771-2015

Final Report

The use of farm data in advisory work and research

Case study and development of concept 2011-2015

The project was funded by Stiftelsen Lantbruksforskning – The Swedish Farmers' Foundation for Agricultural Research under the title: **Grower-generated information knowledge systems – a way to identify and reach potential yield, project no. 1044083.**

Otto Nielsen (on@nordicbeetresearch.nu)
Robert Olsson (ro@nordicbeetresearch.nu)

Magnus Ljung
Christina Lundström
Swedish University of Agriculture, Skara

www.nordicbeetresearc.nu

The use of farm data in advisory work and research

Case study and development of concept 2011-2015

Otto Nielsen[1], Robert Olsson[1], Magnus Ljung[2], Christina Lundström[2]

[1]Nordic Beet Research; [2]Swedish University of Agriculture, Skara

Table of contents

1. Introduction

A. The aim

In the original description of the project, the following aims were specified:

- To improve the basis and the motivation of farmers to achieve the highest possible yields
- To develop efficient data sampling techniques
- To collect and organise field data (database)
- To develop knowledge exchanges between farmers, agricultural advisors and researchers

B. The concept

The basic concept was that farmers would be able to improve their yields through:

- Awareness of the situation in the field (based on photos and plant growth data on the internet)
- An end of season follow-up (field report including benchmarking)
- Overview of common and new cultivation practices (based on physical and internet-based contact with other farmers)
- Supplying agricultural advisors with data, results and conclusions.

A further aim was to supplement conventional research through statistical analyses. An example would be to study the effect of crop rotation by combining data from a large number of farms.

C. Project activities (summary)

Data collection

Twelve sugar beet growers (from three separate regions) in Sweden participated in the project in 2011 and 2012. Due to technical problems in relation to canopy reflection measurements (see below) and an ambition to improve weather data collection, no farm-specific data were collected in 2013. In 2014, a new NBR project (5T; projekt5T.nu) was started. That project involved ten growers in 2014 and the data collected from those farms supplemented the data collected in the present project.

Plant growth

A rather laborious part of the project was quantifying plant growth during the growing season. Quantification of plant growth was expected to make an important contribution to understanding the reasons for growth limitations in the field. Therefore two different methods that could potentially reduce the workload connected to measuring plant growth were applied. In the first method, plants were dug up and tap root and leaves were photographed in order to predict weight based on image analyses. In addition, tap root length and maximum tap root perimeter were measured, as was the weight of the individual tap roots. In the other method, canopy reflection was measured during the growing season. Due to technical problems and a restricted period with appropriate (dry) weather, rather few measurements were made in 2011-2012. Thus, the study period in 2013 was used to find an alternative solution for measuring reflectance and this was the basis for the measurements made on the ten farms in 2014.

Weather data

Weather data were used in the project to calculate potential growth, which was a prerequisite for the part of the work described in Sections 4-6. In 2011, no weather data were available locally. In 2012, temperature and relative humidity were measured by loggers that were placed on the farms. Rain was either measured by the farmer or (at four sites) by rain gauges connected to a logger. The weather data from 2011-2012 were supplemented with data from private and public weather stations located in the region. For the ten farms that participated in 2014, weather data for five of these were collected as in 2012, while weather stations (Adcon) were placed on the other five farms.

Communication and knowledge transfer
In order to provide the farmers with access to data and photos, a project website was created. The website was active in 2011-2012 and made available to farmers organised data (e.g. growth curves) and photos from the field.

Project meetings involving all participants were arranged, at which results were presented and discussed. Physical meetings were arranged in the field during the growing season in 2011-2012 with the four participating farmers within each of the three regions of Sweden. These meetings focused on knowledge transfer between farmers based on the actual situation in the field. Data collected to date were presented to the farmers to get their feedback on how the aims listed above could be fulfilled. This presentation of data was mainly made at meetings at the end of the growing season.

Concept evaluation
At the meetings in 2011-2012, the farmers were asked to validate the different products (photos, growth curves, input-output correlations, field reports) that were outcomes of the project. In May 2013, interviews were held with ten of the twelve participating farmers from 2011-2012 in order to get their personal evaluations of the concept. These evaluative interviews took about one hour and were performed as semi-qualitative field interviews.

D. Acknowledgements

We wish to thank all the participating growers for their willingness and openness to share and discuss data and results.

A special thank you is addressed to AB Sugar for giving us the opportunity to use their i-BeetGro growth model.

This project was funded by Stiftelsen Lantbruksforskning – The Swedish Farmers' Foundation for Agricultural Research under the title: Grower-generated information knowledge systems – a way to identify and reach potential yield, project no. 1044083.

2. Quantification of plant growth

A. Sampling of plants

Data were collected in the period 2010-2014. In 2013 only one site was monitored (Sofiehøj) in order to focus on the use of canopy reflectance to measure plant quality and growth.

In 2011 and 2012, an observation strip of about 50 m wide x field length was chosen for data collection. Within the observation strip, six plots were marked out for hand harvesting after plant emergence. Each plot consisted of two 4-m lengths rows, which were harvested at intervals of around six weeks throughout the growing season (Figure 2.1).

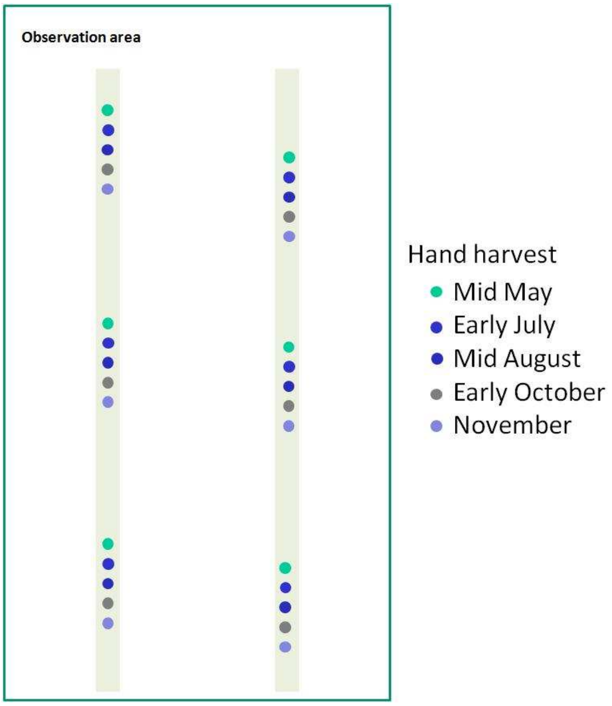

Figure 2.1 Within the observation strip (soil cultivated as reported by the farmer), six plots were marked out. Within each plot, two rows were hand-harvested up to five times during the growing season as shown (see key). Further details are given in Table 2.1.

In 2014, plot length was extended to 6 m and plots were hand-harvested three times in total (mid-June, mid-September and mid-November). The plots were placed in order to represent an adequate and regular plant stand of 8-10 plants/m^2. The changed design in 2014 reflects a different aim of the 5T-project (comparison of “farm” yield (mechanical harvesting) and “achievable” yield (hand harvesting).

Additional observations were available from a survey in 2010 in which five fields were followed in the same manner as in 2011-2014, but plot dimensions were different (4 rows x 2 m long) and in each field two areas were studied.

In general, tap roots were taken to the laboratory and washed before weighing. Leaves were weighed in the field and a sub-sample was taken to the laboratory for dry matter estimation.

A summary of the plant material collected is given in Table 2.1, along with information about additional measurements that are further described below.

B. Analyses of dry matter and sugar

Tap root and leaves were dried at 80-90^{o}C to determine the dry matter content. Larger tap roots and leaves were cut into smaller pieces and a sub-sample was analysed. Sugar content was analysed at the laboratories of Nordic Sugar in Örtofta (Sweden) or Maribo Seed near Holeby (Denmark).

Table 2.1 Summary of field studies performed in the period 2010-2014

	Year				
	2010	**2011**	**2012**	**2013** [1]	**2014** [2]
Sites and plots					
- number of sites	5	12	12	1	10
- plots/site	2 x 4	6	6	6	6
- plot dimensions	4 rows x 2 m	2 rows x 4 m	2 rows x 4 m	2 x 6-9 m^2	2 rows x 6 m
- harvesting times per growing season	4	5	5	6	3
- yield using mechanical harvesting					x
Dry matter and sugar					
- fresh weight of tap root and top	x	x	x	x	x
- dry matter content of tap root and top		x	x	x	x
- sugar content September					x
- sugar content at final harvest	x	x	x	x	x
Additional analyses of 24 beets per site					
- fresh weight of individual tap root		x	x		
- length of individual tap root		x	x		
- perimeter of individual tap root		x	x		
- image analysis of photo of growing plant	x				
- surface of tap root + top			X		
- surface of tap root based on washed beets			X		
Canopy reflectance					
- sensors					
- Skye	x	x	X	x	
- Yara N-sensor		x	X	x	
- GreenSeeker				x	x
- number of measurements per plot/season/sensor	18	5	6	20	13

[1]All activities were based at Sofiehøj Research Centre, Holeby, Denmark (see section 2E)

[2]Similar data sampling is ongoing in 2015 and planned for 2016 at 11 sites

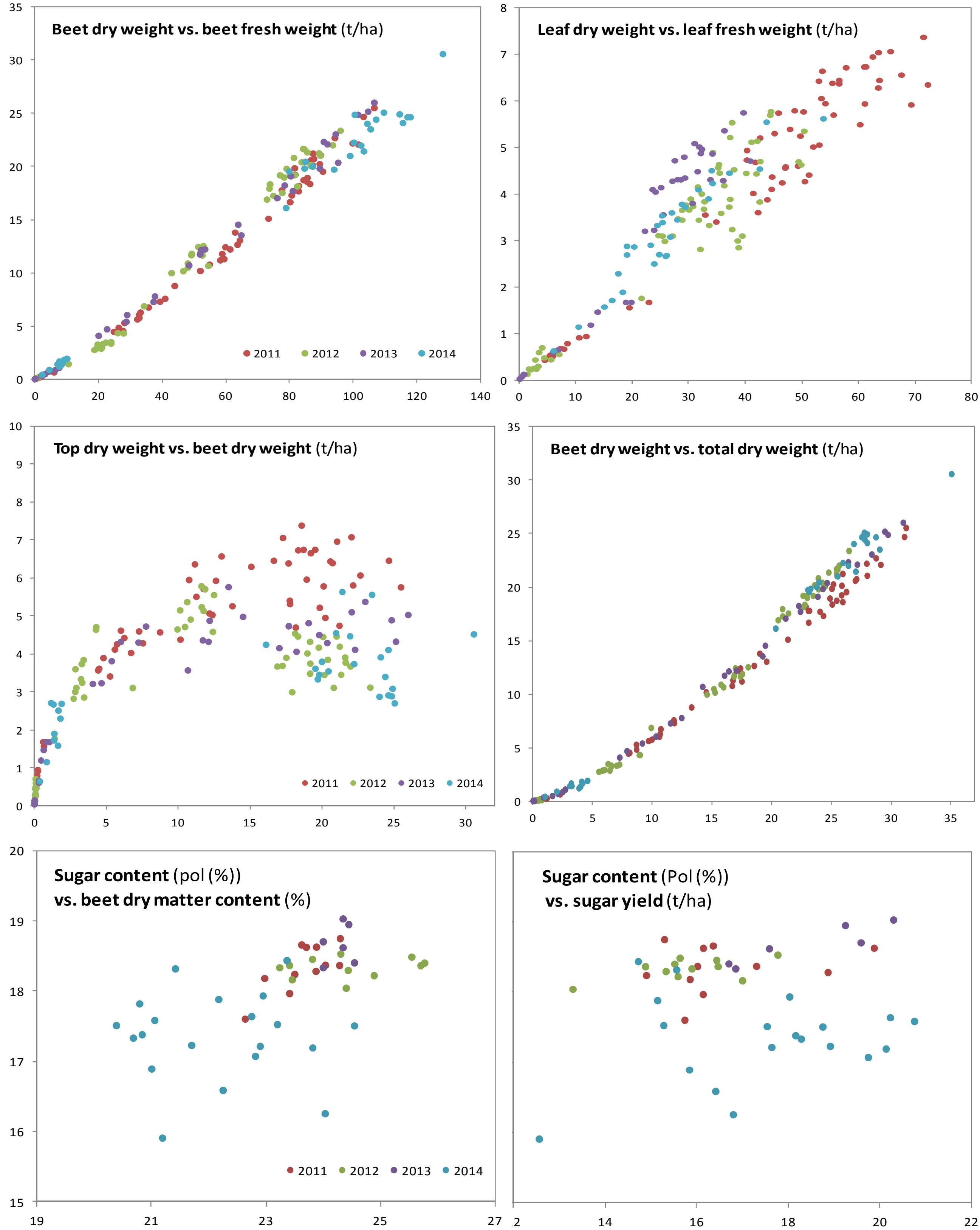

Figure 2.2 Relationships between fresh matter, dry matter and sugar content in different beet plant fractions in the period 2011-2014 (dry matter was not measured in 2010).

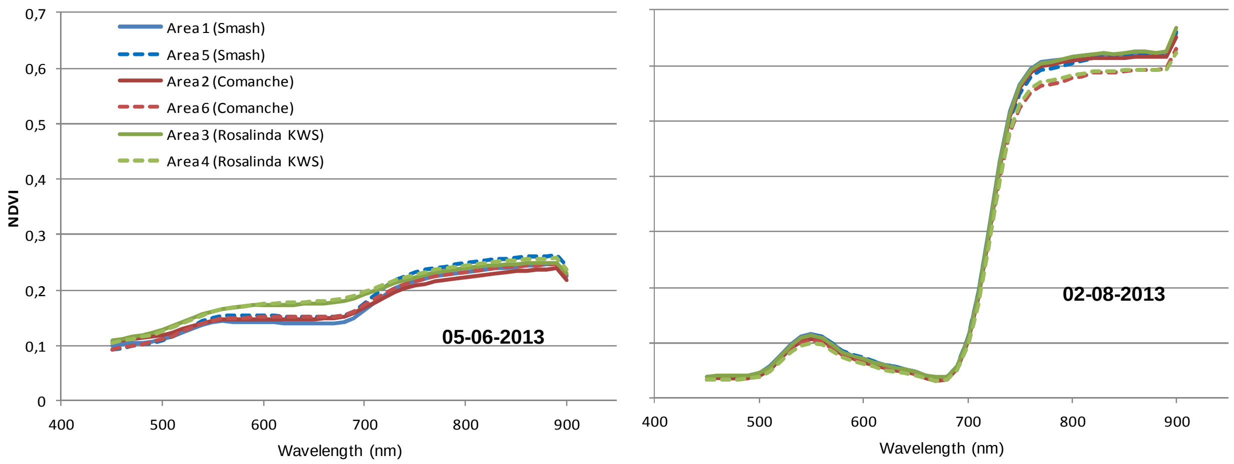

Figure 2.3 Light reflectance in June and August from the sugar beet canopy (beet varieties Smash, Comanche and Rosalinda KWS) in the six areas at Sofiehøj Research Centre. The measurements were made using the Yara N-sensor (Table 2.3).

C. Relationship between fresh and dry weight

The dry matter content of both tap root and leaves differed from year to year. The largest differences and variability were observed for leaves. In 2013, leaves had a markedly higher dry matter content than in other years and the maximum amount of leaves was generally at a lower level (Figure 2.2). Tap root dry matter content was the lowest of all years studied at the end of the growing season in 2014.

Table 2.2 Different types of vegetation index, where R indicates the amount of red light and NIR the amount of near-infrared light. The SAVI index attempts to correct for different amounts of noise from the soil surface by adding the factor L (Modified from Baret *et al*., 1995).

Vegetation index	Formula	Reference
RVI	NIR/R	Pearson & Miller 1972
NDVI	(NIR-R)(NIR+R)	Rouse et al. 1974
SAVI	(NIR-R)(NIR+R+L)*(1+L); L=0.5	Huete 1988

D. Relationship between tap root weight and leaf weight

There were some obvious differences in terms of this parameter. Towards the end of the growing season in 2011, the ratio between leaf weight and tap root weight was the highest of the years studied. In 2014, the ratio was the lowest (Figure 2.2) and 2014 was also the year with the highest sugar yield. Part of the explanation for this could be that at the end of the season, the tap root comprised a relatively high proportion of the total dry matter.

Figure 2.4 In 2011-2013, an ATV equipped with sensors from Skye and Yara was used to measure canopy reflectance.

E. Yield and sugar

The relationship between dry matter content and sugar content differed clearly between years (Figure 2.2). The lowest ratio was observed in 2014.

E. Canopy reflectance and growth

Introduction

Plants reflect sunlight at different wavelengths in the visual and non-visual part of the spectrum (Figure 2.3). This light can be measured with sensors that either operate at a range of wavelengths or at a few plant-specific wavelengths. As long as the crop only covers part of the ground, there is some kind of relationship between magnitude of reflectance and real plant growth. This means that canopy reflection is less than the maximum until row closure in a sugar beet crop. After row closure, reflectance mainly depends on the quality of the leaves and, as such, reflects potential energy assimilation.
The measured data are often converted into different types of vegetation index, of which RVI and NDVI are the most commonly used (Table 2.2). These indices only require reflection to be measured in the red (around 660 nm) and near-infrared range (around 800 nm). In addition to measuring canopy reflection, incoming light must also be measured (by upward-pointing sensors), or alternatively the sensor must emit light in the specific wavelengths measured (“active” sensor).

Table 2.3 Equipment used in the project period for measuring canopy reflectance

Sensor	Application
Yara N-sensor Constructed for mounting on a tractor roof	The equipment consists of a total of five sensors. One sensor on each side that measure ahead and two sensors that measure behind the vehicle. The last sensor points upwards to measure incoming light. The sensors measure at wavelength between 450 and 900 nm (10 nm intervals). The data are logged on a PC together with GPS-coordinates. The Yara N-sensor is used in precision farming. 
GreenSeeker	The hand-held sensor emits light in the red (660 nm) and the infrared region (780 nm) and the reflected light is then measured. The sensor is held 60–120 cm above the crop and scans an area of ¼ - ½ m^2. By constantly activating the sensor, a running mean is calculated until the button is released. In this way, a larger area can be scanned and converted into the desired number of measurements. 
Skye Instruments	Two downwards pointing double-sensors (measuring at 655 nm (red) and 810 nm (infrared)). One measures over the row and the other between the rows. The two sensors together cover an area of around 0.5 m^2 but by moving along the rows a larger area can be measured. In addition, one upward-pointing sensor measures incoming radiation. Data are logged on a pc. 

Equipment

The first measurements were made in 2010 with sensors from Skye (Table 2.3). As a single sensor covers only around 0.3 m^2 (depending on height above the canopy), it was rather time-consuming to get representative measurements from plots distributed across a field (Figure 2.1). Therefore, an ATV was equipped with sensors for the purpose of measuring canopy reflectance while passing over the plots (Figure 2.4). To ensure an even weighting of rows and areas between rows, two sensors were mounted side by side and 25 cm apart (half row spacing). In addition, a Yara N-sensor was mounted on the ATV to compare downward-pointing sensors (Skye) and the more flat measuring angle of the Yara N-sensor. In 2013, a third sensor was included in the study. This was the hand-held GreenSeeker from Trimple. In contrast to the procedure with two other sensors, measurements with the GreenSeeker were made while walking across plant rows, as this ensured a correct weighting of within-/between-row areas. The sensors are further described in Table 2.3.

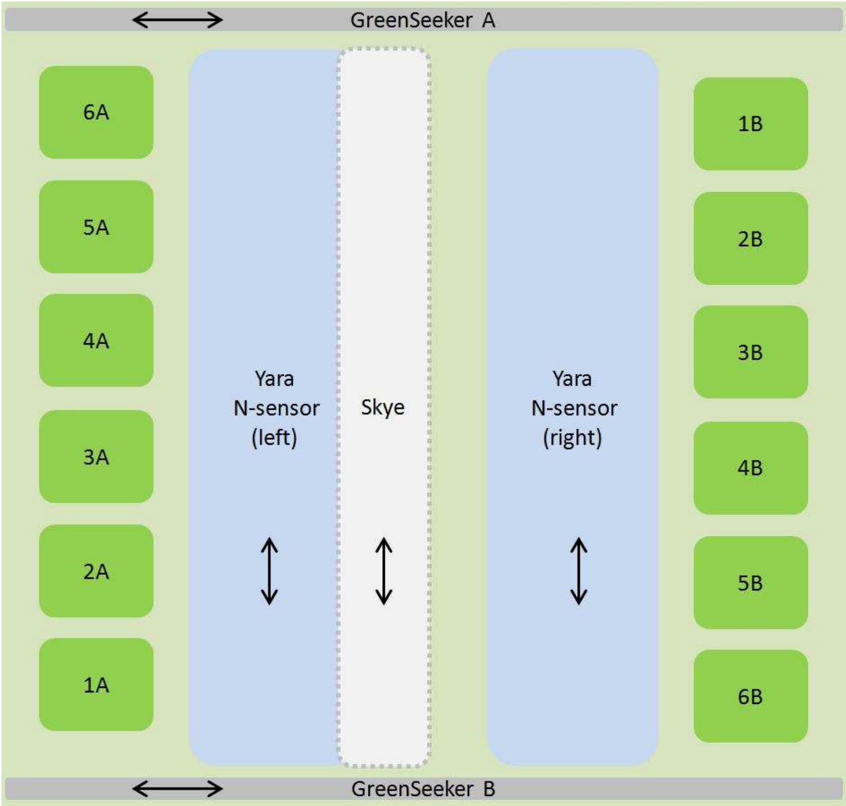

Figure 2.5 Plot design used in 2013 for measuring canopy reflectance with three different sensors (Table 2.3). The dimensions of the whole plot were 24 m x 24 m. The ATV with sensors was driven through the middle of the plot while measuring reflectance with the Skye sensors and the Yara N-sensor, whereas measurements with the GreenSeeker were made while walking perpendicular to the rows, along both ends of the plot. The areas 1A-5B were hand-harvested (12 m^2) or machine-harvested (6A-6B, 18 m^2) during the season to quantify growth. In total, six plots comprising 2 x 3 beet varieties (see Figure 2.6) were monitored from drilling in May to final harvest (6A-6B) in November.

Project activities

The project activities involving canopy reflectance are summarised in Table 2.1. Due to a range of different technical and practical limitations, fewer data than planned were collected in 2011 and 2012 (5-6 measurements/season). In 2010, 18 measurements were made during the season. The results of the 2010 measurements have been reported earlier (2011), but because dry matter was not measured, these

Figure 2.6 Placement of the six plots studied in 2013 at Sofiehøj Research Centre. Measurements included canopy reflectance using three different sensors and hand-harvesting six times during the growing season (Figure 2.9). Variety: Red = Comanche, green = Rosalinda KWS), blue = Smash.

data are not applicable for this study and are not further mentioned. Based on the experiences during 2011 and 2012, it was decided to focus more intensively on reflectance measurements in 2013. The aim was to:

1) Compare sensors of different designs and with differing sampling methodology (Table 2.3)

2) Compare reflectance profiles of different beet varieties (Figure 2.3) and further relate reflectance profiles to real growth.

In 2014, ten sites were monitored with reflectance measurements approximately every two weeks using the hand-held GreenSeeker. The aim was to describe the quality of the canopy and to relate reflectance profiles to real growth.

The methodology for data collection in 2013 is shown in Figures 2.5-2.6. In 2014, canopy reflectance was measured by walking across 40-60 rows in six different positions in the field near the plots used for harvesting during the season (see Figure 2.1).

In 2013, weather data were collected locally (temperature and rainfall) or obtained from the weather station at Abed (17 km away). In 2014, weather data were obtained from different sources depending on site (see Section 4).

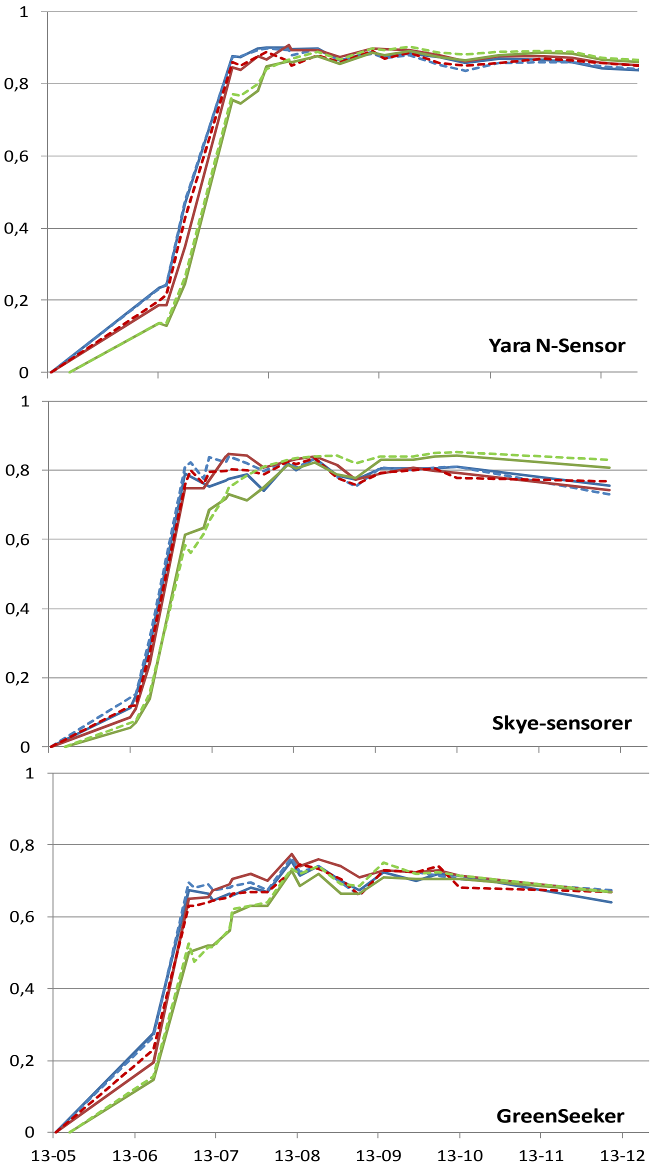

Figure 2.7 Vegetation reflectance index (NDVI) for the six areas studied in 2013, measured with three different types of sensors. Beet variety: Red = Comanche, green = Rosalinda KWS), blue = Smash.

In addition, soil samples were taken and analysed for their content of clay, silt, sand and humus (soil texture). The weather and soil data were used to calculate theoretical growth using the AB Sugar i-BeetGro model (see Section 4 for further details about growth modelling).

Yield predictions based on canopy reflectance and the AB Sugar i-BeetGro Model.

Through the measurements of canopy reflectance, a form of quantification of plant quality was obtained. The question was whether this could be used to predict plant growth. A relatively straight-forward approach would be to combine theoretical growth data from a model and e.g. NDVI. Here, NDVI was measured with three types of equipment in six areas in 2013 (Figure 2.7) and in the following these data are combined with results obtained with the AB Sugar i-BeetGro model.

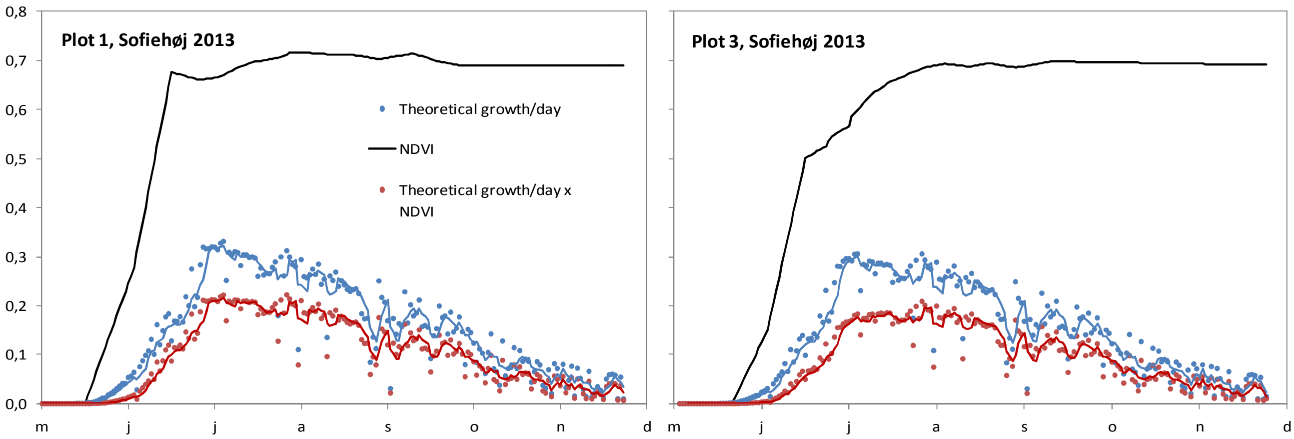

Figure 2.8 Theoretical dry matter production (based on the AB Sugar i-BeetGro Model) and NDVI-corrected dry matter production.

The first step was to model daily dry matter production (DDP) for the six areas studied. DDP proved to be almost identical for all areas, as the weather was the same (all areas were at Sofiehøj (Figure 2.6)) and soil texture almost the same (data not shown). An important variable was beet variety, as these differ in terms of relative yield. Relative yield data for the varieties grown in the study areas in 2013 were obtained from the national variety testing and standardised as described in Section 4.

The next step was to estimate daily reflectance figures (NDVI) based on the 20 measurements throughout the growing season. Initially, the measurements were adjusted by calculating a running mean based on up to five measurements (actual measurement and the two before and after this). This was done to reduce the impact of single measurements, as these are sometimes overly affected by the time of the day at which they were carried out (leaves are generally more vigorous in the morning). Next, linear interpolation was used to calculate reflectance on days without real measurements.

The third step was to multiply DDP and NDVI to obtain NDVI-corrected dry matter production (estimated yield; EY) (Figure 2.8).

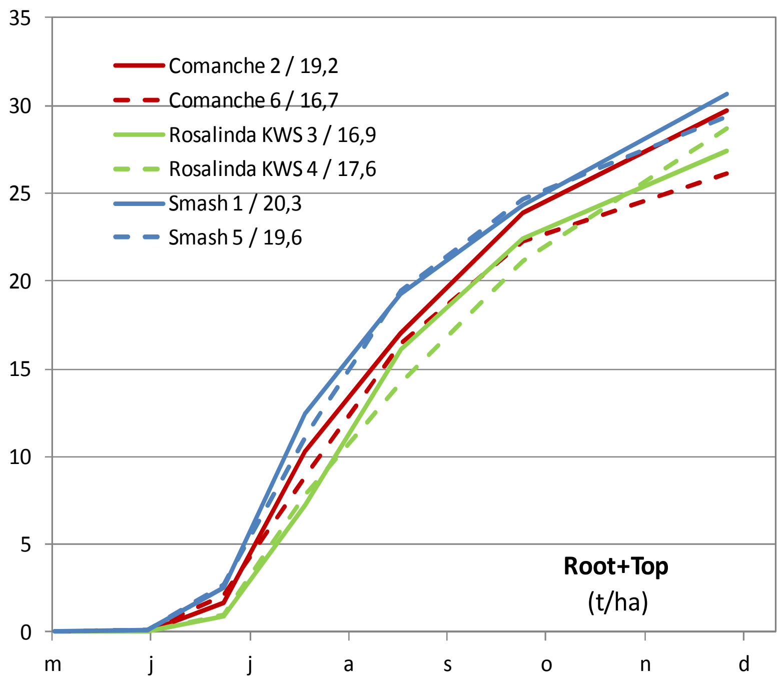

Figure 2.9 Observed growth of beets in the six areas in 2013. Key shows beet variety, plot number and sugar yield (t/ha) at final harvest. The graph cannot be used to compare beet varieties, as yield also varied due to position in the field and drilling time (see Figure 2.8).

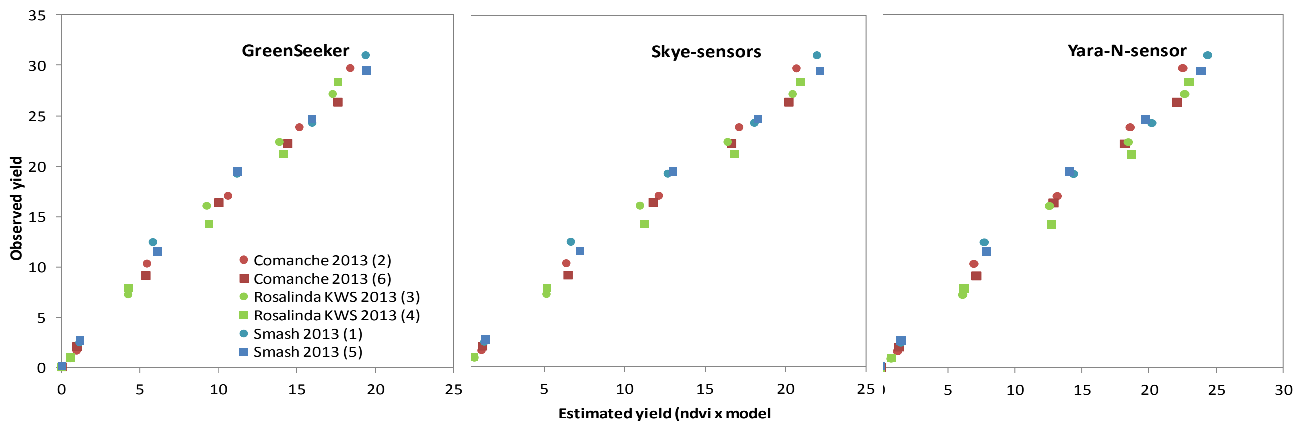

Figure 2.10 Correlation between growth estimated by the combination of theoretical growth data and NDVI and observed growth in 2013.

The fourth step was to combine EY and observed yield (OY) obtained from six harvest times throughout the growing season for both total plant growth and tap root growth (Figures 2.9-2.10).

On the basis of the data displayed in Figure 2.10 and analysis of variance, the following conclusions can be drawn:
1) The relationship between OY and EY depended on equipment used.
2) The relationship between OY and EY depended (slightly but significantly) on sugar beet variety.

The differences between equipment can be explained by the fact that the sensors scan the field at different angles, as sensors used at a vertical angle (GreenSeeker and Skye) can detect bare areas to a higher degree than sensors used at a flat angle (Yara).

For all three sensors, the correlation between estimated and observed yield was at a high level, as illustrated in Figure 2.11. In general, the GreenSeeker gave the best correlation and when the sensor was used to estimate root growth, the correlation was above 0.9 for all harvest times.

In 2014, ten sites were measured with the GreenSeeker 13 times during the growing season. These data were combined with theoretical growth obtained from the AB Sugar model using the same steps as in 2013. The correlation between observed and estimated yield was not as good as in 2013 and the relationship was different. This is shown in Figure 2.12, where the results from 2013 and 2014 were combined. Figure 2.13 illustrates why downward-pointing sensors are better for scanning bare areas.

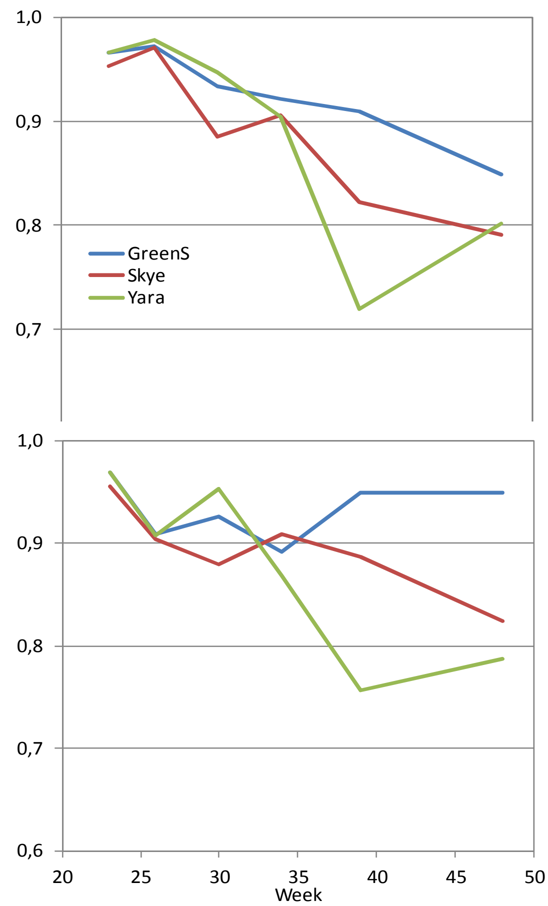

Figure 2.11 Correlation between estimated and observed growth for each sensor and harvest time (based on data displayed in Figure 2.10). Upper graph is correlation to total growth and lower to tap root only.

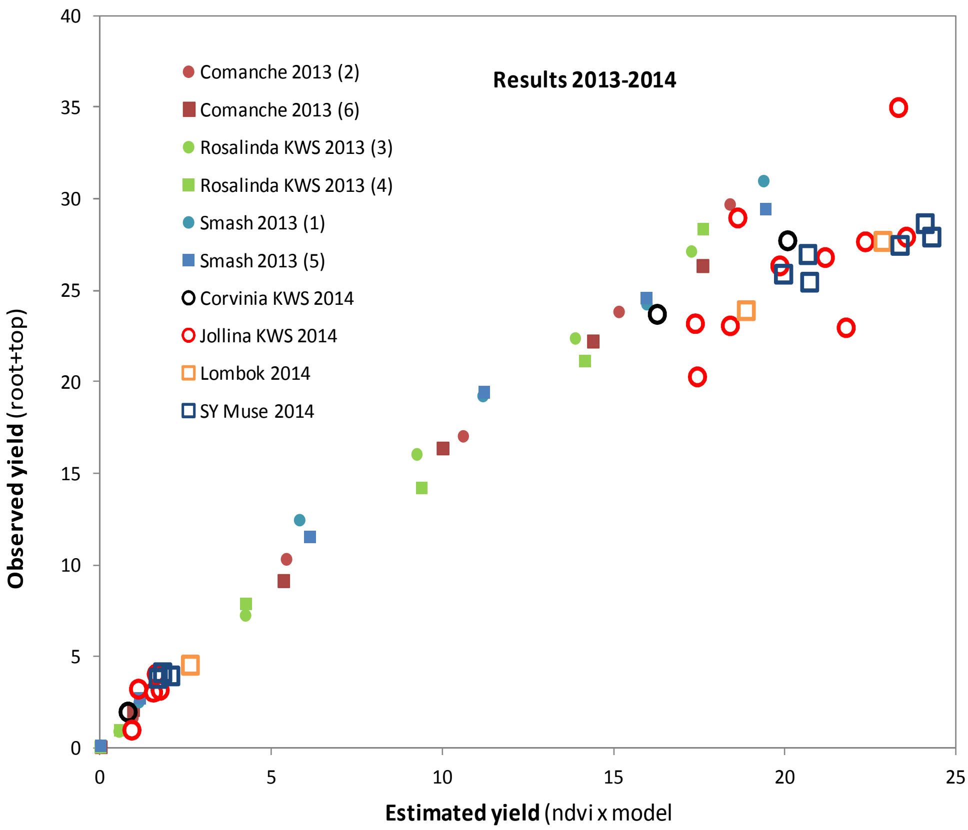

Figure 2.12 Correlation between growth estimated by the combination of theoretical growth data and NDVI and observed growth in 2013-2014.

Figure 2.13 Crop sensors that point downwards can detect bare areas better than sensors mounted at a flat angle.

F. Relationship between beet shape and beet weight

Hand-harvesting of beets is very costly in terms of time (and money) and thus alternatives to digging up, washing and weighing beets would be an advantage. For that reason, data on tap root weight and shape were collected for more than 1200 individual tap roots in 2012 in order to predict tap root weight on the basis of tap root length, perimeter or area (Figure 2.14). Area was determined by digitally measuring the tap root surface on a photo. The beets that were used were randomly chosen in each field by picking beet nos. 4, 5, 7 and 11 in the first row and beet nos. 3, 5, 8 and 10 in the second row (counting from the opposite end) in three of the six plots.

The closest relationship was found between weight and perimeter and the next closest between weight and area, whereas the relationship between weight and length was poor (Figure 2.14). Further analyses revealed that for both area- and perimeter-based estimation of tap root weight, the impact of site (field) was statistically significant.

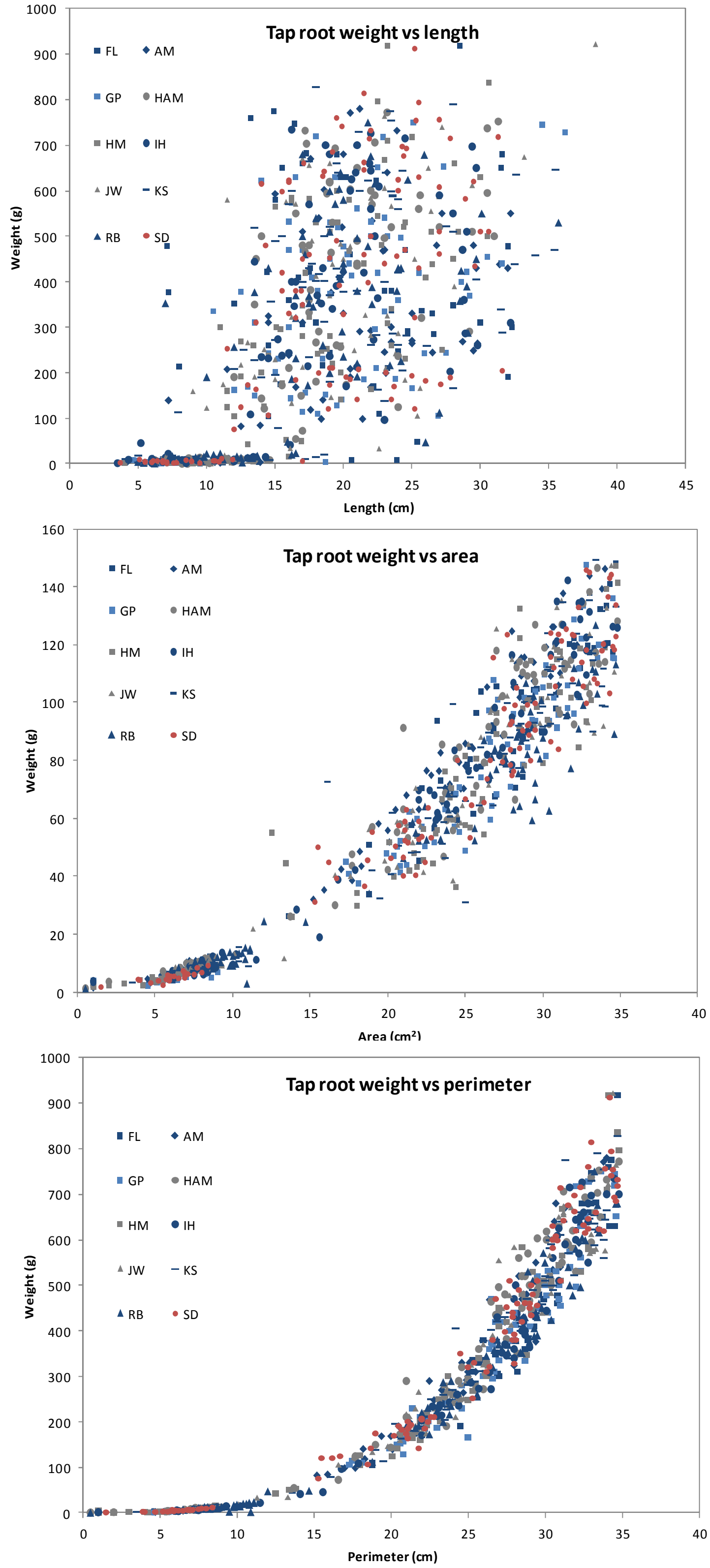

Figure 2.14 Relationship between beet weight and: (top) tap root length, (centre) tap root area and (bottom) tap root perimeter. Tap root area was measured using photometry.

3. Collection of site-specific data

A summary of the data collected is given in Table 3.1 and the different data types are commented upon in the following text.

Soil texture and nutrient content

The analyses were performed as standard analyses in the specific country where the survey was made. In 2014, samples were analysed in both Denmark and Sweden, as the methodology differs in some cases and because results are reported and used differently in the two countries.

Comparison of analyses from the two countries in 2014 revealed that clay content differed by on average eight percentage points. This is problematic, as soil texture affects the calculated theoretical growth (see Section 4).

In 2012 and 2014, soil texture was also determined for the B-horizon (30-60 cm). Soil density was determined in 2012 in the A- and B-horizons (2 x 8 rings/sites (100 cm^3)). Soil texture in the B-horizon and soil density may be used in some growth models (e.g. Daisy) to improve simulations. Along with soil texture analysis, the nutrient content was determined for the 2014 samples from 30-60 cm depth.

Table 3.1 Summary of data collected (in addition to growth measurements listed in Table 2.1). See text for details and comments

	Year 2010	2011	2012	2013[1]	2014[2]
Sites					
- number of sites	5	12	12	1	10
Soil texture and nutr. cont. (0-30 cm)					
- texture	x	x	x	x	x
- organic matter	x	x	x	x	x
- pH	x	x	x	x	x
- P, K, Mg	x	x	x	x	x
- Ca	x	x	x		x
- B	x			x	x
Soil texture and nutr. cont. (30-60 cm)					
- texture			x		x
- organic matter			x		x
- pH					x
- P, K, Mg					x
- Ca					x
N-min and soil density (depth)					
- N-min (0-75 cm)				x	x
- soil density (approx. 15 cm)			x		
- soil density (approx. 50 cm)			x		
Plant pathogens (depth)					
- Beet cyst nematodes (0-30 cm)		x	x	x	x
- Free-living nematodes (spade)					x
- Fungi (spade)		x	x		x
- Rhizomania (spade)					x
Cultivation					
- year specific[3]	x	x	x	x	x
- historically[4]	x	x	x		x
Photos (Figure 3.1)					
- "field"		x	x		
- "zoom" (close-up of plants)		x	x		
- "air" (from 2 m height)		x	x		
Weather[5] (site-specific loggers)					
- temperature			(12)	1	10
- rainfall			(12)	1	8
- relative humidity				(1)	5
- radiation					5
- wind speed					5

[1]All activities based at Sofiehøj Research Centre, Holeby, Denmark (see section 2E)
[2]Similar data sampling is ongoing in 2015 and planned for 2016 at 11 sites
[3]Date, equipment/product and amount
[4]Approximate figures for crop sequence, ploughing intensity, organic matter input- and output etc.
[5]Numbers in brackets: Data from some sites not used due to missing data.

N-min

Nitrogen mineralisation (N-min) samples are normally taken in February. As choice of field and placement of plots until 2012 were decided after plant emergence (and application of fertiliser), N-min analysis was only available from 2013 and onwards.

Plant pathogens/parasites

Analysis for beet cyst nematodes is relatively common in both Sweden and Denmark and was included in all years from 2011.

Analysis for root-attacking fungi (mainly *Aphonomyces*) was bio-assay-based (cultivation of beets in soil sample in greenhouses for six weeks and final grading of attack level (wilting index)). This test is mainly used in field studies and as a general characterisation at trial sites.

In recent years, there has been growing interest in the impact of free-living plant parasitic nematodes. At NBR, surveys have been carried out for some years, including the sites in this project in 2014.

Rhizomania is not very common in Scandinavia but is a very serious plant pathogen. All samples were free from this pathogen in 2014.

Table 3.2 Recording of year-specific cultivation. Input provided by the farmer

Variable	Input
Site identification	Year, country, grower
Date	The date a specific activity was finished
Activity	Tillage, drilling, fertilisation, plant protection, liming, harvest etc.
Tool	Plough, harrow, sprayer etc.
Material	Fertiliser, seed, herbicide, fungicide etc.
Product	e.g. Betanal Power etc.
Active ingredient	e.g. N, Glyphosate etc.
Amount per ha	Intended amount
Unit	g/ha, kg/ha, t/ha, l/ha
% active ingredient	
Machine producer	e.g. Väderstad
Machine model	e.g. Cultus
Working width	Machine dimension
Working depth	Intended/approximate

Figure 3.1 Examples of photos taken systematically during 2011-2012. These photos were defined as: “field” photos (photo taken from around 1 m height and covering approximately six plant rows in the centre of the photo), “zoom” photos (close-up photo focusing on one plant) or “air” photos (photo taken vertically downward and covering approximately five plant rows).

Cultivation

This information was reported by the grower and is valid for the plots studied and not necessarily for the surrounding field.

Year-specific cultivation can be expected to be close to actual activity in the plots, but data quality will depend on correct recording, calibration and use of machinery and products. Table 3.2 gives a summary of the information collected.

“Historical cultivation” is an attempt to quantify or characterise previous cultivation at the study sites (Table 3.3). The data were collected through interviews with farmers and then harmonised. In this process, rough estimates or approximations were sometimes used. The roughest estimates were generally made for dry matter production by the catch crop and in some cases for straw removal. The effects of historical events are often difficult to test in trials. This project attempted to use a model-based approach to compare sites and years (Section 5) and here the variables marked with a hash tag in Table 3.3 were included.

Photos

Photography was used systematically in 2011 and 2012. The photos were defined as three different types: “Field view”, “zoom” and “air” (Figure 3.1). All photos were arranged in Picasa (online accessible photo database provided by Google) and tagged with identification code (photo type and farmer name) and GPS coordinates (geo-tagging).

Weather

Weather data document the growing conditions throughout the years and are used in the AB Sugar model. Over time, site-specific loggers were placed at more and more sites. In 2014, Adcon weather stations were placed at five of the sites (and in 2015 at all sites). Temperature and relative humidity were to some degree recorded locally by Hobo loggers. Rainfall was recorded locally using a combination of electronic rain gauge (rain-O-matic/Hobo) and manual recording by farmers. In the cases where weather was not recorded locally (2010-2011 and partly in 2012 and 2014), weather data were taken from the nearest weather station (SMHI and Nordic Sugar) or by combining data from two or more stations. All data were carefully validated to avoid false or missing values.

Table 3.3 Recording of historical cultivation. Input was provided by the farmer and harmonised for further use

Variable		**Input** (approximate amounts)
Site identification		Year, country, farmer
crop_year_1 crop_year_2 crop_year_3		Crop before beets in three previous years
beet_pct_20 barley_pct_20 wheat_pct_20 oilseed_pct_20 grasseed_pct_20 grass_pct_20 corn_pct_20 potatis_pct_20 veg_pct_20 pea_pct_20 other_pct_20	# # 	Percentage of years with a given crop over the last 20 years
manure_1 manure_20 slurry_1 slurry_20 other_organic_1 other_organic_20		Use of manure, slurry and other organic input (e.g. NovoGro) in current year and over the last 20 years on average (t/ha)
organic_total_20	#	Sum of input of manure, slurry etc.
Catch crop types catch_crop_1 catch_crop_20	 #	Name of catch crop and biomass production in autumn in the year before and over the last 20 years on average (t/ha)
straw_remov_1 straw_remov_20	 #	Removal of straw over the last 20 years on average (t/ha)
flime_1 flime_20 lime_1 lime_20 lime_total_20	 #	Use of lime/factory lime before current year and over the last 20 years on average (t/ha)
plough_1 plough_pct_4 plough_pct_20	# #	

4. Growth modelling

A. Growth models

Introduction

In this project, the AB Sugar i-BeetGro Model was used for simulation of beet growth. This model is well-known within sugar beet research and was kindly supplied by AB Sugar. As an alternative (or addition), the use of the Dutch SUMO-Model has been considered and discussed with our Dutch colleagues from IRS. We decided against use of that model, as it requires regional historical yield as an input (Noud van Swaaij, pers. comm. 2011) and these data are not available for Denmark and Sweden. The Danish Daisy model was also considered but not included as: 1) the sugar beet module needs to be updated and calibrated (Per Abrahamsen, pers. comm. 2012) and 2) the model require assistance from external parties, which was not possible within the project period.

Table 4.1 Average soil parameter values used to define water availability in the AB Sugar i-BeetGro model. When soil texture and organic matter content were analysed, more precise values could be calculated (see Table 4.2)

Soil Texture Type	Available Water Content (%)	Soil "b" parameter
Sand	12.0	1.6
Loamy sand	15.0	1.9
Sandy loam	17.0	2.1
Sandy silt loam	21.0	2.8
Silt loam	23.0	3.3
Sandy clay loam	19.0	2.4
Clay loam	20.0	2.6
Silt clay loam	21.0	9.2
Silt clay	19.0	11.2
Clay	17.0	13.5
Peat	25.0	5
Organic	25.0	5

B. Model input

The AB Sugar model is available in an Excel version that requires the input described below. The first version of the model was developed based upon yield data from 1980-1991 and an improved version was released in 2011 (Aiming et al., 2013).

Table 4.2 Simulated yield based on different choices of soil parameters for a specific site (SF2014)

Water availability		Water-limited		Water-unlimited	
SAWC[1]	b	DM	Sugar	DM	Sugar
15	1.5	23.4	13.3	29.8	18.5
	2.5	26.1	15.5	29.8	18.5
	3.5	26.7	16.0	29.8	18.5
18	1.5	27.9	14.4	36.7	21.1
	2.5	31.0	16.7	36.7	21.1
	3.5	31.7	17.2	36.7	21.1
21	1.5	27.9	14.4	36.7	21.1
	2.5	31.0	16.7	36.7	21.1
	3.5	31.7	17.2	36.7	21.1
24	1.5	27.9	14.4	36.7	21.1
	2.5	31.0	16.7	36.7	21.1
	3.5	31.7	17.2	36.7	21.1

[1]Soil available water content

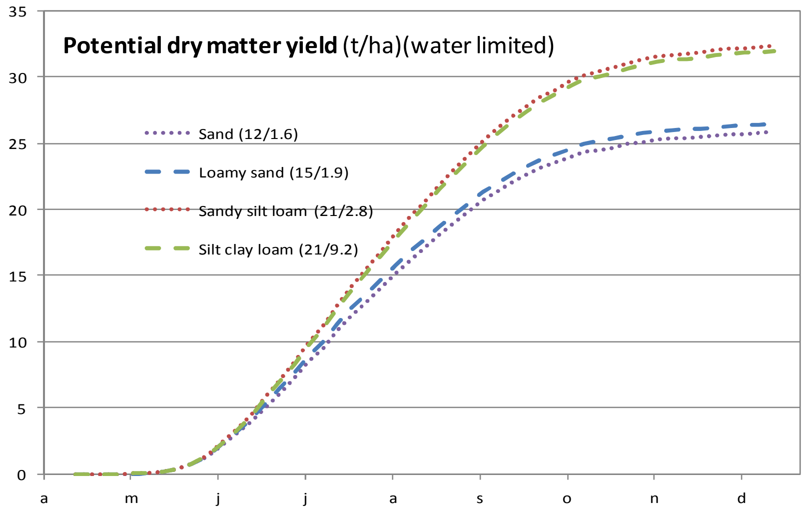

Figure 4.1 Simulated yield based on different choices of soil parameters for 2014 (average weather (ten sites) and drilling April 1).

Water availability

Water availability is described by the soil parameter "b" and the amount of plant-available water. Both factors are linked to the soil type (Table 4.1). In the project, the value for soil-available water was specifically calculated for each site (data not shown). The calculations were based on the content (%) of clay, sand and organic matter in the A-horizon in 2010-2013 and the A- (75% weight) and B-horizons (25% weight) in 2014. For the calculations, equations developed by Dr. Keith Saxton were used (available as Excel file). The general effect of different combinations of soil water availability on yield is shown in Table 4.2 and Figure 4.1.

Table 4.3 Relative (rel.) yield of sugar beet varieties in relation to year and country. The original relative yield from variety trials were standardised using Rosalinda KWS as a reference (relative yield = 100). Rosalinda KWS was also used in the latest revision of the growth model

		Variety test		Standardised
Year	Variety	Sugar	Rel.	rel. yield
2010	Rosalinda KWS	12.8	105.0	100.0
2010	Mixer	12.6	103.2	98.3
2011	Rosalinda KWS	14.9	105.3	100.0
2011	Mixer	14.1	99.8	94.8
2012	Rosalinda KWS	14.5	103.0	100.0
2012	SY Muse	14.5	102.5	99.6
2013	Rosalinda KWS	14.4	101.9	100.0
2013	Comanche	13.6	95.8	94.1

As described earlier (see Section 3), some uncertainty exists as to the accuracy of soil texture analysis. Furthermore, the above-mentioned equations generated values that were generally markedly lower than reported elsewhere (Madsen and Platou 1983) and a general adjustment (x 1.7) was applied to all calculations of soil-available water. Due to this, it is highly recommended that the estimation of water availability is critically reviewed.

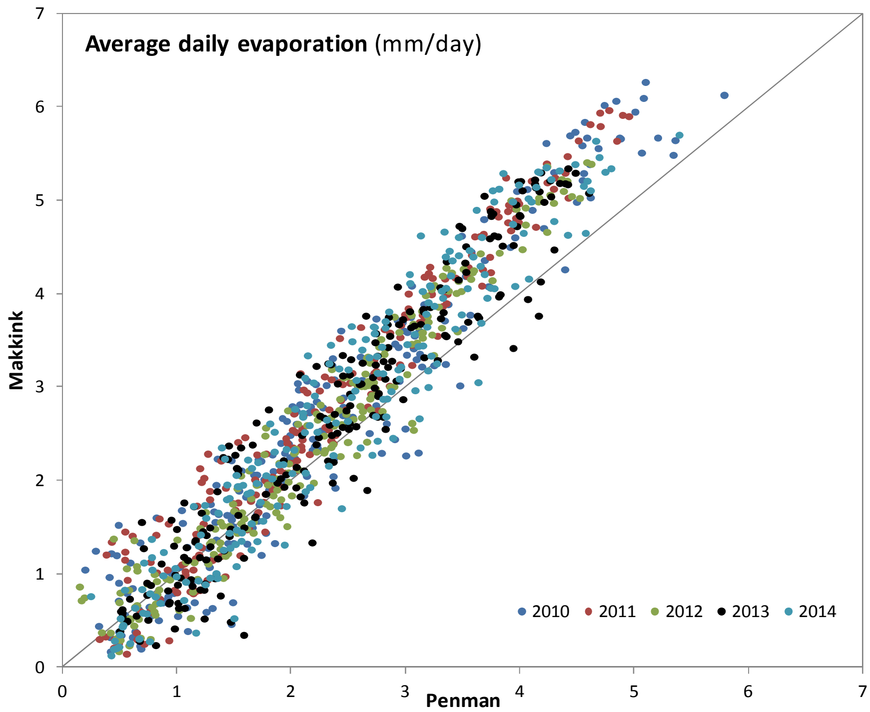

Figure 4.2 Evapotranspiration was estimated by a modified Penman equation in all simulations used in this report (as in the original calibration of the i-BeetGro model). A Makkink-based equation that requires fewer weather variables was also tested.

Weather

The i-BeetGro model requires input in the form of daily minimum and maximum temperature, rainfall, radiation and evapotranspiration. Evapotranspiration was estimated here using a modified Penman equation that in addition to the weather data mentioned requires minimum and maximum humidity and wind speed. In Denmark, evapotranspiration is often based on a modified (and much simpler) Makkink equation that requires fewer weather variables (Carsten Petersen, University of Copenhagen; Jens Bliggard, Seges; pers. comms. 2015). Whether one or the other formula was used had a clear effect on the results, e.g. the simulated yield was on average 1-3% lower in the years 2010-2014, when Makkink was used instead of Penman (data not shown). Because the i-BeetGro model was initially based on a Penman equation, all simulations in this report used the modified Penman equation (Figure 4.2).

Relative yield of beet varieties

The AB Sugar i-BeetGro model must be adjusted for variety effects. In this report this was done using the same variety as standard (relative yield=100) in each year. Rosalinda KWS was chosen as the standard variety because relative yield data are available for this variety from variety testing in all study years 2010-2014 (Table 4.3) in both countries (six variety tests/year/country) and because this variety was originally used for calibration of the model.

C. Model output

Water limited and unlimited growth

Based on the above-mentioned input, the i-BeetGro model generates an output consisting of the following four variables for each input of harvest dates: 1) Water-limited dry matter yield, 2) water-limited sugar yield, 3) water-unlimited dry matter yield and 4) water-unlimited dry matter yield. The output for all simulated combinations of year, site and harvest dates is shown in Figure 4.3. In comparison with other years, 2011 showed a smaller difference between water-limited and water-unlimited yield.

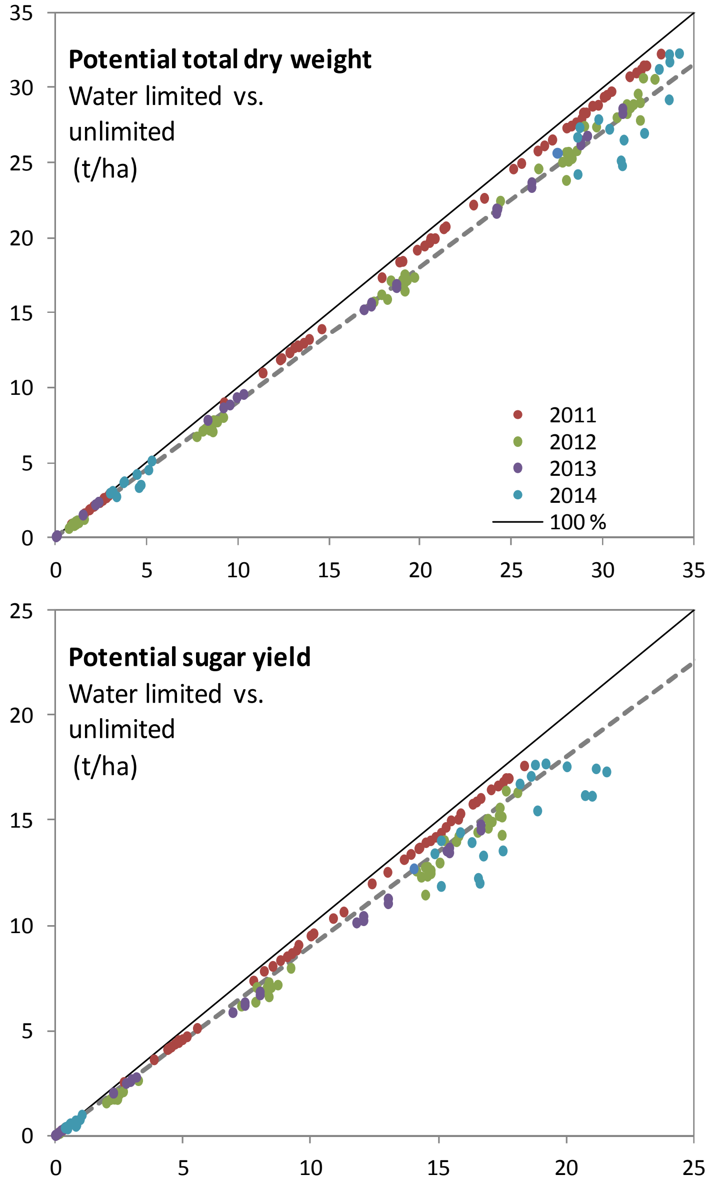

Figure 4.3 Model output showing the difference between water-limited and water-unlimited dry matter yield (upper diagram) and sugar yield (lower diagram).

Effect of soil parameters

The effect of changing soil parameters, as shown in Table 4.2 and Figure 4.1, was small. The model-simulated yield only differed slightly for sand/loamy sand and sandy silt loam/silt clay loam, respectively.

Effect of weather data

Weather varies from year to year and from site to site. Another parameter is the accuracy of weather data due to e.g. the distance between logger and field. Therefore, different data sets were run to examine the effect of certain changes of temperature (+0.2°C), relative humidity (+10%) and radiation (+2%) (Figure 4.4). The magnitude of these changes was chosen to reflect expectable errors. Changes in temperature and radiation had a very low effect (1%) on yield (water-limited dry matter yield), whereas changes in relative humidity increased yield by around 3%.

Weather effect between years

Based on the average weather at the sites studied, growth curves were simulated for each of the years 2010-2014 (Figure 4.5). In these simulations, soil conditions (silt clay loam) and drilling time (April 1) were kept constant so that only the weather differed. Surprisingly, the highest simulated yields were found for 2011 and not for 2014 (the year with highest observed yields). The explanation is probably that drilling (on average) was two weeks later in 2011 than in 2014.

Weather effect between sites

Figure 4.6 shows the effect of site-specific weather when soil conditions (silt clay loam) and drilling time (April 1) were kept constant. The simulations were made for the ten farms that participated in 2014 and revealed differences of up to 8% in yield.

Effect of drilling time

The i-BeetGro model may also be used to simulate the effect of drilling time. As an example, drilling times from March 1 to April 10 were applied to one of the farms in 2014 (Figure 4.7). Yield only differed slightly by delaying drilling from March 1 to March 10, whereas with further delay simulated yield losses were up to 8%. Actual drilling time for the specific farm was March 20.

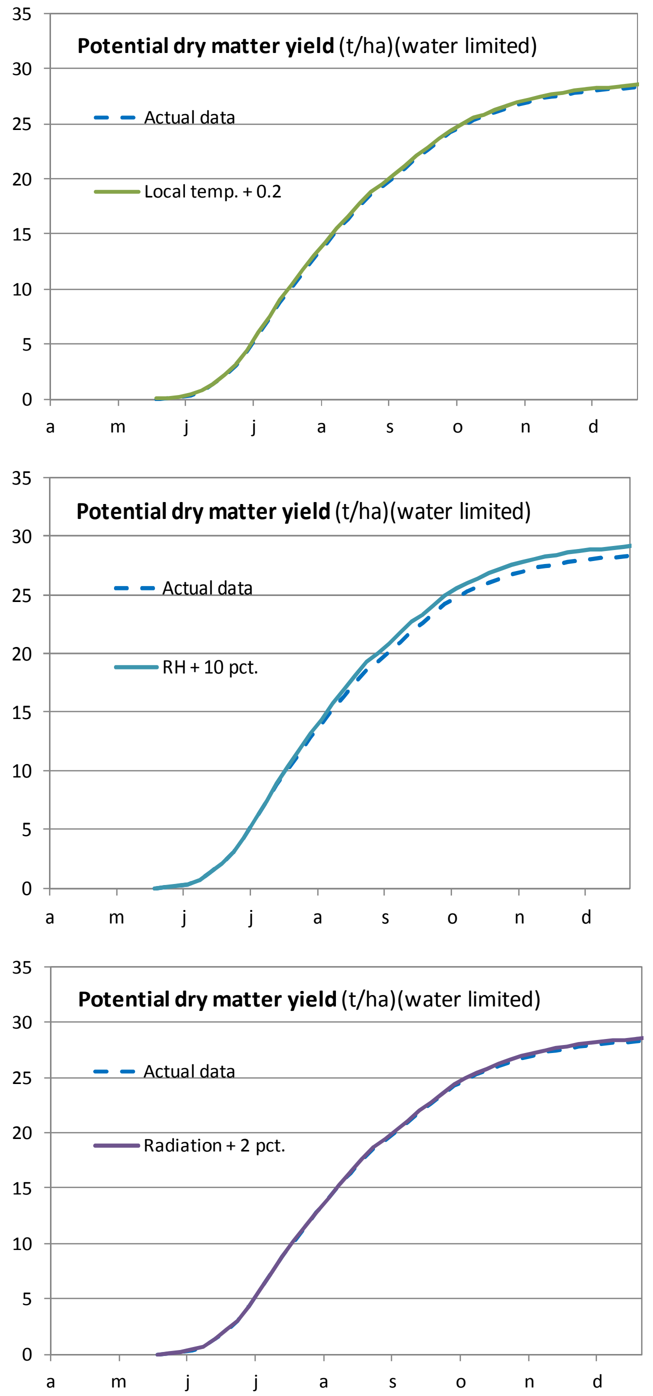

Figure 4.4 Effect of changes in weather data (e.g. caused by differences between field and logger position).
Upper graph: Increase in temperature of 0.2°C
Middle graph: Increase in humidity of 10%
Lower graph: Increase in radiation of 2%

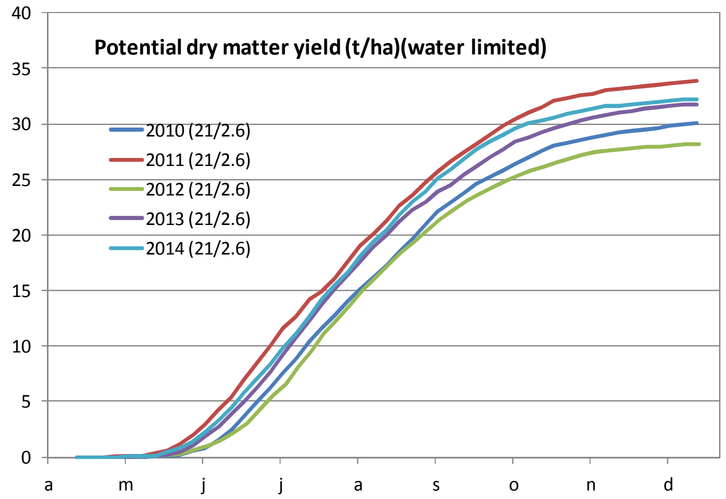

Figure 4.5 Effect of weather on yield in the years 2010-2014, assuming that drilling time and soil parameters were the same.

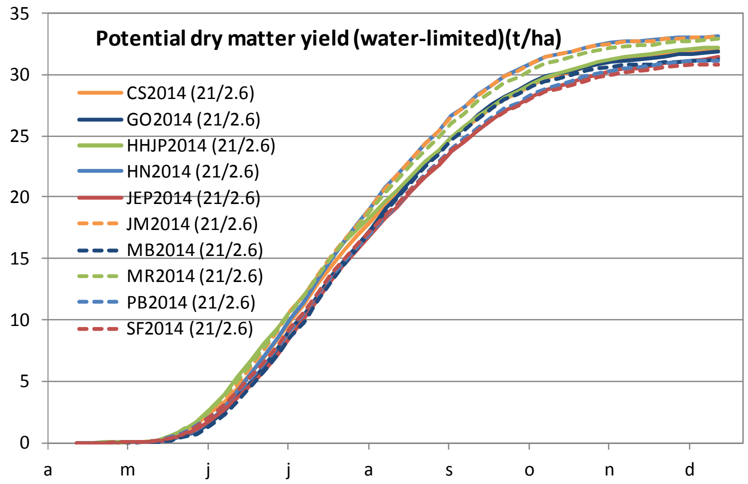

Figure 4.6 Effect of weather on yield at the sites studied in 2014, assuming that drilling time and soil parameters were the same

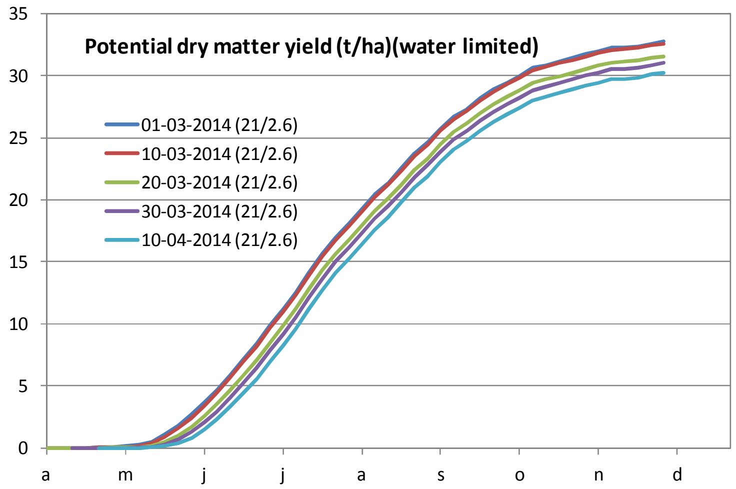

Figure 4.7 Effect of drilling time on yield at site SF, 2014.

5. Farm-based research

A. Validation of growth model

Growth and yield of farm crops are known to be highly variable, as they depend on a number of factors e.g.:

1) Weather in a given year and at a given site.
2) Soil conditions.
3) Drilling and harvest time (length of season).
4) Optimal use of equipment (type and timing).
5) Soil fertility and use of fertiliser.
6) Growth inhibitors, weeds, pathogens etc.

In this project, items 1-3 were incorporated into the i-BeetGro model (see Section 4), which then calculated the potential yield for every single site. The main advantage of this step is that variations due to year and site can be neglected. Of course this requires that the model generally simulates yield correctly and this depends on the correctness of input (weather and soil data are crucial) and adequate calibration of the model to the environment where it is used. The AB Sugar i-BeetGro model used in this project has been fitted to British and partly German conditions, but the question is whether it works under Scandinavian conditions. One approach to answer this question was to plot the observed yield versus the simulated yield.

The graphs in Figure 5.1 show the four different outputs of the model. The following findings should be noted:

1) Some observed yield values were higher than simulated water-limited dry matter yield, in particular the data from 2013, which represent one site (see Section 2). This may indicate that the model is not calibrated to meet these conditions or that input (weather and soil data) or observed yield data are erroneous.

2) Besides the results from 2013, the results from different years agreed reasonably well when looking at both water-limited and water-unlimited yield. Thus on average, the model probably compensates correctly for year and site effects (remember, however, that different fields (and farms) were compared from year to year (see below) in this project.

3) In contrast to water-limited and water-unlimited yield, sugar yield clustered to a large extent in relation to year. This may indicate that the model wrongly converts total dry matter into leaf/tap root fractions and/or wrongly estimates the sugar fraction of total dry matter.

4) The plot of observed dry matter yield versus water-unlimited potential yield mainly had all data-pairs on or below the 1:1 line. This should be the case, as observed yield should not exceed unlimited potential yield. The result may also indicate that the underestimated water-limited yield could be due to erroneous data in respect to water availability (more water was actually available than was estimated).

In general, it was concluded that the growth model (on average, but probably not site-specifically (see Section 5C) gave a reasonable simulation of biomass, whereas the accuracy of simulated sugar yield was questionable.

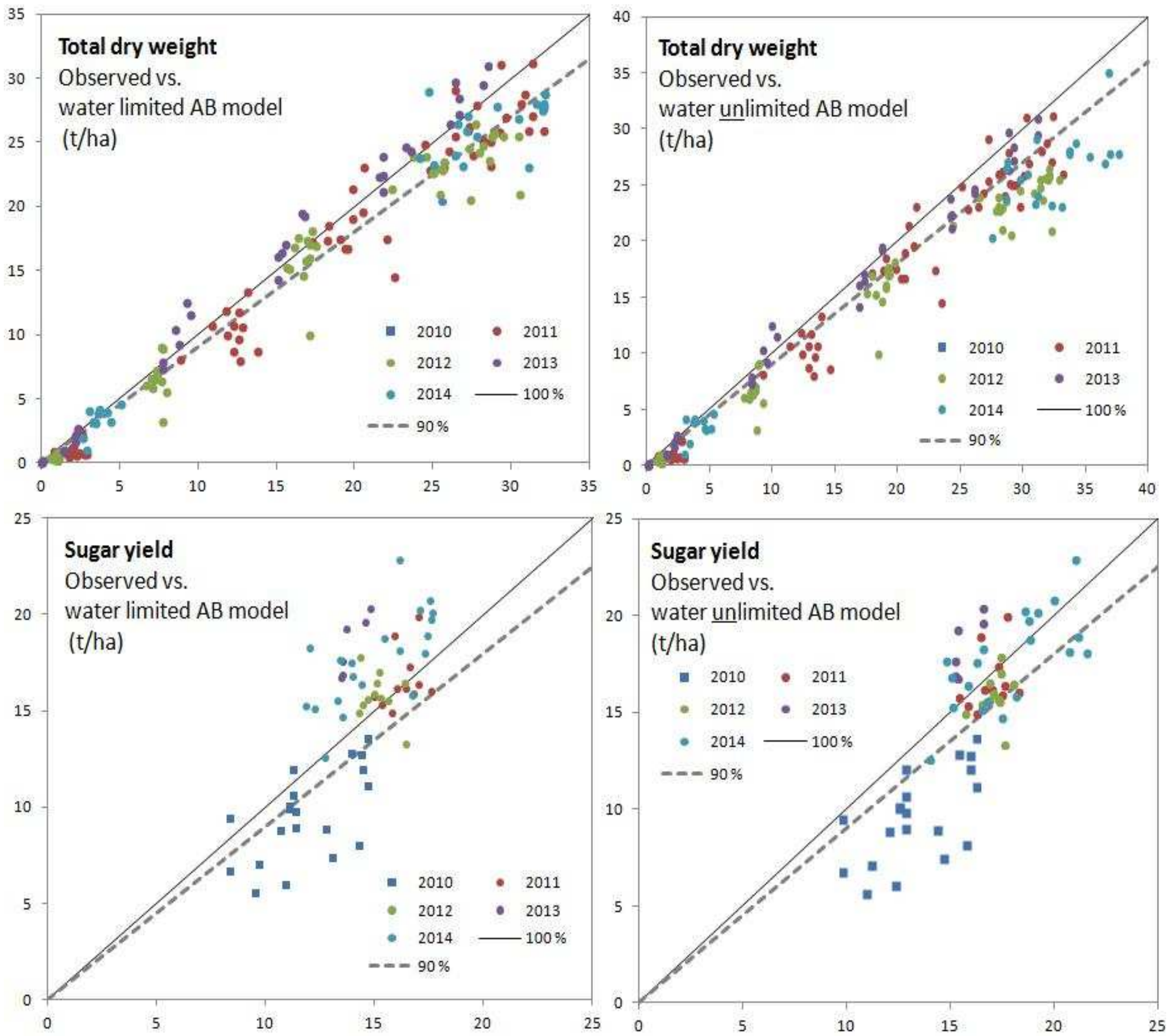

Figure 5.1 Relationship between observed and potential yield for the four different outputs of the AB Sugar i-BeetGro (AB) model.

Table 5.1 Cultivation-specific (CS) variables) that were determined in the project

No.	Variable	Type[1]	Unit	Input category[2]		
Rotation						
1	- frequency of beets	h	%	20	-	24
2	- frequency of oilseed rape	h	%	20	-	24
Input and output of carbon						
3	- organic matter input (total[3])	h	t/year	3	-	6
4	- use of catch crop (biomass production)	h	t/year	0.25	-	0.74
5	- removal of straw	h	t/year	0.4	-	1.1
Lime use						
6	- lime/factory lime[4]	h	t/year	0.5	-	1.4
Soil conditions (content of)						
7	-clay	a	%	12	-	19
8	- organic matter	a	%	1.5	-	2.9
9	- pH	a	-	6.5	-	7.4
10	- P (Al-based)	a	mg/100g	6	-	11
11	- K (Al-based)	a	mg/100g	8	-	14
12	- Mg (Al-based)	a	mg/100g	6	-	8
13	- Ca (Al-based)	a	mg/100g	300	-	799
Soil pathogens						
14	- wilting risk (based on bioassay)	a	Index	40	-	59
15	- beet cyst nematodes	a	no/100g	0.3	-	0.9
Fertilisation						
16	- N	a	kg/ha	100	-	110
17	- P	a	kg/ha	20	-	29
18	- K	a	kg/ha	40	-	79
19	- Na	a	kg/ha	40	-	79
20	- S	a	kg/ha	8	-	19
Incorporation of fertiliser (out of total)						
21	- N	a	%	34	-	67
22	- all elements, total	a	%	34	-	67
Plant protection						
23	Herbicides	a	Index			
24	Insecticides	a	Index	Not determined		
25	Fungicides	a	Index			
Tillage						
26	- Ploughing	a		no	-	Yes
27	- Ploughing (proportion of fields)	h	%	50	-	79
28	- operations since previous crop	a	no.	4	-	5
Plant stand						
29	- Count in June	a	no./ha	75	-	89
Variety						
30	- Relative yield in variety test	a	rel.	99	-	102

[1]h=historically (approximate average of last 20 years); a=actual year
[2]The level of each input was arranged into three categories. Displayed numbers are borders for the middle category
[3]Summed amount of manure, slurry and others (e.g. NovoGro)
[4]The liming effect of factory lime was set to 53% (www.sukkerroer.nu)

B. Growth and yield in relation to farm-specific activities (input-output relations)

The purpose of this part of the report is to try to explain deviations (yield gaps) between observed and potential yield. In addition, these tests may add to the validation in Section 5A.

In order to explain the yield gap, a range of data was collected from the farms (see Section 3). From controlled trials, we already know the general effect of some of these factors and that these effects sometimes have complex (non-linear) dose-response relationships (e.g. the effect of nitrogen fertiliser). Thus, to simplify data analyses and to reduce the number (and complexity) of explanatory variables in a statistical model, the collected data were condensed into 30 cultivation-specific (CS) variables, each with three categories of input (Table 5.1). The CS variables were divided into two types, i.e. quantifying the cultivation-specific activities in or just before the actual year (actual (a)) or within the last 20 years (historically (h)).

As the response variable, the observed total dry matter yield relative to water-limited potential yield was used (yield gap (%)). As the response may depend on yield level (time of the year), the yield level was further split into three categories (middle category=10-20 t/ha potential dry matter).

Because of the high numbers of explanatory CS variables compared with the number of observations, the explainable value of each CS variable was tested individually and ranked in terms of F-value (Table 5.2). This was intended to give an indication of the impact of the different CS variables. These tests showed significant effects of five CS variables (nos. 27, 20, 26, 14). None of the CS variables tested interacted with yield level (all P>0.05).

In a following test, ten CS-variables were chosen, the five

Table 5.2 Statistical analysis of the effect of single cultivation-specific (CS) variables (see Table 5.1). The results only give a first indication of possible significant effects (see text and Table 5.3)

			Main effect		Main x yield level[1]	
No.	**Variable**	**n**	**F-value**	**P-value**	**F-value**	**P-value**
27	Plants/ha	147	10.8	<0.0001	1.2	0.32
20	S fertiliser	132	6.7	0.0017	1.2	0.31
26	Beet variety	124	4.5	0.04	1.3	0.28
22	N incorp. (%)	132	4.0	0.02	0.1	0.96
14	Wilting risk	147	3.3	0.04	0.9	0.47
21	Fert. incorp. (%)	132	2.5	0.08	0.4	0.81
8	Soil org. mat.	89	2.4	0.12	1.3	0.28
10	Soil P	147	2.1	0.12	0.4	0.78
5	Straw removal	139	2.1	0.13	0.6	0.67
3	Manure use etc.	139	2.0	0.14	0.8	0.49
16	N fertiliser	132	1.6	0.20	1.0	0.44
6	Liming	139	1.5	0.23	1.3	0.29
18	K fertiliser	132	1.4	0.24	0.3	0.87
7	Soil clay	89	1.2	0.30	2.4	0.06
17	P fertiliser	132	1.2	0.30	0.3	0.91
24	Ploughing (h)	130	1.2	0.31	0.7	0.59
2	Oilseed rape (%)	139	1.1	0.35	0.2	0.96
19	Na fertiliser	132	0.9	0.41	0.3	0.85
13	Soil Ca	147	0.5	0.63	0.4	0.75
1	Beet (%)	139	0.4	0.66	0.1	0.98
11	Soil K	147	0.4	0.67	1.4	0.25
9	Soil pH	147	0.3	0.72	0.6	0.68
4	Catch crop	136	0.2	0.67	0.1	0.87
25	Operations	132	0.1	0.87	0.4	0.84
15	Beet cyst nem.	147	0.1	0.88	0.4	0.80
12	Soil Mg	147	0.1	0.94	0.4	0.84
23	Ploughing (a)	139	0.1	0.80	0.3	0.75

[1]Interaction between the listed variable and the three yield level

that had the highest impact individually (Table 5.2) and another five historical CS variables. In addition, the effect of year was tested (Table 5.3). In this test, only the CS variable "Plants/ha" had a significant effect (relative yield was reduced to 66% of potential yield when plant numbers in June were less than 75 000/ha). The effect of year was almost significant. However, the data were extremely biased, as the same growers participated in 2011 and 2012, whereas other growers participated in 2014. It is thus not possible to judge whether the discrepancy between years was due to farmer performance (better in 2014 than in 2011-2012) or the calibration accuracy of the model.

Another finding of the test results (Table 5.3) was that the yield gap depended on yield level, as it was greater (65% relative yield) at the beginning of the growing season compared with later in the growing season (91/84% relative yield).

C. Low- and high-end growers

An alternative approach used to possibly explain the yield gap between observed and potential yield was to compare growers with a large yield gap (low-end growers) and growers with a low yield gap (high-end growers) (Table 5.4). In this approach, best farming practice for each single CS variable would be expected to have a high frequency of high-end growers. Table 5.4 shows high- and low-end growers at two harvest times (early and late season) and for that reason the table is somewhat complex to read. The easiest way to read the table is probably to look for extreme values (marked with red or green) for the high-end farmers at the later harvest. For instance, all high-end growers belonged to category 1 for beet cyst nematodes (<0.3 eggs/100 mg soil), whereas the low-end growers had 20% in category 3 (>0.9 eggs/100 mg soil). Thus it can be concluded that high levels of nematodes could have a negative impact on yields. However, this conclusion is only valid for the late harvest, as the corresponding figures for early harvest to some extent show the opposite (no effect of nematodes in the early season, but an accumulated effect over the whole season).

Table 5.3 Effect of ten cultivation-specific (CS) variables on relative yield. The effect of year and yield level is also shown

			Yield gap / category[1]		
Variable	**F-value**	**P-value**	**1**	**2**	**3**
Year[2]	2.9	0.07	72	75	94
Yield level[3]	23	<0.0001	65[a]	91[b]	84[b]
Plants/ha	4.4	0.02	66[a]	85[b]	90[b]
P fertiliser	0.01	0.99	81	80	80
S fertiliser	2.3	0.11	67	95	79
Beet variety	0.001	0.98		80	81
Wilting risk	0.06	0.94	81	77	83
Beet (%)	0.8	0.47	82	87	72
Oilseed rape (%)	0.4	0.71	75	83	83
Manure, tillage etc.	1.2	0.31	90	89	62
Straw removal	0.3	0.73	73	78	90
Liming	0.02	0.98	81	82	78

[1]Observed dry matter yield as a percentage of potential yield.
- category: See Table 5.1
[2]1=2011, 2=2012, 3=2014
[3]1=below 10 t/ha; 2=10-20 t/ha; 3=>20 t/ha (corresponds mainly to harvest time)

Please note that the statistical results in Table 5.4 were based on relatively few observations and serve mainly to exemplify how the collected data can be used to explain the differences between low- and high-end growers.

Table 5.4 Frequency (%) of high-end growers (high relative yield) and low-end growers (low relative yield) in three defined categories of input level (see Table 5.1)

Rel. yield level	**Category (early season)**			**Category (late season)**		
Variable	**1**	**2**	**3**	**1**	**2**	**3**
High-end growers						
Beet (%)		36	64	44	11	44
Oilseed rape (%)	45	27	27	44	33	22
Manure use etc.	64	27	9	67	33	
Catch crop	100			100		
Straw removal	36	36	27	44	33	22
Liming	64	36		78	11	11
Soil clay		70	30	43	57	
Soil org. mat.		80	20		86	14
Soil pH	9	36	55	11	44	44
Soil P		82	18		67	33
Soil K	27	64	9		89	11
Soil Mg		55	45	33	11	56
Soil Ca	27	73		56	44	
Wilting risk	36	45	18	22	44	33
Beet cyst nem.	91		9	100		
N fertiliser	18	18	64	22	22	56
P fertiliser	18	64	18	33	56	11
K fertiliser	9	55	36		78	22
Na fertiliser	36	64		22	67	11
S fertiliser	36	55	9	22	56	22
Fert. incorp. (%)	64	18	18	89		11
N incorp. (%)	55	9	36	67	22	11
Ploughing (a)	10	40	50	13	63	25
Operations	64	36		33	67	
Beet variety		82	18		63	38
Plants/ha		64	36		56	44
Low-end growers						
Beet (%)	13	50	38		67	33
Oilseed rape (%)	75	25		44	44	11
Manure use etc.	88		13	78	22	
Catch crop	100			89	11	
Straw removal	50	38	13	44	33	22
Liming	63	25	13	78	22	
Soil clay	33	50	17		67	33
Soil org. mat.		67	33		67	33
Soil pH	20	70	10	20	50	30
Soil P	10	40	50		50	50
Soil K	10	80	10	10	70	20
Soil Mg	10	50	40		70	30
Soil Ca	50	50		20	70	10
Wilting risk	30	40	30	40	30	30
Beet cyst nem.	100			80		20
N fertiliser	11	33	56		38	63
P fertiliser		67	33		63	38
K fertiliser	22	56	22	25	38	38
Na fertiliser	11	78	11	38	50	13
S fertiliser	56	33	11	88	13	
Fert. incorp. (%)	89		11	50	25	25
N incorp. (%)	89		11	50		50
Ploughing (a)		50	50		22	78
Operations	56	44		63	38	
Beet variety		50	50		71	29
Plants/ha	20	40	40		50	50

D. Input-output regressions

A simple approach to get an overview of the data is to plot the various outputs (yields) against the various inputs. The advantages of these plots are that variations in magnitude of input and output are visually very clear and that trends in the data can be detected. As an example, in Figure 5.2 the tap root weight in June, August and November and the final sugar yield are plotted against the amount of N-fertiliser used.

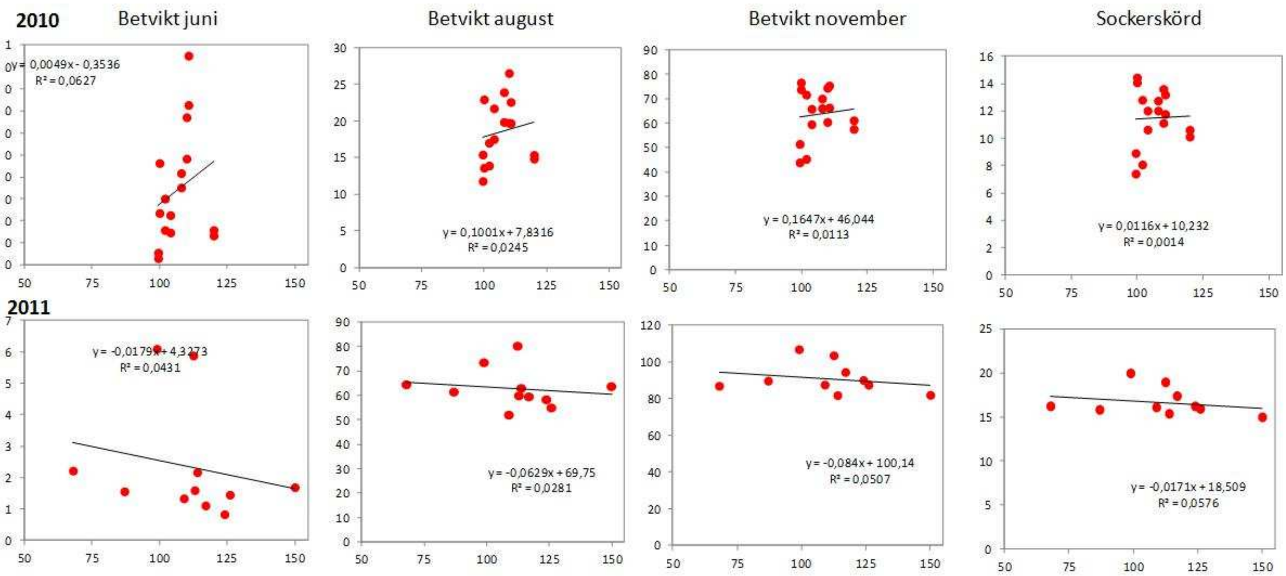

Figure 5.2 Input-output relationship exemplified by use of N-fertiliser in 2010 and 2011.

It is obvious that the range of N inputs was much narrower in 2010 than in 2011 and that sugar yield varied much more in 2010 than in 2011. Regarding the correlation between N input and yield, no obvious trends seem to be present in 2010, whereas the 2011 data indicate a negative relationship between input and output.

Table 5.5 Correlation between yield of tap root and top at different harvest times (B-Z, Z=final harvest). The interval between harvest times was approximately six weeks in both years

Year		Tap root dry matter					Top dry matter				
		C	D	E	Z	Sugar	C	D	E	Z	Sugar
2011	B	0.74	0.91	0.87	0.80	0.82	0.64	0.46	0.03	0.04	0.75
	C		0.72	0.55	0.53	0.55		0.69	0.19	0.22	0.38
	D			0.75	0.61	0.63			0.70	0.82	0.40
	E				0.97	0.97				0.95	0.11
	Z					0.99					0.11
2012	B	0.81	0.56	0.06	0.15	-0.11	0.50	0.47	0.16	0.09	0.25
	C		0.88	0.32	0.60	0.32		0.63	0.05	0.06	0.22
	D			0.59	0.80	0.62			0.53	0.32	0.60
	E				0.81	0.72				0.64	0.22
	Z					0.87					0.34

E. Yield correlations between harvest times

In 2011-2012, the plots were harvested five times during the growing season. The correlations between yield values at the different harvest times (Table 5.5) can be used to: 1) Decide the frequency and timing of harvest and 2) get a picture of growth over time. Based on Table 5.5, the following was concluded:

1) Root growth correlated better between harvest times than top growth.
2) The correlation between first harvest (B) and following harvests (D-Z) differed between years (better correlation in 2011 than in 2012). The fact that dry weight at first harvest was higher in 2011 (0.25 t/ha root) than in 2012 (0.08) may have had an impact.
3) The correlation between two subsequent harvests was higher towards the end of the growing season than at the beginning of the growing season in both years.

6. Communication

A. Access to data

All data from the years 2010-2014 were organised in Excel files with very simple structures (data lists). By combining these in different ways (using the flexible statistical program SAS), examples of output were constructed. During the project period, these examples were presented to the participating farmers and their advisors in order to get feedback and subsequently develop data-based "products" which could have value for the farmers. One example of a product is given in Table 6.1. In the period 2011-2012, the farmers had access to the products shown in Figure 6.1. In addition to tables and figures, the products included photos from the field (see Section 3).

	MENY		
Tillväxt	Grafer 2010	Grafer 2011	Grafer 2012
Plantor		2011	2012
Odling	Rapport		
Redskap	Lista		
Odling & tillväxt	Betor	Blast	
Odling & skörd	Socker m.m.		
Foton	Picasa webalbum		Picasa webalbum

Figure 6.1 In 2011-2012, the participating farmers had access to data- and photo-based "products" (Excel-file on project website).

B. Grower evaluations

The collection of data from the farmers provided the possibility to return the results to the farmers (and their advisors) in an organised form (cultivation report) in order to validate and possibly improve their performance simply by increasing awareness of their own performance. The development of a cultivation report was not originally planned, but was suggested by the farmers as they felt that they needed a summary and an evaluation of the growing season. The cultivation report could include farm data and evaluations, as exemplified in Table 6.2.

C. In-field meetings/internet-based knowledge exchange

An important dimension and innovative approach in this project was to examine the potential of new networks and ways of interacting for learning outcomes and concrete improvements on farm level. From earlier research, we knew quite well how knowledge is diffused among farmers and between farmers and advisors, and we also suspected that new IT tools could increase our ability for scale-up and roll-out of new technologies. To increase farmers' learning and adoption rate, more participatory approaches were implemented. By organising in-field meetings, enabling internet-based knowledge exchange and other joint activities, this project aimed to communicate research results as an ongoing process of implementation. This involved shifting from a perspective where the research is completed and the results are then communicated to an approach where knowledge development and dissemination are two aspects of the same process.

Table 6.1 Example of data-based products (number and types of operation between previous and studied crop)

Year	Grower	Plough	Roller on plough	Deep loose-ning	Harrow	Roller on harrow	Strip tillage harrow	Roller	Operations Total
2010	AM1	1			3				4
2010	AM2	1			3				4
2010	BB1	1			2			1	4
2010	BB2	1			2			1	4
2010	GN1				2				2
2010	GN2				2				2
2010	GP1	1	1		5			2	9
2010	GP2	1	1		5			2	9
2010	SH1	1			4			1	6
2010	SH2	1			4			1	6
2011	AM	1			3				4
2011	FL	1			2	2			5
2011	GN				2	1		1	4
2011	GP	1	1		5	2		2	11
2011	HM	1			2				3
2011	IH	1			1			1	3
2011	JW	1			3				4
2011	KS				7				7
2011	LAP	1			1				2
2011	LP	1			3				4
2011	RB				4				4
2011	SD	1			1			1	3
2012	AM	1			2				3
2012	BB				2				2
2012	FL	1	1		2	1			5
2012	GN						1	1	2
2012	GP	1			3			1	5
2012	IH	1			1				2
2012	KS				1				1
2012	RB				4				4
2012	SD	1			3			1	5
2014	CS	1			3				4
2014	GO	1			2				3
2014	HHJP	1			2				3
2014	HN			1	2				3
2014	JEP	1			2				3
2014	JM	1			1				2
2014	MB	1			2				3
2014	MR		1		3				4
2014	PB	1			3				4
2014	SF		1		2				3

The experiences gained in this project show that there is great potential for further development of approaches which build on a combination of in-field meetings and internet-based decision support systems. Whether the internet results in increased knowledge exchange is a question of time. Developing more flexible and interactive interfaces, using new techniques for automatic data collection, and advisory services with the ability to interpret and apply both the new aggregated data and local site-specific data waits around the corner. Communication within projects and of research results will then improve. This project has already contributed to common knowledge in this regard.

Table 6.2 Example of grower evaluations. Note that all data are fictional.

Grower data	Item (example)	Value (fictive data)		Value relative to (fictive data) High yielding fields	Recom-manda-tions	Potential yield
Field characterization	Soil K	7,1	mg/	-12	0	-
	N-min	30	kg/ha	-20	0	-
	Wilting risk	65	index	17	22	-
Acutal input	Operations	3	no	-18	-30	-
	N-fertilizer	100	kg/ha	-3	-6	-
	Hoing	1	no	65	0	-
Historical input	Beet frequency	33	%	30	35	-
	Liming	0,1	t/year	-247	-126	-
	Organic input	20	t/year	65	-	-
Observed output	NDVI, June	34	index	88	25	
	Top, July	2,1	t/ha	92	-	105
	Root, Nov.	21	t/ha	96	-	96

7. Evaluations by the growers

The farmers' evaluations were based on interviews with farmers carried out in 2013 by the Swedish University of Agriculture, Skara.

All participating farmers were interested sugar beet growers and joined the project to learn more about this crop, with which it is possible "to get bogged down quite badly". In the interviews, most of the farmers commended NBR for good work in developing Swedish sugar beet production, organising interesting meetings and enabling good cooperation between industry and growers. However, there was also criticism about increased control from industry and a sense of decreased trust between the actors.

The farmers were positive to the concept, including large-scale data collection on each farm, new meetings and the ambition to create learning communities. The majority of farmers had looked at the images from their own fields and those of others. It was interesting for them to follow the development of the crop, but at the same time difficult to interpret and use this information as a basis for decision making. All farmers were very positive to the database in the beginning, but at the end of the project they had become more critical. They complained that the huge amount of data reported was not compiled in such a way that they could use it. They also asked for better and more well-developed interpretations of the data. Furthermore, the design of the website was not fully developed during the project. There had been possibilities to influence the design and function of the database, but the farmers thought it was difficult to give input so late in the development process.

When the farmers were asked about future decision support systems, they highlighted the need for simplicity, interactivity and immediate feedback. One farmer said that a decision support system must be simple, include data from his own farm, but at the same time with a minimum of data input and it must be credible for the local context. Some of the growers were convinced that a considerable amount of the difference in yield originated from differences in basic pre-conditions due to soil quality, climate and so on and that some areas were always better than others and it was impossible to change that. Others discussed farmers' management as very important: "I think it's more about the individual farmer's management – how good he is at doing the right things at the right time, because in some way that later determines the … detail". The weather was also mentioned as being important: "If it doesn't rain there'll be no crop and if rains too much there'll be no crop" and the fact that the cultivation situation is very complex and it is difficult for anybody to say: "Do like this and you'll increase yield". One farmer wanted more support in making priorities when something was wrong: "That's where I want project 771 – we have two bad fields … what do I do to make sure they give the absolute maximum yield possible"? During two seasons a researcher investigated the qualities of the seedbed, but without giving feedback to the farmers until much later.

The most important finding from the project was that early sowing always results in higher yield if the emergence of seedlings is acceptable. Most of the farmers said that they knew this already, but that the project had verified it in a very explicit way. Many farmers talked about sowing time and crust breakage as two of the most critical situations in growing sugar beet, but said at same time that the project could not help them in making those decisions. When asked what could help them, some of them wanted a person to advise them when considering sowing and another one wanted help with adjustments of the harrow when breaking the crust: "There's nobody but us who sits and wonders about this and comes by and says perhaps you should raise it …".

Being part of a small learning community was very positive due to the farmers. Some of them had taken part in other groups for organic farmers, seed-growing farmers or private initiatives. They valued the possibility to discuss issues with colleagues both in the field and on meetings: "Sometimes the most important part of the meeting is what goes on at the coffee table”. Learning and discussing experiences in small groups was viewed as very valuable and a common way to learn. Trust and an intention to both listen to others and share information were considered very important to get fruitful cooperation. Two farmers said that it could sometimes be inconvenient to share knowledge and experience with colleagues, because they are also competitors, but if it was a group with people you trust or not very specialist crops, it was ok to share experiences.

8. Discussion

The project had high ambitions in terms of data collection, new forms of IT support and innovative ways of organising learning communities. For different reasons it did not achieve all its ambitions, but it provided important experiences and increased understanding of what it takes to develop the next generation of decision support systems. When developing a database for information exchange, the design and functionality must be well considered and probably interactively developed together with the end-users to be perceived as useful in practice. If there are field trials or investigations, farmers must be offered the results in a reasonable time. Furthermore, the collection of data must be well adapted to the intended outcome in terms of interpreted and applied results, as otherwise farmers will not use it. Increased exchange of information between researchers and farmers is one way to avoid unnecessary data reporting. Learning communities and other ways of letting farmers discuss experiences are another way and very well appreciated, being in line with how farmers say they learn and collect information.

This project demonstrated that much data can potentially be derived from cultivation of crops (here exemplified by sugar beet growing). However, the benefit of collecting these data must exceed the cost and thus it is relevant to discuss the cost-benefit relationship. The benefit for farmers may be difficult to quantify, as it depends on variables that are mainly subjective (e.g. awareness of one's own performance). Further work within the 5T-project will try to quantify this type of benefit by getting feedback from the farmers over the next few years. The benefit for researchers depends on the quality of the input (correctness of data) and cultivation variability (actual and historical) among the participating farmers. Furthermore, a well-calibrated growth model is required to include systematic variables such as weather, soil conditions and length of growing season. The costs connected to data collection could be much lower if more crops were studied, as weather and soil data are independent of crop. Furthermore, soil analyses are valid for several years and in some cases data are already available (nutrient content in soil is routinely quantified on many farms). An important step would be to integrate most of the cultivation-specific data into existing cultivating-planning software. The most costly data to obtain are probably growth data during the season, and for that reason this project focused on alternatives to hand-harvesting. Reflectance is by far the easiest alternative and could be useful for farmers when comparing their performance with that of a relevant reference group, but it must be assumed that reflectance cannot replace the real growth data that are needed in yield gap studies. It might be possible to reduce the workload of hand-harvesting by simply measuring the perimeter of tap roots while they sit in the ground, but that method needs further validation.

9. Conclusions

General conclusions

- Farmers were generally positive to the suggested data-based products, but pointed out that visualisation of data must be simpler and easier to access (e.g. linked to commercial cultivation planning software).
- We believe that the idea of including farmers in the development of products was good, but some of the tools (e.g. data sampling and database) were too premature to get the full advantage of this co-operation.
- The experiences gained in this project show that there is great potential in further development of approaches which build on a combination of in-field meetings and internet-based decision support systems.
- Future development of the concepts should optimally include more crops in order to get the full value of soil and weather data. Scaling up is also necessary to obtain a reasonable basis for research (this project mainly exemplifies the concepts of farm-based research).
- The project has led to further activities in relation to grower-generated knowledge (5T-project) which to a large extent build on the aims of this project.

Specific conclusions

- Yield gap studies (difference between observed and potential yield) are a simple way (if a growth model is available) to analyse data collected across time and place (and crop).
- The AB Sugar i-BeetGro model gave a reasonable simulation of biomass (on average, but probably not site-specifically), whereas the accuracy of simulated sugar yield was questionable (possibly owing to incorrect conversion of total biomass into sugar production of tap root).
    - Estimation of soil-available water content for growth simulations must be revised (data quality and use in the model).
    - Optimal use of growth models requires a network of weather stations to provide good local data.
- Comparison of three different types of sensor for measuring canopy reflectance revealed that vertical measurement appeared to give the best results.
    - Hand-held equipment (GreenSeeker) was successfully applied, but to efficiently increase the number of measurements per season, alternatives must be considered.
    - Reflectance measurements quantified growth, but could not replace real measurements (correlation across years and fields was too poor).
- The close relationship between weight and perimeter of tap root could potentially ease the onerous task of quantifying plant growth manually in sugar beet. The practical impact of different relationships between fields requires further study.
- Data on more than three harvests per year (e.g. mid June, August–September, November) are not expected to improve knowledge about sugar beet growth.

10. Literature

Baret, F.; Clevers, J. G. P. W.; Steven, M.D. (1995). The robustness of canopy gap fraction estimates from red and near-infrared reflectances: A comparison of approaches. Remote Sensing and Environment, 54, 141–151.

Qi, A.; Ober, E. (2013). Updating the BBRO/Broom´s Barn sugar beet growth model. British Sugar Beet Review 81(3) 29-32.