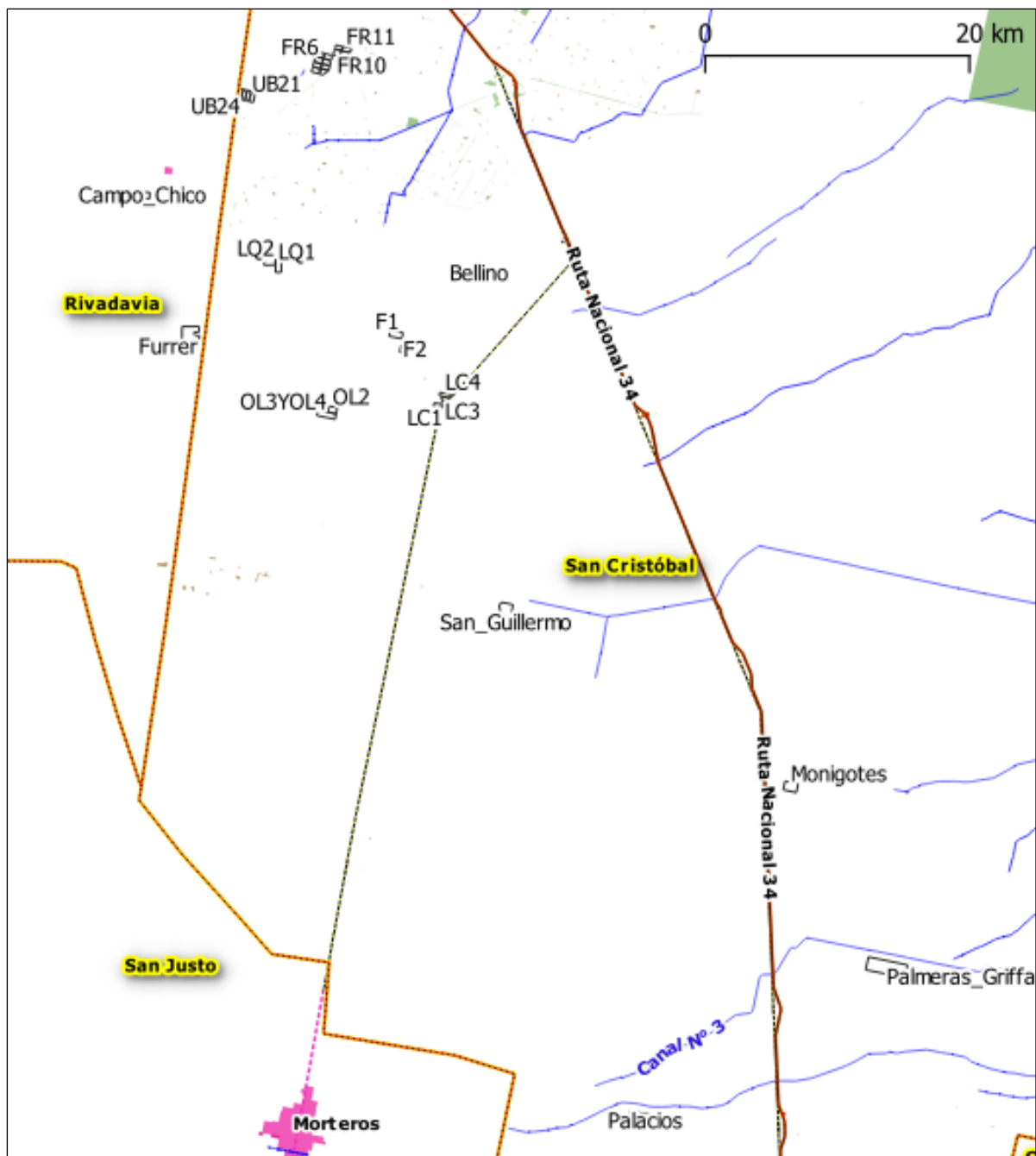


Yield prediction based on ESVI in Argentina/Santa Fé province

Observation area: For different farms and plots we got yield data which was acquired from a weigh bridge. This data seems to be more reliable like data from combine harvesters, which has to be cleaned and normalized. The data was for wheat, corn, sorghum, sunflower and soyabeans.

For yield prediction we applied a zonal statistic for each plot and each acquisition from ESVI map product, which is derived from Sentinel-1 SAR data. Sentinel-1 measures the structure and humidity of the above ground vegetation. It can be seen as a proxy for fresh biomass. We transform the two polarizations VV and VH into a vegetation index (ESVI), which can be transformed directly into a yield prediction. Below you see an overview map with a distribution of the plots.



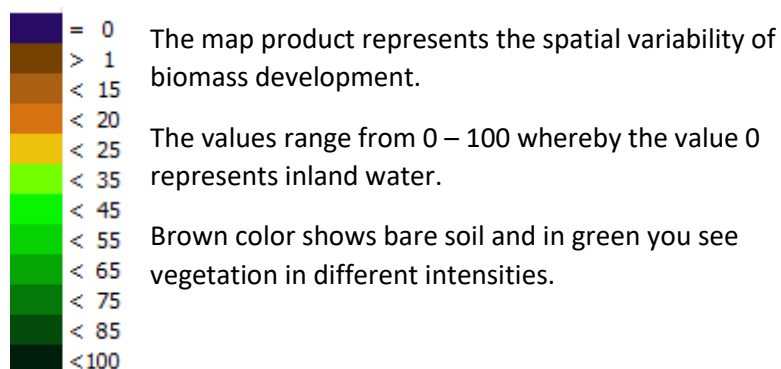
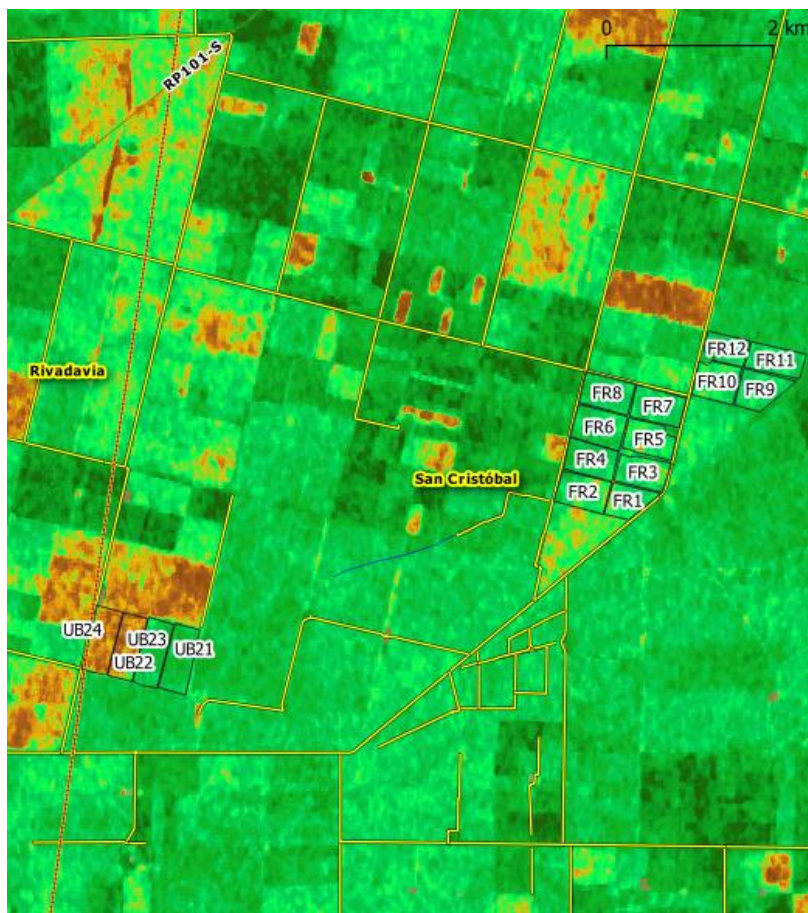
Crop cultivation: The crop cultivation takes place throughout the year. Corn was harvested in 2020 on two plots in summer, and on one plot in winter. (see table on the right)

The harvest of wheat takes place in November. Sorghum and Soybeans is harvested in April and May.

Sunflower is harvested in February.

The cultivation period can alternate from plot to plot and from season to season. This appears to be a challenge for yield modeling.

The image below shows the ESVI from Feb 15, 2021.



| Plot | Date harvest | Crop type | ha |
|-----------------|--------------|-----------|-----|
| Bellino | 27.02.2020 | Corn | 48 |
| F2 | 13.03.2020 | Corn | 24 |
| LC4 | 12.08.2020 | Corn | 24 |
| OL2 | 14.04.2021 | Sorghum | 30 |
| FR10 | 21.04.2021 | Sorghum | 42 |
| Palacios | 03.05.2021 | Soybeans | 267 |
| Monigotes | 06.05.2021 | Soybeans | 68 |
| LC3 | 07.05.2021 | Soybeans | 13 |
| LC4 | 07.05.2021 | Soybeans | 24 |
| Bellino | 08.05.2021 | Soybeans | 47 |
| LC1 | 08.05.2021 | Soybeans | 18 |
| LC2 | 08.05.2021 | Soybeans | 7 |
| San_Guillermo | 10.05.2021 | Soybeans | 134 |
| Furrer | 10.05.2021 | Soybeans | 134 |
| F2 | 12.05.2021 | Soybeans | 24 |
| Campo_Chico | 18.05.2021 | Soybeans | 52 |
| UB24 | 24.05.2021 | Soybeans | 25 |
| UB23 | 25.05.2021 | Soybeans | 25 |
| FR10 | 26.05.2021 | Soybeans | 12 |
| FR12 | 26.05.2021 | Soybeans | 17 |
| FR9 | 27.05.2021 | Soybeans | 18 |
| FR1 | 28.05.2021 | Soybeans | 19 |
| FR5 | 28.05.2021 | Soybeans | 22 |
| FR6 | 28.05.2021 | Soybeans | 18 |
| FR7 | 28.05.2021 | Soybeans | 12 |
| FR8 | 28.05.2021 | Soybeans | 24 |
| LQ1 | 18.06.2021 | Sorghum | 50 |
| F1 | 30.07.2021 | Corn | 48 |
| UB22 | 02.08.2021 | Corn | 24 |
| UB21 | 04.08.2021 | Corn | 24 |
| San_Guillermo | 09.11.2021 | Wheat | 94 |
| Palacios | 02.02.2022 | Sunflower | 267 |
| Palmeras_Griffa | 09.02.2022 | Sunflower | 300 |
| Monigotes | 11.02.2022 | Sunflower | 68 |
| FR10 | 01.05.2022 | Soybeans | 12 |
| FR2 | 01.05.2022 | Soybeans | 24 |
| FR4 | 01.05.2022 | Soybeans | 21 |
| FR6 | 01.05.2022 | Soybeans | 5 |
| FR7 | 01.05.2022 | Soybeans | 10 |
| FR9 | 01.05.2022 | Soybeans | 6 |
| LC4 | 05.05.2022 | Soybeans | 24 |
| UB21 | 08.05.2022 | Soybeans | 25 |
| UB22 | 08.05.2022 | Soybeans | 25 |
| F1 | 10.05.2022 | Soybeans | 47 |
| F2 | 10.05.2022 | Soybeans | 24 |
| OL3YOL4 | 13.05.2022 | Soybeans | 35 |
| San_Guillermo | 18.05.2022 | Soybeans | 94 |
| LQ2 | 18.05.2022 | Soybeans | 50 |
| FR11 | 03.06.2022 | Soybeans | 24 |
| OL2 | 15.06.2022 | Soybeans | 30 |
| FR10 | 07.06.2022 | Sorghum | 12 |
| FR12 | 08.06.2022 | Sorghum | 17 |
| FR5 | 11.06.2022 | Sorghum | 22 |
| FR6 | 11.06.2022 | Sorghum | 18 |
| FR1 | 13.06.2022 | Sorghum | 18 |
| FR9 | 15.06.2022 | Sorghum | 18 |
| UB23 | 16.06.2022 | Sorghum | 25 |
| UB24 | 17.06.2022 | Sorghum | 25 |
| San_Guillermo | 25.07.2022 | Corn | 134 |
| Furrer | 25.07.2022 | Corn | 134 |
| Bellino | 31.07.2022 | Corn | 47 |
| Campo_Chico | 01.08.2022 | Corn | 53 |
| FR3 | 06.08.2022 | Corn | 24 |
| FR7 | 06.08.2022 | Corn | 12 |
| FR8 | 06.08.2022 | Corn | 24 |
| Palacios | 17.11.2022 | Wheat | 267 |
| Monigotes | 19.11.2022 | Wheat | 68 |
| Palmeras_Griffa | 23.11.2022 | Wheat | 300 |

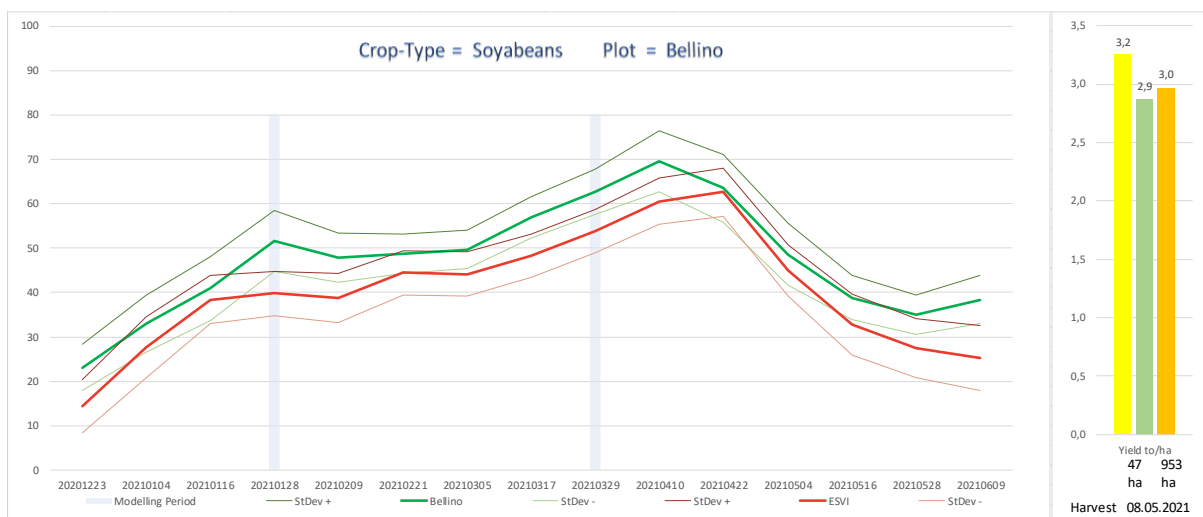
Soyabeans

The example below shows the result over all soyabean plots, which were harvested between early May and mid of June 2021. The thick red curve represents the mean ESVI values over all soyabean plots. Above and below the thinner red lines represents the single standard deviation +/- the mean value. The green curves stand for a single plot, which is here "Bellino".

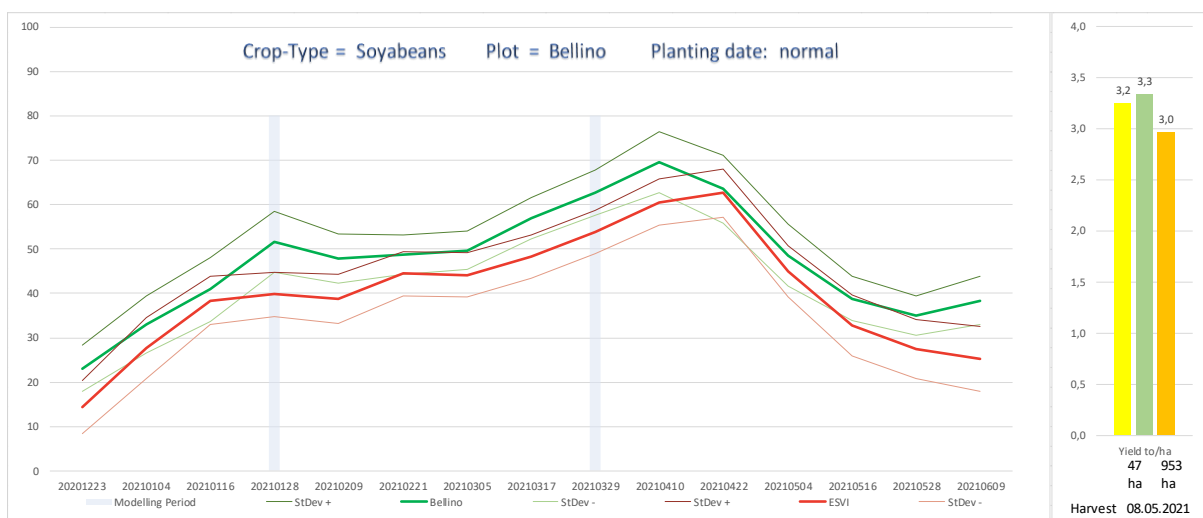
The two grey bars indicate the period of 5 succeeding Sentinel-1 acquisitions which were used to model the yield prediction.

On the right side you see three columns. The left column shows the average yield/ha, which was here 3.2 tons for the plot Bellino. The average yield for all soyabean plots, you see in the right column. It lies at around 3.0 tons.

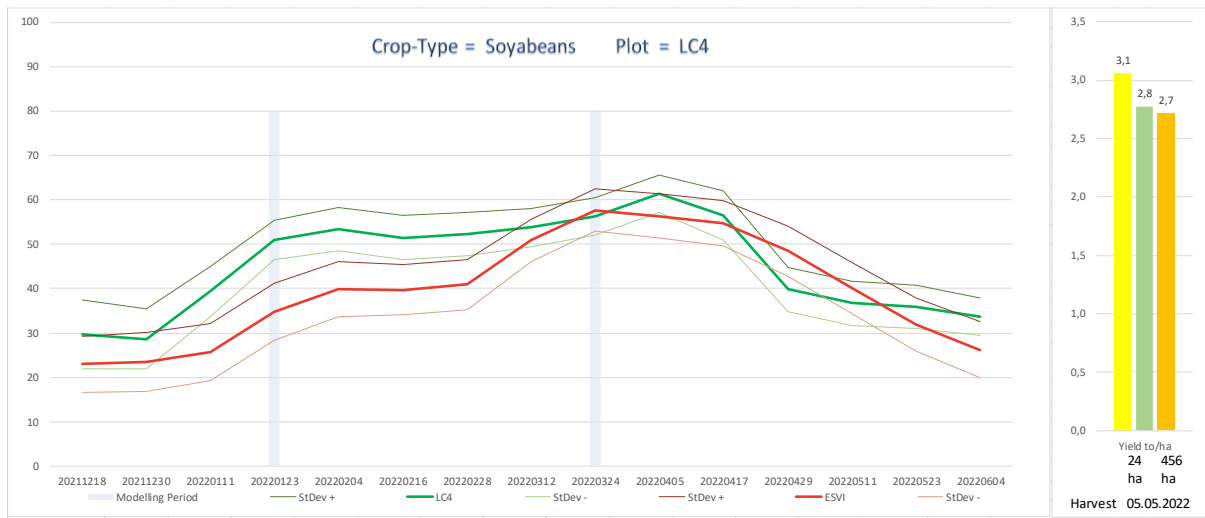
The central column shows the modeled yield, here for all soyabean plots. The value is 2.9 tons.



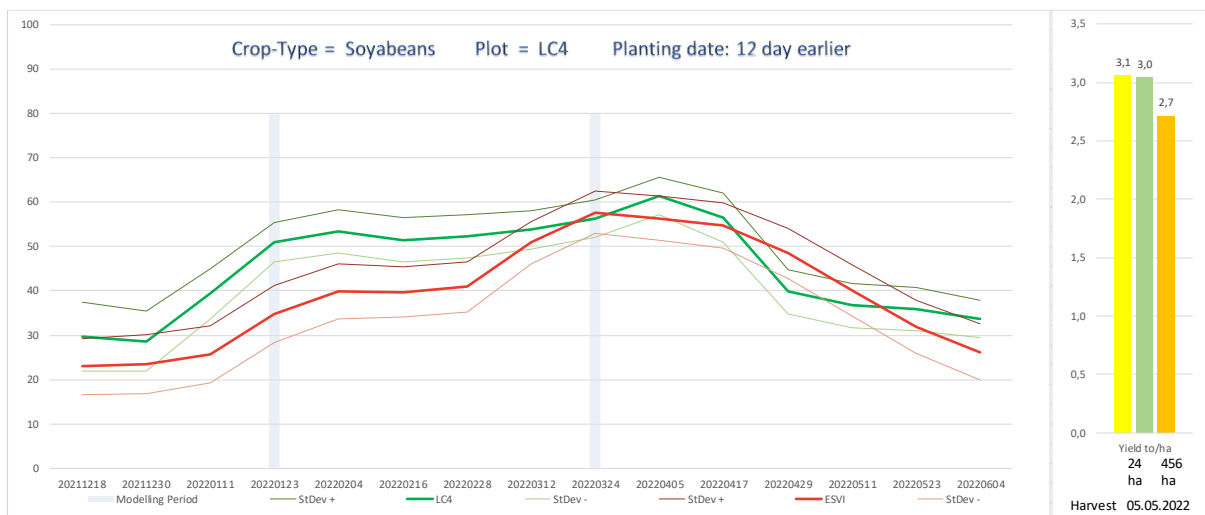
The second image basically shows the same graph, but the modeled yield is for the single plot. The single plot "Bellino" shows a slightly higher ESVI curve and was estimated with a higher yield. The value overestimates the measured yield by 2.6 %.



The following two examples represent data from the succeeding year 2022. The period for yield estimation is more or less the same. The formula for the model is identical. The measured yield and the modeled yield show a close match.

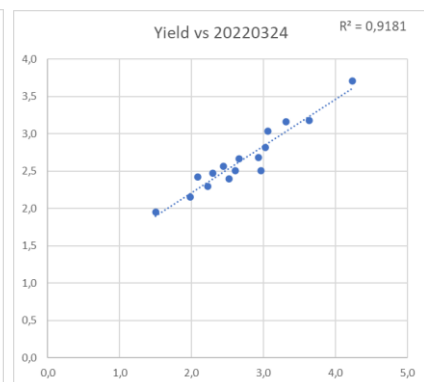
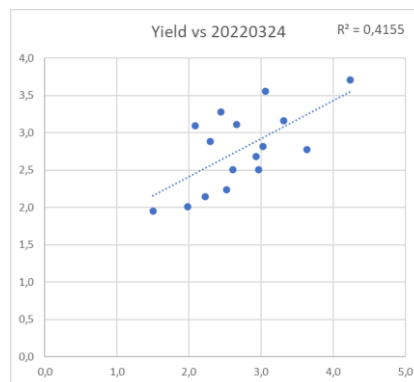


In this case it was assumed, that the plot was planted 12 days earlier, since the curve, which represents vegetation growth raises up a bit earlier.



The start of season is a relevant information for the yield modelling. If we apply the same formula and the same weighing table over all plots of the same crop-type we have to consider the planting dates.

The correlation plot on the left shows the correlation between measured yield and yield prediction without normalization of the planting date. On the right side the planting dates were normalized.



The two tables show the deviation of the modeled yield vs the measured yield.

The first table shows the result for all soyabean plots in 2021.

The upper line shows the date on which the model calculated the yield.

In the second line you see the average result over all soyabean plots for this season.

A value of 98 (average on March 17, 2021) means that the model underestimated the yield by 2 %.

| Deviation | 20210209 | 20210221 | 20210305 | 20210317 | 20210329 | 20210410 | 20210422 | 20210504 | 20210516 | 20210528 | 20210609 |
|---------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 100 | 112 | 105 | 98 | 99 | 100 | 100 | 103 | 98 | 92 | 84 |
| Palacios | 125 | 114 | 108 | 104 | 109 | 108 | 104 | 104 | 102 | 101 | 99 |
| Monigotes | 123 | 132 | 124 | 115 | 119 | 118 | 119 | 118 | 109 | 99 | 81 |
| LC3 | 129 | 123 | 106 | 102 | 98 | 96 | 92 | 91 | 85 | 80 | 74 |
| LC4 | 105 | 109 | 96 | 90 | 87 | 81 | 81 | 85 | 80 | 74 | 66 |
| Bellino | 143 | 146 | 131 | 124 | 117 | 112 | 113 | 116 | 106 | 98 | 87 |
| LC1 | 137 | 136 | 114 | 111 | 111 | 108 | 103 | 102 | 95 | 92 | 88 |
| LC2 | 111 | 114 | 100 | 97 | 97 | 93 | 88 | 87 | 84 | 81 | 77 |
| San_Guillermo | 143 | 148 | 122 | 94 | 77 | 77 | 80 | 82 | 74 | 63 | 53 |
| Furrer | 98 | 118 | 109 | 103 | 102 | 95 | 93 | 97 | 97 | 96 | 92 |
| F2 | 98 | 110 | 109 | 105 | 100 | 98 | 91 | 88 | 81 | 75 | 68 |
| Campo_Chico | 89 | 110 | 107 | 92 | 90 | 87 | 85 | 90 | 86 | 79 | 64 |
| UB24 | 73 | 76 | 78 | 63 | 98 | 130 | 135 | 148 | 143 | 128 | 110 |
| UB23 | 69 | 74 | 74 | 51 | 83 | 113 | 118 | 132 | 128 | 113 | 94 |
| FR10 | 82 | 111 | 107 | 100 | 99 | 98 | 100 | 104 | 98 | 97 | 95 |
| FR12 | 97 | 124 | 116 | 108 | 105 | 104 | 107 | 113 | 110 | 112 | 110 |
| FR9 | 57 | 92 | 97 | 97 | 98 | 99 | 102 | 108 | 103 | 101 | 97 |
| FR1 | 19 | 70 | 93 | 103 | 115 | 124 | 136 | 148 | 141 | 132 | 124 |
| FR5 | 17 | 64 | 85 | 92 | 99 | 111 | 123 | 135 | 128 | 124 | 116 |
| FR6 | 15 | 58 | 76 | 85 | 94 | 98 | 104 | 112 | 107 | 104 | 99 |
| FR7 | 9 | 36 | 48 | 55 | 60 | 63 | 66 | 71 | 69 | 67 | 64 |

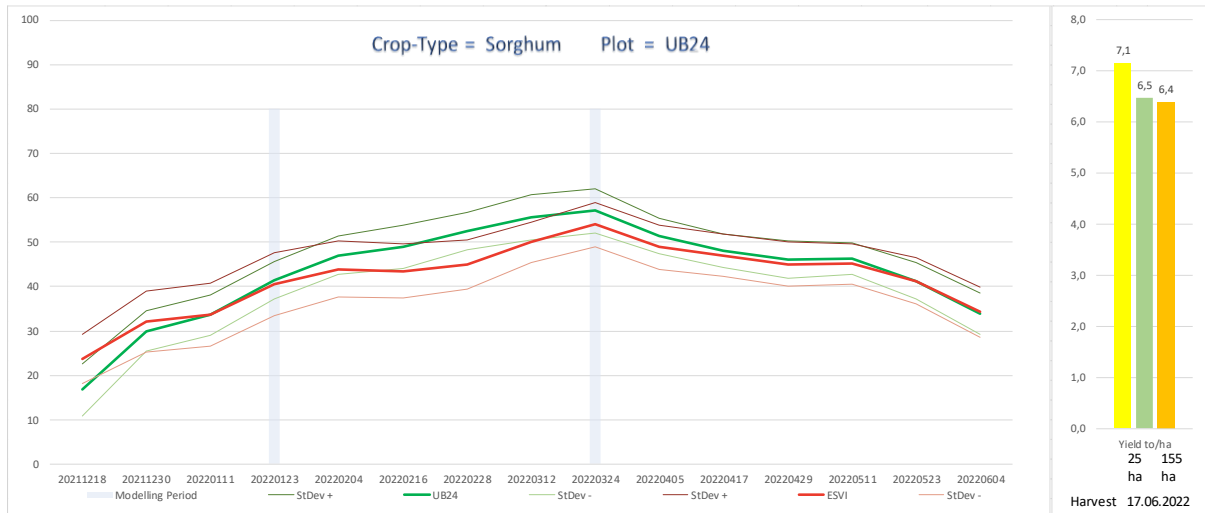
In 2022 we use the same model and weighing table for different plots and get comparable results.

| Deviation | 20220204 | 20220216 | 20220228 | 20220312 | 20220324 | 20220405 | 20220417 | 20220429 | 20220511 | 20220523 | 20220604 |
|---------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 89 | 89 | 87 | 92 | 98 | 98 | 103 | 109 | 101 | 92 | 89 |
| FR10 | 91 | 95 | 89 | 88 | 92 | 91 | 93 | 96 | 88 | 81 | 84 |
| FR2 | 168 | 113 | 91 | 91 | 109 | 130 | 151 | 172 | 163 | 151 | 144 |
| FR4 | 163 | 131 | 108 | 114 | 130 | 146 | 169 | 198 | 187 | 170 | 162 |
| FR6 | 97 | 105 | 99 | 104 | 108 | 106 | 110 | 113 | 103 | 93 | 92 |
| FR7 | 102 | 87 | 80 | 88 | 103 | 118 | 137 | 151 | 140 | 131 | 134 |
| FR9 | 114 | 113 | 99 | 96 | 93 | 88 | 88 | 88 | 80 | 74 | 78 |
| LC4 | 79 | 90 | 95 | 99 | 99 | 94 | 93 | 92 | 84 | 77 | 71 |
| UB21 | 31 | 36 | 46 | 68 | 85 | 90 | 97 | 104 | 93 | 76 | 58 |
| UB22 | 44 | 49 | 57 | 78 | 96 | 101 | 107 | 113 | 102 | 84 | 66 |
| F1 | 89 | 94 | 93 | 93 | 88 | 79 | 77 | 78 | 74 | 72 | 71 |
| F2 | 53 | 71 | 84 | 103 | 116 | 119 | 124 | 130 | 119 | 106 | 98 |
| OL3YOL4 | 93 | 84 | 82 | 86 | 87 | 82 | 83 | 88 | 84 | 80 | 77 |
| San_Guillermo | 87 | 102 | 99 | 101 | 105 | 104 | 108 | 111 | 105 | 100 | 99 |
| LQ2 | 80 | 102 | 100 | 102 | 100 | 96 | 98 | 98 | 87 | 78 | 77 |
| FR11 | 96 | 82 | 78 | 86 | 95 | 99 | 110 | 123 | 118 | 114 | 119 |
| OL2 | 91 | 96 | 96 | 97 | 95 | 89 | 88 | 89 | 85 | 80 | 77 |

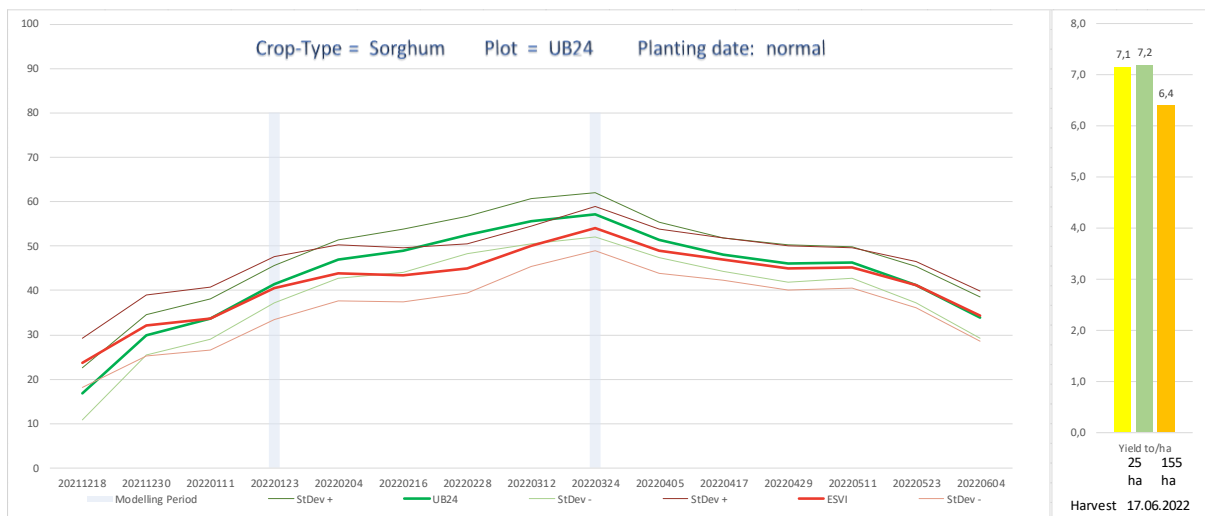
Sorghum

The next example shows the result for the sorghum plots in 2022. The red curves again represent the average +/- a single standard deviation from all sorghum plots.

The green curves represent one single plot. The modeled average yield over all sorghum plots is close to the measured yield and lies at 6.5 tons/ha.



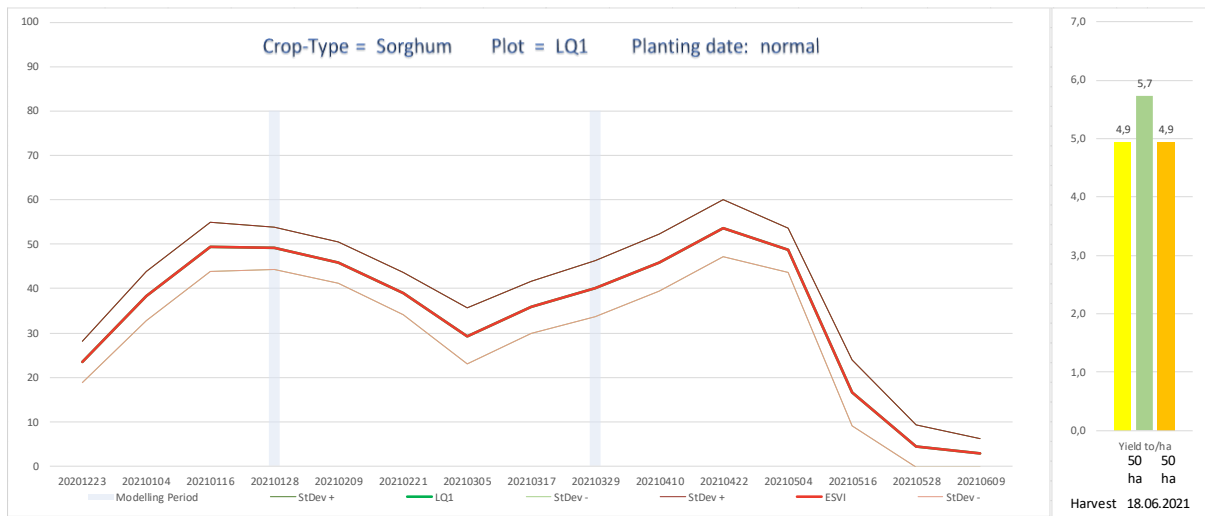
The single plot, which is represented by the green lines is the plot "UB24". The ESVI curves show slightly higher values and hence there was more biomass. The model calculates a higher yield, which is as well close to the measured yield with 7.2 to/ha.



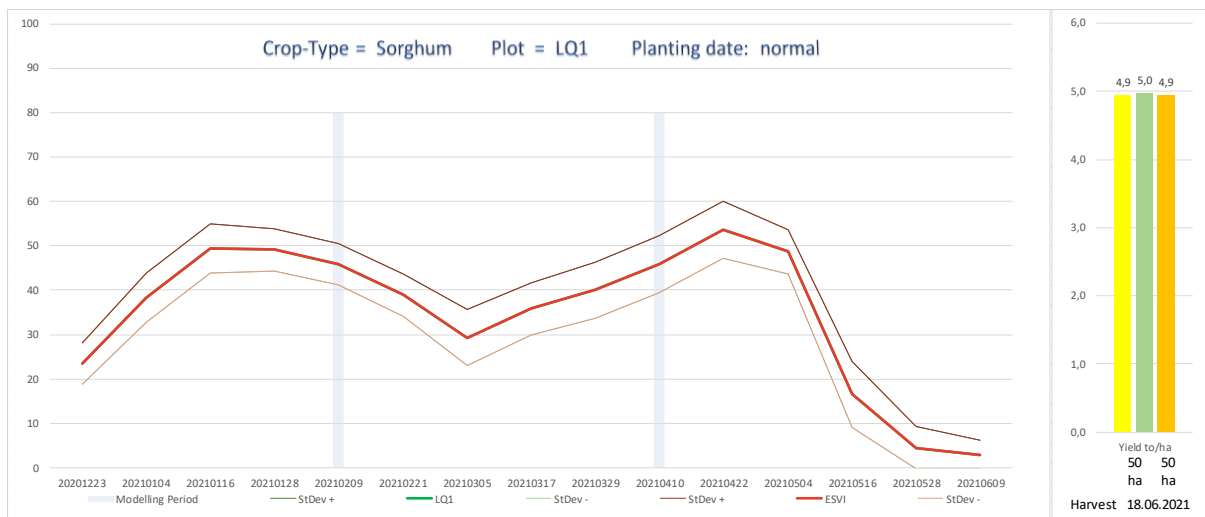
The deviation of the measured vs. the modeled yield over all plots and the whole season in 2022.

| Deviation | 20220204 | 20220216 | 20220228 | 20220312 | 20220324 | 20220405 | 20220417 | 20220429 | 20220511 | 20220523 | 20220604 |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 100 | 101 | 100 | 101 | 101 | 101 | 103 | 103 | 100 | 100 | 102 |
| FR10 | 101 | 99 | 101 | 101 | 102 | 104 | 108 | 114 | 113 | 114 | 116 |
| FR12 | 112 | 110 | 106 | 106 | 105 | 104 | 103 | 100 | 96 | 96 | 99 |
| FR5 | 105 | 106 | 103 | 103 | 101 | 101 | 103 | 103 | 100 | 100 | 102 |
| FR6 | 116 | 105 | 100 | 102 | 100 | 99 | 103 | 107 | 104 | 101 | 99 |
| FR1 | 106 | 108 | 107 | 108 | 105 | 104 | 106 | 107 | 106 | 108 | 111 |
| FR9 | 108 | 105 | 102 | 101 | 97 | 95 | 97 | 100 | 98 | 100 | 104 |
| UB23 | 75 | 86 | 90 | 96 | 100 | 102 | 101 | 98 | 94 | 92 | 92 |
| UB24 | 80 | 90 | 93 | 98 | 101 | 102 | 103 | 99 | 94 | 92 | 93 |

From the previous year 2021 we had only one Sorghum plot with harvest date in June.
 The growing curve shows a significant depression in value.
 If we use the same period for yield estimation the result is overestimated by about 16 %.



If we shift the period for yield estimation by 12 days the result nearly matches the measured yield.

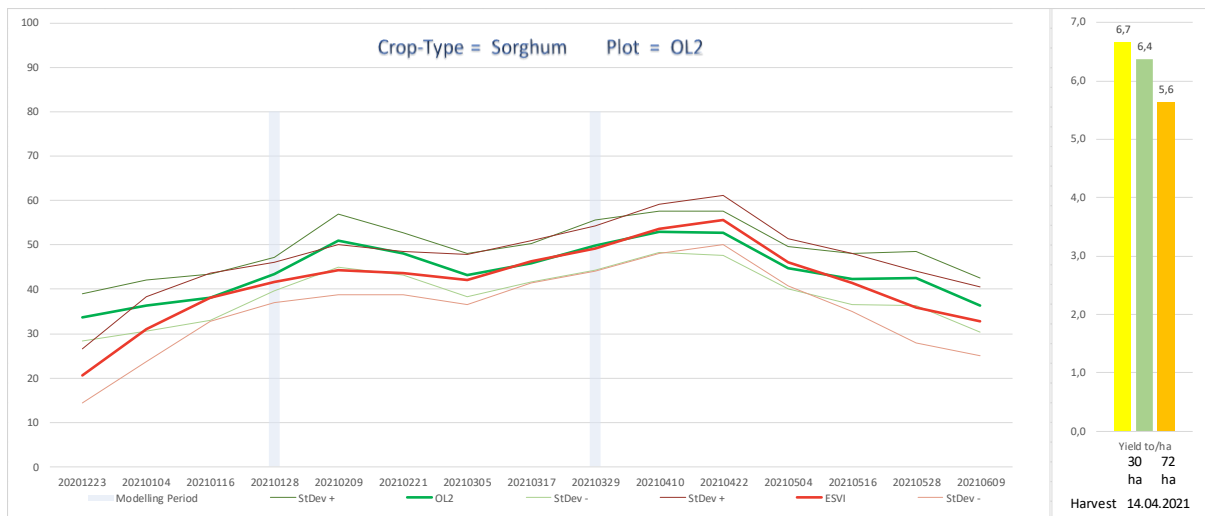


Due to the depression in the curve a valuable yield prediction over the season was not possible.

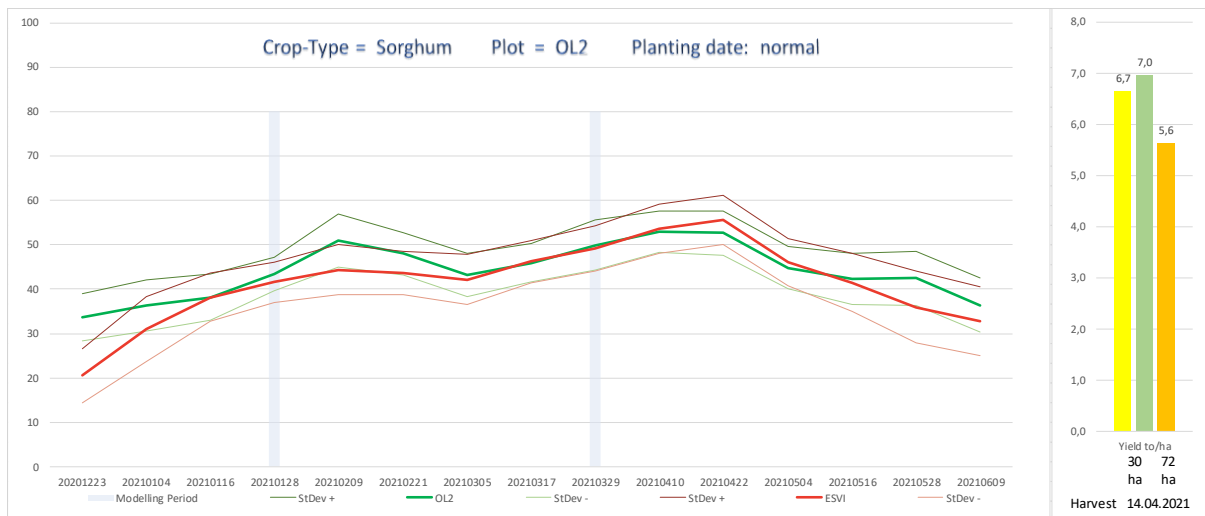
| Deviation | 20210209 | 20210221 | 20210305 | 20210317 | 20210329 | 20210410 | 20210422 | 20210504 | 20210516 | 20210528 | 20210609 |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 156 | 165 | 159 | 136 | 116 | 101 | 96 | 108 | 117 | 125 | 115 |
| LQ1 | 156 | 165 | 159 | 136 | 116 | 101 | 96 | 108 | 117 | 125 | 115 |

Two more Sorghum plots were already harvested in April 2021.

The predicted yield for the average value lies about 13 % above the measured yield.



For the single plot we nearly match the measured yield value. The curve for this plot lies slightly above the average, which is reflected in the yield prediction. The yield estimation lies about 4% above the measured yield.

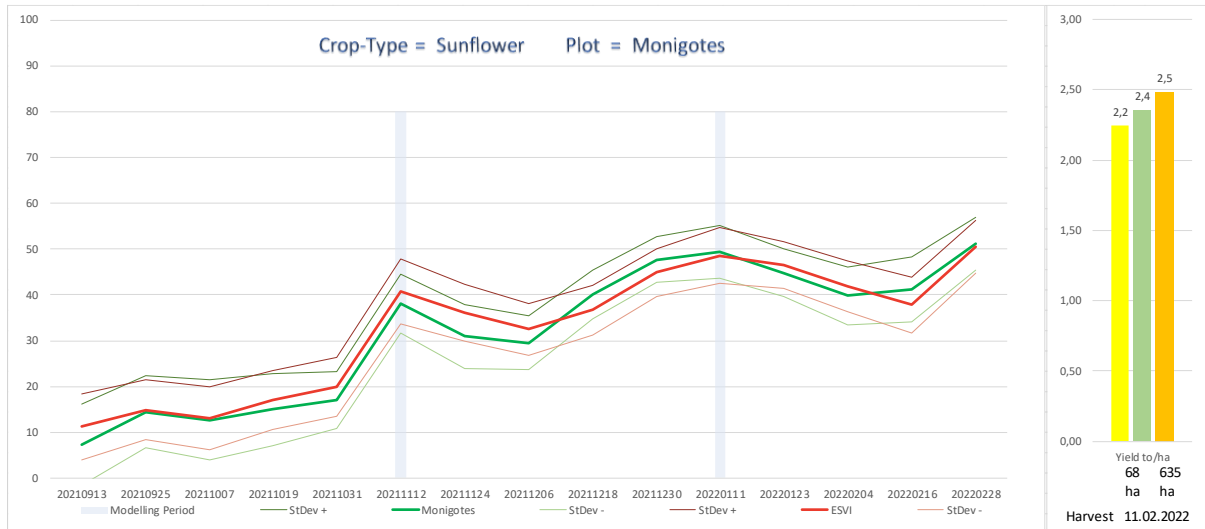


| Deviation | 20210209 | 20210221 | 20210305 | 20210317 | 20210329 | 20210410 | 20210422 | 20210504 | 20210516 | 20210528 | 20210609 |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 112 | 119 | 120 | 116 | 113 | 110 | 110 | 114 | 117 | 123 | 121 |
| OL2 | 118 | 109 | 107 | 107 | 105 | 98 | 94 | 96 | 98 | 102 | 101 |
| FR10 | 104 | 132 | 138 | 130 | 125 | 128 | 133 | 141 | 144 | 155 | 150 |

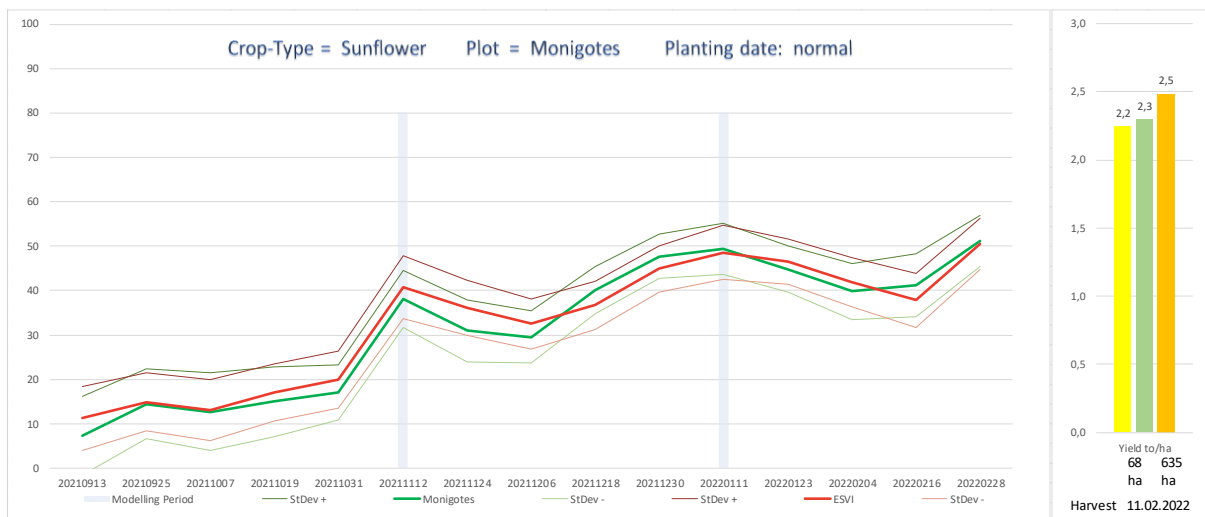
Sunflower

The next example is Sunflower, which was harvested in February 2022.

The model underestimates the average yield slightly with 2.4 to/ha. The measured average yield was 2.5 to/ha.



The single plot here “Monigotes” was slightly overestimated.

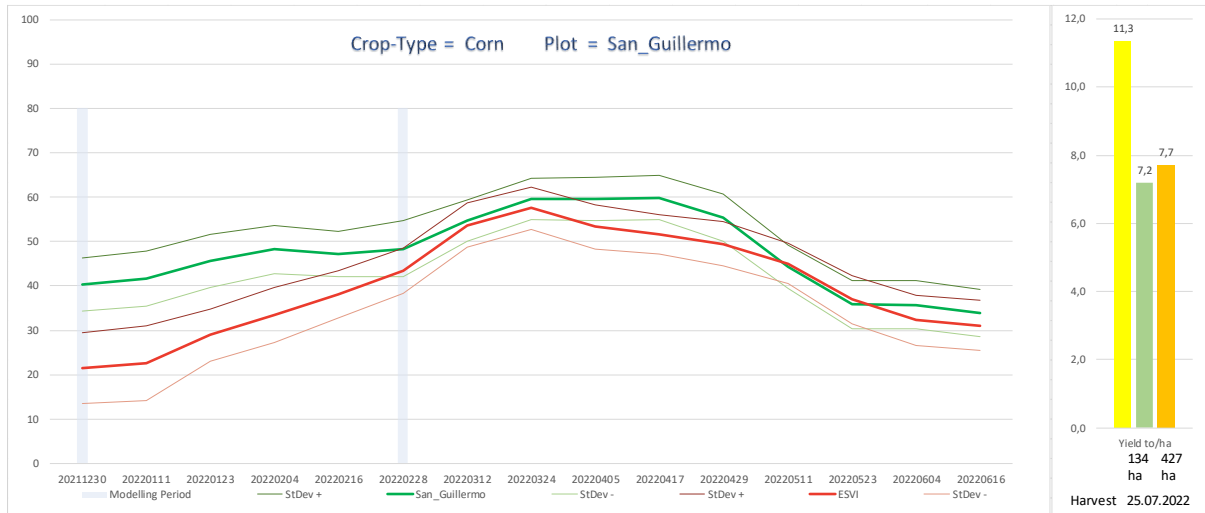


| Deviation | 20211031 | 20211112 | 20211124 | 20211206 | 20211218 | 20211230 | 20220111 | 20220123 | 20220204 | 20220216 | 20220228 |
|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 113 | 113 | 121 | 132 | 122 | 119 | 97 | 102 | 110 | 106 | 100 |
| Palacios | 99 | 99 | 107 | 115 | 102 | 100 | 80 | 82 | 91 | 90 | 87 |
| Palmeras_Griffa | 140 | 127 | 139 | 158 | 152 | 142 | 116 | 117 | 118 | 113 | 107 |
| Monigotes | 108 | 117 | 123 | 131 | 122 | 122 | 102 | 115 | 129 | 120 | 111 |

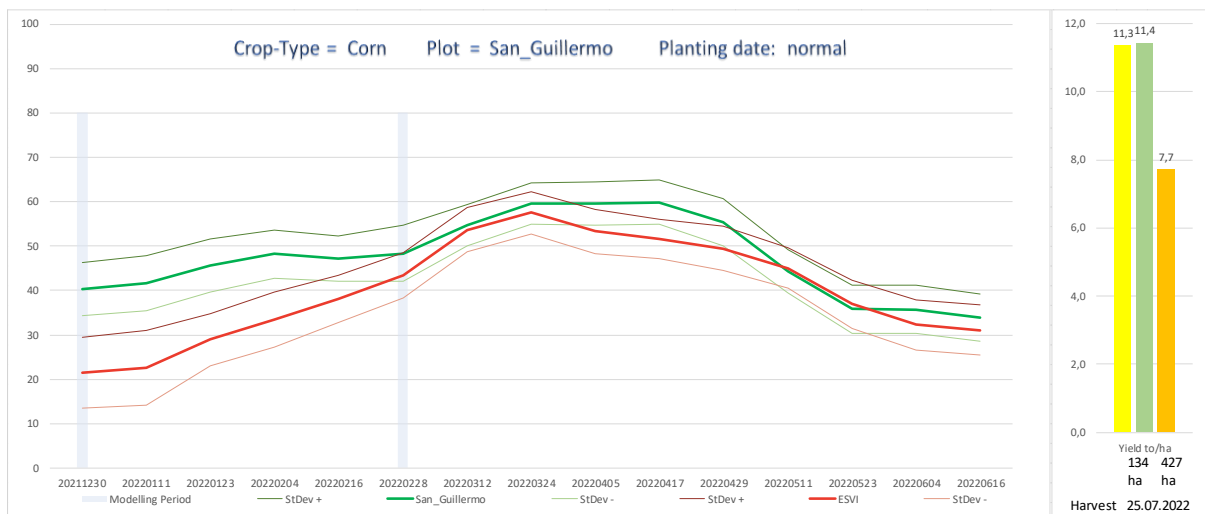
For sunflower we didn't have reference data from 2021.

Corn

Corn was harvested in July, which is winter time in Argentina. The average yield was underestimated with the model by about 7 %.



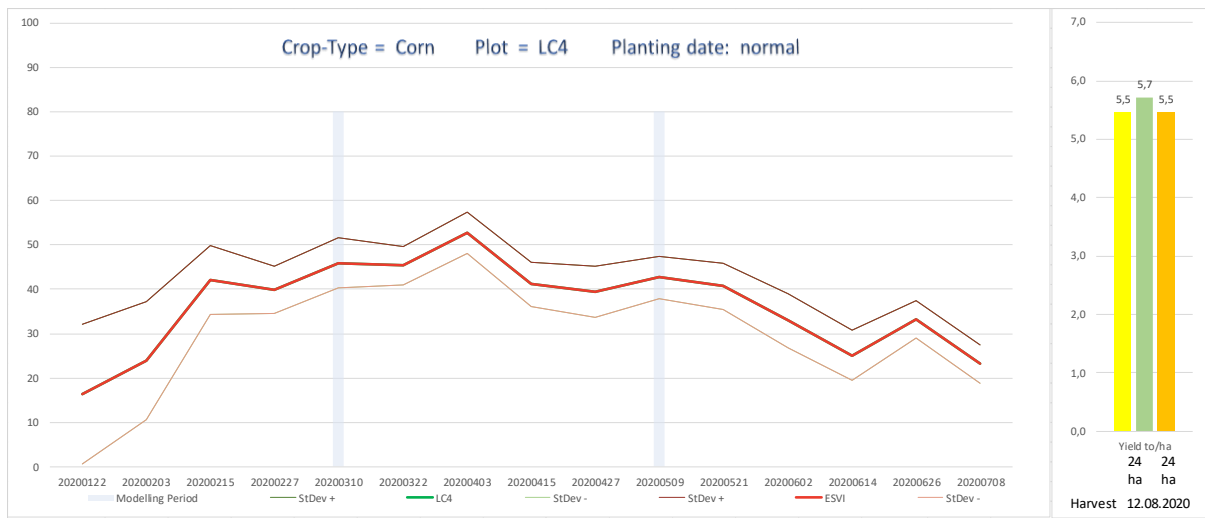
The single plot was estimated quite well in the same period. The result here is 11.4 to/ha.



The plot Bellino has a measured yield of 2.8 to/ha only, which is quite doubtful. Either the yield was wrong measured, or the culture had a lot of biomass and a comparable low yield, due to any reason.

| Deviation | 20220228 | 20220312 | 20220324 | 20220405 | 20220417 | 20220429 | 20220511 | 20220523 | 20220604 | 20220616 | 20220628 |
|---------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 96 | 111 | 106 | 91 | 84 | 88 | 83 | 79 | 75 | 76 | 68 |
| San_Guillermo | 104 | 106 | 90 | 70 | 61 | 63 | 61 | 60 | 56 | 55 | 47 |
| Furrer | 55 | 78 | 76 | 63 | 55 | 56 | 53 | 50 | 46 | 46 | 41 |
| Bellino | 365 | 360 | 322 | 268 | 237 | 239 | 218 | 208 | 212 | 234 | 233 |
| Campo_Chico | 80 | 99 | 100 | 92 | 85 | 88 | 83 | 78 | 71 | 70 | 59 |
| FR3 | 99 | 118 | 115 | 101 | 94 | 98 | 91 | 86 | 82 | 84 | 77 |
| FR7 | 79 | 95 | 96 | 90 | 91 | 103 | 101 | 98 | 96 | 99 | 87 |
| FR8 | 76 | 98 | 101 | 94 | 90 | 95 | 86 | 80 | 76 | 76 | 67 |

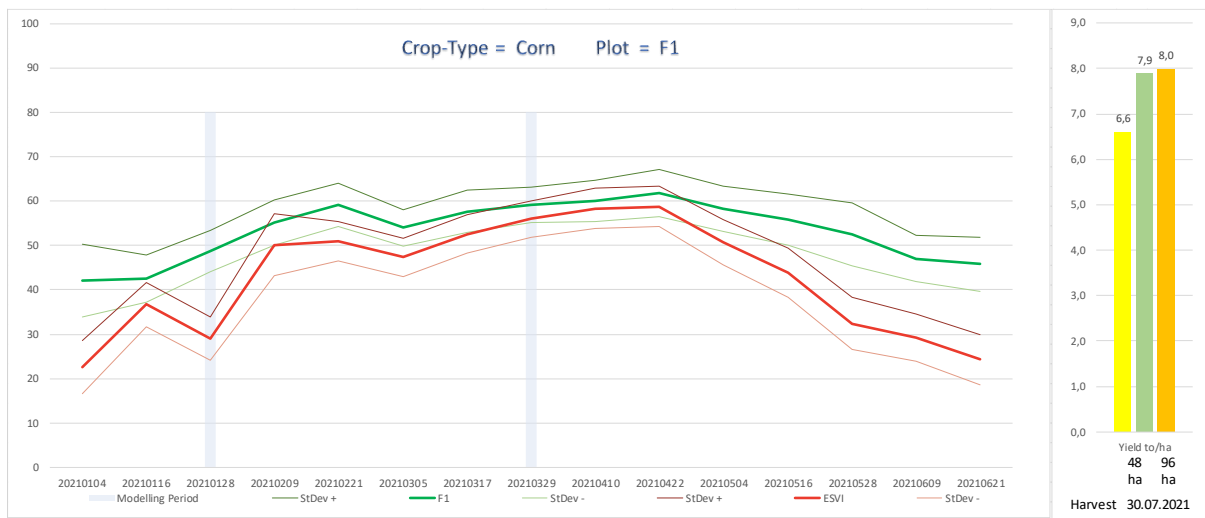
In 2020 we had only one plot for Corn.



And in 2021 we had 3 plots with corn, but the values are a bit strange.

The yield prediction matches the measured yield over all plots quite good.

The curve for the single plot lies above the average, but the measured yield is below average.

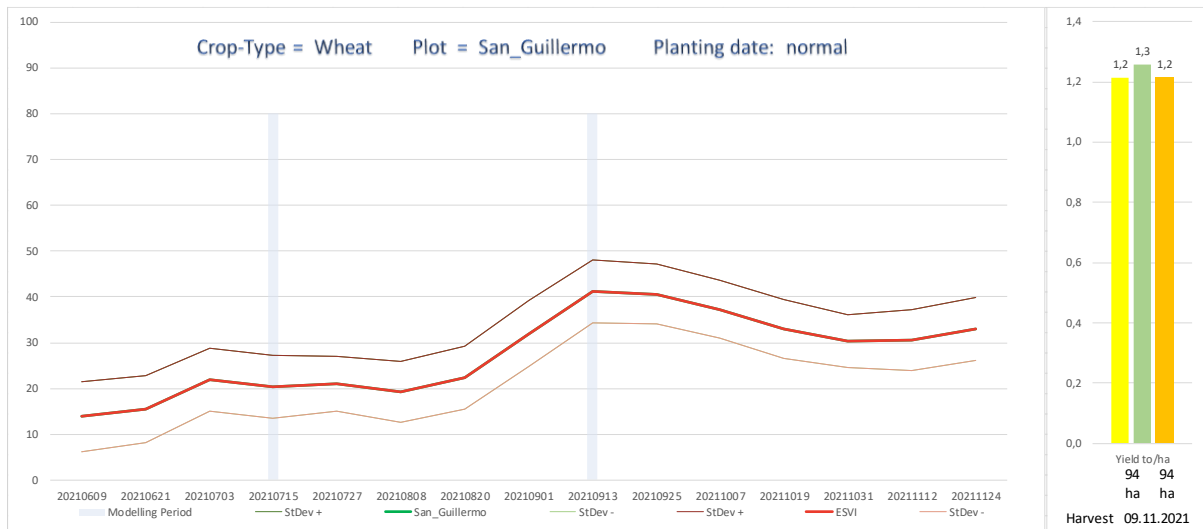


| Deviation | 20210221 | 20210305 | 20210317 | 20210329 | 20210410 | 20210422 | 20210504 | 20210516 | 20210528 | 20210609 | 20210621 |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 101 | 123 | 109 | 99 | 81 | 80 | 81 | 84 | 83 | 85 | 73 |
| F1 | 178 | 187 | 169 | 134 | 111 | 106 | 105 | 107 | 108 | 119 | 114 |
| UB22 | 74 | 100 | 86 | 87 | 72 | 72 | 75 | 78 | 76 | 73 | 56 |
| UB21 | 70 | 96 | 86 | 84 | 68 | 68 | 69 | 73 | 72 | 71 | 59 |

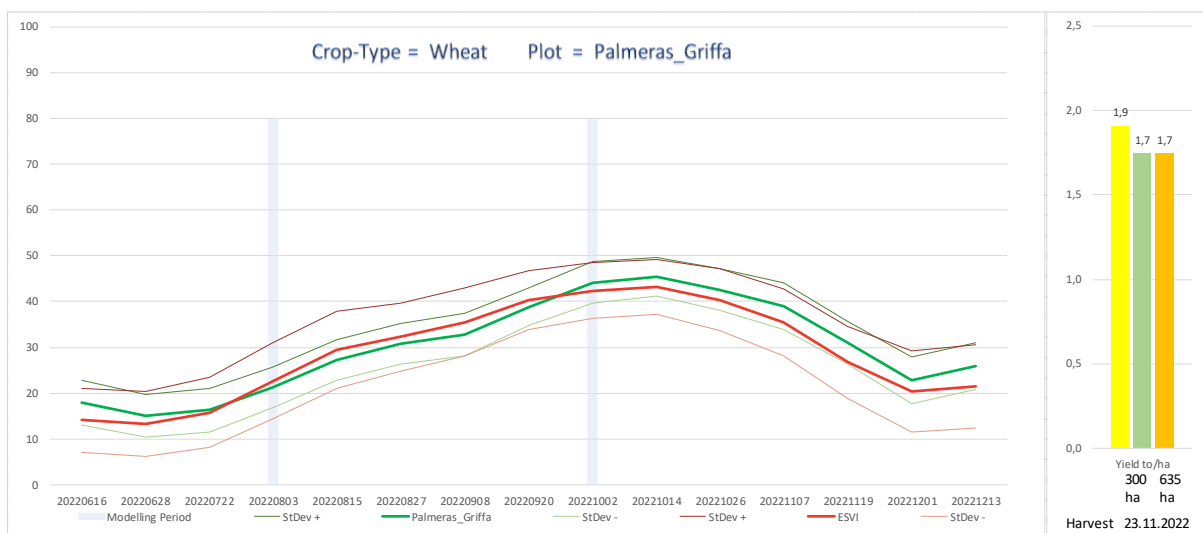
Wheat

Wheat is harvested in November. From the season in 2021 we have only one plot. Therefore the red curve which represents the average lies above the green curve, that represents the single plot.

The yield was estimated quite well and is only 1.3 to/ha.



One year later in 2022, we have 4 wheat plots. The average value was 1.7 to/ha and the model matches this value exactly.

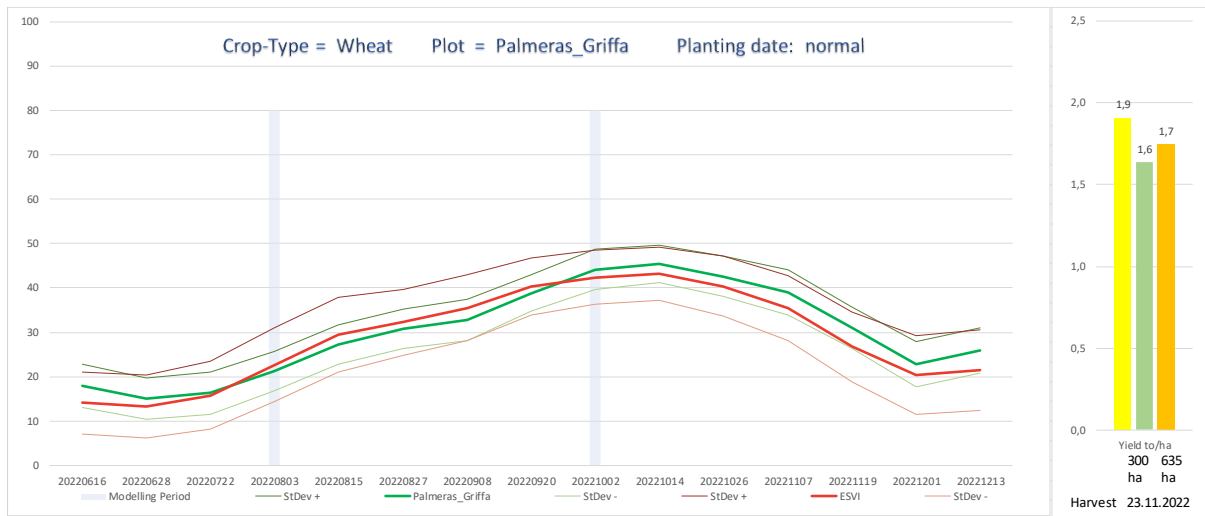


The measured yield of Palacios lays about 30% below the other two plots. The curve for the ESVI is above average. Therefore the modeled yield was overestimated significantly.

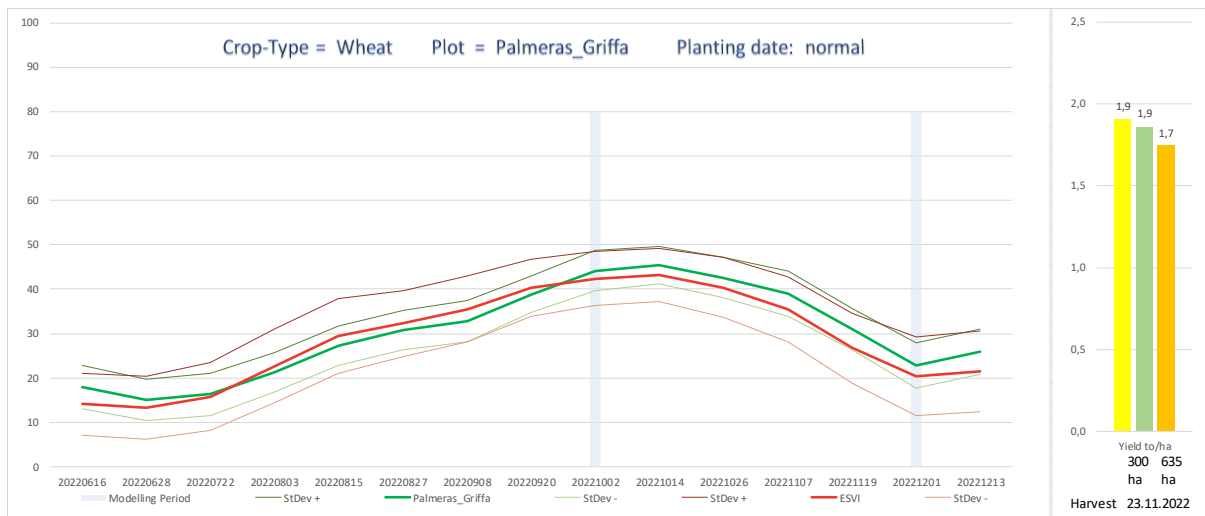
| Deviation | 20220815 | 20220827 | 20220908 | 20220920 | 20221002 | 20221014 | 20221026 | 20221107 | 20221119 | 20221201 | 20221213 |
|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Average | 103 | 103 | 101 | 102 | 102 | 102 | 102 | 104 | 101 | 102 | 102 |
| Palacios | 123 | 139 | 137 | 138 | 133 | 126 | 122 | 119 | 116 | 123 | 130 |
| Monigotes | 76 | 77 | 80 | 85 | 89 | 93 | 94 | 95 | 90 | 85 | 77 |
| Palmeras_Griffa | 114 | 103 | 95 | 93 | 93 | 94 | 96 | 101 | 102 | 105 | 106 |

For the single plot we see an underestimation of the predicted yield.

The green curve, which represents the single plot lies a bit below the red curve in the period, where we model the yield.



In a later stage of the season the green curve lies slightly above the average, which is reflected as well in the yield prediction. In this period the yield estimation was correct.



It can be concluded that ESVI as stand-alone product is suitable to predict yield for arable crops with **one** formula and a weighing table for each crop-type. No additional data like weather data or soil data is needed.

The seasonality has to be considered. This means, that in the ongoing season we need to detect the start of season for the single plots. From the ESVI data we can observe a steady increase in value and hence identify the begin of the cultivation period.