BBRO 05/23 - Analysis of the causes of recent changes in beet amino-N and alkalinity

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Summary

Since the mid 1990s, the average concentration of amino-N in beet delivered to British Sugar factories has decreased progressively from around 160 to 70mg/100g/sugar. A decade ago less than 1% of the delivered beet had amino-N concentrations of less than 70 mg/100g sugar – the proportion is now over 30%. A similar pattern has been seen in the Sudzucker factories in Germany.

In commercial practice, amino-N concentrations are expressed relative to sugar (as milli-equivalents or mg/100g sugar) – a decrease in concentration can therefore be brought about by decrease in the yield of amino-N *per se* (kg/ha) or through dilution by an increase in sugar yield. Both factors have played a role. In the extensive NIAB variety trials, sugar yields have progressively increased over the past 20 years from just over 7 to almost 11 t/ha. The factors contributing to increased sugar yield have been well documented; they include improved varieties, better agronomy and husbandry, prolonged seasonal growth brought about by milder autumns and better late-season disease control, and greater recoveries of harvestable yield.

During the same period, the mean yields of amino-N have decreased from around 13 to 9 kg/ha, and this report primarily concentrates on the factors likely to have caused this decrease including (a) how far they are due to changes in varieties and agronomic practices; (b) the contribution of changing disease patterns (especially rhizomania) and disease control measures (such as the use of imidacloprid insecticides and triazole fungicides), and (c) whether significant changes have occurred in patterns of N uptake and distribution within the plant.

The effects of soil type and agronomy were examined using data from British Sugar's 1994-2005 annual crop surveys of yield and beet quality. Changes due to variety were examined using data from past NIAB variety trials. Process models were used to quantify the practical and financial implications of low amino-N on beet alkalinity and chemical usage in the factory process.

The main conclusions relating to the recent downward trends in the amino-N contents of beet (kg/ha) were that (a) they were not associated with lower inputs of N from fertilizers or manures and (b) they were associated more with improvements in agronomy, husbandry and seasonal growing conditions than with the introduction of varieties having a lower concentration of amino-N.

The main agronomic factors that appear to have influenced amino-N contents were:

1. Changes in disease patterns. Virus yellows increases amino-N concentrations by 20-30%, so part of the decline in amino-N in commercial beet could have partly resulted from a lower incidence of diseases through the use of imidacloprid seed dressings. Rhizomania, on the other hand, decreases the amino-N content of beet, primarily by restricting N uptake. This has been more evident on the continent where Rhizomania is more prevalent.

2. The use of triazole and strobilurin fungicides to control late-season leaf diseases, particularly powdery mildew which has increased considerably over the past decade. As well as controlling leaf diseases, these fungicides have the additional physiological benefit of maintaining a green, photosynthetically-active leaf canopy later into the autumn thus prolonging sugar accumulation. By delaying leaf senescence, the fungicides slow the remobilisation of nitrogen leaving more of it in the shoot at harvest and less accumulated as amino-N in the storage root. In the UK, crop surveys showed that triazole and strobilurin fungicides decreased amino-N concentrations from 106 to 88 mg/100g sugar, and fungicide trials showed decreases of between 10-18% especially when disease levels were high, but also

produced a significant decrease in the absence of disease. Similar effects have been reported on the continent.

Low concentrations of amino-N in beet were not uniquely associated with low uptakes of N, so it was possible to achieve high sugar yields with low levels of amino-N.

The natural alkalinity of beet has been defined in terms of the ratio of K+Na (as the alkali contributors) to amino-N (with glutamine being the major acid contributor). Optimum sugar extraction is achieved when this ratio is about 10. In the mid 1990s, the mean national alkalinity ratio varied between 7 and 9; from 2000 onwards the average has been close to 10 with an exceptional increase to 13 in 2001. The changes in the alkalinity ratio were primarily driven by decreases in amino-N content than by increases in K and Na.

The practical and financial implications of low amino-N concentrations and high alkalinities in delivered beet were quantified in terms of chemical usage during the factory processing using the formula of Hein & Pollach and data from British Sugar tarehouses from the 1995-2005 processing campaigns. These datasets were extended with exceptionally high alkalinity datasets from Rhizomania-infected (> 40) and fungicide-trial fields (*ca* 20).

The change in the national mean alkalinity ratio from 7 in the mid 1990s to 10 in the 2000s would introduce the equivalent of an extra 10 kg of soda ash alkali/100 tonne of beet into the factory process, and an increase in the ratio to 20 a further 25 kg of soda ash/100t beet. This extra alkali has to be neutralised with acid to ensure normal factory sugar production. There is therefore a considerable cost penalty in processing beet with very low levels of amino-N. The extra cost of acid neutralisation to compensate for an increase in the alkalinity ratio from the 1990-2000 mean of 9 to the ratio of 20 seen in some high-alkalinity beet is estimated to be £3.5/100 tonnes of beet. This is equivalent to £210,000 per year for the whole of the UK beet crop. Costs will be much higher were a large proportion of the UK crop to become infected with Rhizomania. Greater use of rhizomania-tolerant varieties would minimise the risk of this happening.

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I. Analysis of changes in the beet crop

Introduction

Since the mid 1990s, the average concentration of amino-N in beet delivered to British Sugar factories has decreased progressively from around 160 to 70mg/100g/sugar at a rate of approximately 8 units per year (Fig. 1). The decrease has been accompanied by a marked shift and narrowing of the frequency distribution of the amino-N contents of individual contracts (Fig. 2) so that over 30% of the national contracts now deliver beet with less than 70 mg amino-N/100g sugar compared with less than 1% a little over a decade ago (Fig. 1). The decrease in the national mean concentration of amino-N is accompanied by a narrowing of the frequency distribution indicating that concentrations have also become much less variable (Fig. 2).

The current low levels of amino-N have been interpreted, by some, as a sign that modern, higher-yielding sugar-beet crops are receiving too little N. Low concentrations of amino-N may also have increased the natural alkalinity of the delivered beet and affected the efficiency of the factory process (the filtration problem encountered during the 2001/02 processing campaign may be a particular case).

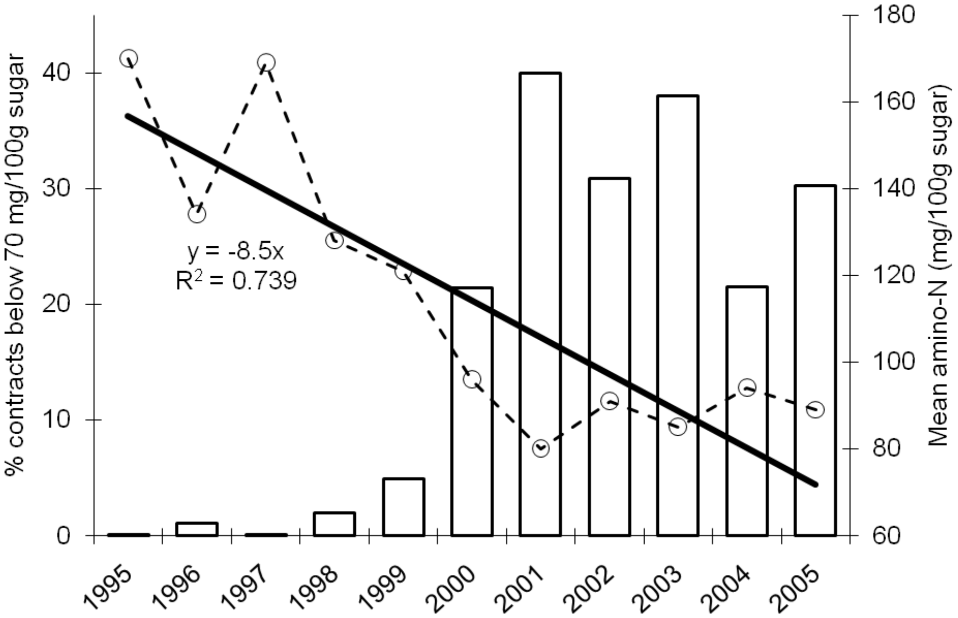

Fig. 1. *Changes in the amino-N content of beet delivered to British Sugar plc factories between 1995 and 2005 (circles) and in the percentage of contracts delivering beet with less than 70 mg amino-N/100g sugar (columns).*

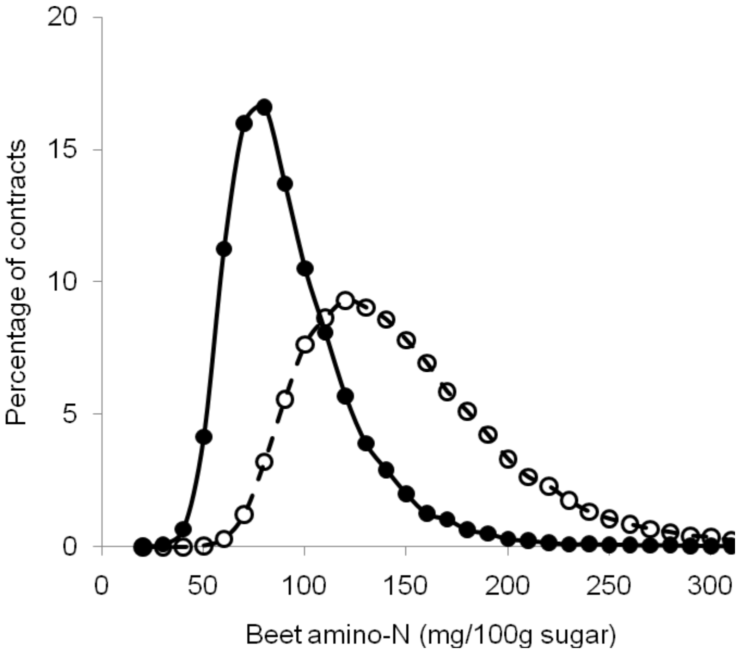

Fig. 2. *Changes in the frequency distributions of the amino-N concentrations of beet delivered in 1995-99 (open circles) and 2001-05 (closed circles) processing campaigns.*

Increase in sugar or decrease in amino-N?

It must be borne in mind, however, that amino-N concentrations are expressed relative to sugar (i.e. as milli-equivalents or mg/100g sugar) in commercial practice. This means that changes in the concentration of amino-N relative to sugar may be brought about by a decrease in the amount of amino-N *per se* or through the diluting effect of increased yields of sugar. Figure 3 shows the changes in amino-N and sugar yields in commercially-delivered beet over the past 20 years.

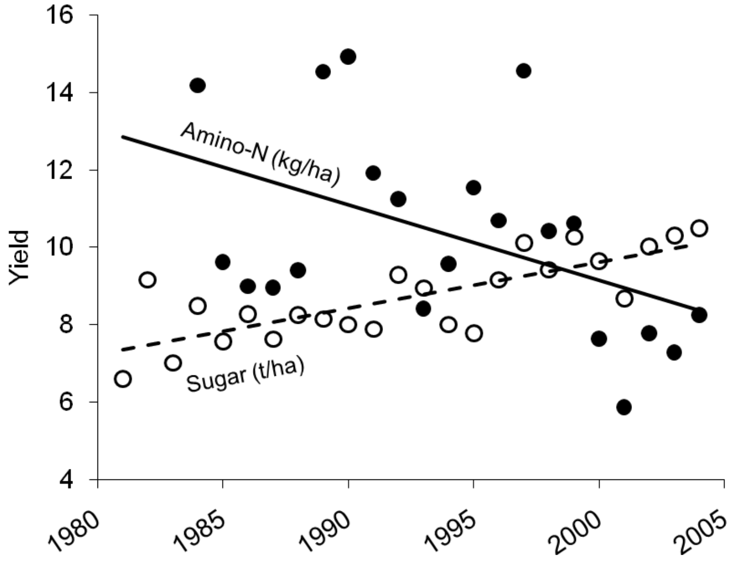

Fig.3. Changes *in the national mean yields of sugar and amino-N in delivered beet (1982-2004).*

Over this period, sugar yields have progressively increased from just over 7 to almost 11 t/ha at a average rate of 0.12 t/ha/annum and the yields of amino-N, given fluctuations due to drought, have decreased from around 13 to 9 kg/ha at an average rate of 0.20 kg/ha/annum. Consequently, the national mean concentration of amino-N relative to sugar in delivered beet decreased from around 170 to 90 mg/100g sugar. Calculations show that the increase in sugar yield by itself would have diluted the concentration of amino-N in beet by about 25%, whereas the decrease in amino-N content by itself would have decreased the concentration by 40%. The factors contributing to increased sugar yield have been well documented, they include: improved varieties, agronomy and husbandry, a longer growing season with the prolonged accumulation of sugar during the autumn as a consequence of milder weather and greater use of late season fungicides. In the following sections, we concentrate on the factors likely to have caused the amounts of amino-N to decrease.

The biological basis of amino-N accumulation

When considering the accumulation of amino-N in beet, it is important to remember that the sugar-beets are biennial. The plant has a natural 2-year development cycle with a first year of vegetative growth being followed, after a period of over-winter vernalization, by flowering and seed production in the second year. During its vegetative growth, the plant accumulates the resources needed for flowering and seed production in the beet (which, anatomically, is the swollen taproot). These resources include nitrogenous constituents (such as amino-acids and amides) to provide the essential structural and enzymatic proteins, and sugar to provide structural carbohydrates and energy for growth. Commercial beets are harvested for the sugar they contain toward the end of their first-year's vegetative growth. The nitrogenous compounds that are present in the beet at this time impair the efficiency of sugar extraction (Dutton & Huijbergts 2006)[1] - although some of them, such as betaines, are useful by-products,

The concentration of amino-N in the storage root, therefore, ultimately depends on three factors:

the amount of N taken up by the plant;
the proportion of the plant's N that is partitioned to the storage root; and
the proportion of the storage-root's N that accumulates as amino-N.

The inter-relationships between these three factors and soil N were established by Pocock *et al.* (1990)[2] and Milford (2006)[3] using data from the extensive BBRO-funded 1985-90 series of N-response trials and 1990-95 series of Beet Quality trials. They are reproduced in Fig. 3, and the resulting overall relationship between crop N uptake and the concentration of amino-N relative to sugar in Fig. 4.

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[1] **Dutton J & Huijbregts T (2006).** Root quality and processing. In: *Sugar Beet,* pp. 409-442. Oxford: Blackwell Publishing Ltd.

[2] **Pocock T O, Milford GFJ & Armstrong MJ (1990).** Storage root quality in sugarbeet in relation to nitrogen uptake. *Journal of Agricultural Science, Cambridge* **115**, 355-362.

[3] **Milford GFJ (2006).** Plant structure and crop physiology. In: *Sugar Beet* (Ed. AP Draycott), pp. 30-49. Oxford: Blackwell Publishing Ltd.

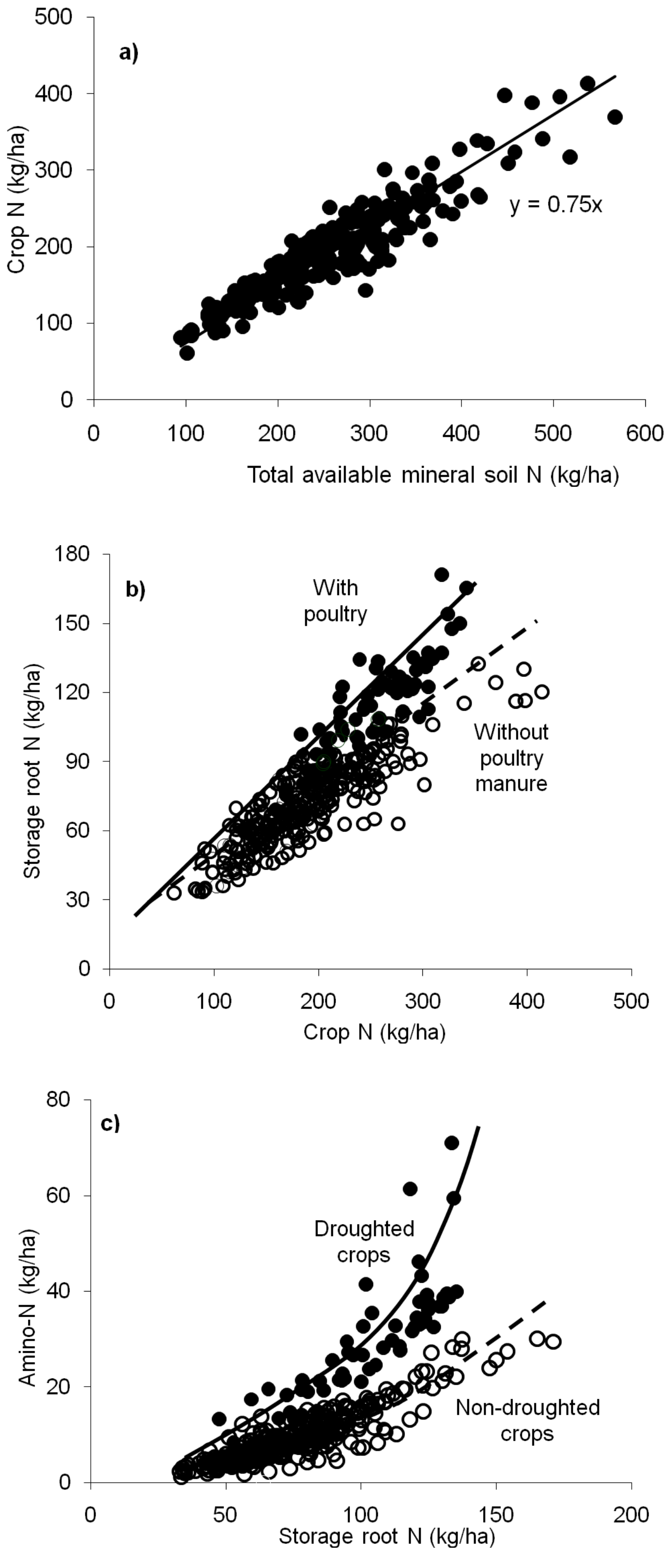

Fig. 3. *Relationships between (a) available mineral N in the soil and crop N uptake, (b) crop N and storage root N and (c) and storage root N and amino-N in the 1985-90 N-response trials and 1990-95 Beet Quality trials.*

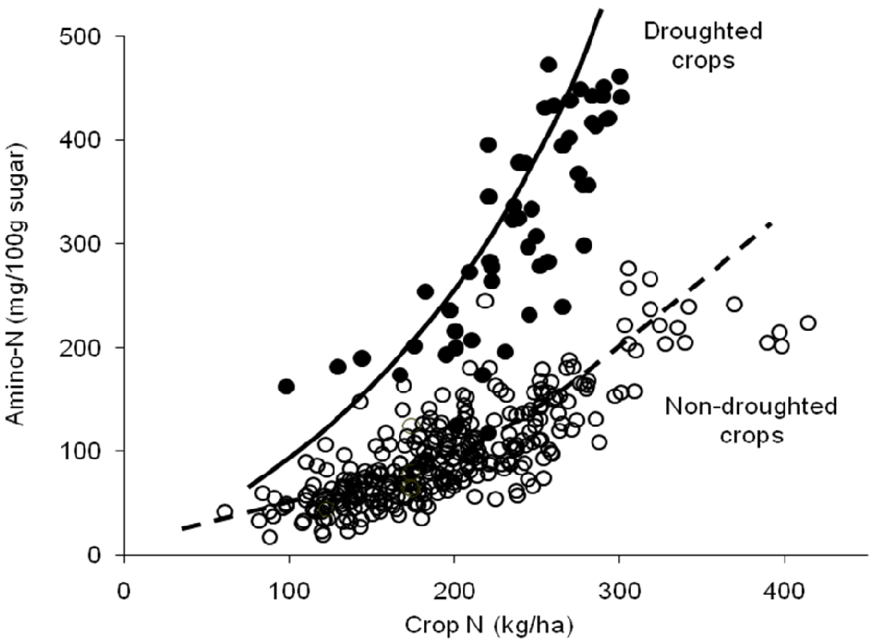

Fig. 4. Overall r*elationships between crop N uptake and beet amino-N relative to sugar in the 1985-90 N –response trials and 1990-95 Beet Quality trials.*

The main features of note are that:

(a) Crop N uptake is driven more by the availability of mineral N in the soil than by crop demand. This is because much of the extra N that is surplus to the needs for canopy expansion accumulates in storage proteins within the shoot. These can later be remobilised to support the growth of the storage root.

(b) A higher proportion of the N in the crop is present in the storage root at harvest when poultry manures are applied than when conventional mineral N fertilisers are used (*i.e.* 45% *vs* 35%). This is because organic manures are applied over winter and the mineral N derived from them is often leached to depth. It is consequently often taken up late in growth after canopy growth has ceased and, therefore largely accumulates as amino-N compounds within the storage root.

(c) Drought greatly increases the proportion of the total in the storage root N that accumulates as amino-N. This is because severe late-summer and early-autumn droughts cause the older leaves on the plant to senescence and remobilise and transport the N they contain to the storage root.

Large uptakes of N therefore increase the concentration of amino-N in beet, especially when they exceed the amount required for maximum yield – *i.e.* 220-250 kg N/ha (Fig. 5). Exceptionally large uptakes occur when excessive amounts of fertilizer or manure N are applied and when sugar beet is grown on high organic matter soils, such as fen peats, containing potentially large amounts of mineralizable N. Amino-N concentrations are greatly increased by large applications of poultry manure and late-summer or early-autumn drought (as in 1995, 1997 and 2004; Fig. 1).

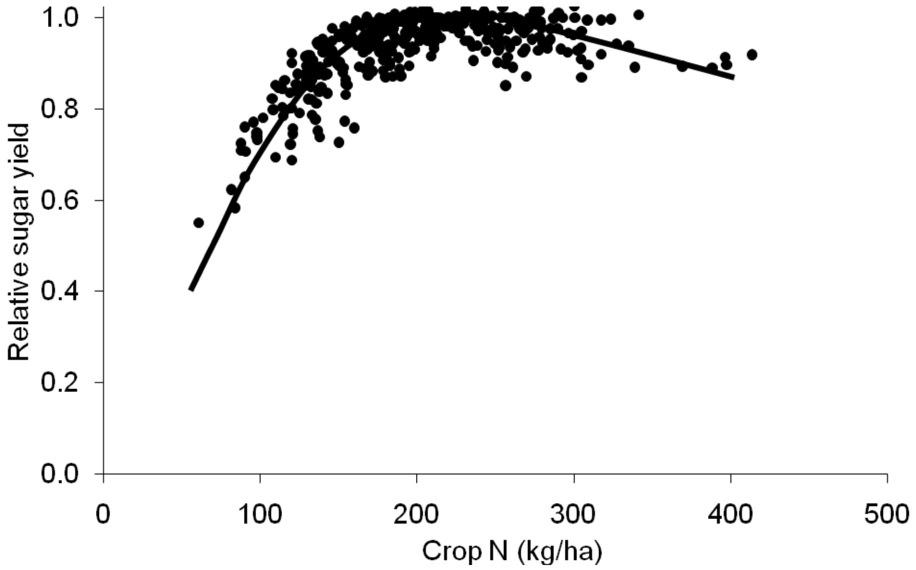

Fig. 5. *Relationship between crop N uptake and sugar yield in the 1985-90 N-response trials and 1990-95 Beet Quality trials.*

The objectives of the present study that forms Part I of this report were to:

(a) examine how far changes in agronomic practices and varieties have been responsible for the marked decrease in the amino-N content of delivered beet in recent years;

(b) determine how far particular diseases (especially rhizomania) or disease control measures (such as the use of imidacloprid insecticides and triazole fungicides) have contributed to low concentrations amino-N; and

(c) examine whether significant changes have recently occurred in patterns of N uptake and distribution in the national crop.

The effect of soil type and agronomy was examined using British Sugar's 1994-2005 annual crop survey involving 600 or so statistically selected fields that were sampled for yield and beet quality and, for which associated details of location, soil type, husbandry, fertilizer and manure inputs, and insecticide and fungicide use were collated. Changes due to variety were examined using data from past NIAB variety trials and British Sugar's national records of varietal seed sales.

The additional objective considered in Part II was to quantify the practical and financial implications of low amino-N on beet alkalinity and chemical usage during the factory process.

Fertiliser and manure use

When UK factory-tarehouse measurements of beet amino-N started in the early 1980s, sugar-beet crops were receiving an average of 140 kg/ha of N as fertilizer - often in addition to that applied in manures – and, nationally, the mean amino-N concentration in delivered beet was between 180 and 200 mg/100g sugar (Fig. 6). Intensive advisory campaigns in following years resulted in a rapid decrease in amount of N being applied to sugar beet so that, by the mid 1990s, the amount of N being applied had fallen to around 110 kg/ha and amino-N concentrations were down to 140 mg/100g sugar. Since then, N fertilizer inputs have decreased further (they averaged 90 kg/ha in 2007/08) and amino-N concentrations have continued decrease (reaching a record low of less than 70 mg/100g sugar during the 2007/08 processing campaign).

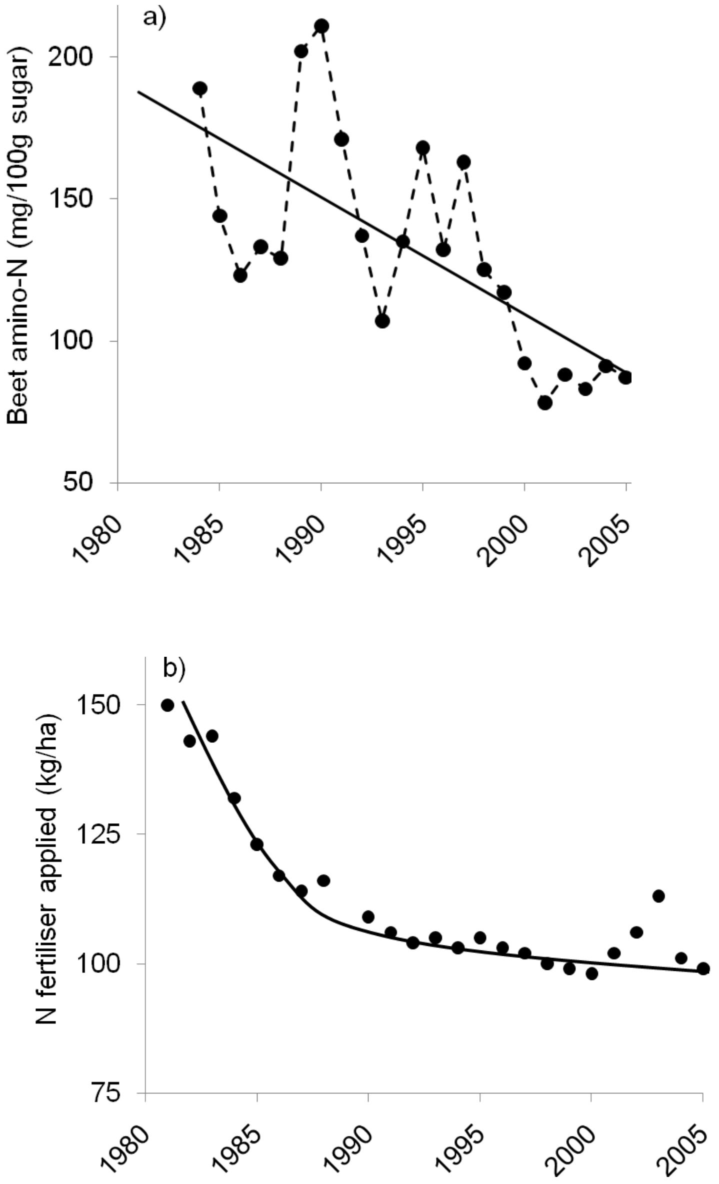

Fig. 6. *Changes in (a) beet amino-N and (b) N fertiliser use since the early 1980s.*

Table 1 presents a more detailed analysis of the changes between the late 1990s and the early 2000s in N fertiliser use and beet amino-N derived from British Sugar’s field survey data. Between these two periods, the mean concentration of amino-N in delivered beet fell from 140-186 mg/100g sugar (depending on whether or not organic manures were applied) to 85-95 mg/100g sugar, but there was no evidence that the decrease was associated with a shift in the types of soil on which the beet was grown (as a result of factory closures) or with smaller amounts of fertilizer or manure N being used.

Table 1. *Comparison of the soil types and fertilizer and manuring practices used for growing sugar beet in 1995-99 and 2001-05.*

	1995-99	2001-05
	(a) Soil type - percentage of fields	
Sandy loams	26.9	32.4
Clays & clay loams	30.3	31.0
Sands & sandy loams	15.0	13.5
Peat & organic	6.5	4.9
Silts & silty loams	4.1	4.7

(b) N fertilizer and manure use

	1995-99			2001-05		
	% of fields	Total N applied kg/ha	Amino-N mg/100g sugar	% of fields	Total N applied kg/ha	Amino-N mg/100g sugar
Non-manured fields	63.8	104	140	64.4	103	89
Fields receiving farm yard manure	13.7	126	152	13.1	120	95
Fields receiving poultry manure	5.4	138	186	5.8	154	85

Changes due to variety

The introduction of new varieties has continued to improve the quality attributes of commercial beet. The potential influence of the introduction of new varieties on the amino-N content of delivered beet was tracked using data for commercial and near-commercial varieties evaluated in the 14 or so NIAB annual Recommended-List variety trials done between 1993 and 2004. This series of trials has provided the most comprehensive set of data relating to changes in amino-N and sugar yield for sugar beet grown using a standard protocol. The progressive changes in the relative mean yields of amino-N (kg/ha) and sugar (t/ha) between the mid 1990s are shown in Fig. 7. The amino-N contents of the beet (kg/ha) generally increased linearly with sugar yield, with the slope of the relationship representing the overall mean amino-N concentration (mg/100g sugar) for each period. These progressively decreased from 164 mg/100g sugar in the mid 1990s to 77 mg/100g sugar in the mid 2000s. The dashed lines linking the mid-points of the regressions with the vertical and horizontal axes show that the decrease in concentration resulted from a progressive increase in the mean yield of sugar (from 10.5 to 14.5 t/ha) coupled with a progressive decrease in that of amino-N (from 16 to 9 kg/ha).

At first sight, this might be taken to imply that the decrease in amino-N concentration in commercial beet in recent years has largely resulted from varietal improvements in beet quality. This is not entirely true. Sugar-beet varieties tend to have a short lifespan and turnover rapidly in Recommended List trials. Varieties such as Roberta (to a lesser extent Triumph and Celt) are exception in that they have remained in the trials for 10-14 years. Roberta has therefore been used as a control against which the overall varietal improvement has been judged. The downward trend in the concentration of amino-N in Roberta almost exactly paralleled that of the other varieties (Fig 8), implying that the changes in amino-N had more to do with improvements in agronomy, husbandry or seasonal growing conditions than with any varietal improvements in beet quality. This assumes, however, that the quality attributes of Roberta have not progressively changed over the years in line with those of the other varieties (which is unlikely, given that Triumph and Celt showed similar trends).

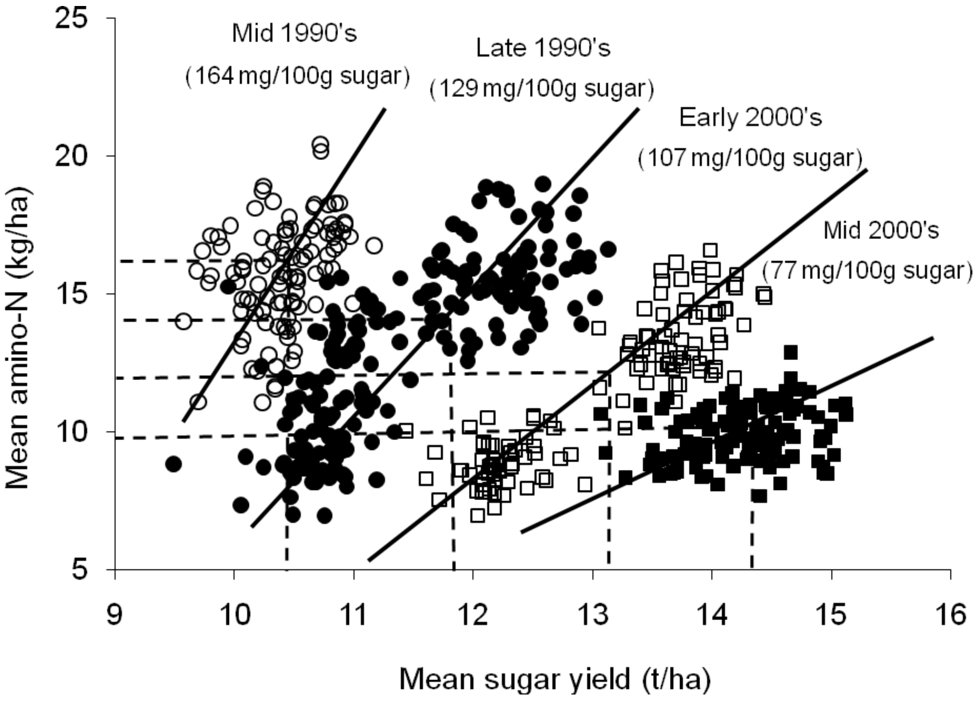

Fig. 7. *Progressive changes in the relationships between beet amino-N content and sugar yield of varieties in NIAB/British Sugar recommended-list trials.*

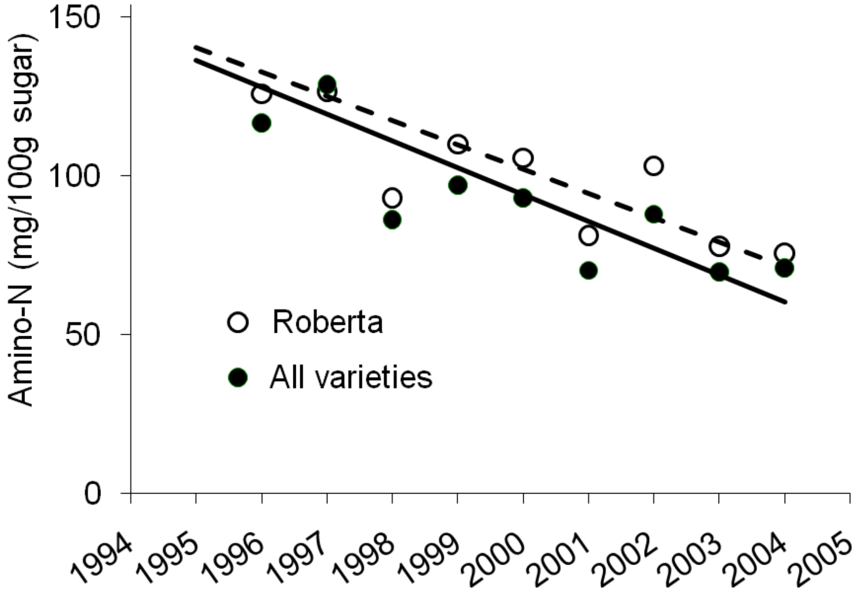

Fig. 8. *Comparison of the trends in the mean concentration of amino-N of all varieties with that of Roberta in the 1996-2004 NIAB Recommended List trials.*

Effect of disease

The two diseases most likely to affect the amino-N content of beet are virus yellows and rhizomania.

Virus yellows slows sugar beet growth by decreasing green area, radiation interception and photosynthetic efficiency of the leaf canopy, and lowers sugar yield by decreasing beet yield rather than sugar concentration. Controlled-infection studies in the field[4,5] show that virus yellows increases amino-N concentrations in beet by 20-30% (Table 2). The incidence of virus yellows has been decreased in recent years by increased control of the *M. persicae* aphid vector through the use of imidacloprid seed dressings. A decrease in the incidence of virus yellows could have indirectly contributed to the decline in amino-N.

Table 2. *Concentrations of amino-N in healthy and and virus-yellows-infected sugar beet.*
(After Glover *et al.* 1999[5])

Amino-N (mg/100g sugar)

	Healthy crop	Virus-infected crop	LSD (*P* = 0.05)
1993	66	78 *	4.0
1994	89	110 *	14.9
1995	128	165 *	15.9

* significant increase

Rhizomania decreases the amino-N content of beet. Very severe incidences on the continent, for instance, decreased amino-N concentrations from 30 to 5 mg/100g beet primarily by restricting N uptake[6]. The disease is less severe and not as widespread in the UK as on the continent - the number of confirmed cases of rhizomania rose from 3 fields in Suffolk in 1987 to 609 in 2003, mainly in Norfolk and Suffolk (Fig. 9). This increase in rhizomania could have partly contributed to the overall decline in beet amino-N.

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[4] **Smith HG & Hallsworth PB (1990).** The effects of yellowing viruses on yield of sugar beet in field trials, 1985 and 1987. *Annals of Applied Biology* **116**, 503-511.

[5] **Glover GRG, Azam-Ali SN, Jaggard KW & Smith HG (1999).** The effects of beet yellows virus on the growth and physiology of sugar beet (*Beta vulgaris*). *Plant Pathology* **48**, 129-138.

[6] **Heijbroek W (1989).** The development of rhizomania in two areas of the Netherlands and its effect on sugar-beet growth and quality. *Netherlands Journal of Plant Pathology* **95**, 27-35.

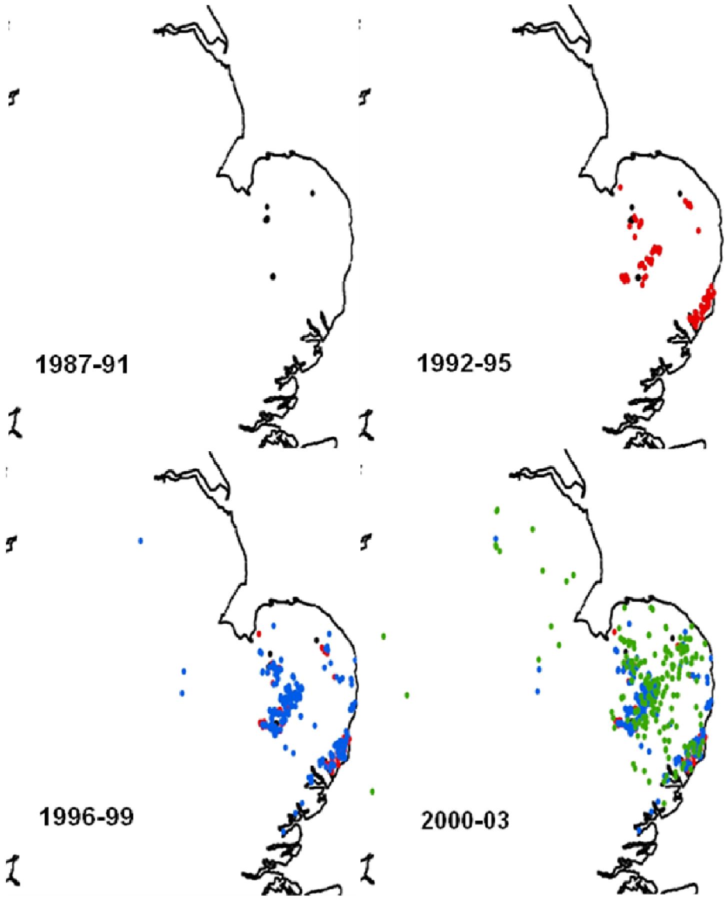

Fig. 9. *The spread of confirmed cases of rhizomania in the UK, 1987-2003.*

During the 2003/04 beet processing campaign, British Sugar arranged to have all contracts flagged as having, or having had, rhizomania delivered to the Bury factory for separate processing within the 2-week period from 17th to 29th November. The concentrations of amino-N in the 1337 flagged loads from known rhizomania-infected farms were generally larger than those of the 17216 non-flagged loads processed alongside them (i.e. 92 vs 83 mg/100g sugar; LSD = 1.15). The frequency distributions of these loads show that the differences mainly occurred at the upper end of the amino-N range (Fig. 10). This UK pattern of amino-N in rhizomania-infected beet is unlike that experienced on the continent where rhizomania seems to decrease, not increase, amino-N.

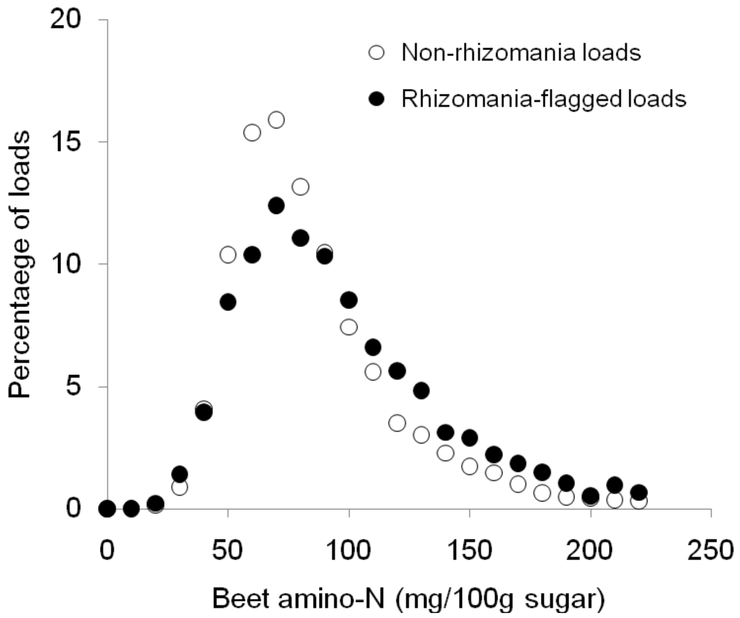

Fig. 10. *Frequency distributions of the amino-N contents of unflagged and rhizomania-flagged loads of beet processed at the Bury factory between 17-29 November 2003.*

Continental experience

European databases were collated from Sweden (Danisco Sugar AB), Northern Germany (Sudzucker AG) and the Netherlands (CSM Suiker) for comparison with UK data. They range from national to individual factory tarehouse records and ancillary information.

Data from Sweden which has reported very little incidence of Rhizomania and the Netherlands which has had widespread Rhizomania and increasingly resorted to growing Rhizomania-resistant varieties was used to examine the potential effects of Rhizomania on amino-N.

All countries have show a general decline in national average amino-N figures over the last 20 years similar to that found in the UK. However, the sugar company CSM Suiker reported a trend for a small rise in amino-N since 2000 in the Netherlands. This has been attributed to the rise in use of Rhizomania resistant varieties in the Netherlands which have increased from 44% of the crop area in 2000 to 97% in 2006 (Fig. 11) This implies that the decline in amino-N levels before 2000 was, to some extent, caused by the increase in the area infected with the disease.

In direct contrast to the Netherlands, the number of Rhizomania outbreaks reported in Sweden is very small. Weekly campaign data of amino-N for the 2000 to 2004 sugar beet campaigns was supplied by Danisco Sugar AB for their two factories Kopingebro and Ortofta as well as the national average figures. The latter are shown in Fig. 12. Amino-N values in general increased throughout the campaign which is similar to that observed in the UK and reflects the increasing amount of stored beet being processed as the campaign progresses. Amino-N values across the campaign appeared to be more related to climatic and growth factors than any particular change in sugar beet agronomy.

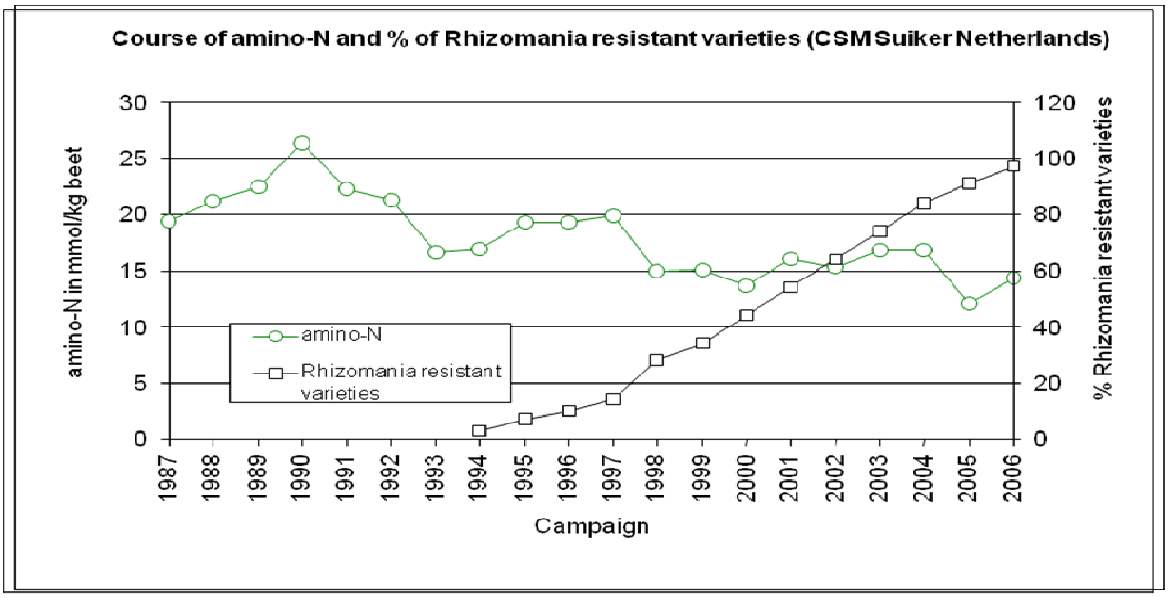

Fig. 11. *Campaign average amino-N concentrations and percentage market share held by Rhizomania resistant varieties in the Netherlands (CSM Suiker).*

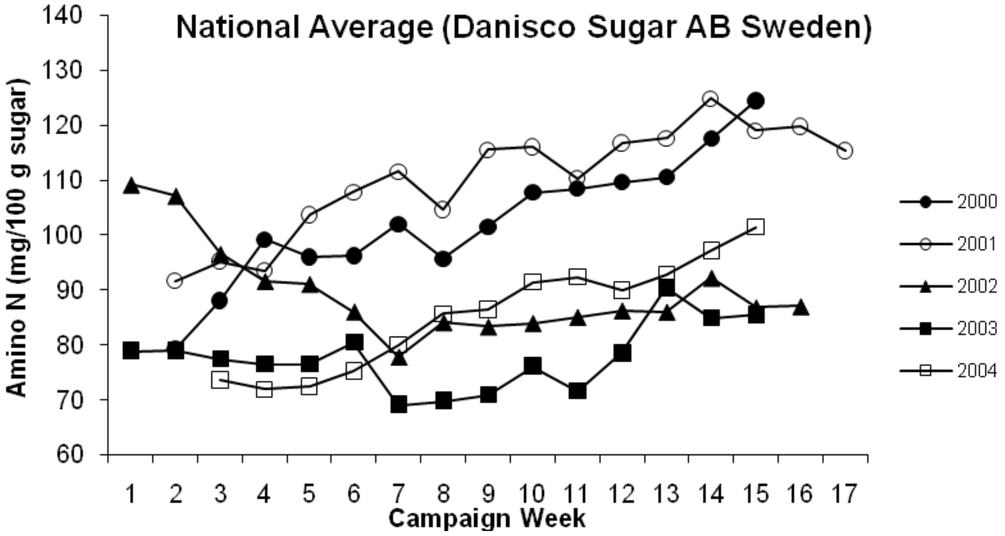

Fig. 12. *National average weekly campaign amino-N values from 2000 to 2004 (Danisco Sugar AB Sweden).*

Effect of late-season triazole and strobilurin fungicides

The use of triazole and strobilurin fungicides to control late-season leaf diseases, particularly powdery mildew, has increased considerably during the past decade. These fungicides were not used on commercial sugar beet prior to 1997 but, by the mid 2000s, their use had extended to almost 80% of the national crop (Fig. 13).

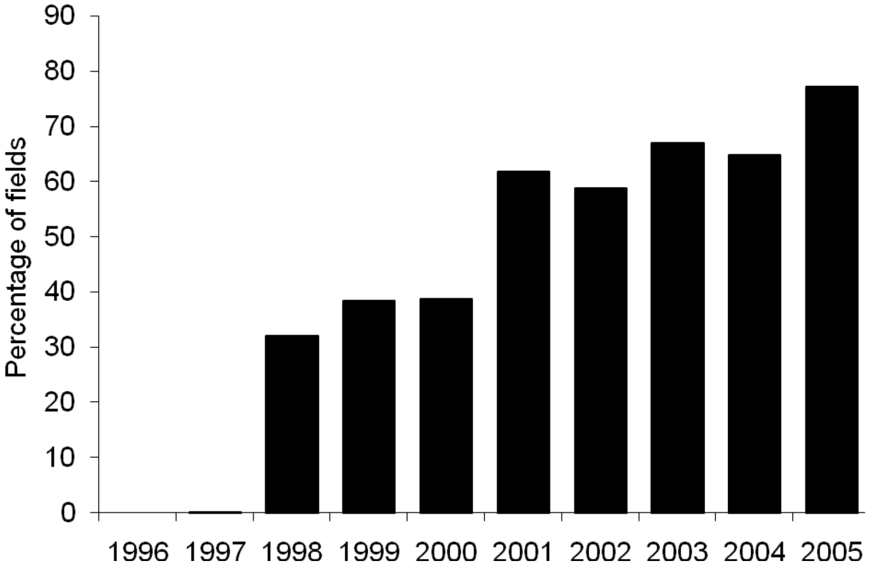

Fig. 13. *Increasing use of late-season triazole and strobilurin fungicides on UK sugar beet in the past decade (British Sugar plc field survey data).*

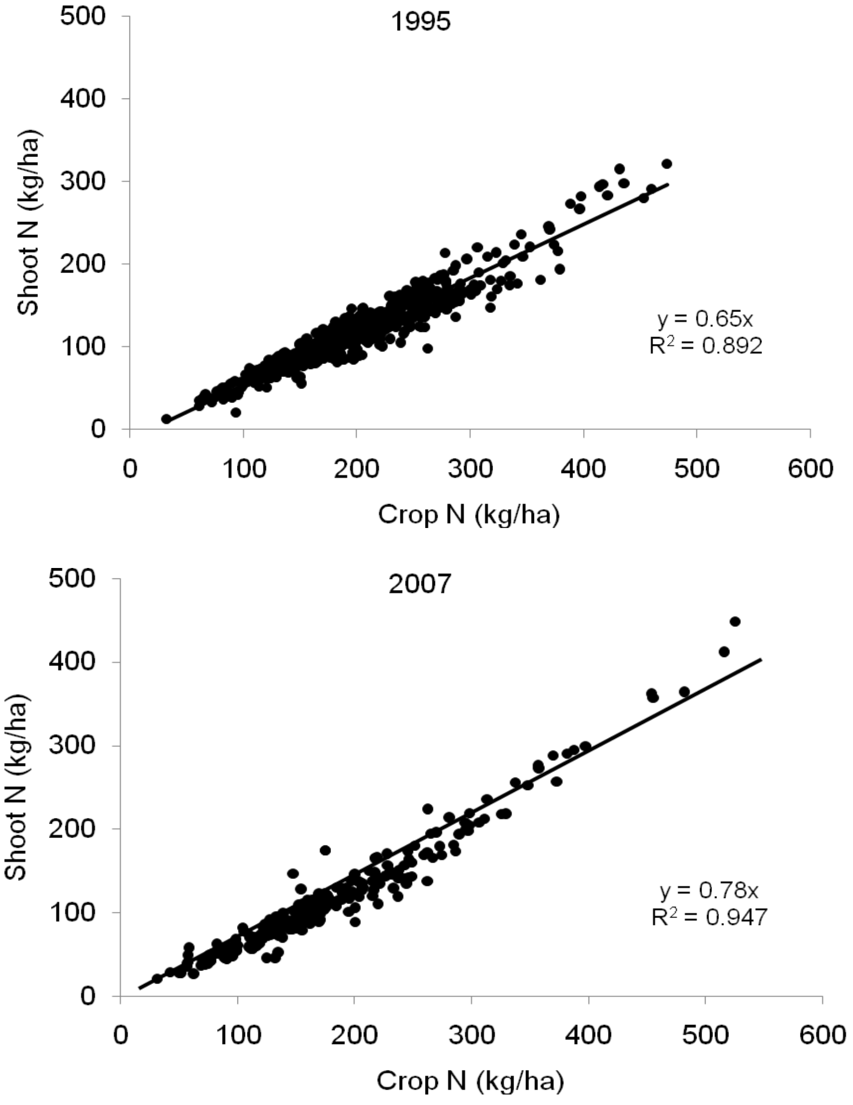

Fig. 14. *Changes in the distribution of N in sugar beet crops during the past decade.*

As well as controlling leaf diseases, triazole and strobilurin fungicides have the further beneficial physiological cytokinin-like effect of maintaining the leaf canopy in a green, photosynthetically-active state for much later into the autumn and thus prolonging sugar accumulation. By delaying leaf senescence, these fungicides slow the remobilisation of nitrogen, so more remains in the shoot at harvest and less accumulates as amino-N in the storage root. Figure 14 highlights the change over the past decade in the proportion of the total crop N remaining in the shoots of commercial crops at harvest. These measurements show that, between 1995 and 2007, the proportion of N retained by the shoot has increased from 65% to 78%. It is probable that the increased use of these fungicides during the past decade contributed significantly to this.

In recent crop surveys, growers were questioned on their use of late-season triazole and strobilurin fungicides; their fields were also sampled for yield and beet quality analysis. Beet from fields that had been treated with triazoles or strobilurins contained significantly lower concentrations of amino-N than beet from untreated fields (Fig. 15). Overall, triazole and strobilurin fungicides decreased amino-N concentrations by about 17% (i.e. from 106 to 88 mg/100g sugar).

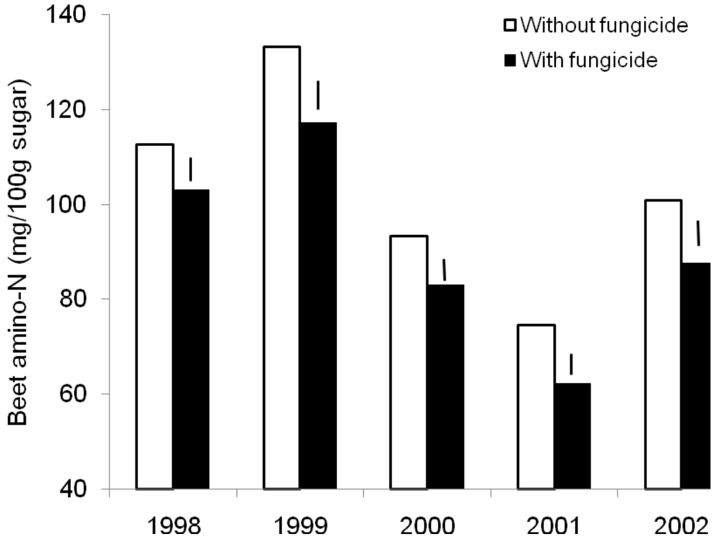

Fig. 15. *Mean amino-N concentrations of beet samples from untreated crops and crops treated with triazole or strobilurin fungicides. Vertical lines indicate least significant differences. (British Sugar 1998-2002 field surveys).*

Late season powdery mildew fungicide trials 2002 – 2004

A detailed analysis of 23 late season fungicide trials carried out in the UK between 2002 and 2004 showed interesting relationships between amino-N levels and the fungicides applied. The trials were mainly concerned with the effect of powdery mildew infections on beet yield and quality. Eighteen sites had no or low levels of powdery mildew infection (< 15%) and 5 sites, mainly sited at Broom's Barn and inoculated with powdery mildew, had high levels of infection (> 25%). The main fungicides tested were a range of triazoles (Punch C containing flusilazole + carbendazim and three cyproconazole-containing products Alto, Cabaret and Fort) which were compared with untreated plots and plots treated with the old industry standard, Thiovit containing elemental sulphur. In addition, a limited number of strobilurin-containing products (Comet containing pyraclostrobilurin and Opera containing epoxiconazole + pyraclostrobilurin) and the systemic non-triazole fungicide Fortress (containing quinoxyfen) were tested. The data allowed Thiovit, Fortress and the individual triazoles to be compared with the untreated controls and the triazole and strobilurin fungicides to be compared as separate groups.

Table 3. *Effects of different triazole products on beet amino-N concentrations (mg/100g sugar) in late-season powdery mildew fungicide trials*

	2002-04 Punch C (23) (flusilazole + carbendazim)	2002 Alto (8) (cyproconazole)	2003 Fort (6) (cyproconazole)	2004 Cabaret (7) (cyproconazole)
Untreated	74.7	71.4	91.4	67.1
Triazole	68.4	61.5	83.8	58.5
SED	2.08	2.45	6.2	2.68
LSD	4.31	5.79	15.93	6.56
	**	**	ns	*

The effect of the four triazole products on amino-N root impurities are compared with the untreated control plots in Table 3. Three out of the four products tested significantly decreased the level of amino-N in the beet when compared with the control plots. The decreases for Punch C, Alto and Cabaret were 8.4%, 13.9% and 12.8%, respectively. As specific groups, the triazole and strobilurin fungicides decreased root amino-N concentrations by 10% and 18%, respectively. Thiovit or Fortress did not significantly affect amino-N concentration (Table 4).

There was also sufficient data for the triazoles as a group to analyse their effects on amino-N concentrations at sites with low (0.6%) and high (36.9%) powdery mildew infection (Table 5). Interestingly, the use of triazole fungicides significantly decreased amino-N concentrations (by 8.8%) even when no appreciable disease was present, but decreased concentration more (*i.e.* by 14.3%) when the crops were highly infected with powdery mildew.

Triazole and strobilurin fungicides are more recent introductions for the control of powdery mildew and other late-season leaf diseases and have taken over from elemental sulphur products like Thiovit as the main types of fungicides used on the beet crop. They are now used on a significant area of the UK sugar beet crop and appear to be one of the likely factors contributing to the reduction in amino-N in the commercial crop.

Table 4. *Effect of triazole and strobilurin-containing fungicides and Fortress and Thiovit on amino-N concentrations (figures in parentheses indicate the number of sites).*

	Fungicide			
	Triazoles (45)	Strobilurins (10)	Fortress (17)	Thiovit (12)
Untreated	75.0	68.5	74.2	84.3
Fungicide	67.6	56.4	72.7	82.5
	***	*	ns	ns.
SED	1.43	4.42	1.83	2.16
LSD	2.89	9.99	3.88	4.76

Table 5. *Effect of triazoles on amino-N concentrations at sites of low and high powdery-mildew infection (figures in parentheses indicate the number of sites).*

	All triazoles combined		
	Low infection sites (35)	High infection sites (10)	All sites (45)
Untreated	77.4	66.6	75.0
All triazoles	70.6	57.1	67.6
	***	**	***
SED	1.74	2.11	1.43
LSD	3.54	4.76	2.89

Continental experience

The potential effects of triazole and strobilurin fungicides were also assessed by comparing trials data and historical changes in the factory amino-N profile of the UK national crop with that of Sweden (Danisco Sugar AB) where the fungicides have not been used commercially to date and the Netherlands (CSM Suiker) and Northern Germany (Sudzucker AG) where their use is similar to the UK.

In both Germany and the Netherlands the use of triazole and strobilurin sugar beet fungicides have been regarded as one of the contributory causes of the recent lowering of amino-N. In the Netherlands, a total of nine fungicide trials (six in 2002 and three in 2003) showed that amino-N values fell from an average of 22.1 mmol/ kg beet when fungicides were not applied to beet crops to 18.2 mmol/ kg beet when they were applied. This equates to a 21% reduction in root amino-N concentration and consistent with the UK findings from this project.

Detailed factory tarehouse information from Sudzucker showed that the distribution of amino-N had also changed dramatically. For the five year periods 1982-86, 1987-91, 1992-96 the mean values from the distribution curves were approximately 26, 24 and 20 mmol/ kg beet respectively with 15% of loads in this band. For the later periods 1997-2001 and 2002-05 the mean amino-N had decreased to about 16 mmol/ kg beet for almost 25% of beet loads delivered (Fig. 16). This data strongly supports the ‘step change’ in amino-N identified from British Sugar tarehouse data described previously with more beet being delivered with lower amino-N concentrations. Similar to the UK situation there has also been a narrowing of the frequency distribution of the amino-N of the delivered beet.

Although the Sudzucker data does not directly relate to the use of fungicides, or indeed the incidence of Rhizomania, the similar usage of triazole and strobilurin fungicides in this region and the UK lends support to the UK trials results and crop survey data.

Up to 2005, these late season fungicides did not have commercial clearance in Sweden and were not applied to the commercial crop. Weekly campaign data from the Kopingebro and Ortofta Danisco Sugar AB sugar factories and the national average figures already discussed under Rhizomania, showed amino-N values across the campaign to be more related to climatic and growth factors than any particular change in sugar beet agronomy. However, even without the use of these fungicides on the Swedish national sugar beet crop, annual average amino-N values have fallen fairly consistently since 2000.

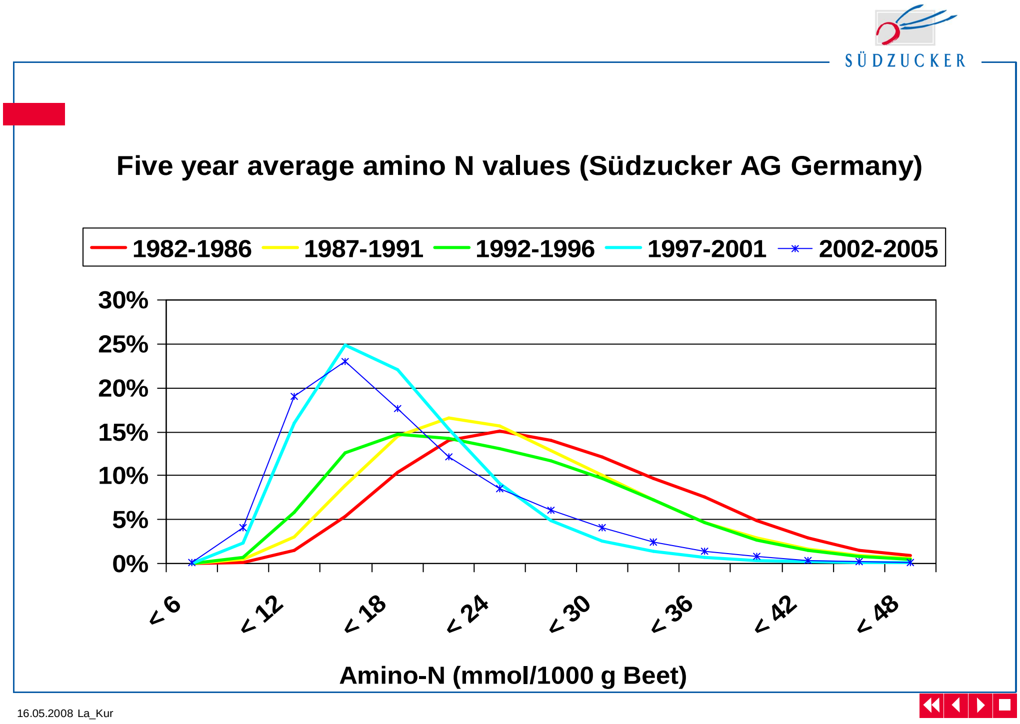

Fig. 16. *Changes in the frequency distribution of amino-N concentrations in beet delivered German factories during the past 25 years.*

Implications of low amino-N for yield

Because the high inputs of N being used in the 1980s and early 1990s were largely responsible for high levels of amino-N content in delivered beet, factory-tarehouse records were used as part advisory campaigns to decrease N inputs to improve beet quality. Remembering this, growers ask whether the generally low current levels of amino-N mean that N applications are now less than optimal. This question cannot be directly answered because there is no simple correlation between amino-N content and yield. There is indirect evidence, however, to show that low levels of amino-N are not consistently associated with low uptakes of N, and that, high yields are achievable even with low levels of amino-N.

Figure 17 shows the frequency distributions of the amino-N contents of low (< 40 t/ha), average (40-65 t/ha) and high (> 65 t/ha) yielding sugar-beet crops sampled during British Sugar's 1994-97 and 2002-05 field surveys. Amino-N concentrations averaged around 150 mg/100g sugar in the mid 1990s and 95 mg/100g sugar in the mid 2000s. There was no evidence that low yields were associated with a low concentration of amino-N. The histograms show there were similar percentages of low, average and high-yielding crops within each amino-N category across the whole range, and that a substantial number of crops with beet amino-N concentrations of 80 mg/100g sugar or less managed to yield well over 65 t clean beet/ha. This was particularly evident in the mid 2000s by which time the decline in the national mean amino-N concentration to below 100 mg/100g sugar had produced a larger number of low amino-N crops.

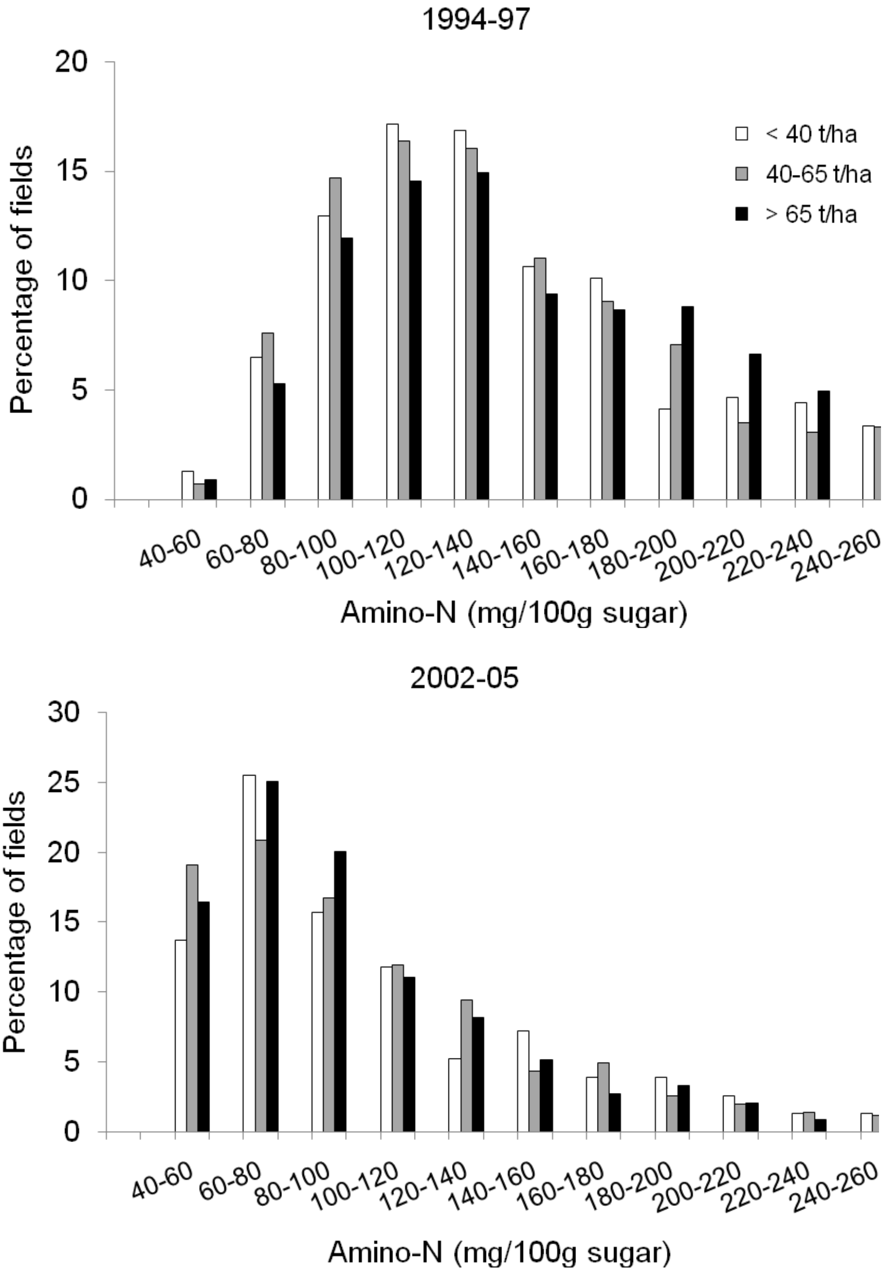

Fig. 17. *The distribution of beet amino-N concentration in low, average and high-yielding commercial sugar-beet crops grown between 1994-97 and 2002-05.*

The approximate amounts of N in sugar-beet crops were estimated from factory tarehouse measurements of beet K using the relationships between plant K and plant N established in recent BBRO-funded projects on nutrient interactions in sugar beet [7,8,9]. They were used, in the absence of direct measurements of crop N, to examine whether low concentrations of amino-N in delivered beet indicated that the uptakes of N were were below the 220-250 kg/ha shown to be needed in Fig. 5 to obtain maximum yield.

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[7] **Milford GFJ & Armstrong MJ (2003).** Review of the interactions of nutrients in the growth, productivity and quality of sugar beet. *Report on BBRO Project 02/05, April 2003.*

[8] **Jarvis PJ, Barraclough PB, Jones J & Milford GFJ (2004).** Establishing the potassium requirements of modern high-yielding sugar beet crops for yield and beet quality.

[9] **Milford GFJ, Jarvis PJ, Jones J & Barraclough PB (2008).** An agronomic and physiological re-evaluation of the potassium and sodium requirements and fertilizer recommendations for sugar beet. *Journal of Agricultural Science, Cambridge* **146**, 1-15.

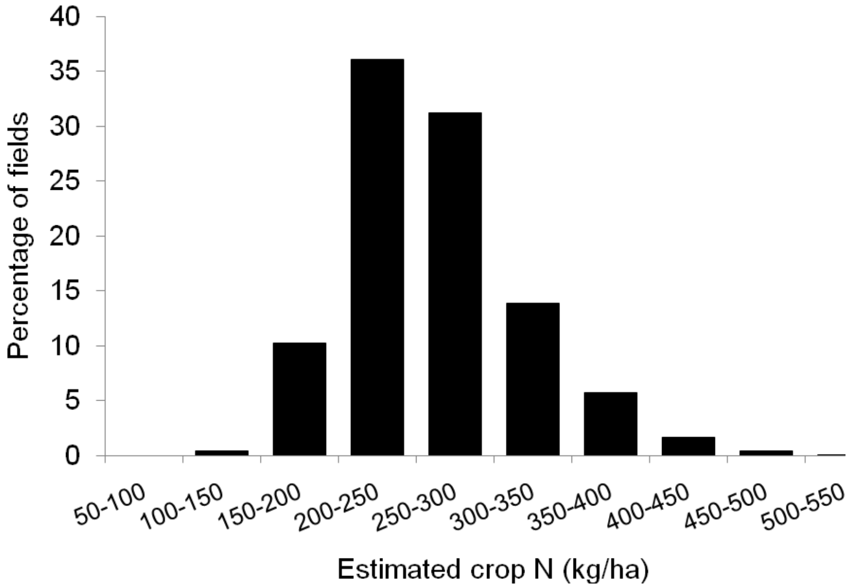

Fig. 18. *Distribution of the estimated N uptakes of crops from the 2002-04 British Sugar field surveys with beet amino-N concentrations of less than 75 mg/100g sugar.*

N uptakes were estimated for 1950 of the crops involved in British Sugar's 2002-04 field surveys; 952 of these crops produced beet with less than 75 mg amino-N/100g sugar. The breakdown of the N uptakes of these low amino-N crops in Fig. 18 shows that only 10% of the them had less than adequate N (< 220 kg/ha), that 67% had adequate N, and that 22% had more than adequate N. There are no grounds, therefore, for assuming that low concentrations of amino-N in delivered beet indicate an insufficiency of N in the crop.

A further example is provided by factory tarehouse data for commercial beet delivered by 13,600 contracts during the 2004/05 and 2006/07 processing campaigns. The beet of a third of these contracts had amino-N concentrations that were below 75 mg/100g sugar. Only 11% of these low-amino-N contracts, however, delivered clean beet yields below 40 t/ha. Two-thirds of the contracts delivered yields of 40-60 t/ha, and almost a quarter of them delivered yields of over 60 t/ha. There is therefore little evidence from commercial practice to support the view that low concentrations of amino-N in delivered beet indicate that insufficient amounts of N, likely to limit yield, are being applied.

Long term fertiliser trial 1964 - 2004

Figures 19 and 20 describe the changes in sugar beet amino-N root concentrations from 1965 to 2004 sampled from the Broom's Barn long term fertiliser ($N^{o.}$ 2) trial. Amino-N is expressed on both sugar (Fig. 19) and on beet (Fig. 20).

There was a gradual reduction in amino-N root concentrations from 1964 to 2005 expressed on both sugar and beet. However, there were considerable annual fluctuations over this period and no obvious 'step change' reduction in amino-N levels from 2000 onwards as indicated from British Sugar factory tarehouse data. For instance, data from the trial for the 2000 to 2004 period for the standard rate fertiliser plots (125 kg N/ha) had the lowest amino-N concentration in 2000 (51 mg N/100 g sugar) and the highest in 2002 (110 mg N/100 g sugar). Amino-N values for the comparative treatment which also received the standard rate of inorganic fertiliser but in addition received a dressing of 61 t/ha of farmyard manure followed a similar pattern. The annual fluctuations in amino-N therefore appeared to be more related to climatic and growth factors than any particular change in sugar beet agronomy although the trend is for a general reduction in amino-N expressed on both sugar and beet over the period of the trial.

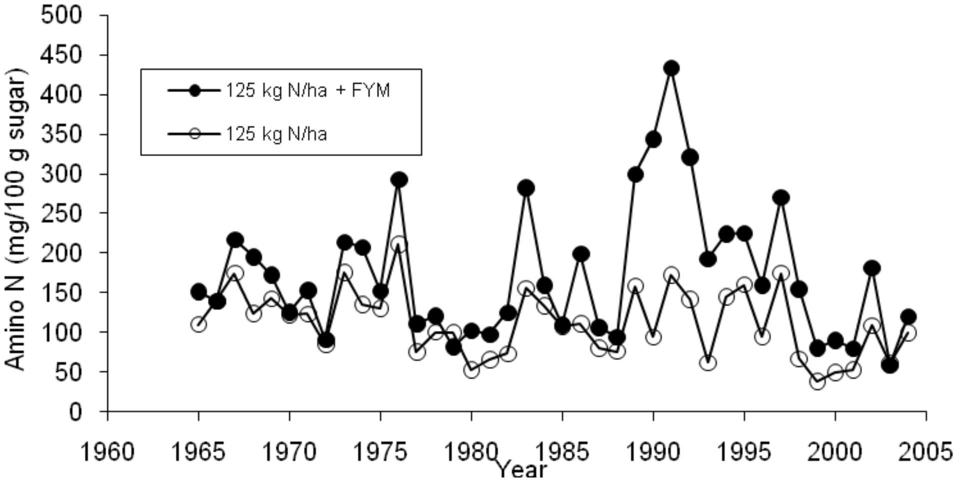

Fig. 19. *Amino-N data expressed as mg/100 g sugar for plots receiving 125 kg N/ha as ammonium nitrate and plots receiving the same rate of inorganic N plus 61 t/ha of FYM.*

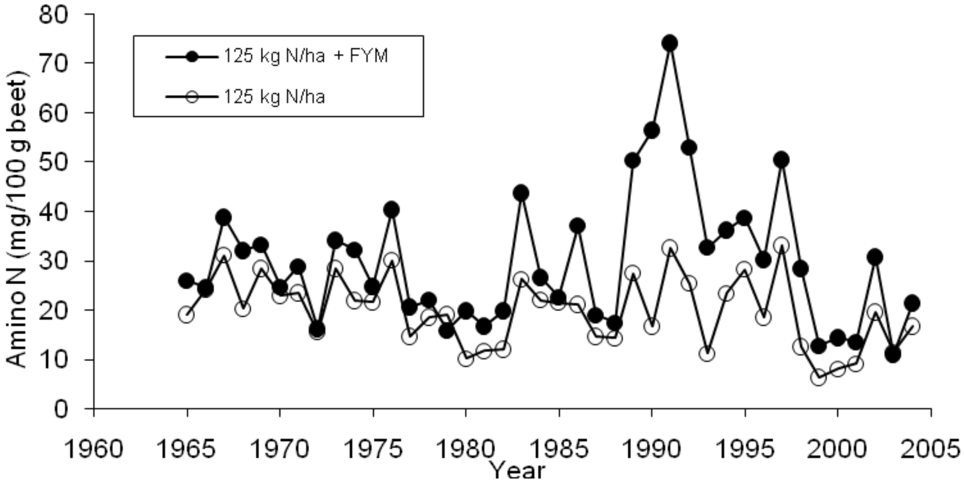

Fig. 20. *Amino-N data expressed as mg/100 g beet for plots receiving 125 kg N/ha as ammonium nitrate and plots receiving the same rate of inorganic N plus 61 t/ha of FYM.*

II. Implications of changes in amino-N for beet alkalinity and the factory process

Amino-N and the factory process

Problems have been experienced in the past because of high levels of amino-N and glutamine in delivered beet which are converted to pyridolone carboxylic acids during processing that lower juice pH. This results in crystalline sugar being lost to invert sugars. Equations have been produced to quantify the alkali balance of processed beet (van der Poel *et al.*)[10]. The simplest use only Na, K and amino-N whereas more complex equations require fuller information on the chemical composition of the beet (Andersen & Smed)[11]. The natural alkalinity of the beet provides buffer capacity in the juice after the carbonatation stage in the factory. If too little or too much natural alkalinity is present then chemicals have to be added to the factory juices to balance the pH. Adding sodium carbonate or calcium chloride to the raw juice before carbonatation will increase or decrease the buffer capacity. Considerable attention has been given, in the past, to lowering the N inputs used to grow the crop to bring the acidifying amino-N levels of the beet down to acceptable levels for processing. However, as foreseen by Oldfield *et al.*[12] and Harvey & Dutton[13], the pendulum may now be swinging too far and concentrations of amino-N in delivered beet may now approach levels that cause beet alkalinity to be too high. The high alkalinity of process juices is believed to have been a contributory factor in recent slowdowns and loss of production at the Wissington factory through problems with filtration.

Beet alkalinity is defined as the ratio of K+Na (as alkali contributors) to amino-N (glutamine, especially, being a major acid contributor). Optimum sugar extraction is achieved when the weekly average alkalinity ratio of beet entering the factory is about 10. The increased alkalinity of beet in recent campaigns has been driven more by a decrease in amino-N content than by an increase in K and Na (British Sugar plc, unpublished data). These data also show that the alkalinity ratios of commercial beet increase exponentially to above 30 when amino-N concentrations fall below 60 mg/100g sugar. As indicated above, such levels of amino-N are becoming increasingly more prevalent and their practical and financial impacts on beet alkalinity and the factory process need to be determined.

Modelling the processing costs of beet of different natural alkalinity

The aim of the first part of the beet modelling aspect of the programme was to quantify the practical and financial implications of low amino-N and high alkalinity in delivered beet for chemical usage during the factory processing of this beet. The whole exercise will allow delivered beet to be valued on the basis of their alkalinity-determining constituents, taking into account the chemical costs or savings needed to process them. This will allow the industry to best consider its options to manage these costs.

A search was conducted for suitable formulae which could be used to evaluate the alkalinity reserves of sugar beet by using analytical data from a range of beet samples. The sugar industry literature identifies several notable attempts to quantify the effects of beet natural alkalinity (BNA) once the foundations of the relationship between beet impurities and the sugar factory performance were established. Although P W van der Poel *et al.*[10] list a multitude of formulas produced between 1930 and 1994 to predict the alkalinity reserves in purified juices from beet analyses, it is comparatively recently that the importance of the beet alkalinity has been taken seriously widely. Although the early work of Carruthers & Oldfield[14] established practical ways to

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[10] **PW van der Poel *et al.* *(1998).*** *Sugar Technology: Beet and Cane Sugar Manufacture.* pp. 216-225, 486-489. Verlag Dr. Albert Bartens KG: Berlin.

[11] **E Andersen & E Smed (1963).** The chemical composition of sugar beet and the effective alkalinity and sugar loss in molasses. *Comptes Rendus de la XII Assemblée Génerale de la Comission Internationale de la Sucrière.* pp. 395-406.

[12] **JFT Oldfield, MShore, M Senior (1970).** Thick juice pH control by cation exchange. *International Sugar Journal* **72**, 323-327, 355-359.

[13] **CW Harvey, JV Dutton (1993).** Root quality and processing. In: *The Sugar Beet Crop: Science into Practice.* Eds DA Cooke and RK Scott, pp. 571-617. London: Chapman & Hall.

[14] **A Carruthers, JFT Oldfield (1962).** Methods for the assessment of beet quality. *International Sugar Journal* **63**, 72-74.

assess beet quality, an interest in beet alkalinity was primarily used, historically, as a research tool in the beet-growing regions of Europe.

The publication of the work of Andersen & Smed[11] produced a simpler practical formula, and that of Wieninger & Kubadinow[15] gave an alkalinity coefficient (AK) formula to identify beet with not enough alkali for the Austrian sugar factories at a time when low pH and acid corrosion became a major problem. Subsequent researchers building on the work of colleagues in other countries eventually led to the formulas of Schiweck & Burba[16] and Hein & Pollach[17] which attempt to define an "alkali reserve" in the beet to be available for the pH balance in the factory juices, again just from beet analyses.

These three formulas were finally chosen as the most representative and practical to be tested on the beet analytical data:

Andersen & Smed[11]

Effective Alkalinity (EA) = 0.58(wK +wNa +wN) – 6.8 (all in mmol/100g sugar)

Schiweck & Burba[16]

Ionic Balance = 0.92(wNa+wK) – (0.57wN +1.9wIn +2.9) (all in mmol/100g beet)
or IB = 0.92(wNa+wK) – (0.57wN +4.0) if no invert sugar (wIn) analyses available.

Hein & Pollach[17]

Ionic Balance = 0.19wK + 0.13wNa - 0.85wN -1.51wIn +6.5 (all in mmol/100g S)

(in each formula: wK is the potassium concentration, wNa sodium, wN the amino-N and wIn the invert sugar concentration.)

Although these formulas have been derived independently using different techniques at different times and places they attempt to measure largely the same parameter. It is clear by inspection alone that there are considerable differences. For example the Schiweck & Burba[16] formula reflects virtually the whole change in the beet potassium and sodium as increases in the alkalinity reserves; this is likely to be an overestimate as only part will be released as free alkali in processing from the precipitation of oxalate, etc. The Hein & Pollach[17] study as well as being the last of the line was a thorough examination of the subject producing a formula based on practical laboratory studies across a range of beet types processed through to thick juice. This seemed likely to be the most useful in predicting changes in the factory alkali requirement from changes in the beet non-sugars.

All three formulas were tested on the analytical data from the beet samples.

It was found that the formula of Hein & Pollach[17] gave the most realistic results in a useful form so as to relate the beet constituents directly to the process juices. This formula has the potential to use potassium, sodium, amino-N and the glucose and fructose when all this data is available.

From a point of view of simplicity the ratio of potassium + sodium/amino-N remains a valuable index by which to rank beet samples for their natural alkalinity.

Results from using the chosen mathematical model

Initially, the Hein and Pollach[17] formula was used to calculate alkalinity ratios (K +Na/amino-N) and to quantify their effect in terms of providing alkali in process calculated as soda ash equivalent from the campaign average values of sugar percentage and amino-N, potassium and sodium root impurities for 1995 to 2005 (Table 6). In practice the results of these calculations are best viewed in relative terms. This is because the absolute value of the alkali released into the process juices is

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[15] **L Wieninger & N Kubadinow (1971).** *Zucker* **24**, 599-604.
[16] **H Schiweck & M Burba (1993).** *Zuckerindustrie* **118**, 241-247.
[17] **W Hein & G Pollack (1994).** *Zuckerindustrie* **119**, 15-21

impossible to calculate without a detailed knowledge of the individual factory conditions and processes. A full analysis of the chemical components in the juices would be necessary before the beet contribution could be arrived at. In any case it is the changes in the amount of alkali that is available in the process that is important and the formulas which been developed are likely to reflect this much better. The soda ash equivalents for the individual campaigns were therefore compared in the table with the average for the period (1995 – 2005) to calculate the relative soda ash equivalents and relative cost of beet.

There has been a gradual increase in the natural alkalinity ratio from 7-8 during the period 1995-98, increasing to 9 in 1999, and averaging around 10 between 2000-05 with an exceptional high average of over 13 in 2001. These changes directly reflect the overall reduction in average campaign amino-N values over the same period. Although the average alkalinities did not differ dramatically between the campaigns, the relative soda ash equivalent and relative cost compared to the period average did increase significantly over these years. Up to 1999, the relative cost of the processed beet was always negative (being a cost saving to the process) but from 2000 onwards, the relative cost became positive (and an extra cost to the process) as more alkali became available within the process through the natural alkalinity of the processed beet (see Table 10).

Table 6. *Alkalinity ratios for the individual UK beet campaigns and calculated relative soda ash equivalent and relative cost to the process as compared with the period mean (1995 – 2005).*

						HEIN & POLLACH FORMULA 1994		
	S%	Amino-N	Na	K	Alkalinity ratio	Equivalent to soda ash kg/100t beet	Relative soda ash kg/100t beet	Relative cost £/100t beet
Mean 1995-2005	17.42	114	85	938	9.0	27.23	Relative to mean	
1995	16.41	169	117	1053	6.9	3.08	-24.2	-2.42
1996	18.14	134	83	962	7.8	17.72	-9.5	-0.95
1997	17.18	169	118	1048	6.9	3.05	-24.2	-2.42
1998	17.39	128	75	972	8.2	20.38	-6.9	-0.69
1999	17.17	121	94	999	9.0	26.16	-1.1	-0.11
2000	17.03	96	83	928	10.5	35.96	8.7	0.87
2001	17.15	80	75	979	13.2	46.90	19.7	1.97
2002	17.42	90	72	857	10.3	36.38	9.2	0.92
2003	18.87	85	66	817	10.4	40.16	12.9	1.29
2004	17.79	94	83	840	9.8	34.67	7.4	0.74
2005	17.04	89	73	867	10.6	36.63	9.4	0.94

The Hein & Pollach[17] formula has been applied to data from British Sugar tarehouse records at the extremes of the alkalinity ratio. Contracts from the 2000 to 2005 processing campaigns were selected with alkalinity ratios of approximately 10 (the general norm for UK beet) and with higher ratios of 20, 30 and above. On average, in these years, there were 30 to 40 contracts with an average alkalinity ratio of approximately 20 and a further 10 or so with a ratio of 30 or more. The 2001 campaign had over 150 high-alkalinity contracts with ratios above 20, in contrast to the 1995 campaign which only had 3 contracts with ratios above 10. These data were used to calculate the relative value of the alkali to the factory or, with high ratios, the cost of neutralising chemicals to counteract the excessive amounts of alkali they supplied to the process.

There was a strong relationship between alkalinity ratio and calculated relative soda ash using the Hein & Pollach[17] formula (Fig. 21). Beet with an alkalinity ratio of 10 provides approximately an extra 10 kg of soda ash equivalent/100 tonne of beet compared to the average for the 1995-2005 campaigns. Beet with an alkalinity ratio of 20 provides the equivalent of a further 25 kg of soda ash (*i.e.* a total of about 35 kg soda ash/100 tonne of beet). The problem with this relationship lies in determine when the natural alkalinity of the beet expressed as soda ash is of benefit to the process or becomes a problem in having to be neutralised.

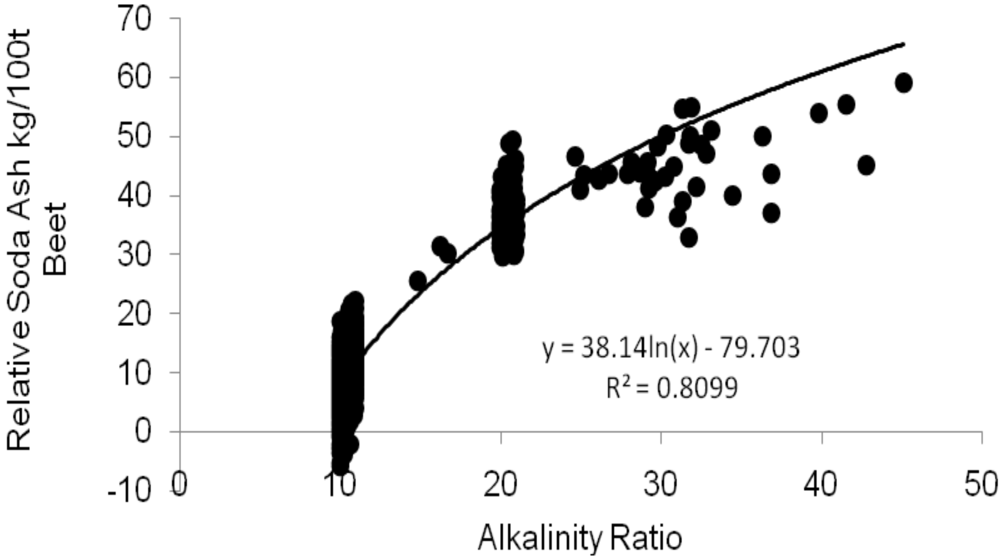


Fig. 21. *Relative soda ash equivalent plotted against alkalinity ratio for contract average tarehouse data between 2000 and 2005 (6500 data points).*

Cost of the higher Natural Alkalinity

A natural alkalinity ratio of above 10 appears to be the norm for modern beet crops. Should it increase to 20, the equivalent of a further 25 kg of soda ash becomes available within the process juice which has to be neutralised for normal sugar production to proceed. The cost involved in dealing with this extra alkali can estimated by valuing the alkali as a soda ash equivalent costing £100/tonne and a simple conversion to the commercial value of the chemical equivalent of acid needed for neutralisation in the factory. One neutralisation option is to add calcium chloride to the juice after diffusion in controlled quantities to provide the correct pH profile during evaporation and crystallisation. The 25 kg of soda ash equivalent to the extra alkali which becomes available when the natural alkalinity ratio rises to 20 has been valued at 2.5p/tonne of beet assuming a price for soda ash of £100/tonne. An equivalent amount of acid would be needed to balance this approximately. This type of evaluation can of course be applied to each load of beet for which the basic factory tarehouse sugar percentage, potassium, sodium and amino-N data are available.

Trials to examine the changes in the chemical components of beet natural alkalinity

Three sets of data were used in a more detailed study to examine the effects of diseases, especially Rhizomania, on beet amino-N. Two of these related to Rhizomania-infected fields (one on which a resistant variety was grown and the other with a susceptible variety) and the other to a replicated trial of late-season fungicides. A much wider range of anions and cations were measured in these beet because we specifically wished to examine how other they related to the routinely-measured potassium and sodium cations. Unfortunately, invert sugars were not measured but, anyway, changes in these are difficult to interpret because they can result from the breakdown of the stored sucrose in ways that are often unrelated to trial treatments, e.g. storage of beet or samples.

The three dataset were:

Chippenham: comparing healthy and Rhizomania-infected beet of a susceptible variety;
Sudbourne: comparing healthy and Rhizomania-infected beet of a resistant variety; and
Welbourne: a trial with Powdery Mildew-infected beet and healthy beet sprayed with a triazole fungicide (Spyrale containing difenoconazole + fenpropidin).

Table 7. *Overview of the analytical results with comments on the quality of the beet for processing in respect of their impurity components and the natural alkalinity.*

AMINO N PROJECT: QUALITY DATA FOR ALKALINITY MEASUREMENTS 2007

TABLE 7 OVERVIEW

TRIAL	**TREATMENT**	**OVERVIEW OF THE CHEMICAL COMPOSITION OF THESE BEET**		
CHIPPENHAM			ALL BEET IN THIS TRIAL ARE EXTREMELY HIGH NATURAL ALKALINITY OF 40+	
	Rhizomania	ZERO AMINO-N	STRIKING EXAMPLES OF RHIZOMANIA EFFECT ON AMINO-N	
	No Infection	AMINO-N APPROX 20		
SUDBOURNE			LESS EXTREME BEET THAN THE CHIPPENHAM TRIAL	
	Rhizomania	AMINO-N APPROX. 20	EXTREMELY HIGH NATURAL ALKALINITY BEET AROUND 40+	
	No Infection	AMINO-N APPROX. 40	LESS EXTREME BEET; NATURAL ALKALINITY ABOUT 20	
WELBOURNE			ALL BEET IN THIS TRIAL OF VERY GOOD PROCESSING QUALITY	
	No Fungicide		LOW BEET IMPURITIES; NATURAL ALKALINITY AROUND 20	
	Fungicide		SIMILAR BEET; AMINO-N APPROX 40; NATURAL ALKALINITY 20+	

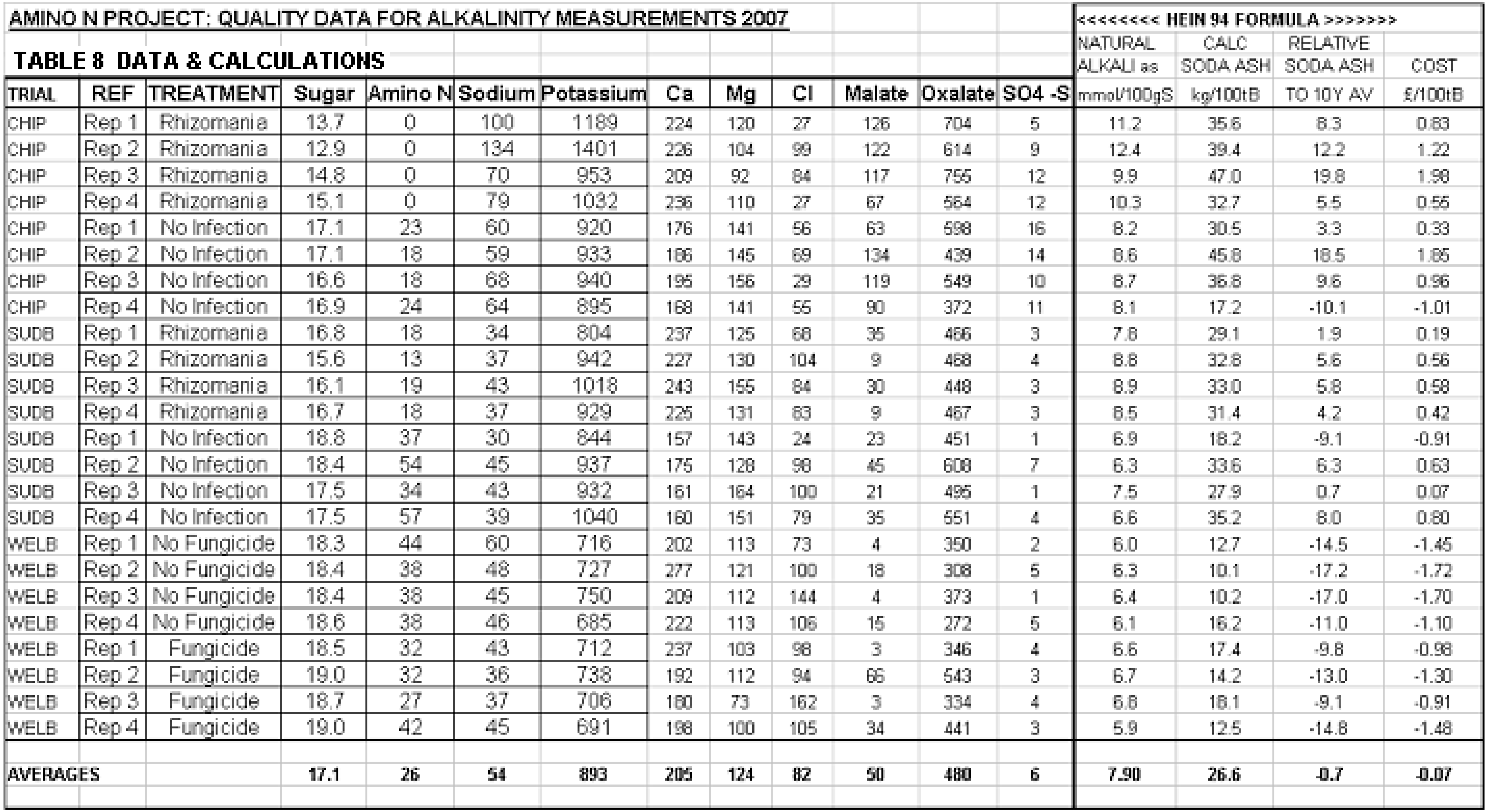
Table 8 shows the more significant analyses from these trials and the calculations from these data. Beet from Rhizomania fields, whether infected or not, had very low concentrations of amino-N and high natural alkalinity ratios. In the Chippenham trial, beet from the uninfected plots had amino-N concentrations of only about 20 mg /100g sugar beet, and those of the Rhizomania-infected beet were immeasurably low. The amounts of the alkali provided to process - calculated by the Hein and Pollach[17] formula - were very similar for both of these sets of beet which was not surprising given their very high natural alkalinities of greater than 40. The results for the Sudbourne trial (which had slightly higher levels of amino-N than at Chippenham) were similar but less pronounced.

The cost of the extra alkali provided by this beet (Table 8) represents some £1-2/100 tonne of beet more than the 10-year average for the years 1995-2005. The quality of the Chippenham trial beet was so extreme they were unlikely to be processable.

Table 9 outlines how the other components of the beet balanced other cations and anions and contributed to the natural alkalinity of the beet. The sum of the oxalate, chloride, malate and sulphate anions are in reasonable consistent balance with the potassium and sodium cation content even in this extreme alkalinity-ratio beet (allowing for the analytical errors in this type of analysis).

There has always been risk in using only potassium, sodium and amino-N to calculate the natural alkalinity of beet because this assumes that the anionic components do not vary much. It has been assumed that they release a fixed proportion of the alkalis into process when anions like oxalate are eliminated at the carbonatation stage in the factory. Magnesium and calcium are consumers of alkali in process and are not routinely measured; again it can be seen that they are at a relatively consistent level in these beet.

Table 8. *Processing quality of beet sampled from Rhizomania-infected fields and late-season fungicide tria*

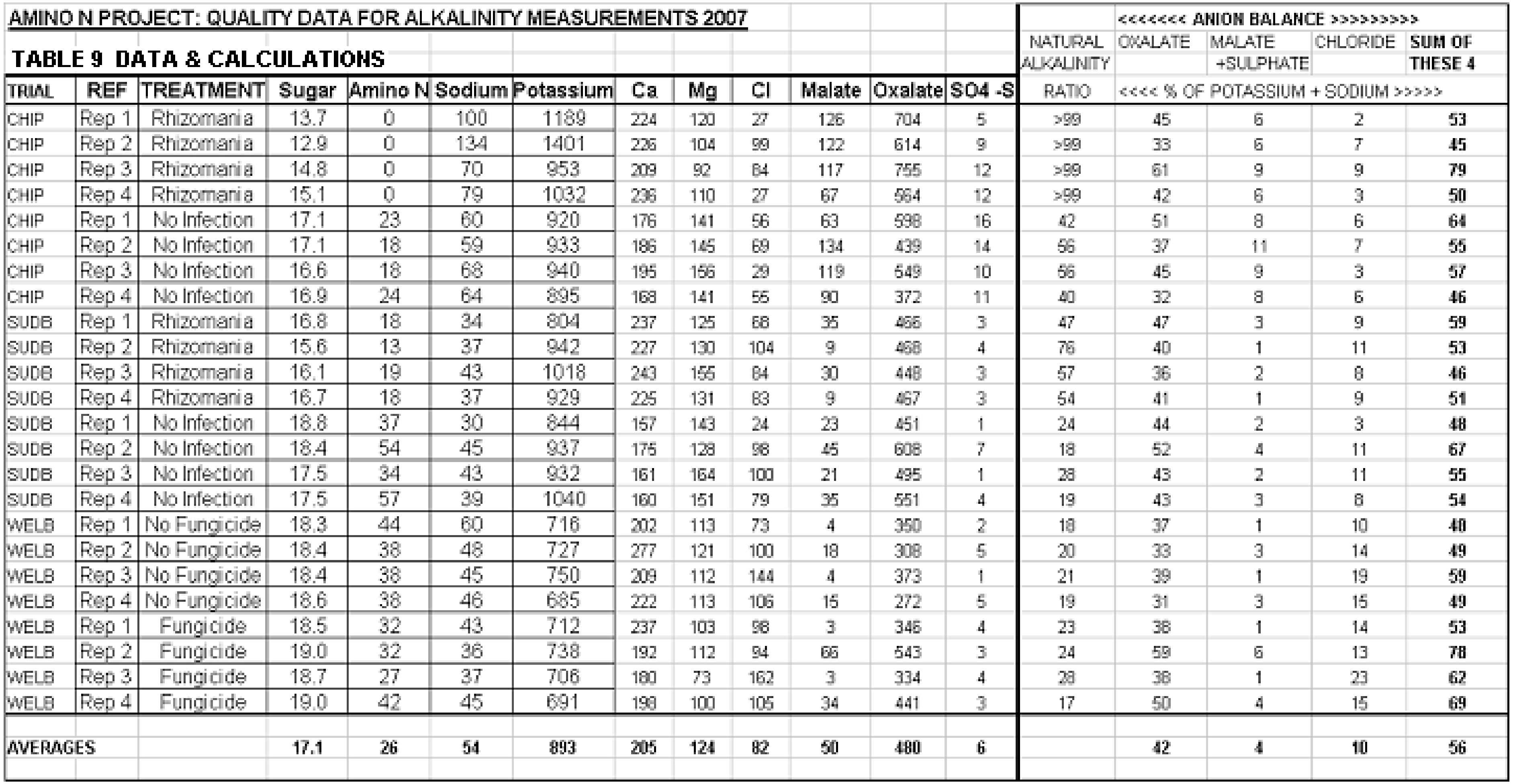


AMINO N PROJECT: QUALITY DATA FOR ALKALINITY MEASUREMENTS 2007

TABLE 8 DATA & CALCULATIONS

													<<<<<<<< HEIN 94 FORMULA >>>>>>>			
TRIAL	REF	TREATMENT	Sugar	Amino N	Sodium	Potassium	Ca	Mg	Cl	Malate	Oxalate	SO4 -S	NATURAL ALKALI as mmol/100gS	CALC SODA ASH kg/100tB	RELATIVE SODA ASH TO 10Y AV	COST £/100tB
CHIP	Rep 1	Rhizomania	13.7	0	100	1189	224	120	27	126	704	5	11.2	35.6	8.3	0.83
CHIP	Rep 2	Rhizomania	12.9	0	134	1401	226	104	99	122	614	9	12.4	39.4	12.2	1.22
CHIP	Rep 3	Rhizomania	14.8	0	70	953	209	92	84	117	756	12	9.9	47.0	19.8	1.98
CHIP	Rep 4	Rhizomania	15.1	0	79	1032	236	110	27	67	564	12	10.3	32.7	5.5	0.55
CHIP	Rep 1	No Infection	17.1	23	60	920	176	141	56	63	598	16	8.2	30.5	3.3	0.33
CHIP	Rep 2	No Infection	17.1	18	59	933	186	145	69	134	439	14	8.6	45.8	18.5	1.85
CHIP	Rep 3	No Infection	16.6	18	68	940	195	156	29	119	549	10	8.7	36.8	9.6	0.96
CHIP	Rep 4	No Infection	16.9	24	64	895	168	141	55	90	372	11	8.1	17.2	-10.1	-1.01
SUDB	Rep 1	Rhizomania	16.8	18	34	804	237	125	68	35	466	3	7.8	29.1	1.9	0.19
SUDB	Rep 2	Rhizomania	15.6	13	37	942	227	130	104	9	468	4	8.8	32.8	5.6	0.56
SUDB	Rep 3	Rhizomania	16.1	19	43	1018	243	155	84	30	448	3	8.9	33.0	5.8	0.58
SUDB	Rep 4	Rhizomania	16.7	18	37	929	225	131	63	9	467	3	8.5	31.4	4.2	0.42
SUDB	Rep 1	No Infection	18.8	37	30	844	157	143	24	23	451	1	6.9	18.2	-9.1	-0.91
SUDB	Rep 2	No Infection	18.4	54	45	937	175	128	98	45	608	7	6.3	33.6	6.3	0.63
SUDB	Rep 3	No Infection	17.5	34	43	932	161	164	100	21	496	1	7.5	27.9	0.7	0.07
SUDB	Rep 4	No Infection	17.5	57	39	1040	160	151	79	35	551	4	6.6	35.2	8.0	0.80
WELB	Rep 1	No Fungicide	18.3	44	60	716	202	113	73	4	350	2	6.0	12.7	-14.5	-1.45
WELB	Rep 2	No Fungicide	18.4	38	48	727	277	121	100	18	308	5	6.3	10.1	-17.2	-1.72
WELB	Rep 3	No Fungicide	18.4	38	45	750	209	112	144	4	373	1	6.4	10.2	-17.0	-1.70
WELB	Rep 4	No Fungicide	18.6	38	46	685	222	113	106	15	272	5	6.1	16.2	-11.0	-1.10
WELB	Rep 1	Fungicide	18.5	32	43	712	237	103	98	3	346	4	6.6	17.4	-9.8	-0.98
WELB	Rep 2	Fungicide	19.0	32	36	738	192	112	94	66	543	3	6.7	14.2	-13.0	-1.30
WELB	Rep 3	Fungicide	18.7	27	37	706	180	73	162	3	334	4	6.8	18.1	-9.1	-0.91
WELB	Rep 4	Fungicide	19.0	42	45	691	198	100	105	34	441	3	5.9	12.5	-14.8	-1.48
AVERAGES			**17.1**	**26**	**54**	**893**	**205**	**124**	**82**	**50**	**480**	**6**	**7.90**	**26.6**	**-0.7**	**-0.07**

Table 9. *Natural alkalinity ratio and anion balance of beet sampled from Rhizomania-infected fields and late-season fungicide trial.*



AMINO N PROJECT: QUALITY DATA FOR ALKALINITY MEASUREMENTS 2007

TABLE 9 DATA & CALCULATIONS

														<<<<<<< ANION BALANCE >>>>>>>>>			
													NATURAL ALKALINITY	OXALATE	MALATE +SULPHATE	CHLORIDE	**SUM OF THESE 4**
TRIAL	**REF**	**TREATMENT**	**Sugar**	**Amino N**	**Sodium**	**Potassium**	**Ca**	**Mg**	**Cl**	**Malate**	**Oxalate**	**SO4 -S**	RATIO	<<<< % OF POTASSIUM + SODIUM >>>>>			
CHIP	Rep 1	Rhizomania	13.7	0	100	1189	224	120	27	126	704	5	>99	45	6	2	**53**
CHIP	Rep 2	Rhizomania	12.9	0	134	1401	226	104	99	122	614	9	>99	33	6	7	**45**
CHIP	Rep 3	Rhizomania	14.8	0	70	953	209	92	84	117	755	12	>99	61	9	9	**79**
CHIP	Rep 4	Rhizomania	15.1	0	79	1032	236	110	27	67	564	12	>99	42	6	3	**50**
CHIP	Rep 1	No Infection	17.1	23	60	920	176	141	56	63	598	16	42	51	8	6	**64**
CHIP	Rep 2	No Infection	17.1	18	59	933	186	145	69	134	439	14	56	37	11	7	**55**
CHIP	Rep 3	No Infection	16.6	18	68	940	195	156	29	119	549	10	56	45	9	3	**57**
CHIP	Rep 4	No Infection	16.9	24	64	895	168	141	55	90	372	11	40	32	8	6	**46**
SUDB	Rep 1	Rhizomania	16.8	18	34	804	237	125	68	35	466	3	47	47	3	9	**59**
SUDB	Rep 2	Rhizomania	15.6	13	37	942	227	130	104	9	468	4	76	40	1	11	**53**
SUDB	Rep 3	Rhizomania	16.1	19	43	1018	243	155	84	30	448	3	57	36	2	8	**46**
SUDB	Rep 4	Rhizomania	16.7	18	37	929	225	131	83	9	467	3	54	41	1	9	**51**
SUDB	Rep 1	No Infection	18.8	37	30	844	157	143	24	23	451	1	24	44	2	3	**48**
SUDB	Rep 2	No Infection	18.4	54	45	937	175	128	98	45	608	7	18	52	4	11	**67**
SUDB	Rep 3	No Infection	17.5	34	43	932	161	164	100	21	495	1	28	43	2	11	**55**
SUDB	Rep 4	No Infection	17.5	57	39	1040	160	151	79	35	551	4	19	43	3	8	**54**
WELB	Rep 1	No Fungicide	18.3	44	60	716	202	113	73	4	350	2	18	37	1	10	**40**
WELB	Rep 2	No Fungicide	18.4	38	48	727	277	121	100	18	308	5	20	33	3	14	**49**
WELB	Rep 3	No Fungicide	18.4	38	45	750	209	112	144	4	373	1	21	39	1	19	**59**
WELB	Rep 4	No Fungicide	18.6	38	46	685	222	113	106	15	272	5	19	31	3	15	**49**
WELB	Rep 1	Fungicide	18.5	32	43	712	237	103	98	3	346	4	23	38	1	14	**53**
WELB	Rep 2	Fungicide	19.0	32	36	738	192	112	94	66	543	3	24	59	6	13	**78**
WELB	Rep 3	Fungicide	18.7	27	37	706	180	73	162	3	334	4	28	38	1	23	**62**
WELB	Rep 4	Fungicide	19.0	42	45	691	198	100	105	34	441	3	17	50	4	15	**69**
AVERAGES			**17.1**	**26**	**54**	**893**	**205**	**124**	**82**	**50**	**480**	**6**		**42**	**4**	**10**	**56**

The beet natural alkalinity contributors can be grouped into four types:

1. **Major alkalis**: Potassium and sodium.
2. **Acid formers in process**: Chemical breakdown of the glutamine component of the amino-N and of invert sugars during beet processing.
3. **Alkali providers in process**: Anions eliminated or partly eliminated in carbonatation such as oxalate, phosphate, citrate, malate, sulphate.
4. **Alkali consumers in process**: Cations eliminated or partly eliminated in process such as magnesium, calcium & ammonium.

Components which pass through the process to molasses unchanged have much less effect on pH, although they may contribute buffering capacity to the process juices. This is also true for betaine, amino acids, chloride, nitrate and the surviving anions from elimination and chemical breakdown. Potassium and sodium (including any added to balance the pH) pass through process unchanged and so provide by far the majority of the potential alkali in the juice.

The data from these agronomic trials gives an insight into the components of the beet which make up the natural alkalinity. Although it is the four headline constituents: potassium, sodium, amino-N and invert sugar, which are responsible for the major changes in processing beet, important roles are played by others, some of which have been studied here. As well as invert sugar, the important impurities betaine, citrate and nitrate were not measured and their effect on the beets natural alkalinity could therefore not be assessed in this study.

It is necessary to state that the beet from these trials were at the high end of natural alkalinity and give some insight of what could occur in extreme situations. Some of these samples may not have been acceptable for processing to sugar.

Cost of high natural alkalinity to UK beet sugar industry

Looking at the overall effect of high levels of beet natural alkalinity on the UK beet sugar industry gives the situation shown in Table 10. Calculating from the base of the average crop in the years 1995 to 2005, crops with a beet natural alkalinity defined by the formula (K +Na)/amino-N of 10 provide more alkali in process. This extra alkali is equivalent to adding soda ash at 10 kg/100t of beet to juice in the factory. The value of this alkali is approximately 1.0p/tonne of beet and so would be a similar cost if it had to be neutralised by an acid added into process.

If the natural alkalinity reaches 20, as with the majority of the samples examined in these agronomic trials, then extra alkali equivalent to soda ash of 25 kg/100t of beet appears in processing. To neutralise this is an extra cost of £3.5/100 tonnes of beet compared to the 10 year average 1995 to 2005 would be expected. Extrapolated to the whole UK beet crop this is a cost of some £210,000 per year to the factories. Clearly, the cost would be much higher if a large proportion of the UK crop was composed of beet infected with Rhizomania with extreme alkalinity ratios (Table 9). This is highly unlikely to happen as the market share of Rhizomania resistant varieties in the UK continues to increase. However, the performance of such varieties needs to be closely monitored by the beet industry as the Rhizomania infected beet from the Sudbourne site were from an apparent Rhizomania resistant variety. Almost half the field was infected, and as yet there is no obvious explanation for this unusual event.

Table 10. *Calculated costs to UK beet industry of high alkalinity beet.*

	Beet natural alkalinity	Calc$^{d.}$ extra soda ash provided kg/100 t beet	Pence per tonne of beet	Cost for UK beet crop £K
Average crop 1995 - 2005	9	0		
Post 2000 beet	10	10	1	60
High alkalinity beet	20	35	3.5	210

Costs based on 1 million tonnes of sugar processed each year
Costs to neutralise soda ash valued at £100/t of chemical equivalent

A relative evaluation of each load of beet delivered is possible using the simple beet natural alkalinity formula, (K+Na)/amino-N, so that extreme beet can be identified and investigated. There is also the possibility of using this formula for bonus or malus payments if required.