

## Yield prediction for arable crops based on ESVI

For a farm in Thuringia/Germany, we have developed a model based on historical yield data and ESVI (enhanced SAR Vegetation Index) that enables the yield to be reliably estimated.

Sentinel-1 satellites deliver data regularly every 12 days worldwide with a resolution of 20x20 m.

The ESVI is based on this data and can be seen as a proxy for fresh biomass.

SAR data are independent of daylight and atmospheric disturbances and are therefore ideal for time series analysis. In this evaluation we used yield and satellite data from all years 2018 - 2022.

**Data:** Zonal statistics were created for all individual plots, all years and for each acquisition date, which resulted in the mean value, the maximum and the minimum being extracted from the respective ESVI data sets.

This data was then compiled in data tables and compared with the yield data for the respective years. Yield data results from weighing logs captured after harvest.

**Method:** For the modeling of the yield values, 5 consecutive ESVI datasets were used.

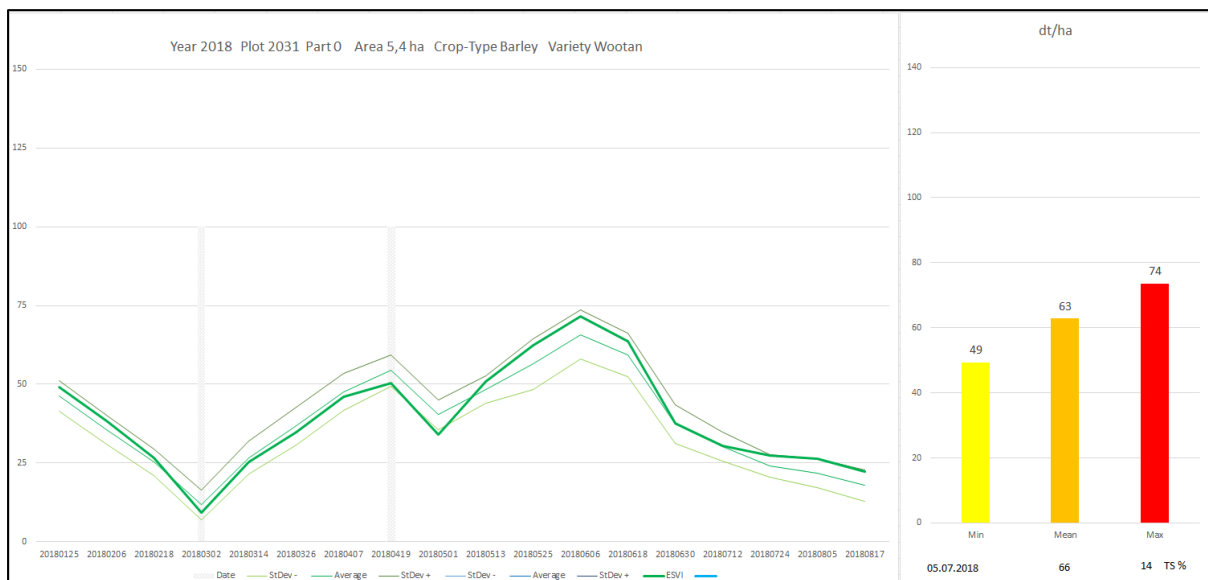
The same formula was used for all cultures and all years.

The formula depends on a weighting table for each crop-type, which is valid for all years.

Depending on the weather conditions, the start of the season may be delayed by a few days.

The model allows a corresponding adjustment, if it becomes apparent that the growth phase in the current year will start much earlier or later than in 'normal' years.

The **evaluation** in the graphic below, for one plot and one year shows a slightly thicker green line. It represents the mean value of the individual plot. The line is flanked by 3 other lines showing the mean value over all plots of the same crop-type and the same year. In addition, you see the simple standard deviation around the mean as a confidence interval. The two gray bars indicate the period for which the yield modeling was calculated in this example (early March – mid April).



On the right-hand side you can see the modeled yield values for the individual plot (minimum, mean and maximum) in the bar chart and below that the harvest date, the measured yield and the moisture content in the grains.

**Results:** The tables for each single year can be seen in the Annexes 2-6. In the header of each table you can see the acquisition dates on which the last of the 5 succeeding ESVI datasets was used for yield modelling. The table shows the deviation of the modelled yield/ha from the measured yield/ha. A value of 104 in this table means, that the model overestimated the yield by 4 %.

In the first line of each table you see the deviation of the modeled yield from the mean ESVI value over all plots of the same crop-type and the same year.

Plots with relatively low yield values but high ESVI values were massively overestimated. However, it is also possible that the assignment of yield per plot data, in the logistic chain or the weighing log was not always without errors. On average over the entire farm, the results are surprisingly good.

In the following table you see an aggregation over all five years. The result from all years, all plots and all varieties show a result close to 100% compared to the measured yield.

Yield prediction can be done from early April and with high reliability from early May to mid of June.

Deviation from yield	Mid April	End April	Early May	Mid May	End May	Early June	Mid June	End June	Mid July	End July
All crops	96	99	100	101	102	101	103	102	102	92
Rapeseed	101	95	97	100	105	105	108	105	99	92
Wheat	96	103	105	107	107	103	102	101	103	89
Barley	90	96	96	97	96	97	99	100	104	97

Overall, it can be said that the model seems to be stable over the years. Even if individual plots stand out as outliers, the average over all plots of one crop type is close to the measured yield.

The standard deviation indicates, that yield prediction between early and mid May, for each single crop and over all crop-types deviates from the real yield in 2 from 3 years by less than 10 %.

Only in 1 from 20 years it can be expected, that the predicted yield deviates by more than 20%.

Standard Deviation	Mid April	End April	Early May	Mid May	End May	Early June	Mid June	End June	Mid July	End July
All crops	9,8	10,6	8,9	10,0	12,1	15,5	15,5	11,3	9,3	14,4
Rapeseed	8,8	4,5	5,7	9,8	11,3	9,1	9,2	6,8	9,2	14,0
Wheat	8,2	9,1	9,4	9,0	11,7	14,7	15,0	14,2	10,7	16,1
Barley	10,3	14,9	9,6	6,5	9,5	21,2	20,7	12,0	7,4	12,8

Based on this data, a farmer can plan at an early stage how much storage capacity is needed or how much of his predicted yield he can sell in advance into the market.

Various applications based on yield estimation can be seen in crop insurance and agricultural trading.

Considering the current situation in Ukraine, a reliable and early yield forecast would be important for the entire logistics chain right down to the end consumers.

**Implementation:** The software enterprise **ESRI** built an application where the algorithm for the yield prediction is already onboarded. The tool allows the farmer to select single plots or all plots of one crop-type to calculate the yield prediction for the actual year, based on the map product ESVI.

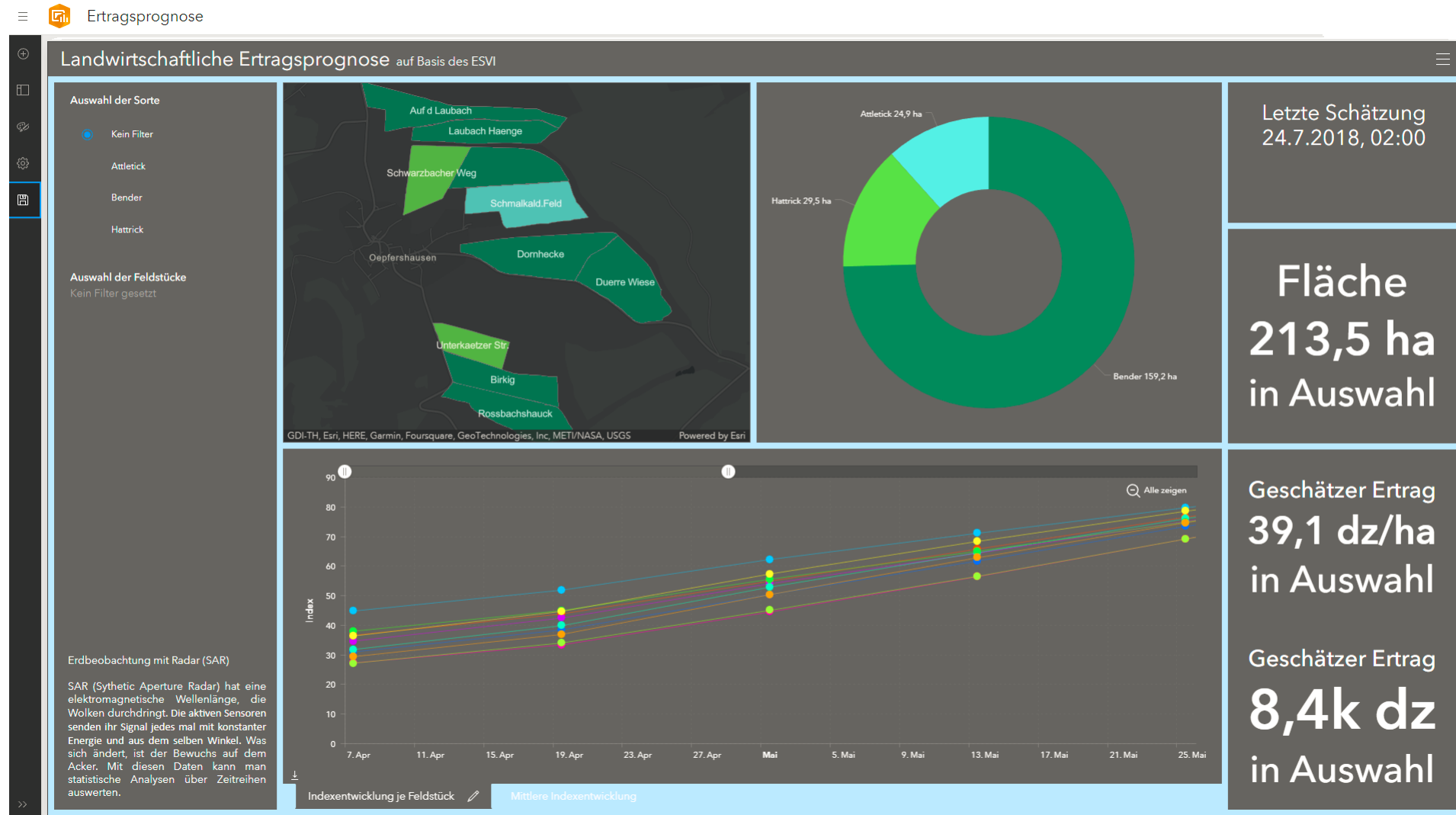
Customers who register for that service have as well access to other map products from the same sensor like SWI (SAR Water Index), which is useful to monitor drought condition in cropland.

Within ArcGIS online they can easily apply seasonal and annual change detection on-the-fly.

The data will be actualized according to the acquisition schedule of Sentinel-1 with a delay of less than 48 hours and is later available in the online platform ArcGIS Imagery

## Annex 1: Dashboard in ArcGIS Insights

The interactive tool enables the farmer to select per crop-type and variety to get an actual yield prediction based on the latest ESVI map products.



**Annex 2: Results from all plots and the 3 crop-types Rapeseed, Wheat and Barley in 2018.**  
 The first line under the header shows the modelled yield for the mean ESVI over all plots.

Plot ID	Variety	Yield	20180407	20180419	20180501	20180513	20180525	20180606	20180618	20180630	20180712	20180724
Average	Rapeseed	39	88	92	104	115	123	120	123	117	102	88
6	Bender	41	77	82	96	107	115	113	116	112	100	86
12	Hattrick	39	70	74	90	106	119	119	123	122	114	104
14	Bender	39	96	100	111	121	126	121	122	115	96	76
15	Bender	32	141	137	144	150	155	150	151	135	108	86
16	Hattrick	36	101	104	116	128	135	131	134	131	119	110
1000	Bender	43	77	84	98	108	114	111	112	107	92	79
1008	Attletick	41	88	91	101	110	117	114	117	110	95	79
1011	Bender	41	69	74	88	101	112	112	117	115	105	90
1013	Bender	40	96	96	105	112	118	116	120	114	97	81
2010	Bender	38	82	89	106	120	129	125	126	118	100	87
Plot ID	Variety	Yield	20180407	20180419	20180501	20180513	20180525	20180606	20180618	20180630	20180712	20180724
Average	Wheat	68	93	113	113	112	116	117	117	118	113	89
7	Reform	77	92	115	105	96	94	92	96	103	104	79
1019	Apostel	79	94	103	100	96	98	103	107	108	102	81
1021	Boregar	69	80	91	99	104	111	111	107	103	100	96
1025	Reform	67	101	126	129	124	123	124	124	128	126	99
1026	Apostel	76	78	94	95	93	95	98	99	101	97	79
1028	Boregar	67	59	82	93	101	109	111	107	102	92	72
1034	Reform	73	109	125	117	107	106	108	109	114	118	107
1035	Reform	68	98	127	125	123	124	124	126	125	116	88
1039	Boregar	66	79	101	109	112	121	127	127	121	103	67
1042	Reform	71	100	121	124	120	119	116	115	119	116	88
1043	Reform	75	84	104	101	96	97	97	99	106	108	84
1045	Reform	68	103	119	108	101	102	104	107	112	111	86
2012	Boregar	61	93	111	117	121	126	124	123	123	115	88
2026	Boregar	65	77	95	101	110	123	129	129	128	123	99
7004	Apostel	67	106	123	117	116	123	128	130	132	128	97
7010	RGT Sacran	59	143	150	136	130	132	131	130	132	127	101
7020	Apostel	68	81	99	100	102	109	113	115	119	112	84
8028	Reform	59	90	123	138	146	152	150	145	138	128	104
8031	Reform	60	107	146	158	158	158	153	149	140	125	104
Plot ID	Variety	Yield	20180407	20180419	20180501	20180513	20180525	20180606	20180618	20180630	20180712	20180724
Average	Barley	66	99	117	108	107	111	129	129	117	106	92
2030	Wootan	48	118	139	134	143	160	185	176	153	133	113
2031	Wootan	66	94	109	97	102	113	137	139	124	110	96
2100	Wootan	50	123	143	138	149	165	184	171	154	139	125
2103	Quadriga	64	97	114	109	108	113	134	137	134	130	114
2104	Wootan	53	117	140	131	137	149	169	163	144	126	112
3000	Quadriga	77	87	107	102	98	95	108	109	101	95	85
3003												
3010	Quadriga	74	104	118	105	97	96	117	125	119	109	94
3012	Wootan	73	89	106	96	95	101	125	129	113	98	84
3101	Wootan	64	116	127	111	108	116	135	129	110	96	85
3102	Wootan	69	116	129	117	112	114	129	124	107	94	82
3110	Wootan	66	96	119	104	101	104	120	120	106	95	80
3120	Wootan	77	91	102	96	91	89	108	114	108	99	81
3130	Wootan	71	91	119	114	115	116	133	132	114	97	73
3800	Wootan	68	81	99	101	96	85	85	84	88	90	84
3801	Wootan	65	64	86	90	96	97	115	116	101	88	72

### Annex 3: The results from the year 2019.

Plot ID	Variety	Yield	20190402	20190414	20190426	20190508	20190520	20190601	20190613	20190625	20190707	20190719
Average	Rapeseed	41	104	97	90	92	92	95	95	97	95	104
2103	LG Architek	46	106	96	82	77	75	74	71	72	75	89
3000	Bender	40	108	103	97	100	101	104	105	107	101	103
3003	Bender	45	107	96	85	83	81	83	84	88	92	107
3010	Bender	40	87	86	86	94	99	104	104	106	102	107
3012	LG Architek	39	119	112	101	100	98	101	103	104	100	106
3101	Bender	39	108	101	95	99	100	101	100	99	97	109
3102	Bender	40	105	98	90	92	95	98	98	99	97	110
3110	Bender	39	108	103	97	101	101	104	105	107	104	110
3120	Bender	45	93	85	79	83	84	87	88	90	91	97
3130	Bender	42	99	90	87	93	95	98	99	101	98	104
Plot ID	Variety	Yield	20190402	20190414	20190426	20190508	20190520	20190601	20190613	20190625	20190707	20190719
Average	Wheat	71	110	104	112	117	122	114	109	107	111	98
6	Reform	72	118	112	116	118	119	111	104	101	109	97
12	LG Initial	84	108	103	105	103	104	98	96	99	104	88
14	Apostel	68	128	118	125	129	131	120	115	111	114	98
15	Apostel	66	145	134	137	136	135	122	118	115	120	106
16	LG Initial	100	104	90	90	91	93	87	84	85	88	75
1000	Apostel	72	139	124	124	124	122	107	101	101	109	94
1008	Reform	69	125	125	131	132	131	118	110	105	113	103
1011	Asory	83	101	94	100	105	110	104	97	94	101	93
1013	Reform	78	100	88	96	104	110	105	97	91	97	89
1021	Euclide	56	103	103	118	131	140	136	130	124	131	120
2010	Apostel	71	114	104	112	120	125	117	113	109	110	93
3800	Reform	60	65	77	100	122	139	133	128	128	136	127
3801	Reform	40	56	82	114	145	172	177	179	172	163	139
Plot ID	Variety	Yield	20190402	20190414	20190426	20190508	20190520	20190601	20190613	20190625	20190707	20190719
Average	Barley	85	72	75	82	89	88	82	85	86	93	89
1003	Quadriga	70	115	113	118	123	114	99	93	90	99	99
1006	Quadriga	96	71	71	77	83	79	71	75	76	80	76
1007	Quadriga	81	100	102	105	104	99	91	90	89	99	99
1018	Quadriga	114	68	69	74	78	74	63	61	60	66	62
5201	Quadriga	93	75	77	81	84	82	74	80	85	91	85
5202	SY Galileoc	91	66	62	65	70	71	68	73	76	84	80
5203	Quadriga	90	84	83	88	92	90	85	89	90	98	91
5204	SY Galileoc	98	73	73	76	79	76	69	77	84	93	88
5400	Meridian	70	106	103	112	124	134	139	143	142	159	143
5403	SY Galileoc	81	74	79	87	94	96	90	86	82	91	92
8030	Wootan	78	78	79	86	95	96	91	99	100	97	85
8031	Wootan	96	60	64	68	70	68	62	72	80	85	80
8032	Wootan	73	64	71	82	93	94	91	90	86	86	82
8033	SY Galileoc	96	55	54	58	61	58	52	64	75	88	87
8134	Wootan	76	88	88	95	102	101	96	99	101	112	109
8140	SY Galileoc	63	54	65	90	114	117	110	112	110	122	119
8301	SY Galileoc	94	64	66	75	86	88	83	80	75	83	83
8302	SY Galileoc	64	48	64	84	98	95	87	85	83	93	91
8304	SY Galileoc	82	44	50	64	79	82	78	80	77	82	76

In the case of barley, the Meridian variety in particular seems to have a different ratio of fresh mass to yield than the other varieties.

Annex 4: The results for 2020.

Plot ID	Variety	Yield	20200408	20200420	20200502	20200514	20200526	20200607	20200619	20200701	20200713	20200725
Average	Rapeseed	42	93	88	94	97	101	101	106	107	102	95
1003	Bender	51	84	81	85	87	87	86	89	89	84	74
1006	Bender	47	89	84	90	95	98	97	99	97	88	73
1007	Bender	48	93	90	94	94	96	94	97	96	93	89
1018	Bender	52	81	78	83	88	91	89	92	92	89	88
3800	Bender	47	95	84	84	84	87	90	96	97	96	95
3801	Bender	46	93	85	86	85	87	90	96	96	90	77
5201	Bender	44	105	96	98	98	100	100	105	106	102	93
5202	Bender	42	101	94	95	94	97	99	106	110	114	117
5203	Bender	39	104	99	104	105	109	111	117	120	124	129
5204	Bender	41	85	86	98	106	111	111	114	113	105	95
5400	Bender	32	67	73	93	112	116	120	125	123	111	98
5403	Bender	31	35	47	78	105	127	136	145	146	140	133
8029	Bender	41	107	101	103	104	106	107	112	111	102	93
8030	Bender	41	109	101	104	105	107	108	113	113	102	88
8031	Bender	44	106	97	99	98	100	100	105	107	108	107
8032	Bender	36	100	94	98	100	106	109	116	113	101	94
8033	Bender	40	113	103	105	104	105	105	112	112	105	96
Plot ID	Variety	Yield	20200408	20200420	20200502	20200514	20200526	20200607	20200619	20200701	20200713	20200725
Average	Wheat	77	90	93	94	94	100	103	108	109	109	89
3000	Asory	87	76	79	84	90	99	102	103	101	101	80
3003	Reform	79	110	108	99	90	93	99	107	108	107	85
3004	Asory	92	48	60	69	75	84	85	85	84	91	85
3010	Apostel	76	100	101	100	99	104	105	109	110	109	85
3011	Asory	80	92	97	94	89	90	89	95	102	109	94
3012	Reform	75	89	95	99	101	109	113	116	113	111	86
3013	Asory	67	104	106	107	110	120	128	139	141	144	118
3101	Reform	59	114	107	104	104	110	124	140	143	140	110
3102	Reform	75	106	105	103	100	103	103	106	106	105	82
3110	Apostel	78	84	87	84	81	83	83	88	95	96	76
3120	Reform	90	88	90	87	84	88	86	84	83	85	70
3130	Apostel	69	91	95	102	108	116	122	127	123	117	89
5205		74	85	89	97	105	118	124	128	128	130	106
Plot ID	Variety	Yield	20200408	20200420	20200502	20200514	20200526	20200607	20200619	20200701	20200713	20200725
Average	Barley	67	95	95	94	95	99	103	105	105	103	89
7												
1019	SY Galileo	82	88	91	90	88	90	97	106	116	122	116
1021	SY Galileo	53	108	111	115	120	123	117	118	127	134	128
1025												
1026	SY Galileo	80	69	70	73	77	84	93	97	95	93	78
1028	SY Galileo	69	81	80	84	91	102	114	116	109	98	76
1034	SY Galileo	84	81	80	78	77	86	97	99	98	101	95
1035												
1039												
1042	SY Galileo	54	121	122	121	122	123	125	135	142	135	118
1043	SY Galileo	70	88	86	85	86	89	98	106	110	109	91
1045												
7004	SY Galileo	57	109	108	107	107	104	111	124	133	126	100
7010	SY Galileo	76	96	90	84	79	89	106	115	111	103	85
7020	SY Galileo	40	157	171	175	178	182	180	182	183	176	143

Only plots with low yield values were significantly overestimated.

**Annex 5:** In 2021 the course of the season started delayed compared to the other years. The model allows for a time adjustment for the start of season, which was set for this year for all crops to 18 days.

Plot ID	Variety	Yield	20210403	20210415	20210427	20210509	20210521	20210602	20210614	20210626	20210708	20210720
Average	Rapeseed	44	108	99	95	89	96	99	104	104	112	107
7	Ludger	42	129	116	108	96	100	105	110	110	118	106
16		43	120	111	107	98	103	107	110	108	116	116
1019	Heiner	39	104	100	101	97	103	104	111	112	123	120
1021	Ludger	42	83	79	79	81	89	90	99	103	115	115
1025	Heiner	43	116	105	98	89	94	97	105	106	116	115
1026		46	84	82	83	82	90	93	99	99	107	101
1028	Ludger	47	104	95	91	84	90	93	97	96	104	99
1034	Heiner	47	90	82	79	76	84	88	95	95	103	97
1035	Ludger	42	124	111	106	99	106	109	112	109	114	100
1039	Heiner	47	98	92	91	84	87	88	91	91	100	96
1042	Heiner	39	120	109	106	101	108	111	116	116	126	126
1043	Heiner	40	111	101	95	90	98	104	112	112	122	117
1045	Ludger	45	112	99	92	85	91	96	102	101	108	96
7004		43	120	111	106	97	101	104	108	106	115	114
7010	Ludger	45	106	97	94	88	95	99	103	102	110	98
7020	Heiner	45	108	101	94	88	94	98	103	101	109	105
Plot ID	Variety	Yield	20210403	20210415	20210427	20210509	20210521	20210602	20210614	20210626	20210708	20210720
Average	Wheat	83	87	92	94	98	88	75	73	76	94	109
1003	Asory	82	110	111	107	109	96	79	76	75	93	117
1006	Asory	87	63	79	89	99	93	83	84	82	94	108
1007	Asory	81	104	106	102	105	93	78	78	81	100	115
3800	Emmerick	79	85	94	104	114	99	79	72	78	96	110
3801	Emmerick	82	61	72	82	93	85	71	70	79	100	117
5200	Asory	81	119	115	109	105	87	73	72	77	99	114
5202	Asory	96	74	80	80	77	63	52	52	58	77	89
5204	Asory	99	86	88	89	87	73	60	57	61	81	93
5205	Asory	95	116	113	101	95	79	67	67	70	88	100
5400	Asory	82	74	87	95	101	88	72	69	73	93	106
8028	Foxx	68	97	105	108	122	122	111	108	104	119	135
8029	Foxx	80	124	116	109	114	105	92	90	89	102	115
8030	Asory	85	76	86	90	98	92	80	77	77	96	108
8031	Asory	79	59	73	82	96	95	86	83	83	101	117
8032	Asory	80	41	49	54	66	68	60	58	61	81	96
8033	Asory	79	98	107	105	103	88	73	73	80	103	118
Plot ID	Variety	Yield	20210403	20210415	20210427	20210509	20210521	20210602	20210614	20210626	20210708	20210720
Average	Barley	74	91	97	102	98	87	74	75	93	114	119
6	SY Galileo	70	97	103	108	106	97	82	76	90	111	118
12	SY Galileo	82	79	83	87	85	78	69	70	88	108	114
14	SY Galileo	81	95	99	100	93	81	71	74	91	110	110
15	SY Galileo	76	93	97	100	94	81	69	78	97	116	119
1000	SY Galileo	71	97	98	99	93	83	71	83	104	124	132
1008	SY Galileo	79	89	97	102	98	87	72	69	85	104	106
1011	SY Galileo	70	99	105	110	107	94	79	76	94	119	128
1013	SY Galileo	68	98	106	114	112	100	83	81	100	124	132
2010	SY Galileo	72	76	88	96	96	87	73	75	93	112	120

**Annex 6:** In 2022 there was no yield data for barley but for two spelt plots instead.

Plot ID	Variety	Yield	20220410	20220422	20220504	20220516	20220528	20220609	20220621	20220703	20220715	20220727
Average	Rapeseed	40	111	100	103	107	111	110	112	102	84	68
6	Ludger	43	106	93	93	96	100	99	103	95	82	69
12	Ludger	40	113	100	101	105	109	109	113	106	91	75
14												
15	Daktari	38	121	109	113	117	120	117	118	101	78	60
1000												
1008	Ludger	40	116	102	104	109	113	111	113	99	80	65
1011	Ludger	40	111	100	103	108	113	112	116	110	96	79
1013	Ludger	42	98	91	95	100	104	103	107	101	90	75
2010	Daktari	38	109	99	104	110	115	113	116	104	83	63
Plot ID	Variety	Yield	20220410	20220422	20220504	20220516	20220528	20220609	20220621	20220703	20220715	20220727
Average	Wheat	63	98	113	113	112	107	104	103	97	86	61
7	Asory	73	96	106	103	98	93	93	97	99	88	59
16	Asory	64	99	113	113	112	110	110	112	106	92	64
1019	Asory	66	97	114	114	113	111	107	104	97	91	69
1021	Asory	57	82	98	109	120	117	113	108	106	111	97
1025	Asory	62	97	110	112	109	100	96	97	96	89	63
1026	Asory	64	83	96	100	106	106	103	99	86	70	44
1028	Asory	64	90	105	105	102	94	89	88	82	69	46
1034	Asory	64	104	117	116	113	107	102	99	91	82	62
1035	Jonte	59	94	119	127	127	120	116	114	103	81	51
1039	Asory	60	115	121	114	108	106	107	111	108	96	65
1042	Asory	57	111	123	125	126	123	120	119	111	100	74
1043												
1045	Jonte	60	97	116	118	115	109	105	104	96	84	63
7004	Asory	69	89	102	103	101	97	94	94	89	80	54
7010	Asory	61	123	134	129	122	115	109	107	98	85	60
7020	Asory	67	101	119	115	107	102	101	104	96	76	49
Plot ID	Variety	Yield	20220410	20220422	20220504	20220516	20220528	20220609	20220621	20220703	20220715	20220727
Average	Spelt	42	93	108	100	86	86	89	92	96	107	88
8028	Zollernper	47	86	98	90	77	76	83	96	114	139	121
8030												
8031	Zollernper	38	108	124	114	98	100	99	97	95	106	85