the clamps, the effect of the position of a column of samples was never significant. Therefore, we are reasonably confident that the duration of storage really caused the storage period effects. Storage period had large significant effects on some quality parameters and on losses, and these have been described first.

Dirt and tops tare

The dirt and tops tare of the samples analysed immediately after harvest indicate important aspects of the quality of the beet being stored (Table 1). The dirt tare of the samples was likely to be biased towards smaller values than the clamp as a whole, especially where the beet were grown on stony or silty clay soils. For example, the beet for Clamp 8 were grown on a silty loam and the sample from the harvester contained balls of mud; these were not included in the nets, nevertheless the dirt tare averaged 10·8%. All of the samples were within the range of dirt tare commonly measured when beet are delivered to sugar factories.

Table 1. *Dirt and tops tares* (*as a percentage of the dirty*, *untopped weight*) *of sugarbeet samples taken immediately before the start of storage in England 1992–94*

Clamp No.	Dirt tare	Tops tare
1	4·3	5·2
2	8·2	6·5
3	6·1	1·8
4	5·4	4·3
5	0·6	1·5
6	8·6	1·7
7	2·6	3·2
8	10·8	8·4
9	5·2	5·4
10	6·3	4·8
11	9·5	6·0
12	5·2	4·5
13	1·9	3·2
14	5·1	3·8
15	5·8	6·6
16	3·7	4·9
17	4·0	7·0
18	4·7	8·0
Mean	5·4	4·8

In most of the clamps, storing the beet had no significant effect on dirt tare. In Clamps 7 and 13, dirt tare increased significantly, particularly after *c.* 55 days of storage, to 6·3 and 4·8%, respectively. This did not represent soil adhering to the beet, but new shoots sprouting from the crowns. These sprouts, produced in warm dark conditions, were knocked off the beet during washing and therefore they appear as dirt tare, not as tops tare. In Clamp 6 dirt tare appeared to decline during storage. This probably represents rough handling during sample retrieval when soil and sprouts fell out of the nets: subsequently the handling procedure was improved; nevertheless this change in soil tare might mean that calculations of weight and sugar loss from this clamp were slightly overestimated.

The tops tare of material going into the clamps (Table 1) was typical of much of the beet harvested on farms in England: the tares ranged from 1·5 to 8·4% of the total beet weight and averaged 4·8%. Usually, storage duration had no significant effect on tops tare; in six cases the tare increased significantly during storage and in two it decreased. There was no convincing pattern to these changes; for example, in Clamp 15 the tops tare at the outset was 6·6% of total

Table 2. *Sugar concentration (%) in samples of beet retrieved after various storage periods in 18 clamps and during three winters (1992/93 to 1994/95) in England*

		Sugar concentration (%)						
		Storage period						
Season	Clamp No.	0	1	2	3	4	S.E.	D.F.
1992/93	1	15·3	14·8	14·5	14·7	14·3	0·08	72
	2	16·1	16·1	16·2	15·7	15·5	0·09	72
	3	18·0	17·9	18·2	17·9	—	0·16	80
	4	17·7	17·1	17·1	16·8	—	0·13	80
	5	17·5	17·2	17·3	16·9	16·7	0·13	20
	6	19·2	18·8	18·4	17·6	17·3	0·11	30
1993/94	7	16·1	16·5	15·4	15·0	14·7	0·10	76
	8	14·5	—	13·9	13·0	—	0·08	76
	9	16·3	15·9	15·6	15·5	15·5	0·10	76
	10	17·6	17·2	16·9	16·7	16·3	0·06	76
	11	16·9	16·4	16·1	15·9	15·5	0·06	76
	12	19·0	18·1	17·4	17·5	17·2	0·07	76
1994/95	13	18·1	17·7	17·9	17·5	17·1	0·07	76
	14	18·4	18·2	18·3	17·9	—	0·07	76
	15	16·5	16·4	16·1	15·7	15·2	0·08	76
	16	17·5	17·2	17·1	16·9	16·2	0·07	76
	17	17·9	17·4	17·1	15·8	16·1	0·08	76
	18	17·4	16·5	16·1	16·0	—	0·08	76
	Mean	17·2	16·8	16·6	16·2	16·0	0·07	62

Missing values were calculated and used to estimate the means.

weight, after 13 days in store it was assessed at 9·1%, after 41 days at 7·8%, and after 55 days at 8·9% (S.E. ±0·29, D.F. = 51). Real changes in the beet during storage were unlikely to have caused these variations: they are more likely to be the result of small subjective differences in the way the beet were topped in the tarehouse. As far as possible, all the beet from one clamp were topped by the same person, but illness and other commitments meant that sometimes this was not achieved. Even where the operator remained the same, small differences in standard from one date to the next were difficult to eliminate. These subjective errors are the most likely cause of the recorded changes in tops tare.

Sugar concentration and beet weight

Initial sugar concentration (Table 2) ranged from 14·5% (cv. Cordelia grown on a peaty loam soil and harvested following a period of wet weather when the soil was waterlogged) up to 19·2% (cv. Saxon grown on a sandy loam soil with no recent additions of organic manure).

Except in Clamp 3 there was always a significant decline in sugar concentration in storage (Table 2). On average, sugar concentration, when plotted against

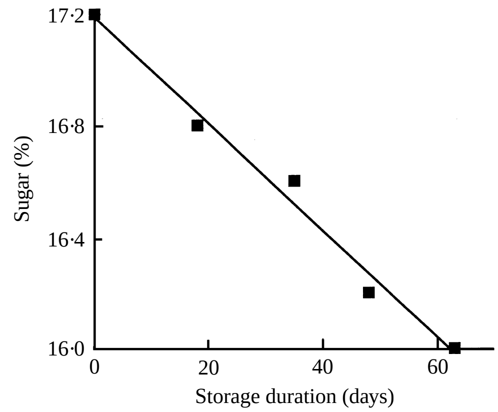

Fig. 1. The average effect of storage duration on sugar percentage in 18 clamps on farms in England: 1992–95. The linear regression equation is:
Sugar (%) = 17·19 (±0·039) −0·02 (±0·0010) × days.

average storage duration (classified in Appendix 2), declined by *c*. 0·02% per day (Fig. 1). This value varied considerably: at Clamp 3 the loss was not detectable, and it was only *c*. 0·5% after 65 days at Clamp 2. Loss of sugar concentration was especially rapid in Clamps 6, 12, 17 and 18; all lost *c*. 0·03% per day. Three of these were on the same farm, but nothing about the beet samples or the clamps made us suspect that these would suffer large losses. Clamp 8, where the soil tare of the samples was 10·8% and where the clamp contained an even larger proportion of soil, did not suffer an abnormally large loss of sugar concentration until after 50 days, when the grower became concerned about the ability of the beet to withstand further storage and promptly delivered it to the factory.

The largest loss of weight was 70 kg/t, at Clamp 4, but this was very unusual; in 13 of the clamps the weight changes were small and not significant. In Clamps 17 and 18, there were significant weight gains after storage but these, along with gains in three other clamps, were probably artefacts resulting from apparent declines in tops tare of the beet during storage. The overall conclusion was that during storage the clean weight of beet seldom changes significantly.

Sugar weight and adjusted beet weight

When the changes in sugar weight and adjusted beet weight in the samples were plotted against storage duration (Fig. 2*a*, *b*), the data for Clamp 15 were omitted because the initial rates of loss appeared extraordinarily large (0·53 and 0·55% per day respectively). This was an artefact caused by an unrealistic change in assessed top tare (see previous section). The standard error about the intercept for the regression line included the origin of the graph, and because an analysis of the residuals about the line

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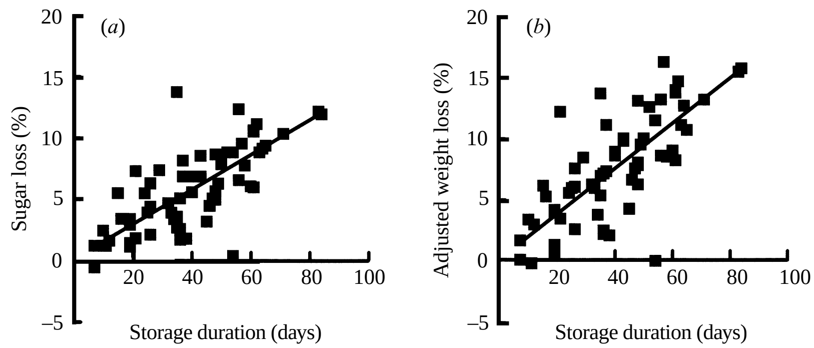

Fig. 2. Relationship between either (*a*) sugar loss (%) or (*b*) adjusted weight loss (%) and storage duration in 17 clamps on farms in England. The data from Clamp 15 have been omitted. The equations for the regression lines are:

$$SL(\%) = 0{\cdot}143\ (\pm 0{\cdot}0068) \times \text{days in store};\ r^2 = 0{\cdot}52$$
$$AWL(\%) = 0{\cdot}187\ (\pm 0{\cdot}0086) \times \text{days in store},\ r^2 = 0{\cdot}54.$$

provided no evidence of a curved relationship, the regression was recalculated with an intercept of zero. This caused a small upward shift in the estimated rate of sugar loss, from 0·133 (±0·0165) to 0·143 (±0·0068)% per day. This is a considerably faster rate than the average of 0·1% per day measured by Oldfield *et al.* (1980) during the winters of the 1960s and 1970s, but not as serious as the 0·25% per day lost in trials in Eire (Rice & Burke 1980).

Clamp 5 lost sugar much faster than most others. It was heavily insulated with a 30 cm deep layer of bunched straw. When wet, this straw could have impeded ventilation and allowed the clamp temperature to rise abnormally, so increasing the respiration rates of the beet and any saprophytic fungi growing on injured tissue. Unfortunately, the internal temperature of this clamp was not monitored. Especially small losses were recorded in Clamps 3 and 14: in neither case can these losses be ascribed to inconsistencies in the tops tare, and these two clamps have few features in common that are not shared by many of the other clamps (Appendix 1).

The rate of sugar loss was linearly related to time (Fig. 2*a*): this contrasts with expectations based on measurements of respiration rates of beet immediately after harvest. Oldfield *et al.* (1971*b*) showed that, at a constant temperature, CO_2 production rate increased rapidly during the first 7–10 days after harvest and declined thereafter, suggesting that sugar losses would be most rapid in the first 7–10 days. We found no evidence for this. The beet in the clamps were initially cool, and gradually warmed up as heat was produced by respiration. Perhaps recent damage caused rapid respiration initially, but this was counterbalanced by the slowing effect of cool temperatures. Later, the underlying respiration rate probably decreased once the effects of cut surfaces and bruising had worn off, but this was balanced by an increased rate in response to the warmer temperatures generated inside the clamps. In addition, soon after being stored, beet probably became colonized by saprophytic and parasitic fungi. Wyse (1980) showed that injured beet easily became infected with *Penicillium* and *Botrytis* spp., and when 20% of the root surface was infected, respiration rate was twice that of healthy control roots.

When beet are stored during warm weather (i.e. in September and October in the UK), the same counteracting influences on respiration rate will probably occur unless the heat produced by respiration can be dissipated. Therefore it is appropriate that a large surface:weight ratio is recommended to aid the ventilation of beet piles at this time of year (Oldfield *et al.* 1971*b*). If piles of this type can dissipate their heat and remain at about the same temperature as the air, then it might be more appropriate to deliver only freshly-harvested beet to the factory in order to avoid the rapid respiration period in the first 7–10 days after harvest. This possibility has never been investigated properly.

In this study, the adjusted clean beet weight was calculated using standard commercial criteria and the losses after storage were correlated closely with the losses of sugar (Table 3). Again, omitting the data from Clamp 15, the rate of loss, averaged over the 62 assessments, was 0·187±0·0086% per day. Because loss of sugar concentration was the principal way in which a loss of sugar yield was manifest, and because the factors used to calculate adjusted tonnage are weighted slightly in favour of large sugar concentrations, the loss of adjusted tonnage, in percentage terms, was greater than the loss of sugar yield.

Impurity concentrations

Amino-nitrogen compounds are important impurities in beet because they cannot be separated from the sugar until the crystallization stage, where they increase the proportion of sucrose retained in molasses. The amino-N concentration is usually expressed

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Table 3. *The loss of adjusted clean beet* (%) *in six clamps in each of three years after various storage times in England*

Campaign	Clamp No.	Adjusted weight loss (%) Storage period 1	2	3	4	S.E.	D.F.
1992/93	1	5·2	11·1	10·0	12·7	0·96	57
	2	5·5	7·3	8·5	10·7	0·82	57
	3	1·2	2·4	−0·1	—	0·80	35
	4	−0·3	5·9	2·1	—	1·22	35
	5	1·6	12·2	13·7	13·2	2·01	15
	6	0·0	3·4	6·9	14·7	1·33	20
1993/94	7	0·5	8·9	13·8	15·8	1·18	57
	8	—	8·0	16·3	—	1·03	57
	9	2·9	5·9	7·5	8·2	0·83	57
	10	3·3	6·2	6·6	9·0	0·62	57
	11	7·5	7·8	11·1	15·5	1·30	57
	12	6·0	8·6	11·5	14·0	0·70	57
1994/95	13	4·1	3·7	6·2	8·6	0·57	57
	14	2·5	2·0	4·2	—	0·67	57
	15	7·1	8·5	10·9	13·6	0·79	57
	16	6·1	8·4	9·8	13·2	0·52	57
	17	3·9	5·3	13·1	12·6	1·06	57
	18	7·1	10·0	9·5	—	0·83	57
	Mean	4·0	7·0	9·0	12·0	0·53	45

Missing values were calculated and used to estimate the means.

Table 4. *The average concentration of amino-nitrogen, sodium and potassium impurities in sugarbeet roots after various periods in storage. Mean of 18 storage clamps*

Impurities (mg/100 g sugar)	Storage period (days) 0	18	35	48	63	S.E. (68 D.F.)
Amino-N	172	171	177	181	181	1·1
Sodium	126	128	128	136	134	1·2
Potassium	1089	1103	1104	1135	1138	3·6

as mg N/100 g sugar. In these studies, storage often led to a small increase in this concentration (Table 4), but only as a consequence of sugar being lost. In three of the clamps (Numbers 9, 12 and 13), the pattern was reversed and amino-N concentrations declined towards the end of the storage period. This was associated with marked regrowth and sprouting of the beet in the clamp. Possibly the amino-N compounds were mobilized to provide the N source for these young leaves.

Like the amino-nitrogen analyses, the concentrations of sodium and potassium in the roots changed little during storage, but tended to increase when expressed on a unit sugar basis (Table 4). On a beet weight basis, these concentrations hardly changed at all. The general tendency for these impurities to remain stable during storage agrees with the findings of a review by Vukov & Hangyál (1985).

In 1993/94 and 1994/95, HPLC techniques were used to measure the concentrations of raffinose, glucose and fructose. The raffinose concentrations remained generally stable throughout storage, starting at an average of 0·47 g/100 g sugar (Table 5). This contrasts with the findings of Wyse & Dexter (1971) who found that raffinose concentration increased markedly during storage when the beet were kept at *c.* 3 °C, but in our studies the temperatures were seldom so cold.

The concentrations of glucose and fructose per 100 g sugar increased steadily throughout the storage period (Table 5), in common with the findings of Vukov & Hangyál (1985). Initially the fructose concentration was small compared to glucose, *c.* 0·05 g/100 g sugar or less. This position changed during storage, at the end of which fructose concentration was still less than that of glucose but usually between 0·2 and 0·25 g/100 g sugar.

This change in reducing sugar concentration, allied to the change in sugar concentration, can have important implications for the extractability of the sugar and its quality. The equation of Pollach *et al.* (1991) incorporates a term for invert sugar concentration and allows an index of sugar extraction to be calculated. This equation was applied to the data, and estimated extraction always decreased after storage, but not alarmingly so. On average, the decrease was from 90·7 to 90·2% in 1993/94 and from 91·3 to 90·2% in 1994/95. When these values were applied to sugar in beet after storage we estimated that only 83% of the original sugar would be extracted (Table 6). Because all factories do not have the same characteristics, these extractability estimates cannot be precise, but they are a predictive index of the likely changes.

Position in the clamp

In all clamps except Numbers 5 and 6, the samples were positioned in predetermined arrays so that there was a chance to detect effects of distance from the clamp edge or depth from the surface on tare, weight and internal quality characteristics. There were no effects of distance from the clamp edge, despite some clamps being *c.* 20 m wide. The air movement over beet near the clamp edge or beet near the middle must have followed very different path lengths through the clamp, but this caused no significant differences in the measurements. By contrast, there were significant effects of depth of the sample from the clamp surface on sugar concentration and beet weight in 11 of the 16 clamps. For sugar percentage (which is measured

Table 5. *Raffinose and glucose + fructose concentrations (g/100 g sugar) in beet before and after storage in clamps on farms in 1993/94 and 1994/95*

		g/100 g sugar					
		Raffinose			Glucose + Fructose		
Site	Days in store	At start	After storage	S.E. (12 D.F.)	At start	After storage	S.E. (12 D.F.)
7	84	0·53	0·33	0·124	—	—	—
8	57	0·35	0·24	0·041	0·12	0·45	0·107
9	61	0·66	0·81	0·086	0·12	1·18	0·215
10	60	0·92	0·67	0·174	0·14	0·28	0·056
11	83	0·43	0·39	0·091	0·04	0·76	0·167
12	61	0·50	0·32	0·113	0·03	0·61	0·148
13	56	0·37	0·40	0·008	0·19	0·57	0·023
14	45	0·45	0·50	0·037	0·21	0·43	0·054
15	53	0·45	0·50	0·002	0·18	0·57	0·011
16	67	0·49	0·44	0·086	0·14	0·59	0·086
17	52	0·20	0·33	0·068	0·06	0·40	0·150
18	49	0·32	0·41	0·101	0·27	0·73	0·227
Mean		0·47	0·45	0·026 (44 D.F.)	0·136	0·597	0·040 (40 D.F.)

Table 6. *Indices of white sugar yield, relative to beet immediately after harvest, after clamping in 1993/94 and 1994/95*

			After storage	
Clamp No.	Initial extractability (%)	Storage period (days	Sugar in clamp (%)	Extractable sugar (%)
7	87·5	84	88·0	76·2
8	86·6	57	89·6	77·1
9	91·4	61	94·0	86·3
10	92·8	60	93·9	86·7
11	91·8	83	87·8	80·3
12	93·6	61	89·3	83·6
13	90·8	56	94·4	85·2
14	92·4	45	97·3	89·4
15	91·0	53	92·1	82·7
16	91·5	67	92·6	84·0
17	91·9	52	89·9	80·4
18	90·3	49	92·5	82·3
Mean	90·9	60·7	91·7	82·8

more accurately than a change in weight) the beet at the base of the clamp had larger concentrations than those near the surface. By the end of the storage period, the sugar concentration was often *c.* 1% greater at the bottom than near the top of the clamp, although in Clamps 5 and 6 the concentration was less than when the beet were first harvested. Only in Clamp 15 was the effect reversed and the largest sugar concentration was near the clamp surface.

In five of the clamps there was no significant effect of depth below the clamp surface on the change in clean, topped root weight, but in the other 11 clamps there were significant weight losses at the bottom of the clamp and only small losses, or even weight gains, near the surface. These changes were shown most clearly in Clamp 14 (Table 7), where the initial dirt tare and sugar concentration was 5·1 (±0·18)% and 18·44 (±0·064)% respectively. After 45 days, the dirt tare at the bottom of the clamp remained almost unchanged, but at the top it had apparently increased to 6·2%. It was unlikely that this was due to changes in the weight of soil attached to the beet, but was probably the result of the sprouting and new leaf production on the beet nearer the surface; sprout production was more prolific near the top of the clamp. In these studies sprouts were designated as dirt tare and not tops tare because they were knocked off the beet and lost during the washing processes, before tops tare was assessed. Commercially, the sprouts would probably be knocked off while beet were being loaded prior to delivery to the factory.

At the base of Clamp 14 the sugar percentage hardly changed during the 45 days; initially it was 18·44% and finally it reached 18·34% (Table 7). However, there was a steady reduction in concentration through the clamp, and at the top it was only 17·56%. Beet at the top of the clamp gained weight by gaining water, and this partly explains the loss of sugar concentration. This gain was consistent, significant and not a quirk caused by the necessarily complex method of calculating gains and losses: netted samples near the clamp surface weighed more

Table 7. *The effect of depth from the clamp surface on the quality characteritics and losses of sugarbeet stored for 45 days: Clamp 14*

Depth from surface (cm)	Dirt tare (%)	Sugar (%)	Impurities (mg/100 g sugar)			Losses (%)		
			K	Na	Amino-N	Clean beet	Adjusted tonnage	Sugar
0–60	6·2	17·56	952	70·8	89	−2·57	4·09	2·32
60–120	5·5	17·77	973	81·5	94	−0·24	4·63	3·32
120–180	5·8	18·00	964	81·4	92	1·73	4·90	4·06
180–240	5·0	18·34	958	73·1	97	2·47	3·18	3·00
S.E. (60 D.F.)	0·28	0·106	13·7	2·69	2·2	0·53	0·94	0·79

Table 8. *Water concentration (%) in beet stored for up to 45 days at a range of depths in Clamp 14, 1994/95*

Depth from surface (cm)	Storage period (days)				S.E. (60 D.F.)
	0	26	38	45	
0–60	—	76·6	76·5	78·9	0·24
60–120	—	76·1	76·6	78·6	
120–180	—	75·8	76·5	78·1	
180–240	—	76·3	76·1	78·1	
Mean	76·1	76·2	76·5	78·4	0·12

at the end of the experiment than at the beginning. Beet at the bottom of the clamp lost weight. Because the changes in weight were opposed by the changes in sugar concentration, there was no significant effect of depth below the clamp surface on loss of adjusted or sugar weight (Table 7), the same was true of all the clamps. The concentrations of sodium and potassium impurities, per unit weight of sugar, changed very little, but the amino-N concentration increased, mostly at the base of the clamp.

These changes in weight and sugar concentration were probably the consequence of complex interactions between loss of sugar due to respiration and translocation to new shoots, loss of water to the ventilation airstream as it was warmed on its way through the clamp, movement of water during growth from dry-matter-rich roots to new, water-rich shoots, and uptake of water from rain. The water content of beet samples in Clamp 14 (Table 8) hardly changed for the first 36 days, when water and dry matter were being lost simultaneously and in equivalent proportions. Thereafter, sprout growth was marked, sugar losses were acute and wet weather led to an increase in sample weight and in water content, especially near the clamp surface. The samples deteriorated least at the base of the clamp. A 3 m limit to clamp height has been suggested (Jaggard *et al.* 1995) on the grounds that ventilation might be inadequate in tall clamps. There is nothing in these results to suggest that height should be restricted on the grounds of beet quality, although a restriction may still be prudent during autumn, when warmer weather may cause overheating and the rapid degradation of stored beet.

Clamp temperature

Air temperature was recorded at or close to every clamp site, except Clamp 5 where recordings were made at a recognized agrometeorological station 10 km away. The warmest maximum air temperature was 15 °C (Clamp 13) and the coldest minimum was −7 °C (Clamps 1 and 2).

The temperature of the clamp should remain above −3 °C to prevent the freezing of any beet (Heijbroek & Huijbregts 1984), but should remain cool to minimize respiration by the beet, growth of moulds and rot-inducing bacteria and the growth of new shoots. However, the benefits of keeping the clamp temperature close to freezing point are small because low temperature storage can induce the production of raffinose. Wyse & Dexter (1971) found, in small-scale storage tests, that so much raffinose was produced at 3 °C that its deleterious effect on sugar extraction almost counterbalanced increased sugar losses due to respiration at 10 °C. Thus reviewers like Vukov & Hangyál (1985) have suggested an ideal clamp temperature of 4–5 °C.

Not surprisingly, thermistor probes buried in some of the clamps showed that reality was far from this ideal. Within *c.* 50 cm of the clamp surface, the atmosphere never became cooler than −0.5 °C. This extreme occurred in Clamp 2 on 3 January, 2 h after the minimum air temperature of −7 °C was recorded. At that time the tops of this clamp and Clamp 1, which experienced similar temperatures, were not insulated. That night local ground minimum temperatures fell to −12 °C, and the clamp surface froze to a depth of two beet. After thawing, these beet deteriorated badly within a few days and they had to be picked off and discarded manually before the clamp contents were suitable for processing. The yield

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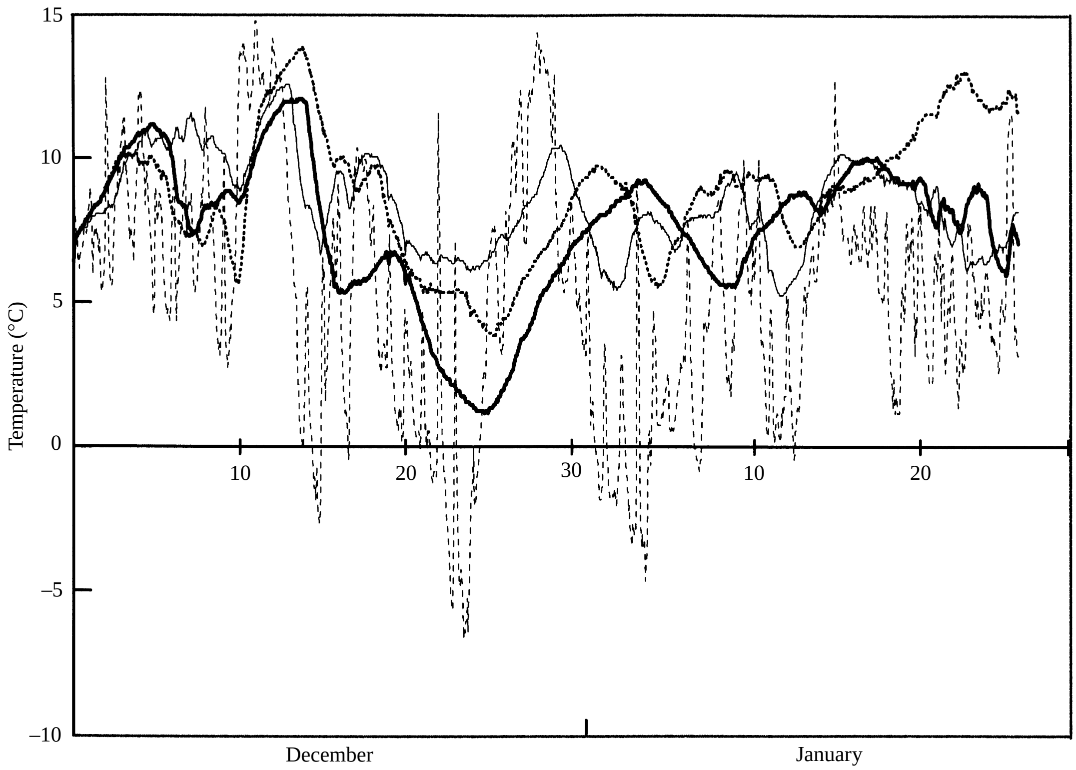

Fig. 3. An example of a temperature profile of a sugarbeet clamp (Clamp 13). The data are the average of duplicate sensors placed at depths of 0·5 m (——), 1·0 m (···) and 2·0 m (▬) below the clamp surface; and a nearby screened sensor 1·25 m above ground level (----). For clarity, the results from the sensor buried 1·5 m deep have been omitted.

loss was 1%. This was estimated from the weight of beet discarded from 10 sample quadrats, each 1m^2, and from the clamp dimensions and weight.

At 14 of the sites the temperature records from within the clamps were almost complete. In none of these was there a consistent effect of depth below the surface on temperature. Sometimes the probes nearest the surface were coolest and fluctuated most, mimicking air temperatures; at other times the deepest probes were coolest. In some clamps the temperature differentials were 5 °C, both vertically and horizontally. Examples of large vertical gradients are shown in Fig. 3. These large variations occurred despite the absence of large amounts of soil which would impede ventilation. The clamp with the largest dirt tare (Clamp 8) was no warmer than its counterparts in the same winter. However, intuitively it seems likely that clamps containing much soil will become hot in those spots where ventilation is restricted. It has been suggested that farmers should monitor clamp temperature to ensure that undue heating and deterioration does not take place (Dunning & Thompson 1982). This study suggests that measurements would need to be made frequently and at many points for this to be realistic; one or two pairs of observations per day could be quite misleading. Even with a large array of thermistors, hot spots are still likely to be missed.

In 12 of the clamps (all except 3–6 inclusive, 12 and 16) the recordings of within-clamp and air temperature were sufficiently complete for an overall comparison to be made. The clamp temperature was simply the average of probes at all depths. The average of all air temperature readings during the storage periods was 4·7 °C, varying from 3·0 °C at Clamp 1 to 6·3 °C at Clamp 13. The average clamp temperature was 6·4 °C, varying from 4·6 °C at Clamp 1 to 8·2 °C at Clamp 2. These extremes all occurred on the same farm in Suffolk, where the building and insulation techniques remained the same throughout. Among all the clamps there was a positive relationship between storage duration and average temperature rise, but this was weak and not statistically significant. The clamp and air temperatures were always similar initially; thereafter the clamp tended to warm up, above the general level of air temperature. However, air temperature can fluctuate rapidly and over a large range but shifts in clamp temperature were much more gradual. Therefore, there was seldom any synchrony in the changes and during the day large

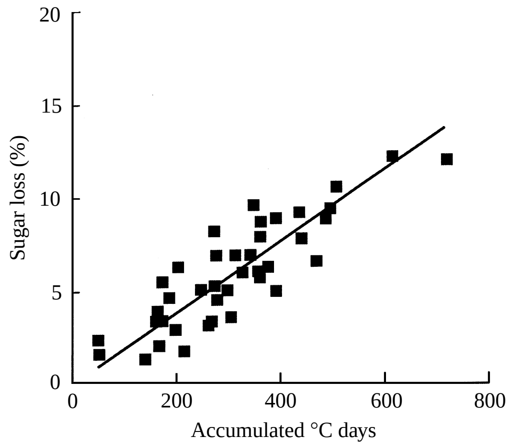

Fig. 4. Relationship between sugar loss (%) and thermal time in store (°C d) in 11 clamps of sugarbeet on farms in eastern England, 1992–95. The regression equation is: SL(%) = 0·0188 (±0·00068) × °C days; $r^2 = 0.73$.

parts of the clamp were often cooler than the air (e.g. Fig. 3). The temperatures inside a beet and in the surrounding atmosphere were monitored in Clamp 13. The difference between them was never > 1 °C (data not presented): the warmer of the two varied but not in a way that could be predicted simply depending upon whether the clamp was warming or cooling.

Losses and clamp temperature

Regression analyses were made to examine the relationships between yield loss (sugar or adjusted tonnage) and the storage temperature of the beet. Storage temperature was calculated as the daily average of the data from all sensors in the clamp, accumulated above a base temperature of 0 °C. Data from Clamp 15 were excluded. The relationships accounted for > 64% of the variance, were linear, positive, and had intercepts which were not significantly different from zero. The regressions were recalculated to pass through the origin and showed that the losses were 0·0250 (±0·00109)% of adjusted weight and 0·0188 (±0·00068)% of sugar per °C day (Fig. 4). The relationship with thermal time accounted for 73% of the variance in sugar losses, 5% more than was accounted for by storage duration. Clearly much of the difference in yield loss was associated with differences in internal clamp temperature.

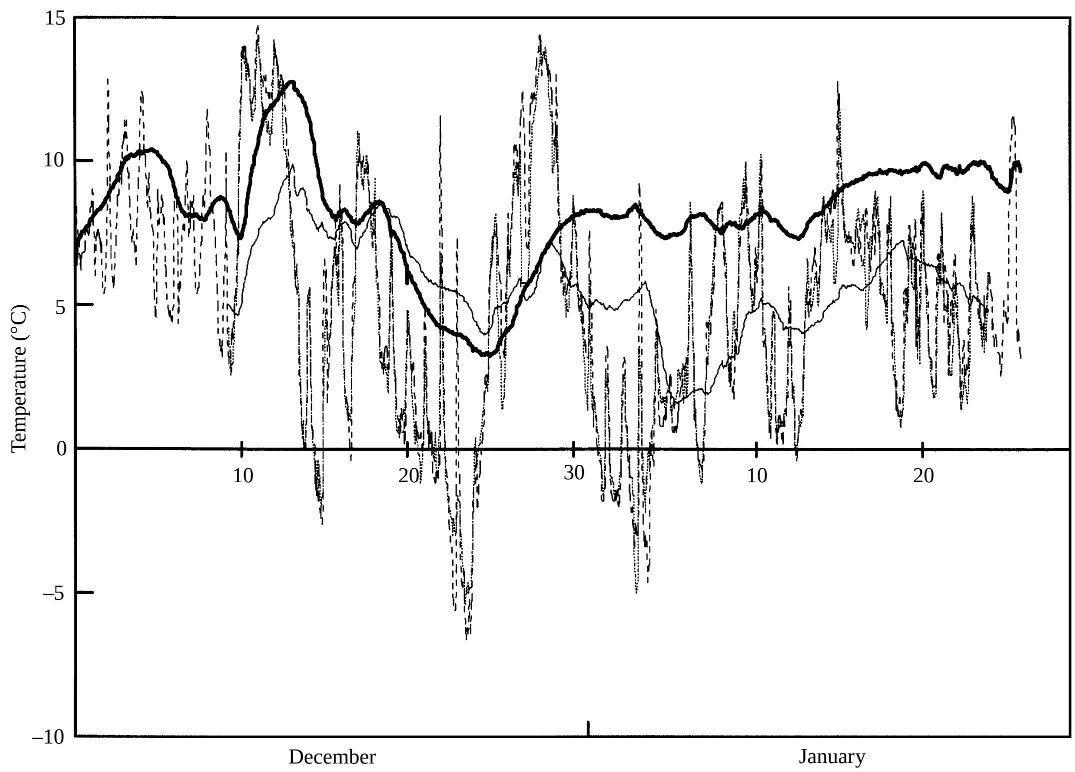

Fig. 5. A comparison of the average clamp temperatures and ambient air temperatures throughout the storage periods in Clamps 13 and 14 in eastern England during the winter of 1994/95. Clamp 13 beet (▬▬) and ambient air (----) temperatures. Clamp 14 beet (——) and ambient air (···) temperatures.

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Sometimes the average temperatures of the clamps unexpectedly differed by several degrees and this affected the amount of sugar lost. For example, Clamps 13 and 14 were of similar size and had a long storage period in common, during which the ambient temperatures were very similar (Fig. 5). Clamp 13 was on an exposed site, surrounded by straw bales and covered with white, woven polypropylene sheeting from 23 December onwards. Clamp 14 was in a sheltered location against buildings and, from the outset, was covered with a thick layer of straw (Appendix 1). Because it was constructed later, Clamp 14 was cooler than Clamp 13 until about 13 December; for the next 10 days clamp temperatures were very similar. Thereafter the woven polythene sheeting was put on Clamp 13 and it became well insulated from the ambient air. The straw seemed to offer much less insulation and probably allowed better ventilation. During this well-insulated period Clamp 13 accumulated an extra 108 °C day, and on the basis of the regression in Fig. 4, this additional heat would cause 2·03% of the sugar to be lost.

This difference in behaviour cannot be accounted for by restricted ventilation within the clamp (i.e. due to a difference in soil tare); the average soil tares assessed when every load was delivered to the sugar factory were 5 and 6% respectively. Although the beet cultivar differed from clamp to clamp (Appendix 1), Rice & Burke (1980) and Oldfield *et al*. (1980) showed that this factor had no significant effect on storage losses. Also, the difference was not related to damage experienced by the beet during harvest and clamp construction. The average diameter of the broken surfaces on the roots was 1·6 and 3·1 cm for Clamps 13 and 14 respectively. None of the rates of loss were related to this index of damage. Clearly, in this instance, straw was the better covering material, but it is not popular because its use is labour-intensive. Also there is anecdotal evidence that it can become saturated with rain and act as an impervious barrier to air movement. The woven polypropylene sheets probably act as a similar barrier when the spaces between the warp and the weft become filled with water. There is a need to find a covering material which will protect beet from severe frosts, shed water and still allow ventilation so that heat is not trapped inside the clamp. A polypropylene felt, which is being tested in Germany (Gunther 1995) deserves consideration.

CONCLUSIONS

When this study started it was common for the top surface of large, flat-topped clamps to be left uncovered. These clamps do not generate enough heat to remain frost-free, and a layer of beet (*c*. 1% of the clamp) was damaged and rendered unprocessable when air temperatures fell to below *c*. −5 °C. Temperatures in the clamps varied greatly with position and over time, but not in a way that could be predicted simply. Thus, there is little prospect of monitoring clamp temperature accurately without using many sensors and frequent data collection.

Beet in the clamp seldom lost weight; the losses were almost exclusively reductions in sugar concentration, which declined by *c*. 0·02% per day. The parameter of crop quality which deteriorated significantly during storage was reducing sugar concentration. On average it increased from 0·14 to 0·60 g/100 g sugar. The loss of sugar yield was 0·143% per day, or 0·0188% per °C day. This loss rate appeared linear. Because changes in sugar yield occurred as changes in sugar concentration, and because there is a small premium for beet with a high sugar concentration, the loss of adjusted weight was larger, 0·187% per day or 0·025% per °C day. There was little evidence of any systematic effect of position within the clamp on losses. However, in two clamps losses of sugar concentration were less at the bottom than at the top.

Thermal time experienced by the beet in clamp was a good indicator of sugar and yield losses, but clamp temperature could not be predicted simply.

Research is needed to find more effective insulators which will allow the clamps to ventilate more readily.

Eight farms were involved in these studies, which were successful only because we had the willing support and co-operation of the farm staff and haulage contractors: we are grateful to them, and to colleagues at all three centres who helped with field work and analysis. The study was sponsored by the National Farmers Union.

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Appendix 1. *Characteristics of the 18 sugarbeet clamps used for storage studies*

Clamp No.	Grid Ref.	Start date	Cultivar	Soil	Harvester		Foundation	Surround (no. of walls)	Covering			Weight (t)	Dimension (m)		
					No. of rows	Topper			Open face	Sides	Top		H	L	W
1	TL 77	01/12/92	Giselle	LS	6	knife	Soil	Bales (2)	W	Straw	—	1047	2·5	29	24
2	TF 59	14/12/92	Saxon	ZL	3	f & s	Soil	—	—	Straw	—	867	2·5	37	19
3	SE 44	16/12/92	Rex	SCL	6	f & s	Concrete	Bales (3)	Straw		—	250	3·0	14	9
4	SJ 72	09/12/92	Regina	SCL	4	knife	Concrete	Sleeper (2)	W	Straw	—	403	3·0	16	12
5	TL 79	01/12/92	Saxon	PL	1	knife	Grass	—	Canvas	Straw	Straw	250	2·5	24	6
6	TM 09	16/12/92	Saxon	SL	6	knife	Concrete	Bales (3)	Straw		Straw	350	3·5	16	9
7	TL 87	01/12/93	Triumph	LS	6	knife	Grass	Bales (2)	W	Straw	W	1027	2·5	26	24
8	TF 59	25/11/93	Cordelia	ZL	6	f & s	Concrete	Bales (2)	Straw	Straw	Straw	960	2·5	26	21
9	SE 44	07/12/93	Zulu	SCL	6	f & s	Soil	Sleeper (2), bales (1)	W		W	440	3·5	18	10
10	TF 27	10/12/93	Amethyst	SCL	6	f & s	Concrete	Brick (2), bales (1)	PI		PI	310	3·5	16	8
11	TL 58	02/12/93	Cordelia	PL	4	knife	Soil	Bales (3)	Straw		—	350	3·0	22	11
12	TM 09	15/12/93	Saxon	SL	6	knife	Concrete	Bales (2)	Straw	Straw	Straw	300	2·8	10	18
13	TL 87	30/11/94	Saxon	LS	6	knife	Soil	Bales (3)	W		W	800	2·5	29	20
14	TF 41	09/12/94	Celt	ZL	6	knife	Concrete	Brick (1), bales (2)	Straw		Straw	1078	2·7	22	24
15	SE 44	22/12/94	Saxon	SCL	6	f & s	Concrete	Sleeper (2), bale (1)	W		W	140	2·8	11	7
16	TF 27	20/12/94	Zulu	SCL	6	f & s	Concrete	Brick (2), bale (1)	PI		PI	130	3·0	12	5
17	TL 58	02/12/94	Celt	PL	6	knife	Soil	Bales (3)	Straw		—	600	3·0	23	20
18	TM 09	30/11/94	Celt	SL	3	knife	Concrete	Bales (2)	Straw	Straw	Straw	550	2·5	30	8

The following codes are used in the table:

LS = Loamy sand.
ZL = Silty loam.
SCL = Sandy clay loam.
SL = Sandy loam.
PL = Peaty loam.

f = flail.
s = scalper.

W = woven polypropylene.
PI = plastic coated cloth.
— = not covered.

Appendix 2. *The date of harvest and storage duration of the 18 sugarbeet clamps*

Clamp No.	Harvest date	Storage duration (days)				
1	01/12/92	16	37	50	64	
2	14/12/92	24	37	58	65	
3	16/12/92	19	36	54		
4	09/12/92	11	25	36		
5	01/12/92	7	21	35	56	
6	16/12/92	7	21	35	49	62
7	01/12/93	19	40	61	84	
8	25/11/93	—	48	57	—	
9	07/12/93	12	33	47	61	
10	10/12/93	10	32	46	60	
11	02/12/93	26	48	63	83	
12	15/12/93	26	40	54	61	
13	30/11/94	19	34	48	56	
14	09/12/94	26	38	45	—	
15	22/12/94	13	27	41	55	
16	20/12/94	15	29	43	71	
17	02/12/94	19	35	48	52	
18	30/11/94	36	43	49	—	