ENVIRONMENTAL ASSESSMENT OF SUGAR BEET PRODUCTION

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Abstract

Environmental impact assessments are often used to aid decision-making on complex planning issues and the use of such techniques within agriculture is about to come of age. Sophisticated risk assessment methods are now available for planning pesticide strategies and mathematical models have been developed which simulate the nitrogen dynamics within arable land to generate field specific fertiliser recommendations. In addition, energy budgeting techniques have been published in the scientific press. However, to date few have attempted to draw together these techniques to quantify the environmental impact of a specific crop.

The British Beet Research Organisation has a key research target to improve the environmental impact of the sugar beet crop and the sugar industry. Consequently, they have funded a research project to use state-of-the-art tools to compare the potential environmental impact of a range of conventional beet production systems in the UK and to present the findings alongside an economic assessment. This paper will provide an insight to the techniques being used and will present the interim project findings.

Introduction

Agriculture has a complex relationship with the environment because of its dependence on natural resources and natural processes. Farm practices have an impact on the environment within the farm itself, but these impacts, both positive and negative, can be felt well beyond the farm gate. The potential impacts are very diverse (e.g. pollution and loss of biodiversity) and result from farm inputs (fertilisers and pesticides, non-renewable resources such as fossil fuels) and land management practices which result in the loss of wildlife habitats.

Sugar beet is an important crop within many arable rotations and is commonly grown in conjunction with wheat, barley or potatoes. It is a valuable break crop, preventing the build up of disease and reducing the need for pesticides in the following crops. This is a fundamental strategy of Integrated Crop Management. However, the general public seem to believe that sugar beet production is environmentally damaging. Without a detailed study designed to identify and quantify environmental impacts, farmers and the beet sugar industry have no ammunition to dispel such claims.

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The British Beet Research Organisation has a key research target to improve the environmental impact of the sugar beet crop and the sugar industry. Consequently, they have funded a research project to use state-of-the-art tools to compare the potential environmental impact of a range of conventional beet production systems in the UK and to present the findings alongside an economic assessment. This paper will provide an insight to the techniques being used and will present the interim project findings.

Methods

Twelve scenarios featuring different soil types, fertiliser, crop protection regimes and geographical locations were evaluated for their potential efficiency for production of sugar beet and likely environmental impacts. The twelve scenarios are as follows:

I SAND + 30 t Farmyard Manure + 80 kg Ammonium nitrate + irrigation
II SAND + Min. fertiliser (120 kg Ammonium nitrate) + irrigation
III SAND + Min. fertiliser (120 kg Ammonium nitrate) + cover crop + irrigation
IV SAND + 10 t broiler manure + 40 kg Ammonium nitrate + irrigation
V SAND + Min. fertiliser (120 kg Ammonium nitrate)
VI SAND + Min. fertiliser (120 kg Ammonium nitrate) + minimum tillage
VII SANDY LOAM + 30 t Farmyard Manure + 80 kg Ammonium nitrate
VIII SANDY LOAM + Min. fertiliser
IX CLAY LOAM + Min. fertiliser (120 kg Ammonium nitrate)
X SILT + Min. fertiliser (120 kg Ammonium nitrate)
XI PEAT + Min. fertiliser (120 kg Ammonium nitrate) + cover crop
XII PEAT + Min. fertiliser (120 kg Ammonium nitrate)

Assessment of pesticide strategies

(I) The Technique
A new risk assessment system for pesticides, known as p-EMA (Lewis et al., 2002) has been designed and developed for use at farm-level by agronomists, farm advisers and farmers themselves. The approach adopted is consistent with methods used currently for regulatory assessment of pesticides in the UK, however, adjustments are made to reflect the local site conditions and the environmental costs and benefits of varying management practices.

Simple models of the dispersion pathways of the pesticide in the local environment (field soil, margin soil, surface water via drift and drainage, and groundwater) are used to estimate the predicted environmental concentrations (PECs) to which various organisms will be exposed. A full description of the methodologies applied has been given in Brown et al. (2002).

Environmental risk is then assessed by comparing the predicted environmental concentrations with the toxicity of the pesticide to the different organisms that might be exposed. A full description of the risk methodology is given in Hart et al. (2002). Basic risk indices are determined (Toxicity : Exposure ratios, (TERs)) using the same methods utilised during initial UK regulatory assessments. Modifications are then made to allow consideration of specific site features and particular farming practices. Taxa considered for exposure risk include mammals, birds, earthworms, honeybees and various aquatic organisms (fish, algae, daphnia and lemna). As data from regulatory studies on arthropods do not generally show dose-response relationships, risk assessment using TERs is not feasible. Consequently, a different approach applying a scoring system based on pesticide type (e.g. insecticidal action, selectivity) and habitat (e.g. flowering weeds, unsprayed margins etc.) has been developed as a surrogate risk index.

To aid interpretation data is summarised to convey the key information. However, the underlying more detailed information is available if required. This summary provides an average field risk value as a measure of performance. This value is derived from the mean risk value across all active substances in each product applied to the field. This field average may, however, 'smooth' the data and hide potential high-risk applications and so an 'icon alert' system is used to highlight any risk 'hot spots'.

The theoretical range of TER indices is 0 to infinity, which could mean that interpretation by inexperienced users becomes difficult. This is overcome by converting the TERs into eco-scores that lie on a defined scale (Lewis et al., 2002). The scale has been set at 0 to -100 in order to allow easy visualisation and understanding of the eco-scores and benchmarks.

This scale has been used to harmonise the p-EMA system with a related software package used by the UK agricultural Industry, EMA (Environmental Management for Agriculture) as described by Lewis and Bardon (1998). EMA is a whole-farm environmental auditing system within which a positive eco-score is used to show environmental benefits whilst negative eco-scores convey potential damage and the zero point indicates a relatively benign activity. For some activities the full positive-negative scale may not be utilised e.g with pesticides. This is because the activity may have no real environmental benefit but be necessary to protect financial investments. It may be argued that, in some circumstances, pesticides do have an environmentally beneficial role to play such as eliminating non-native, proliferous species that may be suffocating more desirable native species. However, applications of pesticides on field crops are generally made to protect yields and quality. While this may be essential to ensure the short-term business viability, the longer-term sustainability issues also need to be seriously considered. Consequently, in both EMA and p-EMA eco-scores span the negative portion of the scale and best practice would lead to eco-scores close to zero. The scale and benchmark classifications used in EMA and p-EMA are given in Figure 1.

The 0 to -100 scale is then sub-divided further into three bench-mark categories; eco-scores between 0 and -40 are considered to be 'good average practice', eco-scores between -40 and -70 are considered to warrant 'orange risk alerts' with the bench-mark category of 'review recommended'. Eco-scores less than -70 warrant 'red risk alerts' and have the benchmark 'poor'.

The p-EMA risk assessment system has been piloted and evaluated (Lewis et al., 2002) successfully to date but work continues. A number of different mechanisms have helped achieve this including release as a beta-version of the software to several hundred potential users via the EMA-2001 CD ROM, comparative exercises with other European pesticide risk systems (Reus et al., 1999) and a number of individual case-studies. The research described here is one such case-study. The final version of the package will be released with EMA-2002.

(II) Methods

(III) Results

Assessment of nitrogen strategies

(I) The Technique

The evaluation of nitrogen use and fate forms one component of an overall project to produce energy and environmental impact assessments (EIA's) as well as economic appraisals for sugar beet production systems in the UK. A range of real and potential systems are considered so that ultimately the best options can be targeted for future development and promotion. Leaching of nitrates from agricultural land is well documented to cause environmental problems by polluting ground water. The following project uses SimUlation of Nitrogen Dynamics In Arable Land (SUNDIAL), developed at IACR-Rothamsted, to evaluate different soil management regimes for sugar beet and the risk they may pose to contamination of ground water. SUNDIAL is a computer model of nitrogen turnover in the crop and soil system and uses data collected from field and laboratory studies on the individual processes of nitrogen turnover to simulate nitrogen movement within the soil eco-system. To date SUNDIAL has been widely used to interpret the results of field experiments, in particular the effects of crop management, soil type and different weather patterns on nitrate leaching. SUNDIAL also contains a 'Fertiliser Recommendation System' that provides further information on the optimisation of timing and amount of nitrogen fertiliser application.

(II) Methods

Each simulation used three crops: a winter cereal followed by sugar beet then finally a spring cereal. The first crops was Winter wheat drilled on 1/10/98 and harvested 15/9/99 with ammonium nitrate applied at 80 kg/ha on 15/3/99 and 50 kg/ha on 9/4/99.

The second crop was sugar beet grown under one of the twelve scenarios previously described.

The third crop i.e. that following sugar beet was spring barley drilled on 1/3/01 & harvested 1/9/01 with ammonium nitrate applied at 45 kg/ha 1/4/01 & 45 kg/ha 30/4/01. A second simulation using winter barley drilled on 15/9/01 & harvested 1/8/02 with ammonium nitrate applied at 45 kg/ha on 15/3/02 & 45 kg/ha on 9/4/01 instead of spring barley was also run.

Cultivations: sub-soil (40cm moderate mix), plough & press (20 cm moderate mix), tine cultivate (10 cm moderate mix), seedbed cultivation (10 cm moderate mix).

Weather: Suffolk inland (587mm), Nottingham (650mm), West Midlands (670mm).

(III) Results

Nitrogen inputs and outputs during the sugar beet crop and the following crop of spring barley are summarised in figures 1 and 2 respectively. Changes in nitrate content of the soil during the second and third crop are summarised in Figure 3. Leaching of N during growth of the sugar beet crop appeared dependent on geographical location, with none leached under Suffolk weather conditions but 2 kgN/ha under West Midlands weather conditions in each scenario.

The highest fertiliser N inputs during the growth of sugar beet occurred in those scenarios in which livestock manure was added (I, IV and VII). De-nitrification was also significantly greater in these three scenarios compared to the others.

I 15/3-15/12 55t SAND + 30 t Farmyard Manure + 80 kgN/ha ammonium nitrate + irrigation. Nitrogen uptake by the sugar beet crop was 151 kgN/ha. Most nitrogen was lost through de-nitrification (31 kgN/ha). SUNDIAL recommended an additional 40 kgN/ha on 16/3 which increased N uptake by the crop from 151 to 153 kgN/ha [estimated 180 kgN/ha present in 30 t of cattle FYM; only 20% is available to the following crop if it is applied between February and April and not incorporated within 24 hrs ie 180 * 0.2 = 36 kgN/ha available (RB209 7th Edition pp38). If the extra 40 kgN/ha is applied on 16/3 an estimated 11kgN/ha is leached in the following spring barley crop. SUNDIAL made no further recommendation for the same parameters under West Midlands weather conditions, presumably because of the further increase in N leached with the associated increase in rainfall (if an additional 40 kgN/ha is applied on 16/3 an estimated 23kgN/ha is leached in the following spring barley crop). Low quantities of N were lost through de-nitrification in the following spring barley crop. If the following crop is spring barley 80 kgN/ha of inorganic N with 30 t of FYM applied to the sugar beet crop appears to be the maximum if leaching is to be avoided. If an autumn sown crop follows sugar beet, in this example winter barley, leaching of 7 kgN/ha occurs in the following crop under Suffolk weather conditions – not yet simulated West Midlands weather conditions or with the addition of SUNDIAL recommendations.

IV 15/3-15/12 60t SAND + 10t broiler manure + 40 kgN/ha ammonium nitrate + irrigation. Again the greatest loss of N from the sugar beet crop occurred through de-nitrification (71 kgN/ha). Nitrogen uptake by the sugar beet crop appeared to be influenced by geographical location. It was the lowest of all the scenarios when using weather data for Suffolk (125 kgN/ha) but not in the West Midlands when uptake increased to 151 kgN/ha. In suffolk SUNDIAL warns that the sugar beet crop N uptake is only 77% of the total required, that the yield may be lower than expected and recommends an additional 60 kgN/ha to be applied on 22/3. This increases nitrogen uptake by the crop from 125 to 172 kgN/ha [estimated 288 kg N in 10 t broiler manure but 30% available to the following crop if applied between February and April after 24 hrs ie 288 * 0.3 = 86.4 kgN/ha available to sugar beet crop (RB209 7th Edition pp40). In the West Midlands SUNDIAL warns that the sugar beet crop N uptake is only 87% of the total required, that the yield may be lower than expected and recommends an additional 40 kgN/ha on 22/3. This increases nitrogen uptake by the crop from 151 to 172 kgN/ha. Most N lost in following crop was through de-nitrification. If the following crop is spring barley leaching does not occur for this scenario in either Suffolk or West Midlands. Incorporation of the SUNDIAL recommendation of an additional 60 kgN/ha on 22/3 causes no leaching in Suffolk [but 65 kgN/ha (5 kgN/ha leached in following crop); 70 (9); 75 (10); 80 (11)]. In the West Midlands 1 kgN/ha is leached if an additional 40 kgN/ha is applied on 22/3 [if an additional 60 kgN/ha is applied then 19 kgN/ha is leached]. If the following crop is winter barley 9 kgN/ha is leached under Suffolk weather conditions – not yet simulated West Midlands weather conditions or with the addition of SUNDIAL recommendations.

VII 17/3-1/12 55t SANDY LOAM + FYM + 80 kgN/ha ammonium nitrate. Most N lost through de-nitrification (28 kgN/ha). N uptake by sugar beet crop 153 kgN/ha, SUNDIAL made no further recommendations. Low amounts of N lost through de-nitrification in the crop following sugar beet. No N is leached in the following spring barley crop.

The fertiliser N inputs for sugar beet in scenarios II, V, VIII, IX and X consisted of 120 kgN/ha in a 40 : 80 split (minimum fertiliser).

II 15/3-15/12 55t SAND + Minimum fertiliser + irrigation. Nitrogen uptake by the sugar beet crop was 147 kgN/ha. SUNDIAL made no further recommendations under 'Amount of fertiliser only' but recommended 20 kgN/ha to be applied on 22/3/00 under 'Complete fertiliser recommendation'. If the latter recommendation is incorporated the amount of N taken up by the sugar beet crop increases from 147 kgN/ha to 153 kgN/ha. No N is leached in the following spring barley crop.

V 15/3-15/12 55t SAND + Minimum fertiliser. N uptake by sugar beet crop was lower than scenario II at 135 kgN/ha. SUNDIAL made no further recommendations. No N is leached in the following spring barley crop.

VIII 17/3-15/12 55t SANDY LOAM + Minimum fertiliser. N uptake by the sugar beet crop was 153 kgN/ha. SUNDIAL made no further recommendations. No N is leached in the following spring barley crop.

IX 2/4-15/10 55t CLAY LOAM + Minimum fertiliser. Nitrogen uptake by the sugar beet crop was 152 kgN/ha. SUNDIAL made no further recommendations under 'Amount of fertiliser only' but recommended 20 kgN/ha to be applied on 5/4/00 under 'Complete fertiliser recommendation'. If the latter recommendation is incorporated the amount of N taken up by the sugar beet crop increases from 151 kgN/ha to 153 kgN/ha. No N is leached in the following spring barley crop.

X 2/4-15/10 65t SILT + Minimum fertiliser. Nitrogen uptake by the sugar beet crop was 143 kgN/ha. SUNDIAL warns that the sugar beet crop N uptake is only 79% of the total required and that the yield may be lower than expected. SUNDIAL made no further recommendations under 'Amount of fertiliser only' but recommended 60 kgN/ha to be applied on 5/4/00 under 'Complete fertiliser recommendation'. If the latter recommendation is incorporated the amount of N taken up by the sugar beet crop increases from 147 to 192 kgN/ha. No N is leached in the following spring barley crop.

Assuming the straw is removed scenario VI had the lowest N input (36 kgN/ha was lost with the straw).

VI 15/3-15/12 50t SAND + Minimum tillage. The N uptake by the sugar beet crop was 135 kgN/ha. This was the only scenario in which the nitrate content of soil increased during the growth of the sugar beet crop and as a result 11 kgN/ha was leached from the following spring barley crop. The most likely explanation is that the straw incorporated in the other scenarios immobilises some N preventing an increase in soil nitrate content.

Assessment of energy requirements

Conclusions

Summary of nitrogen issues:

- Most nitrogen lost through de-nitrification during growth of the sugar beet crop, greatest amounts in those having received livestock manure, particularly broiler manure.
- No leaching in any scenario during growth of the sugar beet crop under Suffolk weather conditions, 2 kgN/ha for each scenario under West Midlands weather conditions. No leaching if the following crop is spring barley in any scenario except 11 kgN/ha in the minimum tilled scenario when straw from the first crop was removed; if the following crop is winter barley then leaching of 7 and 9 kgN/ha occurs if farmyard manure or broiler manure is applied respectively.
- N uptake by the sugar beet crop lowest in scenarios on sandy soil with no irrigation or with poultry manure.

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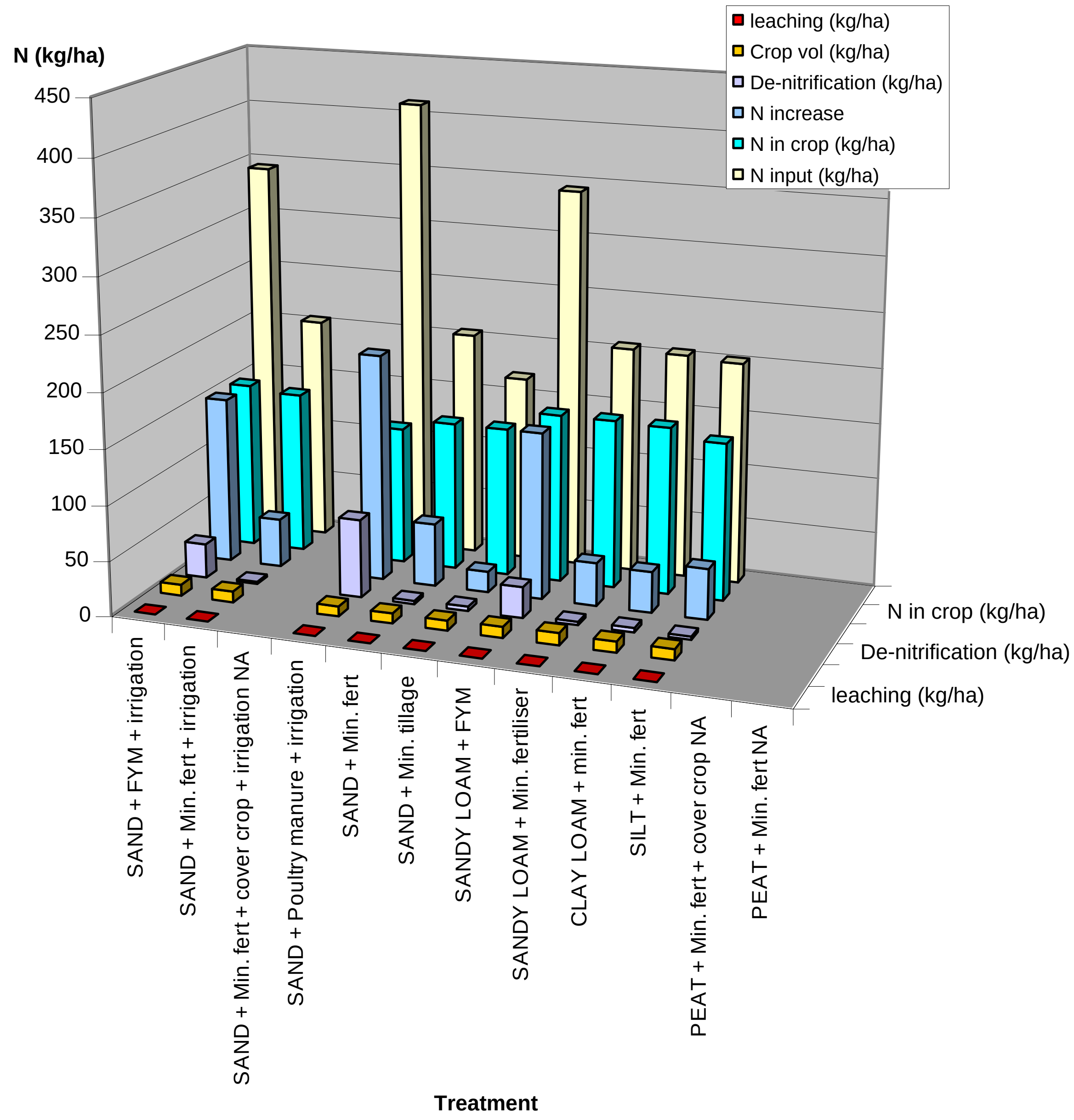
References



SBEP - summary
N inputs and outputs from harvest of winter wheat to harvest of sugar beet
(Suffolk)

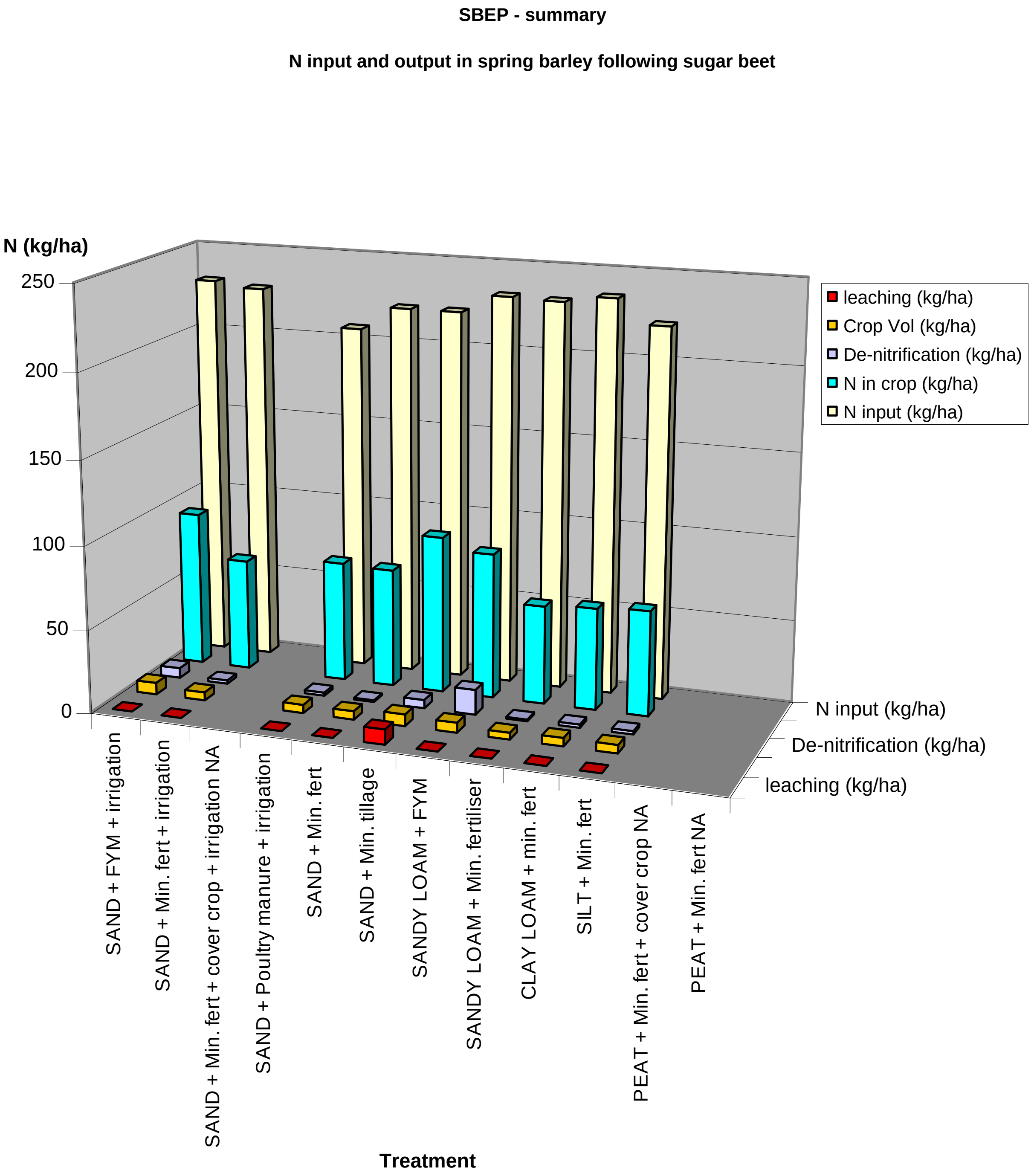

SBEP - summary
N input and output in spring barley following sugar beet
N (kg/ha)
250
200
150
100
50
0
leaching (kg/ha)
Crop Vol (kg/ha)
De-nitrification (kg/ha)
N in crop (kg/ha)
N input (kg/ha)
N input (kg/ha)
De-nitrification (kg/ha)
leaching (kg/ha)
SAND + FYM + irrigation
SAND + Min. fert + irrigation
SAND + Min. fert + cover crop + irrigation NA
SAND + Poultry manure + irrigation
SAND + Min. fert
SAND + Min. tillage
SANDY LOAM + FYM
SANDY LOAM + Min. fertiliser
CLAY LOAM + min. fert
SILT + Min. fert
PEAT + Min. fert + cover crop NA
PEAT + Min. fert NA
Treatment

Figure 2

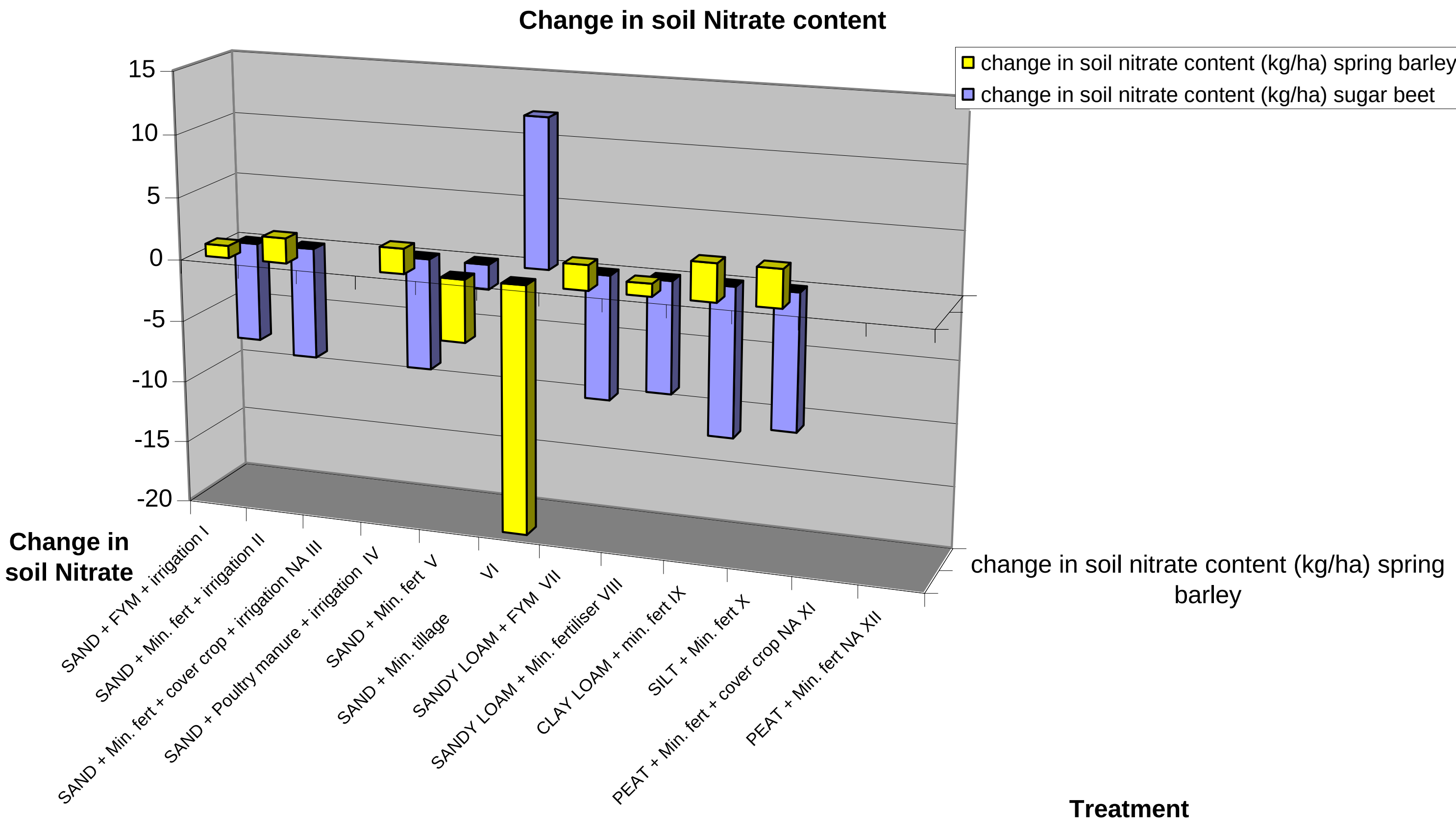

Change in soil Nitrate content
🟨 change in soil nitrate content (kg/ha) spring barley
🟦 change in soil nitrate content (kg/ha) sugar beet
15
10
5
0
-5
-10
-15
-20
Change in soil Nitrate
SAND + FYM + irrigation I
SAND + Min. fert + irrigation II
SAND + Min. fert + cover crop + irrigation NA III
SAND + Poultry manure + irrigation IV
SAND + Min. fert V
SAND + Min. tillage VI
SANDY LOAM + FYM VII
SANDY LOAM + Min. fertiliser VIII
CLAY LOAM + min. fert IX
SILT + Min. fert X
PEAT + Min. fert + cover crop NA XI
PEAT + Min. fert NA XII
change in soil nitrate content (kg/ha) spring barley
Treatment

Figure 3