Technical description of crop model (WOFOST) calibration and simulation activities
Shandong province, China

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1. Sites

To define local crop varieties, sites have been selected using the GYGA-ED Climate Zones (CZ) (Wart et al, 2013). A procedure was designed to find representative location within each CZ for the targeted crop (see separate SIGMA document). Each one or site(s) then represents one GYGA-ED zone and for each site local crop data is collected to calibrate the selected crop growth model. This results in at least one variety for a GYGA-ED zone.

Eight sites were selected, shown in the following Figure 1-1 and Table 1-1.

Table 1-1 Details of selected sites

FID	GYGA CZ	Status	Latitude	Longitude	County	MARS grid cell
0	5203	Kept the same location	36.345	115.692	Liaocheng	3087148
1	5403	Kept the same location	35.262	116.608	Jining	3083152
2	5303	Alternative location	37.500	117.533	Binzhou	3093154
3	4503	Alternative location	37.100	120.317	Qingdao	3092164
4	4403	Alternative location	36.767	119.183	Weifang	3090160
5	4603	Alternative location	36.983	120.817	Yantai	3092166
6	5503	Alternative location	35.250	117.950	Linyi	3083157
7	5203	Yucheng (extra)	36.935	116.619	Dezhou	3090152

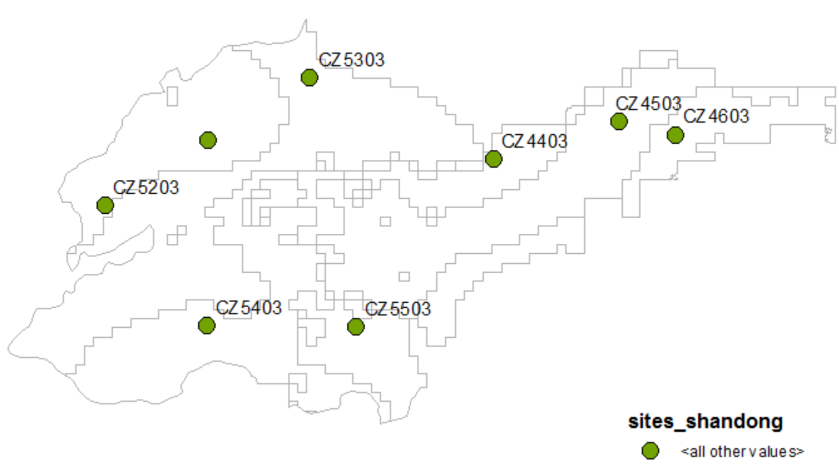
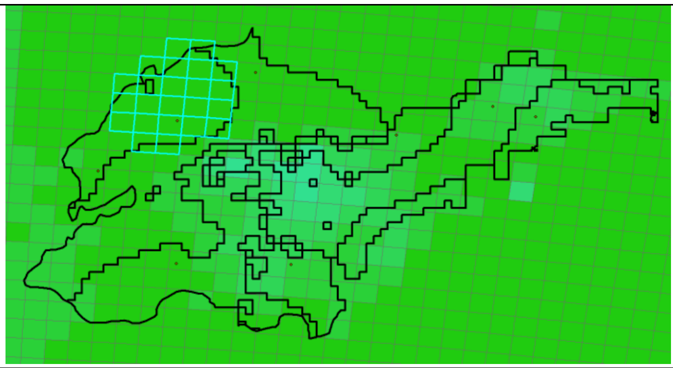


Figure 1-1 Selected sites for calibration

Later one zone CZ5203 was splitted into two zones:

- One around Yucheng (blue highlighted) (grid cells: 3089150, 3089151, 3090149, 3090150, 3090152, 3090153, 3091149, 3091150, 3091151, 3091152, 3091153, 3092149, 3092150, 3092151, 3092152, 3092153, 3093150, 3093151, 3093152, 3093153, 3094151, 3094152) - Remaining grid cells of CZ5203	

2. Data

2.1. Weather

2.1.1. Yucheng

Weather 2003-2008 for this location was provided by RADI (December 15, 2015). According RADI the meteorological data for Yucheng site were extracted from an interpolated product using data from surrounding in-situ data (see station location map).

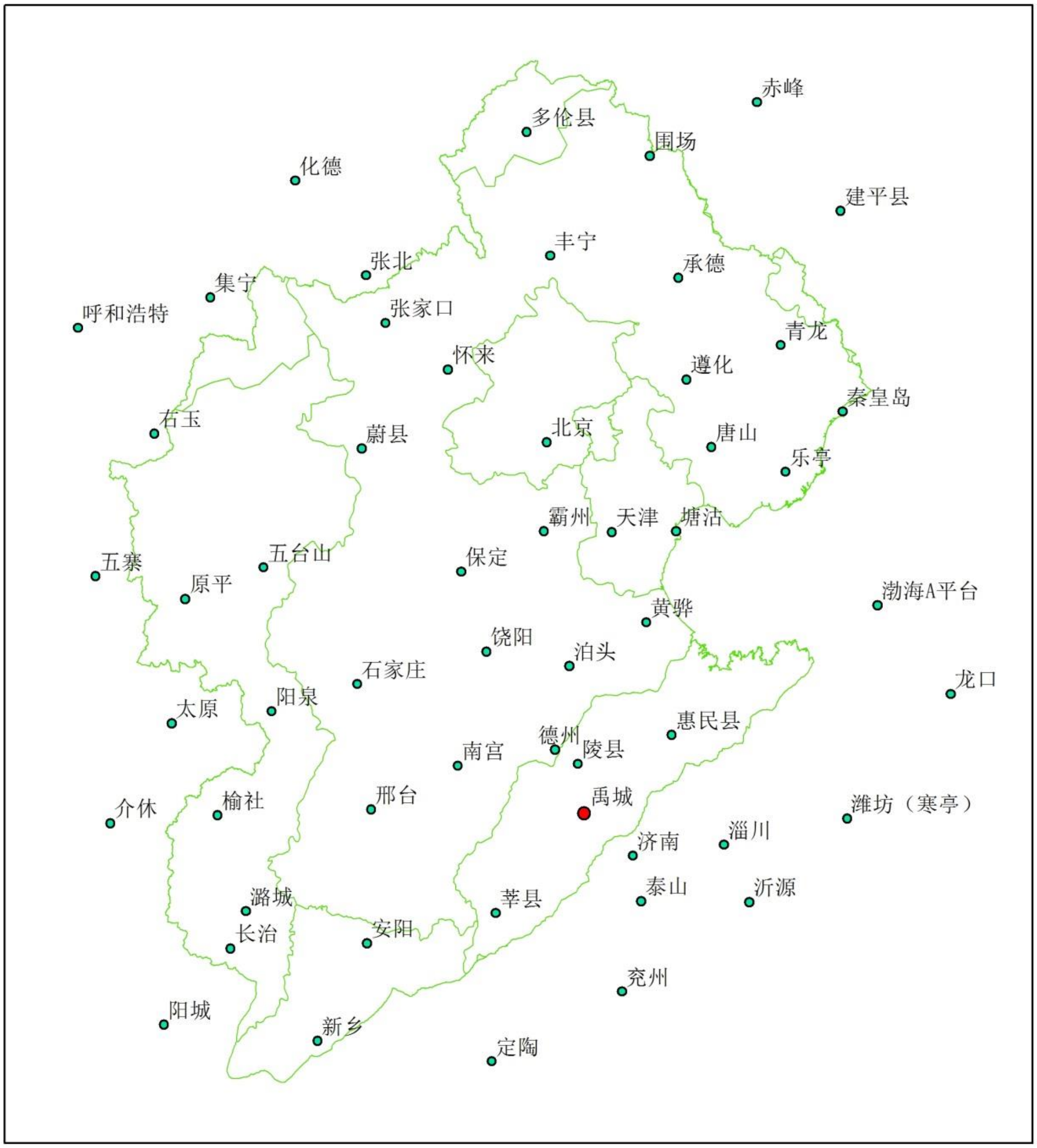


Figure 2-1 Weather stations used to obtain the interpolated product

For each element in-situ data from stations was interpolated to produce the grid data for Hai Basin. Next daily value was extracted from grid data based on the location information of Yucheng. Except rainfall which was taken from the Yucheng Data Centre; blank values were converted into zero values.

Details:

- Minimum and maximum temperature was interpolated using country-level meteorological data.
- Mean wind speed at 2 meter was interpolated using country-level meteorological data.
- Vapour pressure was calculated from relative humidity and saturated vapour pressure following the method described by Allen et al, 1998.

Radiation was first based on actual sun shine duration from Yucheng station, converted to actual radiation according the Angstrom formula. The data were compared to a data set of Tang et al. (2013) (red symbols) and MARS ERA-Interim (see section 4.1; green symbols). From Tang et al. (2013) we took location ID 54823 (Tianqiao; lat = 36.68 and lon = 116.98). The graph below shows clearly that the actual sun shine duration values were not correct leading to wrong radiation values.

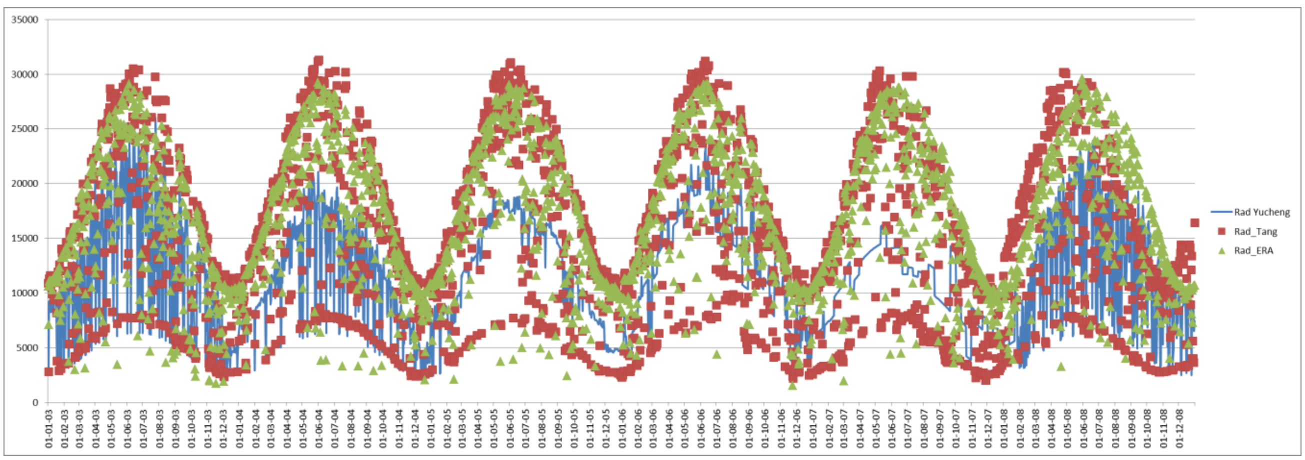


Figure 2-2 Time series of radiation originating from different sources – compare radiation based on sun shine duration of Yucheng weather station

Next radiation data was taken from the Yucheng Data Centre and these values were compared with the following sources:

- JRC_ERA-INTERIM (see appendix I) (most nearby grid cell from global dataset)
- NASA_POWER (see appendix I) (most nearby grid cell from global dataset)
- JRC_CGMS_CHN (see appendix I) (grid 3090152)
- Tang et al. (2013) (ID 54823: Tianqiao; lat = 36.68 and lon = 116.98)

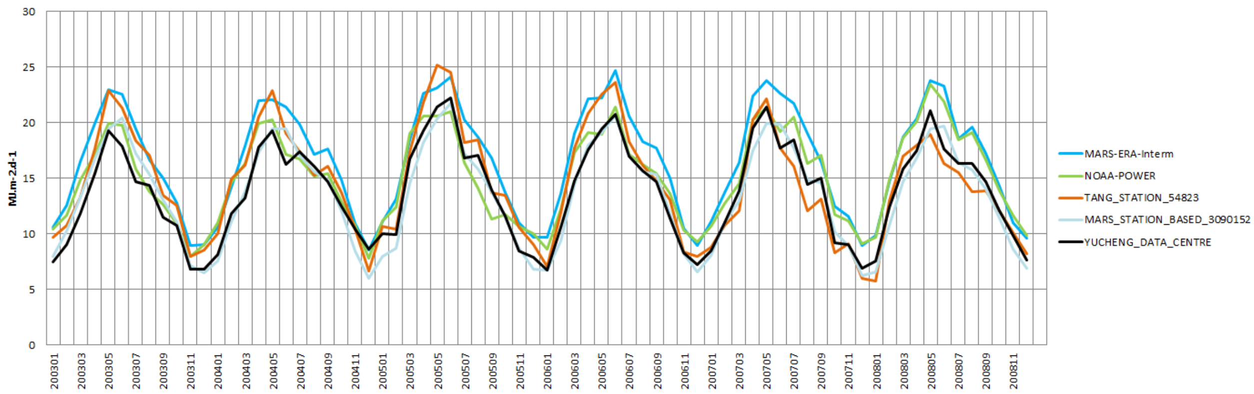


Figure 2-3 Time series of radiation originating from different sources (to compare radiation provided Yucheng Data Centre)

Data of Yucheng Data Centre were also compared to JRC_ERA-INTERIM.

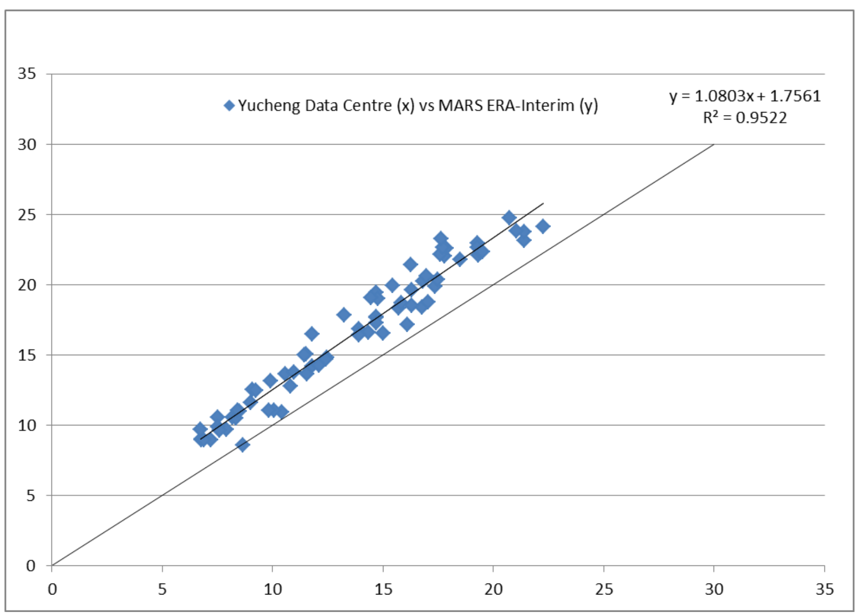


Figure 2-4 JRC_ERA-INTERIM radiation versus radiation provided by Yucheng Data Centre

From this comparison it became clear that JRC_ERA-INTERIM (and NASA-POWER) overestimate radiation. The relative high radiation values of the JRC_ERA-INTERIM data set were earlier discovered in a separate study conducted in the frame of the MARSOP4 project. See map below comparing Tang et al. (2013) (named 50yr DB in map below) and JRC_ERA-INTERIM (named ECMWF in map below). It shows the Mean Error with values around -2 $MJ.m^{-2}.d^{-1}$ for the Shandong province which is similar to the comparison shown above.

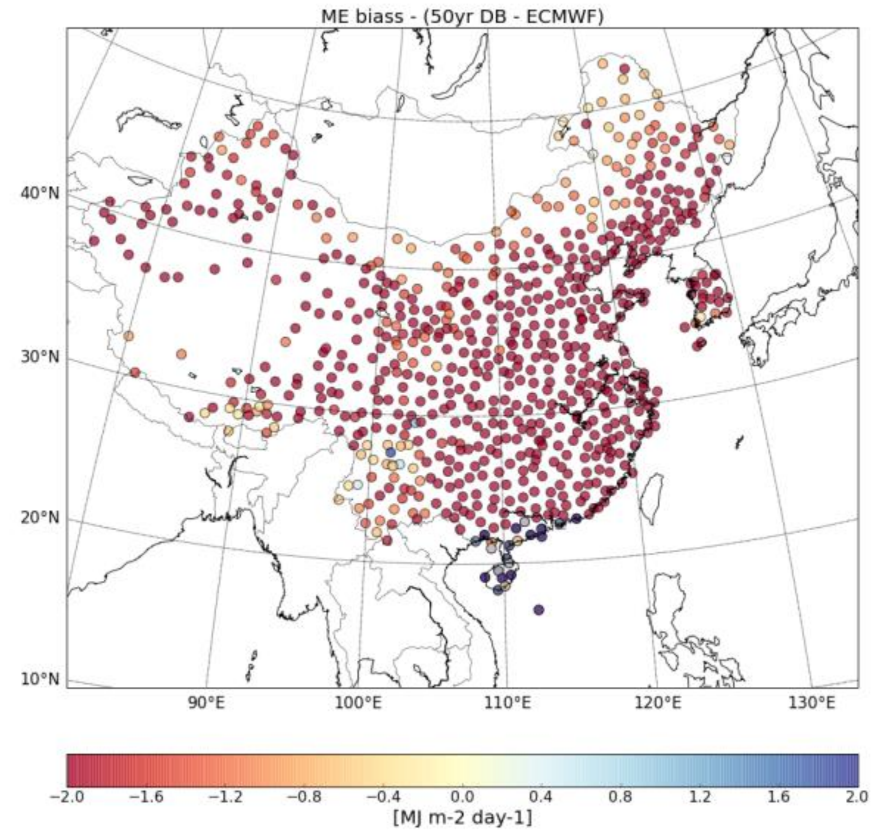
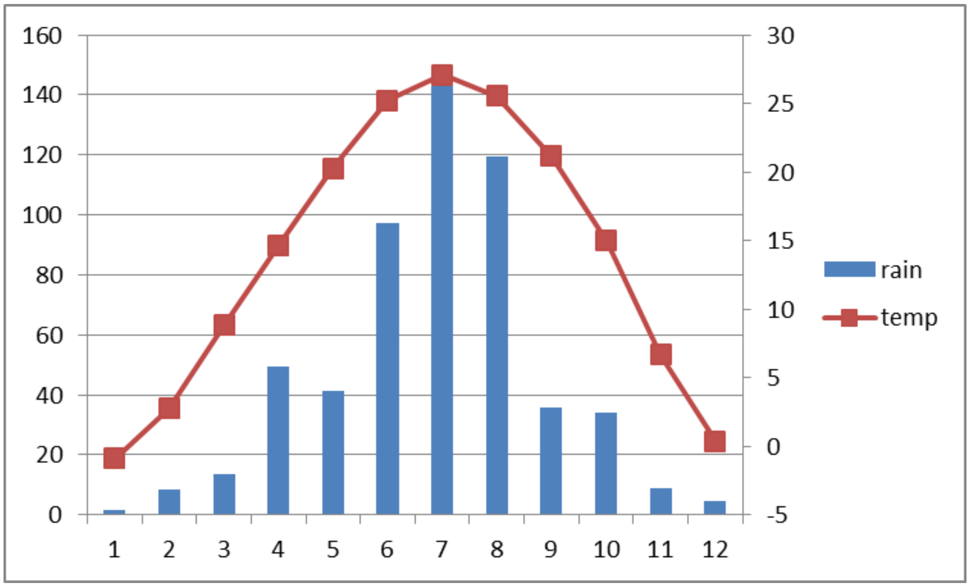


Figure 2-5 Mean error of daily MARS ERA-Interim benchmarked against data set of Tang et al. (2013)

It was decided to use the radiation data of Yucheng Data Centre for Yucheng. Note that for the other 7 sites and the regional implementation radiation was taken from the JRC_CGMS_CHN data set (see Appendix I).

Below the long term average monthly precipitation and long term daily mean temperature values are presented:

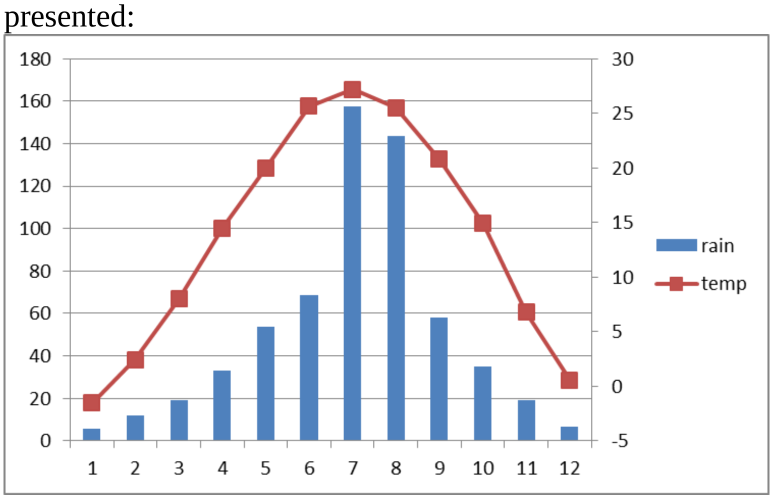


Long term average annual rainfall = 558 mm.

2.1.2. Climate zone 5203 (FID = 0)

Weather data was taken from a nearby weather station XINXIAN (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand01.yyy (daily weather data) and Shand01_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:

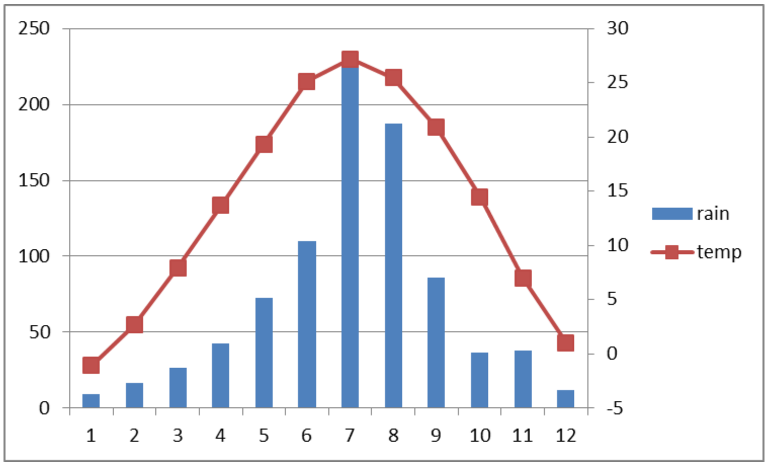


Long term average annual rainfall = 612 mm.

2.1.3. Climate zone 5403 (FID = 1)

Weather data was taken from a nearby weather station YANZHOU (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand11.yyy (daily weather data) and Shand11_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:

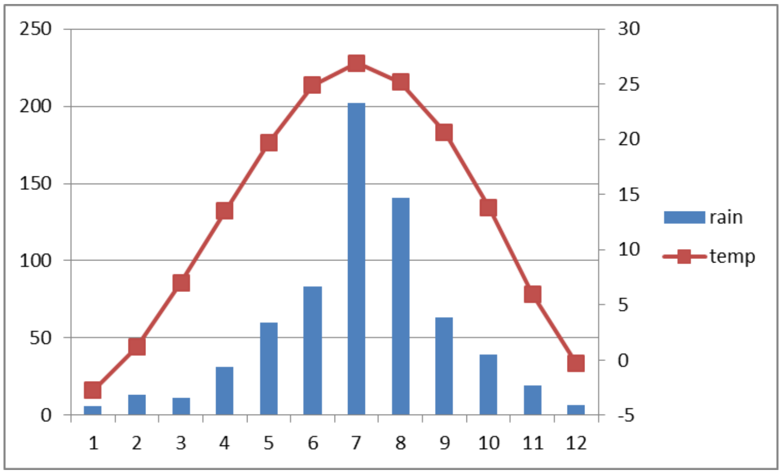


Long term average annual rainfall = 867 mm.

2.1.4. Climate zone 5303 (FID = 2)

Weather data was taken from a nearby weather station HUIMIN (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand21.yyy (daily weather data) and Shand21_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:

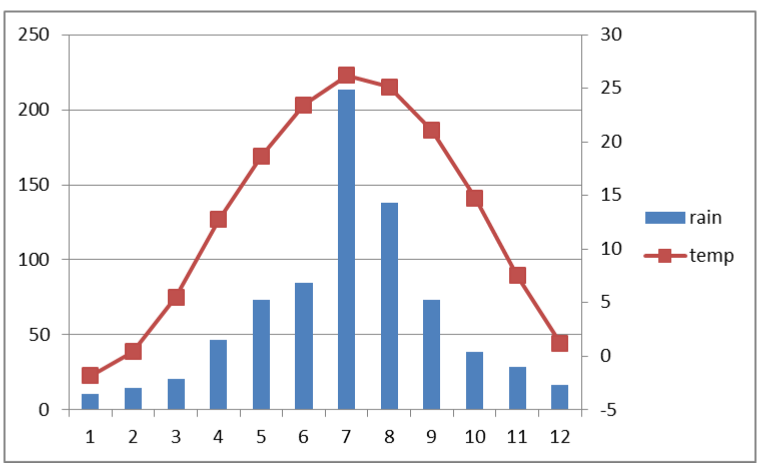


Long term average annual rainfall = 675 mm.

2.1.5. Climate zone 4503 (FID = 3)

Weather data was taken from a nearby weather station LONGKOU (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand31.yyy (daily weather data) and Shand31_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:

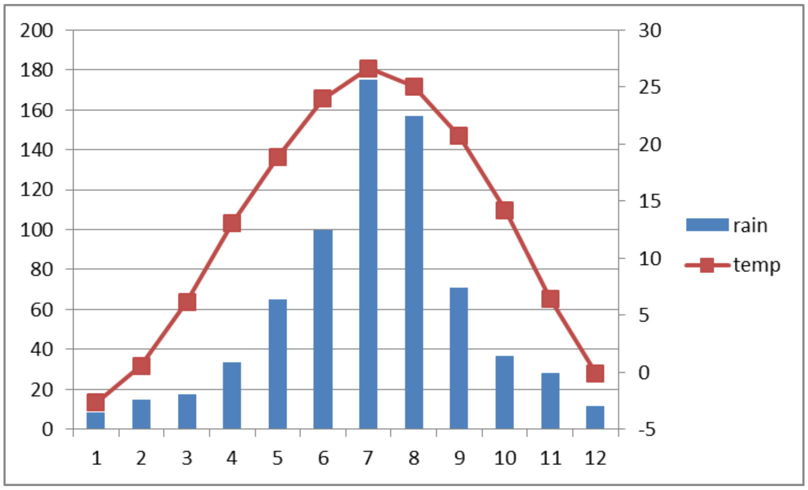


Long term average annual rainfall = 758 mm.

2.1.6. Climate zone 4403 (FID = 4)

Weather data was taken from a nearby weather station WEIFANG (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand41.yyy (daily weather data) and Shand41_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:

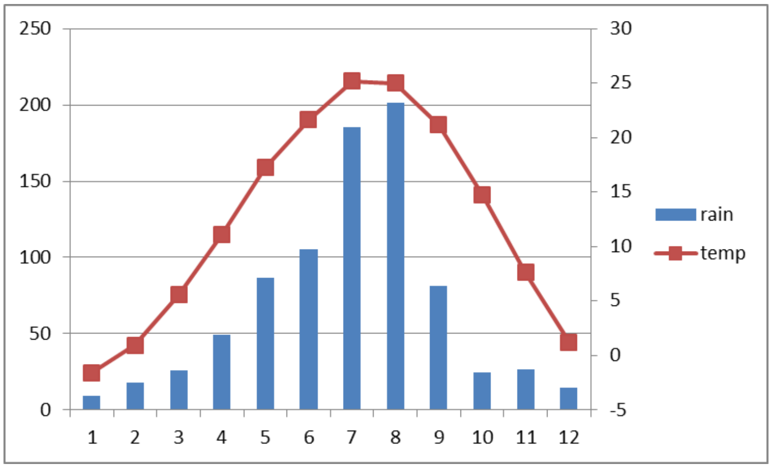


Long term average annual rainfall = 719 mm.

2.1.7. Climate zone 4603 (FID = 5)

Weather data was taken from a nearby weather station HAIYANG (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand51.yyy (daily weather data) and Shand51_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:

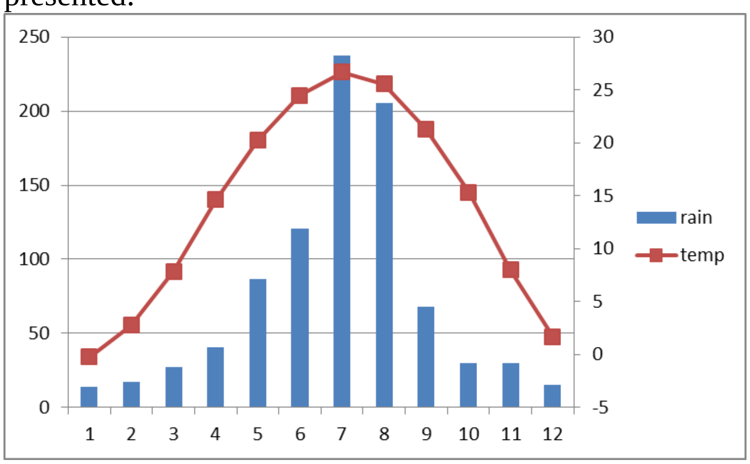


Long term average annual rainfall = 828 mm.

2.1.8. Climate zone 5503 (FID = 6)

Weather data was taken from a nearby weather station FEZXZAN (NCDC_GSOD) and completed with data from JRC_ERA-INTERIM and CHG_CHIRPS using the WEATHER STAC software and database of Alterra. Because radiation is not given by the weather station initially radiation of JRC_ERA-INTERIM was used. However it was found that the radiation of JRC_ERA-INTERIM overestimates radiation for main parts of China. Therefore radiation was taken from an alternative data set JRC_CGMS_CHN (see section 4.1 and Appendix I).

WOFOST CABO weather files were generated: Shand61.yyy (daily weather data) and Shand61_metdata.yyy (reference to source used) for the years 1990-2013. Below the long term average monthly precipitation and long term daily mean temperature values are presented:



Long term average annual rainfall = 892 mm.

2.2. Soil data

The calibration was done for the potential production under irrigated conditions. Therefore data on soils are not required (no drought stress have to be simulated/assessed).

2.3. Crop data – winter wheat

RADI prepared crop calendar data of winter wheat (WHB) for 7 selected sites. It was delivered in an Excel file called *crop calendar Shandong.xlx*.

Phenological descriptors have been converted into the BBCH scale according https://en.wikipedia.org/wiki/BBCH-scale.

Phenological descriptions	BBCH (cereals)
Sowing	00
Emergence	09
Tillering	21
Jointing	30
Heading	55
Full flowering: 50% of anthers mature	65
Milky stage	77
Mature	89

The data have been converted into AGRO-STAC SIF-files which have been imported into the AGRO-STAC database.

In most cases the phenological stage ‘flowering’ is missing. Based on local expert knowledge we applied the rule “added 7 days after heading to come to flowering”.

We selected the WOFOST crop parameter file WWH105.CAB constructed for Europe within the MARS initiative (Lazar, C. and Genovese, G., 2004) as a first approach to parameterize WOFOST for winter wheat. This is a crop parameterization for winter wheat calibrated for Western Europe.

While in the WWH105.CAB parameterization the crop starts from January 1, the phenology is driven by temperature only and vernalization is excluded, in our case we will start from the real sowing or emergence date and include the three major factors influencing the phenological development of winter cereals: temperature, photoperiod and vernalisation (IDSL = 2). Temperature forms the main driving variable of phenological development while photoperiod and vernalization usually act as modifiers of the temperature development rate.

First we have decreased the initial biomass because the simulation will now start from emergence (TDWI = 60).

We have added the parameterization for winter wheat following the approach of van Bussel et al. (2015)[1]. For the photoperiod reduction factor, the approach currently used in WOFOST is applied where a three-stage linear reduction factor is calculated between a critical and an optimal day length. The critical day length was fixed at 8 hours (DLC = 8). The optimal day length (DLO = 15) was estimated as the local maximum occurring day

[1] van Bussel, L.G.J., Stehfest, E., Siebert, S., Müller, C. and Ewert, F., 2015. Simulation of the phenological development of wheat and maize at the global scale. Global Ecology and Biogeography, 24(9): 1018-1029.

length on the 21st of June (or the 21st of December for southern hemisphere)[2]. The underlying assumption is that locally used cultivars are optimally adapted to the local conditions.

The full vernalization requirements (VDfull) was calculated by taking the monthly average temperature over 1990-2013, classifying it's contribution to vernalization according the cardinal temperatures for vernalization (-4, 3, 10, 17) and by multiplying the resulting ratio with an estimate of the maximum number of vernalization days per month. The latter was calculated by assuming a maximum length of winter of five months while the winter-wheat cultivars growing under these conditions have full vernalisation requirements of around 70 days. The base vernalization requirement was estimated as 1/5 of the full vernalization requirement.

The parameterization for China in the MARS project differs from the European implementation (parameterization of WWH105.CAB). In the MARS initiative for China the following parameters were changed:

- Phenology development reduces at average temperatures above 25
- Maximum leaf age is longer (also leading to very high LAI at the end of the crop cycle)
- Allows assimilation activity during colder nights (cold resistant variety)

Crop parameter	WWH105.CAB	MARS
DTSMTB_02	30,30	25,25
DTSMTB_03	45,30	45,25
SPAN	31.3	35
TMNFTB_01	0,0	-5,0
TMNFTB_02	3,1	0,1

Both in the MARS project and underlying SIGMA project we start the simulation in autumn and not at 1 January. Within SIGMA we introduced vernalization while in the MARS project for China only simulation of photo periodicity was included. This has led to following differences of crop parameters between MARS implementation for China and SIGMA.

Crop parameter	Values in SIGMA	MARS	WWH105.CAB
DLC	8	10	-99
IDSL	2	1	0
TDWI	60	60	210

Average area (1000 ha) and yield (fresh weight in $kg.ha^{-1}$) over years 2000-2013 originating from official yield statistics were provided by RADI.

County	**FID**	**Area**	**Yield**	**Yield – dry***
Binzhou	2 (CZ5303)	203	5960	5155
Dezhou	Yucheng	371	6578	5690
Dongying		55	6025	5212
Heze		536	5364	4640
Jinan		203	5521	4776

[2] http://www.solartopo.com/daylength.htm

Jining	1 (CZ 5403)	315	6052	5235
Laiwu		17	4547	3933
Liaocheng	0 (CZ 5203)	358	5938	5136
Linyi	6 (CZ5503)	329	5066	4382
Qingdao	3 (CZ4503)	231	6059	5241
Rizhao		81	5219	4514
Tai'an		187	6137	5309
Weifang	4 (CZ 4403)	330	5934	5133
Weihai		85	5100	4412
Yantai	5 (CZ 4603)	174	4983	4310
Zaozhuang		125	5976	5169
Zibo		107	5857	5066
Statistics		3707 (sum)	5666 (avg)	4901 (avg)

* Converted into 0% dry weight assuming a moisture content of 13.5% (value taken from the GYGA protocol)

2.3.1. Climate zone 5203 (FID = 0)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	286	10	12
9	**315**	**6**	**11**
21	327	9	41
30	96	13	3
55	**121**	**15**	**5**
77	155	2	3
89	**157**	**18**	**2**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 52.5 days
Base vernalization requirement (VDbase): 10.5 days

Four years have a complete calendar including BBCH 9, 55 and 89. These are used for the calibration.

BBCH scale	Campaign year	Observed date
9	1997	08-11-96
55	1997	28-04-97
89	1997	06-06-97
9	1998	08-11-97
55	1998	25-04-98
89	1998	02-06-98
9	2001	04-12-00
55	2001	28-04-01
89	2001	03-06-01
9	2008	04-11-07

55	2008	03-05-08
89	2008	08-06-08

Average actual yield of county Liaocheng over 2000-2013: 5.1 $t.ha^{-1}$ (0% dry weight).

2.3.2. Climate zone 5403 (FID = 1)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	279	9	2
9	**290**	**3**	**15**
21	306	15	4
30	91	11	5
55	**111**	**7**	**7**
77			
89	**156**	**19**	**2**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 52.1days
Base vernalization requirement (VDbase): 10.4 days

None of the years have a complete calendar including BBCH 9, 55 and 89. Therefore we selected a few years that include both BBCH 9 and 89 thus the complete cycle and a number of years including BBCH 55 and 89 assuming an average emergence data. The latter set is important to calibrate a proper ratio between TSUM1 and TSUM2.

BBCH scale	Campaign year	Observed date
9	1997	17-10-96*
55	1997	22-04-97
89	1997	02-06-97
9	1999	17-10-98*
55	1999	21-04-99
89	1999	02-06-99
9	2001	17-10-00*
55	2001	21-04-01
89	2001	06-06-01
9	2002	17-10-01*
55	2002	07-04-02
89	2002	02-06-02
9	2003	10-10-02
89	2003	06-06-03
9	2005	06-10-04
89	2005	05-06-05
9	2006	04-11-05
89	2006	06-06-06

* missing and therefore used the averaged over all years and possibly corrected using the observed planting dates (at least 8 days after planting)

Average actual yield of county Jining over 2000-2013: 5.2 t.ha^{-1} (0% dry weight).

Observed yields reported by reported by Ren et al. (2008) and converted into 0% moisture, assuming 13.5 moisture content of grains:
- 2005 (5.7 t.ha^{-1})
- 2006 (5.5 t.ha^{-1})

2.3.3. Climate zone 5303 (FID = 2)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	280	14	2
9	**287**	**2**	**6**
21	308	15	9
30	97	12	3
55	**125**	**18**	**4**
77	153	6	4
89	**158**	**12**	**2**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 56.0 days
Base vernalization requirement (VDbase): 11.2 days

Only two years have a complete calendar including BBCH 9, 55 and 89. These are used for the calibration. Five other years have been added. In case emergence date was missing an average date has been assumed.

BBCH scale	Campaign year	Observed date
9	1998	18-10-97
55	1998	24-04-98
89	1998	04-06-98
9	2001	14-10-00*
55	2001	30-04-01
89	2001	05-06-01
9	2003	14-10-02*
55	2003	01-05-03
89	2003	06-06-03
9	2004	10-10-03
89	2004	08-06-04
9	2006	16-10-05*
55	2006	06-05-06
89	2006	10-06-06
9	2007	11-10-06*

55	2007	01-05-07
89	2007	06-06-07
9	2012	17-10-11*
55	2012	04-05-12
89	2012	08-06-12

* missing and therefore used the averaged over all years and possibly corrected using the observed planting dates (at least 8 days after planting)

Average actual yield of county Binzhou over 2000-2013: 5.2 t.ha^{-1} (0% dry weight).

2.3.4. Climate zone 4503 (FID = 3)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	277	10	3
9	**279**	**13**	**4**
21	297	12	10
30	97	14	3
55	**124**	**12**	**4**
77	153	8	3
89	**160**	**13**	**1**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 55.9 days
Base vernalization requirement (VDbase): 11.2 days

Three years have a complete calendar including BBCH 9, 55 and 89. These are used for the calibration. Two other years have been added. In case emergence date was missing an average date has been assumed.

BBCH scale	Campaign year	Observed date
9	1998	08-10-97
55	1998	28-04-98
89	1998	10-06-98
9	1999	04-10-98
55	1999	27-04-99
89	1999	08-06-99
9	2001	30-09-00
55	2001	28-04-01
89	2001	08-06-01
9	2006	16-10-05*
55	2006	03-05-06
89	2006	10-06-06
9	2012	11-10-11*
55	2012	04-05-12
89	2012	10-06-12

* missing and therefore used the averaged over all years and possibly corrected using the observed planting dates (at least 8 days after planting)

Average actual yield of county Qingdao over 2000-2013: 5.2 $t.ha^{-1}$ (0% dry weight).

2.3.5. Climate zone 4403 (FID = 4)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	277	9	4
9	**279**	**13**	**2**
21	303	16	5
30	98	11	3
55	**125**	**14**	**4**
77	151	5	2
89	**158**	**16**	**2**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 56.7 days
Base vernalization requirement (VDbase): 11.3 days

The campaign years 1998, 1999, 2001, 2005, 2011-2013 have a complete calendar including BBCH 9, 55 and 89. These are used for the calibration.

BBCH scale	Campaign year	Observed date
9	1998	04-10-97
55	1998	28-04-98
89	1998	08-06-98
9	1999	06-10-98
55	1999	28-04-99
89	1999	08-06-99
9	2001	08-10-00
55	2001	30-04-01
89	2001	06-06-01
9	2005	08-10-04
55	2005	03-05-05
89	2005	08-06-05
9	2011	06-10-10
55	2011	04-05-11
89	2011	08-06-11
9	2012	08-10-11
55	2012	06-05-12
89	2012	08-06-12
9	2013	08-10-12
55	2013	08-05-13
89	2013	10-06-13

Average actual yield of county Weifang over 2000-2013: 5.1 t.ha^{-1} (0% dry weight).

2.3.6. Climate zone 4603 (FID = 5)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	281	5	2
9	**282**	**8**	**13**
21	309	14	12
30	98	18	3
55	**128**	**14**	**2**
77	154	17	3
89	**161**	**3**	**0**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 55.6 days
Base vernalization requirement (VDbase): 11.1 days

Only 2 years have a complete calendar including BBCH 9, 55 and 89. These are used for the calibration. Other years have BBCH 89 missing.

BBCH scale	Campaign year	Observed date
9	1999	08-10-98
55	1999	03-05-99
89	1999	10-06-99
9	2000	02-10-99
55	2000	05-05-00
89	2000	10-06-00

Average actual yield of county Yantai over 2000-2013: 4.3 t.ha^{-1} (0% dry weight).

2.3.7. Climate zone 5503 (FID = 6)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	280	12	2
9	**295**	**5**	**12**
21	312	18	9
30	97	18	3
55	**122**	**12**	**3**
77			
89	**159**	**16**	**2**

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 50.4 days
Base vernalization requirement (VDbase): 10.1 days

One year has a complete calendar including BBCH 9, 55 and 89. Furthermore 3 years only have a missing emergence date which is then replaced by the long term average emergence date provided this emergence is at least 8 days later than sowing. Finally two years of which BBCH = 55 is missing. These years are still valuable to check the crop cycle length. All these years are used for the calibration.

BBCH scale	Campaign year	Observed date
9	1999	22-10-98*
55	1999	26-04-99
89	1999	06-06-99
9	2001	22-10-00*
55	2001	28-04-01
89	2001	06-06-01
9	2004	02-11-03
89	2004	06-06-04
9	2009	08-10-08
89	2009	04-06-09
9	2011	10-10-10
55	2011	03-05-11
89	2011	08-06-11
9	2012	22-10-11*
55	2012	02-05-12
89	2012	08-06-12

* missing and therefore used the averaged over all years and possibly corrected using the observed planting dates (at least 8 days after planting)

Average actual yield of county Linyi over 2000-2013: 4.4 $t.ha^{-1}$ (0% dry weight).

2.3.8. Yucheng

Optimal day length: 15 hours
Full vernalization requirements (VDfull): 51.0 days
Base vernalization requirement (VDbase): 10.2 days

RADI has some observed phenology data:

BBCH	**2004**	**2006**	**2007**	**2008**
0				
9				
21				
30				

55	**24-Apr**	**08-May**	**30-Apr**	**10-May**
65	**30-Apr**			
77				
89	**02-Jun**	**07-Jun**		

The emergence date was estimated by first taking the average emergence data of CZ5203 (11 November), subtracting 5 days and afterwards applying a variation using the data at BBCH = 55. It resulted in the following emergence dates:

- Emergence in 2003 at 27 October
- Emergence in 2004 at 6 November
- Emergence in 2005 at 11 November
- Emergence in 2006 at 3 November
- Emergence in 2007 at 13 November

RADI has access to observations of LAI and biomass for some years (see section 3.1.8).

Moreover the Yucheng Data Centre has the following observed yield data (0% dry weight):

- 2003: 6.823 t/ha (data centre)
- 2006: 5.712 t/ha (station)
- 2007: 5.906 t/ha (station)
- 2008: 5.790 t/ha (station)

This lead to an average yield of around 5.8 t/ha (excluded outlier for 2003, might be error). These yields levels are relatively low and equal to the administrative yields representing the average farmer. This indicates that crop management for wheat at Yucheng Data Centre might not have been optimal.

Average actual yield of county Dezhou over 2000-2013: 5.7 $t.ha^{-1}$ (0% dry weight).

During fieldwork several farmers and government officials in Dezhou county (in which site Yucheng is located) have been interviewed. This has led to the following insights for recent years:

- Information of visited farms and local projects, indicated an average yield of 8.7 $ton.ha^{-1}$ leading to 7.5 $ton.ha^{-1}$ dry weight (0%) applying a moisture content of 13.5%.
- A specific local project was visited[3]. The average harvested yield of 2016 was 8.78 $ton.ha^{-1}$ leading to 7.6 $ton.ha^{-1}$ dry weight (0%) applying a moisture content of 13.5%.

[3] The government runs an Agriculture development project covering an area of 15000-20000 ha. Farmers receive subsidies and support to optimize crop management: amount and timing of fertilizer and irrigation, advices around varieties, plant density, harvest (later harvest) etc.

2.4. Crop data - maize

RADI prepared crop calendar data of maize (MAZ) for 4 selected sites. The other 3 sites are not included because for these 3 sites maize is not considered as one of the major crops

It was delivered in an Excel file called *Maize phenology Shandong.xlsx*.

Phenological descriptors have been converted into the BBCH scale according https://en.wikipedia.org/wiki/BBCH-scale.

Phenological descriptions	BBCH (maize)
Sowing	00
Emergence	**09**
Three leaves	13
Seven leaves	17
Jointing	30
Tasseling	**59**
Milky stage	75
Mature	**89**

The data have been converted into AGRO-STAC SIF-files which have been imported into the AGRO-STAC database.

The phenological stage ‘flowering’ is missing. Based on local expert knowledge we applied the rule “added 4 days after tasseling to come to flowering”.

First we selected the WOFOST crop parameter file MAG204.CAB from the MARS initiative (Lazar, C. and Genovese, G., 2004) as a first approach to parameterize WOFOST for grain maize. This is a crop parameterization for grain maize calibrated for Southern France, Northern Italy, Spain and Portugal. During calibration we decided to follow the parameterization of China of the MARS projects which slightly differs from the parameterization of MAG204.CAB:

Crop parameter	MARS - China	MAG204.CAB
SPAN	35	33
CVO	0.7	0.671
PERDL	0.02	0.03

Average area (1000 ha) and yield (fresh weight in kg.ha^{-1}) over years 2000-2013 originating from official yield statistics provided by RADI.

County	**FID**	**Area**	**Yield**	**Yield – dry***
Binzhou	2 (CZ5303)	189	6486	5481
Dezhou	Yucheng	337	7420	6270
Dongying		52	6603	5580
Heze		249	5679	4799

Jinan		188	6410	5416
Jining	1 (CZ 5403)	208	7341	6203
Laiwu		27	5566	4703
Liaocheng	0 (CZ 5203)	297	6471	5468
Linyi	6 (CZ5503)	220	6028	5094
Qingdao	3 (CZ4503)	212	6915	5843
Rizhao		55	6448	5449
Tai'an		162	7429	6278
Weifang	4 (CZ 4403)	326	6337	5355
Weihai		66	6710	5670
Yantai	5 (CZ 4603)	178	6729	5686
Zaozhuang		97	6835	5776
Zibo		107	7034	5944
Statistics		2970 (sum)	6614 (avg)	5589 (avg)

* Converted to dry weight (0% in crop growth model) assuming a moisture content of 15.5% (following from the GYGA protocol)

2.4.1. Climate zone 5203 (FID = 0)

Summary statistics of observed phenological stages over the period 2002-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	164	11	2
9	171	10	2
59	219	10	3
89	270	9	5

This average maize calendar (start at 164) fits the average calendar of wheat (ends at 157).

7 of the years have a complete calendar including BBCH 9, 59 and 89.

BBCH scale	Campaign year	Observed date
9	2002	18-06-02
59	2002	08-08-02
89	2002	30-09-02
9	2003	22-06-03
59	2003	13-08-03
89	2003	06-10-03
9	2004	18-06-04
59	2004	05-08-04
89	2004	23-09-04
9	2008	18-06-08
59	2008	04-08-08
89	2008	20-09-08
9	2009	18-06-09
59	2009	05-08-09
89	2009	27-09-09

9	2011	20-06-11
59	2011	08-08-11
89	2011	24-09-11
9	2012	20-06-12
59	2012	07-08-12
89	2012	28-09-12

Average actual yield of county Liaocheng over 2000-2013: 5.5 t.ha^{-1} (0% dry weight).

2.4.2. Climate zone 5403 (FID = 1)

Summary statistics of observed phenological stages over the period 1992-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	164	17	8
9	172	13	8
59	216	19	7
89	258	19	9

This average maize calendar (start at 164) fits the average calendar of wheat (ends at 156).

10 of the years have a complete calendar including BBCH 9, 59 and 89.

BBCH scale	Campaign year	Observed date
9	1997	20-06-97
59	1997	01-08-97
89	1997	17-09-97
9	2000	17-06-00
59	2000	06-08-00
89	2000	10-09-00
9	2001	17-06-01
59	2001	01-08-01
89	2001	06-09-01
9	2003	16-06-03
59	2003	05-08-03
89	2003	13-09-03
9	2004	11-06-04
59	2004	27-07-04
89	2004	07-09-04
9	2005	12-06-05
59	2005	26-07-05
89	2005	04-09-05
9	2008	26-06-08
59	2008	08-08-08
89	2008	18-09-08
9	2009	24-06-09
59	2009	08-08-09

89	2009	24-09-09
9	2011	29-06-11
59	2011	14-08-11
89	2011	30-09-11
9	2012	02-07-12
59	2012	15-08-12
89	2012	28-09-12

Average actual yield of county Jining over 2000-2013: 6.2 $t.ha^{-1}$ (0% dry weight).

2.4.3. Climate zone 4403 (FID = 4)

Summary statistics of observed phenological stages over the period 2002-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	161	10	8
9	166	9	8
59	218	9	4
89	262	10	2

This average maize calendar (start at 161) fits the average calendar of wheat (ends at 158).

7 of the years have a complete calendar including BBCH 9, 59 and 89.

BBCH scale	Campaign year	Observed date
9	2003	04-06-03
59	2003	30-07-03
89	2003	18-09-03
9	2004	02-06-04
59	2004	30-07-04
89	2004	16-09-04
9	2005	06-06-05
59	2005	04-08-05
89	2005	22-09-05
9	2008	22-06-08
59	2008	10-08-08
89	2008	22-09-08
9	2009	18-06-09
59	2009	08-08-09
89	2009	18-09-09
9	2011	20-06-11
59	2011	08-08-11
89	2011	18-09-11
9	2012	16-06-12
59	2012	06-08-12
89	2012	18-09-12

Average actual yield of county Weifang over 2000-2013: 5.4 $t.ha^{-1}$ (0% dry weight).

2.4.4. Climate zone 4603 (FID = 5)

Summary statistics of observed phenological stages over the period 1992, 2000-2013

BBCH	Average of Julian day	Number of observations	StdDev of Julian day
0	174	12	4
9	180	9	4
59	225	12	4
89	272	14	7

This average maize calendar (start at 174) fits the average calendar of wheat (ends at 161).

7 of the years have a complete calendar including BBCH 9, 59 and 89.

BBCH scale	Campaign year	Observed date
9	2003	26-06-03
59	2003	14-08-03
89	2003	28-09-03
9	2004	27-06-04
59	2004	14-08-04
89	2004	28-09-04
9	2005	02-07-05
59	2005	15-08-05
89	2005	08-10-05
9	2008	26-06-08
59	2008	16-08-08
89	2008	08-10-08
9	2009	24-06-09
59	2009	14-08-09
89	2009	28-09-09
9	2011	02-07-11
59	2011	17-08-11
89	2011	06-10-11
9	2012	27-06-12
59	2012	10-08-12
89	2012	28-09-12

Average actual yield of county Yantai over 2000-2013: 5.7 $t.ha^{-1}$ (0% dry weight).

2.4.5. Yucheng

RADI has some observed phenology data:

BBCH	2004	2007	2008
0			
9			
55	218	223*	227
59			
89	259**		

* Average of two other years
** Maturity at16 Sep 2004 is in contradiction with the graphs RADI supplied. These graphs suggest at least a crop cycle till 3 October (observation of LAI = 2.9).

Unfortunately no information was given for emergence dates. We estimated the following emergence dates based on observed LAI values. Note that these starts are relatively late. Emergence dates:

- Emergence in 2003 at 1 July 2003
- Emergence in 2004 at 1 July 2004
- Emergence in 2007 at 1 July 2007
- Emergence in 2008 at 1 July 2008

We took the dates of BBCH = 55 (middle of heading) and added 10 days to arrive at flowering: between 16-25 August.

Compared to the other site (CZ5203) the emergence is 10 days later. Thus maturity will be at least 10 days later: first week October. Also the observed times series of LAI and biomass indicates a maturity in the first weeks of October.

RADI has access to observations of LAI and biomass for some years (see section 3.2.5).

Moreover the Yucheng data centre has the following observed yield data:

- 2003: 8.5 t.ha^{-1} (7.0 t.ha^{-1} zero dry weight assuming 18% moisture)

Average actual yield of county Dezhou over 2000-2013: 6.3 t.ha^{-1} (0% dry weight).

During fieldwork several farmers and government officials in Dezhou county (in which site Yucheng is located) have been interviewed. This has led to the following insights for recent years:

- Moisture content could be as high as 18% because this is the upper limit accepted by buyers. In this study we have applied a percentage of 15.5 (following from the GYGA protocol). Therefore the official yield statistics expressed in 0% dry weight might be lower (around 160 kg.ha^{-1}).
- A farmer, practicing proper management, has an average yield of 9-10 ton.ha^{-1} with record yield of around 11 ton.ha^{-1} which correspond to 7.7-8.2 and 9 ton.ha^{-1} dry weight (0%) applying a moisture content of 18%. The latter was confirmed by the farmer.

- Information of other visited farms and local projects, indicated an average yield or 10 $ton.ha^{-1}$ leading to 8.2 – 8.5 $ton.ha^{-1}$ dry weight (0%) applying a moisture content of resp. 18% and 15.5%.

3. Calibration

3.1. Winter wheat

First we calibrated the phenology taking care that the simulated length and flowering matches the observed values. Note that after winter the crop cycle length is relatively short (March-May) allowing a second crop maize but also leading to relatively low yields. Next we checked plausible LAI dynamics:

- Maximum between 3 and 7
- Relative low final value (<1)

We also checked the harvest index which should vary between 0.4 and 0.55. Finally we compared with the estimate actual yield from statistics of different districts within the Shandong province. The averaged simulated yield should be considerable higher than the estimated actual yield because the latter represent the average farmer for which it is difficult or economical unattractive to manage the crop in the most optimal way (sufficient and correct use of input, no weed, pests and diseases). We compared simulated yield levels (zero dry weight) with data from front runner farmers and demonstration projects in the Dezhou county. Again the simulated yield levels should exceed those observed yields to some extent as the farmers will not easily reach the theoretical yield level as it is economically not attractive.

3.1.1. Climate zone 5203 (FID = 0)

Calibration runs over the years 1997, 1998, 2001 and 2008.

We calibrated the following crop parameters (in reference to WWH105.CAB):

1) Changes:
    a. TSUM1 = 660
    b. TSUM2 = 650 (accepted length increase of 3 days)
    c. SLATB_01 changed from 0.00212 into 0.0023 (DVS 0)
    d. SLATB_02 changed from 0.00212 into 0.0023 (DVS 0.5)
    e. SLATB_03 changed from 0.00212 into 0.0023 (DVS 2)
    f. SPAN changed from 31.3 into 23
    g. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
    h. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
    i. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
    j. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
    k. TMPFTB_04 changed from 25,1 into 28,1
    l. TMNFTB_01 changed from 0,0 into -2,0
    m. TMNFTB_02 changed from 3,1 into 1,1
    n. CVO changed from 0.709 into 0.72

Results, averaged, over the 4 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.8	0.4	14.5	6.9	0.48

Simulated maturity is 2 days later to extend the grain filling period and to force a lower LAI at maturity. Simulated TWSO of 6.9 $t.ha^{-1}$ is well above regional statistical estimate: 5.1 $t.ha^{-1}$

3.1.2. Climate zone 5403 (FID = 1)

Calibration runs over the years 1997, 1999, 2001, 2002, 2003, 2005 and 2006.

We calibrated the following crop parameters (in reference to WWH105.CAB):

a. TSUM1 = 572
b. TSUM2 = 737
c. SPAN changed from 25 into 24
d. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
e. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
f. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
g. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
h. TMPFTB_04 changed from 25,1 into 28,1
i. TMNFTB_01 changed from 0,0 into -2,0
j. TMNFTB_02 changed from 3,1 into 1,1
k. CVO changed from 0.709 into 0.72

Results, averaged, over the 7 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.7	0.2	15.9	7.7	0.48

Simulated flowering is 3 days later to extend the vegetative phase while the maturity is one day later leading to a grain filling phase 2 days shorter. Simulated TWSO of 7.7 $t.ha^{-1}$ is:

- well above regional statistical estimate: 5.2 $t.ha^{-1}$
- well above the observed yield 2005 (5.7 $t.ha^{-1}$) and 2006 (5.5 $t.ha^{-1}$) reported by Ren et al. (2008).

3.1.3. Climate zone 5303 (FID = 2)

Calibration runs over the years 1998, 2001, 2003, 2004, 2006, 2007 and 2012.

We calibrated the following crop parameters (in reference to WWH105.CAB):

1) Changes:
    a. TSUM1 = 645
    b. TSUM2 = 680 (accepted length increase of 3 days)
    c. SLATB_01 changed from 0.00212 into 0.0019 (DVS 0)
    d. SLATB_02 changed from 0.00212 into 0.0019 (DVS 0.5)
    e. SLATB_03 changed from 0.00212 into 0.0019 (DVS 2)
    f. SPAN changed from 31.3 into 25
    g. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
    h. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
    i. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
    j. AMAXTB_04 changed from 4.48 into 40 (DVS 2)

k. TMPFTB_04 changed from 25,1 into 28,1
l. TMNFTB_01 changed from 0,0 into -2,0
m. TMNFTB_02 changed from 3,1 into 1,1
n. CVO changed from 0.709 into 0.72

Results, averaged, over the 7 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.4	0.6	15.0	6.8	0.46

Simulated flowering is 1 day earlier to extend the grain filling phase a little bit. Simulated TWSO of 6.8 $t.ha^{-1}$ is well above regional statistical estimate: 5.2 $t.ha^{-1}$

3.1.4. Climate zone 4503 (FID = 3)

Calibration runs over the years 1998, 1999, 2001, 2006 and 2012.

We calibrated the following crop parameters (in reference to WWH105.CAB):

a. TSUM1 = 565
b. TSUM2 = 710
c. SPAN changed from 31.3 into 23
d. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
e. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
f. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
g. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
h. TMPFTB_04 changed from 25,1 into 28,1
i. CVO changed from 0.709 into 0.72

Results, averaged, over the 5 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.9	0.2	15.6	7.4	0.48

Simulated maturity is 2 days later to extend the grain filling phase. Simulated TWSO of 7.4 $t.ha^{-1}$ is well above regional statistical estimate: 5.2 $t.ha^{-1}$

3.1.5. Climate zone 4403 (FID = 4)

Calibration runs over the years 1998, 1999, 2001, 2005, 2011-2013.

We calibrated the following crop parameters (in reference to WWH105.CAB):

a. TSUM1 = 620
b. TSUM2 = 660
c. SPAN changed from 31.3 into 23
d. SLATB_01 changed from 0.00212 into 0.0021 (DVS 0)
e. SLATB_02 changed from 0.00212 into 0.0021 (DVS 0.5)
f. SLATB_03 changed from 0.00212 into 0.0021 (DVS 2)
g. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
h. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
i. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)

j. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
k. TMPFTB_04 changed from 25,1 into 28,1
l. TMNFTB_01 changed from 0,0 into -2,0
m. TMNFTB_02 changed from 3,1 into 1,1
n. CVO changed from 0.709 into 0.72

Results, averaged, over the 7 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
6.3	0.4	15.5	6.8	0.44

Simulated maturity is 2 days later to extend the grain filling phase. Simulated TWSO of 6.8 $t.ha^{-1}$ is well above regional statistical estimate: 5.1 $t.ha^{-1}$

3.1.6. Climate zone 4603 (FID = 5)

Calibration runs over the years 1999 and 2000.

We calibrated the following crop parameters (in reference to WWH105.CAB):

a. TSUM1 = 620
b. TSUM2 = 600
c. SPAN changed from 31.3 into 22
d. SLATB_01 changed from 0.00212 into 0.0019 (DVS 0)
e. SLATB_02 changed from 0.00212 into 0.0019 (DVS 0.5)
f. SLATB_03 changed from 0.00212 into 0.0019 (DVS 2)
g. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
h. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
i. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
j. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
k. TMPFTB_04 changed from 25,1 into 28,1
l. CVO changed from 0.709 into 0.72

Results, averaged, over the 2 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.5	0.5	16.5	7.7	0.47

Simulated flowering is 1 day earlier while the maturity is two days later leading to a grain filling phase 3 days longer. Simulated TWSO of 7.7 $t.ha^{-1}$ is well above regional statistical estimate: 4.3 $t.ha^{-1}$

3.1.7. Climate zone 5503 (FID = 6)

Calibration runs over the years 1999, 2001, 2004, 2009, 2011 and 2012.

We calibrated the following crop parameters (in reference to WWH105.CAB):

a. TSUM1 = 700
b. TSUM2 = 760
c. SPAN changed from 31.3 into 26
d. SLATB_01 changed from 0.00212 into 0.0019 (DVS 0)

e. SLATB_02 changed from 0.00212 into 0.0019 (DVS 0.5)
f. SLATB_03 changed from 0.00212 into 0.0019 (DVS 2)
g. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
h. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
i. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
j. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
k. TMPFTB_04 changed from 25,1 into 28,1
l. TMNFTB_01 changed from 0,0 into -1,0
m. TMNFTB_02 changed from 3,1 into 2,1
n. CVO changed from 0.709 into 0.72

Results, averaged, over the 6 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.4	0.3	14.7	6.4	0.44

Simulated maturity is 3 days later to extend the grain filling phase. Simulated TWSO of 6.4 $t.ha^{-1}$ is well above regional statistical estimate: 4.4 $t.ha^{-1}$.

3.1.8. Yucheng

Calibration runs over the years 2003-2008.

We calibrated the following crop parameters (in reference to WWH105.CAB):

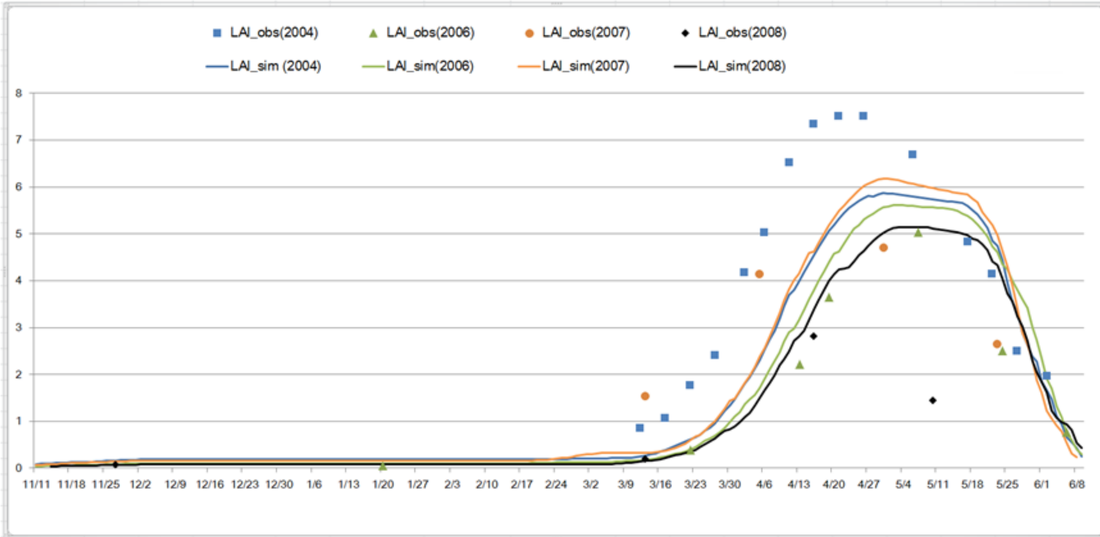
a. TSUM1 = 640
b. TSUM2 = 720
c. SLATB_01 changed from 0.00212 into 0.0022 (DVS 0)
d. SLATB_02 changed from 0.00212 into 0.0022 (DVS 0.5)
e. SLATB_03 changed from 0.00212 into 0.0022 (DVS 2)
f. SPAN changed from 31.3 into 24
g. AMAXTB_01 changed from 35.83 into 40 (DVS 0)
h. AMAXTB_02 changed from 35.83 into 40 (DVS 1)
i. AMAXTB_03 changed from 35.83 into 40 (DVS 1.3)
j. AMAXTB_04 changed from 4.48 into 40 (DVS 2)
k. TMPFTB_04 changed from 25,1 into 28,1
l. TMNFTB_01 changed from 0,0 into -2,0
m. TMNFTB_02 changed from 3,1 into 1,1
n. CVO changed from 0.709 into 0.72

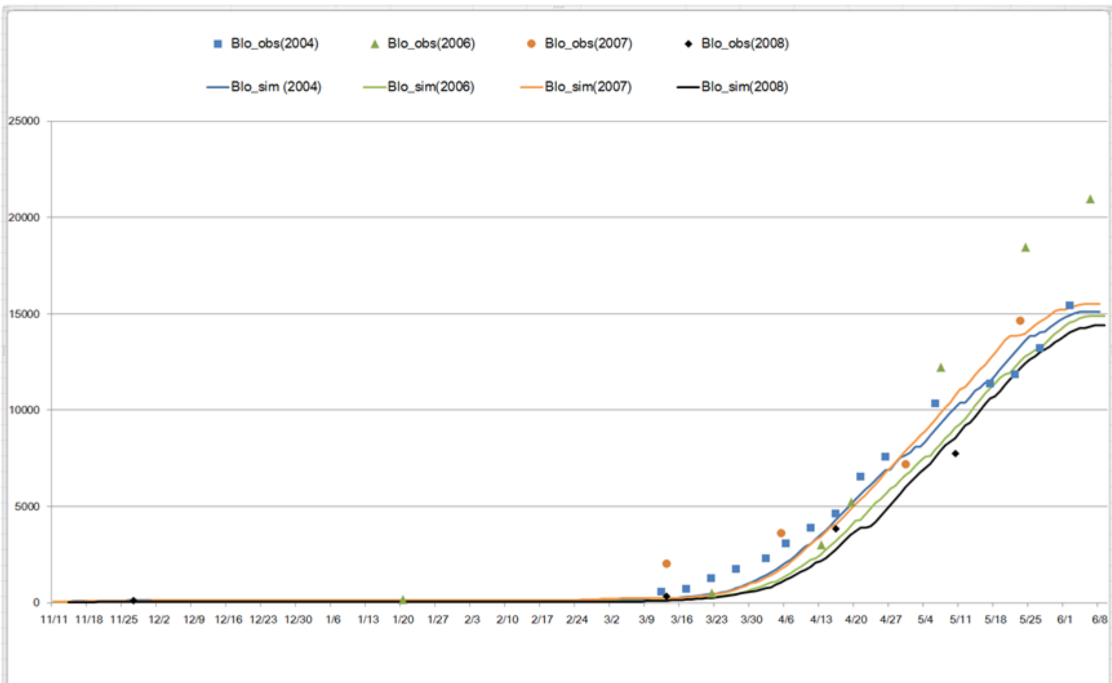
Results, averaged, over the 5 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.6	0.2	15.0	7.1	0.47

Simulated anthesis is 2 days earlier and maturity is 4 days later to extend the grain filling period and to force a lower LAI at maturity.

Below the comparison of simulated LAI and biomass with observations from Yucheng Data Centre:





Simulated TWSO of 7.1 $t.ha^{-1}$ is:

- well above regional statistical estimate: 5.7 $t.ha^{-1}$
- a bit lower than the maximum yield levels reported by farmers and demonstration project: 7.5 $t.ha^{-1}$. Simulated yields of some years (2006 and 2008) are close to this level. Note that indications from local experts are for the current situation while the simulated yields are for 2003-2008.

Simulated yields of resp. 2006, 2007 and 2008 are 7.3, 6.6 and 7.3 $t.ha^{-1}$ while Yucheng Data Centre has observed yields of 5.7, 5.9 and 5.8 $t.ha^{-1}$. It seems that the observed yields of Yucheng Data Centre are relatively low and do not represent optimal crop management.

3.1.9. Summary

Below a summary of the crop parameters is given. Values between brackets refer to the original values of the WWH105.CAB crop parameter file.

TSUM1 and TSUM2 were tuned to the observed calendars but sometimes slightly adapted to allow a longer grain filling phase and a lower LAI at maturity.

Name	FID	TSUM1	TSUM2	TSUM TOTAL
CZ5203	0	660	650	1310
CZ5403	1	572	737	1309
CZ5303	2	645	680	1325
CZ4503	3	565	710	1275
CZ4403	4	620	660	1280
CZ4603	5	620	600	1220
CZ5503	6	700	760	1460
Yucheng	7	640	720	1360

Crop parameters around leaf area dynamics have been (slightly) adapted to increase or decrease LAI and to lower the LAI at the end of the cycle.

Name	FID	SLATB	SPAN
CZ5203	0	0.0023 (0.00212)	23 (31.3)
CZ5403	1	0.00212 (0.00212)	24 (31.3)
CZ5303	2	0.0019 (0.00212)	25 (31.3)
CZ4503	3	0.00212 (0.00212)	23 (31.3)
CZ4403	4	0.0021 (0.00212)	23 (31.3)
CZ4603	5	0.0019 (0.00212)	22 (31.3)
CZ5503	6	0.0019 (0.002)	26 (31.3)
Yucheng	7	0.0022 (0.00212)	24 (31.3)

Crop parameters around gross assimilation have been adapted to allow a more efficient assimilation and to increase yield levels.

Name	FID	AMAXTB _01	AMAXTB _02	AMAXTB _03	AMAXTB _04	TMPFTB _04	TMNFTB _01	TMNFTB _02
CZ5203	0	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	-2,0 (0,0)	1,1 (3,1)
CZ5403	1	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	-2,0 (0,0)	1,1 (3,1)
CZ5303	2	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	-2,0 (0,0)	1,1 (3,1)
CZ4503	3	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	0,0 (0,0)	3,1 (3,1)
CZ4403	4	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	-2,0 (0,0)	1,1 (3,1)
CZ4603	5	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	0,0 (0,0)	3,1 (3,1)
CZ5503	6	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	-1,0 (0,0)	2,1 (3,1)
Yucheng	7	40 (35.83)	40 (35.83)	40 (35.83)	40 (4.48)	28,1 (25,1)	-2,0 (0,0)	1,1 (3,1)

Crop parameters around storage formation rates at (later) crop phases have been adapted for a more efficient conversion and increase yield levels.

Name	FID	CVO
CZ5203	0	0.72 (0.709)
CZ5403	1	0.72 (0.709)
CZ5303	2	0.72 (0.709)
CZ4503	3	0.72 (0.709)
CZ4403	4	0.72 (0.709)

CZ4603	5	0.72 (0.709)
CZ5503	6	0.72 (0.709)
Yucheng	7	0.72 (0.709)

3.1.10. SIGMA compared to the MARS project

Simulation results of the MARS CGMS China implementation have been compared with the SIGMA simulations.

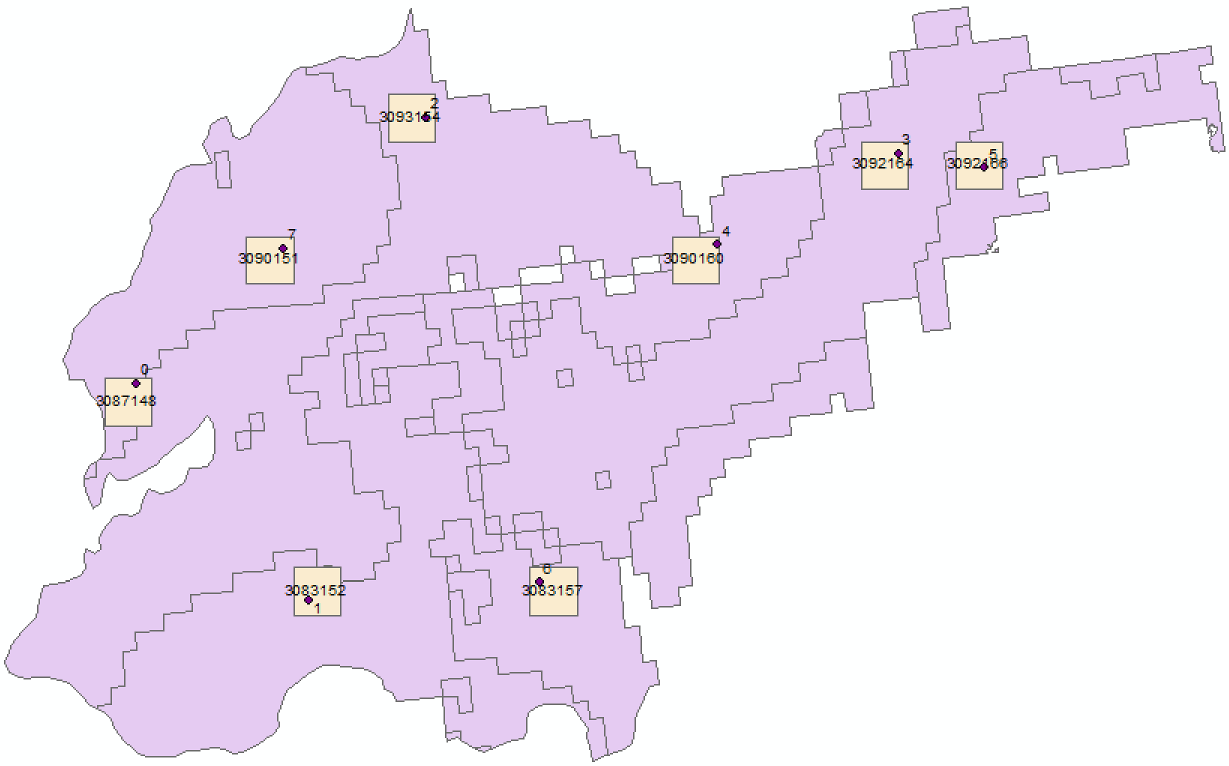


Figure 3-1 SIGMA sites (FID) and linked MARS grid cells codes of CGMS14CHN

Crop calendars:

Site	FID	SIGMA			MARS		
		Emergence	Flowering	Maturity	Emergence	Flowering*	Maturity*
CZ5203	0	11-NOV	6-MAY	6-JUN	06-NOV	11-MAY	18-JUN
CZ5403	1	17-OCT	26-APR	5-JUN	06-NOV	11-MAY	18-JUN
CZ5303	2	14-OCT	10-MAY	7-JUN	06-NOV	13-MAY	20-JUN
CZ4503	3	6-OCT	9-MAY	9-JUN	06-NOV	20-MAY	30-JUN
CZ4403	4	6-OCT	10-MAY	7-JUN	06-NOV	16-MAY	22-JUN
CZ4603	5	9-OCT	13-MAY	10-JUN	06-NOV	20-MAY	30-JUN
CZ5503	6	22-OCT	7-MAY	8-JUN	06-NOV	14-MAY	22-JUN
Yucheng	7	6-NOV	6-MAY	10-JUN	06-NOV	11-MAY	19-JUN

* Reported in dekads, last day of last dekad is given

Analysis of differences:

- MARS has fixed emergence (6 November) while in SIGMA start varies largely: between 6 October and 11 November
- While the emergences dates of the SIGMA sites differ largely, due to vernalization and photoperiodicity in relation to the local climate, calendars are synchronized leading to a small variation of flowering and maturity dates: resp. between 6-13 May (except site 1) and between 5 and 11 June.
- The MARS database shows similar flowering dates but later maturity dates meaning that the grain filling phase is longer than in SIGMA. The difference in maturity is around 7-14 days. Note that the maturity dates of the MARS database are similar to the observed emergence dates of maize while the maturity should be earlier to allow planting of maize.

Simulated crop characteristics:

Name	FID	Type	LAIM	LAI END	TAGP	TWSO	HINDEX
CZ5203	0	**SIGMA**	**5.8**	**0.4**	**14.5**	**6.9**	**0.48**
CZ5203	0	MARS	7.1	4.3	14.6	5.6	0.38
CZ5403	1	**SIGMA**	**5.7**	**0.2**	**15.9**	**7.7**	**0.48**
CZ5403	1	MARS	7.5	4.3	15.1	5.5	0.36
CZ5303	2	**SIGMA**	**5.4**	**0.6**	**15.0**	**6.8**	**0.46**
CZ5303	2	MARS	6.3	5.0	14.1	6.0	0.43
CZ4503	3	**SIGMA**	**5.9**	**0.2**	**15.6**	**7.4**	**0.48**
CZ4503	3	MARS	6.3	4.8	15.6	7.2	0.46
CZ4403	4	**SIGMA**	**6.3**	**0.4**	**15.5**	**6.8**	**0.44**
CZ4403	4	MARS	6.7	4.7	14.7	6.2	0.42
CZ4603	5	**SIGMA**	**5.5**	**0.5**	**16.5**	**7.7**	**0.47**
CZ4603	5	MARS	6.7	5.1	16.0	7.2	0.45
CZ5503	6	**SIGMA**	**5.4**	**0.3**	**14.7**	**6.4**	**0.44**
CZ5503	6	MARS	7.2	5.2	15.6	6.3	0.40
Yucheng	7	**SIGMA**	**5.6**	**0.2**	**15.0**	**7.1**	**0.47**
Yucheng	7	MARS	6.8	4.6	14.4	5.7	0.40
Average		**SIGMA**	**5.7**	**0.4**	**15.3**	**7.1**	**0.47**
Average		MARS	6.8	4.7	15.0	6.2	0.41

Analysis of differences:

- We introduced site specific phenology parameters to reflect the observed phenology.
- LAIM of MARS is higher compared to SIGMA and near the upper limit also in comparison of the observations of Yucheng. To simulated proper LAI dynamics we had to introduce a cold resistant variety allowing assimilation activity during colder nights. This was also done in the MARS simulations. Moreover we introduced site specific SLATB changes to optimize the LAI dynamics.
- LAI end of MARS is much too high and the associated unrealistic shape of the curve leads to an overestimation of evapotranspiration. **It could lead to false alarms on drought!** The SPAN value used in MARS is 35 while in SIGMA we calibrated values of 22-26. We recommend using lower SPAN values in the MARS simulations.
- The biomass and yields of SIGMA are higher than the ones of MARS despite the shorter grain filling phase. This is can be explained by crop parameter changes in SIGMA to introduce a high yielding variety (AMAXTB and CVO) that can

reproduce the yield levels observed/reported in the Yucheng and Shandong region. Note that yield levels of MARS will even be lower when another radiation source will be used (not the biased JRC_ERA-INTERIM values for Shandong).
- SIGMA yield levels of around 7.1 $t.ha^{-1}$ are well above the administrative statistical yield (between 4.3 and 5.7 $t.ha^{-1}$) while the average simulated yield level for Dezhou county (Yucheng location) is somewhat lower than the average observed maximum yields mainly due to one year (2003).
- For the MARS China implementation the following is recommended:
  - Replace JRC_ERA_INTERIM radiation by JRC_CGMS_CHN
  - Re-calibrate using:
    - Vernalization
    - Lower SPAN values
    - One week earlier maturity dates (lower TSUM2)
    - Fine-tune SLATB (LAI dynamics) and TMNFTB (cold resistance)
    - Increase yield levels via AMAXTB / CVO

3.2. Maize

First we calibrated the phenology taking care that the simulated length and flowering matches the observed values. Note that the crop cycle length is relatively short (July-September) as it follows winter wheat leading to relatively low yields compared to single cropping systems. Next, we checked a plausible LAI dynamics:
- Maximum between 3 and 7
- Relative low final value (<1)

We also checked the harvest index which should vary between 0.35 and 0.60. Finally, we compared with the estimate actual yield from statistics of different districts within the Shandong province. The averaged simulated yield should be considerable higher than the estimated actual yield because the latter represent the average farmer for which it is difficult or economical unattractive to manage the crop in the most optimal way (sufficient and correct use of input, no weed, pests and diseases). We compared simulated yield levels (zero dry weight) with data from front runner farmers and demonstration projects in the Dezhou county. Again the simulated yield levels should exceed those observed yields to some extent as the farmers will not easily reach the theoretical yield level as it is economically not attractive.

3.2.1. Climate zone 5203 (FID = 0)

Calibration runs over the years 2002-2004, 2008, 2009, 2011 and 2012.

We calibrated the following crop parameters (in reference to the MARS China parameters):
- TSUM1 = 1050
- TSUM2 = 850
- SLATB_01 changed from 0.0026 into 0.0027 (DVS = 0.0)
- SLATB_02 changed from 0.0012 into 0.0018 (DVS = 0.78)
- SLATB_03 changed from 0.0012 into 0.0014 (DVS = 2)
- SPAN changed from 35 into 32 (DVS = 2)
- CVO changed from 0.70 into 0.72 (value in original MAIZ.W41)
- AMAXTB_04 changed from 49.00 into 55 (DVS = 1.75)

- AMAXTB_05 changed from 21.00 into 35 (DVS = 2)

Results, averaged, over the 7 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.2	0.9	15.5	7.8	0.50

Simulated anthesis is 2 days earlier and maturity is 4 days later to extend the grain filling period and to force a lower LAI at maturity. Simulated TWSO of 7.8 $t.ha^{-1}$ is well above regional statistical estimate: 5.5 $t.ha^{-1}$.

3.2.2. Climate zone 5403 (FID = 1)

Calibration runs over the years 1997, 2000, 2001, 2003-2005, 2008, 2009, 2011 and 2012.

We calibrated the following crop parameters (in reference to the MARS China parameters):
- TSUM1 = 1030
- TSUM2 = 750
- SLATB_01 changed from 0.0026 into 0.0027 (DVS = 0.0)
- SLATB_02 changed from 0.0012 into 0.0019 (DVS = 0.78)
- SLATB_03 changed from 0.0012 into 0.0014 (DVS = 2)
- SPAN changed from 35 into 31 (DVS = 2)
- CVO changed from 0.70 into 0.72 (value in original MAIZ.W41)
- AMAXTB_04 changed from 49.00 into 55 (DVS = 1.75)
- AMAXTB_05 changed from 21.00 into 35 (DVS = 2)

Results, averaged, over the 10 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.8	1.2	14.4	7.2	0.50

The simulated maturity is on average 7 days later than the observed. This was done to increase the simulated yields taking into account the very early maturity date (compared to all other sites) and the still relatively high LAI at maturity. Simulated TWSO of 7.2 $t.ha^{-1}$ is well above regional statistical estimate: 6.2 $t.ha^{-1}$.

3.2.3. Climate zone 4403 (FID = 4)

Calibration runs over the years 2003-2005, 2008, 2009, 2011 and 2012

We calibrated the following crop parameters (in reference to the China MARS parameters):
- TSUM1 = 1050
- TSUM2 = 820
- SLATB_01 changed from 0.0026 into 0.0027 (DVS = 0.0)
- SLATB_02 changed from 0.0012 into 0.0018 (DVS = 0.78)
- SLATB_03 changed from 0.0012 into 0.0014 (DVS = 2)
- SPAN changed from 35 into 33
- CVO changed from 0.70 into 0.72 (value in original MAIZ.W41)
- AMAXTB_04 changed from 49.00 into 55 (DVS = 1.75)
- AMAXTB_05 changed from 21.00 into 35 (DVS = 2)

Results, averaged, over the 7 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.7	1.0	15.9	7.5	0.48

Simulated anthesis is 3 days earlier and maturity is 4 days later to extend the grain filling period and to force a lower LAI at maturity. Simulated TWSO of 7.5 $t.ha^{-1}$ is well above regional statistical estimate: 5.4 $t.ha^{-1}$.

3.2.4. Climate zone 4603 (FID = 5)

Calibration runs over the years 2003-2005, 2008, 2009, 2011 and 2012.

We calibrated the following crop parameters (in reference to the MARS China parameters):

- TSUM1 = 980
- TSUM2 = 760
- SLATB_01 changed from 0.0026 into 0.0027 (DVS = 0.0)
- SLATB_02 changed from 0.0012 into 0.0018 (DVS = 0.78)
- SLATB_03 changed from 0.0012 into 0.0014 (DVS = 2)
- SPAN changed from 35 into 30 (DVS = 2)
- CVO changed from 0.70 into 0.72 (value in original MAIZ.W41)
- AMAXTB_04 changed from 49.00 into 55 (DVS = 1.75)
- AMAXTB_05 changed from 21.00 into 35 (DVS = 2)

Results, averaged, over the 7 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
5.1	1.1	15.8	8.2	0.52

Simulated maturity is 5 days later than the observed to allow lower LAI at maturity and at the same time a sufficient yield level. Still the relatively high LAI end is a point of concern.

Simulated TWSO of 8.2 $t.ha^{-1}$ is well above regional statistical estimate: 5.7 $t.ha^{-1}$.

3.2.5. Yucheng

Calibration runs over the years 2003, 2004, 2007 and 2008.

We calibrated the following crop parameters (in reference to the MARS China parameters):

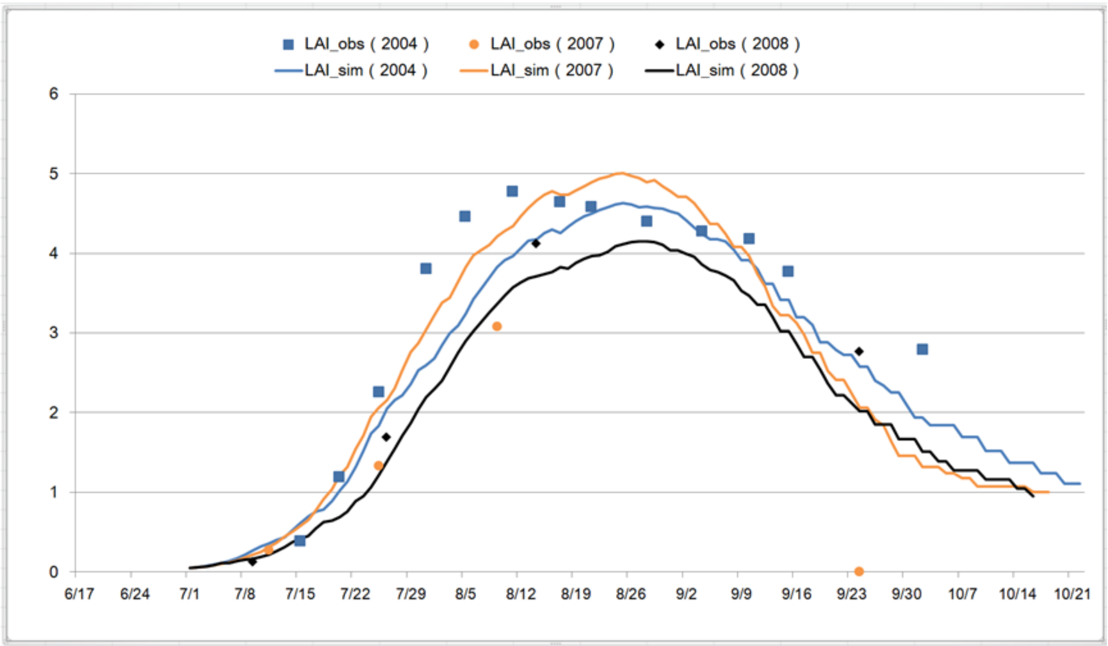
- TSUM1 = 1050
- TSUM2 = 800
- SLATB_01 changed from 0.0026 into 0.0027 (DVS = 0.0)
- SLATB_02 changed from 0.0012 into 0.0018 (DVS = 0.78)
- SLATB_03 changed from 0.0012 into 0.0014 (DVS = 2)
- SPAN changed from 35 into 30
- CVO changed from 0.70 into 0.72 to increase yield (value in original MAIZ.W41)
- AMAXTB_04 changed from 49.00 into 55 (DVS = 1.75)
- AMAXTB_05 changed from 21.00 into 35 (DVS = 2)

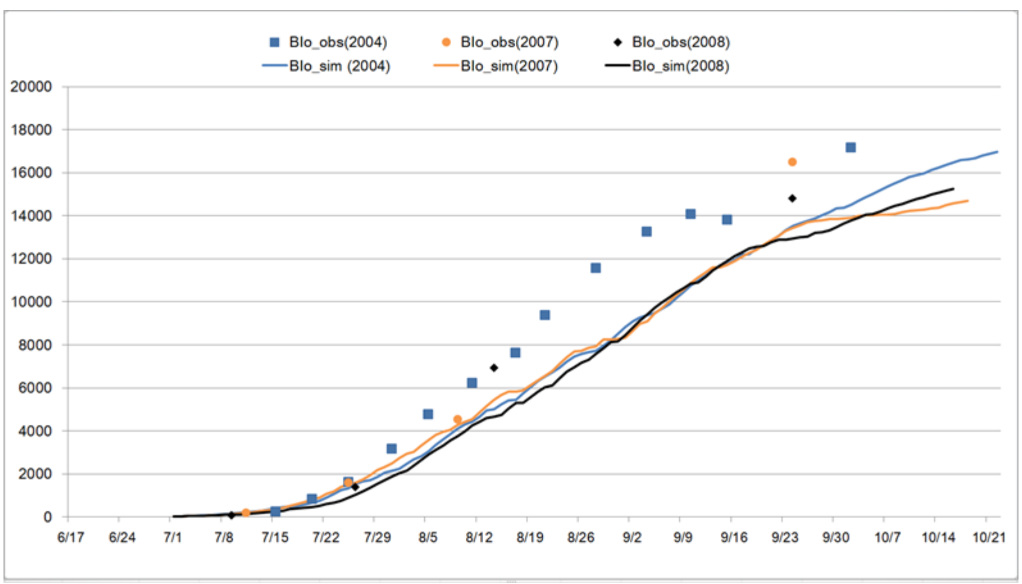
Results, averaged, over the 3 years are:

LAIM	LAI END	TAGP	TWSO	HINDEX
4.2	0.9	14.3	7.5	0.52

Simulated anthesis is 1 days later and maturity is 8 days later to extend the grain filling period and to force a lower LAI at maturity and sufficient yield.

Below the comparison of simulated LAI and biomass with observations from Yucheng Data Centre:





Simulated TWSO of 7.5 $t.ha^{-1}$ is:

- well above regional statistical estimate: 6.3 $t.ha^{-1}$
- it is a bit lower than the maximum yield levels reported by farmers and demonstration project (8.2 – 8.5 $ton.ha^{-1}$ dry weight (0%)) but mainly due to the

simulated yield of 2003: 5.0 t.ha^{-1}. The radiation sum of July-September in 2003 is relatively low. For the other years yields vary between 7.2 and 9.5 confirming the expert estimates.

3.2.6. Summary

Below a summary of the crop parameters that were changed with reference to the MARS China crop parameter file.

TSUM1 and TSUM2 were tuned to the observed calendars but sometimes slightly adapted to allow a longer grain filling phase and a lower LAI at maturity.

Name	FID	TSUM1	TSUM2	TSUM TOTAL
CZ5203	0	1050	850	1900
CZ5403	1	1030	750	1780
CZ4403	4	1050	820	1870
CZ4603	5	980	760	1740
Yucheng	7	1050	800	1850

Crop parameters around leaf area dynamics have been slightly adapted to increase LAI during the crop cycle and to decrease LAI at maturity.

Name	FID	SLATB_01	SLATB_02	SLATB_03	SPAN
CZ5203	0	0.0027 (0.0026)	0.0018 (0.0012)	0.0014 (0.0012)	32 (35)
CZ5403	1	0.0027 (0.0026)	0.0019 (0.0012)	0.0014 (0.0012)	31 (35)
CZ4403	4	0.0027 (0.0026)	0.0018 (0.0012)	0.0014 (0.0012)	33 (35)
CZ4603	5	0.0027 (0.0026)	0.0018 (0.0012)	0.0014 (0.0012)	30 (35)
Yucheng	7	0.0027 (0.0026)	0.0018 (0.0012)	0.0014 (0.0012)	30 (35)

Crop parameters around gross assimilation have been adapted to allow a more efficient assimilation and storage formation rates at (later) crop phases.

Name	FID	AMAXTB_04	AMAXTB_05	CVO
CZ5203	0	55 (49)	35 (21)	0.72 (0.7)
CZ5403	1	55 (49)	35 (21)	0.72 (0.7)
CZ4403	4	55 (49)	35 (21)	0.72 (0.7)
CZ4603	5	55 (49)	35 (21)	0.72 (0.7)
Yucheng	7	55 (49)	35 (21)	0.72 (0.7)

3.2.7. SIGMA compared to the MARS project

Simulation results of the MARS China implementation have been compared with the SIGMA simulations.

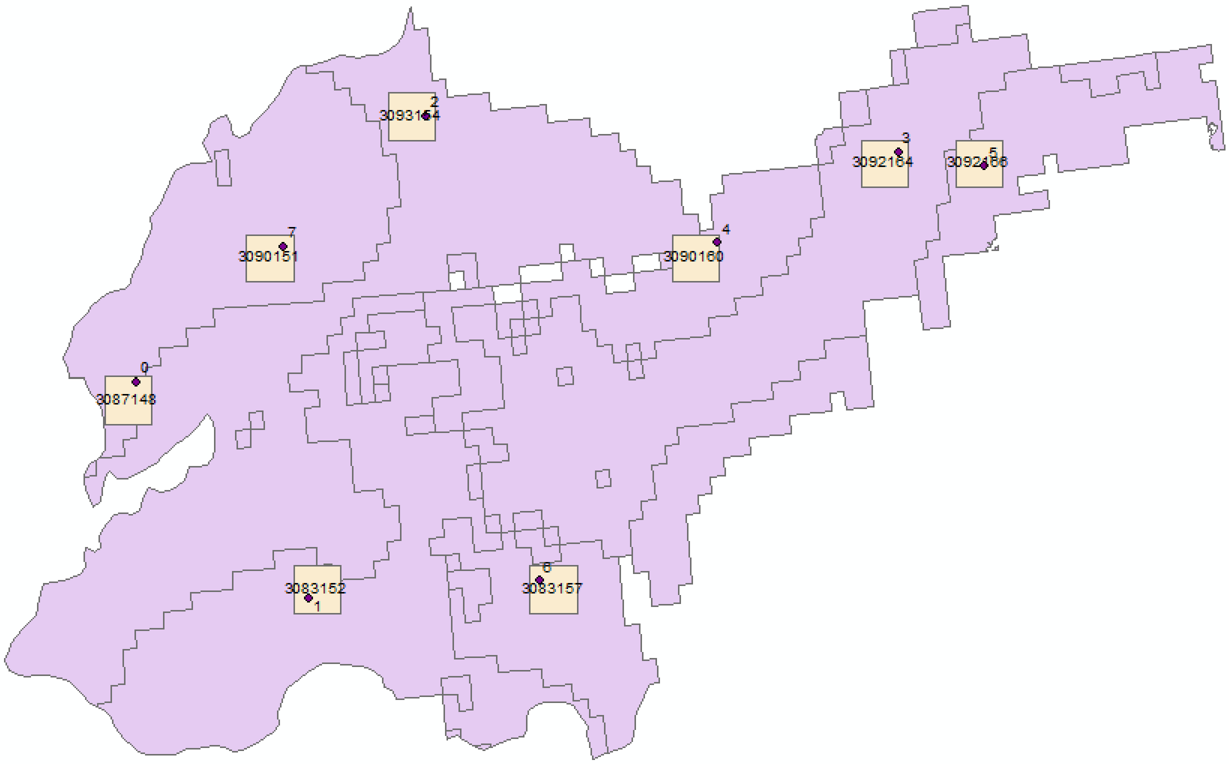


Figure 3-2 SIGMA sites (FID) and linked MARS grid cells codes of CGMS14CHN

Crop calendars:

Site	FID	SIGMA			MARS		
		Emergence	Flowering	Maturity	Emergence	Flowering*	Maturity*
CZ5203	0	20-JUN	11-AUG	27-SEP	26-JUN	18-AUG	05-OCT
CZ5403	1	21-JUN	08-AUG	15-SEP	26-JUN	17-AUG	01-OCT
CZ4403	4	15-JUN	10-AUG	19-SEP	26-JUN	17-AUG	02-OCT
CZ4603	5	29-JUN	17-AUG	29-SEP	26-JUN	18-AUG	09-OCT
Yucheng**	7	1-JUL	20-AUG	15-OCT	26-JUN	18-AUG	04-OCT

* Reported in dekads, last day of last dekad is given

** Phenology data for Yucheng was limited some assumptions were made for instance derive emergence from observed LAI timeseries.

Analysis of differences:

- Emergence in MARS simulations is around 5 days later than SIGMA. For site 5 the maturity date of wheat in the MARS China simulations is later than the emergence of maize.

- The delay in start of the MARS simulations is also translated in a later flowering date meaning that vegetative phase is equal between MARS and SIGMA.
- The maturity date in the MARS simulations is around 10 days later leading to a 5-days longer grain filling phase. Note that in the calibration we allowed a later maturity date 3-7 days which lead maturity dates quite similar of those of the MARS simulations.
- In case yield levels are still on the lower side the grain filling phase could be enlarged. An extension of 7 days could easily lead to an increase of 300-400 $kg.ha^{-1}$. If TSUM2 would be increased the final LAI end must be checked to see whether there are too many living leaves at the end of the cycle.

Simulated crop characteristics:

Name	FID	Type	LAIM	LAI END	TAGP	TWSO	HINDEX
CZ5203	0	**SIGMA**	**5.2**	**0.9**	**15.5**	**7.8**	**0.50**
CZ5203	0	MARS	5.7	1.7	17.9	8.6	0.48
CZ5403	1	**SIGMA**	**5.8**	**1.2**	**14.4**	**7.2**	**0.50**
CZ5403	1	MARS	5.1	1.7	16.4	8.0	0.49
CZ4403	4	**SIGMA**	**5.7**	**1.0**	**15.9**	**7.5**	**0.48**
CZ4403	4	MARS	4.8	1.9	16.4	8.1	0.50
CZ4603	5	**SIGMA**	**5.1**	**1.1**	**15.8**	**8.2**	**0.52**
CZ4603	5	MARS	4.6	1.8	17.3	9.0	0.52
Yucheng	7	**SIGMA**	**4.2**	**0.9**	**14.3**	**7.5**	**0.52**
Yucheng	7	MARS	5.4	1.9	17.3	9.0	0.52
Average		**SIGMA**	**5.2**	**1.0**	**15.2**	**7.6**	**0.50**
Average		MARS	5.1	1.8	17.1	8.4	0.50

Analysis of differences:

- We introduced site specific phenology parameters to reflect the observed phenology.
- The maximum LAI is similar between both data sets. We adapted the SLATB to avoid too low LAI-max values.
- The LAI at maturity is lower in SIGMA (1.0 vs 1.8). Still a value of 1 is relatively high. An unrealistic high LAI in the last part of the growing cycle will lead to over estimation of crop transpiration and could lead to the simulation of extra drought stress. The lower LAI end is due to the use of a lower SPAN values (30-33 versus 35)
- Biomass and yields in SIGMA is lower than in MARS. This is caused by two aspects:
  - The length of the crop cycle which is slightly longer in the MARS simulations.
  - The biased radiation data of the JRC_ERA-INTERIM data set.
- The SIGMA yield levels of around 7.6 $t.ha^{-1}$ are:
  - Well above the administrative statistical yield (between 5.1 and 6.3 $t.ha^{-1}$) and what was found in literature 7.0 $t.ha^{-1}$ (e.g. Chen et al, 2012).
  - For Dezhou county the 7.5 $t.ha^{-1}$ is lower than the 8.0 – 8.5 $ton.ha^{-1}$ dry weight (0%) according local experts but this is mainly caused by the simulation of 2003. The radiation sum of July-September in 2003 is relatively low. For the other years yields vary between 7.2 and 9.5 confirming the expert estimates. Using the radiation values of JRC_ERA-INTERIM the results of 2003 increase to 6.8 $t.ha^{-1}$ (comparable with the

observations of Yucheng data centre: 6.8 $t.ha^{-1}$) instead of 5.0 $t.ha^{-1}$. It is recommended to check the radiation observations for 2003 of the Yucheng data centre.

- For the MARS China implementation the following is recommended:
    - Replace JRC_ERA-INTERIM radiation
    - Re-calibrate using:
        - Lower SPAN values
        - Fine-tune SLATB (LAI dynamics)
        - Increase yield levels via AMAXTB / CVO

4. Regional implementation

To arrive at spatial explicit maps of potential yield levels for winter wheat and grain maize a regional version of WOFOST for these crops has been set-up. The regional implementation includes the following main components to ensure a full spatial coverage:

- Interpolated daily station weather obtained from JRC-MARS (JRC_CGMS_CHN)
- Gridded soil data from WISE30SEC
- Local calibrated varieties linked to GYGA-ED zones
- SIGMA specific spatial schematization combining the 1) MARS China 25 km grid; 2) the WISE30SEC soil grids and 3) the GYGA-ED zonation. The daily weather is linked to the MAR China 25 km grid; soil data originates from the WISE30SEC soil grids (1/120 degree); calibrated varieties are linked to the GYGA-ED zonation (0.08333 degree).

The following sections give more information on the weather, crop and soil data.

4.1. Daily weather data

For China we took the gridded daily weather data set based on the spatial interpolation of daily station weather. This data set was created in the frame of the JRC MARS project and is further referred to as JRC_CGMS_CHN. Daily station data of around 300 stations across China main agricultural lands were collected in the MARS project. Station data covers the following elements:

Cloud cover day time	Daytime mean (i.e. 6-18 UTC) of total cloud cover	octas
Minimum temperature	Minimum temperature	ºC
Maximum temperature	Maximum temperature	ºC
Vapour pressure	Mean daily vapour pressure	hPa
Wind	Mean daily wind speed at 10 meters	m•s-1
Rain	Precipitation between 6 UTC on the day specified and 6 UTC of the next day	mm

Radiation is derived from daily minimum and maximum air temperature and day time mean cloud cover via Supit-VanKappel and the Hargreaves models (see MARS WIKI). To train the models the 50yrRad database of Tang et al. (2013) containing ‘modelled’ radiation data for 716 CMA stations was used. Daily station data were interpolated to the 25 km grid via the CGMS interpolation method (Lazar and Genovese, 2004).

Figure 4-1 Stations used for the spatial interpolation in CGMS14CHN

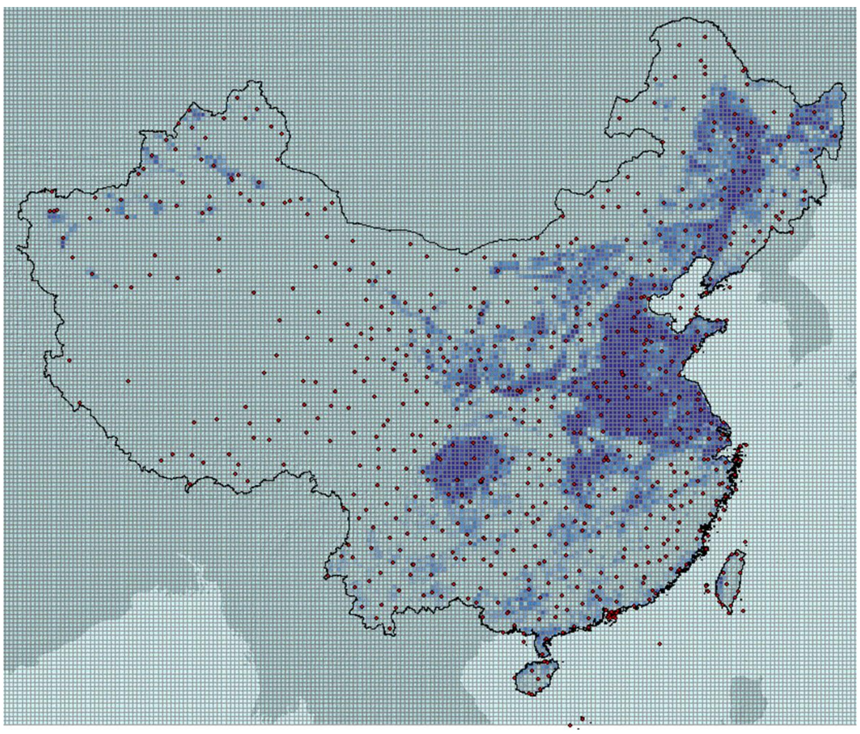


Figure 4-2 Arable land

4.2. Crop data

Crops start at emergence and follow a certain parameterization, determined and calibrated for selected sites in each GYGA-ED zone (see Chapter 2 and 3).

4.3. Soil data

The WISE30SEC version 1.0 soil database was selected. It has some advantages compared to the previous WISE v 1.2 database. For instance the Harmonized World Soil Database (HWSD) is used instead of the Digital Soil Map of the World (DSMW). The former includes more detailed soil maps for some parts of the world like Europe and China (1 to 1 million) while the latter only includes the 1 to 5 million global soil map. Moreover soil characteristics like TAWC are based on twice as much soil profiles increasing the accuracy of these characteristics. Climate data has been used to improve the geo-mapping of soil profiles.

Data have been loaded in tables HW30S_FULL and HW30S_MAPUNIT and processed determining soil physical characteristics (rooting depth and available water capacity) for each soil type unit. This was done by views and scripts according the following steps:

1) Copy MS Access db HW30S_FULL and HW30S_MAPUNIT to ORACLE schema
2) Create views to extract desired structure for WSI:

```
create or replace view soils_smu_temp
as
select
   to_number(substr(newsuid,4)) as idsmu
from hw30s_mapunit;

create or replace view soils_stu_temp
as
select
    to_number(substr(newsuid,4))                  idsmu
  , scid                                          idstu
  , prop                                          percentage
  , max(botdep)                                   soil_rooting_depth
  , sum(tawcc*(botdep-topdep))/sum(botdep-topdep) available_water_capacity
from
  (select
       newsuid              newsuid    -- soil map unit id
     , scid                 scid       -- soil type id
     , prop                 prop       -- proportion of soil type in map unit
     , topdep               topdep     -- top depth of layer
     , botdep               botdep     -- bottom depth of layer
     , (1-(cfrag/100))*tawc tawcc      -- tawc corrected for coarse fragments > 2mm
  from hw30s_full
  where botdep <= 100                  -- skip layers deeper than 1 meter
  and   tawc   >= 0                    -- skip records with -1, -2, -3, -4, -5, -7, -9
  and   to_number(substr(newsuid,4)) not in (0,6997,6998) -- skip records with suid 0, 6997,
6998
)
group by to_number(substr(newsuid,4)), scid, prop
order by to_number(substr(newsuid,4)), scid, prop;
```

The list of soil mapping units is stored in table SOILS_SMU while soil mapping composition and the soil physical characteristics per soil typologic unit are stored in table SOILS_STU.

In the final simulation only suitable soil components are included. These are components having a rooting depth class >= 2 and an available water capacity of 0.1 or more.

Finally it is assumed that all water infiltrate as long as the soil can absorb the water. Percolation rates are set to10 cm per day and a critical air content for oxygen stress of roots is set to 0.06.

4.4. Regional WOFOST database

The table below gives more details on specific data.

Table	Content
CROP	Winter wheat and grain maize
CROP_CALENDAR	Grid and year specific definition of start (emergence), end (maturity) and a grid specific variety (GYGA-ED zone)
CROP_GROUP	Crop group of crops
CROP_PARAMETER_VALUE	Crop parameterization of crops (see chapter 2 and 3)
DATES_75_15	Mapping between dates and dekads
EMU	Overlay between MARS grid and WISE30SEC grid resulting in unique soil associations and their area share within a 25 km grid cell
GRID	MARS grid definition of CGMS14CHN (see globcast report): 25 km spatial resolution in local project co-ordinated system
PARAMETER_DESCRIPTION	Description of crop parameters
INITIAL_SOIL_WATER	Grid and soil component specific soil water available at the start of the soil water initialization which is 60 days before emergence
ROOTING_DEPTH	List of rooting depth classes (20, 40 and 100 cm)
SIMULATION_UNIT	Unique combinations of 25 km grid cells and soil components for each crop
SITE	System wide parameters on infiltration (no surface run-off)
SMU_SUITABILITY	List of soil associations and area percentage of suitable soils based on suitable soil components
SOIL_ASSOCIATION_COMPOSITION	Mapping between soil associations and their soil components of WISE30SEC taken from table SOILS_STU
SOIL_MAPPING_UNIT	List of unique soil associations of WISE30SEC taken from table SOILS_SMU
SOIL_PHYSICAL_GROUP	List of distinct values of available water capacity of WISE30SEC taken from table SOILS_STU. Each value lead to a unique soil group number and associated soil moisture values for pF 2.5 (field capacity) and pF 4.2 (wilting point) and saturation by first defining 0.1 for wilting point, available water capacity plus 0.1 for field capacity and available water capacity plus 0.2 for saturation. Percolation rates of 10 cm per day and a critical air content of 0.06.
SOIL_TYPOLOGIC_UNIT	List of unique soil components of WISE30SEC taken from table SOILS_STU and introducing unique number of distinct rooting depth values and

	unique number of soil groups (see table SOIL_PHYSICAL_GROUP)
STAT_CROP	Mapping between simulation and statistical crops (in this case 1 to 1)
SUITABILITY	List of suitable soil components have a rooting depth class >= 2 and an available water capacity of 0.1 or more
SYSCON	System wide parameters to run WOFOST
VARIETY_PARAMETER_VALUE	Variety specific crop parameters (see chapter 2 and 3)
WEATHER_OBS_GRID	MARS interpolated daily station data for years 1996-2015 (CGMS14CHN) also referred to as JRC_CGMS_CHN
GRID25KM_GYGA_ED	Mapping between the MARS grid and the GYGA-ED zonation based on an overlay between the two grids (25 km grid has assigned the GYGA-ED number based on the largest area)
GYGA_ED_CROP_DATA	Crop and GYGA-ED zone specific start date (emergence)

4.5. Simulation runs

Runs start 60 days before emergence to run a climatic water balance and come to more realistic initial soil water.

Simulation period for each crop:

- Winter wheat: 1997 – 2015 (with starts in 1996 – 2014): 19 years
- Grain maize: 1996 – 2015 (with starts in 1996 – 2015): 20 years

Simulation was carried out with the WOFOST implementation in PCSE (WOFOST71_PP (fully-irrigated) and WOFOST71_WP (water-limited / rain fed)) (http://pcse.readthedocs.io/en/latest/).

Next results of the unique combinations of 25 km grid cells and soil components are aggregated to unique combinations of 25 km grid cells and soil associations allowing the mapping of the results.

The following key characteristics have been derived to evaluate the simulations and to assess the potential yield levels (grain yield) under irrigated and rain-fed conditions:

- Average maximum Leaf Area Index (plausible range: 3-7)
- CV of maximum Leaf Area Index (plausible range: 0 – 0.2)
- Average final Leaf Area Index (plausible range: 0 - 1)
- CV of final Leaf Area Index (plausible range: 0 – 0.2)
- Average above ground biomass (plausible range: 15000 - 20000)
- CV of above ground biomass (plausible range: 0 – 0.2)
- Average grain yield (plausible range: 7500 - 10000[4])
- CV of grain yield (plausible range: 0 – 0.2)
- Average final development stage (plausible range: 195-200)

[4] For winter wheat maximum yields of almost 9 $t.ha^{-1}$ (13.5% moisture) were reported (see section 2.3.8). For grain maize maximum yields of 10 $t.ha^{-1}$ (15.5% moisture) were reported (see section 2.4.5)

- Average harvest index (plausible range: 0.35 – 0.55)

The simulated grain yield from WOFOST is expressed as kg dry weight (zero moisture) per hectare. To enable a correct comparison with downscaled official regional yield statistics, expressed in fresh weight, the modelled grain yield was converted as follows:

- Winter wheat: modelled yield/(1-0.135)/1000 assuming 13.5 moisture in the grains
- Grain maize: modelled yield/(1-0.155)/1000 assuming 15.5 moisture in the grains

4.6. Winter wheat

4.6.1. Comparison with calibrated sites

First the simulated yield of the site calibration and the regional implementation has been compared taking the average of the same years (irrigated run).

Name	FID	Grid reference	Regional v1	Regional v2	Calibrated
CZ5203	0	3087148	**5.7**	**6.7**	**6.9**
CZ5403	1	3083152	**7.4**	**7.4**	**7.7**
CZ5303	2	3093154	**6.7**	**6.7**	**6.8**
CZ4503	3	3092164	**7.9**	**7.9**	**7.4**
CZ4403	4	3090160	**6.7**	**6.7**	**6.8**
CZ4603	5	3092166	**7.9**	**7.9**	**7.7**
CZ5503	6	3083157	**6.8**	**6.8**	**6.4**
Yucheng	7	3090152	**6.8**	**6.8**	**7.1**

Main reason for the differences (regional v1 vs calibrated) is that the temperature data used for the calibration differed substantially from the temperature data used in the regional implementation. For the site calibration we took the most nearby station from the GSOD data portal while for the regional implementation we took the interpolated product, also based on station data. Temperature data from the interpolated products is the average of 1 to 4 surrounding stations and therefore will be slightly different. However this should be a random effect and should not lead to biased results. We checked data for a few specific cases. For CZ 5403 we used station Yanzhou for the site calibration. The associated grid cell (3083152) of the interpolated weather product is based on only one station (54916), also Yanzhou. In this case temperature values should be the same. But this is not the case, especially not for the minimum temperature. The GSOD version has for many situations a lower minimum temperature compared to the station that was used in the interpolated product. This relates to the definition of the minimum temperature.

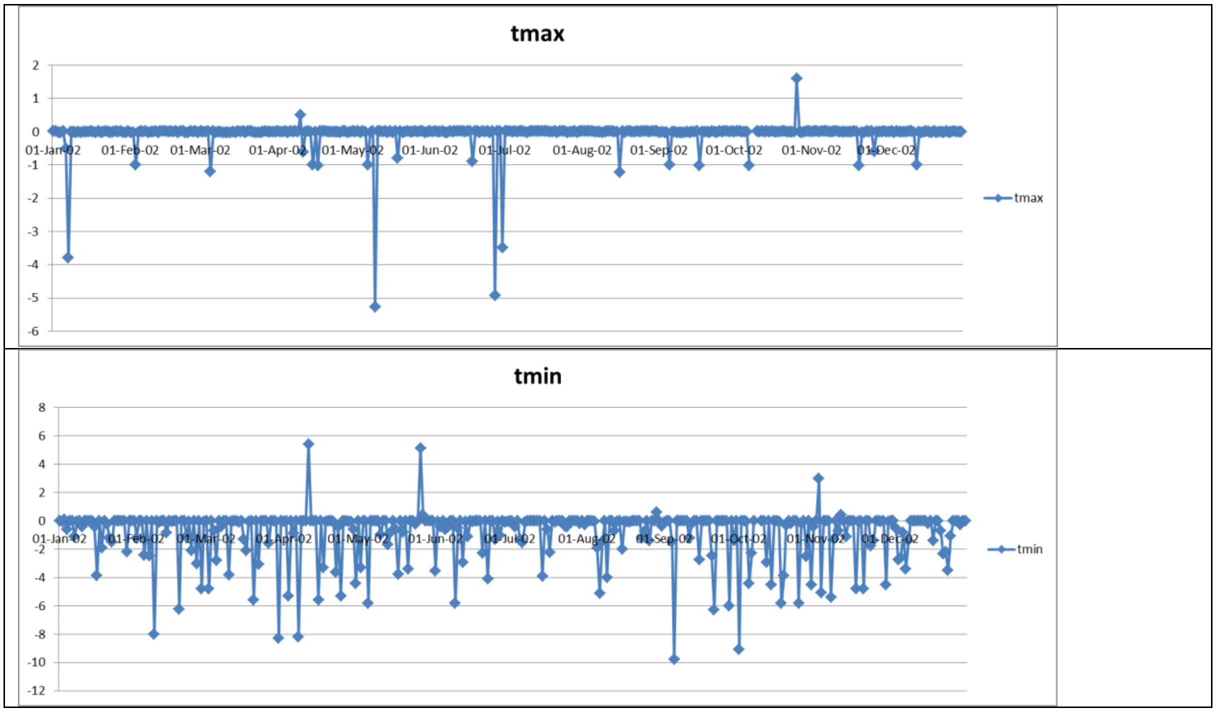


Figure 4-3 GSOD minus interpolated product for CZ 5403 in 2002

In addition we checked CZ 5203 where we used station Xinxian for the site calibration. The associated grid cell (3087148) of the interpolated weather product is based on four stations so in this case we do not compare the same station. Also in this case we see a large bias specifically for minimum temperature probably caused by the definition of the minimum temperature and the selection of stations with a relative high minimum temperature. Note that station density for western Shandong is low and therefore the stations used for interpolation are more distant.

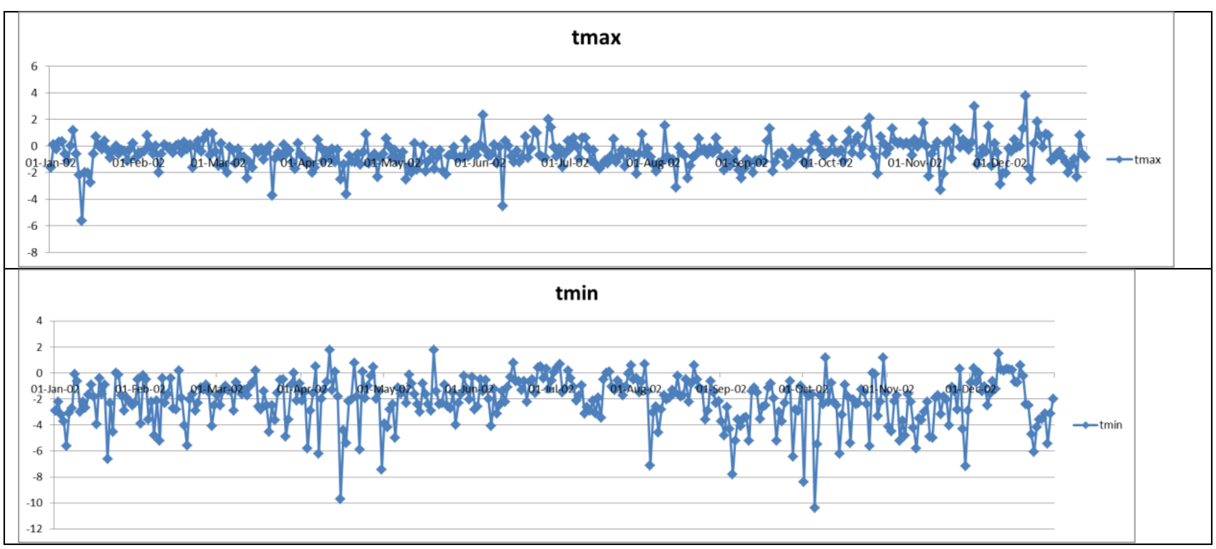


Figure 4-4 GSOD minus interpolated product for CZ 5203 in 2002

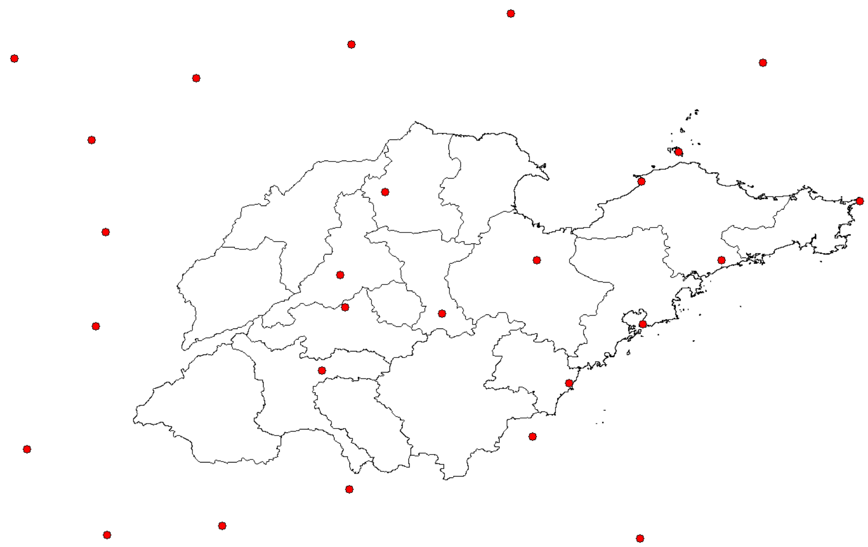


Figure 4-5 Stations used in the interpolated product

The higher minimum temperature, and associated higher average temperature, led to biased result and affected the crop simulation in three ways:

- Accelerated development and thus a shorter crop cycle
- Accelerated leaf senescence
- Softened effect of low minimum temperatures on the assimilation

To avoid the differences between the site and regional simulation the most optimal approach is to redo the site calibration using exactly the same weather data sources as the one being used in the regional implementation. Due to project constraints this was not feasible.

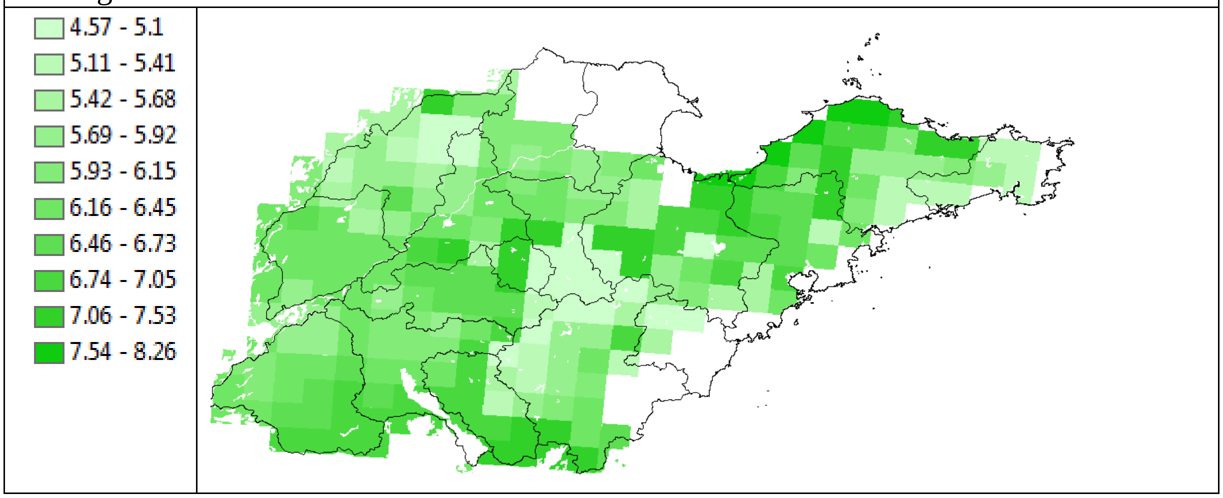
Most locations have similar results except the location of CZ5203. Reason is that the effect of the accelerated development and leaf senescence, leading to lower yields, is compensated by the softened effect of low minimum temperatures on assimilation, leading to higher yields.

So we only did a limited analysis for CZ5203. The simulated yield of the regional approach is much lower than the calibrated site and also for all other locations in this climate zone. We found that the regional simulation results for the site improve substantial by changing crop parameter TSUM2 with 100 degrees and SPAN with 3 days (regional v2). All following results are based on this improvement for CZ5203.

4.6.2. Results irrigated run

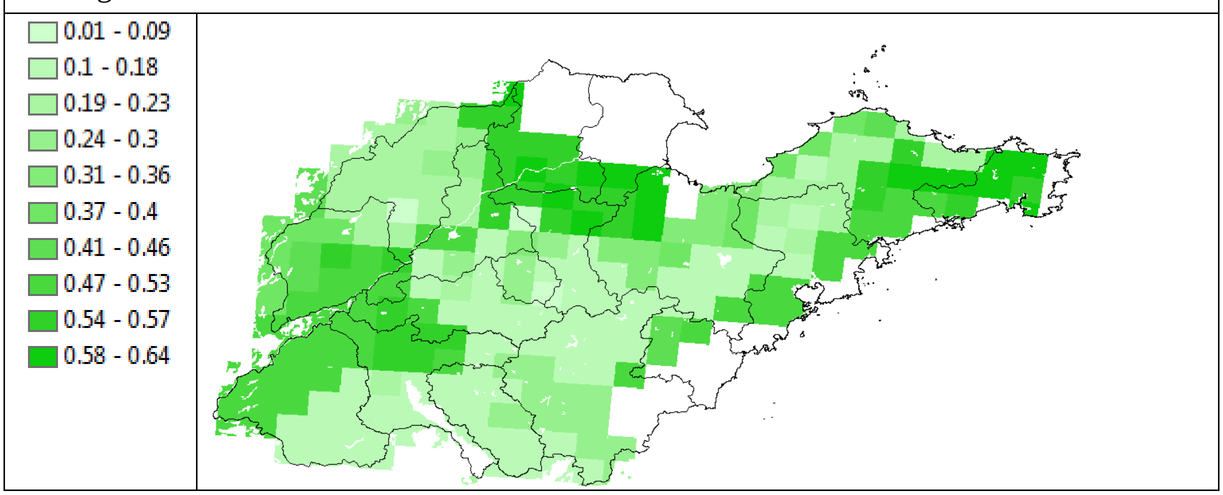
Average maximum Leaf Area Index is within the expected range. The CV (not shown) is lower than 20% indicating stable results over the years. Only some higher CV values for a few locations at the eastern border.

Average maximum Leaf Area Index



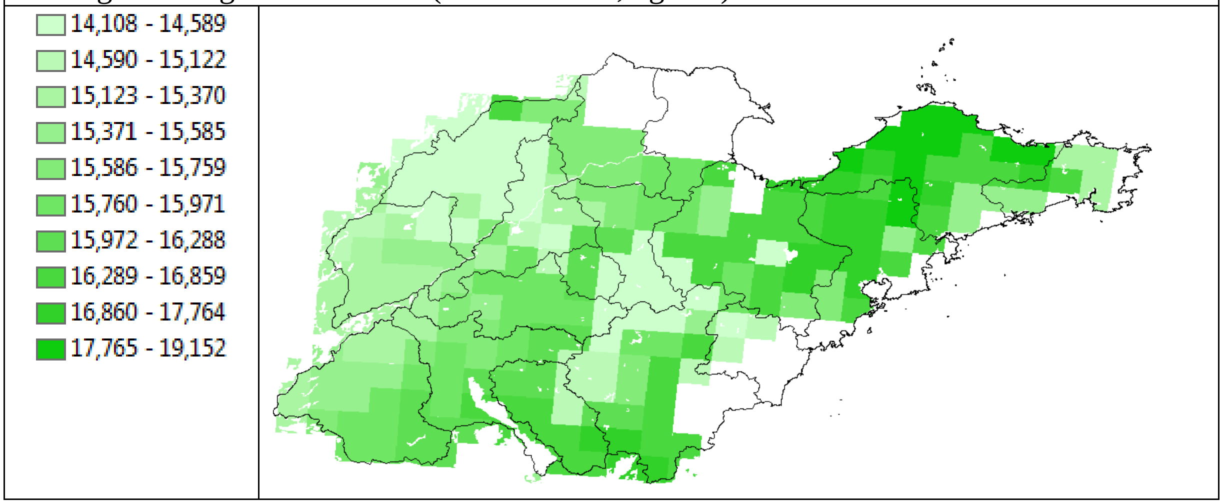
Average final Leaf Area Index is within the expected range. The major parts have a CV(not shown) lower than 20%. Scattered over the region CV values between 20 and 40 can be found. These match areas with the relative low values of the final Leaf Area Index.

Average final Leaf Area Index



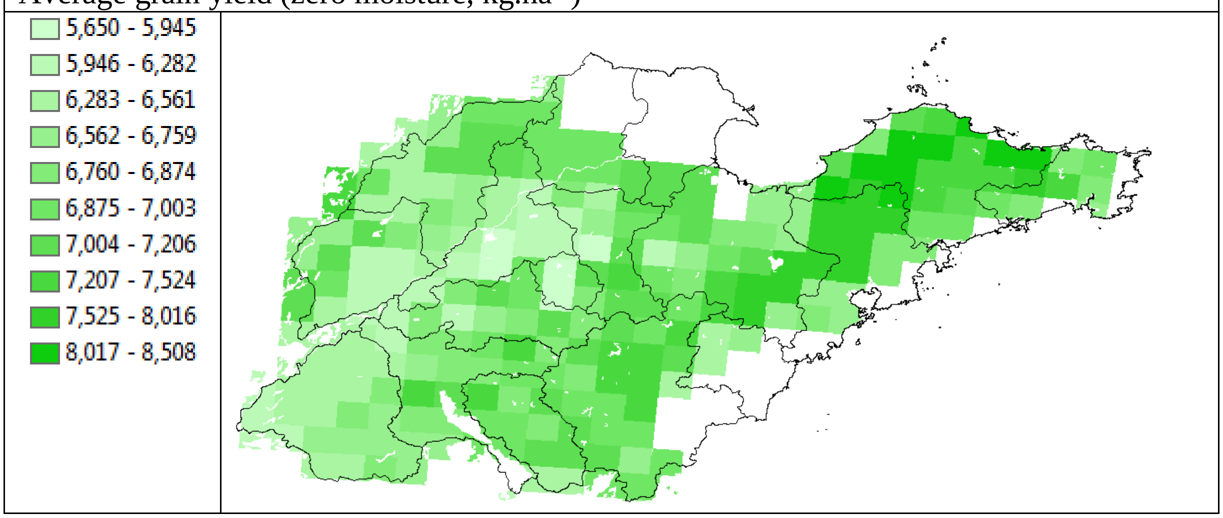
Average above ground biomass is within the expected range. Almost all grid cells have a CV (not shown) lower than 10% except for a few locations at the eastern border (around 27%).

Average above ground biomass (zero moisture, kg.ha^{-1})



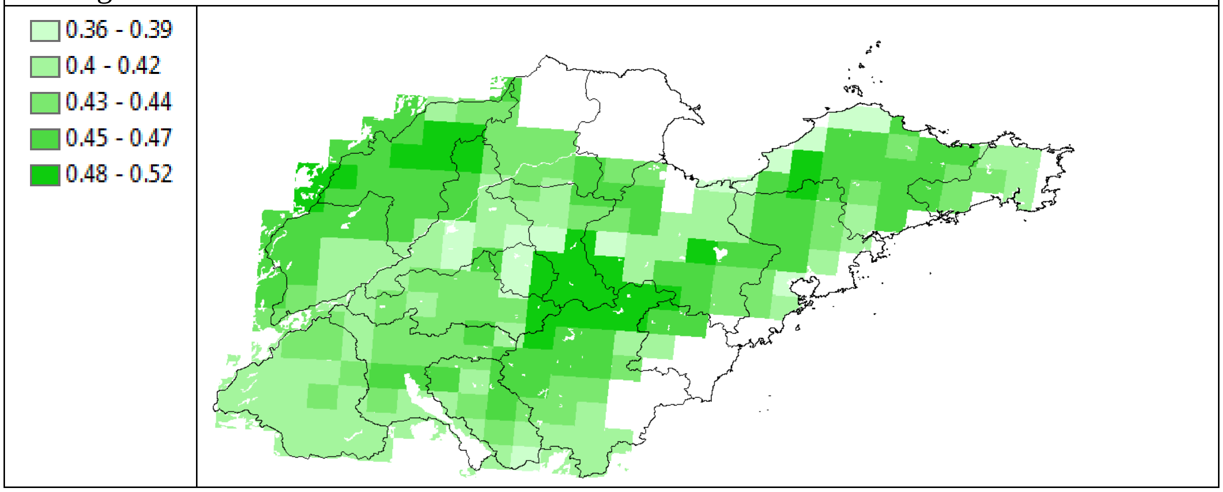
Average grain yield is between 6 – 7.5 ton.ha^{-1}. Almost all grid cells have a CV (not shown) lower than 10% except for a few locations at the eastern border (around 27%).

Average grain yield (zero moisture, kg.ha^{-1})



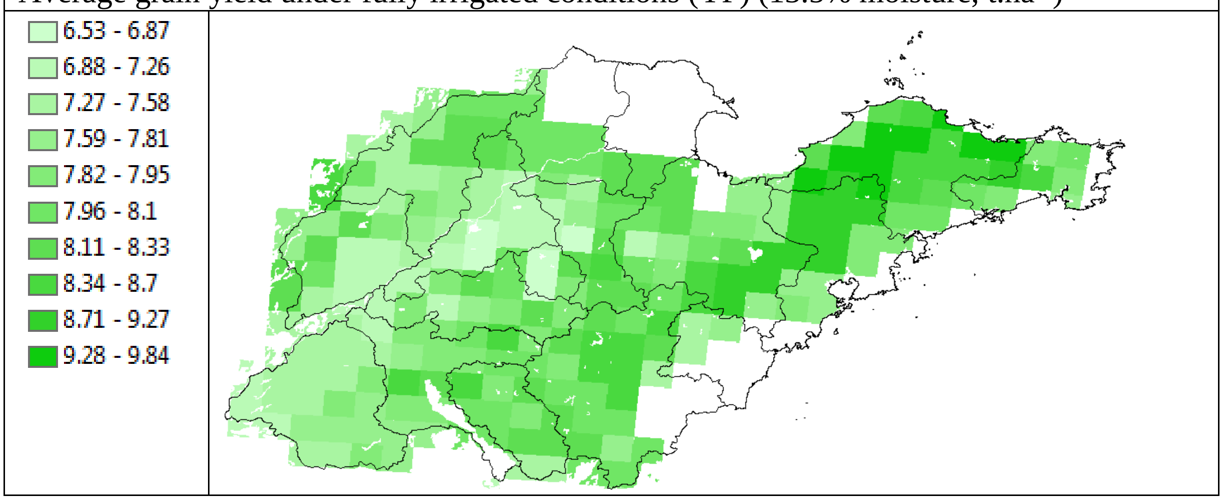
Average harvest index is within the range. Almost all grid cells have a CV (not shown) lower than 10% except for a few locations at the eastern border (around 29%).

Average harvest index



Average grain yield (13.5%) between 6.5 – 10 ton.ha^{-1}.

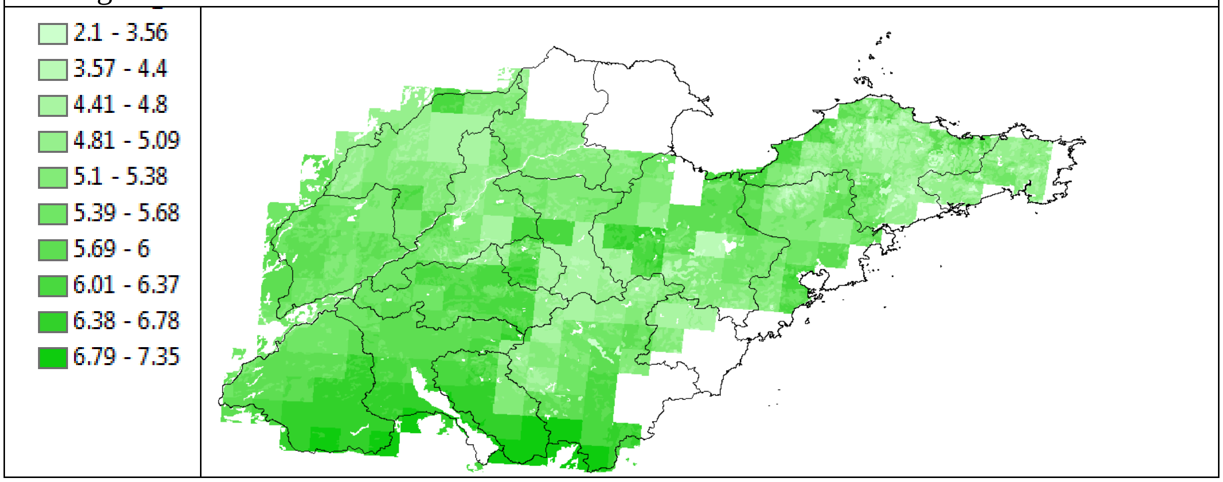
Average grain yield under fully irrigated conditions (YP) (13.5% moisture, t.ha^{-1})



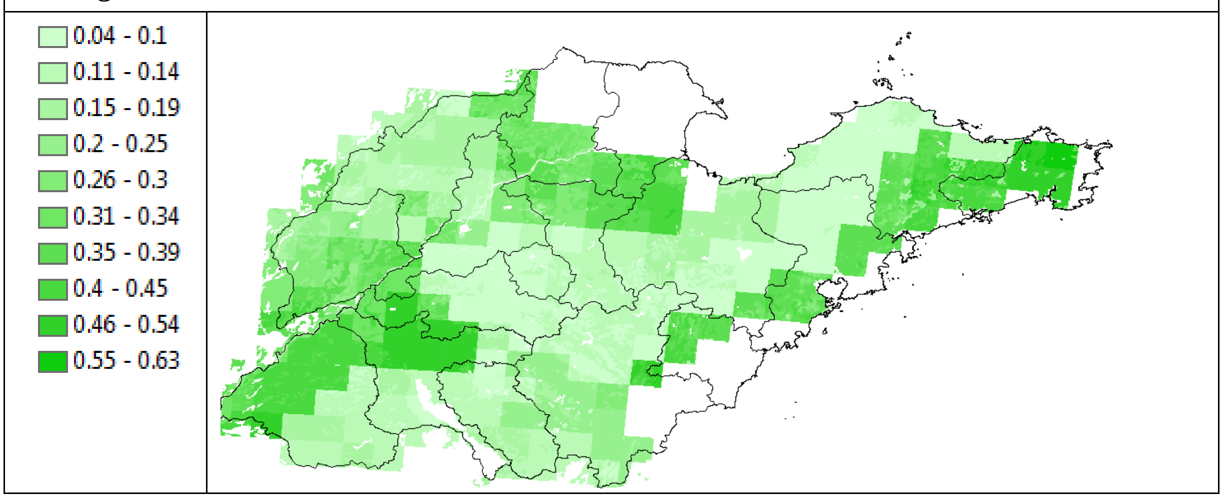
4.6.3. Results water-limited run

The drought effect is large specifically for the biomass and yield levels. On average the water-limited yields are 4 ton.ha^{-1} lower. The drought effect is largest in the north and north east. This is also clear in the figure showing the CV of water-limited yield. The yield levels vary over the years with the lowest CV (<20%) in the south, moderate 20-40% in the middle and north-west and the highest CV (>40%) in the north east.

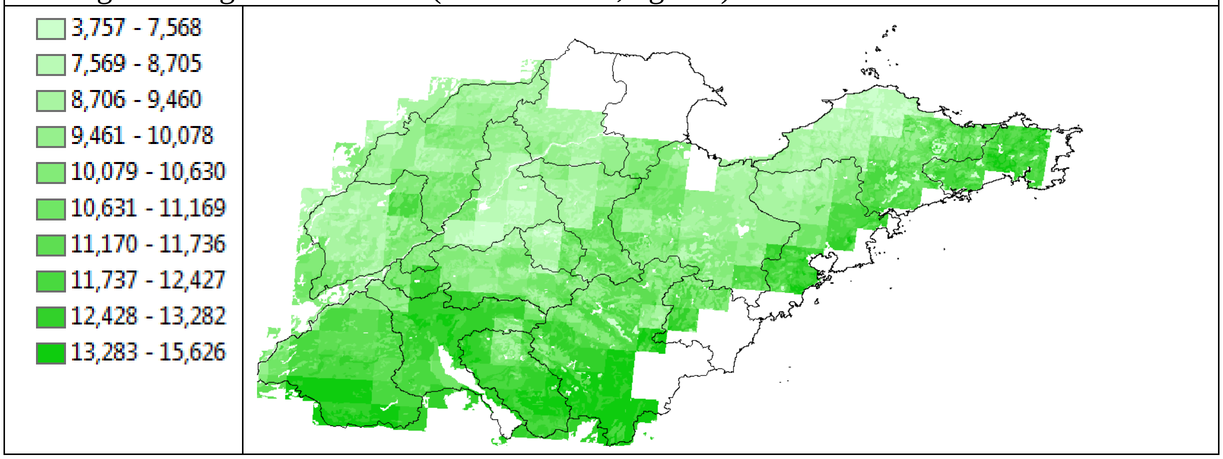
Average maximum Leaf Area Index



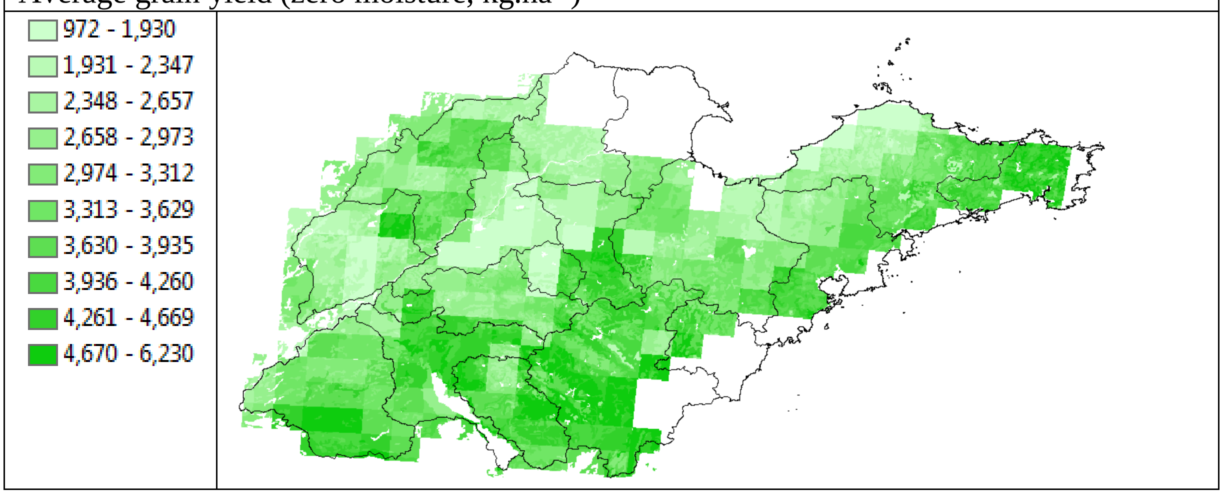
Average final Leaf Area Index



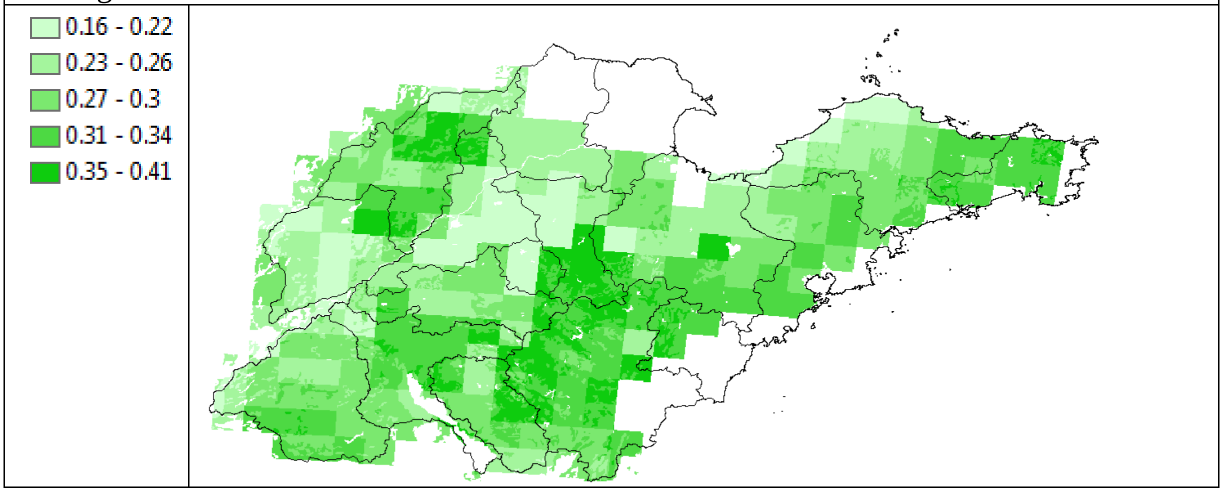
Average above ground biomass (zero moisture, kg.ha^{-1})



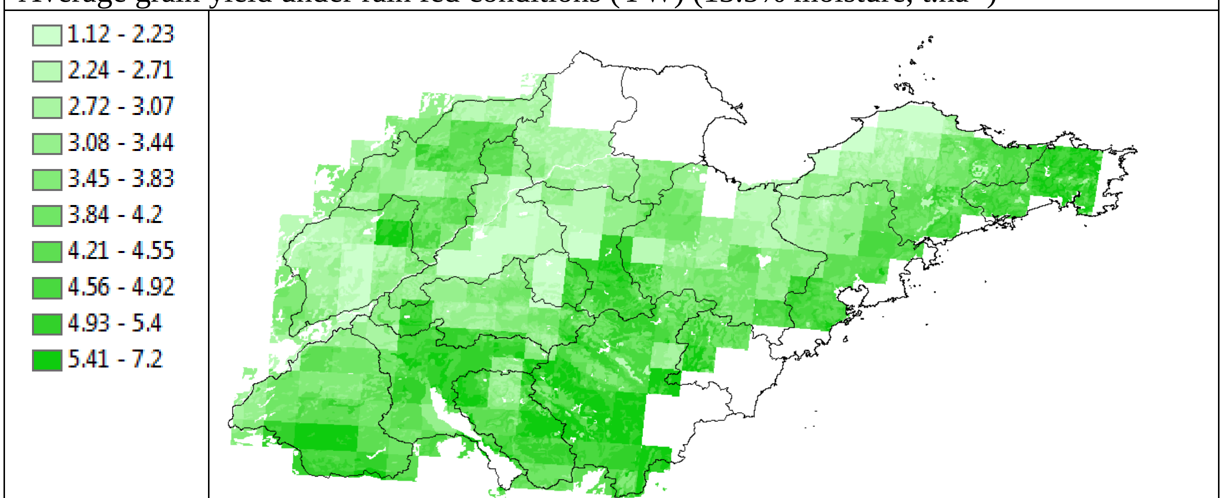
Average grain yield (zero moisture, kg.ha^{-1})



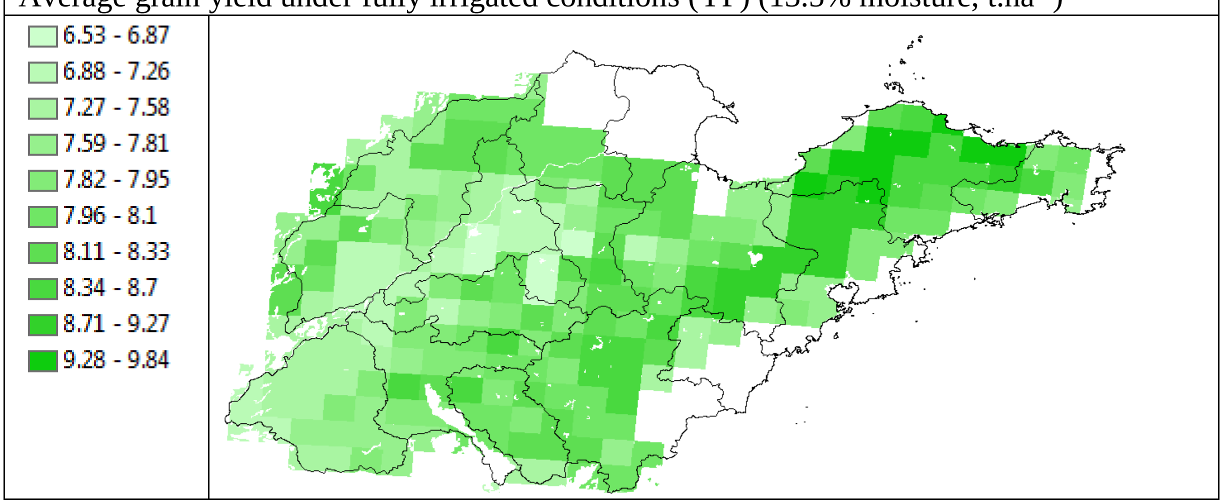
Average harvest index



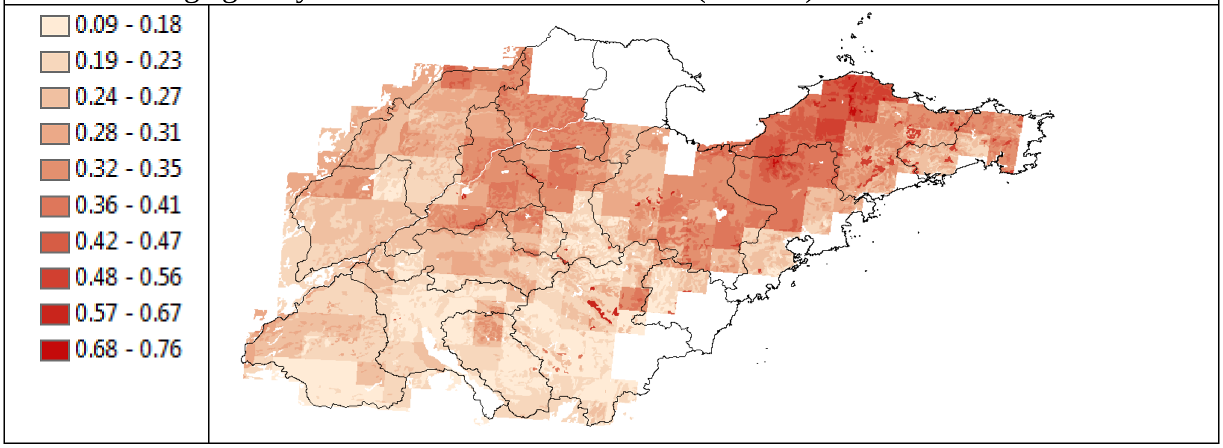
Average grain yield under rain fed conditions (YW) (13.5% moisture, $t.ha^{-1}$)



Average grain yield under fully irrigated conditions (YP) (13.5% moisture, $t.ha^{-1}$)



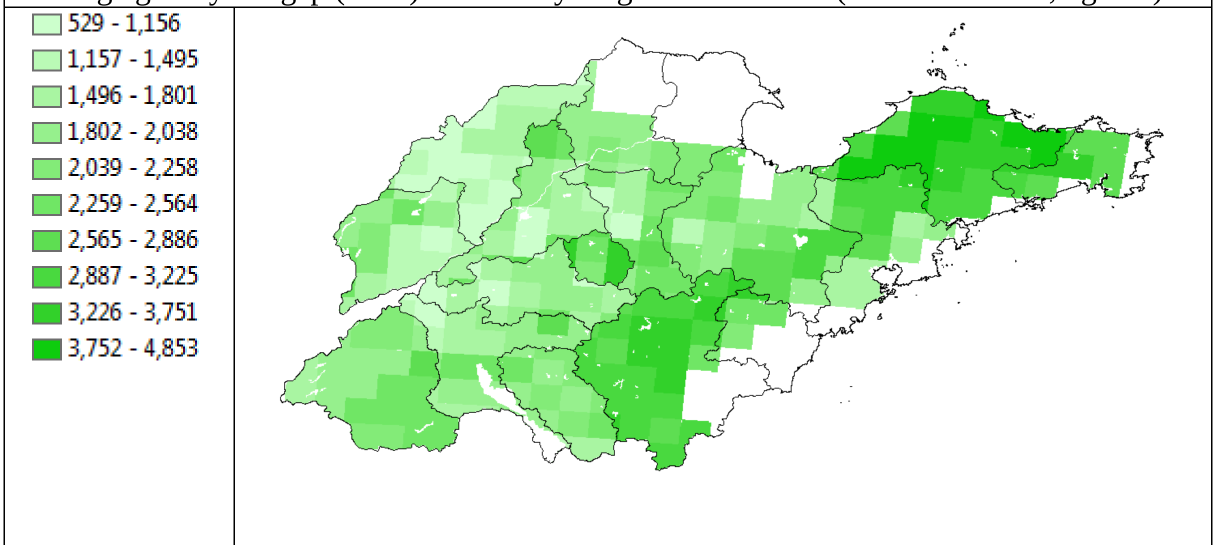
CV of Average grain yield – water-limited / rain fed (fraction)



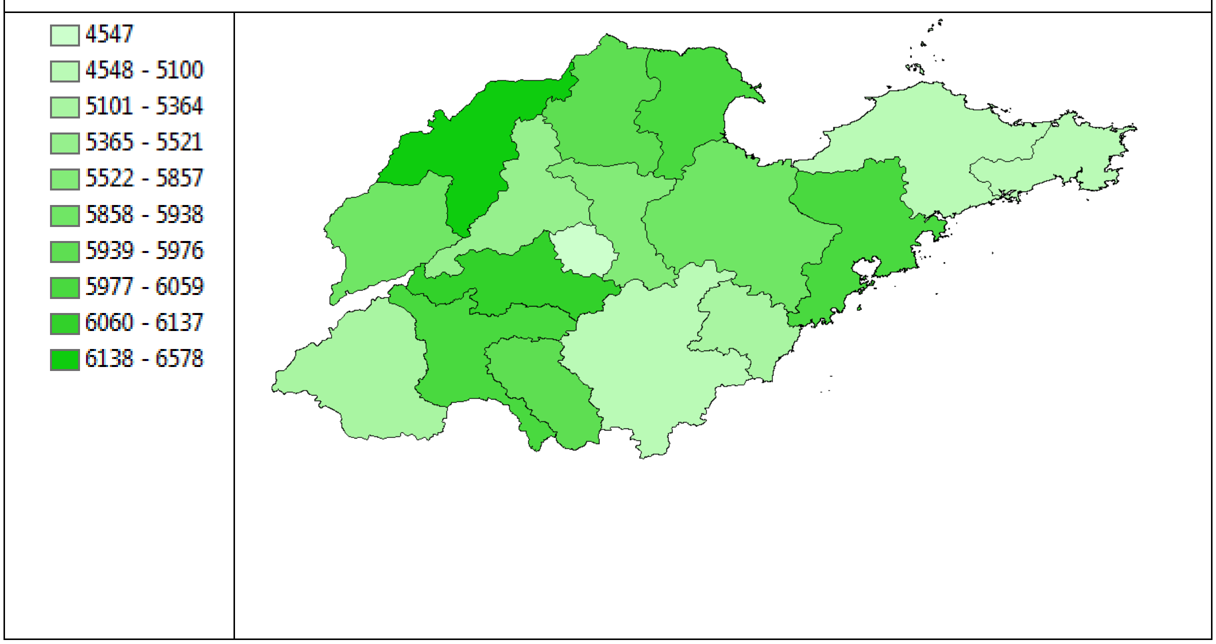
4.6.4. Yield gap under fully irrigated conditions

The actual yield levels vary between 4.5 - 6.5 ton.ha^{-1} (13.5% moisture). Resulting yield gap varies from 4-5 ton.ha^{-1} in the south-east to less than 1 ton.ha^{-1} in the western part. The latter region seems to have a management with sufficient input of water and nutrients while in the south-east yield levels could potential increase. In case water is the limiting factor it must be feasible to further develop irrigation in an economically viable manner. If not such areas should be analyzed against water-limited yields. However simulated yield under rain fed conditions is lower than the actual grain yield indicating that (partial) irrigation takes place.

Average grain yield gap (YGP) under fully irrigated conditions (13.5% moisture, kg.ha^{-1})



Average actual grain yield (YA) (13.5% moisture, kg.ha^{-1}) based on 2000-2013



4.7. Maize

4.7.1. Comparison with calibrated sites

First the simulated yield of the site calibration and the regional implementation has been compared taking the average of the same years.

Name	FID	Grid reference	Regional v1	Regional v2	Calibrated
CZ5203	0	3087148	**6.6**	**7.5**	**7.8**
CZ5403	1	3083152	**6.4**	**7.3**	**7.2**
CZ4403	4	3090160	**7.3**	**7.8**	**7.5**
CZ4603	5	3092166	**7.7**	**8.2**	**8.2**
Yucheng	7	3090152	**6.1**	**7.2**	**7.5**

Main reason for the differences (regional v1 vs calibrated) is that the temperature data used for the calibration differed substantially from the temperature data used in the regional implementation. See section 4.6.1 for more background.

The higher minimum temperature, and associated higher average temperature, leads to biased result and has two effects that both working in the same direction of lower yield levels:

- Accelerated development and thus a shorter crop cycle
- Accelerated leaf senescence

To avoid the differences between the site and regional simulation the most optimal approach is to redo the site calibration using exactly the same weather data sources as the one being used in the regional implementation. Due to project constraints this was not feasible.

All locations have a lower yield in the regional implementation. Largest differences are found for CZ 5203, CZ 5403 and Yucheng. For these zones we changed the following crop parameters:

- TSUM2 increased with 100 degrees, Yucheng with 150 degrees
- SPAN increased with 2 days, Yucheng with 3 days

For the other zones we changed the following crop parameters:

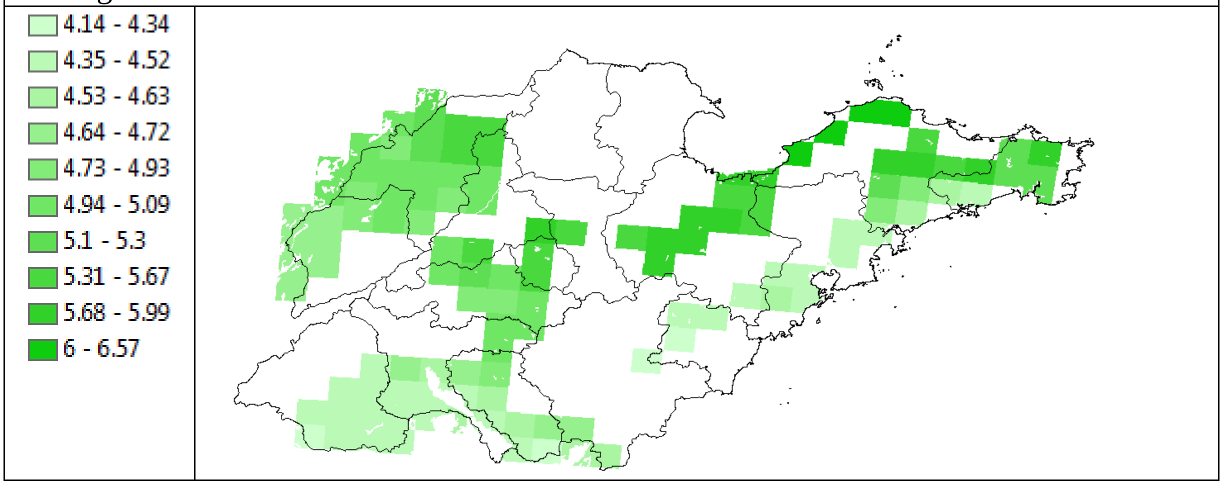
- TSUM2 increased with 50 degrees
- SPAN increased with 1 day

All following results are based on these improvements (regional v2).

4.7.2. Results irrigated run

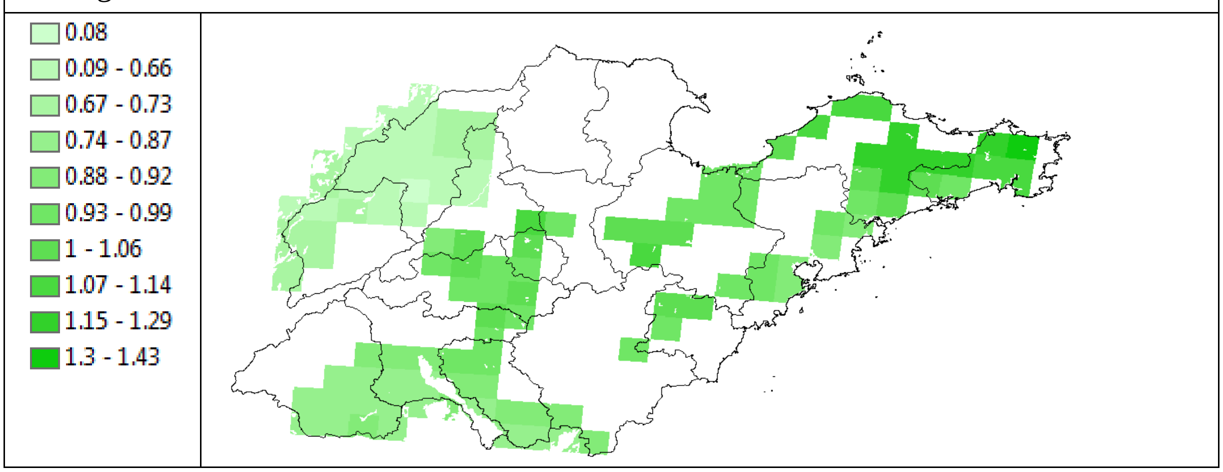
Average maximum Leaf Area Index is in the expected range. The CV values (not shown) are lower 12% thus stable over the years.

Average maximum Leaf Area Index



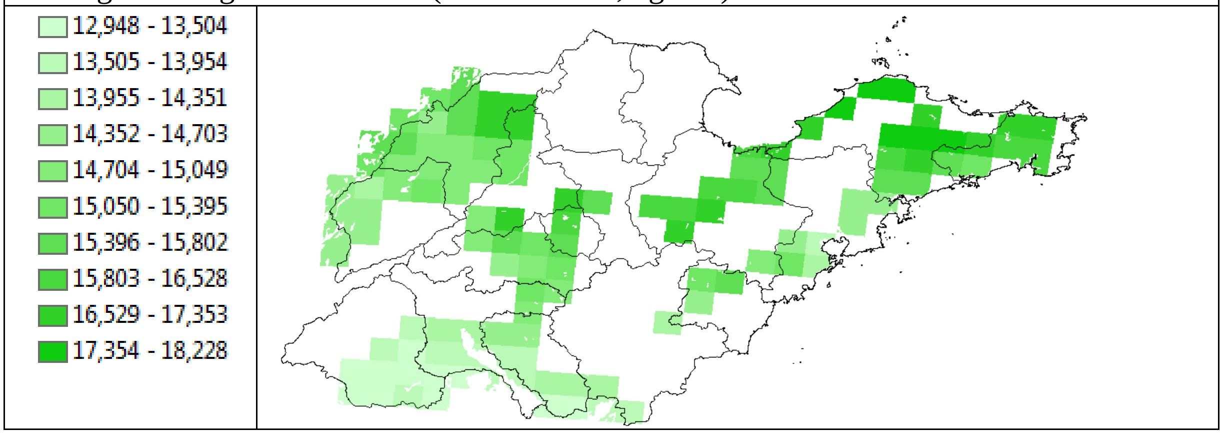
Average final Leaf Area Index is mostly in the expected range except for a few grid cells in the far eastern part with values between 1 and 1.5. The CV values (not shown) are lower than 20% and thus relatively stable over the years.

Average final Leaf Area Index



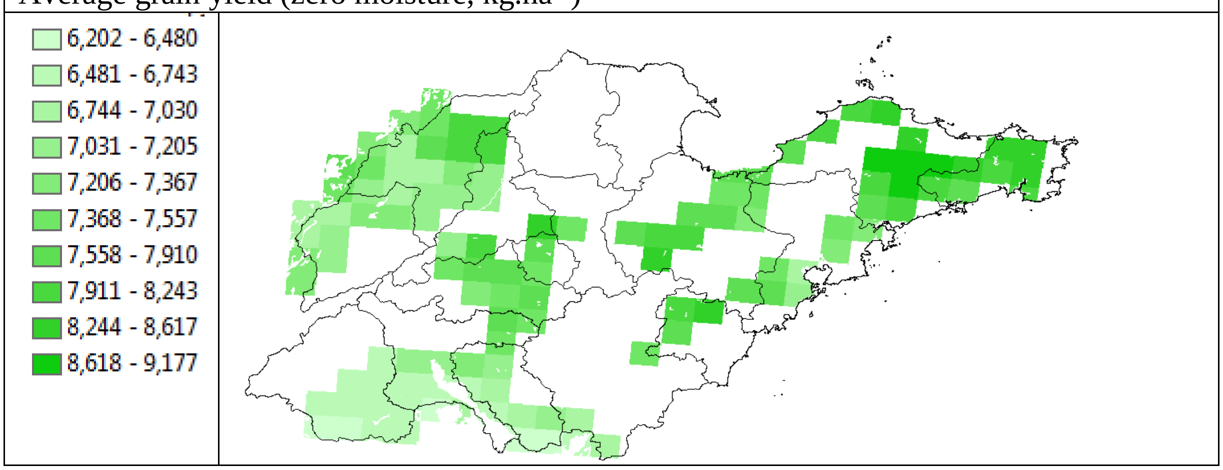
Average above ground biomass is somewhat low with also values starting from 13 ton.ha^{-1}, especially in the south-west; other regions are within the expected range. The CV values (not shown) are lower than 10% and thus stable over the years.

Average above ground biomass (zero moisture, kg.ha^{-1})



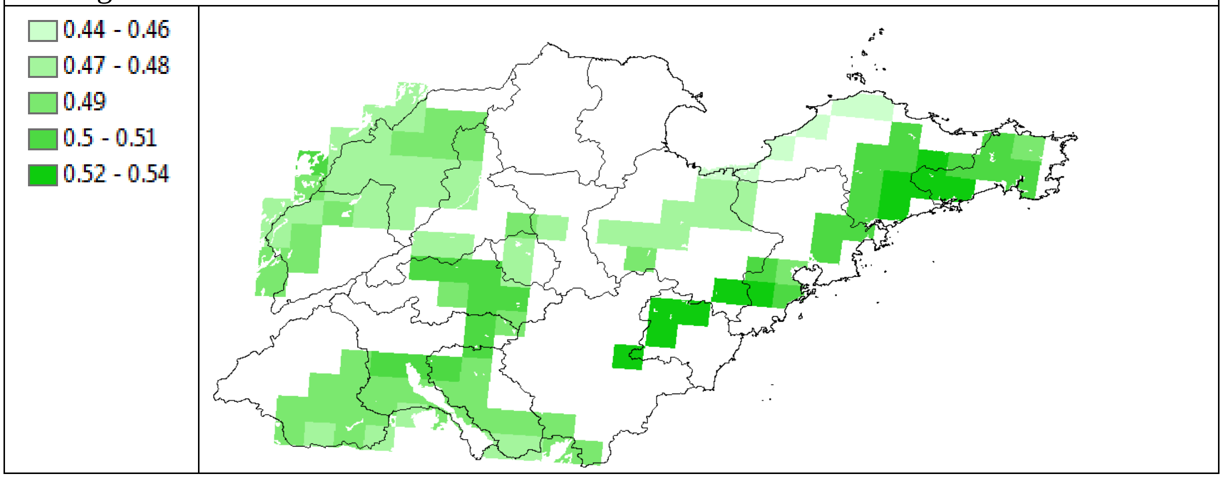
Average grain yield is somewhat low with also values starting from 6 ton.ha^{-1}, especially in the south-west; other regions are within the expected range. The CV values (not shown) are lower than 12% and thus stable over the years.

Average grain yield (zero moisture, kg.ha^{-1})



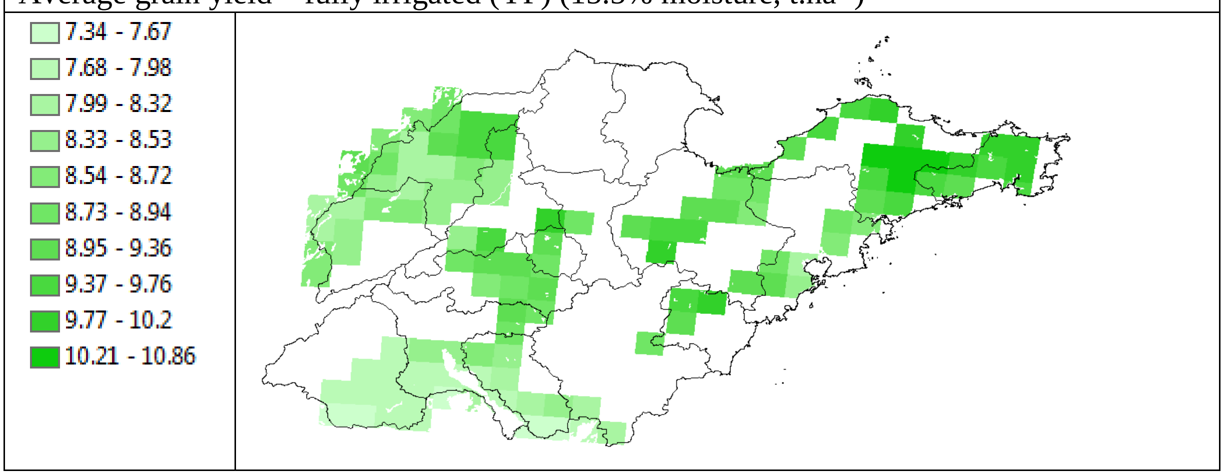
Average harvest index is within the expected range. The CV values (not shown) are lower than 6% and thus stable over the years.

Average harvest index



Average grain yield (15.5%) between 7.3 – 10.9 ton.ha^{-1}.

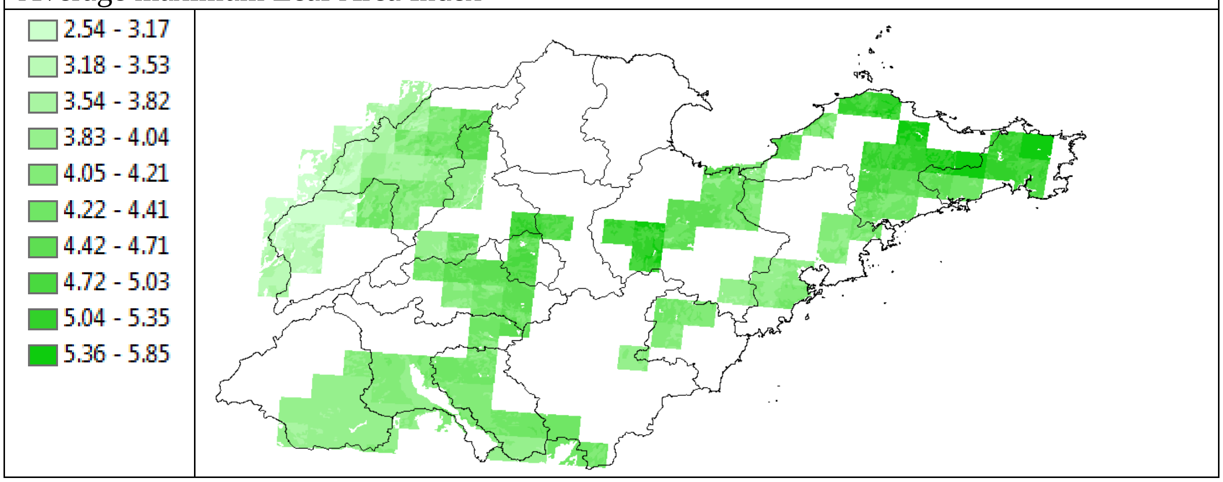
Average grain yield – fully irrigated (YP) (15.5% moisture, t.ha^{-1})



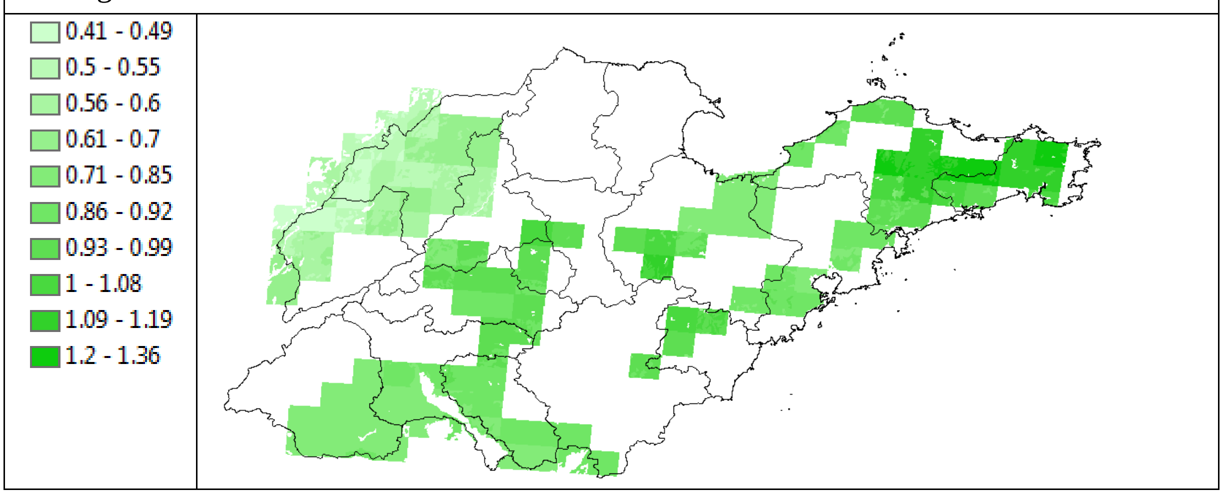
4.7.3. Results water-limited run

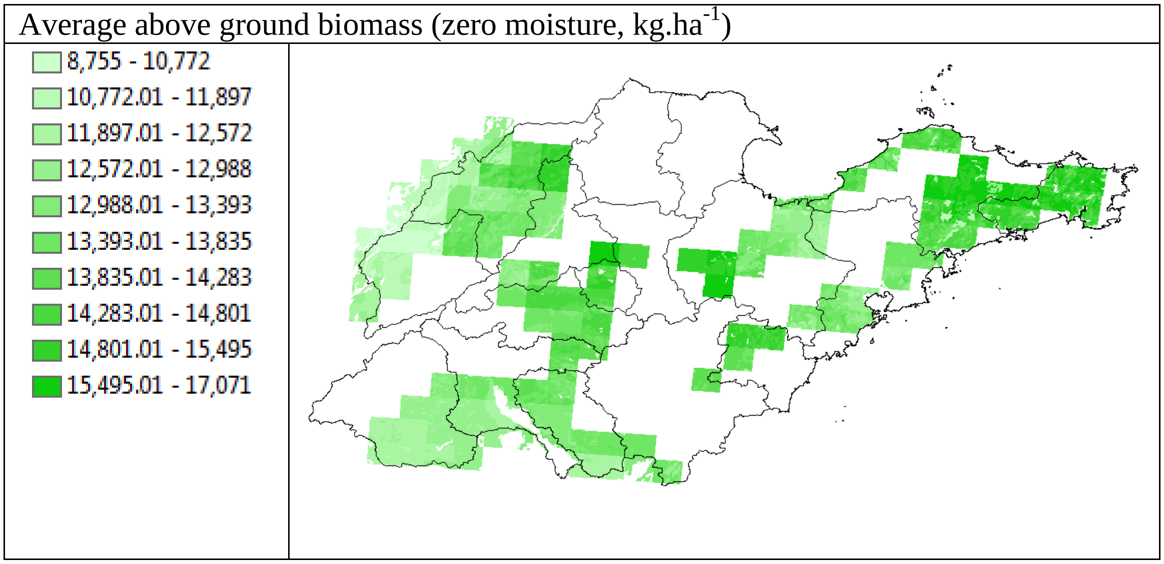
The drought effect is relatively small. On average the water-limited yields are between 0.5 and 1 $ton.ha^{-1}$ lower compared to the run under fully irrigated conditions. The drought effect is largest in the north and north-west. This is also clear in the figure showing the CV of water-limited yield. The yield levels vary over the years with the lowest CV (<20%) in the centre and the south, moderate 20-40% in the east and north, especially on less suitable soils, and the highest CV (>40%) in the north-west.

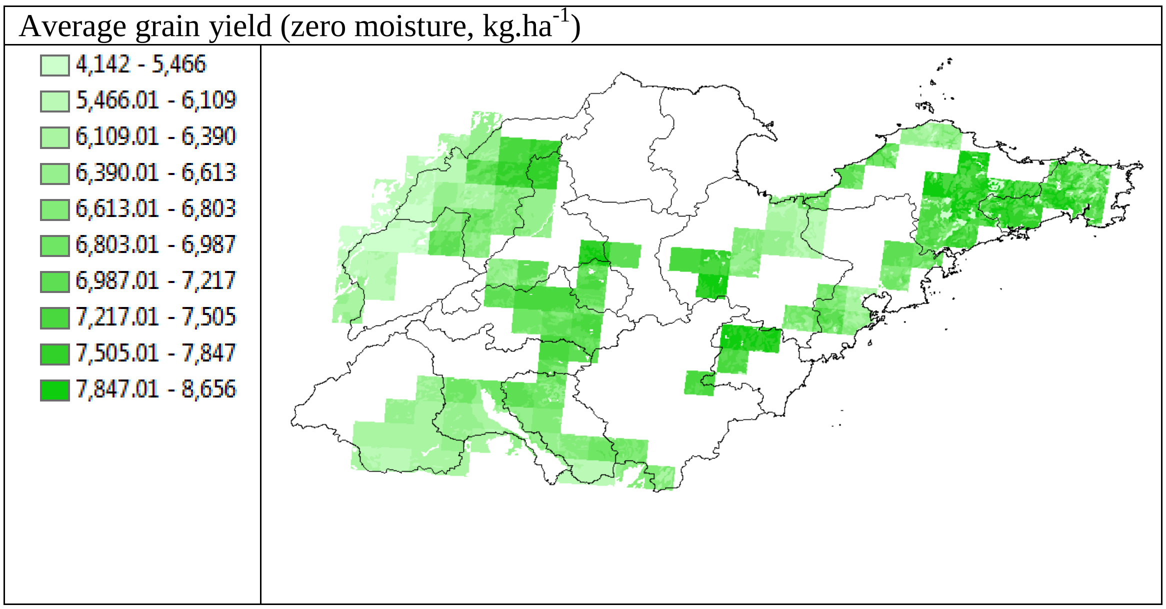
Average maximum Leaf Area Index



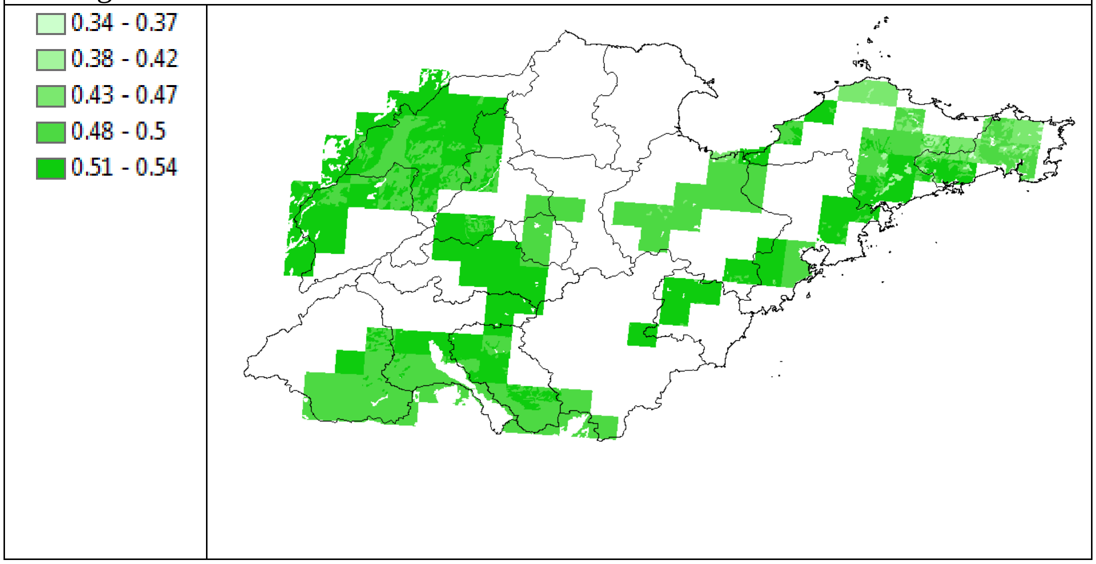
Average final Leaf Area Index




Average above ground biomass (zero moisture, kg.ha^{-1})
8,755 - 10,772
10,772.01 - 11,897
11,897.01 - 12,572
12,572.01 - 12,988
12,988.01 - 13,393
13,393.01 - 13,835
13,835.01 - 14,283
14,283.01 - 14,801
14,801.01 - 15,495
15,495.01 - 17,071

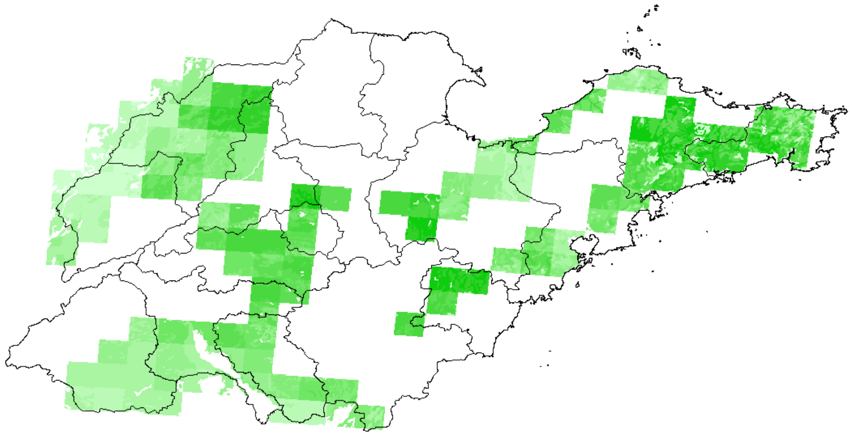

Average grain yield (zero moisture, kg.ha^{-1})
4,142 - 5,466
5,466.01 - 6,109
6,109.01 - 6,390
6,390.01 - 6,613
6,613.01 - 6,803
6,803.01 - 6,987
6,987.01 - 7,217
7,217.01 - 7,505
7,505.01 - 7,847
7,847.01 - 8,656

Average harvest index



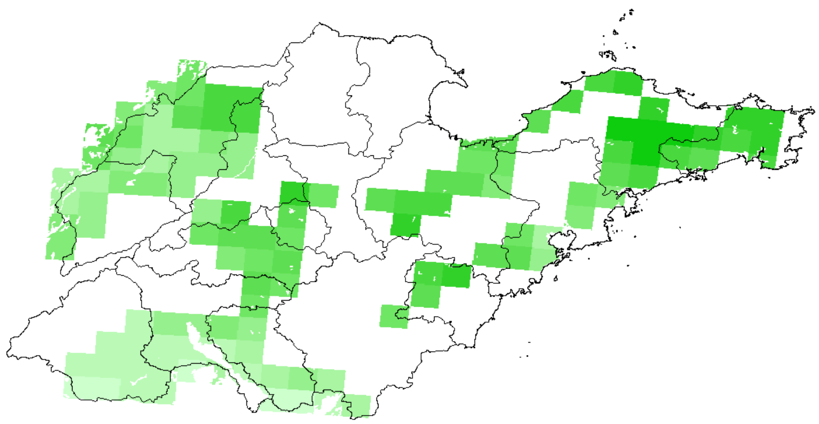
Average grain yield under rain fed conditions (YW) (15.5% moisture, $t.ha^{-1}$)

- 4.9 - 6.47
- 6.48 - 7.23
- 7.24 - 7.56
- 7.57 - 7.83
- 7.84 - 8.05
- 8.06 - 8.27
- 8.28 - 8.54
- 8.55 - 8.88
- 8.89 - 9.29
- 9.3 - 10.24

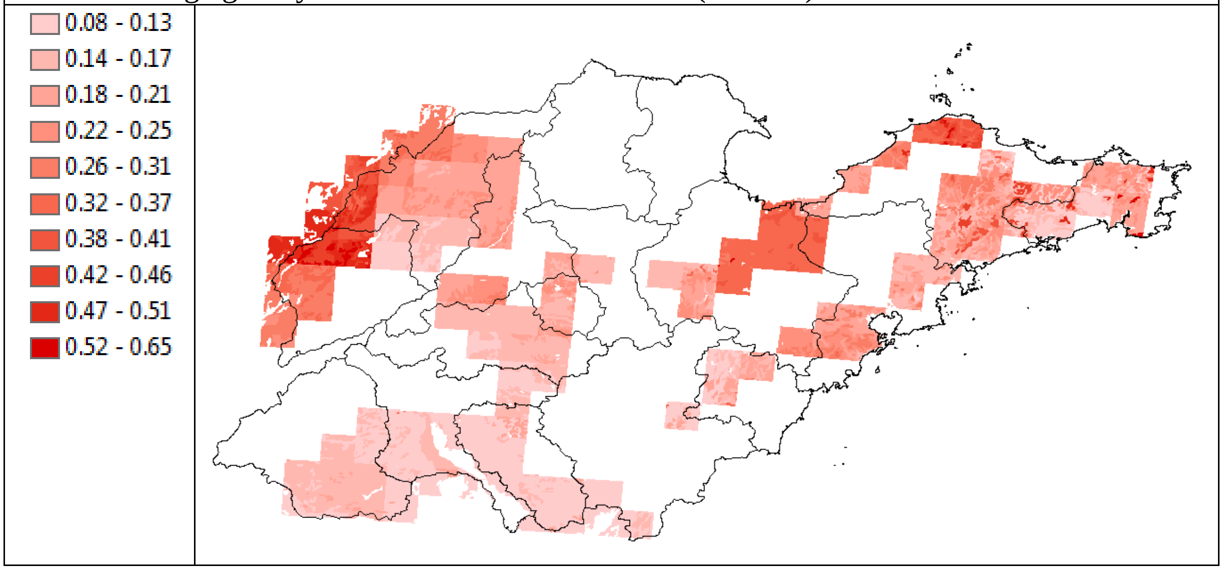


Average grain yield under fully irrigated conditions (YP) (15.5% moisture, $t.ha^{-1}$)

- 7.34 - 7.67
- 7.68 - 7.98
- 7.99 - 8.32
- 8.33 - 8.53
- 8.54 - 8.72
- 8.73 - 8.94
- 8.95 - 9.36
- 9.37 - 9.76
- 9.77 - 10.2
- 10.21 - 10.86



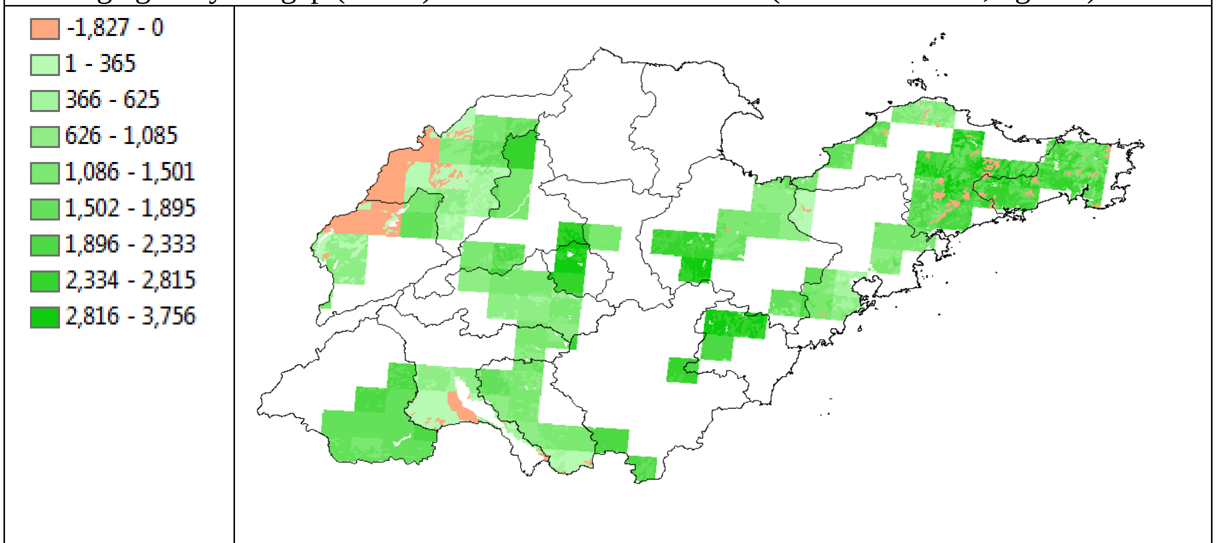
CV of Average grain yield – water-limited / rain fed (fraction)



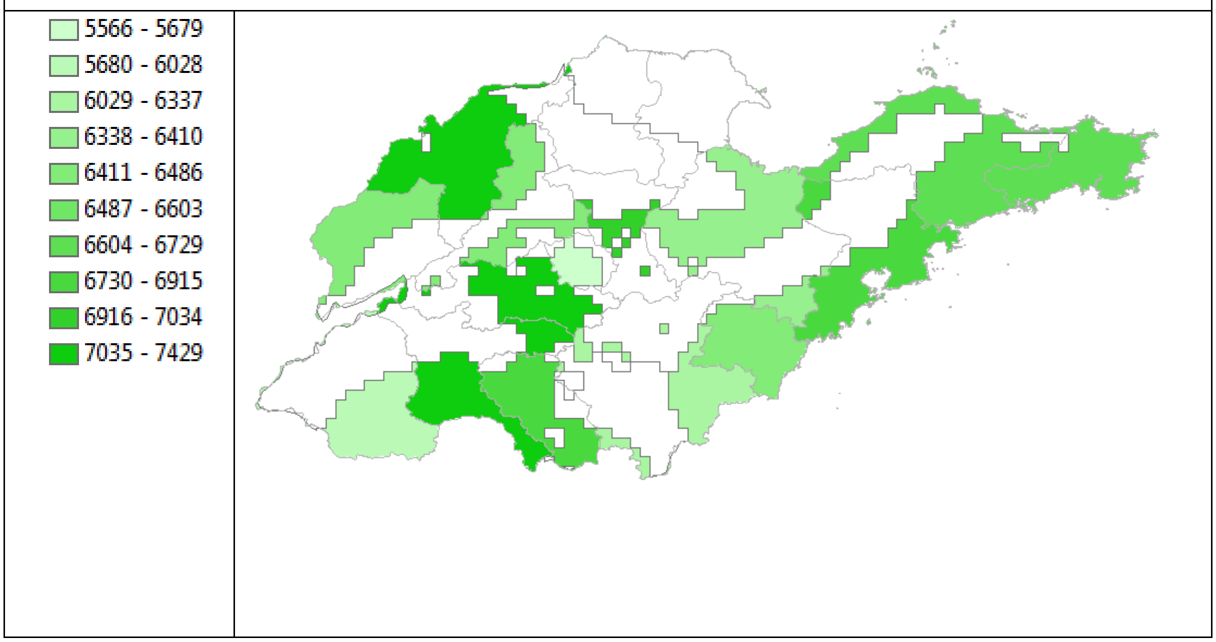
4.7.4. Yield gap under water-limited / rain fed conditions

Actual yield levels vary between 5.5 - 7.5 ton.ha^{-1} (15.5% moisture). Resulting yield gap varies from 0 - 3.8 ton.ha^{-1} with the highest values in the west and centre. A region in the west and some other locations scattered over the province have a negative yield gap due to the low simulated water-limited yield. It is probably caused by lower rainfall amounts in the west and soils with poorer physical properties scattered over the province. In reality some of the regions with drought reduced yields might have irrigation, especially at the start of the growing season. Therefore we also compare with yields under fully-irrigated conditions (see next section).

Average grain yield gap (YGW) under rain fed conditions (15.5% moisture, kg.ha^{-1})



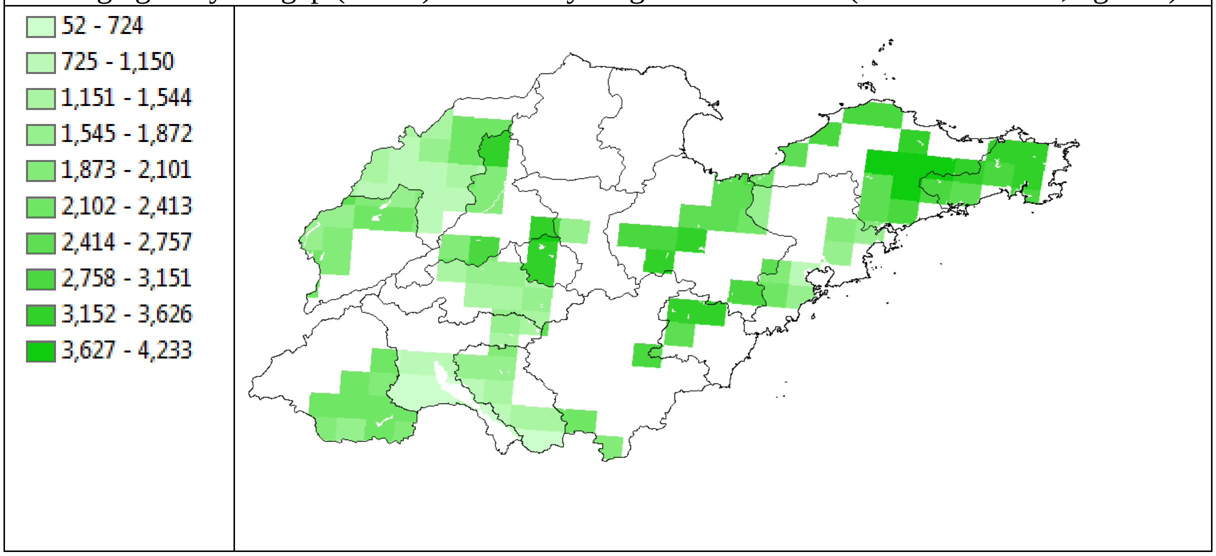
Average actual grain yield (YA) (15.5% moisture, kg.ha^{-1}) based on 2000-2013



4.7.5. Yield gap under fully irrigated conditions

Resulting yield gap varies from 0 - 4.2 ton.ha^{-1} with the highest values in the west and centre. No negative yield gaps anymore. Like winter wheat western part of Shandong shows the most intensive systems while for the eastern part there seems room to optimize cropping systems.

Average grain yield gap (YGW) under fully irrigated conditions (15.5% moisture, kg.ha-^{1})



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Appendix I: Background on climate data

1 NCDC_GSOD

NCDC_GSOD is the daily stations data from NOAA's National Climatic Data Center (NCDC), Global Summary of day data (GSOD)

Temporal resolution: daily
Spatial resolution: station
Download: http://chg.geog.ucsb.edu/index.html
Reference: http://chg.geog.ucsb.edu/index.html

2 JRC_ERA-INTERIM

JRC_ERA-INTERIM data is owned by the MARS AGRI4CAST project of the Joint research Centre (JRC) of European Commission (EC). It is based on the 3-hourly ERA-Interim data obtained from the European Centre for Medium range Weather forecast (ECMWF; Berrisford et al. 2009). The ECMWF ERA-Interim data set is a reanalysis of the global atmosphere of the period 1989 to date. It has a spatial resolution of 0.75 x 0.75 degrees. Due to an improved reanalysis system, ERA-INTERIM has proved to have better performance compared to previous reanalysis data sets such as ERA-40 (ECMWF, 2007). Within the JRC MARS project the data were processed to arrive at daily or 10-daily data (aggregations and bias corrections). First 3-hourly were aggregated into daily data using indicator specific time zones. Next daily data, available at the 0.75 degree grid were downscaled (Inverse distance weight interpolation) to a regular global 0.25 degree grid and afterwards bias corrected. The bias correction between the IDW-interpolated ERA-Interim model and ECMWF operational model data available at the 0.25 degree resolution was done for temperature related elements, radiation and wind speed. The daily data of the ECMWF Operation model, available at the 0.25 degree grid for the period 2008-2010, was used as a training set to determine the bias correction. For rainfall no corrections were applied. The rainfall parameter showed less accurate results in the regression due to its intermittent nature and distribution (see for more information Hartman, 2011).

Temporal resolution: daily
Spatial resolution: 0.25 x 0.25 degree
Download: via JRC (not publicly accessible, but available for SIGMA)
Reference: http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Main_Page

3 NASA_POWER

The POWER project was initiated to improve upon the current Surface Meteorological and Solar Energy (SSE) project data set and to create new data sets from new satellite systems and forecast modeling data. The parameters contained in the agro-climatology archive are based primarily upon solar radiation derived from satellite observations and meteorological data from the Goddard Earth Observing System assimilation model.

Temporal resolution: daily
Spatial resolution: 1.0° resolution
Download: all products can be accessed directly through the dedicated http site: http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov
Reference: NASA (http://power.larc.nasa.gov/common/php/POWER_AboutPOWER.php)

4 JRC_CGMS_CHN

Daily station data of around 300 stations across China main agricultural lands are the basis for the spatial interpolation. Station data covered the main elements except radiation. Radiation was derived from daily minimum and maximum air temperature and day time mean cloud cover via Supit-VanKappel and the Hargreaves models (Supit and Kappel, 1998). To train the models the 50yrRad database of Tang et al. (2013) containing 'modelled' radiation data for 716 CMA stations was used. Daily station data were interpolated to the 25 km grid via the CGMS interpolation method (Lazar and Genovese, 2004).

Temporal resolution: daily
Spatial resolution: 0.25 x 0.25 degree
Download: via JRC (not publicly accessible, but available for SIGMA)
Reference: http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Main_Page

5 CHG_CHIRPS

CHIRPS v2 is a satellite-based rainfall monitoring dataset specifically designed to support trend analysis and seasonal drought monitoring around the world. It is developed as a partnership between the USGS Earth Resources Observation and Science (EROS) Center and the University of California Santa Barbara (UCSB) Climate Hazards. CHIRPS has been supported by funding from USAID, FEWS NET, NASA and NOAA. CHIRPS incorporate satellite imagery with in-situ station data to create gridded rainfall time series.

Temporal resolution: daily
Spatial resolution: 0.25° resolution
Download: all products including the daily data can be also accessed directly through the dedicated ftp site: ftp://chg-ftpout.geog.ucsb.edu/pub/org/chg/products/CHIRPS-2.0
Reference: Funk et al. 2015