Final report for project:

Grower generated information knowledge systems – a way to identify and reach potential yield

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Background

The main idea of the project was to quantify crop growth over time in a number of sites and relate this to input factors (cultivation, soil fertility, weather). As part of this, different approaches of visualizing the data – and comparing the growers – was tested in order to give farmers, advisors and researcher the best possible conditions to document, discuss and understand the relationship between input and yield.

The aim

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

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

The concept

The basic idea 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 web)
- end-season follow-up (field report including bench marking)
- overview of common and new cultivation practices (based on physical and web-based contact to other farmers)
- supplying agricultural advisors with data, results and conclusion

Further, the collected data could possibly supplement traditional research through statistical analyses. One example would be to study the effect of crop rotation by combining data from a larger number of farms.

In this report much information has been condensed. A report containing detailed information will be available on the NBR home page www.nordicbeet.nu from November 2015 (NBR-report no. 2015-771).

Materials and methods

a. Sampling and processing of plants

Data were collected in the years 2010 to 2014. In 2013, only one site was followed (Sofiehøj) in order to focus on the use of canopy reflectance to measure plant quality and growth (Table 1).
Tap roots were taken to the laboratory washed and weighed. Leaves were weighed in the field and a sub-sample was taken home for dry matter estimation at 80–90°C. Larger tap roots and leaves were cut into smaller pieces and a sub-sample was analyzed. Sugar content was analyzed at the laboratories of Nordic Sugar in Örtofta, Sweden or Maribo Seed, Denmark.

Table 1 Overview of data surveys in the years 2010–2014

	Year				
	2010	2011	2012	2013	2014
Quantification of tap root and top weight					
- number of fields	5	12	12	1	10
- plots/field	2 x 4	6	6	6	6
- plot dimensions	4 rows x 2 m	2 rows x 4 m	2 rows x 4 m	4 rows x 4 m	2 rows x 6 m
- harvest times/growing season	4	5	5	6	3
Analyses of fresh and dry matter					
- 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				x
- sugar content at final harvest	x	x	x	x	x
Additonal analyses of 24 beets/site					
- fresh weigth 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 - washed beets			x		
Canopy reflectance					
- sensors					
- Skye	x	x	x	x	
- Yara N-sensor		x	x	x	
- GreenSeeker				x	x
- number of meas./plot/season/sensor	18	5	6	20	13

b. Canopy reflectance

The project activities comprising canopy reflectance is summarized in Table 1. Due to a range of different technical and practical limitations, less data than planned were collected in 2011 and 2012 (5–6 measurements per season). In 2010, 18 measurements were made during the season. The results of the 2010-measurements were reported earlier (2011). 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 with different design and sampling methodology, 2) Compare reflectance profiles of different beet varieties and to relate reflectance profiles to real growth.

The first measurements were made in 2010 with sensors from Skye. As a single sensor covers only around 0.3 m^2 (depending on height above canopy), it was rather time consuming to get representative measurements from plots distributed across a field. Therefore, an ATV was equipped with sensors for the purpose of measuring canopy reflectance while passing by the plots. To ensure an even weighting of rows and in-between rows, two sensors were mounted side by side and 25 cm apart (half row distance). 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, the hand-held GreenSeeker from Trimble was included in the study. In opposite to the two other sensors, measurements with the GreenSeeker were made while walking across plant rows to get an even weighting of rows/in-between rows.

Attempts to calculate actual growth in 2013 based on NDVI included four steps of calculations. The first step was to model daily dry matter production (DDP) .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. This was done to reduce the impact of single measurements as these sometimes were affected by the time of the day they were carried out (leaves are generally more vigour 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 a NDVI-corrected dry matter production (estimated yield; EY). 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.

In 2014, ten sites were measured with the GreenSeeker 13 times during the growing season. These data were combined with potential growth obtained from the AB Sugar i-BeetGro Sugar Beet Growth Model using the same steps as in 2013.

c. 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 would be an advantage. For that reason, values of tap root weight and shape was collected for over 1,200 individual tap roots in 2012 in order to predict tap root weight on the basis of tap root length, perimeter or area. Area was here obtained by digitally measuring the tap root surface on a photo. The beets that were used were randomly chosen in each field by picking beet no 4, 5, 7 and 11 in the first row and beet no 3, 5, 8 and 10 in the second row (counting from the opposite end) in three of the six plots.

d. Soil texture and nutritional content

The analyses were made as standard analyses by commercial laboratories. In 2014, samples were both analyzed in Denmark and Sweden as methodology in some cases differs and because results are reported and used differently in the two countries. In 2012 and 2014, soil texture was also determined for the B-horizon (30–60 cm) and further, soil density was determined in 2012 (sampling of 2 x 8 rings/sites (100 cm^3) in both the A and B-horizon). This information may be used in some growth models (e.g. Daisy) to improve simulations. Along with soil texture analysis, also the nutritional content was determined for the 2014-samples from 30–60 cm. N-min samples are normally taken in February. As choice of field and placements of plots until 2012 were decided after plant emerge (and application of fertilizer) N-min analysis are only available from 2013 and onwards.

e. Plant pathogens/parasites

Analysis for beet cyst nematodes is included in all years from 2011. From 2014 and onwards, soils were also quantified for free living nematodes. Sample for nematodes were taken in the upper 20–30 cm and brought to the nematode laboratory in Alnarp for analysis. Analysis for root-attacking fungi (mainly *Aphanomyces*) was bio-assay-based (cultivation of beets in soil sample in glass houses. Finally, soils were tested for the presence of Rhizomania.

f. Cultivation

This information was reported by the grower. “Historic” cultivation is an attempt to quantify or characterize previous cultivation (last 20 years) at the studied sites. The data were collected through interviews of the growers and finally harmonized. In this process, rough estimates or approximations were sometimes used. The roughest estimates were generally made for dry matter production of catch crop and in some cases for straw removal.

g. Photos

Photography was used systematically in 2011 and 2012. The photos were defined into three different types: Field view, “zoom” and “air” depending on the angle they were taking in. All photos were arranged in Picasa (online accessible photo database provided by Google) and tagged with identification code (photo type and grower name) and GPS-coordinates (geo-tagging).

h. Weather data

Weather data was used in the AB Sugar i-BeetGro model. Gradually 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 collected locally by Hobo loggers. Rain fall was registered locally using a combination of electronic rain gauge (rain-O-matic/Hobo) and manual registrations by the growers. In the cases where weather was not registered locally (2010–2011 and partly in 2012 and 2014), weather data was taken from the nearest weather station (SMHI and Nordic Sugar) or by combining data from two or more stations.

i. Communication and knowledge transfer
In order to give the farmers access to data and photos, a project homepage was created. The homepage was active in 2011–2012. From here, organized data (e.g. growth curves in Excel-database) and photos from the field were available. Project meetings, involving all participants, were arranged where the project results were presented and discussed. Physical meetings were arranged in the field in 2011–2012. These meetings focused on knowledge transfer between farmers based on the actual situation in the field.

j. Growth model
The AB Sugar i-BeetGro model was used for simulation of beet growth. (kindly been supplied by British Sugar). The model requires the input described below. The first version of the model was developed upon yield data from 1980–1991 and in 2011 a second version came which had been improved in a number of ways (Aiming et al., 2013).

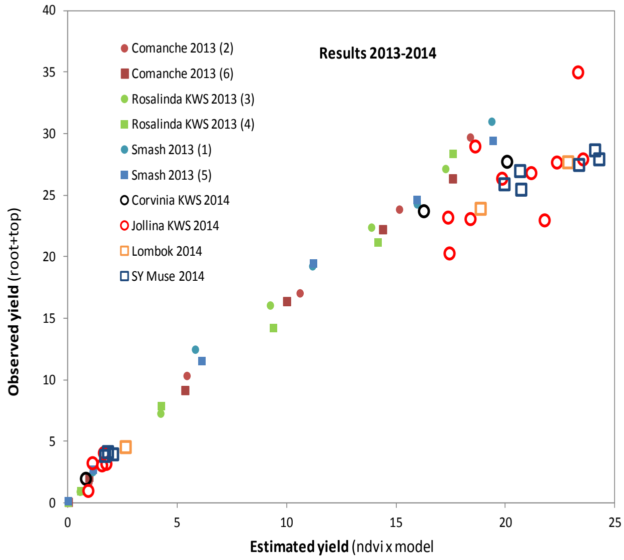

Figure 1. Correlation between growth (estimated by the combination of theoretical growth data and NDVI) and observed growth in 2013–2014. All NDVI-measurements were carried out with GreenSeeker from Trimble

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Water availability is in the model described by the soil parameter “b” and the amount of plant available water. Both factors are linked to the soil type. In the project, the value for soil available water was specifically calculated for each site. The calculations were based on the content (%) of clay, sand and organic matter in the A-profile in 2010–2013 and the A- (75% weight) and B-profile (25% weight) in 2014. For the calculations, formula developed by Dr. Keith Saxton was used (available as Excel file). Some uncertainty exists concerning the correctness of soil texture analysis (conflicting results from laboratories). Further, the above mentioned formula generated values that generally were markedly lower than reported elsewhere (Madsen and Platou 1983) and a general adjustment (x 1.7) has been added to all calculations of soil available water. Due to this, it is highly recommended that the estimation of water availability is critically reviewed.

The model requires input on a daily basis of minimum and maximum temperature, rainfall, radiation and evapotranspiration. Evapotranspiration was estimated by the use of a modified Penman equation that in addition to the above mentioned weather data required minimum and maximum humidity and wind speed. Simulated yields were adjusted for variety effects by using the same variety (Rosalinda KWS) as standard in each year (Rosalinda KWS was also used for calibration of the model in 2011).

k. Evaluation of the concept by the farmers

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 an outcome of the project. In May 2013 interviews with ten of the twelve participating farmers were carried out by SLU, Skara. The evaluative interviews took about one hour and were performed as semi-qualitative field interviews.

l. Data analyses

All data from the years 2010–2014 have been organized in Excel-files with simple structures (data lists). By combining these in different ways (using the statistical program SAS), examples of output have been constructed. For simplifying data analyses and to reduce the number (and complexity) of explanatory variables, the collected cultivation data were condensed into 30 cultivation-specific variables (CS-variables) with each three categories (two for ploughing) of input. As one of 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 (mid-category=10–20 t/ha potential dry matter).

Results

Canopy reflectance and growth

For all three studied sensors, the correlation between estimated and observed yield in 2013 was at a high level. In general, the GreenSeeker gave the best correlation and when the sensor was used to estimate tap root growth, correlation was above 0.9 for all harvest times (data not shown). The correlation between observed and estimated yield correlated less well in 2014 and further, the relationship was different than in 2013 (Figure 1).

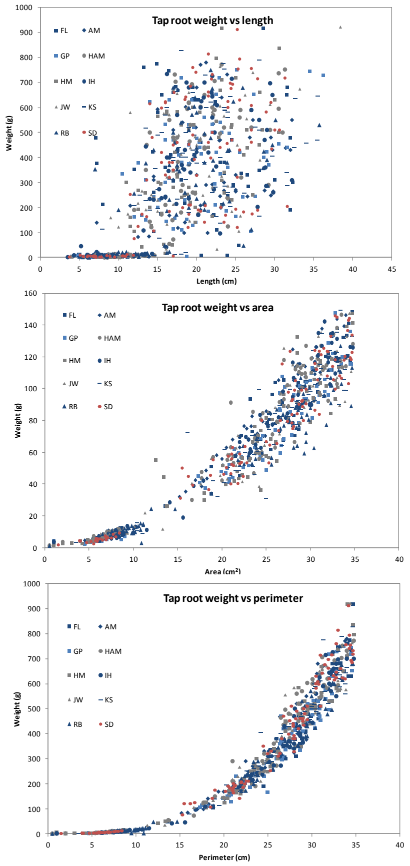

Figure 2. Relationship between tap root length, (upper graph) tap root area or tap root perimeter (lower graph). Tap root area was measured using photometry.

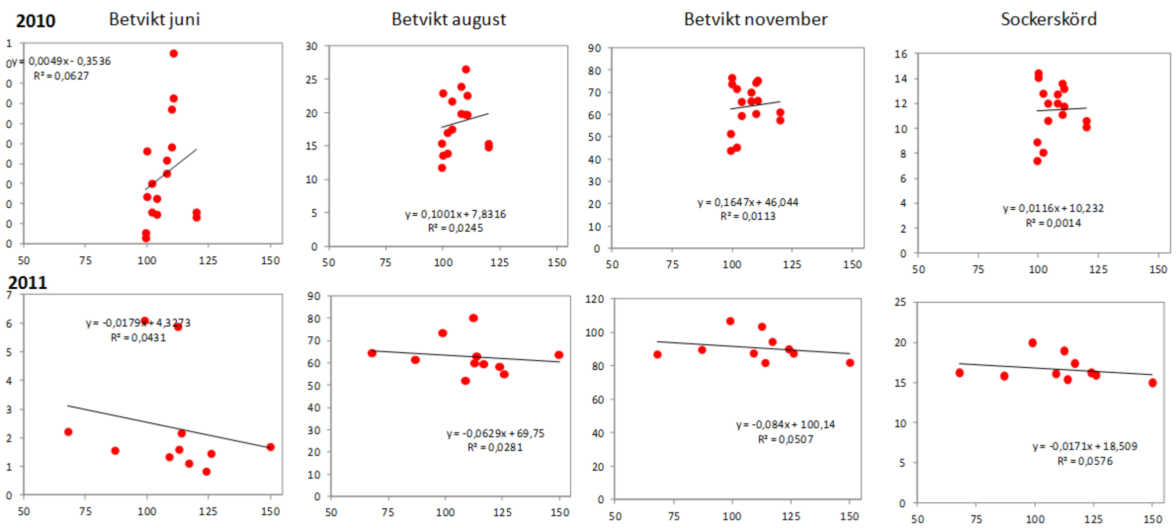

Figure 3. Input-output relationship as exemplified for use of N-fertilizer in 2010 and 2011.

Relationship between beet shape and beet weight

The closest relationship was found between weight and perimeter and secondly between weight and area, whereas the relationship between weight and length was poor (Figure 2). Further analyses revealed that both in the case of area- and perimeter based estimation of tap root weight the impact of site (field) was statistically significant.

Data analyses

In the following, different approaches to use data are given.

a. Input-output regressions

A simple approach to get an overview of the data is to plot the various outputs (yields) versus the various inputs. The advantages of these plots are that variation in magnitudes of input and output becomes visually very clear and that trends in the data can be detected. As an example the tap root weight in June, August and November and the final sugar yield was plotted against used amount of N-fertilizer (Figure 3). It is obvious that the range of N-input was much narrower in 2010 than in 2011 and that sugar yields varied much more in 2010 than in 2011. Regarding the correlation between N-input and yields, no obvious trends seem to be present in 2010, whereas the 2011 data indicate a negative relationship between input and output.

b. Observed and potential yield

The AB Sugar i-BeetGro model was used to estimate potential growth for every harvest time at all sites and next, observed and potential growth was correlated (Figure 4). The explanatory data have been condensed into 30 cultivation-specific variables (CS-variables) with each three categories of input. In addition, the effect of year was tested. In this test (Table 2), only the CS-variable "Plants/ha" had a significant effect (relative yield was reduced to 66% when plant numbers in June were less than 75,000/ha). The effect of year was almost significant. However, data were 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 the years was due to grower's performance (better in 2014 than in 2011–2012) or the calibration accuracy of the model.

Another finding of the test results in Table 2 was that the yield gap depended on yield level as yield gap was bigger (66% relative yield) at low yields (beginning of the growing season) than at high yields (end of the growing season).

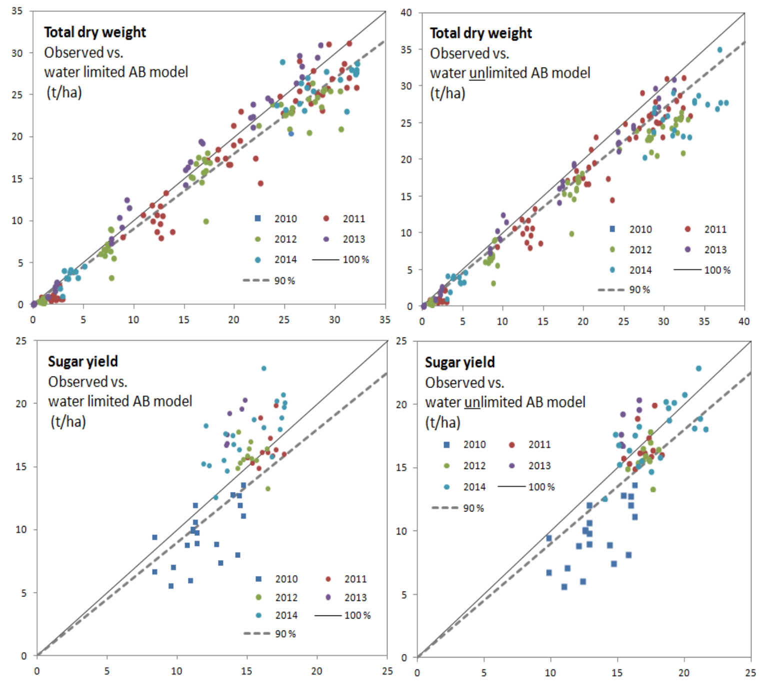

Figure 4. The relationship between observed and potential yield for the four different outputs of the growth model.

The statistical results in Table 2 were based on relatively few observations and serves mainly as an exemplification of how the collected data may be used to explain the differences between growers.

c. Low- and high-end growers
An alternative approach to possible explain the yield gap between observed and potential yield was to compare growers with a big yield gap (low-end growers) with growers that have a low yield gap (high-end growers). In this approach best farming practice for each single cultivation-specific variable (CS-variable) would be expected to have a high frequency of high-end growers. The results are not shown as more data are required before this approach can be expected to lead to valid conclusions.

Table 2. Effect of ten cultivation-specific variables on the relative yields. In addition the effect of year and yield level is shown

			yield gap / category[1]		
Variabel	**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 fertilizer	0,01	0,99	81	80	80
S fertilizer	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
Oil seed 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 mater yield in 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)

Yield correlations between harvest times
In 2011–2012, the plots were harvested five times during the growing season.
The correlations between the yields at the different harvest times (Table 3) may be used to 1) Decide frequency and timing of harvest, 2) Get a picture of growth over time.

Evaluations by the farmers
The farmers were positive to the concept, including large data collection from each farm, new meetings and the ambition to create learning communities. The majority of farmers had looked at the images from their own and others fields. 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 basis for decision making. All farmers had been very positive to the database in the beginning, but at the end of the project they had become more critical. They questioned that the huge amount of data that was reported was not compiled in such a way that they could use it. They were also asking for better and more 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.

Table 3. Correlation between yield of tap root and top at different harvest times (B-Z, Z=final harvest). The interval between harvest times was approximate 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

Discussion
The project had high ambitions in data collection, new forms of IT support and innovative ways of organizing learning communities. For different reasons it did not reach all the way, but it has given important experiences and increased our understanding of what it takes to develop the next generation 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. An increased information exchange

between researchers and farmers is one way to avoid unnecessary data reporting. Learning communities and other ways of letting farmers discuss experiences made are another way and very appreciated, being in line with how farmers say they learn and collect information.

This project demonstrated that much data potentially can be derived from cultivations of crop (here exemplified by sugar beet growing). The benefit of collecting these data must however exceed the cost and thus it is relevant to discuss the cost-benefit relationship. The benefits for the growers may be difficult to quantify as it depends on variables that are mainly subjective (e.g. awareness of own performance). Further work within the 5T-project will try to quantify this type of benefit by getting feed-back from the farmers over the next years. The benefits for research will depend on the quality of the input (correctness of data) and cultivation variability (actual and historic) among the participating growers. Further, a well-calibrated growth model is required to include systematic variables like 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. Further, soil analyses will be valid for several years and in some cases already available (nutritional value of soil is routinely quantified on many farms). An important step would be to integrate most of the cultivation-specific data in already existing cultivating-planning software. The most costly data to get is 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 the farmer to compare them self with a relevant reference group, but we assume that reflectance cannot replace the real growth data that are needed in yield-gap studies. It might be possible to reduce the work load of hand-harvesting by simply measuring the perimeter of tap roots while they sit in the ground, but the method needs further validation.

Conclusions

General conclusions

- Growers were generally positive to the suggested data-based products but visualizing of data must be simpler and easier to access (e.g. linked to commercial cultivation-planning software).
- We believe that the idea of including growers 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 corporation.
- The experiences made in this project have shown that there is a great potential in further development of approaches which build on a combination of in-field-meetings and web-based decision support systems.
- Future develop 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 yields) is a simple way (if a growth model is available) to analyze data that is 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-specific) whereas the correctness of simulated sugar yields was questionable (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 ensure local data.

- Comparison of three different types of equipment for measuring of 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/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 easy the large work of quantifying plant growth manually in sugar beets. The practical impact of different relationship between fields requires additional studies.
- More than three harvests per year (e.g. Mid-June, August–September, November) are not expected to improve knowledge about growth.

Transfer of results to stakeholders and publications

Oral presentation
Results and conclusions at NBR winter meetings during 2011-2014.

NBR Board meetings
Based on the results and experience from this project the NBR Board gave approval to project 5T, a new grower generated knowledge project that started in 2014.

Publication to Beet growers
Otto Nielsen 2014. Sensorbaserade tillväxtmätningar i sockerbetor. Betodlaren 2014-3, 63–66.
Robert Olsson 2014. Nu startar projekt 5T. Betodlaren 2014-1, 38–40.

NBR-report
Otto Nielsen, Robert Olsson, Magnus Ljung, Christina Lundström (in prep.). The use of farm data in extension service and research. Case study and development of concept 2011–2015. NBR-Report 771-2015.