Modellering av korn och havre för bättre och säkrare beslut för odlingen i norra Sverige

Modelling barley and oat for improved decision making in Northern Sweden

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Contributions of Authors

Uttam Kumar – Project management, field data collection, data analysis, modelling, report writing.

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Background

Optimum crop production for a location is based on selection of the best cultivars, crop management practices and crop growing conditions. The selected cultivars based on the their phenology, morphology and physiological requirements most efficiently capture resources (light, water, nutrients) to convert them into yield in different environments. The number of available cultivars and crop management practices for crop production are always definite. However, the climate is variable and unpredictable. Many possible combinations of cultivar, management and climate make it difficult to predict the performance of a cultivar (or crop) in a certain environment. It is sometime difficult for farmers to select a cultivar and a set of management practices that combine to result in the highest possible yield at farm level. To improve the decision making capacity of farmers in selecting cultivars and complementing management practices it is important to provide information on the responses of various cultivars to different management practices and growing conditions.

This constraint can be lessened by studying various current cultivars under different management practices grown for many years, to understand the risks and advantages of the selected cultivar and management options. Such studies conducted in a conventional way, require a large amount of labour, time, money and resources, and hence are very difficult to conduct and are not practical. However, the same goal can be achieved by using other tools for assessing crop production, such as crop models, which take inputs of soil characteristics of the concerned locations, and management decisions, and simulate growth and development of various cultivars.

The objective of this study was to identify the best management practices for improved production and reduced risks for barley and oat varieties at eight locations in Northern Sweden: Röbäcksdalen, Ås, Öjebyn, Offer, Skellefteå, Vojakkala, Sundsvall and Ockelbo (Fig.1) using a crop modelling approach. The additional funding from RJN enabled an on-going project for the first four locations to be extended to four more locations in Northern Sweden.

The APSIM crop model (https://www.apsim.info/) was used for the study. The combinations of management practices we evaluated were: 6-11 different sowing dates, depending on the location, 11 fertilizer treatments and 12 barley cultivars. In addition, 19 years (2000-2018) were simulated for the eight locations. A range of achieved yields, crop failures, best sowing dates, fertilizer treatments and cultivars for each studied locations are discussed under work package 4. We have also included all the field data in this report that were collected during the study for calibrating and validating APSIM. Additionally we have provided growing degrees days for 19 years for all studied locations.

Figure 1: Eight locations in Northern Sweden for the study

Project Structure

Work package 1: Collect growth and development data from on-going barley and oat variety trials from Northern Sweden.

Work package 2: Collect and organise soil and weather data.

Work package 3: Calibrate and validate APSIM Barley and Oat models.

Work package 4: Model application to select best variety and management practices

Activities and Results

Below are descriptions of proposed and completed activities and achieved results for each work package.

Work package 1: Collect growth and development data from on-going barley and oat variety trials from Northern Sweden

Proposed Methods and Activities:

1. Analysis of plant and soil samples collected from an existing project.
2. Collect additional data from variety trials in 2018

Completed activities and achieved results

Barley and oats crop data were collected during the 2017 and 2018 cropping seasons from Ås, Röbäcksdalen, Lännäs and Öjebyn and were prepared for APSIM crop model calibration and validation. Data curation for performing simulation made us realise that growth data from Ås, Lännäs and Öjebyn had a high variability. We used growth data from Röbäcksdalen to perform calibration of phenology and dry matter accumulation and partitioning of 12 barley varieties and 5 oats varieties. For calibration of phenological stages, the data for all four locations were used, not only for two years 2017 and 2018, but from 2014 until 2018 (Table 1). Additionally, data for 2014-2018 from a location in Finland, Ruukki, were obtained for phenology model validation.

Data of some important variables of barley and oats varieties that were used for model calibration are presented in Figures 2 & 3 for barley. An extensive list of variables is presented in Appendix 1 for both crops (barley: Table1 and oats: Table 2).

From the plant samples collected from 2017 and 2018 cropping seasons at Ås, Röbäcksdalen, Lännäs and Öjebyn, different plant parts of barley and oats varieties were analysed for C and N. The aim of this process was to calibrate and validate carbon and nitrogen partitioning to model protein content in the grains.

Since the calibration and validation for yield (carbon portioning) were the major foci to optimize the best management practices of the two crops for the eight locations in Northern Sweden, we did not include N content of different plant parts in the calibration process. Yield formation in APSIM is not directly regulated with N content in the plant organs, rather it is the opposite case: N content is dependent on yield formation. Thus, the calibration and validation of APSIM for yield formation is according to the objectives of this study.

Nevertheless, the C and N data of all the varieties are provided in Appendix 3, and will be made available to open source platforms, such as the SITES portal.

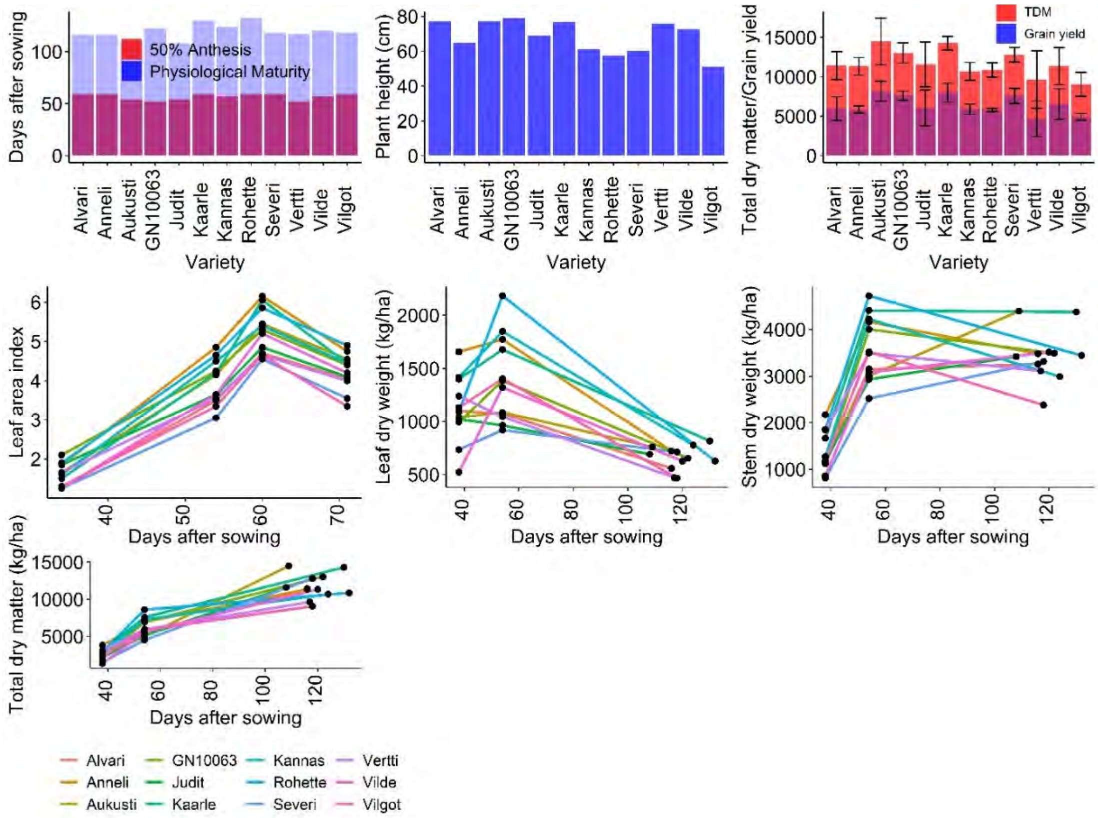


Figure 2: Data on different variables collected from 2017 at Röbäcksdalen for growth and development of twelve barley varieties.

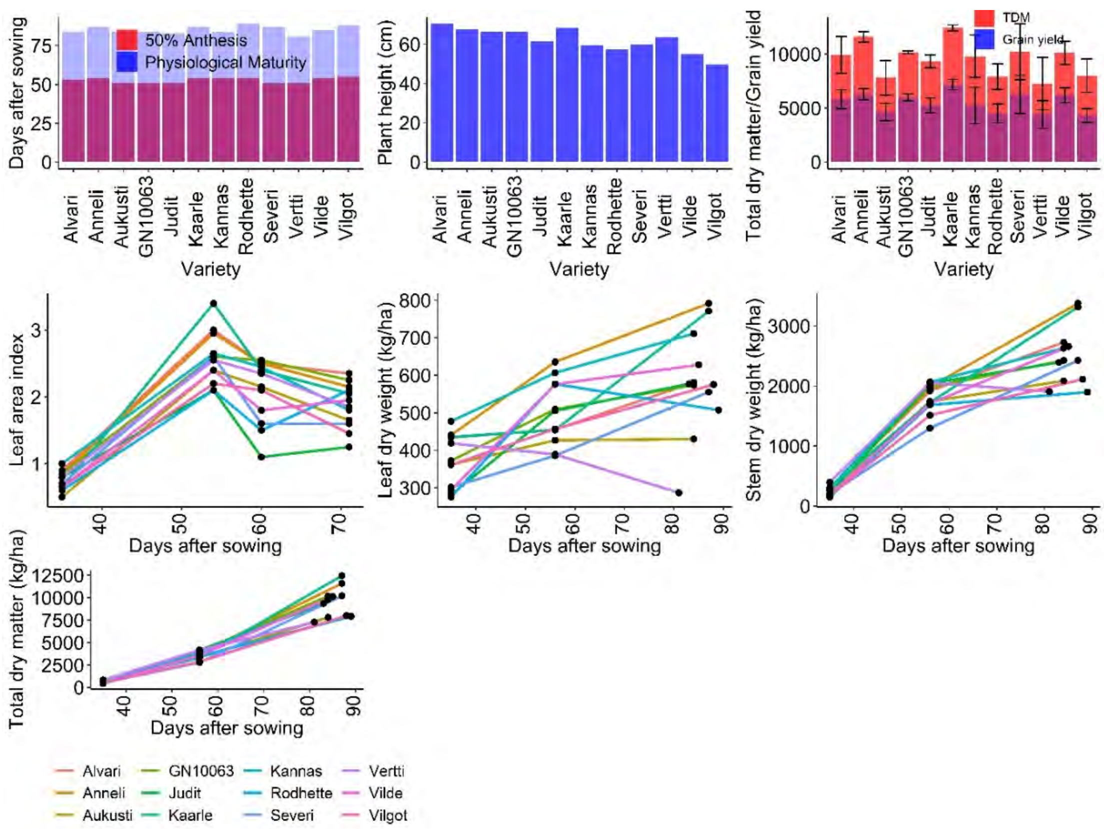


Figure 3: Data on different variables collected from 2018 at Röbäcksdalen for growth and development of twelve barley varieties.

Table 1. Phenology of twelve barley and five oat varieties for the 2014-2018 cropping season. Anthesis: days to 50% anthesis after sowing; PM: physiological maturity; Numbers in the parenthesis indicate a 6-row barley (6R) or a 2- row (2R) variety.

Barley Phenology (days)																						
	Röbäcksdalen							**Öjebyn**					**Offer**					**Ås**				
Varieties	2014	2015	2016	2017		2018		2014	2015	2016	2017	2018	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
	PM	PM	PM	Anthesis	PM	Anthesis	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM	PM
Alvari (6R)				59	116	53	84				110	85				99	75				131	
Anneli (2R)			100	59	116	54	87			104	108	87			107	103	77			109	136	83
Aukusti (6R)	84	105	87	54	109	51	84	74	100	99	105	81	71	100	89	98	74	81	92	100	125	
GN10063 (6R)			98	52	122	51	84			100	108	79				103	74			103	141	
Judit (6R)	76	108	93	54	108	51	83	73	98	97	105	78	70	98	89	93	74	80	83	100	126	
Kaarle		117	100	59	130	54	87		112	126	112			109	116	109			105	109	146	
Kannas (2R)	88	111	105	57	124	54	84	84	110	107	108	86	79	108		104	75	97	98	112	142	83
Rödhette (6R)				59	132	54	89				116	92				109	77				144	82
Severi (6R)	81	116	91	59	118	51	87	76	106	102	109	80	72	106	95	102	74	88	97	103	130	
Vertti (6R)		98	91	52	117	51	81		103	91	107			101	84	94			88	100	124	
Vilde (6R)	83	103	90	57	120	54	85	75	104	97	108	82	72	103	88	101	75	86	96	102	126	
Vilgott (2R)	96	121	104	59	118	55	88	87	114	112	112	90	81	112	99	110	77	103	109	115	139	89
Mean	**84**	**110**	**96**	**57**	**119**	**53**	**85**	**78**	**106**	**104**	**109**	**84**	**74**	**105**	**96**	**102**	**75**	**89**	**96**	**105**	**134**	**84**
SD	**7**	**8**	**6**	**3**	**7**	**2**	**2**	**6**	**6**	**10**	**3**	**5**	**5**	**5**	**11**	**6**	**1**	**9**	**9**	**5**	**8**	**3**
Oats Phenology (days)																						
Akseli	86	105		57	121	57	81	76	109				75	74		103						
Avetron	81	104		57	129	55	83	78	104	98		75	75	74	86	103	74					
Cilla	83	105	99	59	133	56	84	75	102	98		83	74	73	83	101	76					
Haga	92	113	99	61	139	56	84	78	117	101			76	83	88	105	74					
Niklas	81	104	100	57	120	56	80	78	102	97			76	75	83	103						
Mean	**85**	**106**	**99**	**58**	**128**	**56**	**82**	**77**	**107**	**99**		**79**	**75**	**76**	**85**	**103**	**75**					
SD	**4**	**4**	**1**	**2**	**8**	**1**	**2**	**2**	**6**	**2**		**6**	**1**	**4**	**2**	**1**	**1**					

Work package 2: Soil and weather data

Proposed Methods and Activities:

1. Collection of soil samples and analysis of soil properties (including initial soil Nitrogen content, Bulk density, field capacity, wilting point, etc.) at the additional proposed locations.
2. Collection of earlier reports and publications of soil properties for the locations for validation and understanding trends.

Completed activities and achieved results

Soil data for running the model

Soil sample collection for the proposed locations i.e. Vojakkala, Skellefteå, Sundsvall and Ockelbo was originally planned in spring 2019 for analysing field capacity, wilting point and saturation. We collected the samples which were analysed for these soil parameters for Ås, Röbäcksdalen and Lännäs and the results were compared with the data reported in earlier reports[1] using APSIM. Since the purpose of the soil samples collection was for lab analysis and use in modelling barley and oats behaviour, the comparison exercise was important to assess whether or not the lab measured data could improve APSIM calibration and validation. The comparison showed that the APSIM simulated similar outputs with either data set, i.e. the data obtained from the lab or from the historical reports. Based on this, we decided to use the data for Ås, Röbäcksdalen and Lännäs obtained from the lab and for Vojakkala, Skellefteå, Sundsvall Ockelbo and Öjebyn from the reports.

The reports on the characteristics of soils from Norrbotten, Västerbotten, Västernorrland and Jämtland were collected and extracted data were compared with the lab data for the same locations in 2019. Soil characteristics data for all studied locations used for modelling with APSIM are provided in Table 2.

Mean water holding capacity (saturation and field capacity) for a 100 cm soil profile at Ås was the lowest and Röäcksdalen had the highest. Wilting point at Offer was lowest and Ockelbo was highest. For Skellefteå, saturation point was available from the report and other characteristics were assumed to complete the soil profile. For Vojakkala, there were no soil characteristics data available in the reports thus the profile was made similar to Öjebyn.

During the crop duration of 2017 and 2018 soil moisture observations were also recorded with a Diviner2000 to compare with the APSIM simulations. The observed data and simulated response of APSIM are presented in Figure 4. The comparison is shown in two categories: 1) sum of available water of 0-30 cm of soil profile and 2) 0-100 cm of soil profile. The data showed that 2018 cropping season was dry compared to 2017, which was visible in both categories. The soil profile started to dry around 40 days after sowing during the 2018 cropping season. Continuous lines, which represent the APSIM response for both years, showed that the model was in close agreement with the observed data, represented with dots.

[1] Andersson , S. , & Wiklert , P. (1977) . Studier av markprofiler i svenska åkerjordar. Del II. Norrbottens-, Västerbottens-, Västernorrlands- och Jämtlands län . Swedish University of Agricultural Sciences, Department of Soil Sciences, Division of Agricultural Hydrotechnics . Report 104.

Table 2. Soil moisture characteristics for eight locations used in APSIM. Data for Röbäcksdalen, Offer, and Ås were lab measured. The data for Skellefteå, Sundsvall, Ockelbo, Vojakkala were obtained from earlier reports.

Depth (cm)	Saturation point (g/g)	Field capacity (pF 1m) (g/g)	Wilting point (g/g)	Dry bulk density (g/cm³)	Saturation point (g/g)	Field capacity (pF 1m) (g/g)	Wilting point (g/g)	Dry bulk density (g/cm³)
	Röbäcksdalen				Sundsvall			
0-10	37.72	34.20	6.43	1.29	50.20	40.10	8.20	1.28
10-20	46.75	35.32	6.44	1.01	48.10	41.20	9.50	1.29
20-30	62.21	44.78	6.61	0.88	47.95	39.40	9.25	1.31
30-40	62.21	44.78	6.61	0.88	50.05	36.85	8.55	1.22
40-50	50.91	42.74	6.76	1.10	44.85	34.10	9.50	1.43
50-60	50.91	42.74	6.76	1.10	44.90	34.90	11.00	1.43
60-70	40.65	38.20	6.16	1.30	45.65	36.00	13.25	1.38
70-80	40.65	38.20	6.16	1.30	45.50	39.65	15.75	1.41
80-90	40.65	38.20	6.16	1.30	48.45	41.10	16.50	1.36
90-100	44.25	41.29	5.81	1.22	47.95	44.20	17.15	1.32
	Öjebyn				Ockelbo			
0-10	45.55	37.60	14.35	1.28	58.65	40.10	12.25	0.99
10-20	45.55	32.25	14.35	1.28	56.85	41.20	13.30	1.06
20-30	50.05	32.75	15.10	1.42	42.50	34.40	14.10	1.54
30-40	44.25	31.25	18.60	1.44	38.85	29.00	13.85	1.65
40-50	44.00	31.40	20.15	1.43	39.70	31.10	22.00	1.62
50-60	42.50	36.55	6.40	1.51	42.10	34.90	29.85	1.58
60-70	41.90	31.75	2.55	1.53	43.95	36.00	29.65	1.56
70-80	46.90	31.65	12.20	1.41	44.60	39.65	27.85	1.52
80-90	47.15	36.00	16.80	1.40	45.50	39.65	22.75	1.50
90-100	43.90	40.15	3.65	1.53	40.95	39.65	14.75	1.58
	Offer				Skellefteå			
0-10	33.95	29.54	6.28	1.36	58.65	40.10	8.00	1.03
10-20	36.04	29.87	6.23	1.30	58.67	40.10	8.00	1.03
20-30	30.50	27.85	6.55	1.45	56.69	41.20	9.00	1.06
30-40	30.50	27.85	6.55	1.45	56.69	41.20	9.00	1.06
40-50	30.19	26.99	6.26	1.38	56.69	41.20	9.00	1.06
50-60	30.19	26.99	6.26	1.38	56.69	41.20	9.00	1.06
60-70	30.32	28.02	6.32	1.43	42.50	34.40	10.00	1.39
70-80	30.32	28.02	6.32	1.43	42.50	34.40	10.00	1.39
80-90	30.32	28.02	6.32	1.43	42.50	34.40	10.00	1.39
90-100	31.42	29.43	6.32	1.45	42.50	34.40	10.00	1.39
	Ås				Vojakkala			
0-10	32.71	27.53	11.14	1.35	45.55	37.60	14.35	1.35
10-20	33.09	21.18	10.96	1.29	45.55	32.25	14.35	1.29
20-30	36.93	20.39	9.35	1.24	50.05	32.75	15.10	1.24
30-40	36.93	20.39	9.35	1.24	44.25	31.25	18.60	1.24
40-50	19.05	15.99	11.29	1.75	44.00	31.40	20.15	1.75
50-60	19.05	15.99	11.29	1.75	42.50	36.55	6.40	1.75
60-70	25.62	16.96	13.74	1.34	41.90	31.75	2.55	1.34
70-80	25.62	16.96	13.74	1.34	46.90	31.65	12.20	1.34
80-90	25.62	16.96	13.74	1.34	47.15	36.00	16.80	1.34
90-100	25.62	16.96	13.74	1.34	43.90	40.15	3.65	1.34

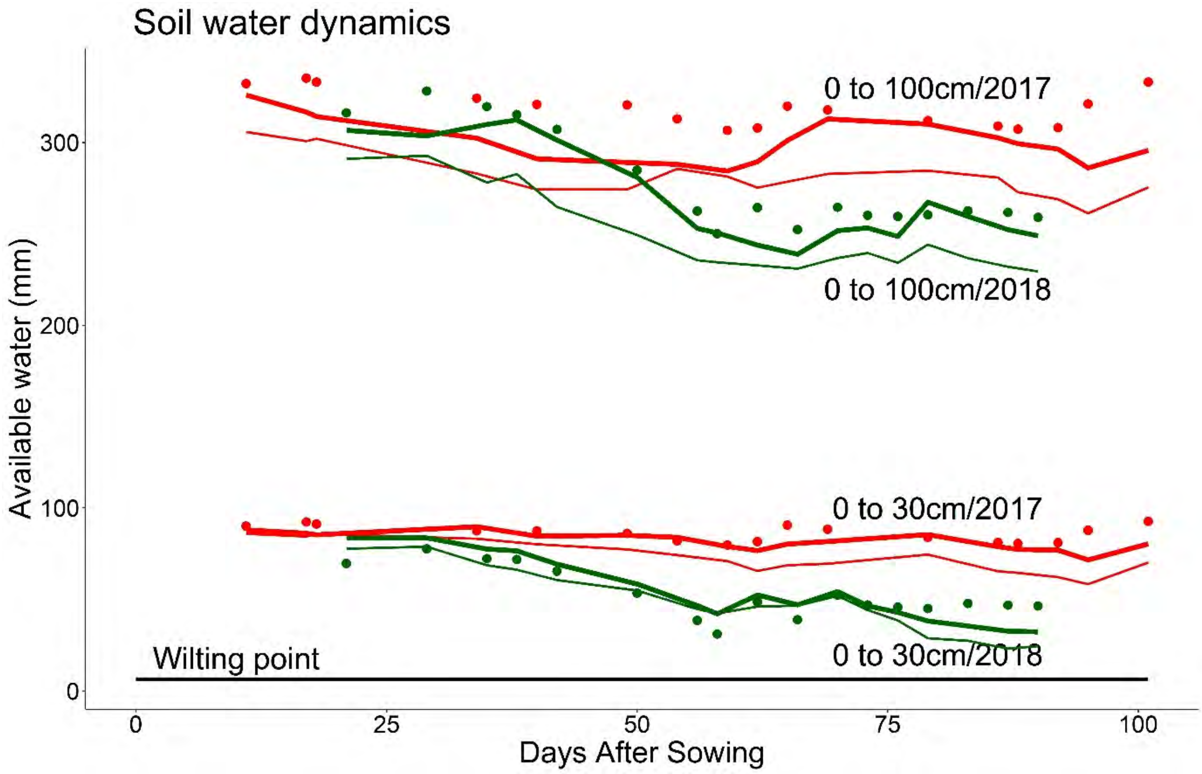


Figure 4. Plant available water dynamics during 2017 and 2018 at Röbäcksdalen. The dots represent the observed data and continuous lines represents APSIM simulations: thick lines are for APSIM7.9 and thin lines are for APSIM-NG simulations.

Weather data for running the model

Historical weather data for 19 years (2000-2018) for all eight locations were downloaded from LantMet and SMHI and prepared for modelling under work packages 3 and 4. The climatic factors that drive phenological and biomass accumulation in APSIM are presented in Figures 5-7. Global radiation regulates biomass accumulation in the model – data are shown each day for all 19 years and eight locations. Maximum and minimum temperature regulate phenological development (Figure 6); and rainfall regulates both phenology and biomass accumulation (Figure 7).

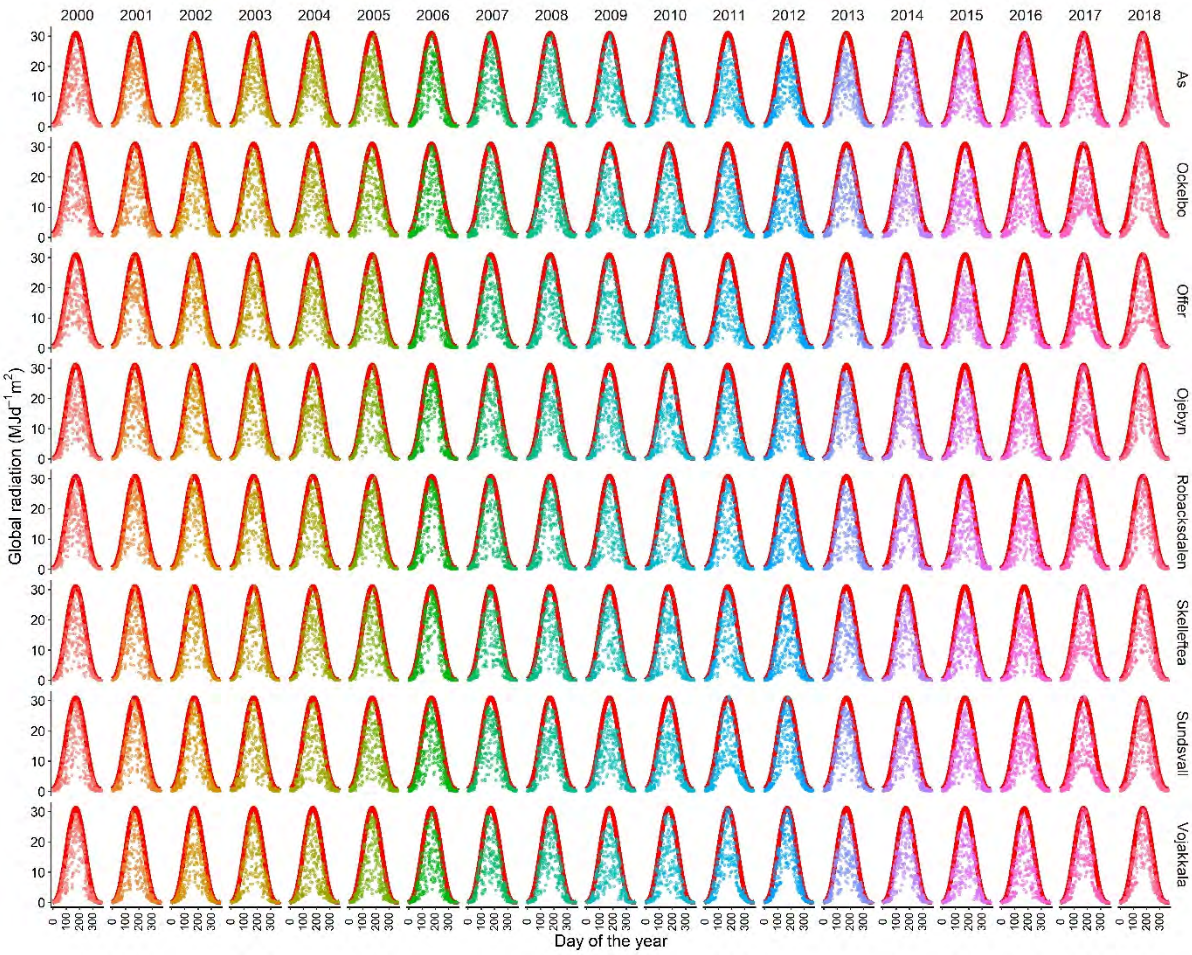


Figure 5. Global radiation at eight locations for 19 years (2000-2018) used to perform the simulations with APSIM. Red continuous line represent the clear sky radiation and dots represent the radiation on all sky conditions for each day of the year.

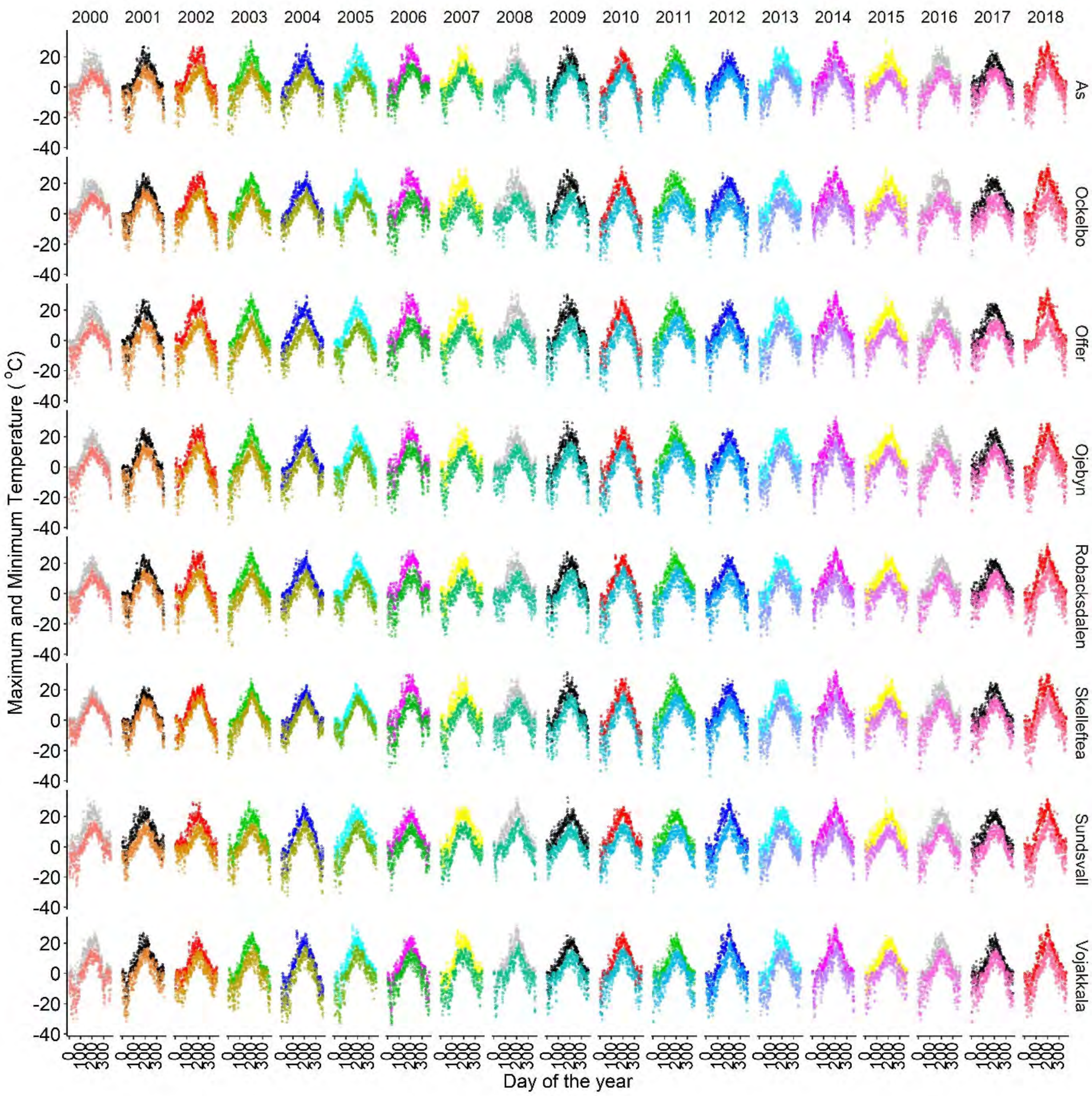


Figure 6. Maximum and minimum temperature at eight locations for 19 years (2000-2018) used to perform the simulations with APSIM. Under each year and for each location the upper set of dots represents the maximum temperature and the lower dots the minimum temperature for each day of the year.

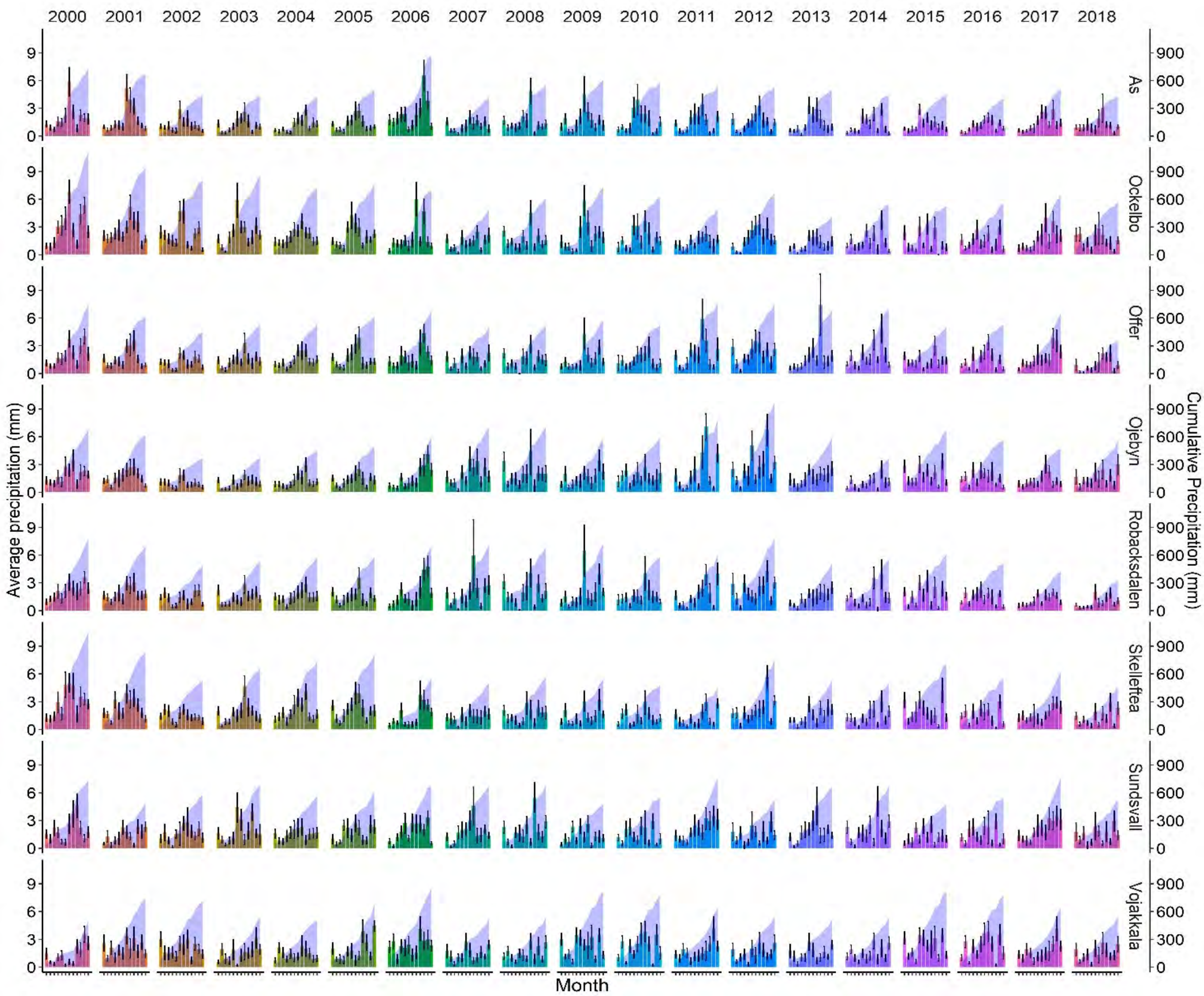


Figure 7. Average precipitation for each month of the year represented by bars and standard deviation at eight locations for 19 years (2000-2018) used to perform the simulations with APSIM. The monthly accumulations of precipitation are represented by area graphs with amounts on the right-hand-side y-axis. Tick marks on the x-axes represent months of the year from January to December.

Degree days for the locations and years

We also calculated degree days from May 01 to November 30, every year for each location. The method of degree day computation was as follows:

$$\sum Degree\ day = \sum \frac{(T_{max} - T_{min})}{2} - 5$$

Where $\sum TT$ is the sum of thermal time from sowing to physiological maturity, T_{max} is the maximum air temperature of the day, T_{min} is the minimum air temperature of the day and 5 is the base temperature.

At Vojakkala, Öjebyn and Ås, the overall degree day accumulation was lowest (Fig. 8). Sundsvall and Ockelbo had the highest degree day accumulation. The results are in line with geographical locations. Vojakkala is at the highest latitude, close to the Finland border in the north. Ås is at the foot of the mountains close to the Norway border (hence, less degree days accumulation) and Sundsvall and

Ockelbo are located at lower latitudes and away from mountains, compared to other studied locations (hence, more degree day accumulation).

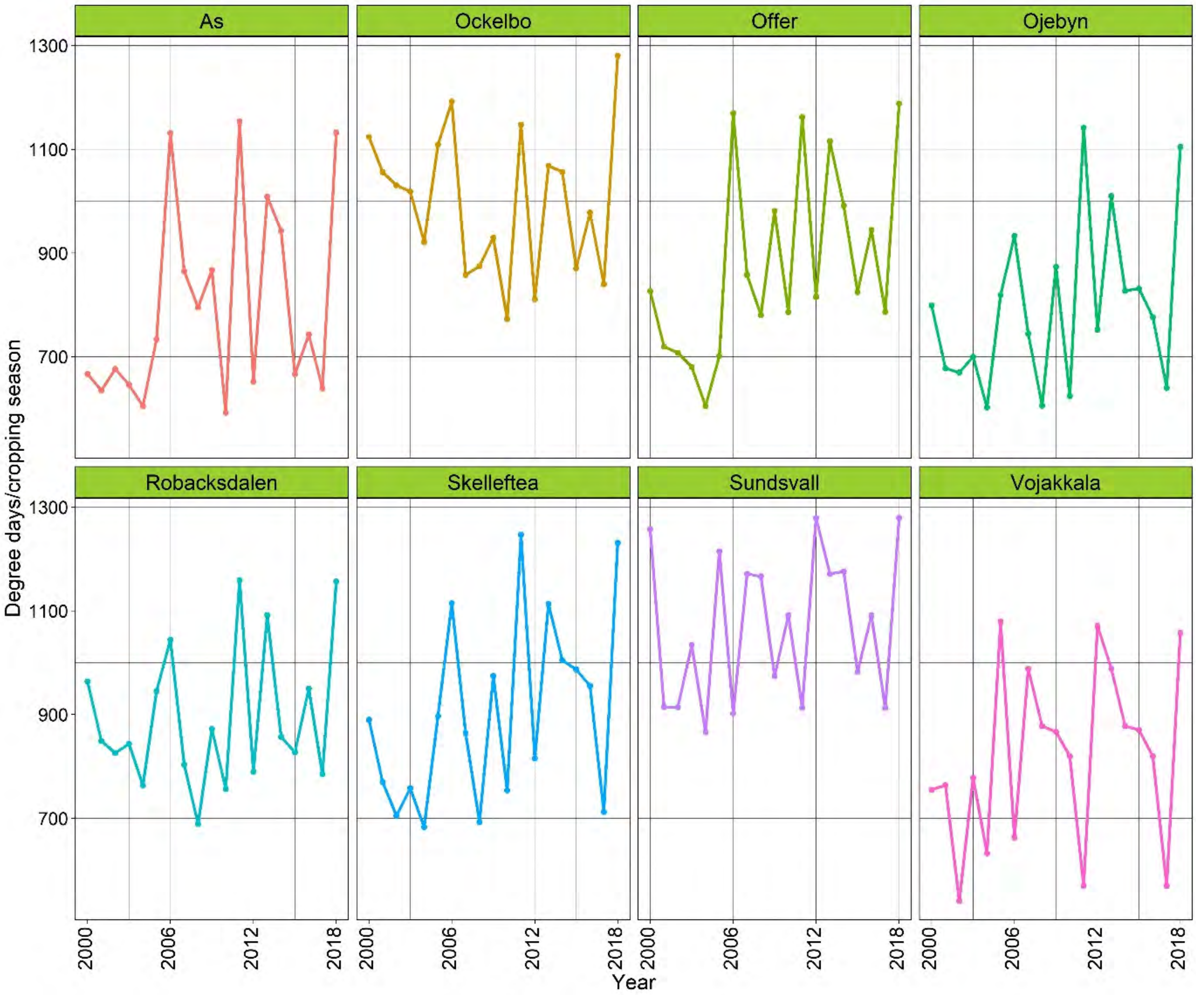


Figure 8. Accumulated degree days per cropping season for 19 years and eight locations.

Work package 3: APSIM model calibration and validation

Proposed Methods and Activities:

1. Model calibration is underway in the on-going project.
2. Further data collection and other existing production data will be used for model validation.

Indicators to assess the model efficiency:

Root Mean Square Deviation (RMSD):

$$RMSD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(O_i - S_i)^2}$$

Where O_i is observed values of the tested variable, S_i is simulated values of the tested variable, n is number of entries for O_i and S_i

Root Mean Square Deviation-systematic error (RMSDsys):

$$RMSDsys = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\hat{S}_i - O_i)^2}$$

Where $\hat{S}_i = a + bO_i$, a = *Intercept*, b = *Slope*

Root Mean Square Deviation-non-systematic error (RMSDnos):

$$RMSDnos = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(S_i - \hat{S}_i)^2}$$

Index of agreement (based on Willmott et al., 2012):

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)}{2 \times \sum_{i=1}^{n}(O_i - \bar{O})}, \ when\ \sum_{i=1}^{n}(S_i - O_i) \leq 2 \times \sum_{i=1}^{n}(O_i - \bar{O})$$

$$d = \frac{\sum_{i=1}^{n}(O_i - \bar{O})}{2 \times \sum_{i=1}^{n}(S_i - O_i)} - 1, \ when\ \sum_{i=1}^{n}(S_i - O_i) > 2 \times \sum_{i=1}^{n}(O_i - \bar{O})$$

Where $\bar{O}$ is mean of the observed values of the tested variable

Sum of residuals (SRES):

$$\boldsymbol{SRES} = \sum_{i=1}^{n}(O_i - S_i)$$

Where O_i is observed values of the tested variable, S_i is simulated values of the tested variable, n is number of entries for O_i and S_i

Completed activities and achieved results

After two years of crop, soil and weather data from Röbäcksdalen were curated we started the calibration of APSIM for both crops, barley and oats. The initial exercise of the model calibration and validation is shown in Figures 9-10 (barley) and Figures 13-14 (oats). The results showed that when APSIM was calibrated using 2017 crop season data and validated with 2018 data there was overestimation of both key phenological stages – 50% anthesis (here after Anthesis) and physiological maturity for both crops (Fig. 9 and Fig. 13). However, when APSIM was calibrated with 2018 data and validated with 2017 data it underestimated both phenological stages (Fig. 10 and Fig. 14).

For the other variables in the barley simulations (leaf number per plant, LAI, Leaf weight, Stem weight Grain yield and above ground biomass) calibration of APSIM with 2018 data and validation with 2017 data were better than the calibration with 2017 and validation with 2018 data, but still not in strong correlation with observed data (Fig. 9-10).

Based on this activity and knowledge we decided to use additional years and locations of data from the variety trials in Northern Sweden for phenology calibration (to achieve convincing or more robust calibration) of the recently released APSIM next generation (APSIM-NG) model and compare it with APSIM regular version (APSIM7.9). According to the developers, these models have improved simulation mechanisms and faster processing capabilities due to a lot of structural changes compared to APSIM7.9. To find the best model for high prediction capacity and reliability for the locations of interest in Northern Sweden, we compared APSIM7.9 and APSIM-NG barley and oats models. This was not initially part of the project plan, but was deemed necessary to do the work as thoroughly as possible.

For this comparison study we obtained data from a location in Finland (Ruukki), and added that to the process of calibration and validation. The result of this phase of calibration and validation is presented in Figures 11-12 (barley varieties) and figures 15-16 (Oats varieties). During the comparison phase we collaborated with a researcher from Luke, Finland to obtain data for Ruukki. In addition, we have had contact with the APSIM developers in Australia to better understand the workings and assumptions of both models.

APSIM7.9 calibration and evaluation: Calibration with 2017 data from Röbäcksdalen and validation with remaining years and locations (24 environments; 5 locations x 5 years; except 2017 RBD)

Phenology calibration of twelve barley and five oat varieties with 2017 weather, management and soil characteristics inputs data from Röbäcksdalen resulted in a perfect correlation for the observed days to anthesis and maturity (Fig. 11A and 15A). Evaluation of calibrated varieties with the remaining seasons and locations that were not used for calibration suggested an overestimation for barley and underestimation for oats for days to anthesis (negative and positive SRE and positive intercepts, respectively) and an overestimation for days to maturity (negative SRE and intercept). A slope lower than one for days to anthesis indicated that the prediction was leaning towards overestimation. The error terms RMSD, RMSDsys, and RMSDnos, and d, were better for barley evaluation than for the oats evaluation. d for days to anthesis was better than for the days to maturity for both crops.

APSIM7.9 calibration and evaluation: Calibration with 2018 data from Röbäcksdalen and validation with remaining years and locations (24 environments; 5 locations x 5 years; except 2018 RBD)

The hot and dry cropping season of 2018 affected days to maturity more than the days to 50% anthesis, compared to the 2017 cropping season (Table 1). The earliness due to hot and dry weather in 2018 among both barley and oat varieties was captured well in this phase of calibration (Fig. 10B and 14B). For the evaluation, the APSIM-barley model underestimated whereas APSIM-Oats overestimated both phenological stages; positive SRE and slope 1>, and negative SRE, respectively. The slope of 1.5 for the oats evaluation indicated a strong tendency for underestimation of days to maturity. Similar to the first round of calibration, the error terms RMSD, RMSDsys, and RMSDnos, and d, were better for barley evaluation than for oats.

APSIM Next generation calibration and evaluation: Calibration with 2017 data from Röbäcksdalen and validation with remaining years and locations (24 environments; 5 locations x 5 years; except 2017 RBD)

The calibration with 2017 data and the evaluation with the remaining data of the next generation barley model showed lower RMSDsys and RMSDnos (Fig. 12A) than the evaluation of APSIM7.9 barley model in the evaluations (Fig. 11A & B) for days to maturity. Overall, the sum of residuals (SRES) was lower for APSIM-NG than for the APSIM7.9 model for the evaluation with 2017 calibration but higher with 2018 calibration. d of APSIM-NG was higher than APSIM7.9 in evaluation with 2017 calibration but lower with 2018. Although the SRES of APSIM-NG was lower with 2017 and higher with 2018 evaluations of APSIM7.9 the intercept and slope was better. For days to anthesis the APSIM-NG barley error terms were higher and d was lower (Fig. 12A & B) than evaluation of APSIM7.9 with 2017 calibration (Fig. 11A), and lower error terms and lower d than evaluation with 2018 (Fig. 11B).

The next generation oats model overestimated both phenological stages (Fig. 16) similar to the evaluations of APSIM7.9 oats model (Fig. 15 A). RMSDsys and RMSDnos of APSIM-NG were lower than APSIM7.9 (Figure 15A) with 2017 calibration but higher than with 2018 (Figure 15B) for days to maturity; however, with opposite responses for days to anthesis. d for days to maturity was higher for APSIM7.9 evaluation (Figure 16B) while it was consistently same for the days to anthesis. The intercept and slope showed mixed responses for all APSIM-NG and APSIM7.9 outputs.

The objective of this comparison study was to identify the best version of APSIMf or each crop, and use that for work package 4. Our comparison, based on the model efficiency indicators, showed that it was difficult to clearly say which model is performing better. Thus, we proceeded further with APSIM7.9 with the study and applied the calibrated model for work package 4 activities.

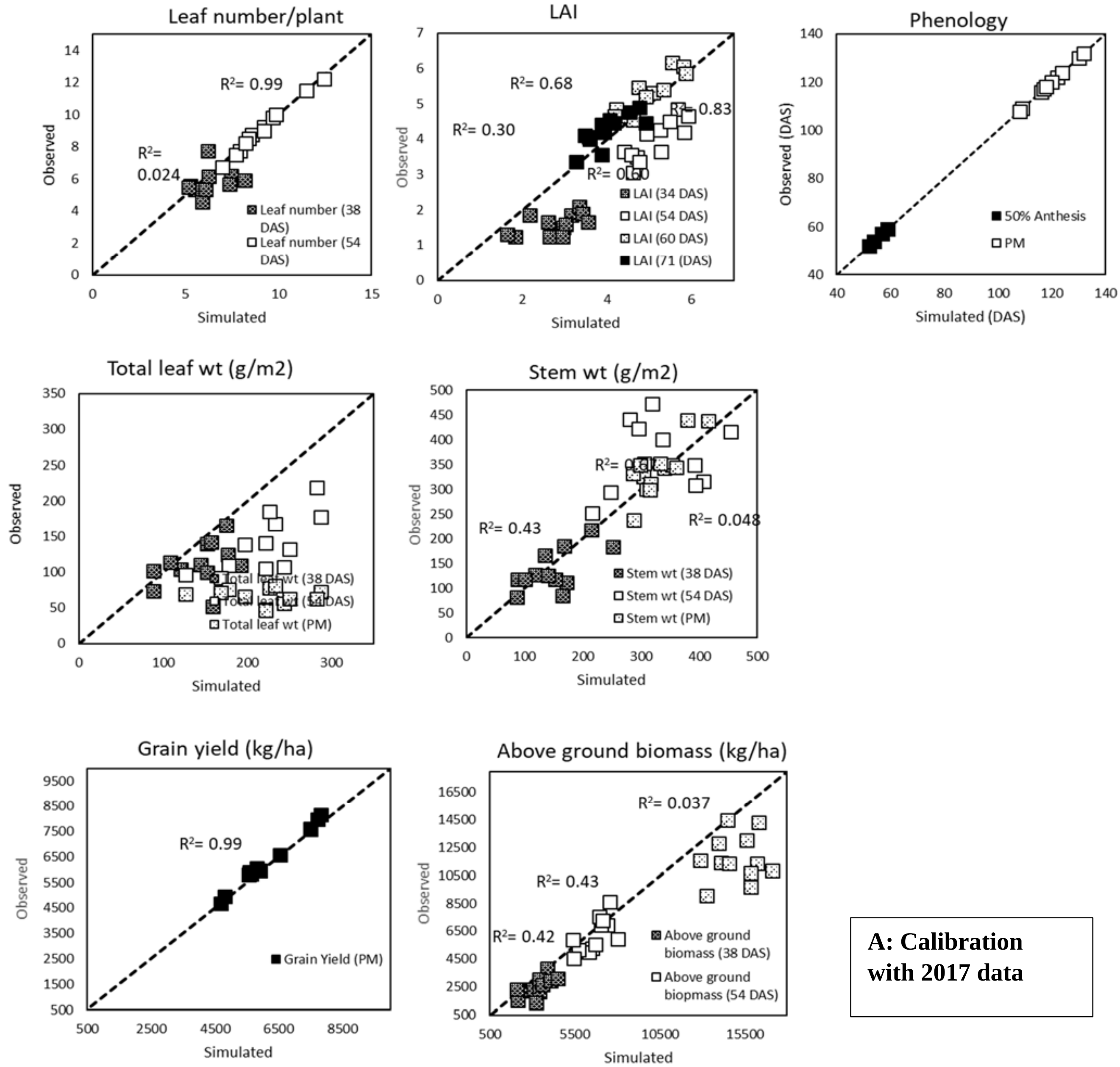


Figure 9A: APSIM-7.9 calibration for twelve barley varieties using 2017 crop data.

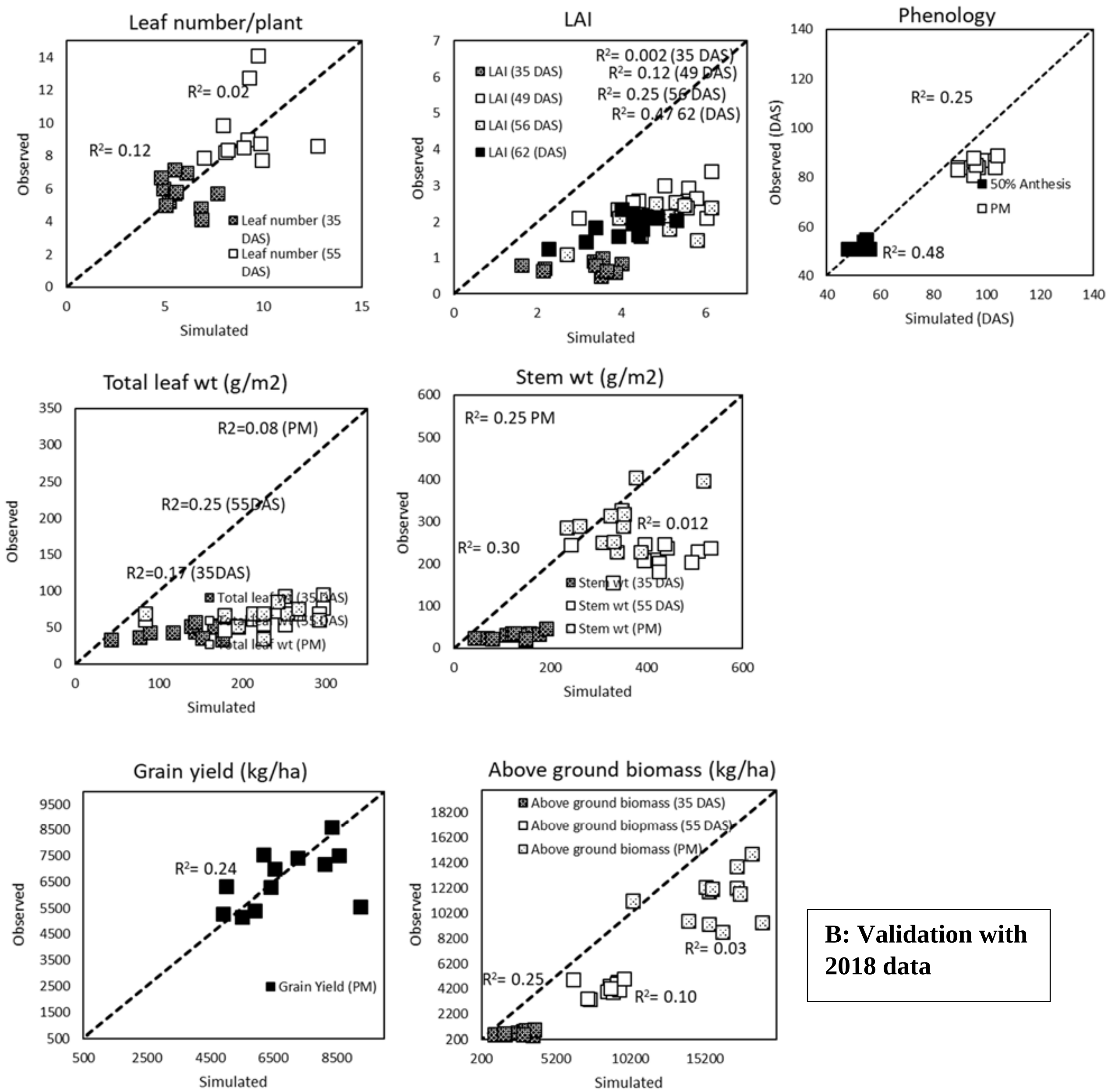


Figure 9B: APSIM-7.9 validation of twelve barley varieties using 2018 crop data, after calibration with 2017 data.

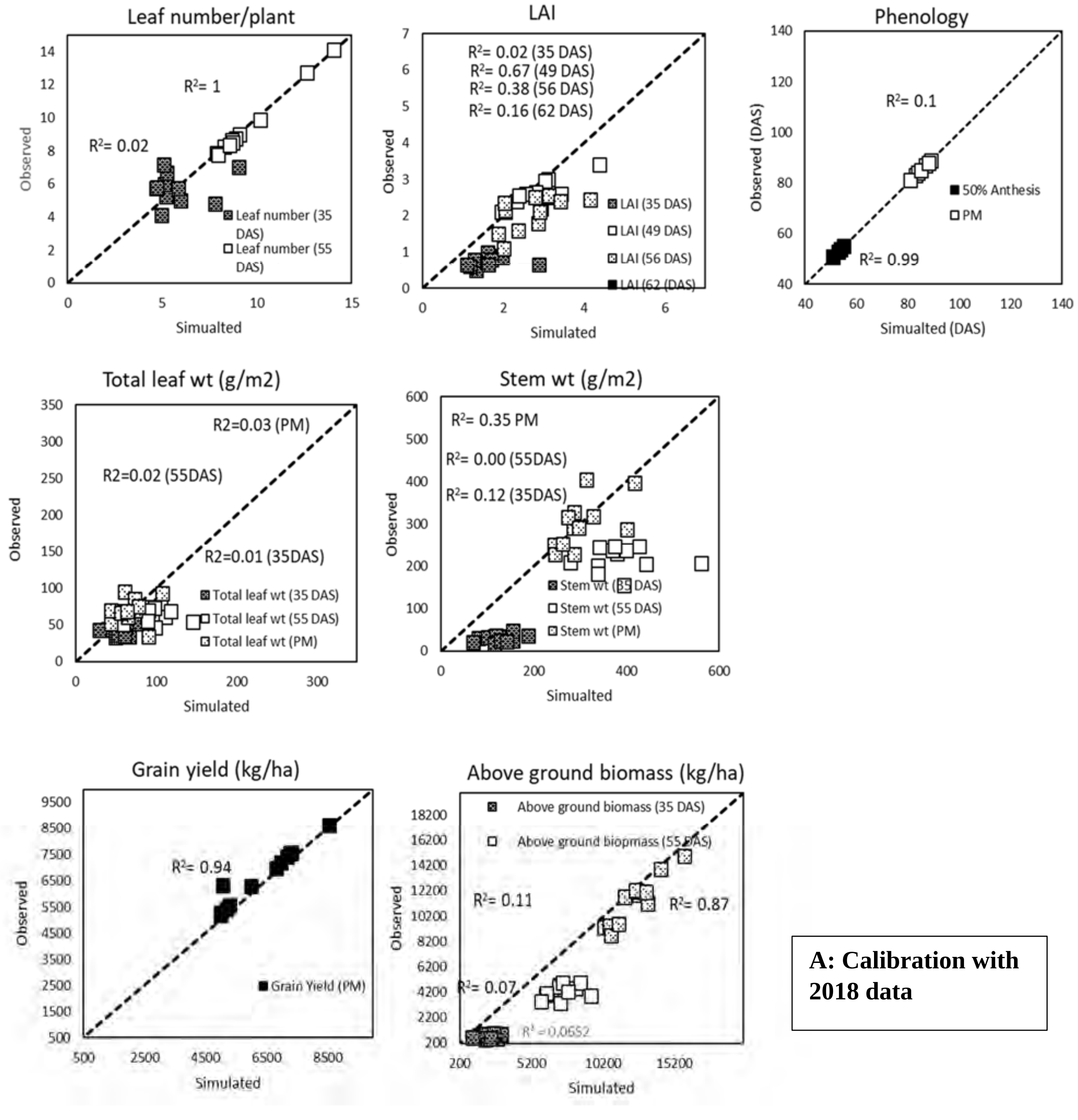


Figure 10A: APSIM-7.9 calibration for twelve barley varieties using 2018 crop data.

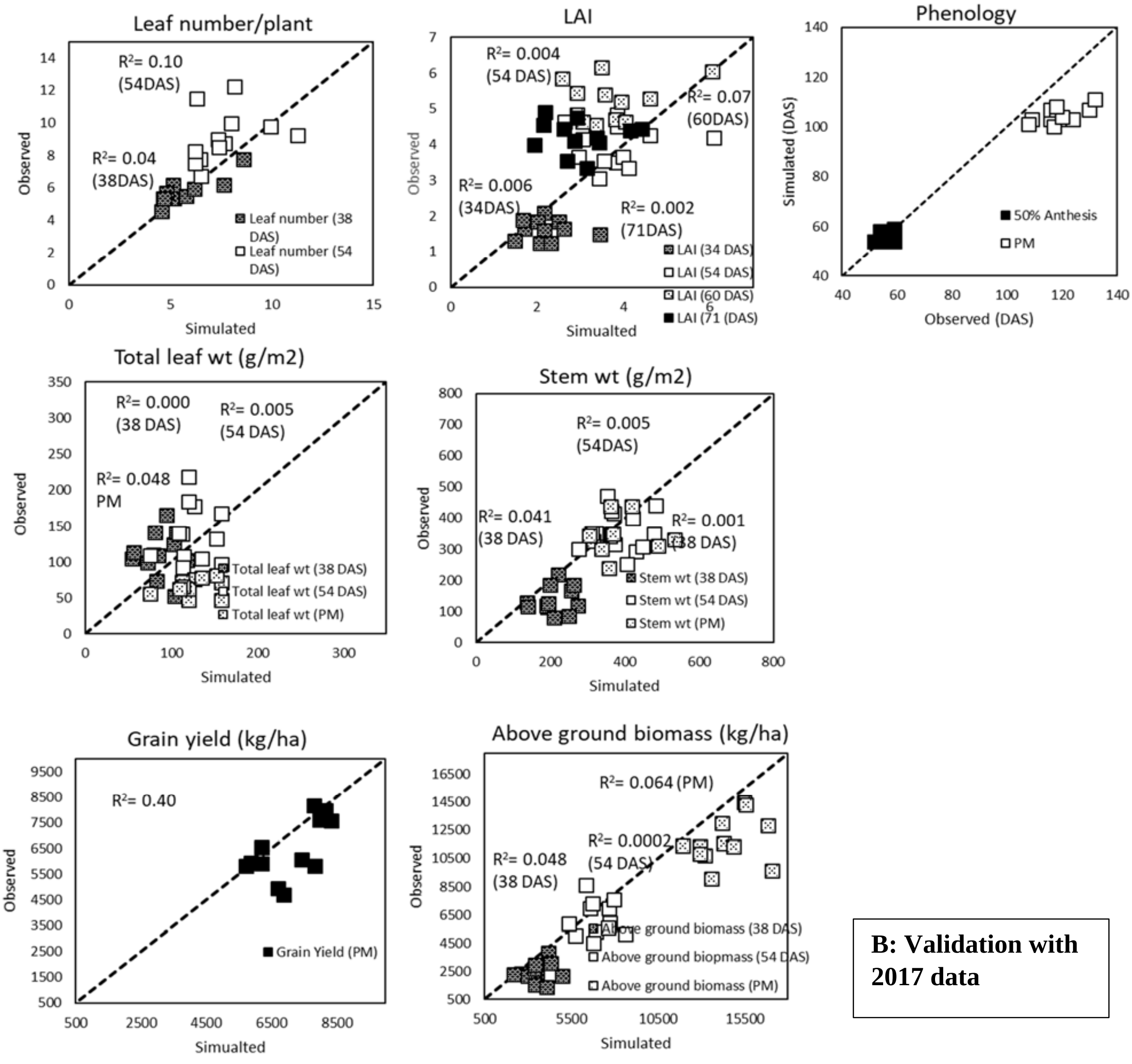
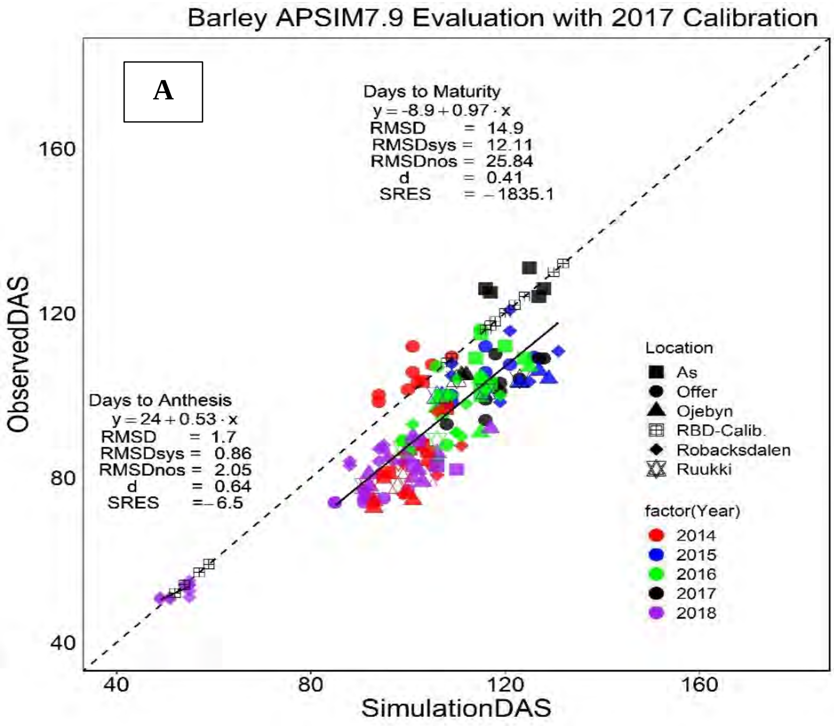


Figure 10B: APSIM-7.9 validation of twelve barley varieties using 2017 crop data, after calibration with 2018 data.



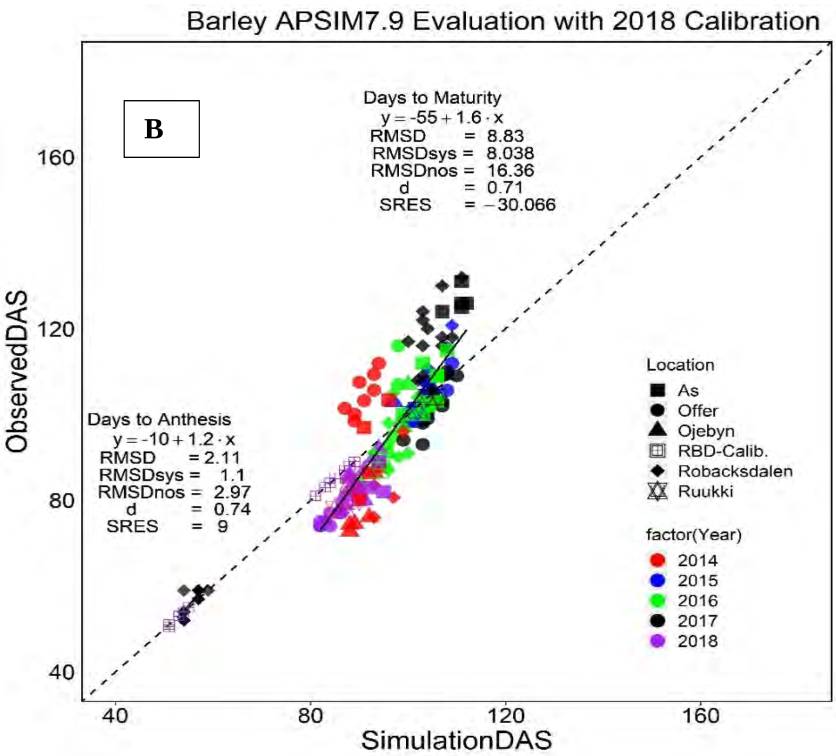


Figure 11. APSIM-7.9 model calibration with 2017 data from Röbäcksdalen and evaluation with five years of data from four locations in Northern Sweden and one from Finland (Ruukki) for phenology of twelve barley varieties. Calibration with 2018 data (A) and validation with remaining years and locations (B).

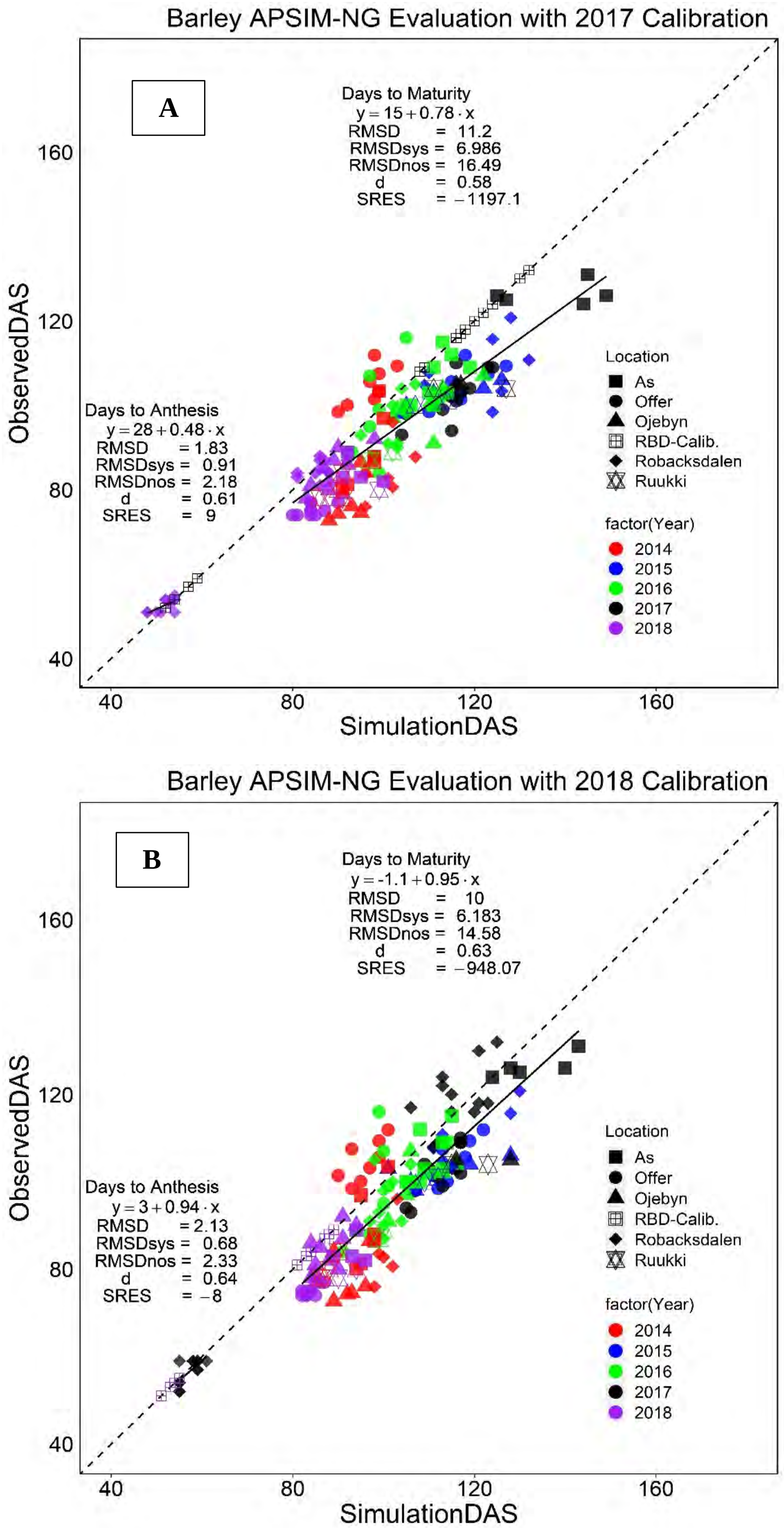


Figure 12. APSIM-NG model calibration with 2017 data from Röbäcksdalen and evaluation with five years of data from four locations in Northern Sweden and one from Finland (Ruukki) for phenology of twelve barley varieties. Calibration with 2018 data (A) and validation with remaining years and locations (B).

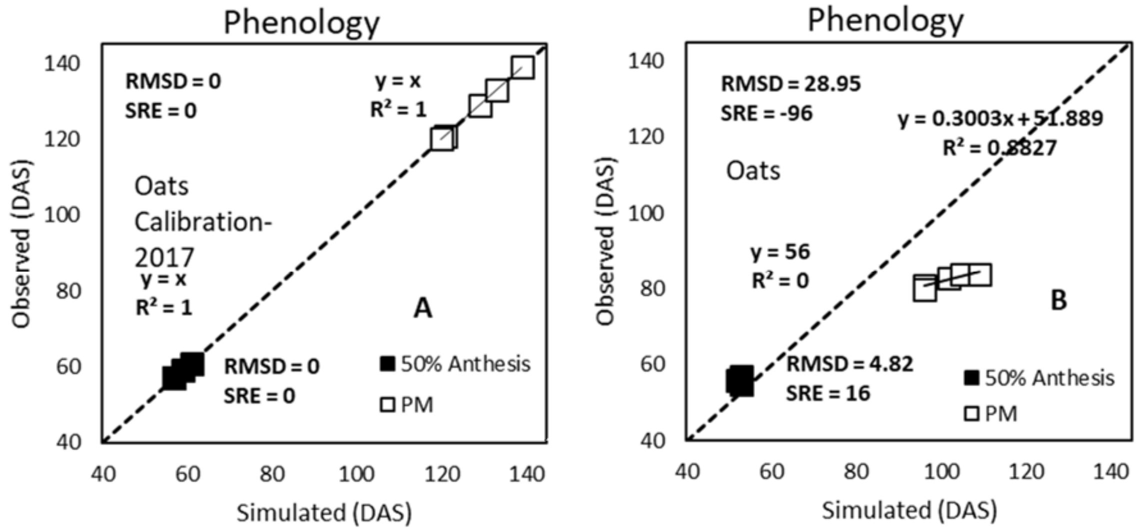


Figure 13: APSIM-7.9 calibration (A) of five oats variety using 2017 crop data, and validation (B) with 2018 data.

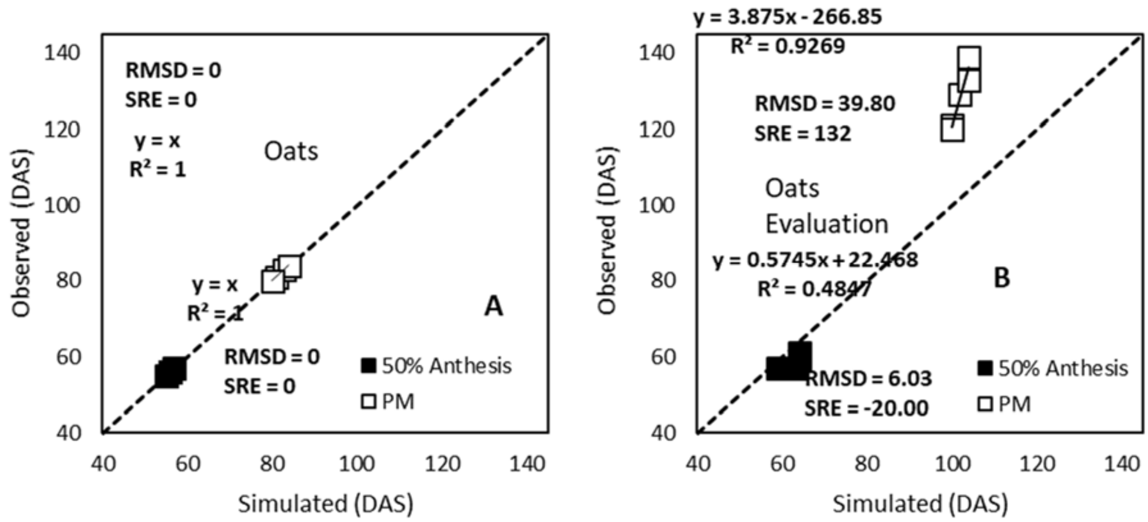


Figure 14: APSIM-7.9 calibration (A) of five oats variety using 2018 crop data, and validation (B) with 2017 data.

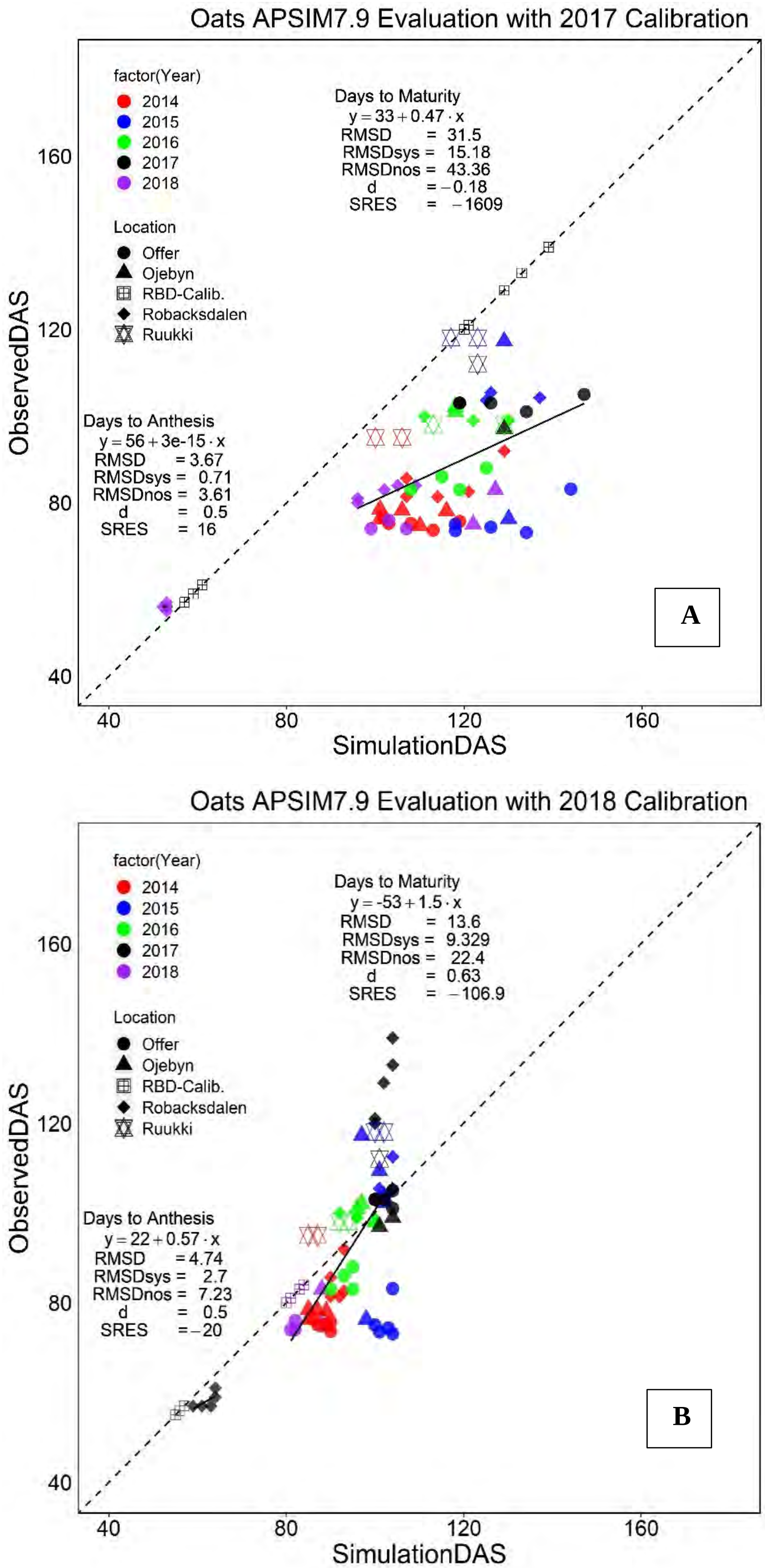


Figure 15. APSIM7.9 model calibration with 2017 data from Röbäcksdalen and evaluation with five years of data from four locations in Northern Sweden and one from Finland (Ruukki) for phenology of five oats varieties (A). Calibration with 2018 data and validation with remaining years and locations (B).

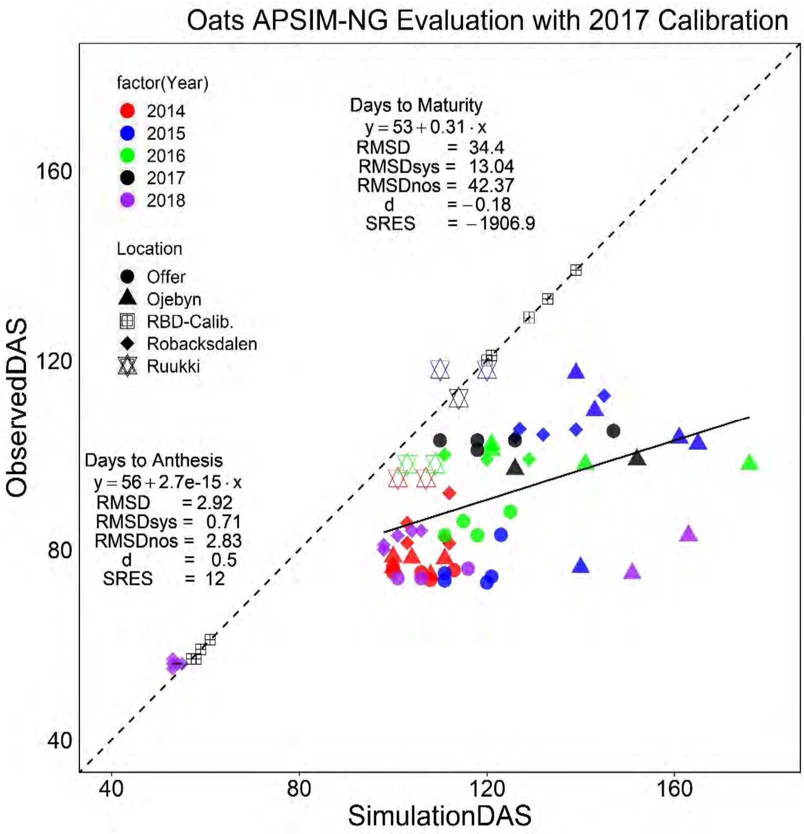


Figure 16. APSIM7-NG model calibration with 2017 data from Röbäcksdalen and evaluation with five years of data from four locations in Northern Sweden and one from Finland (Ruukki) for phenology of five oats varieties.

Work package 4: Model application for best variety and management practices

Proposed Methods and Activities:

1. Collect current and historical climate data for the study locations.
2. Identify realistic sowing windows and ranges of fertilizer.
3. Perform simulations with combinations of variety and management practices
4. Identify and suggest options with best yield and reduced risks for the study locations.

Completed activities and achieved results

This work package focused on results for barley. Similar simulations were planned for Oats; however the work for barley varieties took unexpectedly longer than was anticipated. Therefore the APSIM calibration and validation for oat varieties was reduced. The preparatory modelling, including phenology calibration and validation of APSIM7.9 was completed for oats varieties and presented under work package 3. Work package 5, however, focuses on barley.

For this work package a combination of sowing dates, fertilizer applications and barley varieties were created in APSIM to simulate and find best the management package for eight locations in Northern Sweden. The sowing dates and fertilizer applications used in this process are show in Tables 3 and 4.

Sowing date for the simulations

Depending on the latitudinal position of the locations and their proximity to the mountains, all barley varieties were sown every fourth day for the extent of the sowing window of the location. Ockelbo and Sundsvall being located at lower latitudes and away from the mountains, have longer sowing windows and longer cropping seasons, and the dates 5-May until 24-June were used. Ås is located close to the mountains and Vojakkala is at a much higher latitude. The conditions are responsible for two locations having a relatively shorter sowing window and cropping season; thus the sowing window was 25-May until 14-June. For Öjebyn, Röbäcksdalen, Offer and Skellefteå the sowing window and cropping season duration are in-between, thus at these locations the sowing window was 20-May until 21-June. With these sowing dates, we tried to analyse a slightly broader window than typical practice.

Table 3: Sowing dates at eight location used to perform simulations for management optimization.

Sowing dates							
Öjebyn	**Röbäcksdalen**	**Offer**	**Ås**	**Ockelbo**	**Skellefteå**	**Sundsvall**	**Vojakkala**
20-May	20-May	20-May	25-May	15-May	20-May	15-May	25-May
24-May	24-May	24-May	29-May	19-May	24-May	19-May	29-May
28-May	28-May	28-May	02-Jun	23-May	28-May	23-May	02-Jun
01-Jun	01-Jun	01-Jun	06-Jun	27-Jun	01-Jun	27-Jun	06-Jun
05-Jun	05-Jun	05-Jun	10-Jun	31-May	05-Jun	31-May	10-Jun
09-Jun	09-Jun	09-Jun	14-Jun	04-Jun	09-Jun	04-Jun	14-Jun
13-Jun	13-Jun	13-Jun		08-Jun	13-Jun	08-Jun	
17-Jun	17-Jun	17-Jun		12-Jun	17-Jun	12-Jun	
21-Jun	21-Jun	21-Jun		16-Jun	21-Jun	16-Jun	
				20-Jun		20-Jun	
				24-Jun		24-Jun	

Fertilizer application for the simulations

Table 4: Fertilizer at eight locations used to perform simulations for management optimization. In total, eleven options were tested: single/basal application, F1 (common practice with recommended amount), F7 and F8 and split applications, F2-F6 and F9-F11 at three important growth stages: ZS0 (Zadok stage 0: sowing), ZS30-32 (Zadok stage 30-32: tillering), ZS70-72 (Zadok stage 70-72: grain filling).

Fertilizer application												
Zadock stage (ZS)		**Single/basal application at typical rate (kg/ha)-**	**Split application with recommended amount (kg/ha)**					**Single/basal application with different rates (kg/ha)**		**Split application with more than the recommended amount (kg/ha)**		
	Fertilizer treatment	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**	**F11**
ZS 0		100	33	50	25	25	25	150	50	57	60	44
ZS 30-32			33	25	25	50	30			45	34	44
ZS 70-72			33	25	50	25	35			40	43	44
Total		100	99	100	100	100	100	150	50	142	137	132

For all sowing dates and locations, the number of fertiliser treatments were the same (11). All twelve barley varieties were simulated for each sowing date and fertilizer treatments for each location. The total number of simulations that were conducted were over one hundred and seventy five thousand (Table 5).

Table 5: Total number of simulations with all combinations of sowing date, fertilizer treatment, barley varieties and number of years for the study locations.

Location	No. of sowing dates	No. of fertilizer treatments	No. of varieties	No. of years	Total number of simulations
Öjebyn	9	11	12	19	**22572**
Röbäcksdalen	9	11	12	19	**22572**
Offer	9	11	12	19	**22572**
Ås	6	11	12	19	**15048**
Ockelbo	11	11	12	19	**27588**
Skellefteå	9	11	12	19	**22572**
Sundsvall	11	11	12	19	**27588**
Vojakkala	6	11	12	19	**15048**
				Grand total	**175560**

Effect of sowing date on Phenology and yield

Regardless of the location, the average of 19 years of simulations showed that when the crop was sown in May, varieties needed more days to achieve anthesis and less days to physiological maturity compared to when the crop was sown in June (Fig. 17). In May, the night temperatures are much lower during the early development of the crop, which results in less degree days during the phase compared to when the crop is sown in June. This resulted in the varieties taking around 55-60 days to reach anthesis with the sowings in May and 45-50 days in June. With late sowing, the variability was more in the date of achieving physiological maturity. This is related to the effect of variable weather after anthesis, especially the low temperatures which are more common during the maturing phase. Because of this, the percentage of crops failing to achieve physiological maturity was observed with late sowing in June (Fig. 19). The percentage of crop failure during June was more at Öjebyn, while no crop failure was observed at Ås or Vojakkala.

For all locations, the first sowing in May resulted in the highest average yields (Figure 18). For Ockelbo, Sundsvall and Ås the first two sowings in May resulted in similar average yields, and decreased with each successive sowings. Highest above ground biomass were achieved at Röbäcksdalen and Sundsvall and lowest at Ås. The highest grain yield was achieved at Röbäcksdalen and lowest at Skellefteå.

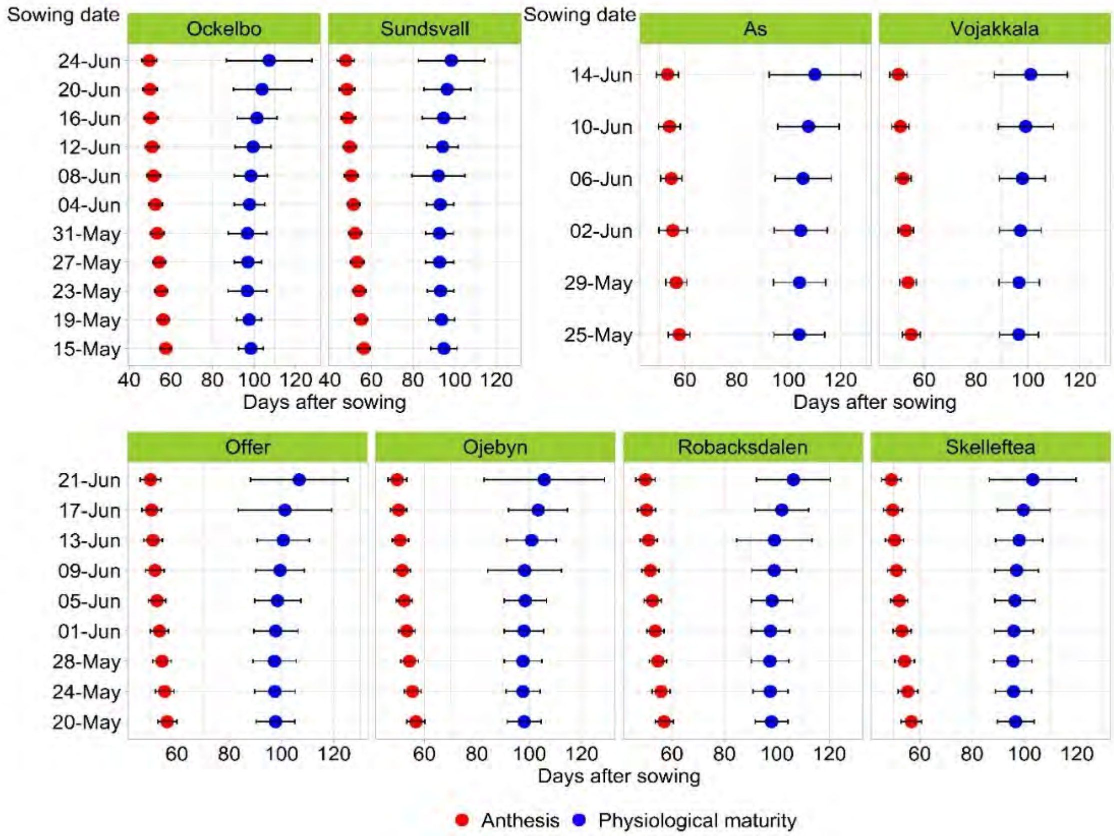


Figure 17. Phenological response of barley varieties to different sowing dates at eight locations. The dots represent means of all combinations of fertilizer and variety for each sowing date for 19 years. The error bars are standard deviations.

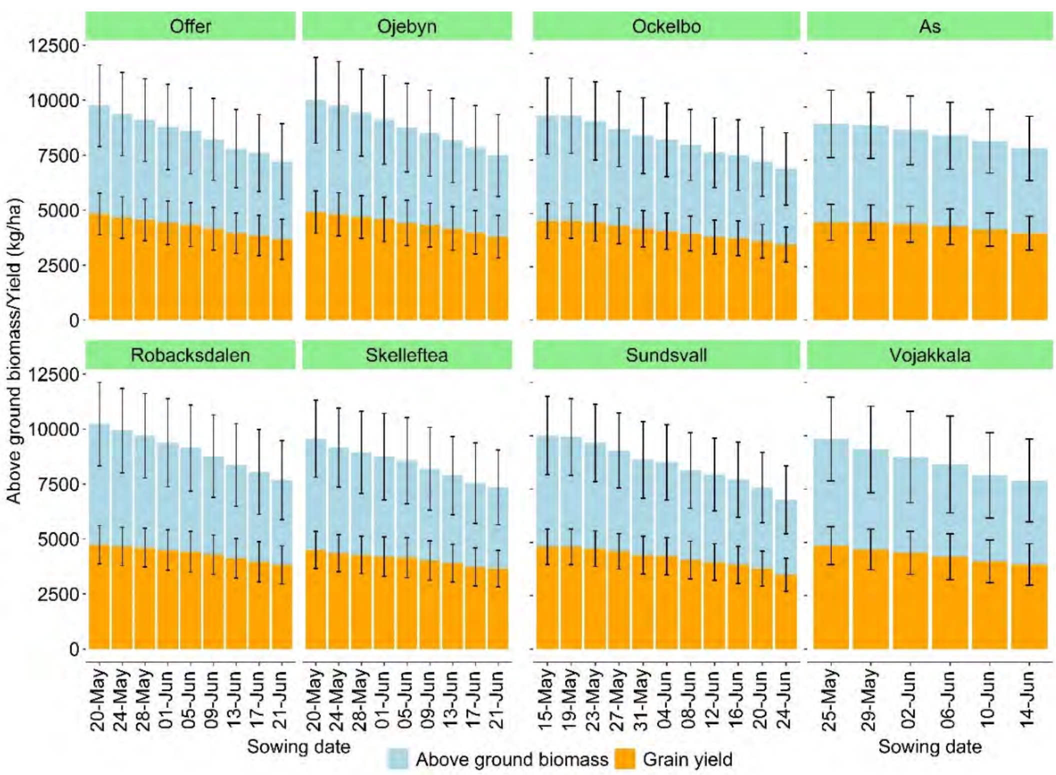


Figure 18. Achieved yields of barley varieties for different sowing dates at eight locations. The bars represent mean of all combinations of fertilizer and variety for each sowing date for 19 years. The error bars are standard deviations.

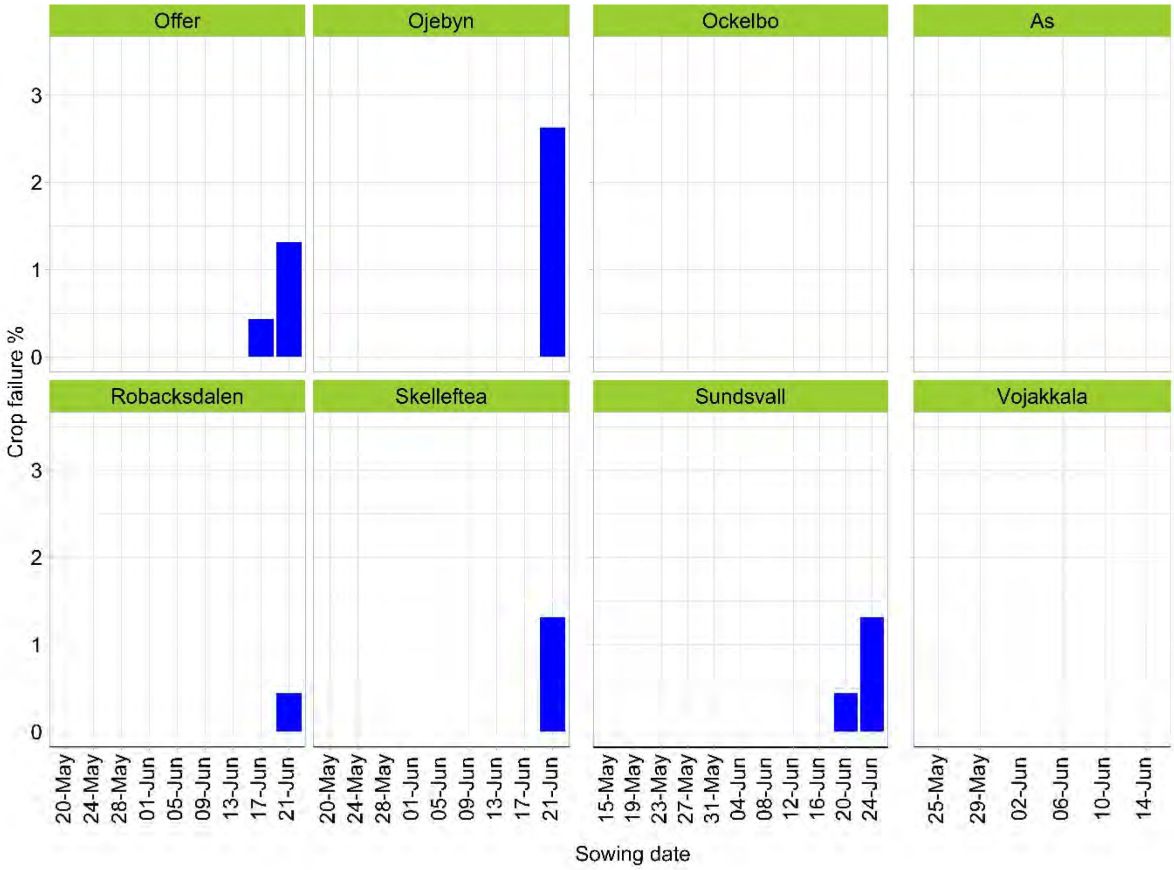


Figure 19. Crop failure percentage for each sowing date for each location. Computed by extracting the total number of simulations that failed to reach Zadok stage 90 (physiological maturity) over the total number of simulations for each sowing date.

Effect of fertilizer treatments on yields

The yields presented in Fig. 20 are averages of simulations of all combinations: 19 years, different sowings dates, varieties, and fertiliser treatments. The results showed that the common practice of applying fertilizer as a basal dose is advantageous in terms of achieving higher yields compare to split applications. However, higher yields were achieved with the F7 treatment with much higher N application (150 N ka/ha) than the current recommended practice (100 N ka/ha). Basal application (F1) was consistently among the top performing fertiliser treatments for all locations. The yields achieved with F3 and F9 were with a proportionally greater basal application and lesser in the succeeding split applications. However, F11 was equal split applications but higher than the recommendation. The yields of F3, F9 and F11 indicate the advantage of a heavy basal application. With the aim to reduce N leaching and environmental degradation, treatments F3 and F1 are promising and better than applications F9 and F11 (much higher amount of N application). Farmers choose single dose application to avoid the extra labour and machinery costs that are needed to apply nitrogen in split applications. For this reason, F1 is the best option, however F3 is the best for reducing N leaching.

The results showed that slightly higher yields were achieved at Röbäcksdalen. The yields at other locations were similar, with minor differences.

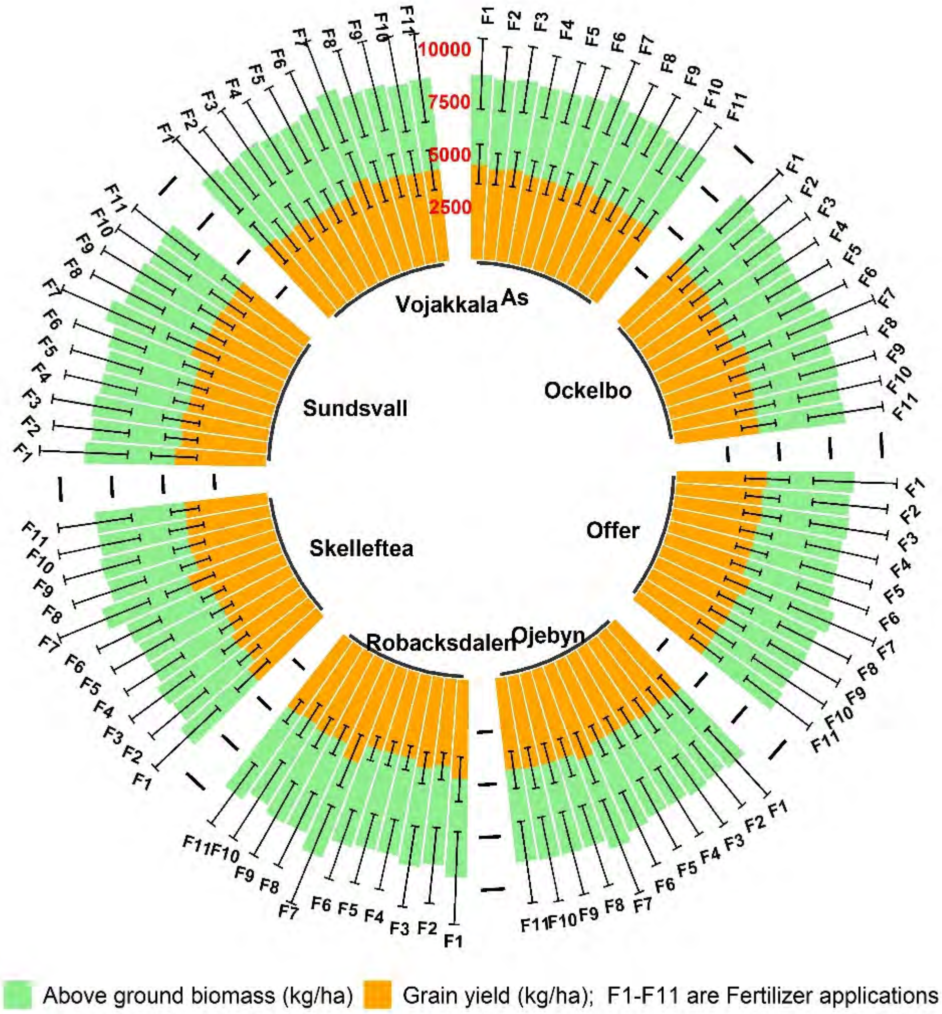


Figure 20. Yields of barley varieties for each fertilizer treatment at eight locations. The bars represent the mean of all combinations of sowing dates and varieties for each fertilizer treatment for 19 years. The error bars are standard deviations.

Response of varieties for all management combinations

Figure 21 shows the response of barley varieties at different locations and suggests which variety is performing better at different locations over 19 years of simulations. The distribution of above ground biomass and grain yield are the results of all fertilizer treatments and 19 years for each variety. Above ground biomass had more variability than grain yields. The outliers of achieved yield by the varieties were lesser at Vojakkala and Öjebyn than other locations.

The range and median of above ground biomass were consistently higher for Kaarle and Judit indicating more variability and higher potential for greater yield. However, for grain yield Kaarle showed higher range and median yield for all locations. Aukusti and Vilgot were the lowest above ground biomass and grain yield producing varieties.

The median of above ground biomass was between 6000 to 12000 kg/ha while grain yield was between 3000 to 6000 kg/ha. Röbäcksdalen and Skellefteå were less variable for yield production, and of the varieties, Vojakkala was the most variable.

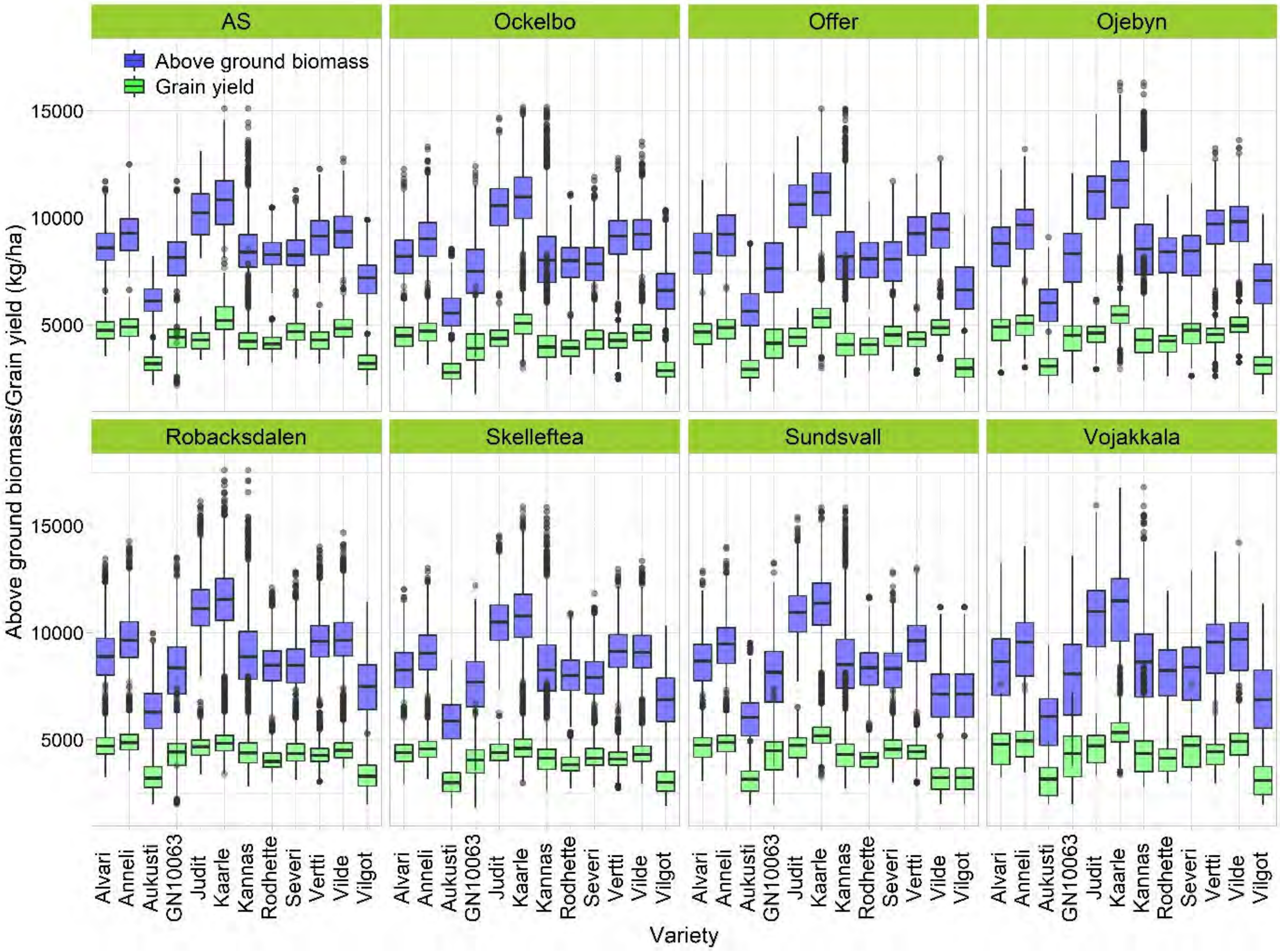


Figure 21. Biomass and grain yields of barley varieties at eight locations. The error bars are standard deviations.

Best five management combinations for the locations

We also determined the top five above ground biomass and grain yield producing combinations at each locations (Fig. 22). The May sowing dates showed the highest yields with F7 (highest) fertilizer treatment for all locations. Highest grain yield was approximately from 6500 to 7500 kg/ha and above ground biomass was approximately from 12000 to 15200 kg/ha. Kaarle and Kannas commonly achieved the highest grain yields. Besides these two varieties, Judit also produced high above ground biomass (Table 6).

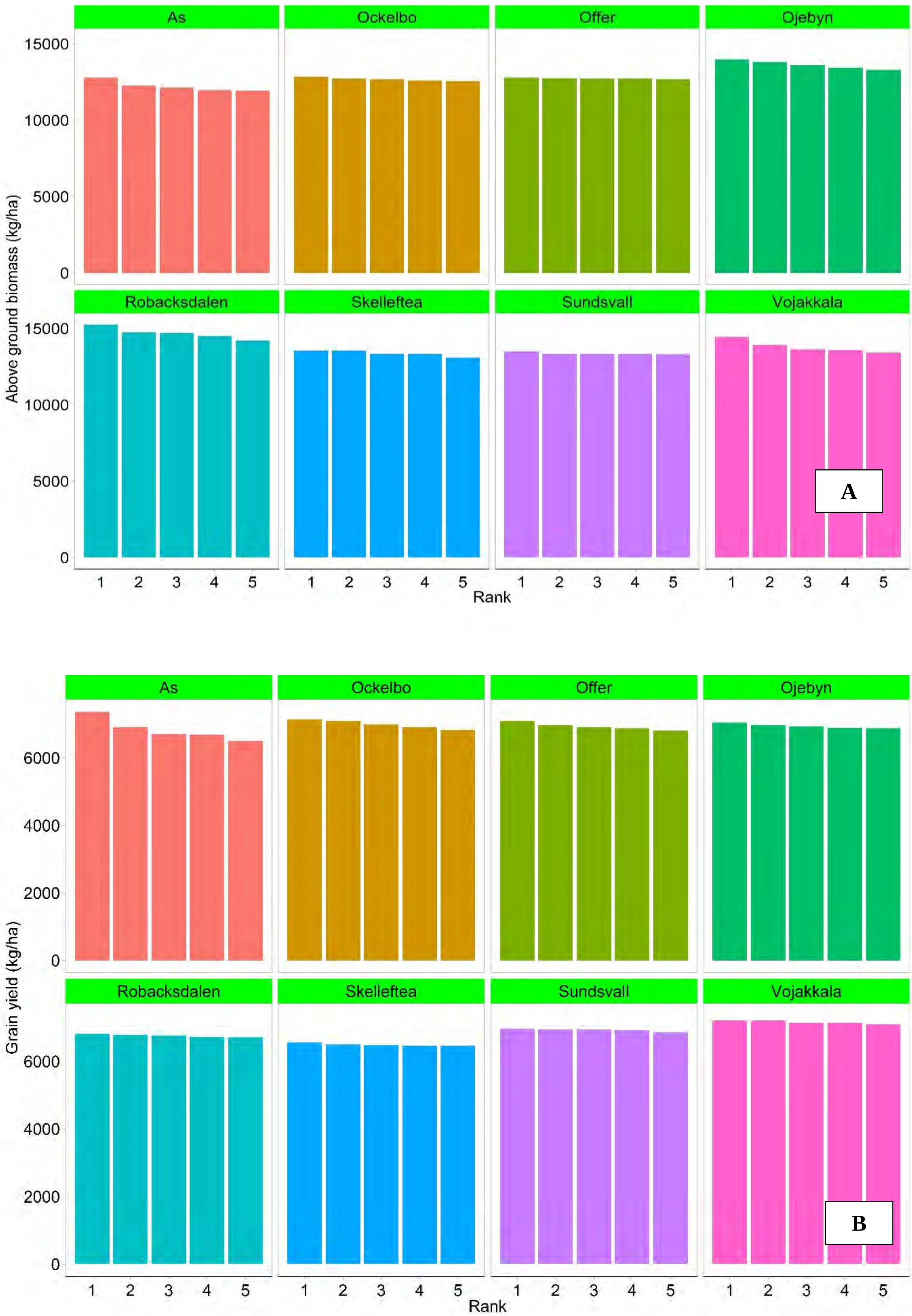


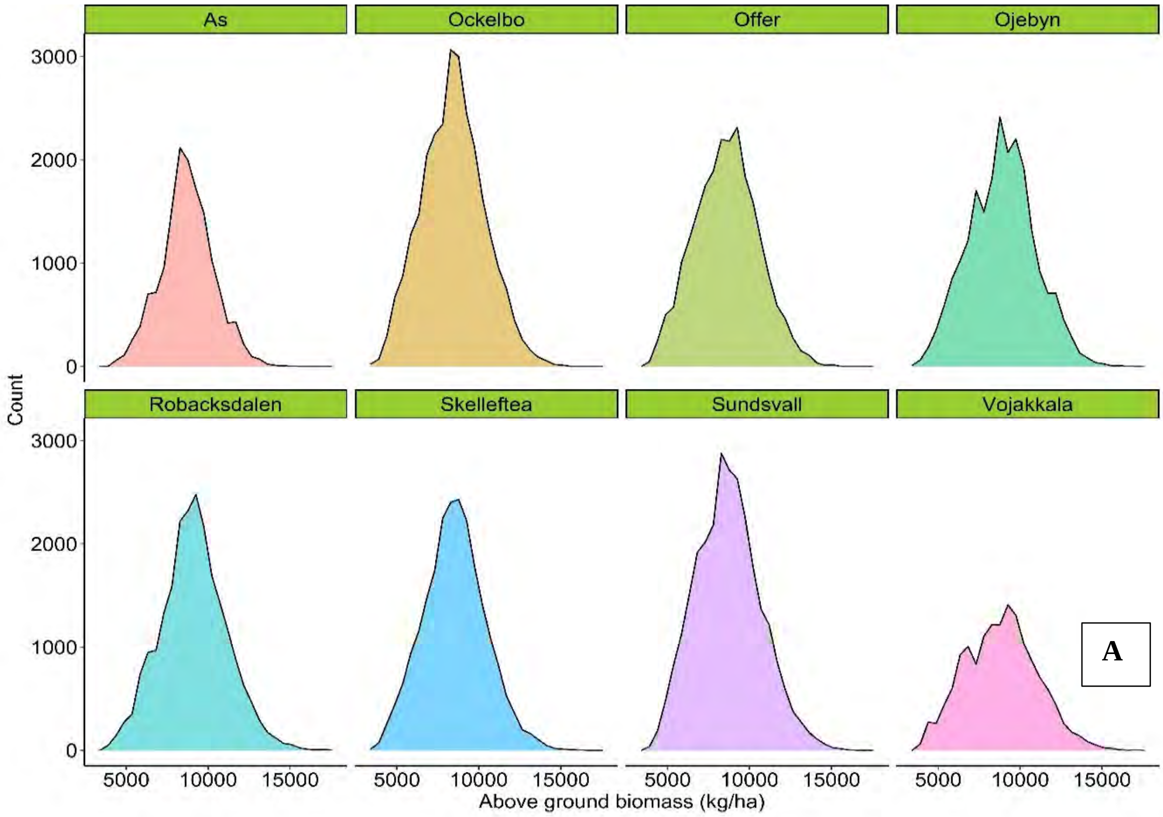
Figure 22. Yields of the best five combinations at the studied locations: above ground biomass (A) and grain yield (B)

Table 6: Cultivar and management combinations of the top 5 highest yielding crops for each site.

Grain yield						Biomass					
Year	Sowing da	fertilizer t	Variety	Location	Rank	Year	Sowing da	fertilizer t	Variety	Location	Rank
2008	20-May	F7	Kaarle	Robacksdalen	1	2006	20-May	F7	Kaarle	Robacksdalen	1
2006	05-Jun	F7	Kaarle	Robacksdalen	2	2006	24-May	F7	Kaarle	Robacksdalen	2
2008	24-May	F7	Kaarle	Robacksdalen	3	2006	28-May	F7	Kaarle	Robacksdalen	3
2006	09-Jun	F7	Kaarle	Robacksdalen	4	2006	20-May	F1	Kaarle	Robacksdalen	4
2018	20-May	F7	Kaarle	Robacksdalen	5	2006	01-Jun	F7	Kannas	Robacksdalen	5
2017	20-May	F7	Kaarle	Ojebyn	1	2006	24-May	F7	Kannas	Ojebyn	1
2006	09-Jun	F7	Kaarle	Ojebyn	2	2006	20-May	F7	Kannas	Ojebyn	2
2018	20-May	F7	Kaarle	Ojebyn	3	2006	24-May	F1	Kaarle	Ojebyn	3
2015	28-May	F7	Kaarle	Ojebyn	4	2006	28-May	F7	Kannas	Ojebyn	4
2008	20-May	F7	Kaarle	Ojebyn	5	2006	20-May	F1	Kaarle	Ojebyn	5
2004	20-May	F7	Kaarle	Offer	1	2002	20-May	F7	Kannas	Offer	1
2008	20-May	F7	Kaarle	Offer	2	2004	28-May	F7	Kannas	Offer	2
2002	20-May	F7	Kannas	Offer	3	2000	20-May	F7	Kannas	Offer	3
2003	20-May	F7	Kaarle	Offer	4	2004	20-May	F7	Kannas	Offer	4
2004	28-May	F7	Kaarle	Offer	5	2000	24-May	F7	Kannas	Offer	5
2008	25-May	F7	Kaarle	As	1	2008	25-May	F7	Kaarle	As	1
2008	25-May	F1	Kaarle	As	2	2008	25-May	F1	Kaarle	As	2
2008	29-May	F7	Kannas	As	3	2008	29-May	F7	Kaarle	As	3
2008	02-Jun	F7	Kannas	As	4	2008	25-May	F10	Kaarle	As	4
2008	29-May	F1	Kaarle	As	5	2008	02-Jun	F7	Kannas	As	5
2017	02-Jun	F7	Kannas	Vojakkala	1	2000	25-May	F7	Kannas	Vojakkala	1
2011	02-Jun	F7	Kannas	Vojakkala	2	2000	25-May	F1	Kaarle	Vojakkala	2
2017	06-Jun	F7	Kannas	Vojakkala	3	2000	25-May	F7	Judit	Vojakkala	3
2011	06-Jun	F7	Kannas	Vojakkala	4	2000	29-May	F7	Kaarle	Vojakkala	4
2017	25-May	F7	Kannas	Vojakkala	5	2000	25-May	F10	Kaarle	Vojakkala	5
2003	20-May	F7	Kaarle	Skelleftea	1	2006	20-May	F7	Kaarle	Skelleftea	1
2003	20-May	F7	Kannas	Skelleftea	2	2006	20-May	F7	Kannas	Skelleftea	2
2006	09-Jun	F7	Kaarle	Skelleftea	3	2006	28-May	F7	Kaarle	Skelleftea	3
2017	20-May	F7	Kaarle	Skelleftea	4	2006	28-May	F7	Kannas	Skelleftea	4
2003	24-May	F7	Kaarle	Skelleftea	5	2006	24-May	F7	Kaarle	Skelleftea	5
2001	23-May	F7	Kaarle	Sundsvall	1	2002	15-May	F7	Kannas	Sundsvall	1
2002	15-May	F7	Kaarle	Sundsvall	2	2001	15-May	F7	Kannas	Sundsvall	2
2001	19-May	F7	Kaarle	Sundsvall	3	2000	23-May	F7	Kannas	Sundsvall	3
2018	15-May	F7	Kaarle	Sundsvall	4	2000	19-May	F7	Kannas	Sundsvall	4
2002	19-May	F7	Kaarle	Sundsvall	5	2002	19-May	F7	Kannas	Sundsvall	5
2008	23-May	F7	Kannas	Ockelbo	1	2018	15-May	F7	Kannas	Ockelbo	1
2008	27-May	F7	Kannas	Ockelbo	2	2018	19-May	F7	Kannas	Ockelbo	2
2008	19-May	F7	Kannas	Ockelbo	3	2007	23-May	F7	Kannas	Ockelbo	3
2018	15-May	F7	Kannas	Ockelbo	4	2008	19-May	F7	Kannas	Ockelbo	4
2008	15-May	F7	Kannas	Ockelbo	5	2008	23-May	F7	Kannas	Ockelbo	5

Distribution of achieved yields with all combination: sowing dates, fertilizer treatments, varieties and 19 years

The distribution of simulation events achieving certain levels of above ground biomass and grain yield were similar between the locations (Fig. 23). However, differences were observed in the mode yield (peak of the distribution). For most locations the mode above ground biomass was approximately 8000 kg/ha (Fig. 23 A) and the grain yield was approximately 4500 kg/ha (Fig. 23 B). Öjebyn and Vojakkala had higher mode grain yields, however the distribution dropped off sharply above the mode yield.



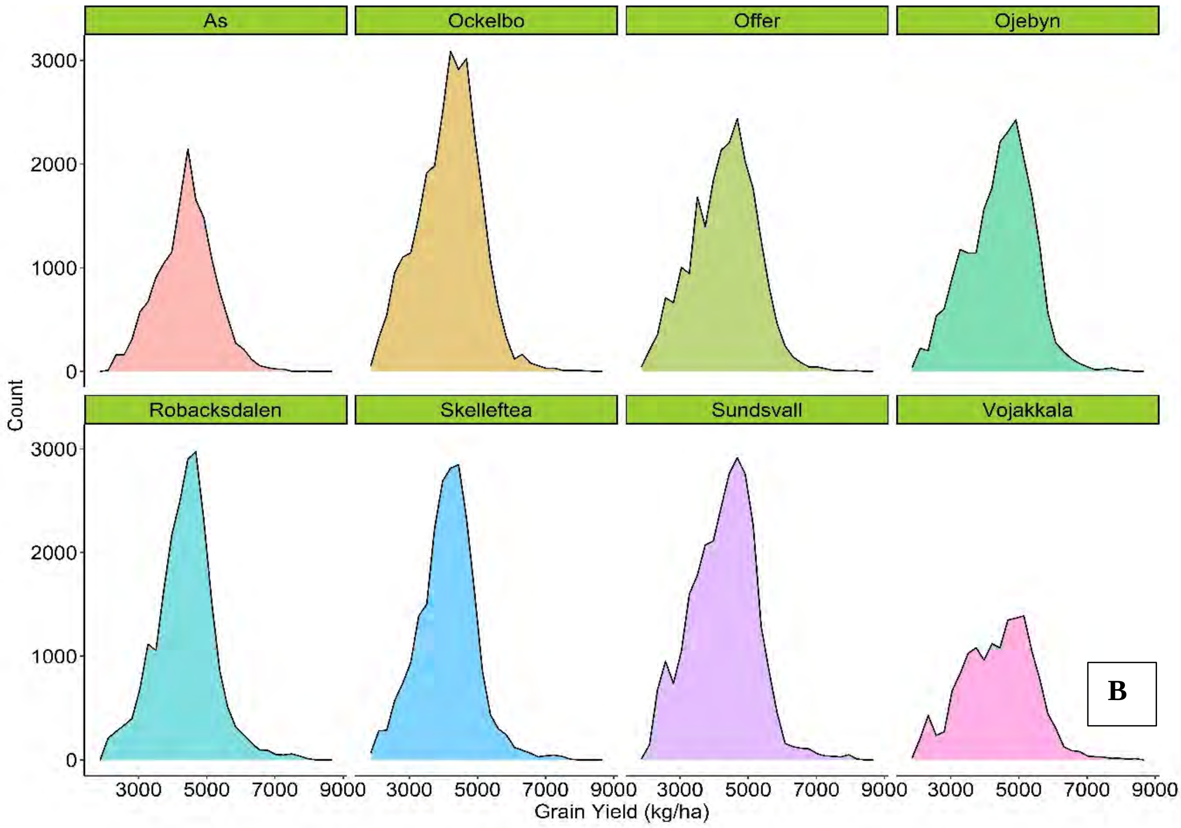


Figure 23. Count of individual above ground biomass (A) and yields (B) simulation events for eight locations.

Work package 5: Distribution of results

Proposed Methods and Activities:

1. Hold meetings with stakeholders, including farmers and advisors.
2. Publish the results in the form of a fact sheet.
3. Publish research results in popular magazines, research journals, and at conferences.

Completed activities and achieved results

An oral presentation about the preliminary results was given in a conference; XVth European Society for Agronomy Congress (ESA) August 27-31, 2018, Geneva, Switzerland, and a poster presentation at the 3rd Agriculture and Climate Change Conference, March 24-26, Budapest, Hungary.

During the project duration, several opportunities were taken to speak about the project and spread the ideas with farmers at field days at several locations in Northern Sweden organised by Lars Erickson. The study and associated links to the farmers were also discussed at a field day at Röbäcksdalen.

A manuscript is in preparation to submit to a journal for publishing on the results of phenology simulating mechanisms in APSIM classical and APSIM next generation models. The detailed and combined calibration and validation is being done to improve the strength of this manuscript. Other scientific publications are planned.

The progress towards scientific publication have necessitated re-running some of the simulations presented in this report. Because of this, a farmer-focused output has not been completed. A “nytt-blad” presenting the results of this study is planned to be completed by the end of 2020.

General concluding comments

Key Findings

- Comparison of APSIM7.9 and APSIM-NG suggests that it is difficult to conclude which model is better. However, in both cases, the barley models were better than the Oat models. The reason is that the barley models were developed with a larger and more varied data set than the oat model.
- Phenology calibration and validation were better than biomass and grain yield for both crop models.
- Vojakkala, Ås, and Öjebyn had shorter sowing windows and less available degree days for barley production. Ockelbo and Sundsvall have longer cropping seasons and more available degree days.
- The best sowing dates for barley varieties to achieve the highest mean production were towards late May, with less chances of crop failure for all locations.
- The crop failure was linked with less available degree days towards maturity.
- Considering labour, time, resources and environmental factors, the best fertilizer application was 100 kg/ N as a basal application for all locations. However, similar yields can be achieved by applying 50% of this fertilizer at sowing and 25% each at tillering (Zadok stage 30-32) and grain filling (Zadok stage 70-72).
- The best performing varieties for simulated above ground biomass were Kaarle and Judit, and for grain yield, it was Kaarle, for all studied locations.
- The ranges of lowest to highest above ground biomass production at the studied locations were similar. In contrast, grain yield was more variable, suggesting that grain filling processes and translocation of stored biomass in stem and leaves towards grains were affected by climatic constraints such as low temperature or precipitation after anthesis.
- The model suggests that the highest producing events for above ground biomass can be as high as approximately 15.5 t/ha, and 7.5 t/ha for grain yield.
- APSIM7.9 and APSIM next generation models can be applied to similar studies in Northern Sweden. However, improving the calibration and mechanistic processes are continuous processes to enhance prediction robustness and reliability.
- Although the study was conducted for eight target locations, the results of the study could be used to inform agriculture stakeholders about the various possibilities and options for barley production more broadly in Northern Sweden.

Recommendations for further research

- This study was more focused on cereal (particularly barley) production and was the first of its type in Northern Sweden. It can potentially open up more avenues of research and collaboration, for example in agronomy, crop physiology, and crop modelling within and outside of Sweden.
- To gain more confidence in the findings and implement them on a broader scale in Northern Sweden, a survey based study or farmer participatory study could be conducted where farmers grow the crops as highlighted in this study.
- With these findings, future research can be directed to conduct similar studies on nitrogen uptake from the different soils and partitioning to the grains in different cultivars. These studies can be beneficial to provide a wider perspective on protein content in different cultivars grown in different soil types.
- Model improvement is a continuous and consistent process. To test different plant and soil processes that are incorporated in the model, future studies can improve the model performance and for wider acceptability for farmer oriented research.

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Appendices

Appendix 1: Growth and development data of twelve barley varieties collected from Röbäcksdalen for 2017 and 2018 for APSIM calibration and validation.

2017												
	Alvari	**Anneli**	**Aukusti**	**GN10063**	**Judit**	**Kaarle**	**Kannas**	**Rödhette**	**Severi**	**Vertti**	**Vilde**	**Vilgot**
Variable												
Days to 50% Anthesis	59	59	54	52	54	59	57	59	59	52	57	59
Days to physiological maturity	116	116	109	122	108	130	124	132	118	117	120	118
Total leaves/plant (54 DAS*)	7.8 ± 1.8	9.3 ± 4.6	6.8 ± 0.4	7.5 ± 2.1	9.8 ± 1.8	8.8 ± 1.1	9 ± 1.4	11.5 ± 0.7	8.5 ± 0.7	10 ± 2.1	8.3 ± 2.5	12.3 ± 2.5
Plant height (cm) (54 DAS)	77.2 ± 4.1	64.6 ± 5.8	77.2 ± 8.4	78.9 ± 1.8	69 ± 1.7	76.7 ± 1.1	61.2 ± 2.1	57.4 ± 20.3	60.1 ± 3.3	76 ± 2.8	72.8 ± 4.9	51.2 ± 1.6
LAI* (34 DAS)	1.25 ± 0.2	1.85 ± 0.1	1.65 ± 0.1	2.1 ± 0.1	1.85 ± 0.6	1.5 ± 0.8	1.6 ± 0.3	1.9 ± 0.6	1.25 ± 0.1	1.65 ± 0.2	1.25 ± 0.1	1.3 ± 0
LAI (54 DAS)	3.5 ± 0.1	4.85 ± 0.6	4.15 ± 0.2	4.25 ± 0.1	3.65 ± 0.6	4.2 ± 0.3	4.5 ± 0.8	4.65 ± 0.1	3.05 ± 0.4	3.55 ± 0.5	3.65 ± 0.6	3.35 ± 0.4
LAI (60 DAS)	4.7 ± 0	6.15 ± 0.4	5.45 ± 0.9	5.3 ± 0.3	4.85 ± 0.6	6.05 ± 0.4	5.4 ± 1	5.85 ± 0.5	4.55 ± 0.6	4.65 ± 0.1	5.2 ± 0.1	4.65 ± 0.1
LAI (71 DAS)	4.05 ± 0.2	4.75 ± 0.5	4.55 ± 0.2	4.4 ± 0	4.1 ± 0.3	4.45 ± 0.1	4.45 ± 0.2	4.9 ± 0.4	3.55 ± 0.2	4 ± 0.1	4.2 ± 0.3	3.35 ± 0.2
Total leaf weight (kg/ha) (38 DAS)	1102 ± 90	1656 ± 272	1040 ± 760	994 ± 135	1022 ± 346	1400 ± 283	1416 ± 441	1095 ± 70	735 ± 155	1240 ± 85	522 ± 236	1132 ± 546
Total leaf weight (kg/ha) (54 DAS)	1075 ± 456	1772 ± 92	1088 ± 75	1385 ± 545	963 ± 370	1677 ± 185	1848 ± 373	2181 ± 128	919 ± 364	1045 ± 170	1323 ± 339	1404 ± 383
Total leaf weight (kg/ha) (PM)	559 ± 20	722 ± 29	759 ± 91	654 ± 84	692 ± 176	815 ± 2	776 ± 217	628 ± 157	712 ± 175	472 ± 54	627 ± 46	467 ± 141
Dead leaf weight (cm) (kg/ha) (54 DAS)	148 ± 89	239 ± 9	93 ± 30	153 ± 17	128 ± 38	191 ± 13	284 ± 40	228 ± 25	97 ± 40	116 ± 40	209 ± 70	260 ± 62
Stem weight (kg/ha) (38 DAS)	1121 ± 39	2172 ± 594	1274 ± 870	1175 ± 959	1174 ± 155	1667 ± 509	1260 ± 51	1854 ± 370	811 ± 72	1840 ± 792	856 ± 141	1170 ± 211
Stem weight (kg/ha) (54 DAS)	3153 ± 1605	4161 ± 138	3005 ± 124	4004 ± 1360	2935 ± 926	4407 ± 428	4224 ± 551	4720 ± 965	2524 ± 613	3496 ± 140	3087 ± 828	3523 ± 807
Stem weight (kg/ha) (PM*)	3258 ± 115	3484 ± 475	4390 ± 940	3491 ± 307	3420 ± 653	4374 ± 27	2992 ± 161	3444 ± 505	3315 ± 102	3112 ± 757	3513 ± 383	2386 ± 402
TDM* (kg/ha) (38 DAS)	2223 ± 129	3828 ± 865	2314 ± 1630	2169 ± 1095	2196 ± 502	3067 ± 792	2676 ± 492	2949 ± 440	1545 ± 227	3080 ± 877	1378 ± 377	2302 ± 757
TDM (kg/ha) (54 DAS)	5281 ± 2566	6951 ± 353	5019 ± 219	6955 ± 2493	5135 ± 1748	7579 ± 766	7284 ± 1016	8597 ± 1335	4520 ± 1377	5953 ± 311	5572 ± 1461	5872 ± 1252
TDM (kg/ha) (PM)	11426 ± 1755	11336 ± 1108	14474 ± 2938	13021 ± 1299	11591 ± 2841	14289 ± 859	10698 ± 1126	10859 ± 901	12806 ± 930	9649 ± 3668	11344 ± 2341	9063 ± 1516
Grain weight (kg/ha) 15%	5966 ± 1507	5841 ± 453	8170 ± 1276	7613 ± 564	6067 ± 2250	7984 ± 1211	5911 ± 644	5814 ± 204	7586 ± 953	4693 ± 2270	6559 ± 1935	4942 ± 418
1000 grain weight (g) (PM)	47.16 ± 0.35	46.01 ± 4.11	45.7 ± 1.98	47.45 ± 1.06	49.48 ± 1.73	45.31 ± 3.25	48.04 ± 1.33	46.43 ± 1.23	47.29 ± 1.72	45.11 ± 1.14	45.38 ± 2.43	45.39 ± 1.68

2018 Variable	Alvari	Anneli	Aukusti	GN10063	Judit	Kaarle	Kannas	Rödhette	Severi	Vertti	Vilde	Vilgot
Days to 50% Anthesis	53	54	51	51	51	54	54	54	51	51	54	55
Days to physiological maturity	84	87	84	84	83	87	84	89	87	81	85	88
Total leaves/plant (54 DAS*)	8.3 ± 1.4	14.1 ± 2	7.9 ± 2.1	9.9 ± 2.5	12.8 ± 3.4	9 ± 1.9	8.8 ± 2.2	8.6 ± 2.2	8.5 ± 0.8	7.8 ± 0.9	8.4 ± 1.8	12.1 ± 1.2
Plant height (cm) (54 DAS)	70.3 ± 4.4	67.6 ± 1.8	66.2 ± 2.6	66.2 ± 4.1	61.4 ± 3.9	68.2 ± 3.7	59.5 ± 2.4	57.3 ± 4.7	59.7 ± 2	63.5 ± 2.5	54.9 ± 3.1	49.5 ± 2.3
LAI * (35 DAS)	0.9 ± 0	0.85 ± 0.35	0.5 ± 0.14	0.85 ± 0.21	0.8 ± 0.42	0.65 ± 0.21	1 ± 0.57	0.6 ± 0	0.7 ± 0.28	0.8 ± 0.42	0.65 ± 0.21	0.65 ± 0.21
LAI (54 DAS)	3 ± 0.28	2.95 ± 0.49	2.4 ± 0.71	2.6 ± 0.42	2.1 ± 0.14	3.4 ± 0.14	2.65 ± 1.2	2.1 ± 0	2.6 ± 0.85	2.55 ± 0.07	2.4 ± 0.85	2.2 ± 0.28
LAI (60 DAS)	2.5 ± 1.27	2.5 ± 0.14	2.15 ± 0.35	2.55 ± 0.07	1.1 ± 0.14	2.4 ± 0.42	2.45 ± 0.64	1.5 ± 0.71	1.6 ± 0.14	2.35 ± 0.35	1.8 ± 0.57	2.1 ± 0.57
LAI (71 DAS)	2.35 ± 0.64	2.15 ± 0.35	1.65 ± 0.07	2.25 ± 0.64	1.25 ± 0.21	2.05 ± 0.78	1.8 ± 0.42	2.1 ± 0.57	1.6 ± 0.14	1.85 ± 0.64	1.95 ± 0.78	1.45 ± 0.21
Total leaf weight (kg/ha) (35 DAS)	434 ± 18	441 ± 128	362 ± 49	372 ± 25	282 ± 14	435 ± 16	477 ± 75	275 ± 63	302 ± 3	419 ± 100	294 ± 8	361 ± 109
Total leaf weight (kg/ha) (56 DAS)	455 ± 14	635 ± 97	427 ± 41	509 ± 5	506 ± 84	454 ± 79	607 ± 56	577 ± 109	386 ± 37	389 ± 40	576 ± 251	457 ± 102
Total leaf weight (kg/ha) (PM*)	581 ± 113	792 ± 52	430 ± 111	574 ± 20	577 ± 11	771 ± 34	711 ± 104	507 ± 74	555 ± 130	287 ± 75	628 ± 11	575 ± 171
Dead leaf weight (cm) (kg/ha) (56 DAS)	197 ± 38	247 ± 90	113 ± 5	96 ± 43	89 ± 13	122 ± 16	255 ± 67	136 ± 23	76 ± 46	122 ± 20	81 ± 31	205 ± 6
Stem weight (kg/ha) (35 DAS)	294 ± 4	287 ± 83	259 ± 16	264 ± 16	203 ± 34	296 ± 12	302 ± 37	148 ± 72	206 ± 6	395 ± 102	190 ± 38	180 ± 37
Stem weight (kg/ha) (56 DAS)	1920 ± 60	1987 ± 202	1742 ± 260	1979 ± 356	2044 ± 2	1725 ± 432	2067 ± 329	1683 ± 259	1298 ± 288	2056 ± 258	1708 ± 594	1513 ± 56
Stem weight (kg/ha) (PM)	2727 ± 405	3377 ± 202	2085 ± 403	2425 ± 107	2392 ± 30	3316 ± 38	2630 ± 115	1898 ± 288	2427 ± 647	1905 ± 745	2657 ± 279	2112 ± 499
TDM * (kg/ha) (35 DAS)	728 ± 23	728 ± 211	621 ± 65	637 ± 41	485 ± 48	731 ± 28	779 ± 113	424 ± 135	508 ± 9	814 ± 202	484 ± 46	542 ± 147
TDM (kg/ha) (56 DAS)	3709 ± 130	3758 ± 599	3350 ± 495	3971 ± 570	4141 ± 188	3292 ± 898	3884 ± 515	3454 ± 674	2782 ± 620	4160 ± 491	3534 ± 1253	2876 ± 245
TDM (kg/ha) (PM)	9938 ± 1699	11598 ± 480	7806 ± 1609	10175 ± 129	9344 ± 600	12450 ± 267	9794 ± 1967	7922 ± 1190	10210 ± 2592	7267 ± 2428	10124 ± 1065	8003 ± 1542
Grain weight (kg/ha) 15%	5821 ± 883	6299 ± 519	4634 ± 802	5995 ± 330	5269 ± 673	7176 ± 480	5237 ± 1670	4512 ± 876	6271 ± 1772	4398 ± 1282	6184 ± 685	4314 ± 615
1000 grain weight (g) (PM)	38.78 ± 1.08	44.24 ± 0.3	36.16 ± 0.43	40.3 ± 0.37	36.89 ± 1.51	39.48 ± 1.22	42.09 ± 3.37	34.49 ± 3.57	37.04 ± 2.45	37.57 ± 2.78	38.43 ± 4.13	43.53 ± 0.34

*LAI: leaf area index; DAS: days after sowing; TDM: total dry matter; PM: Physiological maturity

Appendix 2: Growth and development data of five oats varieties collected from Röbäcksdalen for 2017 and 2018 for APSIM calibration and validation.

2017					
	Akseli	**Averton**	**Cilla**	**Haga**	**Niklas**
Variable					
Days to 50% Anthesis	57	57	59	61	57
Days to physiological maturity	121	129	133	139	120
Total leaves per plant (59 DAS*)	6.3 ± 1.1	6.3 ± 0.4	6.8 ± 1.1	5.8 ± 0.4	6.3 ± 1.1
Plant height (stretched leaf) (cm) (59 DAS)	79.7 ± 1.6	98.4 ± 4.9	84.6 ± 0.7	84.9 ± 3.5	95.7 ± 5
LAI* (34 DAS)	2 ± 0.1	2.5 ± 0	1.7 ± 0.1	2.1 ± 0.2	2.1 ± 0.1
LAI (54 DAS)	3.6 ± 0.2	4 ± 0.6	3.45 ± 0.05	3.65 ± 0.05	3.55 ± 0.05
LAI (60 DAS)	4.15 ± 0.05	4.9 ± 0.3	4.05 ± 0.05	4.35 ± 0.05	4.1 ± 0.1
LAI (70 DAS)	4.3 ± 0	4.7 ± 0.5	4.5 ± 0.5	4.7 ± 0.2	4.2 ± 0.4
LAI (87 DAS)	3.3 ± 0.2	3.35 ± 0.25	3.2 ± 0.3	3.8 ± 0.3	3.15 ± 0.35
Total leaf dry weight (38 DAS)	1269 ± 299	1661 ± 750	915 ± 246	2131 ± 406	1176 ± 370
Total leaf dry weight (59 DAS)	1393 ± 270	1743 ± 304	1281 ± 66	1835 ± 388	1188 ± 251
Total leaf dry weight (kg/ha) (PM*)	757 ± 50	715 ± 114	756 ± 83	799 ± 337	634 ± 68
Dead leaf dry weight (g) (59 DAS)	156 ± 17	147 ± 83	147 ± 23	219 ± 26	145 ± 51
Stem dry weight (kg/ha) (38 DAS)	1964 ± 684	2756 ± 633	1067 ± 308	3476 ± 1667	1808 ± 308
Stem dry weight (59 DAS)	4760 ± 652	6805 ± 1192	4484 ± 296	5963 ± 1195	4683 ± 988
Stem dry weight (g) mean	3797 ± 31	4250 ± 305	4364 ± 468	4092 ± 342	4047 ± 111
TDM* (kg/ha) (38 DAS)	3234 ± 983	4417 ± 1382	1982 ± 554	5606 ± 2073	2984 ± 678
TDM (kg/ha) (59 DAS)	8141 ± 1331	11059 ± 1916	7900 ± 651	10372 ± 2246	7835 ± 1603
TDM (kg/ha) (PM)	11569 ± 340	12647 ± 750	13349 ± 683	13296 ± 690	12203 ± 840
Grain weight (kg/ha) (PM)	5784 ± 407	6659 ± 137	7265 ± 118	7080 ± 107	6187 ± 619
1000 grain weight (PM)	38.68 ± 0.67	43.81 ± 2.68	41.14 ± 2.73	40.94 ± 1.30	39.685 ± 0.64
2018					
Variable					
Days to 50% Anthesis	57	55	56	56	56
Days to physiological maturity	81	83	84	84	80
Total leaves per plant (60 DAS*)	8.4 ± 1.2	10.5 ± 1.8	8 ± 3.2	7.6 ± 2.4	7.5 ± 1.2
Plant height (stretched leaf) (cm) (60 DAS)	65.7 ± 1.9	67.8 ± 4.5	67 ± 2.4	65.1 ± 6.5	70.2 ± 4.9
LAI* (33 DAS)	0.95 ± 0.07	0.8 ± 0.42	0.85 ± 0.07	1 ± 0	0.7 ± 0
LAI (36 DAS)	0.95 ± 0.49	1 ± 0.28	1.2 ± 0.28	0.8 ± 0	1.2 ± 0.28
LAI (47 DAS)	3.15 ± 0.49	2.3 ± 0.28	2.6 ± 0.42	2 ± 1.13	3.05 ± 0.35
LAI (56 DAS)	4 ± 0.71	3 ± 0.71	3.6 ± 0.42	3.4 ± 0.42	3.45 ± 0.21
LAI (60 DAS)	2.35 ± 0.78	1.65 ± 0.49	2.8 ± 0.28	1.95 ± 0.78	2.85 ± 0.07
LAI (64 DAS)	3.4 ± 0	2.55 ± 0.92	2.55 ± 0.21	2.1 ± 0.42	3.1 ± 0
Total leaf dry weight (kg/ha) (36 DAS)	496 ± 51	651 ± 208	582 ± 109	518 ± 172	606 ± 96
Total leaf dry weight (60 DAS)	818 ± 173	842 ± 122	850 ± 216	832 ± 124	696 ± 110
Total leaf dry weight (kg/ha) (PM*)	706 ± 113	648 ± 106	841 ± 6	838 ± 45	752 ± 6
Dead leaf dry weight (g) (60 DAS)	267 ± 167	167 ± 10	212 ± 9	194 ± 49	170 ± 35

Stem dry weight (kg/ha) (36 DAS)	402 ± 68	523 ± 3	591 ± 122	461 ± 131	660 ± 58
Stem dry weight (g) (60 DAS)	2506 ± 248	3270 ± 668	3076 ± 641	2660 ± 168	2387 ± 77
Stem dry weight (kg/ha) (PM)	2896 ± 435	2933 ± 437	3551 ± 80	3342 ± 57	3618 ± 18
TDM* (kg/ha) (36 DAS)	898 ± 119	1174 ± 211	1173 ± 231	980 ± 303	1266 ± 154
TDM (60 DAS)	4760 ± 360	6188 ± 1269	6092 ± 1279	5252 ± 251	4491 ± 254
TDM (15%MC) (kg/ha) (PM)	9618 ± 1745	9053 ± 1667	11194 ± 192	11744 ± 656	11040 ± 529
Grain weight (15%MC) (kg/ha) (PM)	4923 ± 1114	4164 ± 1237	5587 ± 152	5862 ± 706	5199 ± 488
1000 grain weight (PM)	32.85 ± 0.93	30.81 ± 1.4	32.085 ± 3.27	33.735 ± 0.93	36.32 ± 0.65

*****LAI: leaf area index; DAS: days after sowing; TDM: total dry matter; PM: Physiological maturity

Table 3: Carbon (C) and Nitrogen (N) concentrations in different plant organs of barley and oats varieties grown at Röbäcksdalen during 2017 and 2018 cropping seasons.

Oats										
				Mean			SE			
Variety	Date of sampling	Plant organ	Year	ωN/%	ωC/%	C/N ratio	ωN/%	ωC/%	C/N ratio	DAS
Akseli	10/07/2017	Leaf	2017	4.43	44.755	10.10535	0.13	0.915	0.089999	38.00
Akseli	10/07/2017	Stem	2017	2.185	42.69	19.74924	0.215	0.45	2.149239	38.00
Akseli	31/07/2017	Dead	2017	1.85	40.62	21.95506	0.01	0.8	0.313756	59.00
Akseli	31/07/2017	Head	2017	2.055	45.315	22.18061	0.165	0.345	1.613042	59.00
Akseli	31/07/2017	Leaf	2017	2.705	42.765	15.92208	0.225	0.075	1.352114	59.00
Akseli	31/07/2017	Stem	2017	0.81	41.93	53.20526	0.13	0.35	8.971214	59.00
Akseli	05/10/2017	Head	2017	1.945	45.75	23.53528	0.045	0.07	0.580508	121.00
Akseli	05/10/2017	Leaf	2017	1.095	36.33	33.4325	0.075	1.56	3.714555	121.00
Akseli	05/10/2017	Stem	2017	0.38	44.15	116.4694	0.02	0.27	5.419444	121.00
Akseli	29/06/2018	Leaf	2018	5.01	45.66	9.113679	0.02	0.3	0.023498	36.00
Akseli	29/06/2018	Stem	2018	3.645	41.965	11.54008	0.145	0.805	0.679921	36.00
Akseli	23/07/2018	Dead	2018	2.21	41.19	18.64338	0.04	0.09	0.296713	60.00
Akseli	23/07/2018	Head	2018	2.485	46.33	18.64387	0.005	0.09	0.001296	60.00
Akseli	23/07/2018	Leaf	2018	3.325	44.295	13.41794	0.285	0.095	1.121537	60.00
Akseli	23/07/2018	Stem	2018	1.11	43.765	39.43068	0.01	0.055	0.305682	60.00
Akseli	27/08/2018	Head	2018	2.7	47.74	17.70263	0.09	0.12	0.634532	81.00
Akseli	27/08/2018	Leaf	2018	1.42	37.245	26.2246	0.02	0.955	0.303175	81.00
Akseli	27/08/2018	Stem	2018	0.54	48.715	92.67603	0.11	3.665	12.09141	81.00
Alku	29/06/2018	Leaf	2018	5.055	45.265	8.960286	0.115	0.255	0.254289	36.00
Alku	29/06/2018	Stem	2018	3.49	42.74	12.297	0.25	0.61	0.706089	36.00
Alku	23/07/2018	Dead	2018	2.27	39.325	17.35633	0.11	0.385	0.671452	60.00
Alku	23/07/2018	Head	2018	2.3	46.82	20.38365	0.09	0.24	0.693273	60.00
Alku	23/07/2018	Leaf	2018	3.27	40.745	12.48242	0.16	0.515	0.453268	60.00
Alku	23/07/2018	Stem	2018	1.075	43.97	41.09261	0.075	0.15	2.727391	60.00
Alku	27/08/2018	Head	2018	2.725	47.605	17.47659	0.055	0.035	0.339894	PM
Alku	27/08/2018	Leaf	2018	1.465	35.64	24.31936	0.015	1.55	0.809017	PM
Alku	27/08/2018	Stem	2018	0.505	44.615	88.35451	0.005	0.035	0.80549	PM
Avetron	10/07/2017	Leaf	2017	3.77	44.39	11.81135	0.22	0.22	0.630901	38.00
Avetron	10/07/2017	Stem	2017	1.895	41.425	21.8956	0.075	0.055	0.895604	38.00
Avetron	31/07/2017	Dead	2017	2.38	42.125	17.85172	0.21	0.355	1.724312	59.00
Avetron	31/07/2017	Head	2017	2.175	44.99	20.68842	0.035	0.27	0.208779	59.00
Avetron	31/07/2017	Leaf	2017	2.705	39.41	14.63537	0.115	2.52	1.553814	59.00
Avetron	31/07/2017	Stem	2017	0.93	42.26	46.41851	0.13	0.47	6.993986	59.00
Avetron	05/10/2017	Head	2017	1.92	46.055	23.98698	0	0.135	0.070313	129.00
Avetron	05/10/2017	Leaf	2017	0.77	35.87	46.58603	0.01	0.37	0.124494	129.00
Avetron	05/10/2017	Stem	2017	0.3	44.875	149.5833	0	0.075	0.25	129.00
Avetron	29/06/2018	Leaf	2018	4.745	45.535	9.59739	0.045	0.055	0.10261	36.00
Avetron	29/06/2018	Stem	2018	3.19	42.005	13.35335	0.37	0.165	1.600546	36.00
Avetron	23/07/2018	Dead	2018	1.97	39.16	20.58547	0.39	0.99	3.572758	60.00
Avetron	23/07/2018	Head	2018	2.285	46.445	20.39972	0.145	0.305	1.161032	60.00
Avetron	23/07/2018	Leaf	2018	2.985	42.345	14.18479	0.055	0.965	0.061922	60.00

Avetron	23/07/2018	Stem	2018	0.825	44.04	53.47446	0.035	0.07	2.183765	60.00
Avetron	27/08/2018	Head	2018	2.77	47.785	17.81178	0.49	0.055	3.170676	83.00
Avetron	27/08/2018	Leaf	2018	1.4	36.85	26.37845	0.07	0.25	1.140351	83.00
Avetron	27/08/2018	Stem	2018	0.475	45.525	127.931	0.235	0.745	64.86062	83.00
Cilla	10/07/2017	Leaf	2017	4.48	43.215	9.647084	0.04	0.055	0.098411	38.00
Cilla	10/07/2017	Stem	2017	2.885	40.825	14.16844	0.085	0.525	0.599417	38.00
Cilla	31/07/2017	Dead	2017	2.12	41.545	19.6381	0.08	0.755	1.097193	59.00
Cilla	31/07/2017	Head	2017	2.135	45.445	21.34529	0.105	0.345	1.211361	59.00
Cilla	31/07/2017	Leaf	x	2.69	42.36	15.74721	x	x	x	59.00
Cilla	31/07/2017	Stem	2017	0.975	41.89	43.5364	0.105	0.61	5.314176	59.00
Cilla	05/10/2017	Head	2017	1.86	45.185	24.29643	0.02	0.105	0.317704	133.00
Cilla	05/10/2017	Leaf	2017	1.095	34.51	33.10803	0.245	0.32	7.115496	133.00
Cilla	05/10/2017	Stem	2017	0.375	44.05	117.6389	0.015	0.15	4.305556	133.00
Cilla	29/06/2018	Leaf	2018	4.935	45.345	9.201571	0.185	0.025	0.350008	36.00
Cilla	29/06/2018	Stem	2018	3.265	41.93	12.84672	0.075	0.33	0.194029	36.00
Cilla	23/07/2018	Dead	2018	1.57	39.335	26.13867	0.33	0.525	5.15972	60.00
Cilla	23/07/2018	Head	2018	2.375	45.87	19.35233	0.115	0.33	0.798113	60.00
Cilla	23/07/2018	Leaf	2018	2.775	41.995	15.33155	0.345	0.865	1.594373	60.00
Cilla	23/07/2018	Stem	2018	0.86	43.565	50.99912	0.07	0.045	4.203416	60.00
Cilla	27/08/2018	Head	2018	2.465	47.245	19.22845	0.145	0.185	1.056034	84.00
Cilla	27/08/2018	Leaf	2018	1.455	37.88	26.04831	0.025	0.53	0.811827	84.00
Cilla	27/08/2018	Stem	2018	0.415	45.505	109.669	0.005	0.085	1.526132	84.00
Haga	10/07/2017	Leaf	2017	3.46	44.365	12.83489	0.13	0.505	0.336282	38.00
Haga	10/07/2017	Stem	2017	1.76	42.1	24.14351	0.17	0.04	2.309317	38.00
Haga	31/07/2017	Dead	2017	2.275	41.19	18.20297	0.145	0.84	1.52942	59.00
Haga	31/07/2017	Head	2017	2.185	45.85	20.98423	0.005	0.13	0.107515	59.00
Haga	31/07/2017	Leaf	2017	3.03	42.225	14.09329	0.33	0.265	1.447454	59.00
Haga	31/07/2017	Stem	2017	0.965	42.815	46.12157	0.185	0.295	9.147659	59.00
Haga	05/10/2017	Head	2017	1.65	43.61	26.50685	0.09	0.07	1.403404	139.00
Haga	05/10/2017	Leaf	2017	1	37.5	37.59856	0.04	0.96	2.463942	139.00
Haga	05/10/2017	Stem	2017	0.395	43.875	111.208	0.015	0.295	3.476252	139.00
Haga	29/06/2018	Leaf	2018	4.9	45.5	9.28769	0.08	0.15	0.121024	36.00
Haga	29/06/2018	Stem	2018	3.37	42.32	12.56032	0.05	0.07	0.165583	36.00
Haga	23/07/2018	Dead	2018	1.85	37.81	20.60986	0.14	1.32	2.273179	60.00
Haga	23/07/2018	Head	2018	2.25	46.7	20.75931	0.03	0.01	0.281235	60.00
Haga	23/07/2018	Leaf	2018	3.105	43.095	13.88035	0.025	0.085	0.139133	60.00
Haga	23/07/2018	Stem	2018	0.85	43.805	51.73958	0.05	0.365	3.472917	60.00
Haga	27/08/2018	Head	2018	2.715	47.24	17.87253	0.445	0.12	2.885184	84.00
Haga	27/08/2018	Leaf	2018	1.525	39.44	26.66556	0.275	0.54	4.454444	84.00
Haga	27/08/2018	Stem	2018	0.445	44.465	102.2288	0.065	0.385	15.79747	84.00
Niklas	10/07/2017	Leaf	2017	3.71	44.36	11.96389	0.1	0.23	0.260482	38.00
Niklas	10/07/2017	Stem	2017	1.69	42.46	25.23077	0.11	0.01	1.636322	38.00
Niklas	31/07/2017	Dead	2017	1.995	41.9	21.24847	0.225	0.43	2.180905	59.00
Niklas	31/07/2017	Head	2017	2.06	45.235	21.96492	0.03	0.215	0.424246	59.00
Niklas	31/07/2017	Leaf	2017	2.87	41.675	14.61463	0.23	0.005	1.169465	59.00
Niklas	31/07/2017	Stem	2017	0.905	41.86	47.05324	0.115	0.28	6.288533	59.00

Niklas	05/10/2017	Head	2017	1.855	45.365	24.48644	0.065	0.045	0.882274	120.00
Niklas	05/10/2017	Leaf	2017	1.055	40.82	38.99758	0.195	5.86	1.653581	120.00
Niklas	05/10/2017	Stem	2017	0.34	45.08	135.6163	0.05	0.22	20.59063	120.00
Niklas	29/06/2018	Leaf	2018	5.245	45.015	8.585535	0.095	0.075	0.169805	36.00
Niklas	29/06/2018	Stem	2018	3.18	42.93	13.52372	0.14	0.18	0.53878	36.00
Niklas	23/07/2018	Dead	2018	1.695	39.925	23.87015	0.215	0.915	2.487955	60.00
Niklas	23/07/2018	Head	2018	2.35	46.74	19.97704	0.16	0.17	1.287799	60.00
Niklas	23/07/2018	Leaf	2018	3.005	42.12	14.03388	0.115	0.26	0.450548	60.00
Niklas	23/07/2018	Stem	2018	0.985	44.28	44.97	0.015	0.34	1.03	60.00
Niklas	27/08/2018	Head	2018	2.555	47.255	18.50859	0.075	0.215	0.459156	80.00
Niklas	27/08/2018	Leaf	2018	1.66	36.145	21.9375	0.14	0.145	1.9375	80.00
Niklas	27/08/2018	Stem	2018	0.61	43.14	70.82915	0.04	1.83	1.644534	80.00

Barley										
				Mean			SE			
Variety	Date of sampling	Plant organ	Year	ωN/%	ωC/%	C/N ratio	ωN/%	ωC/%	C/N ratio	DAS
Alvari	10/07/2017	Leaf	2017	3.38	43.6	12.9	0.0	1.2	0.5	38.00
Alvari	10/07/2017	Stem	2017	1.79	40.7	22.8	0.1	0.6	0.6	38.00
Alvari	26/07/2017	Dead	2017	2.11	41.7	20.0	0.2	0.1	1.9	54.00
Alvari	26/07/2017	Head	2017	2.09	44.6	21.6	0.2	0.2	2.4	54.00
Alvari	26/07/2017	Leaf	2017	3.405	43.0	12.8	0.4	0.4	1.4	54.00
Alvari	26/07/2017	Stem	2017	1.205	42.1	35.4	0.1	0.3	3.9	54.00
Alvari	05/10/2017	Head	2017	1.935	43.5	22.6	0.1	0.1	1.4	116.0
Alvari	05/10/2017	Leaf	2017	1.705	35.4	21.6	0.3	1.1	4.6	116.0
Alvari	05/10/2017	Stem	2017	0.645	44.0	68.7	0.0	1.3	6.8	116.0
Alvari	26/06/2018	Leaf	2018	4.44	45.8	10.3	0.1	0.3	0.1	35.00
Alvari	26/06/2018	Stem	2018	3.355	42.1	12.8	0.4	0.3	1.5	35.00
Alvari	17/07/2018	Dead	2018	1.505	41.3	27.7	0.2	1.0	2.2	56.00
Alvari	17/07/2018	Head	2018	1.835	45.6	25.4	0.3	0.4	3.6	56.00
Alvari	17/07/2018	Leaf	2018	3.565	43.9	12.3	0.1	0.3	0.3	56.00
Alvari	17/07/2018	Stem	2018	1	44.1	45.2	0.2	0.0	7.2	56.00
Alvari	20/08/2018	Head	2018	2.29	46.3	20.5	0.2	0.3	2.1	84.0
Alvari	20/08/2018	Leaf	2018	1.475	40.8	27.7	0.1	0.0	1.2	84.0
Alvari	20/08/2018	Stem	2018	0.565	45.0	79.8	0.0	0.4	2.7	84.0
Anneli	10/07/2017	Leaf	2017	2.27	41.6	18.6	0.3	0.0	2.3	38.00
Anneli	10/07/2017	Stem	2017	3.675	43.7	11.9	0.0	0.7	0.3	38.00
Anneli	26/07/2017	Head	2017	2.47	44.7	18.6	0.4	0.3	3.1	54.00
Anneli	26/07/2017	Dead	2017	2.115	43.5	21.6	0.4	1.4	5.1	54.00
Anneli	26/07/2017	Stem	2017	1.275	42.9	35.3	0.3	0.1	7.7	54.00
Anneli	26/07/2017	Leaf	2017	3.305	43.1	13.5	0.6	0.4	2.4	54.00
Anneli	05/10/2017	Stem	2017	0.49	45.3	92.8	0.0	0.0	5.8	116.0
Anneli	05/10/2017	Leaf	2017	1.275	32.7	25.7	0.1	2.1	0.7	116.0
Anneli	05/10/2017	Head	2017	1.715	43.4	25.4	0.1	0.1	1.6	116.0
Anneli	17/07/2018	Leaf	2018	3.425	43.4	12.7	0.2	0.3	0.6	56.00
Anneli	17/07/2018	Dead	2018	1.595	40.2	25.4	0.1	0.4	2.6	56.00
Anneli	17/07/2018	Stem	2018	1.085	44.0	41.2	0.1	0.6	5.3	56.00
Anneli	17/07/2018	Head	2018	2.4	45.8	19.1	0.1	0.3	0.9	56.00

Anneli	26/06/2018	Leaf	2018	4.265	45.5	10.7	0.0	0.1	0.1	35.00
Anneli	26/06/2018	Stem	2018	3.5	42.4	12.1	0.0	0.0	0.0	35.00
Anneli	20/08/2018	Stem	2018	0.48	45.0	97.2	0.1	0.3	18.9	87.0
Anneli	20/08/2018	Leaf	2018	1.395	39.9	28.6	0.1	0.5	1.2	87.0
Anneli	20/08/2018	Head	2018	2.575	46.3	18.1	0.2	0.1	1.3	87.0
Aukusti	10/07/2017	Stem	2017	2.29	37.8	16.5	0.0	2.6	1.4	38.00
Aukusti	10/07/2017	Leaf	2017	3.85	44.4	11.6	0.3	0.7	0.8	38.00
Aukusti	26/07/2017	Dead	2017	1.82	41.4	23.8	0.4	0.6	4.8	54.00
Aukusti	26/07/2017	Head	2017	2.41	44.8	18.6	0.0	0.3	0.4	54.00
Aukusti	26/07/2017	Leaf	2017	3.535	42.9	12.1	0.1	0.1	0.2	54.00
Aukusti	26/07/2017	Stem	2017	1.37	42.4	31.0	0.1	0.3	1.6	54.00
Aukusti	05/10/2017	Head	2017	1.775	43.5	24.8	0.2	0.1	2.6	109.0
Aukusti	05/10/2017	Stem	2017	0.58	44.6	81.8	0.1	0.1	19.9	109.0
Aukusti	05/10/2017	Leaf	2017	1.57	35.9	24.0	0.4	3.0	4.3	109.0
Aukusti	26/06/2018	Stem	2018	3.245	42.5	13.7	0.7	0.2	2.9	35.00
Aukusti	26/06/2018	Leaf	2018	4.335	45.2	10.6	0.5	0.6	1.4	35.00
Aukusti	17/07/2018	Leaf	2018	3.675	43.8	12.0	0.2	0.0	0.6	56.00
Aukusti	17/07/2018	Dead	2018	1.58	40.7	26.2	0.2	1.0	3.0	56.00
Aukusti	17/07/2018	Stem	2018	1.12	43.7	39.4	0.1	0.0	4.2	56.00
Aukusti	17/07/2018	Head	2018	1.885	44.5	23.8	0.1	0.3	1.8	56.00
Aukusti	20/08/2018	Stem	2018	1.61	43.5	40.2	0.9	1.0	23.3	84.0
Aukusti	20/08/2018	Leaf	2018	1.7	39.9	23.4	0.0	0.6	0.5	84.0
Aukusti	20/08/2018	Head	2018	2.225	45.8	20.6	0.0	0.2	0.1	84.0
Gn100063	10/07/2017	Stem	2017	2.005	41.5	20.7	0.0	0.3	0.3	38.00
Gn100063	10/07/2017	Leaf	2017	3.81	44.4	11.7	0.2	0.3	0.5	38.00
Gn100063	26/07/2017	Dead	2017	2.16	39.6	19.2	0.5	0.3	4.0	54.00
Gn100063	26/07/2017	Head	2017	1.975	43.7	22.3	0.2	0.2	2.2	54.00
Gn100063	26/07/2017	Stem	2017	1.57	41.4	27.5	0.3	0.2	5.7	54.00
Gn100063	26/07/2017	Leaf	2017	3.49	42.3	12.6	0.7	0.2	2.4	54.00
Gn100063	05/10/2017	Leaf	2017	1.54	33.0	25.1	0.6	1.3	9.3	122.0
Gn100063	05/10/2017	Stem	2017	0.71	43.5	76.4	0.3	0.8	34.5	122.0
Gn100063	05/10/2017	Head	2017	1.63	43.2	27.3	0.3	0.3	4.5	122.0
Gn100063	26/06/2018	Stem	2018	3.475	42.0	12.1	0.2	0.4	0.5	35.00
Gn100063	26/06/2018	Leaf	2018	4.345	46.1	10.7	0.3	0.0	0.8	35.00
Gn100063	17/07/2018	Leaf	2018	3.48	43.0	12.4	0.3	0.0	0.9	56.00
Gn100063	17/07/2018	Dead	2018	1.91	41.8	22.5	0.3	1.4	3.3	56.00
Gn100063	17/07/2018	Stem	2018	1.15	43.7	39.8	0.2	0.2	8.5	56.00
Gn100063	17/07/2018	Head	2018	1.915	44.6	23.3	0.0	0.4	0.2	56.00
Gn100063	20/08/2018	Stem	2018	0.705	43.9	66.5	0.2	0.1	16.7	84.0
Gn100063	20/08/2018	Head	2018	1.965	45.8	23.3	0.0	0.0	0.0	84.0
Gn100063	20/08/2018	Leaf	2018	1.75	39.7	23.5	0.3	0.2	4.3	84.0
Judit	10/07/2017	Stem	2017	2.39	41.4	17.4	0.2	0.7	0.8	38.00
Judit	10/07/2017	Leaf	2017	4.1	44.0	10.7	0.1	0.5	0.4	38.00
Judit	26/07/2017	Dead	2017	2.52	41.7	16.5	0.0	0.4	0.0	54.00
Judit	26/07/2017	Head	2017	2.115	44.5	21.0	0.0	0.0	0.5	54.00
Judit	26/07/2017	Stem	2017	1.58	42.6	27.3	0.2	0.2	3.2	54.00

Judit	26/07/2017	Leaf	2017	4.325	43.2	10.0	0.1	0.3	0.4	54.00
Judit	05/10/2017	Stem	2017	0.64	43.9	69.2	0.1	0.1	6.4	108.0
Judit	05/10/2017	Leaf	2017	1.365	33.6	24.5	0.1	5.7	2.5	108.0
Judit	05/10/2017	Head	2017	2.025	44.0	21.7	0.0	0.1	0.1	108.0
Judit	26/06/2018	Stem	2018	3.02	43.2	14.3	0.1	0.6	0.5	35.00
Judit	26/06/2018	Leaf	2018	3.95	46.1	11.7	0.1	0.0	0.2	35.00
Judit	17/07/2018	Leaf	2018	3.565	45.0	12.6	0.0	1.7	0.6	56.00
Judit	17/07/2018	Dead	2018	1.6	40.1	25.9	0.3	0.0	4.7	56.00
Judit	17/07/2018	Stem	2018	1.165	44.3	39.4	0.2	0.1	7.2	56.00
Judit	17/07/2018	Head	2018	1.82	44.9	24.7	0.0	0.2	0.0	56.00
Judit	20/08/2018	Stem	2018	0.815	44.3	55.5	0.1	0.2	8.1	83.0
Judit	20/08/2018	Leaf	2018	1.905	39.0	20.9	0.3	1.4	2.8	83.0
Judit	20/08/2018	Head	2018	2.355	46.1	19.6	0.1	0.3	1.0	83.0
Kaarle	10/07/2017	Stem	2017	2.405	41.1	17.4	0.3	0.8	2.1	38.00
Kaarle	10/07/2017	Leaf	2017	3.98	44.1	11.1	0.2	0.3	0.5	38.00
Kaarle	26/07/2017	Stem	2017	1.33	41.5	31.8	0.2	0.5	4.6	54.00
Kaarle	26/07/2017	Leaf	2017	3.64	42.2	11.6	0.2	0.1	0.7	54.00
Kaarle	26/07/2017	Dead	2017	1.955	40.0	20.8	0.2	0.4	2.8	54.00
Kaarle	26/07/2017	Head	2017	1.91	44.0	23.2	0.2	0.2	2.1	54.00
Kaarle	05/10/2017	Stem	2017	0.455	45.2	102.9	0.1	0.3	18.6	130.0
Kaarle	05/10/2017	Leaf	2017	1.24	36.8	31.2	0.3	1.2	7.5	130.0
Kaarle	05/10/2017	Head	2017	1.67	42.2	25.6	0.2	1.6	2.3	130.0
Kaarle	26/06/2018	Leaf	2018	4.26	45.6	10.7	0.2	0.0	0.4	35.00
Kaarle	26/06/2018	Stem	2018	3.53	42.3	12.2	0.5	0.1	1.7	35.00
Kaarle	17/07/2018	Leaf	2018	3.735	43.1	11.6	0.2	0.0	0.6	56.00
Kaarle	17/07/2018	Dead	2018	1.64	40.1	24.5	0.1	0.4	1.4	56.00
Kaarle	17/07/2018	Stem	2018	1.185	43.9	37.0	0.0	0.1	0.6	56.00
Kaarle	17/07/2018	Head	2018	2.165	48.8	22.5	0.1	3.9	0.5	56.00
Kaarle	20/08/2018	Stem	2018	0.54	44.3	86.3	0.1	0.1	19.3	87.0
Kaarle	20/08/2018	Leaf	2018	1.415	40.2	29.5	0.3	1.9	5.0	87.0
Kaarle	20/08/2018	Head	2018	2.12	45.9	22.1	0.3	0.0	3.4	87.0
Kannas	10/07/2017	Stem	2017	2.735	40.5	14.8	0.0	0.2	0.0	38.00
Kannas	10/07/2017	Leaf	2017	4.11	43.8	10.7	0.0	0.6	0.1	38.00
Kannas	26/07/2017	Stem	2017	1.36	42.3	31.5	0.2	0.2	3.9	54.00
Kannas	26/07/2017	Leaf	2017	3.465	43.9	12.7	0.2	0.2	0.6	54.00
Kannas	26/07/2017	Dead	2017	1.965	42.1	22.0	0.3	0.2	3.6	54.00
Kannas	26/07/2017	Head	2017	2.25	45.2	20.4	0.3	0.0	2.6	54.00
Kannas	05/10/2017	Stem	2017	0.685	43.3	64.3	0.1	0.7	7.9	124.0
Kannas	05/10/2017	Head	2017	1.81	42.4	23.6	0.1	0.2	1.6	124.0
Kannas	05/10/2017	Leaf	2017	1.89	34.1	19.6	0.6	0.7	5.5	124.0
Kannas	26/06/2018	Leaf	2018	4.455	45.4	10.2	0.2	0.1	0.4	35.00
Kannas	26/06/2018	Stem	2018	3.685	42.0	11.4	0.1	0.5	0.5	35.00
Kannas	17/07/2018	Leaf	2018	3.55	44.2	12.5	0.0	0.1	0.1	56.00
Kannas	17/07/2018	Dead	2018	1.615	41.6	25.7	0.0	0.4	0.6	56.00
Kannas	17/07/2018	Stem	2018	1.095	43.8	40.2	0.1	0.2	3.3	56.00
Kannas	17/07/2018	Head	2018	2.165	44.9	20.8	0.0	0.3	0.3	56.00

Kannas	20/08/2018	Stem	2018	0.715	43.9	61.5	0.0	0.1	1.2	84.0
Kannas	20/08/2018	Leaf	2018	1.515	42.0	28.3	0.2	0.5	4.0	84.0
Kannas	20/08/2018	Head	2018	2.735	46.2	16.9	0.1	0.1	0.3	84.0
Rödhette	10/07/2017	Stem	2017	2.705	40.6	15.0	0.1	0.6	0.6	38.00
Rödhette	10/07/2017	Leaf	2017	4.28	44.6	10.4	0.2	0.5	0.3	38.00
Rödhette	26/07/2017	Dead	2017	2.24	41.2	19.1	0.4	0.1	3.7	54.00
Rödhette	26/07/2017	Head	2017	2.23	45.3	20.4	0.1	0.2	1.2	54.00
Rödhette	26/07/2017	Stem	2017	1.1	42.9	39.0	0.0	0.0	0.3	54.00
Rödhette	26/07/2017	Leaf	2017	3.565	43.2	12.2	0.3	0.4	0.8	54.00
Rödhette	05/10/2017	Stem	2017	0.455	45.4	102.5	0.1	0.0	16.9	132.0
Rödhette	05/10/2017	Leaf	2017	1.105	38.4	35.6	0.2	1.2	6.1	132.0
Rödhette	05/10/2017	Head	2017	1.875	44.5	24.2	0.2	0.3	3.3	132.0
Rödhette	26/06/2018	Leaf	2018	4.56	45.3	9.9	0.1	0.1	0.2	35.00
Rödhette	26/06/2018	Stem	2018	3.485	41.6	12.0	0.3	0.2	0.9	35.00
Rödhette	17/07/2018	Leaf	2018	3.255	42.2	13.0	0.2	1.2	1.1	56.00
Rödhette	17/07/2018	Dead	2018	1.665	41.4	25.5	0.2	0.4	4.0	56.00
Rödhette	17/07/2018	Stem	2018	1.28	43.1	33.7	0.0	0.1	0.4	56.00
Rödhette	17/07/2018	Head	2018	2.04	46.0	22.6	0.1	0.5	1.2	56.00
Rödhette	20/08/2018	Stem	2018	2.225	42.0	34.7	1.5	1.9	23.9	89.0
Rödhette	20/08/2018	Head	2018	1.86	45.7	24.8	0.2	0.2	2.2	89.0
Rödhette	20/08/2018	Leaf	2018	1.61	42.2	26.5	0.2	1.1	3.1	89.0
Severi	10/07/2017	Stem	2017	2.18	41.4	19.1	0.2	0.6	1.8	38.00
Severi	10/07/2017	Leaf	2017	3.705	43.8	11.8	0.2	0.1	0.6	38.00
Severi	26/07/2017	Stem	2017	1.195	41.7	35.6	0.2	0.3	5.2	54.00
Severi	26/07/2017	Leaf	2017	3.025	42.5	14.3	0.5	0.4	2.0	54.00
Severi	26/07/2017	Head	2017	1.755	44.9	25.6	0.1	0.4	1.3	54.00
Severi	26/07/2017	Dead	2017	2.07	41.5	20.1	0.2	0.0	1.5	54.00
Severi	05/10/2017	Stem	2017	0.555	43.2	78.0	0.0	0.9	5.1	118.0
Severi	05/10/2017	Head	2017	1.86	43.6	23.4	0.0	0.0	0.0	118.0
Severi	05/10/2017	Leaf	2017	1.36	33.1	24.5	0.1	0.3	1.8	118.0
Severi	26/06/2018	Leaf	2018	4.45	45.5	10.2	0.2	0.3	0.5	35.00
Severi	26/06/2018	Stem	2018	3.54	42.3	11.9	0.0	0.1	0.1	35.00
Severi	17/07/2018	Leaf	2018	3.66	43.7	12.0	0.3	0.2	0.8	56.00
Severi	17/07/2018	Dead	2018	1.57	41.0	26.3	0.1	0.8	1.9	56.00
Severi	17/07/2018	Stem	2018	1.21	44.4	37.1	0.1	0.3	3.7	56.00
Severi	17/07/2018	Head	2018	1.855	45.3	24.4	0.0	0.2	0.2	56.00
Severi	20/08/2018	Stem	2018	0.76	43.1	59.9	0.2	0.9	14.6	87.0
Severi	20/08/2018	Leaf	2018	1.845	40.5	23.5	0.5	0.8	6.2	87.0
Severi	20/08/2018	Head	2018	2.265	46.5	21.0	0.4	0.4	3.2	87.0
Vertti	10/07/2017	Stem	2017	1.98	41.5	21.1	0.2	0.2	1.7	38.00
Vertti	10/07/2017	Leaf	2017	4.16	45.0	10.8	0.1	0.1	0.4	38.00
Vertti	26/07/2017	Stem	2017	1.75	43.1	24.7	0.0	0.2	0.5	54.00
Vertti	26/07/2017	Leaf	2017	4.54	43.6	9.6	0.0	0.1	0.1	54.00
Vertti	26/07/2017	Dead	2017	2.93	41.7	14.3	0.1	0.3	0.7	54.00
Vertti	26/07/2017	Head	2017	2.335	45.0	19.3	0.1	0.3	0.4	54.00
Vertti	05/10/2017	Stem	2017	0.675	44.8	66.9	0.1	0.2	5.8	117.0

Vertti	05/10/2017	Leaf	2017	1.405	38.7	27.6	0.0	1.1	0.1	117.0
Vertti	05/10/2017	Head	2017	1.635	43.0	26.3	0.2	5.3	0.4	117.0
Vertti	26/06/2018	Stem	2018	2.6	42.8	16.4	0.0	0.1	0.1	35.00
Vertti	26/06/2018	Leaf	2018	4	46.3	11.6	0.3	0.2	0.7	35.00
Vertti	17/07/2018	Leaf	2018	3.75	43.8	11.7	0.0	0.1	0.0	56.00
Vertti	17/07/2018	Dead	2018	1.455	40.3	27.7	0.0	0.1	0.8	56.00
Vertti	17/07/2018	Stem	2018	1.095	44.4	41.2	0.1	0.4	5.0	56.00
Vertti	17/07/2018	Head	2018	1.965	44.4	22.6	0.0	0.1	0.3	56.00
Vertti	14/08/2018	Stem	2018	0.555	44.9	89.2	0.2	0.9	28.1	81.0
Vertti	14/08/2018	Head	2018	2.03	45.7	22.7	0.2	0.0	2.0	81.0
Vertti	14/08/2018	Leaf	2018	1.755	40.5	23.1	0.0	0.9	0.6	81.0
Vilde	10/07/2017	Stem	2017	2.69	39.9	14.9	0.2	0.0	1.3	38.00
Vilde	10/07/2017	Leaf	2017	4.24	43.7	10.3	0.0	0.2	0.2	38.00
Vilde	26/07/2017	Head	2017	2.035	45.5	22.5	0.2	0.1	2.1	54.00
Vilde	26/07/2017	Dead	2017	2.355	40.9	17.4	0.1	0.2	1.2	54.00
Vilde	26/07/2017	Leaf	2017	4.365	44.2	10.1	0.2	0.2	0.4	54.00
Vilde	26/07/2017	Stem	2017	1.77	42.4	24.8	0.3	0.6	4.7	54.00
Vilde	05/10/2017	Stem	2017	0.46	44.0	96.3	0.0	0.0	8.3	120.0
Vilde	05/10/2017	Leaf	2017	1.09	34.4	31.6	0.0	1.9	2.6	120.0
Vilde	05/10/2017	Head	2017	1.625	43.2	26.6	0.0	0.1	0.8	120.0
Vilde	26/06/2018	Leaf	2018	4.75	46.0	9.7	0.0	0.3	0.1	35.00
Vilde	26/06/2018	Stem	2018	3.715	42.4	11.4	0.0	0.1	0.0	35.00
Vilde	17/07/2018	Stem	2018	1.355	42.1	31.2	0.1	1.7	1.6	56.00
Vilde	17/07/2018	Leaf	2018	4.06	43.2	10.7	0.2	0.4	0.7	56.00
Vilde	17/07/2018	Dead	2018	1.655	39.8	25.5	0.4	0.2	6.1	56.00
Vilde	17/07/2018	Head	2018	1.915	44.7	23.4	0.1	0.1	1.1	56.00
Vilde	14/08/2018	Head	2018	2.525	47.5	19.5	0.5	2.0	3.4	85.0
Vilde	14/08/2018	Leaf	2018	2.035	38.7	20.2	0.5	1.6	4.4	85.0
Vilde	20/08/2018	Stem	2018	0.86	42.2	56.0	0.3	0.9	19.1	85.0
Vilgot	10/07/2017	Stem	2017	2.18	41.1	18.8	0.0	0.3	0.1	38.00
Vilgot	10/07/2017	Leaf	2017	3.665	43.3	11.9	0.2	0.0	0.8	38.00
Vilgot	26/07/2017	Stem	2017	1.49	42.0	29.8	0.3	0.5	7.1	54.00
Vilgot	26/07/2017	Head	2017	2.26	46.2	20.6	0.3	1.7	1.6	54.00
Vilgot	26/07/2017	Dead	2017	1.64	41.6	25.4	0.0	0.9	1.1	54.00
Vilgot	26/07/2017	Leaf	2017	3.075	43.2	14.1	0.1	0.1	0.6	54.00
Vilgot	05/10/2017	Stem	2017	0.635	43.5	68.7	0.0	0.8	3.6	118.0
Vilgot	05/10/2017	Leaf	2017	1.745	31.9	18.5	0.3	3.6	1.1	118.0
Vilgot	05/10/2017	Head	2017	1.79	42.5	23.9	0.2	0.3	2.2	118.0
Vilgot	26/06/2018	Stem	2018	4.04	42.5	10.5	0.1	0.3	0.2	35.00
Vilgot	26/06/2018	Leaf	2018	4.435	44.7	10.1	0.1	1.3	0.1	35.00
Vilgot	17/07/2018	Leaf	2018	1.175	43.8	38.6	0.2	0.3	7.3	56.00
Vilgot	17/07/2018	Dead	2018	2.27	45.0	20.0	0.3	0.9	1.8	56.00
Vilgot	17/07/2018	Stem	2018	3.255	43.5	13.5	0.4	0.0	1.6	56.00
Vilgot	17/07/2018	Head	2018	1.265	40.9	32.3	0.0	0.6	0.1	56.00
Vilgot	20/08/2018	Stem	2018	0.605	43.8	74.8	0.1	0.6	14.0	88.0
Vilgot	20/08/2018	Leaf	2018	1.415	39.5	28.4	0.2	0.3	3.5	88.0

Vilgot	20/08/2018	Head	2018	2.45	45.6	18.6	0.1	0.2	0.5	88.0

*ωN/%	gN/(g dry weight of plant organ)*100
*ωC/%	gC/(g dry weight of plant organ)*100