Crop Monitoring as an
E-agricultural tool in
Developing Countries

STRATEGY REPORT ON CGMS ADAPTATION FOR MOROCCO

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Disclaimer

The geographic borders shown in this document are purely a graphical representation and are only intended to be indicative. These boundaries do not necessarily reflect the official EU position.

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ACRONYMS & GLOSSARY

AVHRR	Advanced Very High Resolution Radiometer (sensor)
CGMS	Crop Growth Monitoring System (model software)
DMN	Direction de la Météorologie Nationale (organisation)
DMP	Dry Matter Production (indicator)
DSS	Direction de la Stratégie et des Statistiques (organisation)
E-AGRI	an FP7 research project - funded by the EU - designed to support the uptake of European ICT research results in developing economies
INRA	Institut national de la recherche agronomique (organisation)
JRC	Joint Research Centre (organisation)
LINGRA	LINTUL GRAssland (model software)
LINTUL	Light INTerception and UtiLization simulator (model software)
MARS Unit	Monitoring Agricultural Resources Unit (organisation)
MCYFS	MARS Crop Yield Forecasting System (model software)
NDVI	Normalised Difference Vegetation Index (indicator)
RMSE	Root mean squared error (statistical criterion)
SPOT	Satellites Pour l'Observation de la Terre (satellite)
TDWI	Initial total crop dry weight (model parameter)
TSUM	A temperature sum limit reached upon completion of emergence, vegetative or reproductive stage (model parameter)
SPOT-VGT	Vegetation sensor on board of SPOT (sensor)
UniMi	University of Milan (organisation)
VGT	see SPOT-VGT
VITO	Flemish Institute for Technological Research (organisation)
WOFOST	World Food Studies (model software)

EXECUTIVE SUMMARY

One of the target countries of the e-AGRI project is Morocco, which has an agricultural production system for cereals which is largely rainfed, is dominated by low yielding cereal production and which is highly vulnerable to fluctuations in rainfall. Crop yield forecasting systems could play a significant role to reduce the vulnerability of the Moroccan agriculture to weather risks in the framework of a food security strategy. They could help policy-makers planning in advance for food imports when necessary at best price on international market. The e-AGRI project intends to develop, implement and improve a crop monitoring and yield forecasting system for the Moroccan territories based on the expertise available among several European and Moroccan institutes.

Although a large part of the Maghreb region is also included within the European window of the MARS Yield Forecasting System, it was found that the current performance of CGMS for Morocco is highly unsatisfactory. We concluded that the assumptions on model setup and water balance initialisation in the European CGMS are not valid anymore for the semi-arid climate of Morocco. To improve this we recalibrated the phenological parameters of the model and developed a new initialization strategy for the water balance. Next, we tested the new approach using the Moroccan crop yield statistics at national, regional and provincial level.

The results demonstrate that the adapted CGMS using the new crop calendar, new WOFOST phenological parameters and adapted water balance initialization performs considerably better than MCYFS in explaining the yield variability for Morocco over the period 1999-2010. R^2 values at national level increased from 26% to 75% for durum wheat and from 16% to 65% for soft-wheat. Nevertheless, the remote sensing based yield predictors still outperform CGMS in terms of correlation with reported regional crop yields in most cases.

Further improvements are expected from improved data sources (soil map, weather data) that are available from the Moroccan partners and possibly the use of a variable sowing date taking into account rainfall variability.

1. Introduction

Information on the outlook of yield and production of crops over large regions is essential for government services dealing with import and export of food crops, for agencies with a role in food relief and for international organizations with a mandate in monitoring the world food production and trade. Recent development show that unbalances in the global production of agricultural commodities due to co-occurrence of shortfalls in harvests causes the marked prices of agricultural commodities to peak. These events sparked widespread concern about global agricultural production. Moreover, increased demand for dairy, meat and biofuel products, which require cereals and oil crops, will increasingly compete with the demand for food crops.

In Europe, the necessity for monitoring agricultural production and prediction of crop yield has long been recognized and implemented through the MARS Crop Yield Forecasting System (MCYFS) operated by the Joint Research Centre (JRC). The MCYFS consists of several components such as statistical tools, satellite data processing and a system for weather data collection/processing and crop simulation. The latter is called the Crop Growth Monitoring System (CGMS) and includes the WOFOST and LINGRA crop growth models for simulation of annual crops and perennial grasses.

One of the target countries of the e-AGRI project is Morocco, which has an agricultural production system for cereals which is largely rainfed, is dominated by low yielding cereal production and which is highly vulnerable to fluctuations in rainfall. As a result, Morocco currently imports 50 percent of its cereal needs. Moreover, Morocco is predicted to become drier and hotter in the future, placing increasing stresses on both rainfed and irrigated production. Moreover, climate change in Morocco could raise concerns about food security and further reduction in cereal yields could lead to increasing dependence on food imports. This would make Morocco more vulnerable to increasingly volatile international food prices.

Crop yield forecasting systems could play a significant role to reduce the vulnerability of the Moroccan agriculture to weather risks in the framework of a food security strategy. They could help policy-makers planning in advance for food imports when necessary at best price on international market. They could in addition enhance the new multi-risk insurance system that the Moroccan government attempts to promote in rainfed cereal areas.

The e-AGRI project intends to develop, implement and improve a crop monitoring and yield forecasting system for the Moroccan territories based on the expertise available among several European (VITO, Alterra, JRC, UniMi) and Moroccan institutes (DSS, INRA and DMN). The Moroccan institutions are working together to implement the Crop Growth Monitoring System for Morocco. Finally, the implementation of the Crop Growth Monitoring System must be operational for the Moroccan territories for crop monitoring and yield forecasting of the cereal yields in Morocco.

Although a large part of the Maghreb region (including the northern part of Morocco) is also included within the European window of the MARS Yield Forecasting System (including CGMS), it was found that the current performance of CGMS for Morocco is highly unsatisfactory. The CGMS produces several outputs among which the simulated crop biomass estimates are the most important: these include the total biomass and yield under potential production conditions (no water-stress) and the total biomass and yield under water-limited conditions. Table 1 shows the correlation coefficient (R) between the time-series of the late season simulated biomass values (aggregated to national level) and the reported yields from the Moroccan statistical office at national level. It is evident that the correlation is low (<0.4) which implies that the CGMS results from the European setup will not be useful for yield prediction in Morocco. Instead, a simple yield indicator as "cumulative rainfall September to May" already yields a correlation coefficient of 0.777 (durum wheat) and 0.729 (soft-wheat).

Table 1: Correlation coefficients for the national level, period 1992-2011

Indicator no.	Indicator name	Durum wheat	Soft wheat
1	Potential Above Ground Biomass	-0.095	-0.029
2	Potential Storage Organs	-0.157	-0.148
3	Water Limited Above Ground Biomass	0.374	0.368
4	Water Limited Storage Organs	0.398	0.344
5	Cum. rainfall September to May	0.777	0.729

Based on this result we concluded that some of the assumptions in model setup that underpin the European CGMS are not valid anymore for the semi-arid climate of Morocco. In fact there are several poor assumptions that are likely to cause the poor performance in Morocco.

First of all, winter-wheat growth in the European CGMS is parameterized to start at the 1^{st} of January instead of on the real sowing date in September/October. This decision was taken during setup of the CGMS in the 1990-ies because it was found that the results of WOFOST were inaccurate because the model did not take the effects of vernalization into account (Boons-Prins, 1992). Instead it was found that the results improved when the model was simply started on the 1^{st} of January with a relatively high initial biomass. However, the wheat cultivars in Morocco cannot be regarded as real winter-wheat cultivars because they lack a clear period of dormancy during the winter period. Instead they should be regarded as spring-wheat cultivars which grow during the "Moroccan winter period" because of the favourable climatic conditions. Simulation of wheat in Morocco should therefore be re-parameterized to start at the real sowing date which is usually from 15 November to 25 December depending on the weather. Of course, this is an adaptation to the prevalent weather conditions. Figure 1 shows typical median rainfall and average temperature for Morocco from 1987 to 2004 (from Balaghi et al. 2008). As can be seen, the cropping season spans over two calendar years. It starts around October-November and finishes around May-June, depending on rainfall pattern, latitude and elevation.

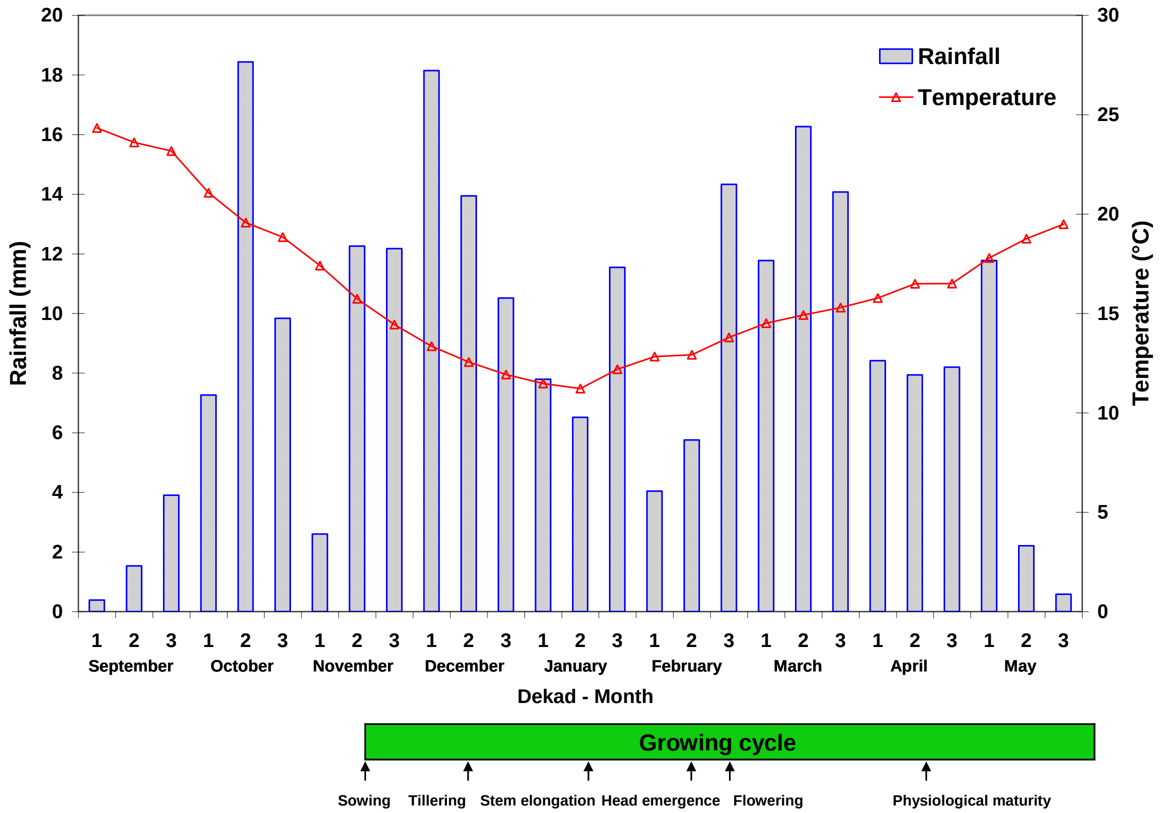


Figure 1: Typical weather conditions during the wheat growing cycle in Morocco

Second, the initial conditions of the soil water balance are probably strongly influencing the results of the WOFOST simulations in Morocco. In the European CGMS it is assumed that the amount of water available at the start of the simulation equals the field capacity of the soil. This is usually not such a poor assumption given the relatively wet winter period in much of Europe in combination with low evapo-transpiration rates which provide ample time to accumulate water in the soil. However, in Morocco this assumption is not valid anymore because the rainfall pattern is much more erratic and has much stronger inter-annual variability (Figure 2) and evapo-transpiration is higher too. Therefore, there will be years with sufficient rainfall to reach field capacity and many others years where this will not be the case. Therefore another initialization strategy must be sought. As far as Figure 2 is concerned: please note the different vertical scales that were used. Furthermore, it should be realised that compared to rainfall in the Netherlands, rainfall in Morocco is less evenly distributed over the season.

Figure 2: Cumulative rainfall over the period 1 September to 1 January over all available years (1975-2012, ordered by rainfall sum) for three areas in Morocco and one in the Netherlands (lower right).

Finally, CGMS simulation results of individual grid cells have to be aggregated to provinces and national level in order to be useful for yield prediction. In the European setup, the aggregation of CGMS results to regional is partially being carried out using soil suitability rules as a proxy for land cover. It is questionable whether this approach works well for Morocco given that large parts of the country are semi-arid. We expect that it will be beneficial to use an arable land mask derived from generally available land cover products to mask only those area which are relevant for agricultural production.

To improve the CGMS results for Morocco, we carried out the following steps:

1. A short analysis on the initialization strategy for the water balance in Morocco.
2. A calibration of the phenological parameters in the WOFOST model in order to start the model on the true sowing date instead of the 1^{st} of January.
3. A short analysis on the distribution of the representative sowing date over the country in order to define the crop calendar.
4. Building an implementation of CGMS for Morocco based on the European setup with improved water balance initialization and crop calendar.
5. Testing the new crop indicators against the Moroccan crop yield statistics and national and regional level.

This document describes the results obtained from the steps above.

2. Data and methods

2.1. Weather and soil data

Weather and soil data were based on the European CGMS setup which also covers the northern part of Morocco. This includes weather data interpolated to 25km grid cells based on 22 stations in Morocco. The soil map is derived from the European soil map 1:1,000,000.

2.2. Crop experimental data

Crop experimental data were provided by INRA and consisted of crop calendars and yields for several cultivars of soft-wheat and durum-wheat over the period 2000-2005 for several experimental stations in the country, located in sub-humid and semi-arid environments. These data were derived from previous monitoring projects. For a better description, see section 2.4 in the Usability Report (D22.1).

The raw crop experimental data contain many observations which are incomplete or unclear (e.g. missing or unclear sowing, flowering or maturity date) and these cannot be used for calibration. Table 2 shows the locations and years for which we received complete and unambiguous data for durum wheat (DW) and soft wheat (SW) that were available for the calibration.

Table 2: Location and years of complete datasets for durum wheat (DW) and soft wheat (SW)

Locations \ Seasons	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005
Jemaa Shaim		DW, SW	DW		DW
Khemiss Zemamra		DW	DW		
Merchouch		DW, SW	SW		DW
Sidi Allal Tazi		SW		SW	
Sidi El Ayedi		DW	DW	DW	
Tassaout	SW	DW, SW	DW	SW	DW

2.3. Calibration WOFOST phenological parameters

The calibration involved the WOFOST parameters TSUM1 and TSUM2 which define the temperatures sums to go from emergence to flowering and from flowering to maturity. The value of 110 degree days for TSUMEM (sowing to emergence) was copied from existing datasets for spring-barley, as we expected to gain very little from calibrating this

parameter. In the crop growth simulations done for Europe, the TSUMEM is normally set to zero in order to compensate for fact that emergence that occurred in the previous calendar year is neglected. Furthermore, initial total biomass for Europe - as reflected by parameter TDWI - is normally set to 210 kg per ha - much higher than the actual amount of seed used for the same reason. For Morocco, TDWI was set to 60 kg per ha.
The calibration was started with Karim durum wheat and Achtar soft wheat as the most important varieties in use in Morocco. A few simulations were done with the WOFOST crop growth model and the results were plotted each time for visual interpretation, until the results were considered satisfactory. The received data did not actually include data about dates that flowering was observed, but rather dates that heading was observed. Flowering dates were estimated by adding 1 week to the heading dates.
Sowing dates for durum wheat were not included in the data either, but these were estimated by subtracting the provided “days to maturity” from the maturity date – at least for those records for which the difference between “maturity date” and “heading date” did not differ more than 5 days from the difference between “days to maturity” and “days to heading”. The obtained sowing dates fell in the period November 23 to December 14.
It was observed that for experiments with durum wheat carried out in so-called Block 1, the sowing dates were the same per location and per year. However, data rows for Block 2 and 3 concerned experiments with very different, rather early or rather late sowing dates. These data rows were therefore discarded – they were only few anyway. For soft wheat, the sowing dates were also the same per location and per year. This allowed us to do one simulation of crop growth per variety per location per year.

The TSUM1 parameter was optimised for both crops (individually) by means of an automated process. This process involved the simulation of potential crop growth, meaning that crop water supply was assumed ideal for the moment. A least squares criterion was used to select the optimum TSUM value. In other words, the differences between observed and simulated dates were squared and the squares were added together, then the TSUM value with the lowest sum of squares was accepted as the optimum one. The root mean squared error or RMSE for most optimizations was approx. 11 days. Data were used for the durum wheat varieties Karim, Oum Rabia, and Tomouh and for the soft wheat varieties Achtar, Kanz, Massira, Arrehane and Mehdia. First, the parameter TSUM1 was optimised for each of these varieties separately. Once the optimum values for TSUM1 were established, the optimization of the TSUM2 parameter could also be performed.

2.4. Analysing the water balance initialization

Simulating water-limited growth involves simulating the soil water balance. Ideally, the initialization of the moisture level is done in such a way that the assumed initial moisture level itself will not affect the actual crop growth during the actual growing season. In most of Europe, it does not matter whether one assumes a dry soil or a wet soil when starting the simulation: the autumn and winter is always so wet that the moisture level reaches field capacity by December 31. In other words, the simulated moisture level of the dry soil case and the simulated moisture level of the wet soil case converge towards field capacity, which means that it is a valid to assume field capacity by December 31. An example of water balance convergence for Wageningen (Figure 3) shows that indeed with a completely dry soil, the soil water balance will converge to a stable soil moisture level for almost all years when started on the 1st of September.

Selecting the best option for the water balance initialization for Morocco was carried by analysing time-series of the WOFOST soil water balance for selected locations and soil types. The WOFOST model was parameterized with the optimized parameter values for TSUM1 and TSUM2 and started on a representative sowing date. Next the simulation was carried out for the period 1980 – 2010 with different initial conditions for soil moisture and lag period. Next, it was analysed whether a setup could be found where the soil water level converged towards a stable value around crop sowing.

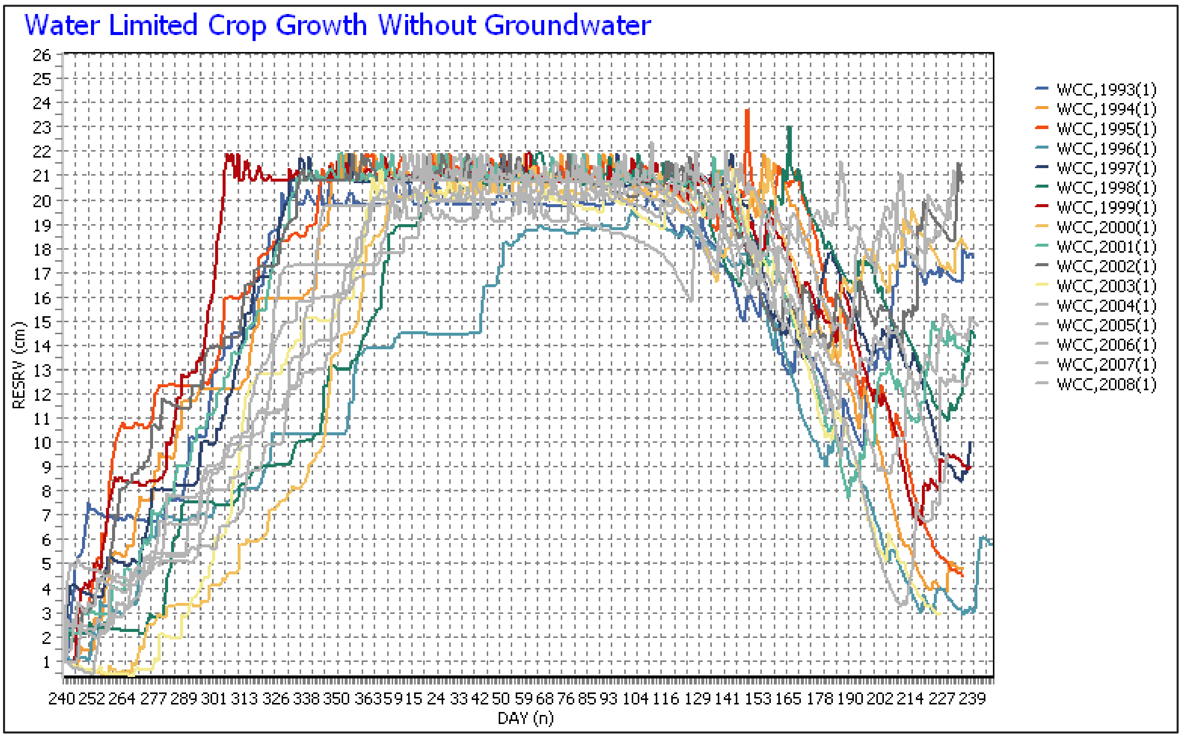


Figure 3. Amount of soil moisture through time for 15 years of simulation of winter-wheat in Wageningen starting the water balance at the 1st of September with a completely dry profile.

2.5. Setting up and testing the improved CGMS

For setting up the improved CGMS, the entire setup regarding weather and soil data were copied from the European CGMS and there will not be discussed here. The following changes were applied:

- The crop calendar was adapted to start the simulation for soft-wheat and durum wheat at the 1st of December (fixed sowing) for each year.
- The crop parameter values were adapted with the updated values for TSUM1 and TSUM2. As not all varieties could be used, we applied the parameters found for the cultivars Karim (durum wheat) and Achtar (soft wheat). Furthermore, the initial total biomass was set to 60 kg/ha which is representative for wheat at sowing.
- The initialization of the water balance was changed: the water balance was started at the 1st of June (before the crop starts) with a completely dry soil profile.
- A new regional division was introduced because the regional division of Morocco that is used in the MCYFS is different from the one used in Morocco itself.
- The spatial aggregation scheme was adapted: simulation results for the 25km grid cells were aggregated to provinces using the arable land mask using the count of arable land pixels per grid as a weight factor. Next aggregation towards agro-zones and national level was done using crop-specific information about cultivated area. A map of the used agro-ecological zones can be found in Annex 1.

Finally, the new CGMS crop yield indicators at national level were tested against the reported crop yield statistics at national, regional and provincial level over the period 1999-2010 using ordinary regression. The period used here was dictated by the available of the satellite archive from SPOT-VEGETATION which starts in 1999.

3. Results

3.1. Calibration of TSUM1 and TSUM2 parameters

Phenological data from experiments conducted in the years 2000 to 2005 in 8 different experimental stations of the Moroccan government were used to calibrate the WOFOST crop growth model for durum and soft wheat. The calibration especially involved the parameters TSUM1 and TSUM2. These govern the development of the simulated crop during the vegetative stage and the reproductive stage.

The calibration was started with Karim durum wheat and Achtar soft wheat as the most important varieties in use in Morocco. A few simulations were done with the WOFOST crop growth model and the results were plotted each time for visual interpretation, until the results were considered satisfactory. The received data did not actually include data about dates that flowering was observed, but rather dates that heading was observed. Flowering dates were estimated by adding 1 week to the heading dates.

Afterwards the TSUM1 parameter was optimised further for both crops by means of an automated process. A least squares criterion was used to select the optimum TSUM value. In other words, the differences between observed and simulated dates were squared and the squares were added together, then the TSUM value with the lowest sum of squares was accepted as the optimum one. The root mean squared error (RMSE) for most optimizations was approx. 11 days. Data were used for the durum wheat varieties Karim, Oum Rabia, and Tomouh and for the soft wheat varieties Achtar, Kanz, Massira, Arrehane and Mehdia. First, the parameter TSUM1 was optimised in steps of 25 degree-days for each of these varieties separately. Once the optimum values for TSUM1 were established, the optimization of the TSUM2 parameter could also be performed.

The results of the optimization demonstrate that the optimized TSUM1 and TSUM2 parameters (Table 3) are quite different from the ones used in the MCYFS for Morocco where values of TSUM1=800 and TSUM2=1100 are used. The parameter values differ somewhat between wheat cultivars and the three durum wheat cultivars tend to have a slightly smaller total TSUM (average: 2100 degree days) compared to the soft-wheat cultivars (average: 2170 degree days).

Figure 4 shows the scatter plots of observed and simulated flowering and maturity dates for the Achtar and Karim wheat cultivars. It is clear that the variability in the observed flowering and maturity dates can only for a relatively small part be explained with the simulations.

Table 3. Optimum values for selected parameters.

Cultivar	Cultivar name	TSUM1	TSUM2	TSUM1 + 2
1	Karim durum wheat	1400	750	2150
2	O.Rabia durum wheat	1300	750	2050
3	Tomouh durum wheat	1350	750	2100
	Average durum wheat	*1350*	*750*	*2100*
4	Achtar soft wheat	1450	775	2225
5	Kanz soft wheat	1375	875	2250
6	Massira soft wheat	1375	800	2175
7	Arrehane soft wheat	1325	825	2150
8	Mehdia soft wheat	1325	725	2050
	Average soft wheat	*1370*	*800*	*2170*

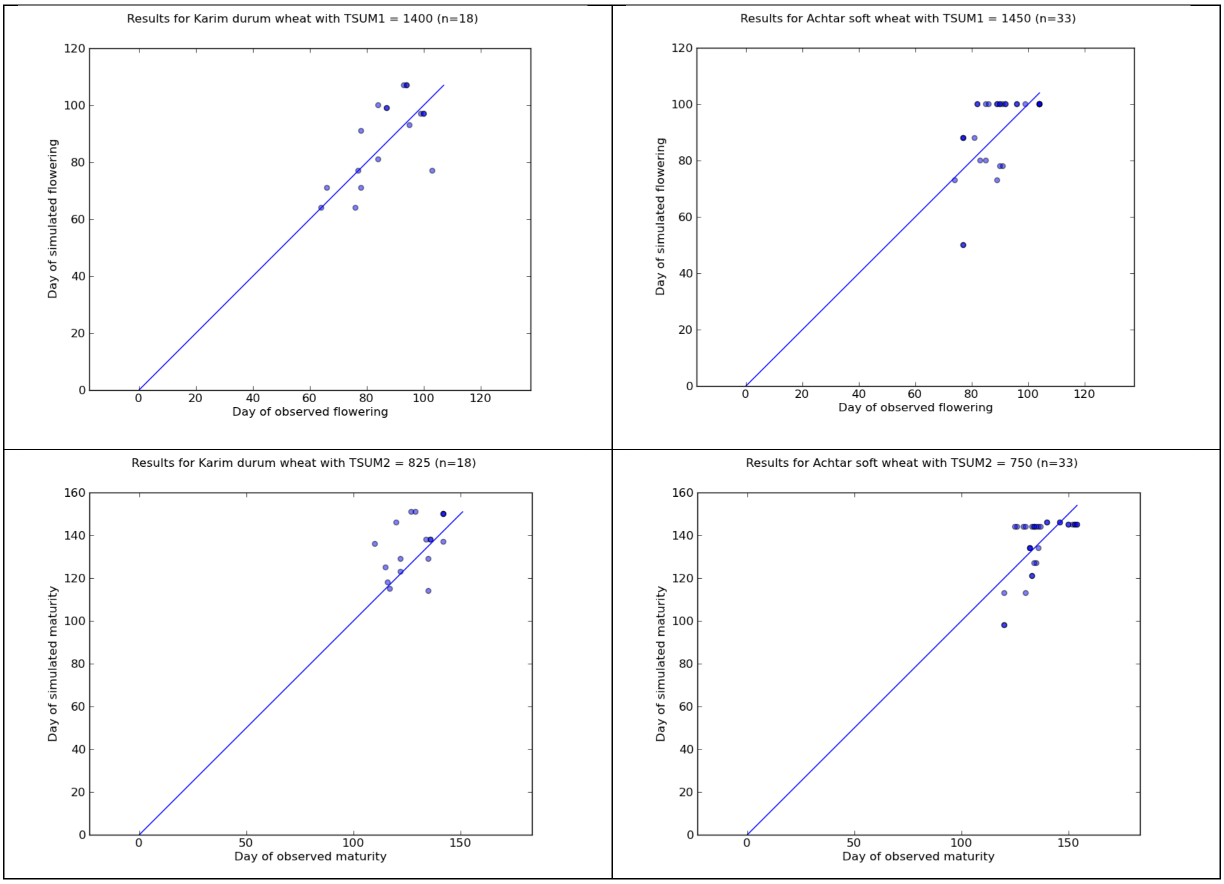
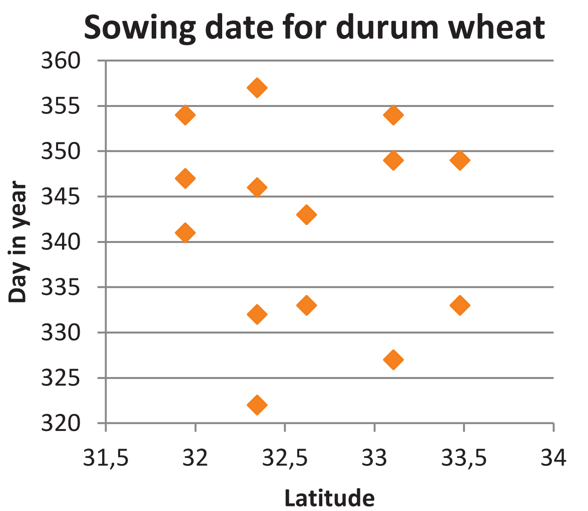


Figure 4: Scatter plots of observed vs. simulated flowering (top) and observed vs. simulated maturity dates (bottom) for the Karim durum wheat (left) and Achtar soft wheat (right) cultivars. Blue line indicating the 1:1 line

Also in the Achtar soft-wheat there is quite some variability in observed dates which cannot be explained by the simulations as is indicated by the “horizontal” stripes in the chart. This is the result of variability in phenology in different treatments at a single station possibly due to different management. For example, water stress in some treatments can accelerate phenological development. However, WOFOST only provides a single estimate of the flowering/maturity date.

3.2. Regional distribution of crop sowing date

For setting up CGMS a spatially distributed sowing date must be defined. In practice, the sowing dates will vary as a result of weather, logistics and local practices but currently we assume a fixed sowing for all years of simulation. In Morocco there is north-south gradient in rainfall pattern and therefore an N-S pattern in sowing dates may exist. In order to observe this pattern, we made a small analysis whether we could discover any trends with latitude in the observed sowing dates from the experimental data (Figure 5). Our conclusion was that such a trend cannot be proven with the currently available data. Therefore a fixed sowing date at December 1st was used.



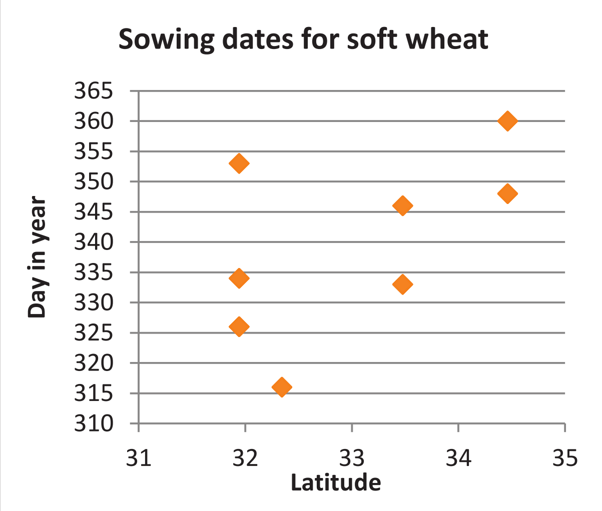


Figure 5: Variability of sowing date with latitude.

3.3. Water balance initialization

In our research, we tested whether we could initialize the soil water balance in a way that is appropriate to the Moroccan situation. This was done for durum wheat at Tassaout in the semi-arid area of Morocco as well as for soft wheat at Sidi Allal Tazi in the sub-humid area. The sowing dates for both durum and soft wheat were set on December 1. The results demonstrate that even when starting the water balance 6 months before the crop sowing (June 1), the soil moisture levels will not converge towards a stable soil moisture level (Figure 6 & Figure 7). In fact around sowing (1st of December) the variability in the available soil moisture is still large. Similar tests at other sites and soil types reveal the same pattern.

Nevertheless, Figure 6 & Figure 7 do demonstrate that whatever the initial soil moisture condition is, all simulations strongly deplete the soil moisture at the end of the growing season converging towards the wilting point. It is therefore better to assume a completely dry profile at the end of the growing season and to let the water accumulate in the months before crop sowing rather than assuming a completely wet profile at the crop start. The assumption presupposes one crop per year under rainfed conditions.

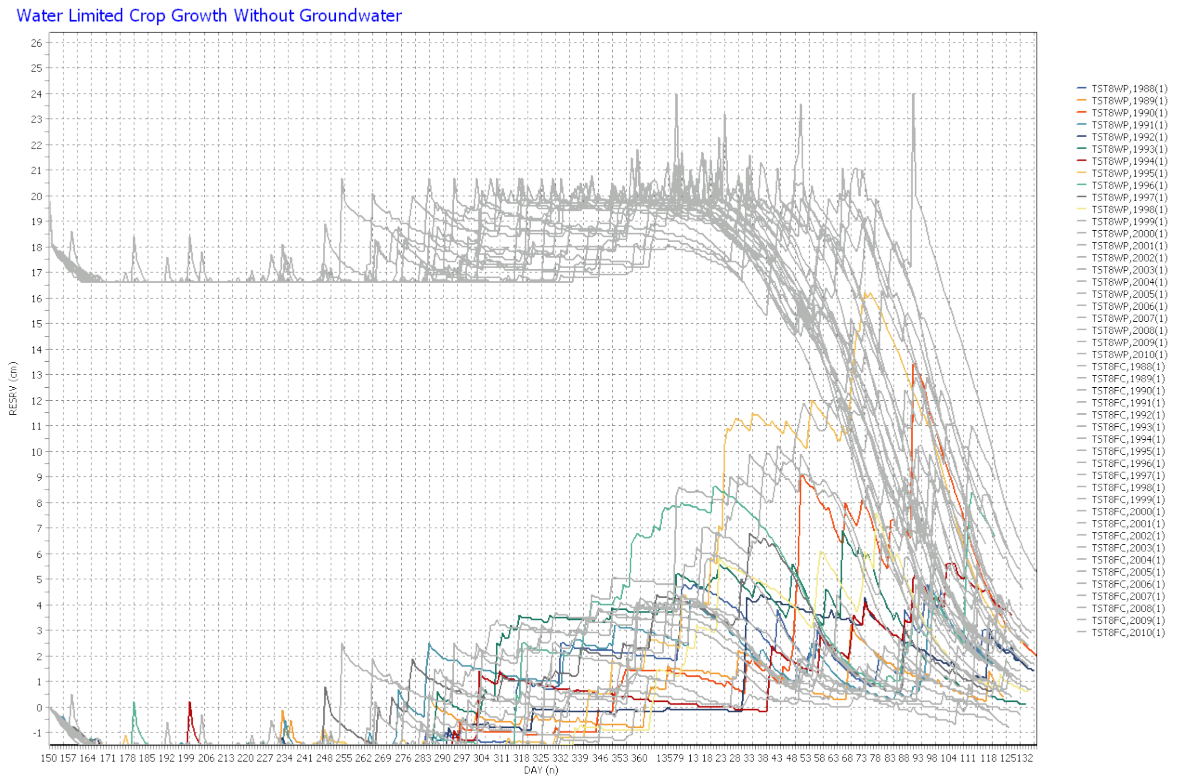


Figure 6: Simulation results at Tassaout for Karim durum wheat for 1988-2010 starting with a completely dry soil profile (lower coloured lines) and a completely wet profile (upper grey lines).

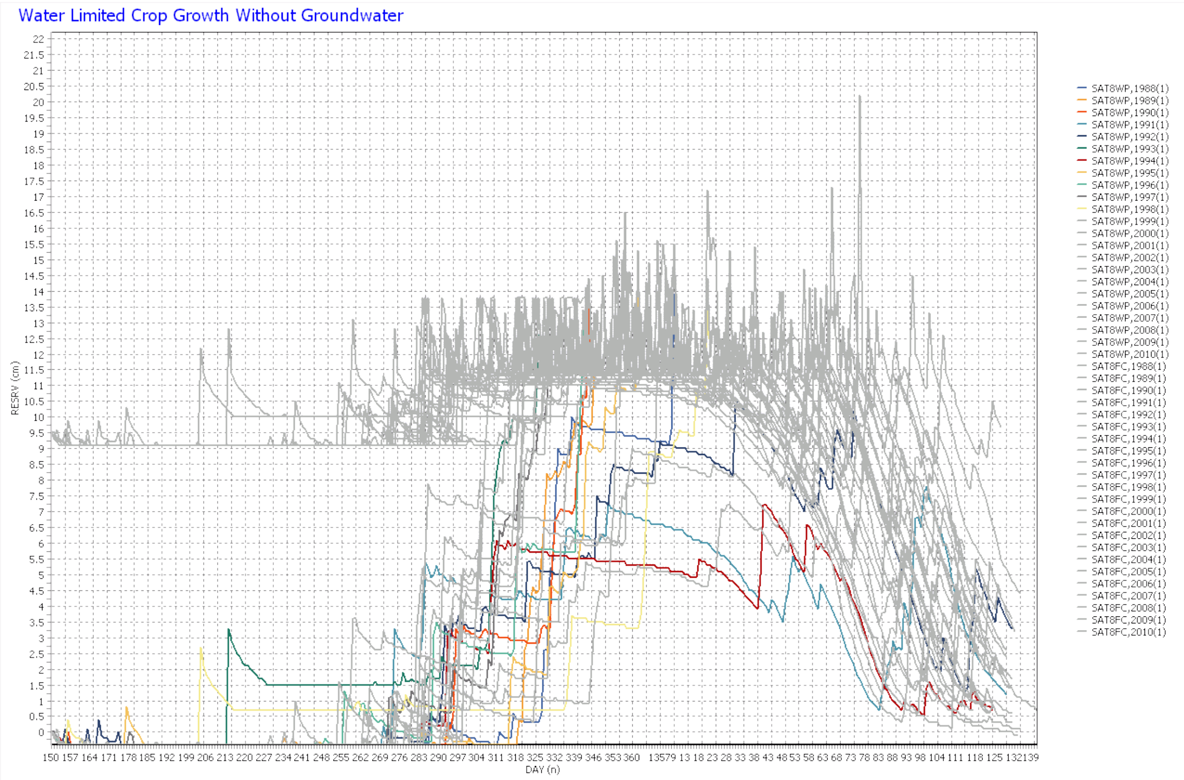


Figure 7: Simulation results at Sidi Allal Tazi for Achtar soft wheat for 1988-2010 starting with a completely dry soil profile (lower coloured lines) and a completely wet profile (upper grey lines).

3.4. Effects on CGMS yield forecasting performance

We applied the CGMS using the improved crop calendar, the recalibrated TSUM1 and TSUM2 parameters and the updated spatial aggregation strategy for the whole of Morocco. Next, the simulation results at national level were tested against the Moroccan crop yield statistics at national level. In this comparison also the indicators from the current MCYFS as well as the satellite-derived indicators and the naïve predictor (the average) were involved. For the comparison the period 1999-2010 was chosen because the satellite indicators derived from SPOT-VGT are only available since 1999.

Table 4 shows the regression results from the different indicators against the Moroccan reported yield for soft and durum wheat. They are all results of single indicator models, without any time trend. As already demonstrated in the introduction, the classic CGMS indicators (grey) do not show any correlation with the reported yields for both soft and durum wheat; R^2 is very low, standard error (SE) is close to the SE of the naïve predictor and all t-values are not significant. Fortunately, the new CGMS indicators (orange) perform considerably better compared to the classic ones. The R^2 of indicator 10 (simulated total biomass) is now 74.81% (compared to 26.21% of indicator 03) for durum wheat and 64.18% (compared to 15.84%) for soft wheat. The indicator 10 is able to reduce the standard error to 0.31 ton/ha, which is roughly halve of the SE of the naïve model (0.59 ton/ha) for durum wheat. For soft-wheat SE can be reduced from 0.56 ton/ha of the naïve model to 0.36 ton/ha for indicator 10. The indicator 11 (simulated yield) shows less good performance but this has been observed in many studies.

The recalibration and improved CGMS setup for Morocco now outperforms the indicator 05 “accumulated rainfall”. However, despite the strong improvement, still most of the satellite-based indicators perform better in explaining crop yield variability in Morocco. The latter may be caused by limitations in the model or model parameterization, or by limitations in the input data. In this respect, it will be interesting to evaluate the Moroccan CGMS; it is intended that that system will operate with improved weather data and soil map. Moreover, the system could benefit from other improvements which are also being investigated in WP3 of the E-AGRI project.

Table 4. Results from regression of several indicators against the reported Moroccan crop yields over the period 1999-2010. Grey: the indicators from the MCYFS; green: indicator from weather data; blue: indicators from satellite observations; orange: recalibrated CGMS results derived in this study; red: naïve predictor (the average). T-values that are in italics are significant at alpha=0.05.

	Durum wheat			Soft wheat		
Indicator	**R^2**	**SE**	**T-value**	**R^2**	**SE**	**T-value**
01 CGMS potential biomass	0.01	0.62	0.029	0.00	0.59	-0.014
02 CGMS potential yield	0.41	0.64	-0.204	1.34	0.60	-0.369
03 CGMS water-lim biomass	26.28	0.54	1.888	15.84	0.55	1.372
04 CGMS water-lim yield	26.11	0.54	1.880	13.28	0.55	1.238
05 Accumulated rainfall Sep-May	70.65	0.36	*4.906*	60.66	0.40	*3.927*
06 Accum. NDVI Feb-May (VGT)	92.76	0.18	*11.318*	90.67	0.19	*9.856*
07 Accum DMP Mar-May (VGT)	84.35	0.25	*7.342*	79.62	0.28	*6.250*
08 Accum. NDVI Feb-May (AVHRR)	89.70	0.21	*9.332*	83.51	0.26	*7.116*
09 Accum DMP Mar-May (AVHRR)	75.58	0.32	*5.563*	68.01	0.35	*4.610*
10 CGMS water-lim biomass (New)	74.81	0.31	*5.450*	64.18	0.36	*4.232*
11 CGMS water-lim yield (new)	51.93	0.43	*3.287*	31.70	0.49	2.154
Naïve predictor	-	0.59	-	-	0.56	-

3.5. Analysis at regional level

The above-mentioned regression analysis with single indicator models - as carried out on the national data - was repeated for the various agro-ecological zones and for the various provinces. Maps of the distinguished regions and provinces can be found in Annex 1. We felt that it was not necessary to distinguish between all the 10 indicators mentioned above; instead we decided to introduce 4 indicator categories:

- Classic – as can be obtained from the MCYFS of JRC
- Cumulative rainfall
- Remote sensing – NDVI and DMP from the sensors AVHRR and VGT
- Improved – as obtained with our improved CGMS setup for Morocco.

For each region and province we determined the maximum R^2 for each of the above categories, for durum and soft wheat. The result for the regions can be seen in Figure 8 & Figure 9.

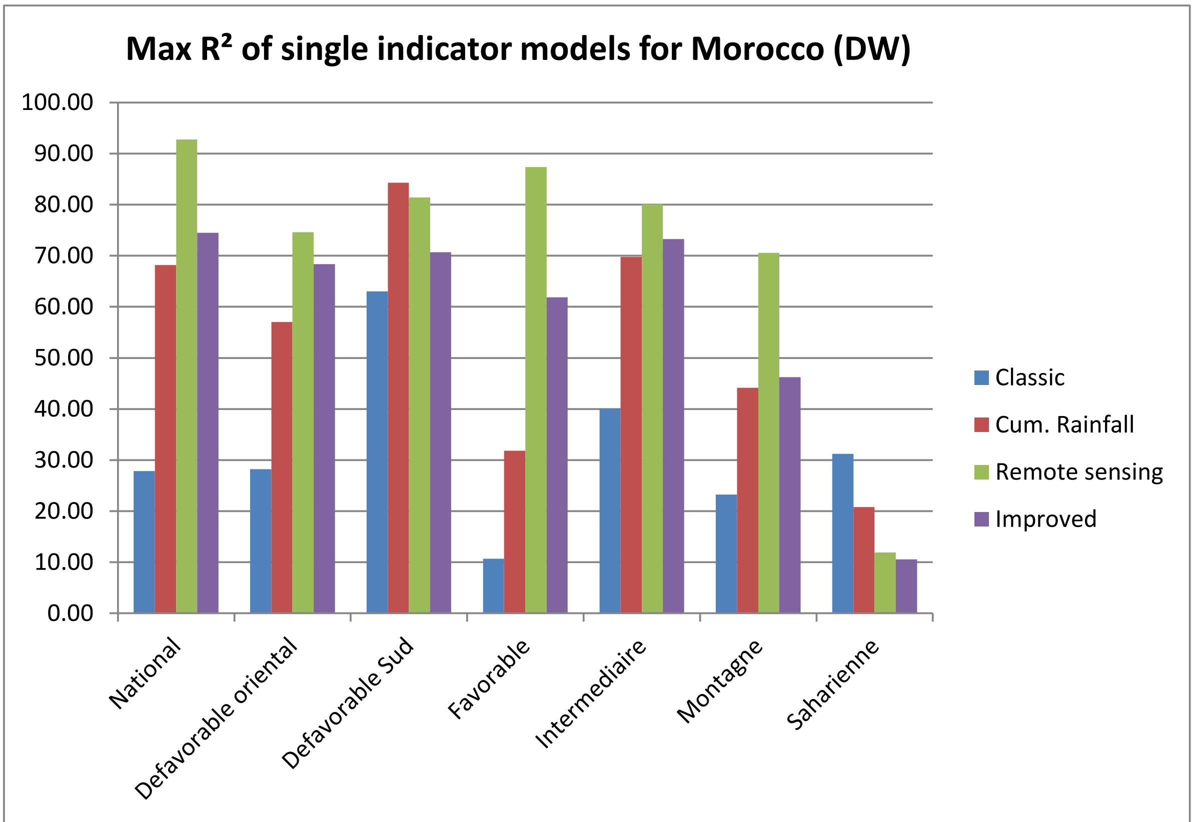


Figure 8: Best performance of the various indicator categories for durum wheat

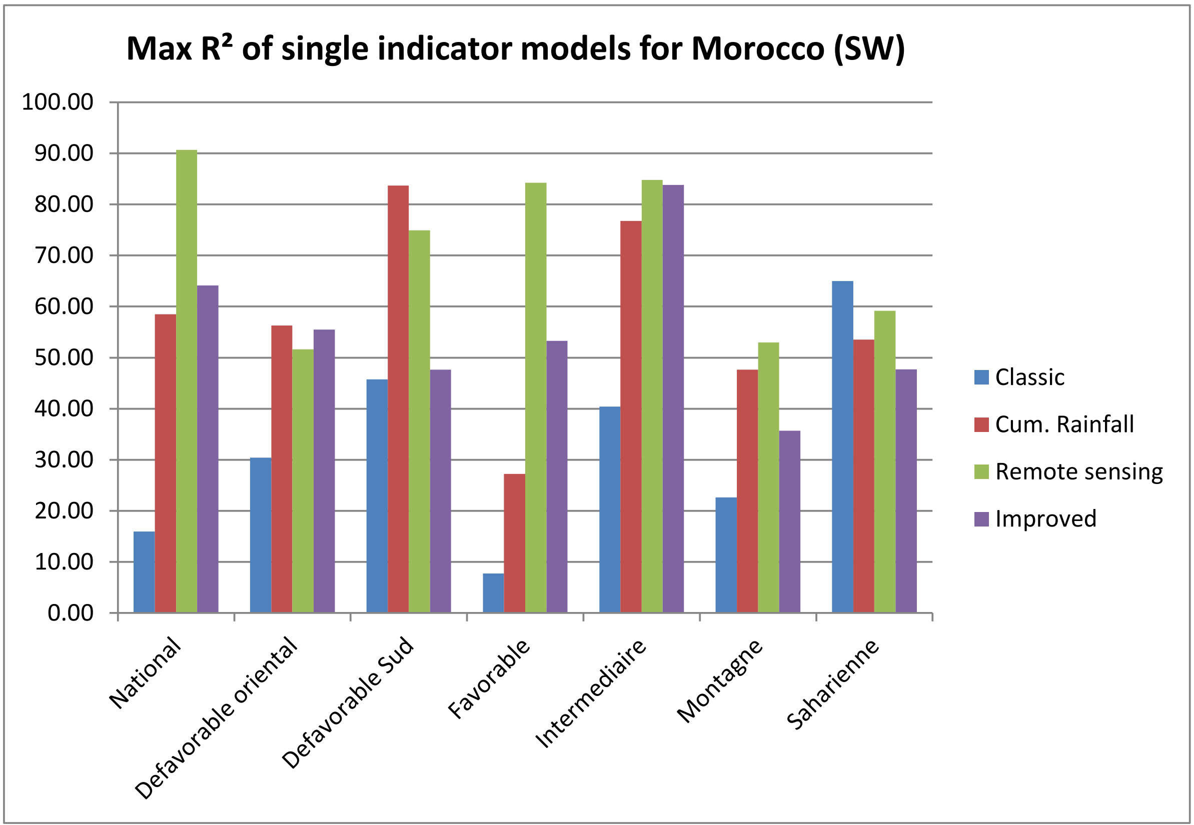


Figure 9: Best performance of the various indicator categories for soft wheat

It is clear that the good performance of the improved indicators at the national level does not always translate to good performance at regional level. Improvements at regional level are most prominent for the regions 'Defavorable oriental', 'Intermediaire' and 'Favorable' which show considerably higher R^2 values compared to the classic CGMS. For durum-wheat, also improvements are clear for 'Montagne' while 'Defavorable sud' is also performing well but this was already the case for the classic CGMS. The region Saharienne is problematic for durum-wheat but cultivated area is very small here and the cultivation is probably limited to small areas with supplemental irrigation. For soft-wheat, the regions 'Defavorable' and 'Montagne' only show small improvements in R^2 values compared to the classic CGMS. Finally, it should be noted that the satellite-based indicators still outperform the improved CGMS indicators in most regions.

The results of the analyses performed for the provinces (Annex 2) often become more erratic and difficult to interpret. For example for durum wheat in region 'Defavorable Oriental' the improvement in R^2 for the entire region can only be found in the provinces 'Al Hoceima' and 'Oujda' but not for 'Boulmane' and 'nador'. For the latter two provinces also the other indicator groups (satellite and cumulative rainfall) are not performing well, so this could be caused by poor regional statistics at province level. A similar pattern can be observed for soft-wheat.

For region 'Defavorable sud', the limited improvement in R^2 at regional level is also present at provincial level as the differences between the classic and improved CGMS at provincial level is generally small.

For region 'Favorable' the strong improvement in R^2 at regional level can also be found in most of the provinces for both soft wheat and durum wheat. Nevertheless, the satellite based indicators outperform the improved CGMS indicators in nearly all regions.

For region 'Intermediaire' the improvement in R^2 at regional level is also present at the province level for all provinces for both soft and durum wheat.

For region 'Montagne' the improvement in R^2 at regional level for durum wheat is mainly caused by the improvements for the provinces 'Beni Mellal' and 'Ifrane' which both show considerable increases in the R^2 values for the improved CGMS Indicators. For soft wheat, there is low R^2 for three out of four provinces. Only the province 'Azilal' show high R^2 values which is for the improved CGMS indicators which is somewhat remarkable as this is the province with the lowest cultivated area for soft wheat in this region.

Finally, the region 'Saharienne' has not been analysed at provincial level as the regional statistics and satellite data were too sparse to provide any meaningful statistics.

4. Conclusions

- The phenological parameters of WOFOST were calibrated according to the Moroccan experimental data. The results demonstrate that the parameter values differ considerably from the parameters in the MARS Crop Yield Forecasting System previously used for Morocco. This is a strong indication that the current MCYFS setup is not appropriate for an application in this country.

- It was demonstrated that the assumption of soil moisture being at field capacity at the start of the crop simulation is inappropriate for Morocco. Instead, it is more realistic to assume that the soil profile is completely dry by June 1 and to start the water balance several months before the crop starts in order to let the rainfall accumulate during the months before the cropping season.

- The adapted CGMS using the new crop calendar, new WOFOST phenological parameters and adapted water balance initialization performs much better than MCYFS in explaining the yield variability of soft and durum wheat in Morocco over the period 1999-2010.

- Further improvements of CGMS for Morocco can perhaps be obtained using local data (weather, soil) from the Moroccan institutes. Another option for improvement is the use of a variable sowing date responding to the local rainfall pattern.

- Finally, there are indications that the modelling of wheat growth in the southern provinces could be improved, if the special growing conditions that are prevalent there are taken into account.

Annex 1: Maps

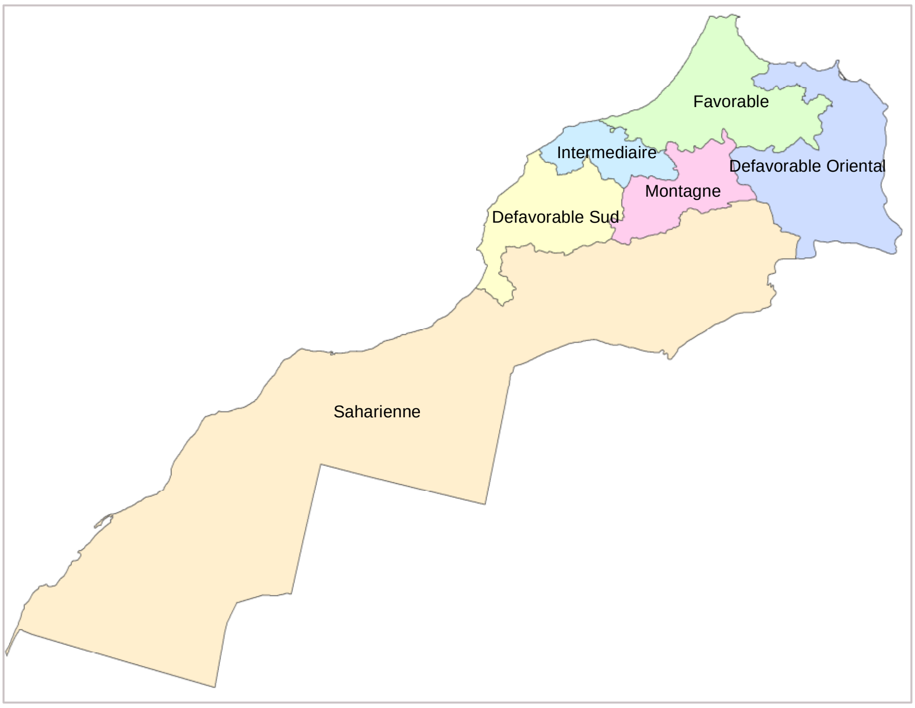


Figure 10: Map of the distinguished agro-ecological zones

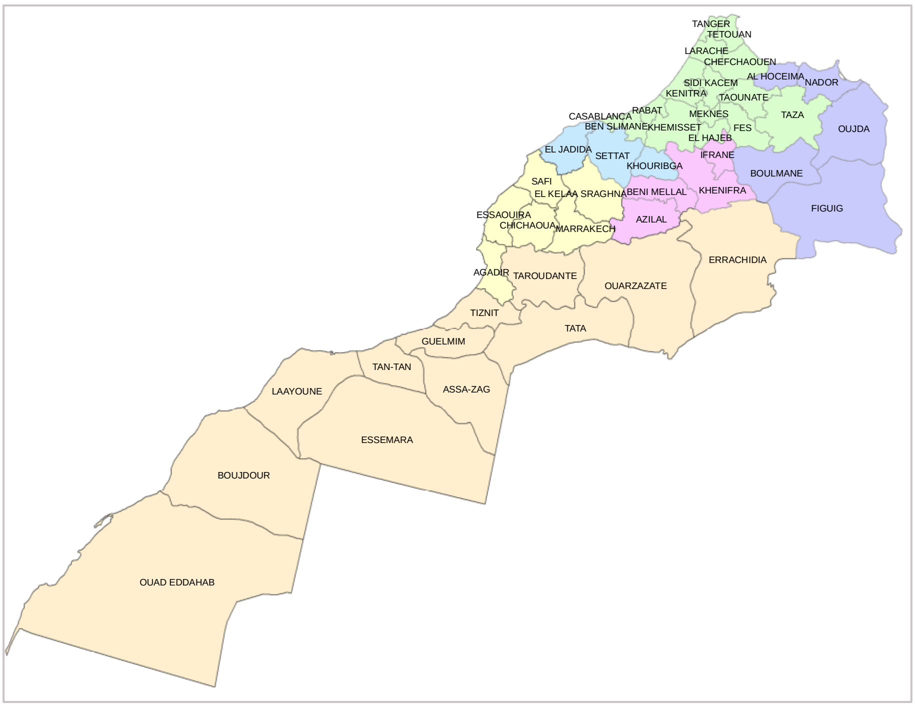


Figure 11: Map of the distinguished provinces

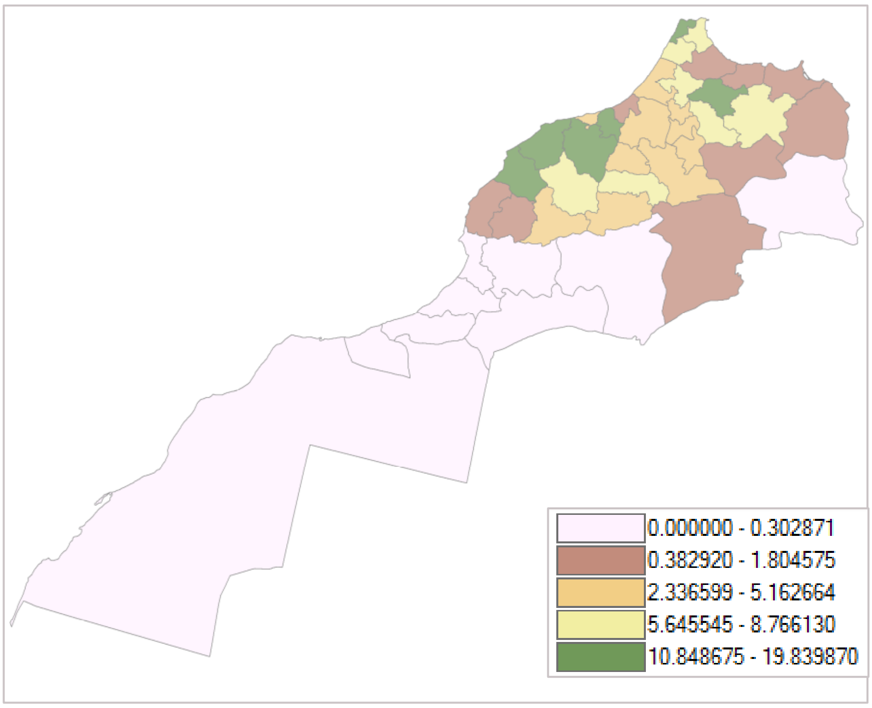


Figure 12: Percentage of area under durum wheat cultivation (1999-2010 average)

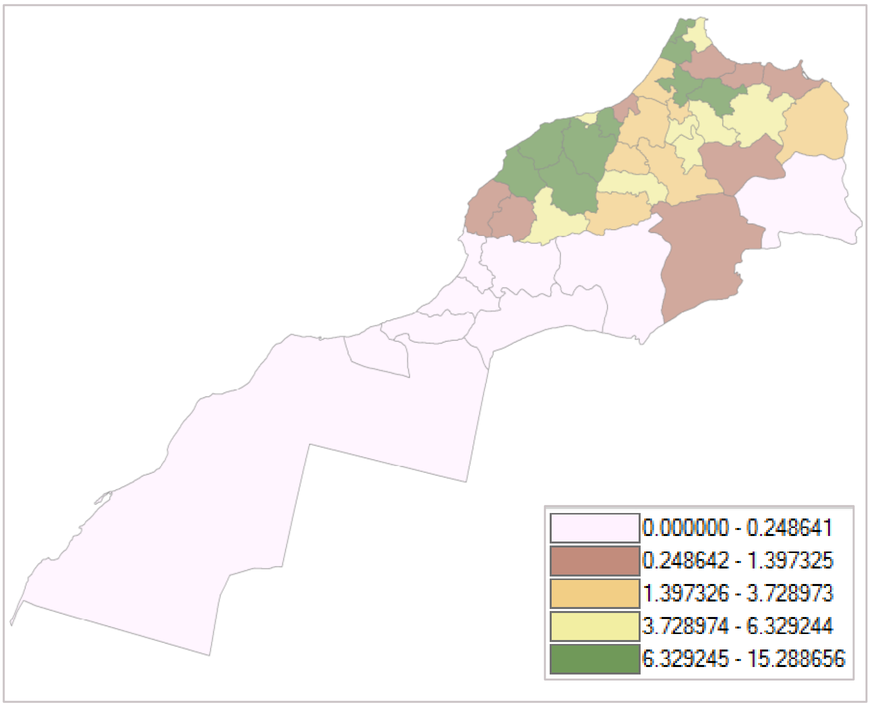
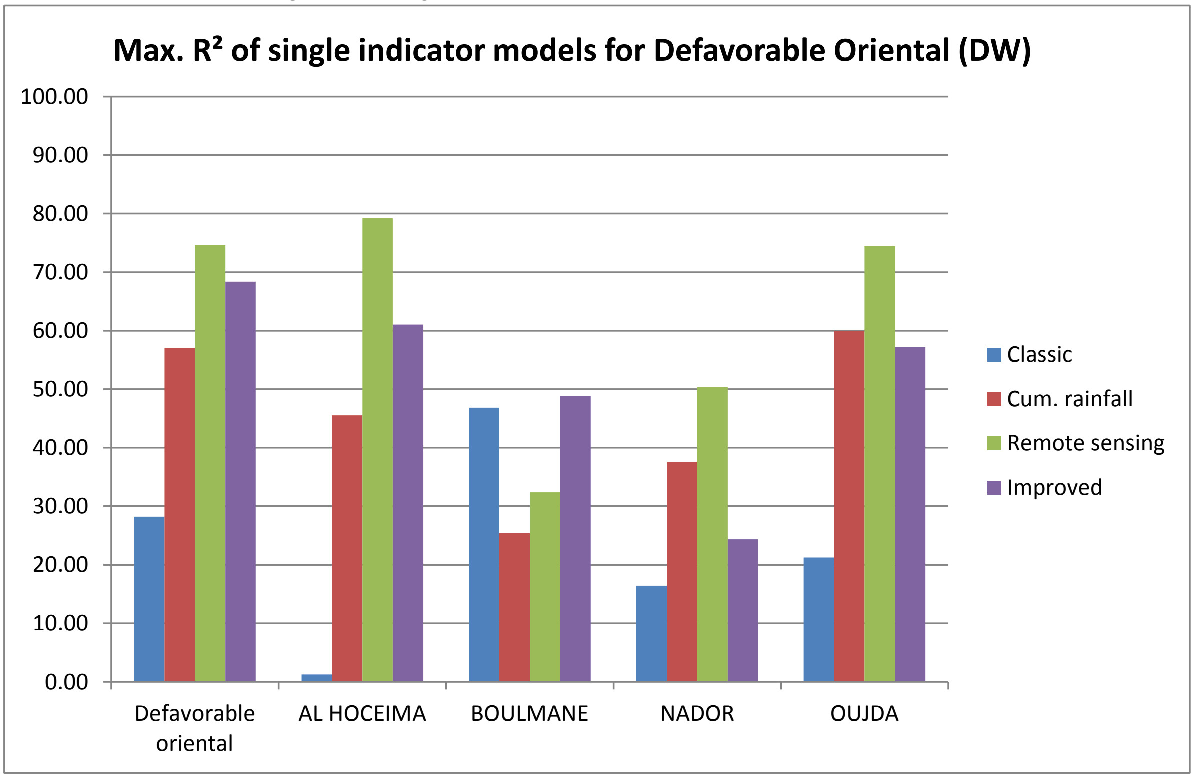
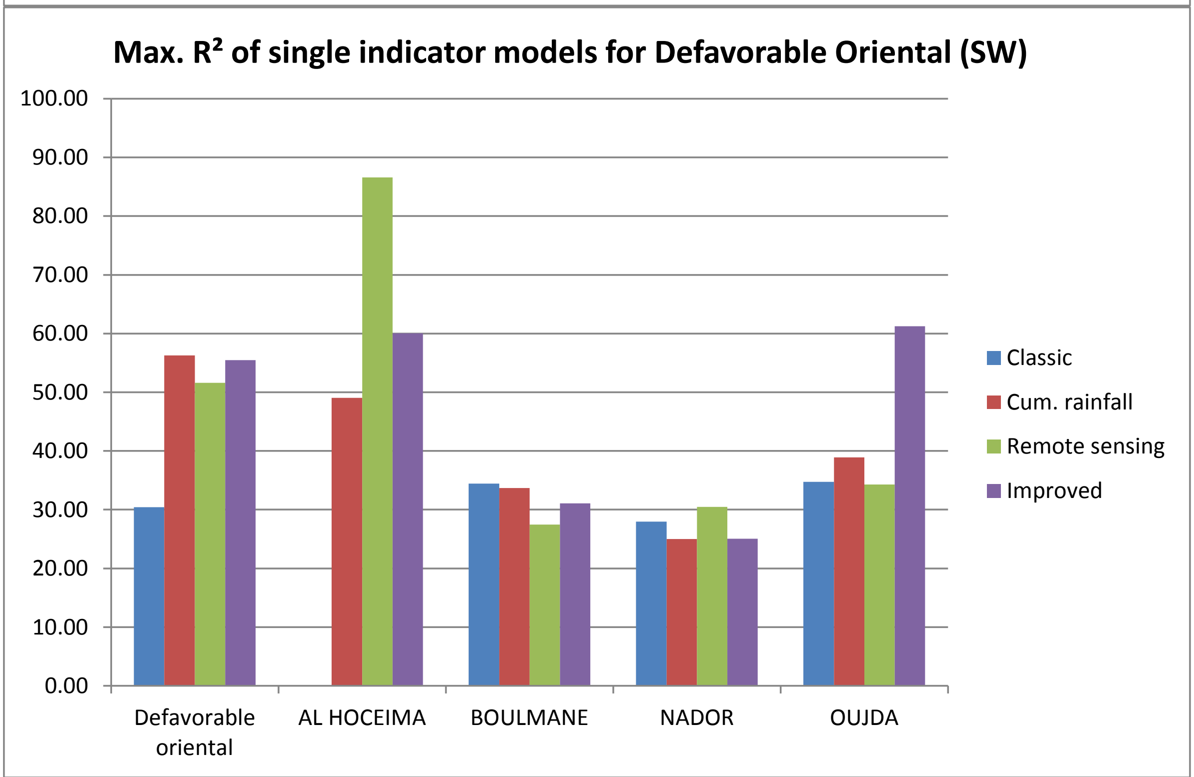
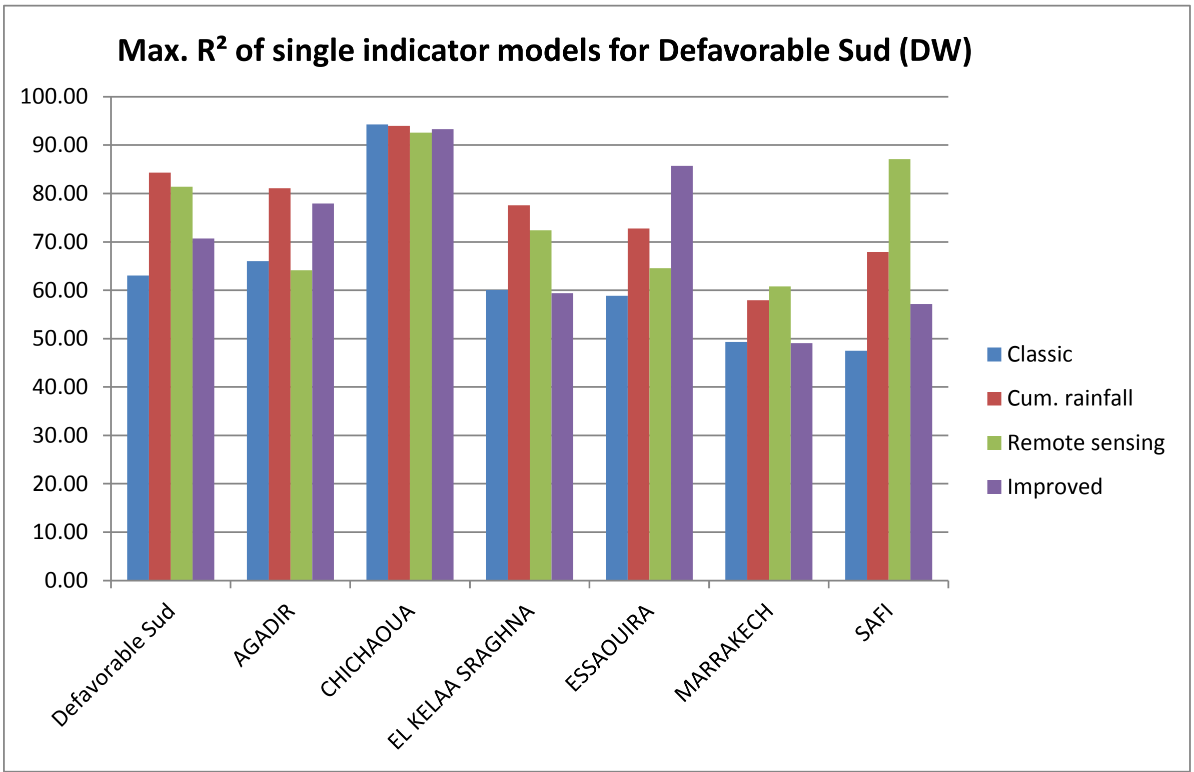


Figure 13: Percentage of area under soft wheat cultivation (1999-2010 average)

Annex 2: Analysis at provincial level






Max. R² of single indicator models for Defavorable Sud (DW)
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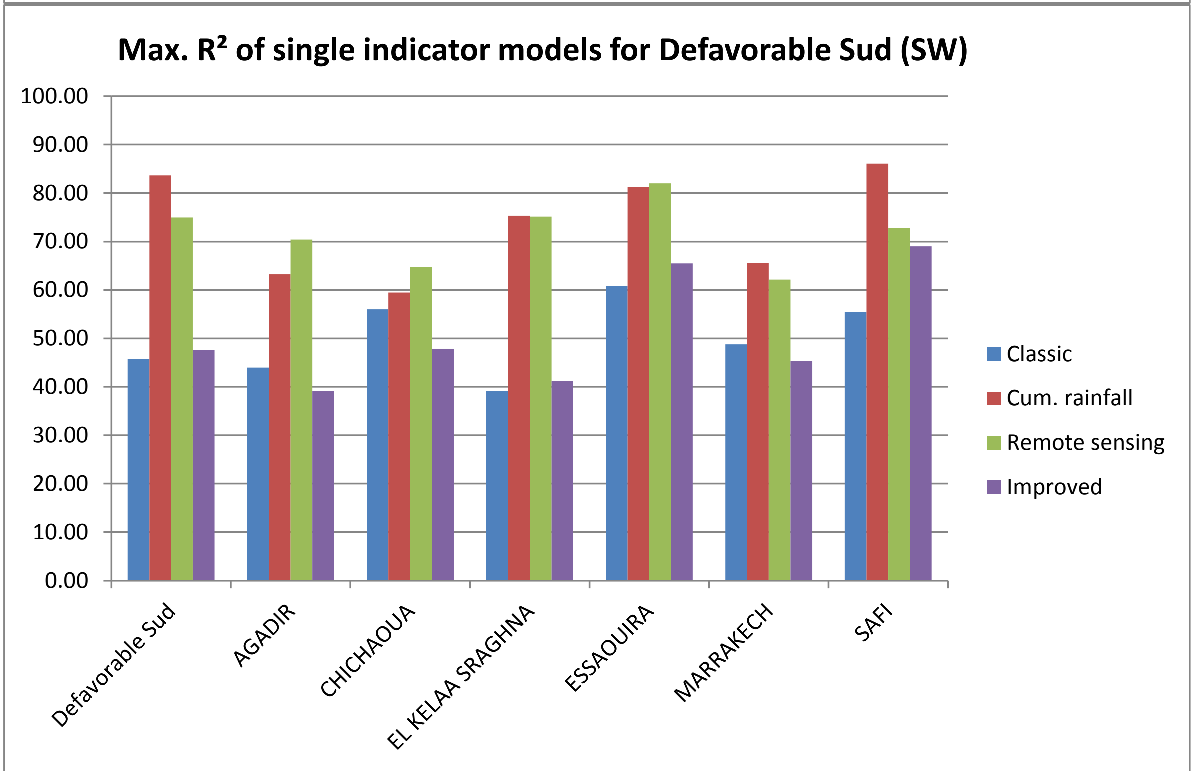
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Defavorable Sud
AGADIR
CHICHAOUA
EL KELAA SRAGHNA
ESSAOUIRA
MARRAKECH
SAFI
Classic
Cum. rainfall
Remote sensing
Improved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10.00
0.00
Defavorable Sud
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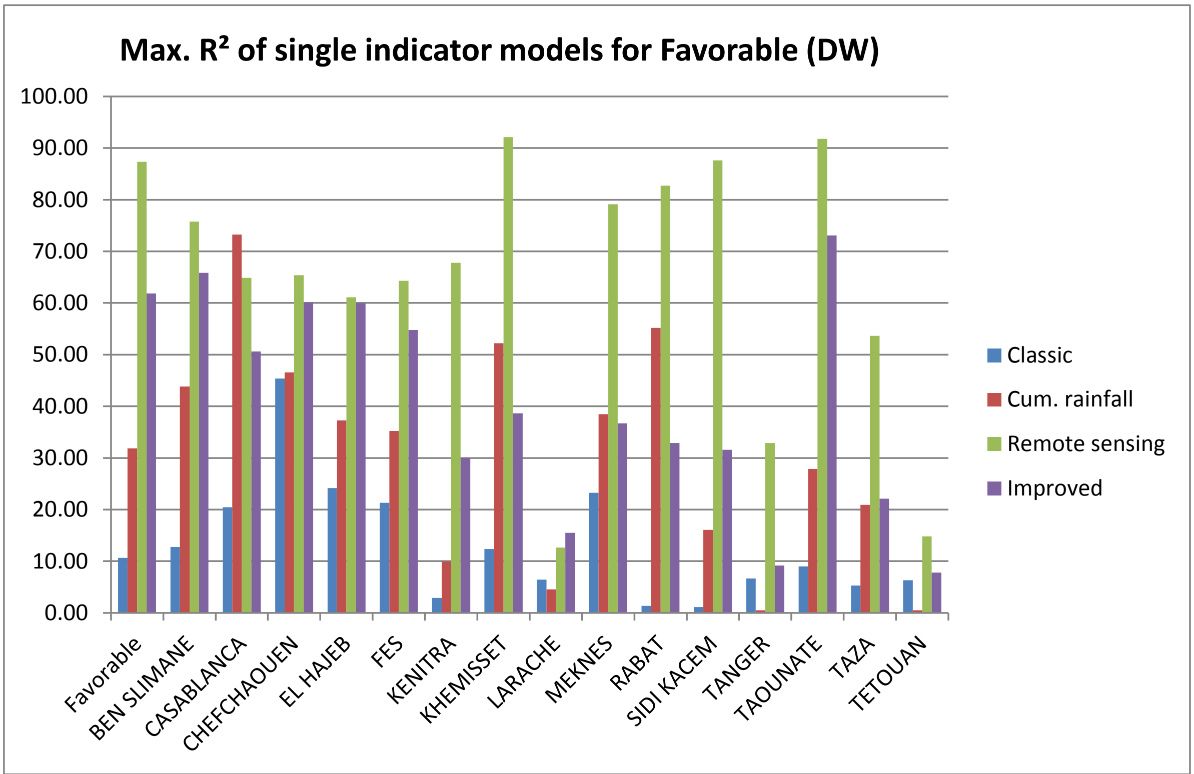
CHICHAOUA
EL KELAA SRAGHNA
ESSAOUIRA
MARRAKECH
SAFI
Classic
Cum. rainfall
Remote sensing
Improved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Favorable
BEN SLIMANE
CASABLANCA
CHEFCHAOUEN
EL HAJEB
FES
KENITRA
KHEMISSET
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SIDI KACEM
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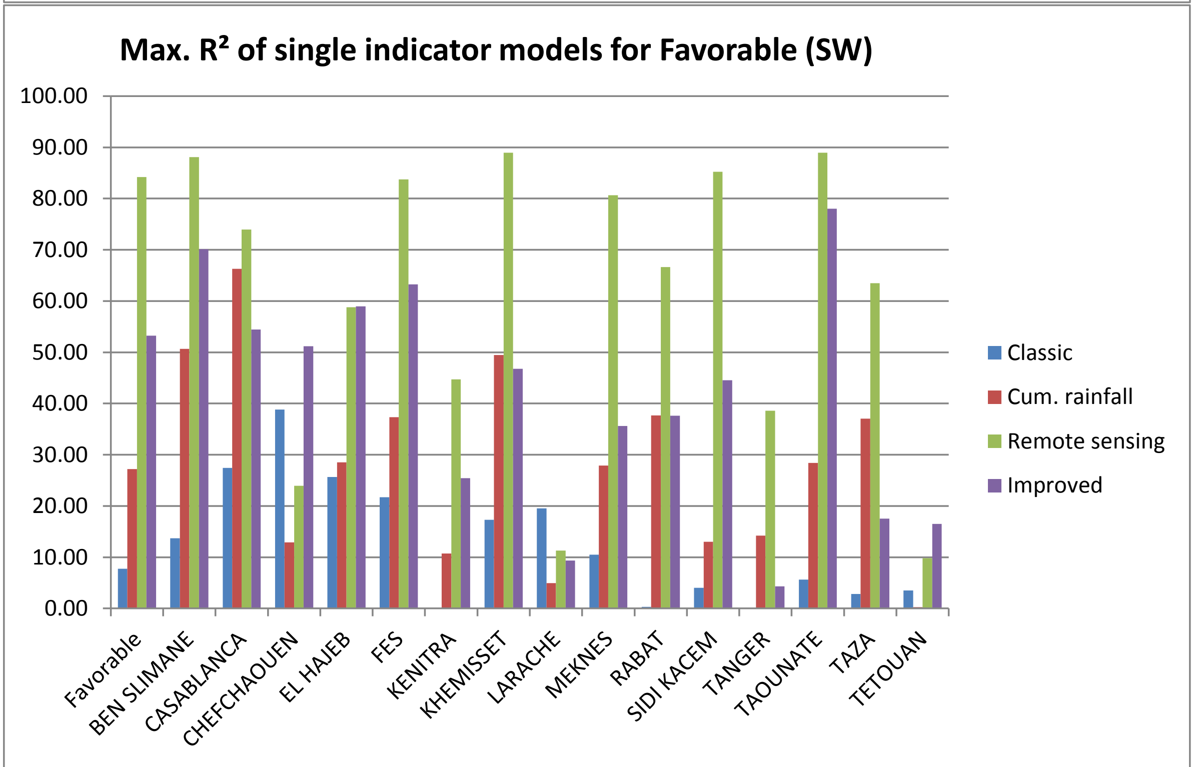
TAZA
TETOUAN
Classic
Cum. rainfall
Remote sensing
Improved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Favorable
BEN SLIMANE
CASABLANCA
CHEFCHAOUEN
EL HAJEB
FES
KENITRA
KHEMISSET
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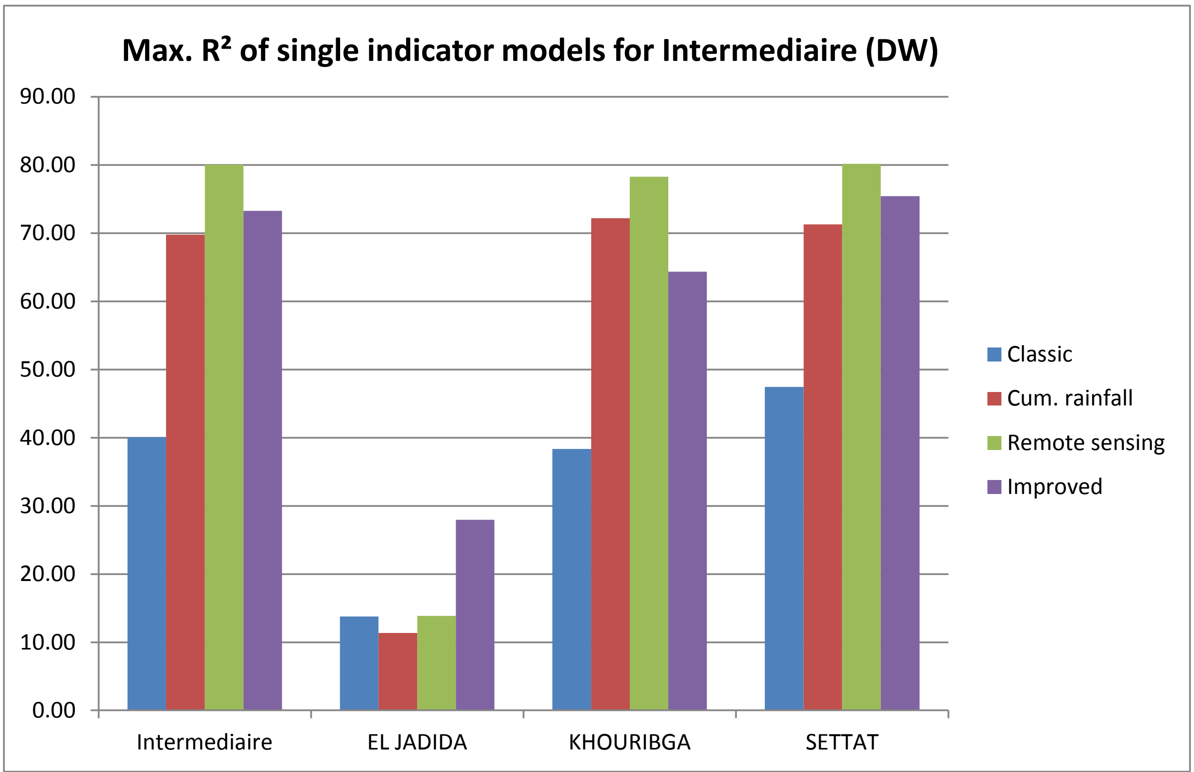
Classic
Cum. rainfall
Remote sensing
Improved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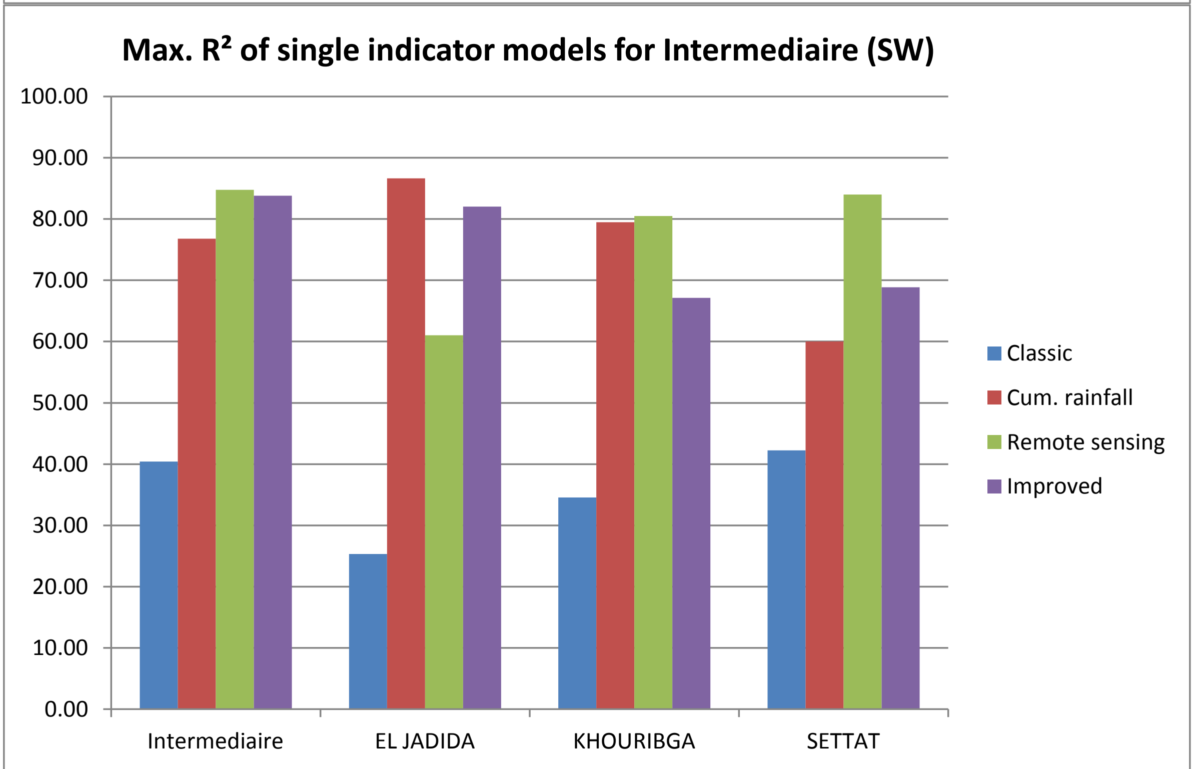
Intermediaire
EL JADIDA
KHOURIBGA
SETTAT
Classic
Cum. rainfall
Remote sensing
Improved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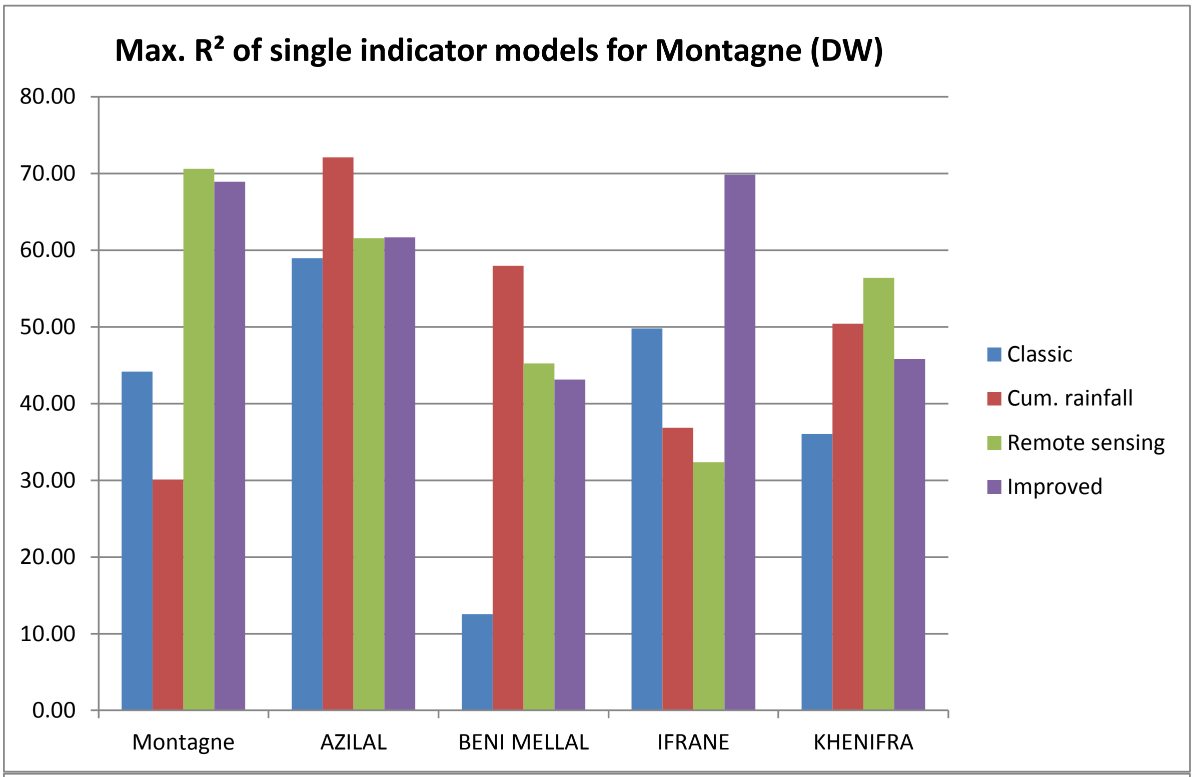
Intermediaire
EL JADIDA
KHOURIBGA
SETTAT
Classic
Cum. rainfall
Remote sensing
Improved


Max. R² of single indicator models for Montagne (DW)
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40.00
30.00
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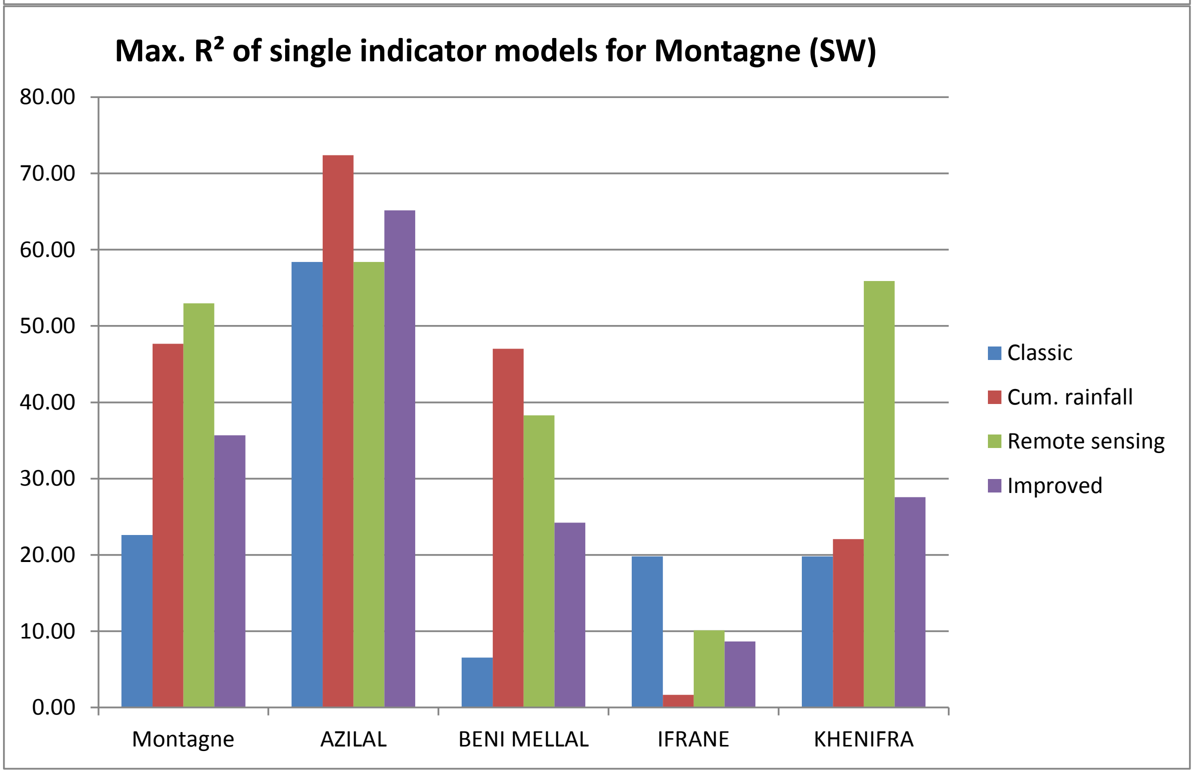
10.00
0.00
Montagne
AZILAL
BENI MELLAL
IFRANE
KHENIFRA
Classic
Cum. rainfall
Remote sensing
Improved


Max. R² of single indicator models for Montagne (SW)
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40.00
30.00
20.00
10.00
0.00
Montagne
AZILAL
BENI MELLAL
IFRANE
KHENIFRA
Classic
Cum. rainfall
Remote sensing
Improved