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Environmental Aspects of Sugar Beet Production in Sweden

Agr Robert Olsson
robert.olsson@danisco.com
Swedish Beet Research
Borgeby Slottsväg 11
SE-237 91 Bjärred

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1 Executive summary

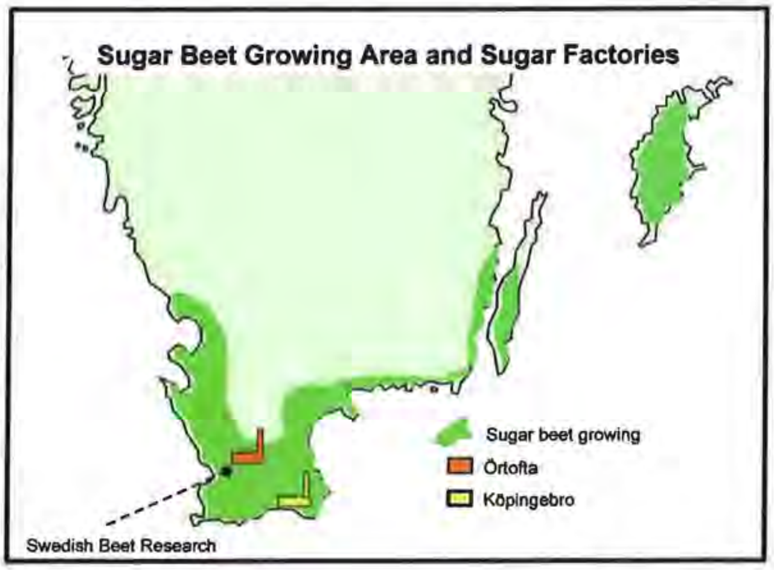
The purpose of this paper is to highlight environmental benefits, possibilities, risks and problems linked to the sugar beet crop, the extent of such problems and the future prospects of sugar beet in relation to alternative crops.

Environmental characterization of the Swedish sugar beet crop:

- A 'cleaning crop' in cereal-dominated crop rotations. Cereals produced after a beet crop require a lower input of pesticides and fertilizers and produce a higher yield compared to cereals after cereals.
- The N balance is better, the N use is lower, and the risk for N leaching from a sugar beet crop is on the same level as, or lower than, that for cereals.
- The use of crop protection products is on the same level as in cereals and significantly lower than in potatoes. All use is under the environmental management system MBO. The risk profile of the main specific sugar beet products does not give cause for any particular concern.
- All sugar beet is grown following the environmental management system MBO – Miljöledning BetOdling.
- Swedish sugar beet production fulfils consumer demand for organic sugar in Scandinavia. By-products such as pressed beet pulp and factory lime are sold to organic milk producers.
- Sugar beet can contribute to a richer, more diverse wildlife population compared to crop rotations with more frequent growing of cereals.
- The sugar beet crop normally has a higher energy output/input ratio than cereals.
- Beets consist of more than sugar. The whole beet is utilized as food, feed or other products recycled back to farmland. One hectare of beets produce feed equivalent to 0.2 ha of cereals and 0.2 ha of grassland.
- Sugar beet growers are well-educated and they - in co-operation with the sugar industry - are strongly supportive of research and development.
- Sugar buyers do not wish GMOs to be used, so no GMOs are used in the growing and processing of sugar beet in Sweden.

2 Introduction

Sugar beet growing was introduced to Sweden in the late 1870s. Sugar beet is only grown in southern Sweden. In fact, 87% of all sugar beet growing is located in the county of Scania, within 100 km of the south coast of Sweden. Most beet is grown on calcareous soils with a clay content between 10-25% and a high fertility level. The landscape of these areas is generally flat or gently sloping.



Average weather data, presented in Tables 3.1.3-3.1.4, show that precipitation is normally high enough to make full use of the temperature-limited yield capacity of the crop without irrigation. Heavy rainfall of more than 30 mm/day or winds stronger than 15 m/s are rare but can occur in some years.

Swedish Beet Research, or Sockernäringens Betodlings-Utveckling AB (SBU), is a research and development company specializing in the sugar beet crop. Close cooperation is maintained with the Swedish University of Agricultural Sciences (SLU) and the local Agricultural Societies in Scania. The work of SBU is coordinated with the work being done by the Alstedgaard Research Foundation for Sugar Beet in Denmark and the CfS Sugar Beet Research Centre in Finland.

Sugar beet is grown on some of the best soils and in the best climate available in Sweden. It is very likely that this land will be kept open and used as agricultural land even in the future. The present review concentrates on the environmental impact of beet growing, focusing on three major areas:

- A statistical overview of beet growing 1975-2004.
- Core environmental values and strengths of the crop.
- A systematic analysis of possible problem areas and the effects of these on soil, water, air, biodiversity and energy.

The purpose of this work is primarily to highlight the environmental benefits, possibilities, risks and problems linked to the sugar beet crop. It also assesses the scope of these problems and how their significance may be affected by any future changes in beet profitability.

3 Statistics

3.1 Acreage, structure and climate

3.1.1 Acreage of sugar beet in Sweden (khectares)

1975	1980	1985	1990	1995	2000	2004[1)]
52	51	51	50	57	55	48

[1)] Predicted *Source: Danisco Sugar AB*

Remarks: The beet acreage remained stable until Sweden became part of the EU in 1995. The EU quota allowed an increased acreage for a few years. Since that time, increasing yields per unit area and thus per unit input have led to a steady decrease in the acreage required to fulfil the national quota.

3.1.2 Acreage per grower (hectares)

1975	1980	1985	1990	1995	2000	2004[1)]
4.5	5.2	6.0	7.1	10.9	12.5	13.5

[1)] Predicted *Source: Danisco Sugar AB*

Remarks: The acreage per grower shows a steady increase. This trend is expected to continue.

3.1.3 Temperature (mean temperature April-October, °C)

1975	1980	1985	1990	1995	2000	2003
13	12	12	12	13	13	13

Source: Danisco Sugar AB

Remarks: The mean temperature has remained stable.

3.1.4 Precipitation (mean precipitation April-October, mm)

1975	1980	1985	1990	1995	2000	2003
276	390	320	420	370	420	363

Source: Danisco Sugar AB

Remarks: Precipitation shows some variation but is normally high enough not to be a major yield-limiting factor. About 10% of the acreage is irrigated with 30-120 mm.

3.2 Yield and quality

3.2.1 Root yield (5-year average, tonnes/ha: last year of period given in table)

1975	1980	1985	1990	1995	2000	2003
40.4	40.3	42.1	44.5	43.8	44.4	48.0

Source: Danisco Sugar AB

Remarks: The root yields were exceptionally high in 1989 and 1990 due to very favourable weather conditions.

3.2.2 Sugar content (5-year average, %: last year of period given in table)

1975	1980	1985	1990	1995	2000	2003
17.27	17.18	17.22	17.87	17.20	17.67	17.60

Source: Danisco Sugar AB

Remarks: The sugar content is stable at a high level in European terms.

3.2.3 Sugar yield (5-year average, tonnes/hectare: last year of period given in table)

1975	1980	1985	1990	1995	2000	2003
6.98	6.92	7.25	7.94	7.53	7.85	8.44

Source: Danisco Sugar AB

Remarks: The steady increase in sugar yield per unit area has been obtained with equal or even lower inputs of fertilizers and crop protection products per hectare. Per unit product, total inputs are strongly decreasing.

3.2.4 Clean beets (5-year average, % of total weight delivered: last year of period given in table)

1975	1980	1985	1990	1995	2000	2003
84.1	82.3	83.0	85.0	86.9	89.8	91.5

Source: Danisco Sugar AB

Remarks: Significant improvements have been made to achieve a top level in European terms.

3.2.5 Dirt tare (5-year average, % of total weight delivered: last year of period given in table)

1975	1980	1985	1990	1995	2000	2003
12.7	14.6	13.9	11.8	9.8	6.8	5.0

Source: Danisco Sugar AB

Remarks: Significant improvements have been made to achieve the lowest dirt tare level in Europe.

3.3 Fertilization

3.3.1 Chemical fertilizer use

3.3.1.1 Nitrogen from fertilizer use (kg N/ha)

1975	1980	1985	1990	1995	2000	2004[1)]
134	128	123	116	113	107	103

[1)] Predicted

Source: Danisco Sugar AB

Remarks: Compared to many other crops, sugar beet has a relatively low nitrogen requirement. A steady decrease of the application rate has been recorded.

3.3.1.2 Phosphate from fertilizer use (kg P/ha)

1975	1980	1985	1990	1995	2000	2004[1)]
54	45	36	23	21	18	17

[1)] Predicted *Source: Danisco Sugar AB*

Remarks: Phosphate is only applied if the level in the soil is low. A steady decrease of the application rate has been recorded.

3.3.1.3 Potassium from fertilizer use (kg K/ha)

1975	1980	1985	1990	1995	2000	2004[1)]
105	99	90	62	57	44	39

[1)] Predicted *Source: Danisco Sugar AB*

Remarks: Potassium is only applied if the level in the soil is low. A steady decrease of the application rate has been recorded.

3.3.2 Organic manure use (percentage of total sugar beet acreage)

1975	1980	1985	1990	1995	2000	2004[1)]
68	68	64	57	53	38	38

[1)] Predicted *Source: Danisco Sugar AB*

3.4 Crop protection products

3.4.1 Herbicide use (kg active ingredient per hectare)

1975	1980	1985	1990	1995	2000	2003
			3.7	3.4	2.8	2.6

Source: Danisco Sugar AB

Remarks: A steady decrease has been recorded. This is primarily due to the introduction of repeated low dose applications during the 1990s.

3.4.2 Insecticide use (kg active ingredient per hectare)

1975	1980	1985	1990	1995	2000	2003
			0.1	0.0	0.0	0.0

Source: Danisco Sugar AB

Remarks: Insecticide use is very low - close to zero.

3.4.3 Fungicide use as foliar application (kg active ingredient per hectare)

1975	1980	1985	1990	1995	2000	2004[1)]
0.0	0.0	0.0	0.0	0.0	0.0	0.0

[1)] Predicted *Source: Danisco Sugar AB*

Remarks: No systemic fungicides are used. Fungal diseases are primarily controlled by use of resistant varieties.

4 Core values of the sugar beet crop

4.1 Crop rotation effects

Beet, by regultation and for the reasons of sustainable pest and disease control, cannot be grown on the same piece of land any more frequently than every third year. The frequency is normally 4-6 years. Therefore the area of the crop (50,000 ha per year) has an influence on the environment of more than 250,000 ha and on 3,600 farms. Thus, beet must be grown in rotation with other crops, and this ensures a diverse range of habitats.

The most common crops grown on beet-producing farms are winter cereals with spring cereals as number two. Cereals alone are estimated to cover 60% of the acreage in the beet-growing region (A. Lindkvist, personal communication, 2004).

Continuously growing closely-related crops leads to a build-up of pests and diseases, which, if not controlled by other means, cause yields to decline. Arable farmers try to use break crops to prevent this. There is little opportunity to expand the area of other break crops, as they are not sufficiently profitable or their market is satisfied. Therefore any reduction in the beet area will tend to increase the area of cereals.

- Second wheat crops yield about 1 tonne/ha less than the first and cost about 30 €/ha more to grow, mostly because they require more nitrogen fertilizer. (G. Hansson, personal communication, 2004).
- Swedish crop rotation trials show that sugar beet as a previous crop has a favourable effect on the yield of many crops, especially spring cereals. The yield increase is 10-20% compared to the yield after two years of successive cereal growing (Agerberg, 1965).
- Practical experiences from HIR Malmöhus confirm a 10% yield decrease for barley after barley compared to barley after sugar beet. Again, added to this difference in yield should be the increased cost and requirement for nitrogen and fungicides (G. Hansson, personal communication, 2004).

In conclusion: Sugar beet can be regarded as a 'cleaning crop' in cereal-dominated crop rotations. Cereals produced after a beet crop require a lower input of pesticides and fertilizers and produce a higher yield compared to cereals after cereals.

4.2 Low N use and low N losses

Sugar beet is in many ways an important part of a healthy crop rotation in southern Sweden. There are well-known advantages concerning weed management and pest management deriving from the use of sugar beet as a 'break crop' in a crop rotation that would otherwise be dominated by cereals. There are also advantages concerning N use efficiency.

The nitrogen balance is very favourable for sugar beet. This means that the degree of N utilisation is higher and the N excess is lower compared to that for many other crops such as cereals, oilseed rape or potatoes (A. Henriksson, personal communication, 2004; G. Hansson, personal communication, 2004).

Due to its long growing period, sugar beet efficiently utilizes soil mineral nitrogen during autumn. Soil mineral N at harvest is in general determined by fertilizer residues not taken up, mineralization of N from soil organic matter and from crop residues. Therefore, cultivation of sugar beet is of great advantage in mixed farming, since the long growing period enables the beet crop to utilize not only large amounts of soil mineral N, but also large amounts of N originating from manure.

Several investigations in Sweden and in other European countries have concluded that only small amounts of nitrogen are found in the soil profile at harvest of sugar beet, especially at late harvest. N losses through leaching have been proven to be small. Compared to winter wheat the N leaching from sugar beet normally is smaller or at the same magnitude. For literature, please see Appendix 3.

Due to the low leaching risk, the Swedish Board of Agriculture considers sugar beet to be a green cover autumn crop. Growing sugar beet is one important measure in minimizing N leaching from the crop rotation (Swedish Board of Agriculture, 2000).

Aboveground crop residues of agricultural crops typically contain 20-120 kg N ha^{-1}. In Sweden sugar beet tops normally contain 80-100 kg N ha^{-1} at harvest. Once mineralized from crop residues, the N can contribute to the fertilizer requirements of subsequent crops or become a pollutant. This includes nitrate leaching to water sources and gaseous losses to the atmosphere. Part of the crop residue may contribute to the soil organic matter pool. Several studies have shown that sugar beet residues contribute to a very small extent to N leaching, although some of the N in the residues might be mineralized during late winter and spring. For further details, see Appendix 3.

In-row application of nitrogen and often also P, K, Na and micronutrients is gaining in importance and now covers 10-15% of the total sugar beet area. This new technique will improve nitrogen efficiency even further in the future.

- Swensson (2002), Sweden: Studying nitrogen balances, using the farm gate method, for 283 conventional dairy farms situated in southern Sweden, it was found that N use efficiency was significantly higher on farms where sugar beet was included in the crop rotation. The more varied production on the dairy farms growing sugar beet was reflected in the higher output of N in their crops. One important conclusion was that mixed farming is one way of improving the N use efficiency at farm level.

- Aronsson & Torstensson (2003), Sweden: In a long-term field experiment in southern Sweden, studying N dynamics and N leaching, sugar beet was studied in two crop rotations during 1993-2003. At harvest of sugar beet in September/October, the soil (0-60 cm) contained approximately 15 kg N ha^{-1}. This was lower than after conventional cereals and at the same level as after cereals undersown with a catch crop. N leaching from sugar beet was on average 20 kg N ha^{-1} and at the same level as from cereals.

- Thomsen et al. (1993), Denmark: The leaching losses of nitrate from a sandy loam receiving inorganic N according to recommended rates were lower from the sugar beet crop compared to continuous cereals but higher compared to cereals undersown with grass. When crops received the recommended fertilizer rates partly as animal slurry or inorganic fertilizer at 50% above recommended rates, the cumulative nitrate losses from the four-year crop rotation with cereals grown continuously exceeded those from crops in rotation with sugar beet.

In conclusion: The N balance is better, the N use is lower, and the risk for N leaching from a sugar beet crop is on the same level as, or lower than, that for cereals.

4.3 Crop protection product use in comparison with other crops

The pesticide use in sugar beet, measured as number of hectare-doses, is on the same level as in cereals but significantly lower than in potatoes.

Over 95% of the pesticide use in sugar beet is herbicides. In contrast to most other crops, foliar application of insecticides or fungicides is normally not carried out. Seed pre-treatment with fungicides and insecticides leaves about 95% of the soil 'untreated'.

The properties of some of the active ingredients used for weed control in sugar beet indicate a certain risk for leaching. On the other hand, this risk is lowered by favourable conditions for soil degradation. Over 90% of the pesticides used on sugar beet are applied during April, May or June. This gives a long period with suitable conditions for soil degradation.

The handling chain (storage – sprayer filling – spraying – sprayer cleaning) for pesticides in sugar beet is strictly regulated in the inter-professional agreement between Danisco Sugar and each grower through the environmental management system, MBO (Odlingsanvisningar, Danisco Sugar, 2002).

The environmental risk when using recommended beet crop protection programmes is on the same level as, or lower than, that when using recommended programmes in cereals. Replacing sugar beet with other crops such as cereals, potatoes or winter rape would maintain or increase the environmental risk.

- A survey carried out by Odling i Balans on their beet growing farms during 2001-2003 gave the following average number of ha-doses: sugar beet 2.5, winter wheat 2.5, spring barley/oats 1.9 and potatoes 9.2 (Törner, 2004).

- Specific sugar beet products (metamitron, ethofumesate, fenmedifam) were not among the 11 active ingredients found in drinking water analyses from 1985-2001, nor were they among the 10 most frequently found active ingredients in surface water analyses from 1985-2001 (Törnquist et al., 2002).

- The so-called Vemmenhög project studied the levels of pesticide residues in running surface water flowing through an intensive agricultural area with 23-28% of the arable land cropped with sugar beet in crop rotations dominated by cereals during 2001-2002. The main active ingredients used in sugar beet were occasionally but not generally found in running water samples. However some products mainly used in cereals were more frequently found (Kreuger, 2002; Kreuger et al., 2003; Appendix 2).
- The leaching risk was simulated for a 4-year rotation with winter wheat - sugar beet - spring barley - winter wheat typical for the Vemmenhög area. This crop rotation was compared to the same rotation without the sugar beet and a rotation where beet was replaced by winter rape. A relevant crop protection programme for each crop was chosen by local extension service managers from the Agricultural Socitety. The MACRO simulation model was used. The conclusion was that replacing sugar beet with either more cereals or more winter rape would give a minor increase in the total leaching risk (Jarvis, 2004).
- Responses to the e-mail question: 'Have you experienced any environmental problems related to pesticide use in sugar beet; damage or other effects due to wind drift, complaints or opinions from the public at large?' sent by Scania county administration to the environmental officers in 33 communities in the region did not indicate any environmental problems linked to sugar beet growing (K. Larsson, personal communication, 2004).

In conclusion: The amount of crop protection products used in sugar beet is on the same level as in cereals and significantly lower than in potatoes. All use is under the environmental management system MBO. The risk profile of main specific sugar beet products does not give cause for particular concern.

4.4 Growing and documentation – third party audit

All sugar beet in Sweden is grown under the environmental management system MBO – Miljöledning BetOdling. This became part of the Swedish Inter-professional Agreement in 1999. Participation in the system was voluntary in 1999 but became compulsory for all growers in 2000 (R. Olsson, 2002).

MBO is a tool to show that the Swedish sugar beet growers do as they say – a kind of open door to the public. The nine parts of MBO are described in Figure 1. The principal concept is very much the same as for ISO 9001 or 14001. The system includes grower training, defined environmental objects and targets, compulsory grower activities and a third party audit (Figure 1).

MBO puts the emphasis on:

- Compliance with Swedish law
- Sugar as a product
- Sustainability in the sugar beet production system

For more detailed information, see Appendix 1.

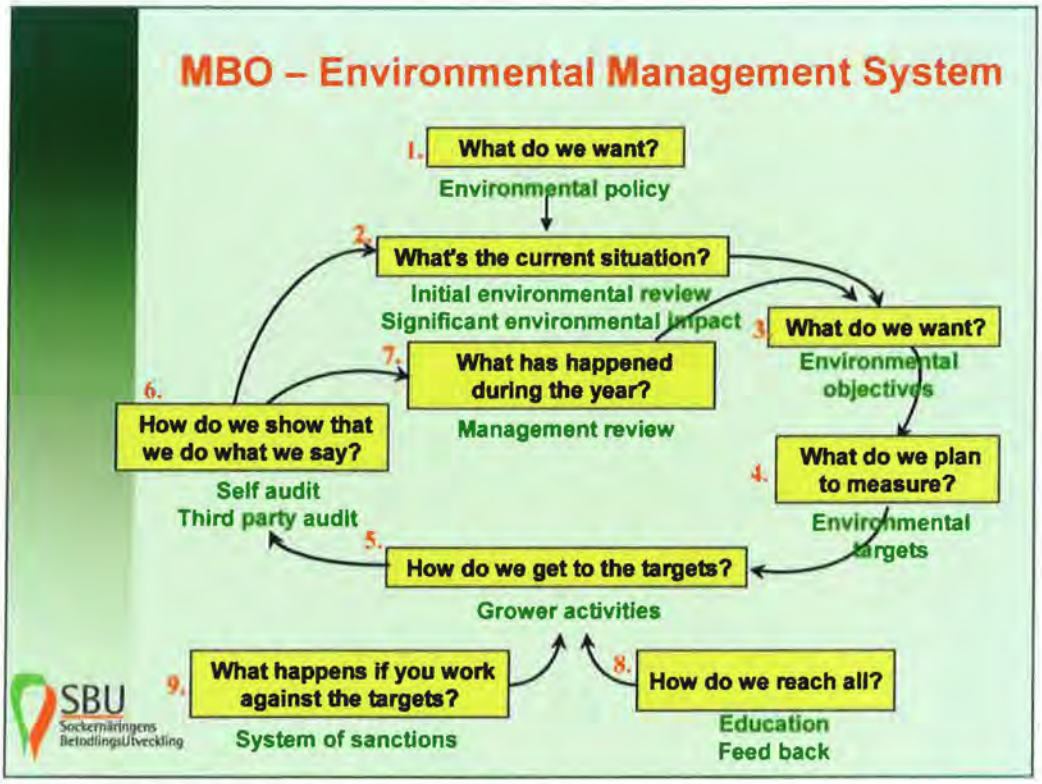


Figure 1. The structure of the environmental management system MBO.

In conclusion: All sugar beet is grown in accordance with the environmental management system MBO – Miljöledning BetOdling.

4.5 Organic sugar beet production

Swedish retailers started to demand organic sugar at the beginning of the 1990s. As a result, organic beet growing following EEC Directive 209201//91 began in 1994. Since then, the acreage has increased from 60 ha to 500-600 ha in 2001-2003 in order to fulfil consumer demand in Scandinavia. Sweden has a leading position in the organic growing of sugar beet in Europe.

In conclusion: Swedish sugar beet production fulfils consumer demand for organic sugar production. By-products such as pressed beet pulp and factory lime are sold to organic milk producers.

4.6 Wildlife effects

Beet crops retain an open vegetation structure and areas of bare soil until early summer, providing nesting sites for many ground-nesting birds such as lapwing and skylark. The opposite is true of winter crops, which are sown in September and October for harvest during the following August. Such land is being prepared for sowing or is cropped for 11 months of the year and the crops have a dense canopy structure for much of the spring and early summer, thus being unsuitable habitats for many farmland bird species. Beet occupies about 75% of the area of open-canopy cropping in regions where it is grown (A. Lindkvist, personal communication, 2004).

About 80% of the beet crop is harvested after mid-October and the next crop is therefore not sown until spring. Of all the arable crops, it is the last one to be harvested. Many birds and mammals can shelter in, and feed on, this crop. After harvest, mammals such as roedeer, other deer species and birds can feed on the remnants of the crop left in the field. In comparison to other crops, sugar beet provides shelter and feed over a much longer period.

A significant amount, about 5 000 tonnes of beet annually, is used as feed for roedeer and other deer during the winter months (P.E. Jensen, personal communication, 2004).

In general, sugar beet hosts a completely different population of insects and fungi than other crops in the rotation such as cereals or potatoes.

In conclusion: Sugar beet can contribute to a richer and more diverse wildlife population compared to crop rotations with more frequent growing of cereals.

4.7 Light/energy transformation

Sugar beet has green foliage during most of the vegetation period and is therefore an effective light transformer. The energy consumption per kg white sugar produced has shown a steady decrease over the past 30 years.

- Energy input/output calculations on Odling i Balans farms were carried out for different crops during 2000. The energy consumption level for sugar beet growing was about 5 000 kWh/ha. This includes input manufacture (seed, fertilizers, pesticides, etc.), agricultural operations, transport and machinery manufacture. This was the same as or slightly more than for cereal cropping. The energy output in delivered beets was about 60,000 kWh, giving output/input ratios typically around 10 with variations from 6-14. Output/input ratios for cereal cropping would typically be somewhat lower (Törner, 2002).

In conclusion: Sugar beet as a crop has a higher energy output/input ratio than cereals.

4.8 By-product production – recycling

The feed products originating from sugar production also provide added value from an environmental point of view. Apart from sugar, a 50 tonne beet crop would produce the following approximate quantities of feed products per ha:

Beet pulp:	**2 500 kg dry matter**
Molasses:	**1 500 kg (Rt 78)**
Factory lime:	**2 100 kg (60-65% dry matter)**

About 90% of the sugar in the beet ends up as sugar products for human consumption. The rest of the sugar beet becomes a valuable animal feed product such as molasses or various beet fibre products.

About 55% of the pressed beet pulp produced per season is sold as fresh weight directly to dairy and beef cattle farmers, in order to avoid energy consumption for drying. The rest is dried and pelleted and either sold to the feed industry, with or without molasses added, to be incorporated into compound feeds or sold via retailers as a single feed to farmers. A small proportion of the fibrous part of the beet is sold as the dietary fibre 'Fibrex' for human consumption.

All feed products are produced according to Good Manufacturing Practice applying HACCP principles and beet pulp production is certified according to both ISO 9001:2000 (quality) and ISO 14001:1996 (environment). The feed products are highly appreciated in animal nutrition for their nutritional value, consistency and safety. Beet pulp is an excellent complementary feed to cheap grain, where starch becomes the limiting factor. Beet fibre significantly increases milk yield, while feeding beet pulp makes it possible to optimize the crude protein rate in the feed and thereby minimize nitrogen emissions.

From a feed formulation point of view, the beet pulp could be replaced by approx. 50% cereals and 50% grass. To replace the feed production from one hectare of sugar beet by-products, about 0.2 ha of barley and 0.2 ha of grassland would be needed. The feed production from beet is generated without any extra use of inputs such as nitrogen or crop protection products. The energy consumption rate is also favourable if pressed pulp is used.This has to be considered when energy, pesticide or fertilizer use in sugar beet is compared to that for crops such as cereals.

All harvested crops remove nutrients from the field, including beet. Lime is used in the factory process to remove the nutrients from the sugar juice. These nutrients, together with the lime, are recycled back to farmers to neutralize and condition agricultural soils. The product 'Sockerbrukskalk' is also approved for organic growing.

In conclusion: Beets consist of more than sugar. The whole beet is utilized as food, feed or products recycled back to farmland. One hectare of beet by-products produces feed equivalent to about 0.2 ha of cereals and 0.2 grassland.

4.9 Research and development – grower training

The sugar beet crop has its own independent organisation for research and development, Swedish Beet Research (Sockernäringens BetodlingsUtveckling AB, SBU), which is located in Borgeby outside Malmö.

Sugar beet growers are highly skilled. The sugar company, Danisco Sugar AB, together with the Association of Swedish Beet Growers, Betodlarna, have a long tradition of running a well established extension service for all growers. The service includes free courses, information bulletins and information on www.sockerbetor.nu and www.betodlarna.se, as well as agricultural advisors available for free phone consultations or farm visits. New knowledge is also circulated to all growers 4 times a year through the magazine 'Betodlaren', twice a year through the magazine 'Betmagasinet' and 15 times a year through the information letter 'Agrinytt'. As a part of the environmental management system MBO, each grower takes part in a full-day course dedicated to environmental aspects of beet growing.

4.10 Use of genetically modified material

No GMOs are used in the growing and processing of sugar beet in Sweden. To prevent infestation or contamination via sugar beet seed, all seed lots are tested for the presence of GMOs and these tests are audited.

4.11 Human safety

The cultivation of sugar beet requires approximately the same farm operations as the other crops that could potentially replace sugar beet. Growing sugar beet is neither positive nor negative for human safety.

5 Environmental impacts and natural resource protection

5.1 Overview

The environmental problems linked to sugar beet growing are few and in most cases marginal. Where problems have been identified, the trend is for the magnitude of the problem to diminish over time. The replacement of sugar beet with the most likely alternative crop would in general terms not lead to any environmental improvements.

5.2 Soil

5.2.1 Soil erosion

Soil erosion due to water or wind is a marginal problem in Swedish sugar beet growing. The main reasons for this are:

- Soil is normally frozen during January-February.
- Heavy rain or storms are rare
- Only a small proportion, about 10%, is sandy soil susceptible to wind erosion
- Topographical differences within fields are small

together with the fact that precautions to minimize erosion are taken by sugar beet growers.

The most sensitive period from the soil cover point of view is from drilling to establishment of the crop during April and May. However, the area requiring re-drilling during the past ten years (1993-2003) has never exceeded 1% (K. Elfström, personal communication, 2004).

The beet would be replaced by cereals in the first instance, but the choice of spring barley or winter wheat would depend on the price ratio between malting and feed grain. It is reasonable to expect that fewer erosion prevention measures would be used in cereal crops, so there is probably little difference between the crops.

In conclusion: A change from beet to cereals would have little impact on the current situation as regards erosion (A. Ljungars, personal communication, 2004).

5.2.2 Soil compaction

5.2.2.1 Background

Soil compaction can damage the soil structure and therefore reduce the function of the soil. This can reduce the productivity of the soil, and may also have other negative effects such as the increased soil resistance increasing the draught force requirement, leading to higher energy consumption and more wear and tear on equipment. Furthermore, soil compaction can increase the risk for water erosion and increase the relative importance of macropore flow. The amount of workable days may also be decreased.

Generally, new generations of machinery are larger and heavier than the previous generations. There is therefore a risk that the degradation of the soil structure will accelerate in the future. Whereas damage to the topsoil structure can be regenerated by tillage and weather, the damage to subsoil structure caused by heavy machinery is more difficult to regenerate. This is a problem relating not only to sugar beet growing, but also to all agriculture operations.

5.2.2.2 Soil compaction and field operations

Until now, attention in soil compaction research has been devoted to sugar beet harvesting, since sugar beet harvesters are heavy and often operate during relatively wet conditions. Large ruts are often taken as an indication of a large degree of soil compaction. However, recent research has shown this view to be too simplistic. We need to broaden our perspective and also evaluate field operations that occur during relatively dry conditions. This has not been done until now, because it has been believed that the soil stress propagates deeper when the soil is wet than when the soil is dry (Söhne, 1958). However, a precondition for this theory is that the loaded soil does not yield and crack, since this will completely alter the mechanical properties and therefore the stress transmission into the soil. However, with the load intensities encountered in modern agriculture, most soils will crack in the proximity of the loaded area. Therefore, Söhne's (1958) stress concentration theory has now been questioned for stress levels related to agricultural field traffic (Trautner, 2003). Instead, Trautner (2003) has produced a relatively large amount of field measurements to show that the drier a soil volume or soil layer, the more direct and unattenuated the stress transmitted to the underlying soil. This is in agreement with data published by Danfors (1974) and Kushwaha et al. (2003).

The practical consequence is that field traffic on relatively dry topsoil may propagate deeper into the subsoil than anticipated. It should be clear that all types of field traffic have adverse effects on soil structure and not just those linked to one specific crop.

5.2.2.3 Soil compaction and plant growth

It is often claimed that subsoil compaction can persist for decades, or even be permanent. This is frequently taken as an indication that subsoil compaction poses a serious threat to long-term soil productivity. Field measurements have shown that even relatively small load intensities may displace the subsoil (Trautner, 2003). Even so, it can be argued that field trials have in general failed to show that subsoil compaction decreases yields. For example, Arvidsson (2001) conducted a large field experiment where the soil was compacted by four repeated rut-by-rut traffic applications with a fully loaded sugar beet harvester weighing 34 tonnes on two axles. Even with this high load intensity, no significant decrease in crop yield was found in the following years.

To provide an explanation for this, we must analyse the different functions that the topsoil and the subsoil have on plant growth. It is clear that the upper 20-25 cm of soil is quite sufficient to sustain plant growth, provided that the plant has access to an adequate supply of water, sunlight and nutrients. The topsoil structure is therefore very important for plant growth, and it is well-documented that topsoil compaction has a relatively large, negative effect on crop yields. In addition, if plant roots are restricted from accessing subsoil water when topsoil water is inaccessible, this has a significant effect on plant growth. Consequently, crop yields would therefore be expected to be lower in compacted soil only in years with dry conditions. This is supported by Hansen et al. (2002), who analysed a large number of experiments conducted in Denmark 1981 to 1998.

There are other reasons to question whether the adverse effect of subsoil compaction on crop productivity may be exaggerated. Tracer-experiments have revealed that vertical worm-burrows can function as macropore pathways for rapid water transport deep into the soil (Ritsema and Dekker, 1994; Flury et al., 1994). Their existence is likely to be very important for crop growth, since roots are often found within worm-burrows in the subsoil. Using staining techniques, C. Petersen (personal communication, 2004) found four times as many roots in worm burrows as in the surrounding soil. Roots can penetrate deep into the subsoil via macropore pathways, even if the soil bulk density is very high.

Unfortunately, many methods applied to determine the compactness or the function of the subsoil fail to take into account the soil function as affected by macropore pathways and their spatial distribution, e.g. soil penetrometer or the sampling of 'undisturbed' soil samples. Since such methods do not reflect the actual function of the soil, they may therefore lead to erroneous conclusions regarding the impact of soil compaction on the soil function.

The application of tracers to the soil surface in 1.6 x 1.6 m plots (Gjettermann et al., 1997) is conducted at a scale that is large enough to allow the study of the soil function. Tracer experiments often show a dense plough sole just below the tilled soil layer. Whereas the deeper subsoil is largely compacted by compressive forces that do not necessarily close the vertical macropore pathways, the plough sole is formed by both compressive and shearing forces and is therefore characterised by a discontinuity of the macropores. Therefore, a plough sole may effectively inhibit the roots from penetrating into the subsoil and accessing the subsoil water. Hence, we must also devote some attention to the adverse effects on the soil of conventional ploughing with one set of tyres in the furrow. At 0.5 m depth, Keller et al. (2002) found stresses as high as 130 kPa in the soil during conventional ploughing. The shear stress at the plough base must be expected to be larger during ploughing. Soil shearing has an adverse effect on porecontinuity (Horn, 2001) and therefore on the soil function and ploughing may therefore have a relatively large, negative impact on soil structure.

Therefore, we must look at means to decrease the ground pressure below machines, as well as methods to disperse the plough sole and create a good subsoil structure.

5.2.2.4 Future possibilities of reducing the ground pressure

Traditionally, there has been focus on the axle load, but it is the ground pressure that determines the soil stress. Technically, it is possible to decrease the ground pressure by increasing the contact area. In the beet harvesting operation, recent years have shown more use of wider tyres with low tyre pressure, vehicles with more axles and even the application of tracks. It is obvious that such measures are expensive and they must be proven to be cost effective if they are to be widely adopted.

5.2.3 Soil contamination

5.2.3.1 Nutrient application

Application of fertilizers, organic manure or slurry could be regarded as a soil contamination problem if the amounts of nutrients applied are higher than crop requirements and uptake.

This is not the case in sugar beet growing, since there is a strong negative correlation between nitrogen application rates and sugar content in the beet. Beet with a low sugar content commands a lower price than beet with a high sugar content. Consequently, application of excessive amounts of nitrogen to sugar beet reduces grower income.

Soil analysis of all the main nutrients is a compulsory tool for all sugar beet growers in Sweden. The fertilizer recommendations for sugar beet are based on long-term field experiments, and maximum rates may not be exceeded. The amounts applied are in balance with the uptake and removal from the field by the crop products harvested. This implies that the status of the soil as regards nutrient elements is rather stable and that no contamination takes place. The fertilization system is checked in practical use by a third party audit.

Replacing sugar beet with cereals would most probably not lead to any change in the risk level. If anything, the risk with cereals would be slightly increased due to less stringent control systems.

5.2.3.2 Crop protection products

Pesticides are always unwanted in the environment outside the target field. After application and intended action, the pesticide should mineralize normally within the growing season, in many cases within days or weeks.

Pesticides are used on 99% of the Swedish beet area. Herbicides are normally used during late April to early June as spray applications. Fungicide and insecticide application are to a very large extent used only as seed treatments. In some cases, foliar spray applications against pest and leaf diseases may take place during July and August. In all cases, pesticides are applied in the beginning or middle of the growing period, when effective biological degradation can take place.

5.2.3.2.1 Outside the sugar beet field

Pesticides used in sugar beet, as in any other crop, can end up outside the targeted fields due to:

- Wind drift
- Mistakes or incorrect handling during filling, transport or storage.

Nearly all the insecticides and fungicides are used as seed treatments. This method of application gives a very low risk of products ending up outside the sugar beet field.

Swedish sugar beet contracts stipulate that pesticide regulations must be followed. A compulsory environmental management system with a third party audit was introduced in the year 2000.

5.2.3.2.2 Residues in the soil

With only a few exceptions, the herbicides used on sugar beet, as well as the seed treatment products against pests and diseases, are not used on other crops in the rotation. This, together with the fact that beet is grown in only one year out of 3-6, provides a good base for ensuring that there is no pesticide build-up in the soil.

The degradation of four beet herbicides was investigated in Finland, which has less favourable climatic conditions than in Sweden, during 1999-2001. No residues were found in either the topsoil or the subsoil one year after a triple application programme with standard Finnish rates of metamitron, desmedifam and fenmedifam. Small residues of ethofumesate were found in the tillage layer (0-30 cm), if soil type was very fine sand. The ethofumesate level found in spring samples of light soil was between 4.1 and 6.2% depending on the amount used in the summer before, but it was reduced to 1.7% after ploughing and harrowing of the field (L. Eronen, 2004).

There is no use of nematocides or granular insecticides in Swedish sugar beet growing.

The average application rates of all the herbicides used have decreased significantly over recent decades, as demonstrated in the following table.

Changes in application rates per treatment of main sugar beet herbicides in Sweden (kg/ha)

Active ingredient	Product	1970s	1980s	1990s	2000s
Metamitron, 700 g/l	Goltix	2-5	1.5-2.5	0.75-1.5	0.5-1.25
Fenmedifam, 160 g/l	Betanal	2-5	1.5-3	1-2	0.75-1.5
Ethofumesate, 500 g/l	Tramat	0.8-1.2	0.4-0.8	0.1-0.4	0.05-0.2
Chloridazone, 630 g/l	Pyramin	4-5	1.5-5	1-4	0.3-1.5*

Source: Danisco Sugar AB

Remarks: * About 5% of growers use a higher rate for pre-emergence weed control.

Replacing sugar beet with cereals would lead to increased spraying with insecticides and fungicides and possibly a slightly decreased use of herbicides. Some of the herbicides used in cereals are phytotoxic to sugar beet crops grown in the year after cereals. Such products have to be regarded as fairly long-lasting in the soil.

In conclusion: Using of crop protection products in sugar beets has not led to soil contamination.

The risk level for contamination of the soil with crop protection product residues is the same for growing of sugar beet and cereals. Any difference would be to the advantage of sugar beet growing.

It should be borne in mind that all sugar beet growing is carried out under an environmental management scheme with third party audits focusing on correct pesticide use. This is not the case for most cereal growing.

5.2.3.3 Heavy metals

Application of heavy metals is in principle neither a problem nor a risk in sugar beet growing.

The following should be noted concerning field external cadmium - unwanted from an environmental point of view:

Sugar factory lime is a valuable product for farmers in sugar beet growing areas. It contains a significant proportion of many of the nutrients delivered in the beet to the factory. This is particularly of importance for phosphorus, which is a limited resource in many areas. However sugar factory lime sold as 'Sockerbrukskalk' also contains most of the cadmium taken up from the soil by the delivered beet.

A sugar beet crop on average takes up 1.8 g of cadmium/ha from the soil. The recommended application rate of Sockerbrukskalk, 7 tonnes/ha every 8-10 years, would return about 3.5 g/ha. That is, a 4-5 year rotation would balance inputs and outputs of Cd. The total amount of Cd in the 25 cm upper soil layer is about 600 g/ha.

Provided that the sugar factory lime is returned to the sugar beet grower in the same amounts as those taken away by the beet, application of this lime product would give no increase in the soil content of Cd.

5.2.4 Soil salination

Salination does not occur in Sweden.

5.2.5 Soil organic matter

Changes in soil organic matter occur through a very slow process. Changes in arable use between sugar beet and cereals are not regarded as being of significance.

5.2.6 Soil removal – dirt tare

Soil adheres to sugar beet, as to any root crop, when harvested. However, soil removal compared to the total amount of soil is very limited. The upper 20 cm of the soil layer has a weight of approximately 3 000 tonnes/ha. The removed soil is normally less than 3 tonnes/ha.

Soil removal has decreased significantly during the last 20 years, from 16-17% in 1980-81 to 5-6% in 1999-2001 (see 3.2.5). The 2003 harvest was noted for the lowest dirt tare level ever, only 4%. This gives Swedish beet growing a leading position in Europe in terms of beet production with low dirt tare.

The great achievements in dirt tare reductions during the past two decades (Table 5.2.6.1) are a result of investments in improved harvesters and cleaner loader machinery, better storage sites and plant breeding towards a rounder and smoother beet, together with systems of economic incentives encouraging clean beet production. The development of a clean beet is now well under way but further progress is expected (Sperlingsson, 2004; www.daniscoseed.com)

5.2.6.1 Dirt tare (kg) per white sugar (kg) produced (w/w)

1975	1980	1985	1990	1995	2000	2003
1.22	1.93	1.25	0.96	1.02	0.60	0.52

Source: Danisco Sugar

5.2.7 Soil fertility and productivity

Because of the fertilization system described in 5.2.3.1, there has been no decrease in soil fertility through sugar beet growing. In fact, sugar beet growing is contributing to improved soil productivity. Beet is often grown in cereal-dominated crop rotations. Alternative crops – like sugar beet – improve soil productivity as discussed in 4.1. This is indirectly confirmed by the trend for yield increases in cereals in the main beet growing area of Sweden.

5.2.7.1 Average yield level (5-year average, kg/ha) of the most frequent cereal crops in the main Swedish sugar beet growing area (Scania), 1968-2002

	1968-72	1978-82	1988-92	1998-02
Winter wheat	4 750	5 260	6 630	7 700
Spring barley	3 770	4 120	4 360	5 460

Source: SCB statistics www.scb.se

5.3 Water

5.3.1 Water use

Water availability in the sugar beet growing area of Sweden is good and normally not a limiting factor for growth. Sugar beet growing in Sweden is generally possible without irrigation. If the crop is irrigated, a sprinkler irrigation system is used to apply surface water or groundwater. Up to 20% of the growing area can be irrigated, but only 10% of the area is irrigated during a normal year, with 30-100 mm of water/year (K. Elfström, personal communication, 2004). In years with a shortage of rainfall, other crops such as potatoes and vegetables are irrigated first and sugar beet seldom has the highest priority.

5.3.2 Water contamination

5.3.2.1 Fertilizers

Several studies have shown that sugar beet residues contribute to a very small extent to N leaching, although some of the N in the residues might be mineralized during late winter and spring. A more complete review of the scientific literature is given in Appendix 3.

Phosphorus can reach waterways primarily through surface run-off. Application of phosphorus to sugar beet poses no special threat to water contamination. As for other nutrients, phosphorus application is situation-guided (soil sampling) and special precautions for avoiding spread outside the field are compulsory.

5.3.2.2 Crop protection products

The environmental management system MBO stipulates a number of precautions to be taken in order to prevent contamination of water with, for example, crop protection products used in sugar beet. For detailed information, see Appendix 1.

Residues from the main sugar beet crop protection products are not found in groundwater (Kreuger 2002, Törnquist et al. 2002; Kreuger et al. 2003).

In surface water, residues of sugar beet herbicides above the detection limit have occasionally been found. For detailed information, see Appendix 2.

5.4 Air

Contamination by crop protection products or greenhouse gases.

5.4.1 Air contamination

5.4.1.1 Nitrous oxide (N_2O)

Nitrous oxide (N_2O) is produced from mineral N in soil during nitrification and denitrification. Climate and weather conditions seem to be of greater importance than crop choice. For detailed information, see Appendix 3.

5.4.1.2 Plant protection products

Generally speaking, the risk is low due to the low vapour pressure of the active ingredients used. With only a few exceptions, insecticides and fungicides are only applied as seed treatments, giving an extremely low risk for air contamination.

Herbicide use in sugar beet offers a risk equal to that in cereals. The environmental management system MBO guarantees that best practice is used. For detailed information, see Appendix 1.

5.5 Biodiversity

Sugar beet contributes to biodiversity on a landscape level. Fewer sugar beet crops would most likely mean more cereals, which already cover more than 60% of the agricultural area in the sugar beet growing region.

A crop rotation including several different types of crops such as cereals, grassland, root crops or protein crops would also contribute to diversity in field populations of flora and fauna species.

5.6 Energy consumption

The energy consumption per hectare in sugar beet production is on the same level as for cereal production.

6 Conclusions

Today European and most certainly Swedish beet production and sugar processing meet high sustainability standards, but there is still room for further improvement. When the production chain from seed to customer is analysed in the three areas 'people, planet and profit', it is obvious that concerning the area 'people' - in all aspects such as health, social care, ethics etc. - European beet production and sugar processing are far ahead of all alternative producers. Concerning the areas 'planet' and 'profit', there is great potential for yield increases and lower inputs per unit produced, through considerably increased efficiency in the use of natural renewable resources.

Strong plant breeding capacity and R&D will continue to be of vital importance.

Sperlingsson (2004) summarizes the potential for improvement towards long-term sustainable production as follows:

- A competitive price will be of vital importance for a sustainable beet sugar sector
- A continued focus on food safety and high social and environmental standards is important
- In beet growing, considerably increased sugar yield is necessary and possible
- The largest potential for a yield increase in the beet crop is found in improved management of activities in the total crop rotation, to the mutual benefit of the crops involved
- Co-ordination of harvest and efficient beet transport can decrease sugar and quality losses
- The clean beet concept will open up new opportunities
- Reduced energy consumption and the possibility of finding alternative energy production solutions are central questions in sugar processing
- Effective customer-adapted logistic solutions are necessary
- Sugar beet growing and sugar production are important components in the maintenance of sustainable production in European crop rotations that include cereals
- Joint investments in R&D and breeding capacity have to be continued.

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8.3 Personal communications

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Hansson, G. 2004	HIR Malmöhus	gunnel.hansson@hs-m.hush.se
Henriksson, A. 2004	Agellus	annika.henriksson@agellus.se
Jensen, P.E. 2004	Agro	poul-erik.jensen@swipnet.se
Larsson, K. 2004	Länsstyrelsen	kerstin.larsson@m.lst.se
Lindkvist, A. 2004	Betodlarna	anders.lindkvist@betodlarna.se
Ljungars, A. 2004	HS	arne.ljungars@hs-l.hush.se
Petersen, C. 2004.	KVL	carsten.petersen@agsci@kvl.dk
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The Environmental Management System MBO

Signing the contract means agreeing to grow sugar beet in accordance with the specified conditions in the annual growing instruction agreed between the Association of Swedish Beet Growers and Danisco Sugar.

Each grower receives an action list of 30 points from Danisco Sugar in July. This has to be filled in with a YES or a NO for each point by the farmer, signed and returned to Danisco Sugar. This paperwork can also be completed via the internet.

Farmers adhering to the terms of the contract should be able to put a YES for all 30 points. Finally, a third party audit is carried out on a limited number of randomly chosen growers. Serious deviations from the regulations or misleading information on the action list could lead to sanctions for the grower.

The necessary conditions for growing are summarized below. As can be seen, most of the points concern plant protection and plant nutrition.

Compulsory conditions for growing of sugar beet in Sweden following the Inter-professional agreement of 2001

General

- *Checklist for environmental law fulfilment;* fulfilled
- *Crop rotation;* beet grown at maximum every third year
- *Variety use;* only from approved variety list

Plant nutrition

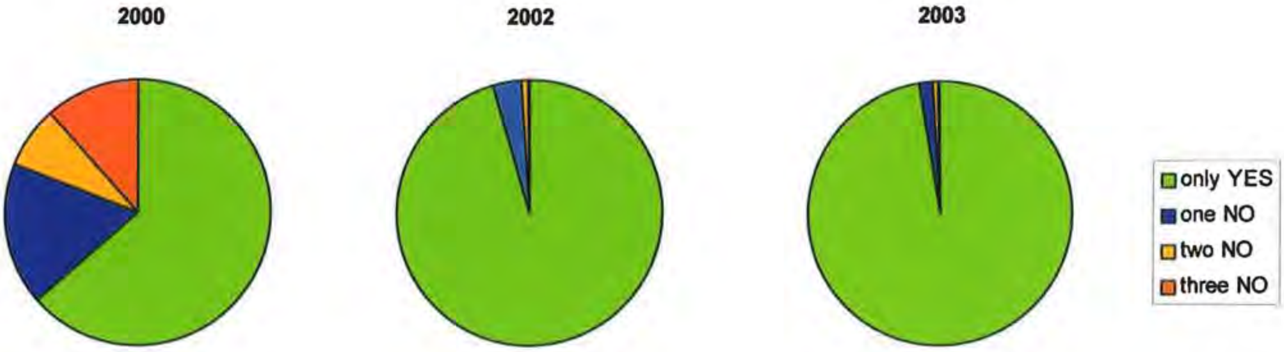
- *Cadmium;* maximum 50 mg Cd/kg P in fertilizer to beet
- *Nitrogen;* limits for amount and application time of nitrogen
- *Fertilizer;* precautions to prevent spreading outside the field
- *Animal slurry analysis;* compulsory
- *Sewage sludge;* not allowed
- *Soil analysis;* compulsory
- *Field-specific application of nutrients;* compulsory
- *Documentation of applied nutrients;* compulsory

Plant protection

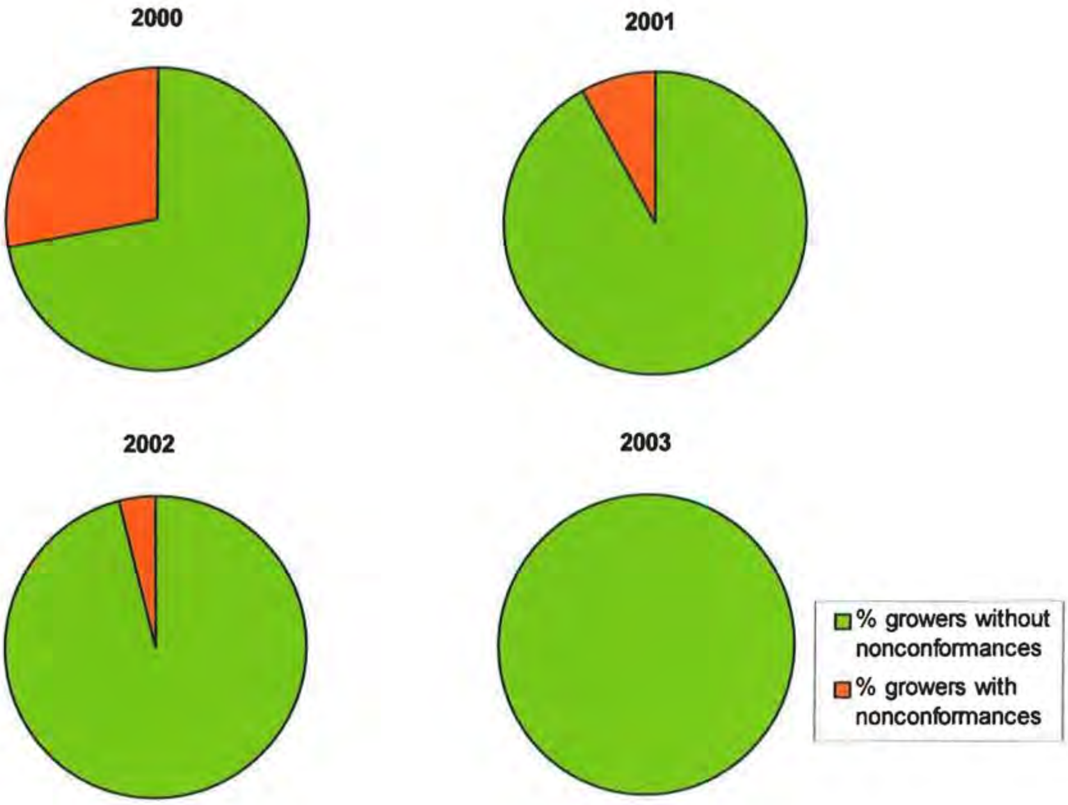
- *Approved training in use of pesticides;* compulsory
- *Pesticide use;* limitations on the use of products, application times and doses
- *Additives;* only vegetable oils as additives to pesticides
- *Storage and destruction of pesticides;* following Swedish recommendations for safe plant protection use
- *Sprayers;* official testing compulsory
- *Filling and cleaning of sprayer;* following Swedish recommendations for safe plant protection use
- *Spray free zones;* 1 m to wells, 6 m to waterways
- *Field-specific application of pesticides;* compulsory
- *Documentation of applied pesticides;* compulsory

The results from returned checklists and from the third party audits effectively demonstrate that this environmental management system is an efficient tool for environmental improvement.

Checklist results 2000–2003



Results from third party audit 2000-2003



Residues of crop protection chemicals found in running surface water in 2001 and 2002 in an agricultural area with sugar beet growing. Results from 26 samples taken May-Nov. 2001 and 29 samples taken May-Dec. 2003. Water samples were analyzed for 81 active ingredients in 2001 and 77 active ingredients in 2002

Active ingredient	**Samples in which residues were found, %**			
	Above detection limit 2001 Above limit of detection 2002		**Above 0.1 microgram/l**	
	2001	**2002**	**2001**	**2002**
alpha-cypermetrin (I)	0	-	0	-
atrazine (H)	77	31	0	0
DEA (M)	42	3	0	0
DIPA (M)	4	-	0	-
azoxystrobin (F)	4	0	4	0
BAM (M)	77	34	8	3
bentazon (H)	100	66	4	3
bitertanol	-	17	-	7
cyanazine (H)	12	0	4	0
2,4-D (H)	-	0	-	0
cypermetrin (I)	0	-	0	-
diflufenican (H)	15	21	0	0
dicamba (H)	-	0	-	0
dichlorprop (H)	50	10	0	3
diuron (H)	-	0	-	0
esfenvalerate (I)	0	-	0	-
ethofumesate (H)	15	10	4	0
fenmedifam (H)	0	0	0	0
fenoxaprop (H)	4	-	0	-
fenpropimorf (F)	27	0	4	0
fluoroxipyr (H)	73	28	15	0
glyphosate (H)	100	72	58	62
AMPA (M)	46	28	42	28
hexazinone	-	0	-	0
iprodion (F)	0	-	0	-
isoproturon (H)	88	69	35	45
chlorpyralid (H)	62	31	19	7
chloridazon (H)	-	0	-	0
Lindan	-	3	-	0
MCPA (H)	85	45	23	17
mecoprop (H)	96	41	0	7
metamitron (H)	4	14	4	14
metazachlor (H)	54	7	19	0
pirimicarb (I)	4	3	0	0
propiconazole (F)	15	0	12	0
terbuthylazine (H)	96	31	12	0
DETA (M)	-	34	-	0
trifensulfuronmethyl (H)	0	-	0	-
tribenuronmethyl (H)	7	3	0	0
trifluosulfuronmethyl (H)	0	-	0	-

Source: (Kreuger 2002; Kreuger et al. 2003)

Low N use – high N output in sugar beet

Literature review by:
Agr Anette Bramstorp
Agricultural Society,
HIR Malmöhus
Borgeby, Sweden

Sugar beet is in many ways an important part of a sound crop rotation in southern Sweden. As stated before in this paper, there are well-known advantages concerning weed management and pest management associated with the use of sugar beet as a break crop in a crop rotation that would otherwise be dominated by cereals. There are also advantages concerning N use efficiency.

- Swensson (2002), Sweden: Studying nitrogen balances, using the farm gate method, for 283 conventional dairy farms situated in southern Sweden, it was found that N use efficiency was significantly higher on farms where sugar beet was included in the crop rotation. The more varied production on the dairy farms growing sugar beet was reflected in the higher output of N in their crops. One important conclusion was that mixed farming is one way of improving the N use efficiency at farm level.

Low N losses

Long growing period – reduces N leaching

Due to its long growing period, sugar beet efficiently utilizes the soil mineral nitrogen during autumn. Soil mineral N at harvest is in general determined by fertilizer residues not taken up, mineralization of N from soil organic matter and from crop residues. Cultivation of sugar beet is of great advantage in mixed farming. The long growing period of sugar beet not only enables the crop to utilize large amounts of soil mineral N but also large amounts of N originating from manure.

Several investigations in Sweden as well as in other European countries have concluded that small amounts of nitrogen are found in the soil profile at harvest of sugar beet, especially at late harvest. N losses through leaching have been proven to be small. Compared to winter wheat, the N leaching from sugar beet is normally of the same magnitude or less.

- In Sweden the soil profile normally contains very small amounts of mineral N at harvest of sugar beet, 10-20 kg (0-90 cm). Due to this the Swedish Board of Agriculture considers sugar beet to be a green autumn cover crop. Growing sugar beet is one important measure in minimizing N leaching from the crop rotation.[1]

[1] Swedish Board of Agriculture, 2000. *Sektorsmål och åtgärdsprogram för reduktion av växtnäringsförluster från jordbruket.* In Swedish.

- Aronsson & Torstensson (2003), Sweden[2]: In a long-term field experiment in southern Sweden, studying N dynamics and N leaching, sugar beet was investigated in two crop rotations during 1993-2003. At harvest of sugar beet in September/October, the soil (0-60 cm) contained approximately 15 kg N ha^{-1}. This was lower than after cereals and at the same level as after cereals undersown with a catch crop. N leaching from sugar beet was on average 20 kg N ha^{-1} and at the same level as from cereals.

- Thomsen et al. (1993), Denmark [3]: The leaching losses of nitrate from a sandy loam receiving inorganic N according to recommended rates were lower from the sugar beet crop compared to continuous cereals but higher compared to cereals undersown with grass. When crops received recommended fertilizer rates partly as animal slurry or inorganic fertilizer at 50% above recommended rates, the cumulative nitrate losses from the four-year crop rotation with cereals grown continuously exceeded those from crops in rotation with sugar beet.

Crop residues rich in N – yet small impact on N leaching

Aerial crop residues of agricultural crops may typically contain 20-120 kg N ha^{-1}. Normally in Sweden sugar beet tops contain 80-100 kg N ha^{-1} at harvest. Once mineralized from the residues, the N can contribute to the fertilizer requirements of subsequent crops or become a pollutant. This includes nitrate leaching to water sources and gaseous losses to the atmosphere. Part of the crop residue may contribute to the soil organic matter pool.

Several studies have shown that sugar beet residues contribute to a very small extent to N leaching, although some of the N in the residues might be mineralized during late winter and spring.

- Aronsson & Torstensson (2003), Sweden[4]: Incorporating the sugar beet tops resulted in 5 kg N ha^{-1} higher leaching losses compared to removing the sugar beet tops from the field. The sugar beet tops contained approximately 80 kg N ha^{-1} and the C/N-ratio was approximately 17.

- Olsson & Bramstorp (1994), Sweden[5]: The soil content of mineral N after sugar beet harvest was measured during winter and spring. Observing the changes in the soil layers 0-30 cm, 30-60 cm and 60-90 cm, an approximate balance sheet of top-N could be created. It was suggested that from the time of harvest until the end of April, the soil mineral N content increased by 15-25 kg N ha^{-1} when the sugar beet crop was harvested in September and the tops incorporated in November. Immediate incorporation resulted in an increase of 30-50 kg N ha^{-1} and 50-80 kg N ha^{-1} in the case of harvest in September and November respectively. The losses as leaching and/or denitrification seemed to be small. The nitrogen balance sheet showed that early harvest followed by late incorporation resulted in a loss of 10-15 kg N/ha. In the case of immediate incorporation after an early harvest, losses increased somewhat. The balance suggested 25-30 kg N/ha. Late harvest, although the tops were incorporated immediately, probably had a positive effect on N leaching/denitrification. The losses were 10-20 kg N/ha and the major proportion probably occurred during early spring.

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[2] Aronsson, H. & Torstensson, G., 2003. Höstgrödor-Fånggrödor-Utlakning. Kvävedynamik och kväveutlakning i två växtföljder på moränlättlera i Skåne. Resultat från 1993-2003. *Ekohydrologi* 75. Div. of Water Quality Management, Swedish Univ. Agric. Sciences.
[3] Thomsen et al., 1993. Effects of cropping system and rates of nitrogen in animal slurry and mineral fertilizers on nitrate leaching from a sandy loam. *Soil use and Management*, **Vol 9, No 2**..
[4] Aronsson, H. & Torstensson, G., 2003. Höstgrödor-Fånggrödor-Utlakning. Kvävedynamik och kväveutlakning i två växtföljder på moränlättlera i Skåne. Resultat från 1993-2003. *Ekohydrologi* 75. Div. of Water Quality Management, Swedish Univ. Agric. Sciences.
[5] Olsson, R. & Bramstorp, A., 1994. Fate of nitrogen from sugar beet tops. *Proceedings of the International Institute for Sugar Beet Research, 57th winter congress*, Brussels, 189-212.

- Wilting (1992), the Netherlands[6]: Only a small proportion of the initial 114 kg N per hectare in harvested sugar beet tops was found in the soil profile (0-90 cm) during winter and spring. The amount of soil mineral-N that was thought to originate from sugar beet tops varied among the samples from 9-33%, with an average of 16%. The duration of the period in which the tops were left on the ground between harvest and incorporation into the soil did not affect the results.

Possible N losses through denitrification

Denitrification from a sugar beet field may be high during late autumn and winter due to a slightly compacted soil after the sugar beet harvest in combination with heavy rainfall in autumn, winter and early spring. Emission of gaseous molecular nitrogen and nitrous oxides may be the result. Nitrous oxide (N_2O) is produced from mineral N in soil during nitrification and denitrification and contributes to the greenhouse effect and the destruction of stratospheric ozone.

Few reliable data are available on the amount of N_2O emanating from soils and on the quantitative influence of different parameters and their interaction with the process resulting in N_2O production. This scarcity of data is partly due to methodological problems. The gaseous transport in the soil is rather slow, which gives variable time lags between the cause, the result and the monitoring, and thus the actual values obtained are difficult to interpret. Furthermore, N_2O produced in deeper soil layers might be reduced to N_2 by the time it reaches the soil surface[7].

- Kirschmann (1985), Sweden: In a laboratory experiment, 2-6% of the nitrogen applied as green manure was found to be lost through denitrification.

N losses through ammonia emission before incorporation

N losses as ammonia emission from sugar beet residues may be high if the tops are left on the ground after an early harvest.

As for denitrification, losses through ammonia volatilisation have not been investigated in any depth in either model systems or under field conditions. The rate and amount of ammonia emission depends on moisture, N content, acidity and C/N ratio of the decomposing plant material, on air temperature and on acidity and exchange capacity of the soil.

- Marstorp (1990)[8], Olsson & Bramstorp (1994)[9], Sweden: Field trials, partly with measurements by the chamber technique, and laboratory investigations indicated that losses through ammonia emission might be as high as 20-40% of the top N during a period of 40-60 days lying on the soil surface after harvest. The results showed that there was a delay, an initial phase, before ammonia emission accelerated. Under the prevailing weather conditions, the initial phase was 7-14 days. Measurements in the field trials revealed large differences in

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[6] Wilting, P., 1992. Onderzoek naar het vrijkomen van stikstof, kalium en natrium uit biete-blad gedurende de wintermaanden en het vroege voorjaar. Interne mededeling nr. 134, Instituut voor Rationele Suikerproduktie, The Netherlands. 40 p.

[7] Swets, M. et al., 1992. Continuous monitoring of N2O and N2 productions in soil cores. *Workshop, Nitrogen cycling and leaching in cool and wet regions of Europe*, Belgium 1992, pp. 31-32.

[8] Marstorp, H., 1990. Ammoniakavdunstning från sockerbetsblast. The Department of Soil Sciences, The Swedish University of Agricultural Sciences, Uppsala, Sweden, Paper 5 p. In Swedish.

[9] Olsson, R. & Bramstorp, A., 1994. Fate of nitrogen from sugar beet tops. *Proceedings of the International Institute for Sugar Beet Research, 57th winter congress*, Brussels, 189-212.

ammonia emissions between years. In 1992, the emissions measured 27 kg N ha^{-1} during 50 days but only 5 kg N ha^{-1} during 37 days in 1993. This was mainly due to plant residues being extremely rich in nitrogen in 1992, which was the result of a dry growing period, and later harvest in 1993, meaning lower air temperatures during the first 20 days of decomposition.

- Nielsen (1991, 1993), Denmark [10] [11]: A field trial in Denmark revealed that on average 42% of the sugar beet top N was lost during 39 days on the ground after harvest. The results were calculated by mass balance. Ammonia emission was not measured.

N recovery in the following crop

N recovery in the crop following sugar beet depends on climatic conditions, crop rotation and soil properties. According to various experiments, the N recovery in a spring-sown cereal might typically be 10 kg N ha^{-1} and in an autumn-sown cereal 20 kg N ha^{-1}.

- Koch (1993), Germany[12]: Using information from various sources the author concludes that decomposition and mineralization of sugar beet tops incorporated into the soil enhance the available N and thereby the N uptake of the subsequent autumn-sown crop (in most cases winter wheat). At most, approximately 30% of the total nitrogen from tops can be utilized in the first year.

[10] Nielsen, C.J., 1991. Forsog 900: Roetopnedbrydning-N effekt. *Danmarks resultatredovisning för 1990 års försök*, delrapport, Paper 3 p.
[11] Nielsen, C.J., 1993. Sukkerroetoppens nedbrydning - Aftoppet og spredt på marken. *Dyrker Nyt*, No. 71, 10-13.

[12] Koch, H.J., 1993. The fate of nitrogen from sugar beet tops remaining on the field. Paper 4 p.