Crop Monitoring as an
E-agricultural tool in
Developing Countries

EVALUATION REPORT ON WHEAT SIMULATION AT REGIONAL LEVEL IN MOROCCO

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EXECUTIVE SUMMARY

This report presents the results of the evaluation of the spatially distributed simulations of wheat growth and development in Morocco performed with the multi-model approach (i.e., the CropSyst and WOFOST models). Parameters used for the three models are those calibrated and evaluated for E-AGRI deliverable D34.3.

The values of final aboveground biomass simulated by the two models are analysed. The simulations were performed under both potential and water limited conditions, although most of the wheat cultivated in Morocco is not irrigated. Results of the simulations performed by CropSyst and WOFOST in the driest and wettest seasons in the period 2000 - 2012 are shown as examples.

Productions simulated by CropSyst and WOFOST under potential conditions ranged from 10000 kg ha^{-1} to some peaks higher than 22000 kg ha^{-1}. Maximum values under potential conditions were reached in the southern areas.

Under water limiting conditions, aboveground biomass ranged from 500 kg ha^{-1} to values higher than 12500 kg ha^{-1}, reached in the northern part of the region, where precipitations were abundant during the wheat growing season. Rainfall confirmed to be the main driver for wheat production in the driest year of the analized time series, whereas in the wettest year, although precipitations in the southern regions were lower, it was enough to guarantee high productions.

The two models, that performed in a similar way after calibration, shown a markedly different behaviour when applied to the whole wheat-cropped Moroccan area, because of the different response to weather variable explored in the Country. This can be considered as a justification for the use of a multi-model approach to crop growth simulation and to yield forecasting activities.

1. Introduction

Among the advanced functionalities implemented in BioMA, one of the most relevant is that its structure, based on multi-approach components for the simulation of biophysical processes, allows for running multi-model simulations. This increases the capability of the modelling system to capture the peculiarities related to specific locations or seasons. This is due to the different approaches adopted by the different models to reproduce crop growth and development under conditions defined by the environment explored and – in general – by the different factors modulating or limiting crops' productivity.

The crop models currently implemented in BioMA for wheat growth and development, via the CropML (Crop Model Library) component, are CropSyst (Stöckle et al., 2003) and WOFOST (Van Keulen and Wolf, 1986). These models greatly differ in the approaches used to reproduce light interception, biomass accumulation, assimilates partitioning, and leaf area evolution. Moreover, they proved to differ also in terms of complexity (Confalonieri et al., 2009), robustness (Confalonieri et al., 2010) and plasticity (Confalonieri et al., 2012).

2. Materials and methods

2.1. Large scale wheat simulation in Morocco

Simulations were performed on each Moroccan grid cell where wheat is grown according to the EC-JRC MARS crop mask. The resolution of the cell (25 × 25 km) is derived from the resolution of the primary model input, i.e., the meteorological data. The next subsections report a description of the two models – useful to discuss results – and of the database used to run the simulations.

2.1.1. The crop models

The spatially distributed wheat simulations were performed by using the CropSyst (Stöckle et al., 2003) and WOFOST (Van Keulen and Wolf, 1986) models. WOFOST is a model generic for herbaceous species simulations, and it is operationally used by the European Commission for yield forecasts within the European Commission MARS Crop Yield Forecasting System (http://mars.jrc.it/). CropSyst has been used in many studies worldwide for evaluating the impact of management and climatic scenarios for a variety of crops. The two models differ for the approaches used to reproduce the different processes related to crop growth and development, for the amount of data needed for their use, and for their behaviour, being characterized by a different degrees of complexity.

The two models simulate crop development as a function of the thermal time accumulated, with options to account for photoperiod.

Concerning daily biomass accumulation, CropSyst is based on the Tanner and Sinclair (1983) relationship between aboveground biomass (AGB), potential transpiration, vapour pressure deficit (VPD) and a VPD-corrected transpiration use efficiency (TUE_{VPD}). The instability of the Tanner and Sinclair equation for low values of VPD leads to the adoption of a temperature-limited RUE approach when these conditions occur. CropSyst simulates leaf area development as a function of AGB, a constant specific leaf area and an empirical coefficient, without the simulation of dynamic AGB partitioning to the different plant organs.

WOFOST is the most sophisticated in reproducing the biophysical processes involved with crop growth, calculating gross photosynthesis, growth (during photosynthates partitioning to plant organs) and maintenance respirations. Partitioning of assimilates is thus driven by growth respiration, development-specific partitioning factors and efficiencies of assimilates conversion into the different organs. Leaf area expansion is calculated as a function of temperature for leaf area index (LAI) lower than one, and derived from specific leaf area and development stage elsewhere. WOFOST has a three-layer canopy representation, with a spherical leaf angle distribution and LAI split among the layers using a Gaussian integration. Leaves death is simulated by CropSyst as driven by senescence, with WOFOST reproducing this process also as a function of leaves self-shading.

2.1.2. Database structure

Weather data

Weather data are retrieved from the MARS database of the Joint Research Centre of the European Commission. This database is operationally used by the commission within the MARS Crop Yield Forecasting System (http://mars.jrc.it/) and data are available at 25 × 25 km grid resolution from 1975 to 2012. The meteorological data obtained from the MARS database are:

- daily minimum and maximum temperature;
- daily minimum and maximum relative humidity;
- daily global solar radiation;
- daily cumulated precipitation;
- daily horizontal wind speed.

Given the high variability of the agrometeorological conditions explored by the crop in the part of the country where agriculture is allowed (with Northern and Western zones more favourable, and suboptimal conditions experienced in the Southern and Eastern zones), water stress is among the main factors influencing crop growth and development.

For this reason, we decided to show and discuss here the results of spatially distributed simulations for WOFOST and CropSyst only in the driest and wettest years within the last 12 years. Different agro-climatic indices reported in literature are based on the use of information from precipitation (e.g., Barnett et al., 2006), thus, for the selection of the most arid and wet years, cumulated rainfall during the wheat growing period (i.e., from December to June) was calculated. It was calculated the sum of precipitations in all the grid cells of the moroccan cultivated region, and the values obtained were then averaged. This analysis showed that the 2011/2012 and the 2009/2010 were the driest and the wettest seasons of the time series, with 130 and 491 mm of rainfall respectively. The normal (i.e., calculated on the whole dataset) rainfall value cumulated from wheat sowing to harvest on the crop mask area was about 290 mm.

Model parameters

The complete list of the values of calibrated parameters for WOFOST and CropSyst is detailed in the final version of deliverable D34.3 (appendix tables). These values were obtained by using the 2011-2012 and 2012-2013 field observations, collected in the central-western part of the cultivated country. The presence of well-differentiated agrometeorological regions leads farmers to differentiate the choice of the cultivar on the basis of the conditions explored. This is reproduced by the models by using three parameter sets: (i) soft wheat - high potential, (ii) soft wheat - low potential, and (iii) durum wheat.

Management information

According to field experiments used for model calibrations, the main wheat growing season was from December to June, thus the sowing date was set to the 1st of December in all the grid cells where simulations were performed.

The crop mask (25 × 25 km resolution) was provided by the JRC partners and it is represented in Figure 1. As the figure shows, wheat is mostly cultivated in the north-western zone alongshore, due to the presence of the Saharan desert in the central and southern parts of the country.

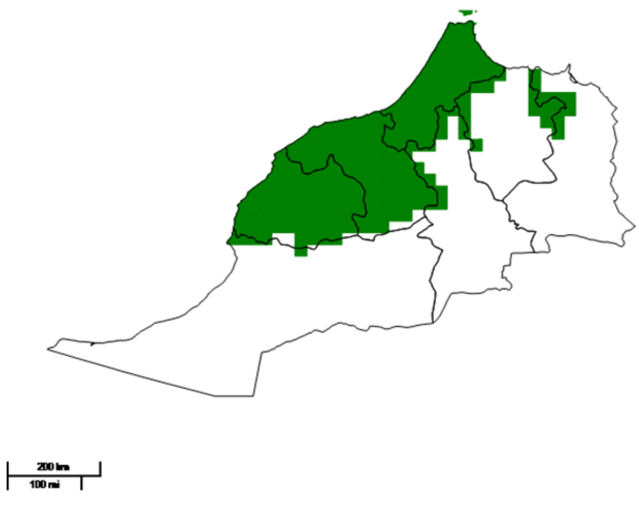

Figure 1 Crop mask of wheat (green areas) in Morocco

Soil parameters

Water limited simulations were performed using soil parameters obtained from the CGMS soil database. For each grid unit of the crop mask, the most representative Soil Typological Unit (STU) was chosen to perform spatial simulations..

3. Results and Discussion

Spatial simulations of Aboveground Biomass (AGB) at physiological maturity were performed by using the crop models CropSyst and WOFOST. This variable was chosen since it can be considered as a synthetic representation of the culmination of all the biophysical processes involved with crop growth and development.

3.1. Meteorological data

Prior to the discussion of the models results, the spatial distributions of the meteorological inputs of the driest (i.e. 2009-2010) and wettest season (i.e. 2011-2012) of the time series are shown from Figure 2 to Figure 4.

Daily values of maximum and minimum temperature and global solar radiation of each grid unit, referred to the wheat growing period (i.e. from December to June), were averaged. Daily values of rain for each grid unit were summed to find the cumulated rainfall of the crop growing period.

Figure 2 shows the patterns of averaged daily global solar radiation: in both the years the variable follows a clear north-south trend, with highest values at the southern part of the cultivated region. In the season 2011-2012, radiation values were higher than for 2009-2010 both in the southern and in the northern areas: values ranged from 12-14 MJ m^{-2} (at north) to 18-20 MJ m^{-2} (at south) in 2009-2010 (Figure 2a) and from 14-16 MJ m^{-2} to 20-22 MJ m^{-2} in 2011-2012 (Figure 2b).

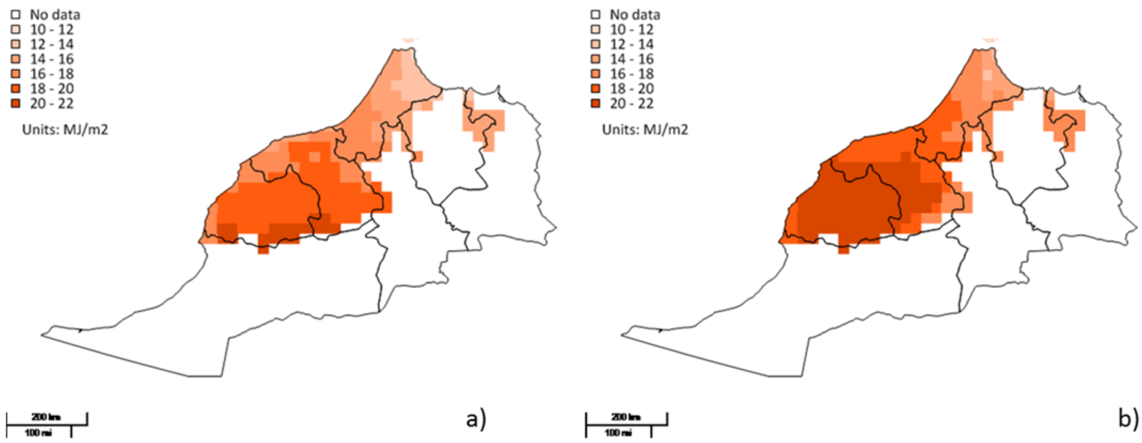

Figure 2 Daily global solar radiation averaged from: a) December 2009 to June 2010; b) December 2011 to June 2012.

Figure 3 shows averaged daily minimum and maximum temperature trends. Daily maximum temperatures were characterized by north-south gradient, like that discussed for global solar radiation. Maximum temperature values were approximately the same in the two studied years, ranging from 15-17 °C to 25-27 °C (Figure 3a and Figure 3c). The trend of daily minimum temperature is different from the other two variables: higher values were reached at the northern and southern part of the area and alongshore, whereas in the central part and inland minimum temperatures were lower. It can also be noted that minimum temperature values were lower in all the grid units in 2011-2012 than in 2009-2010: in 2011-2012 the predominant classes at northern-southern and central part of the area were 9-11 °C and 6-9 °C, respectively (Figure 3b). In 2009-2010 the most represented classes were 11-13 °C and 9-11 °C at north-south and centre of the region, respectively (Figure 3d).

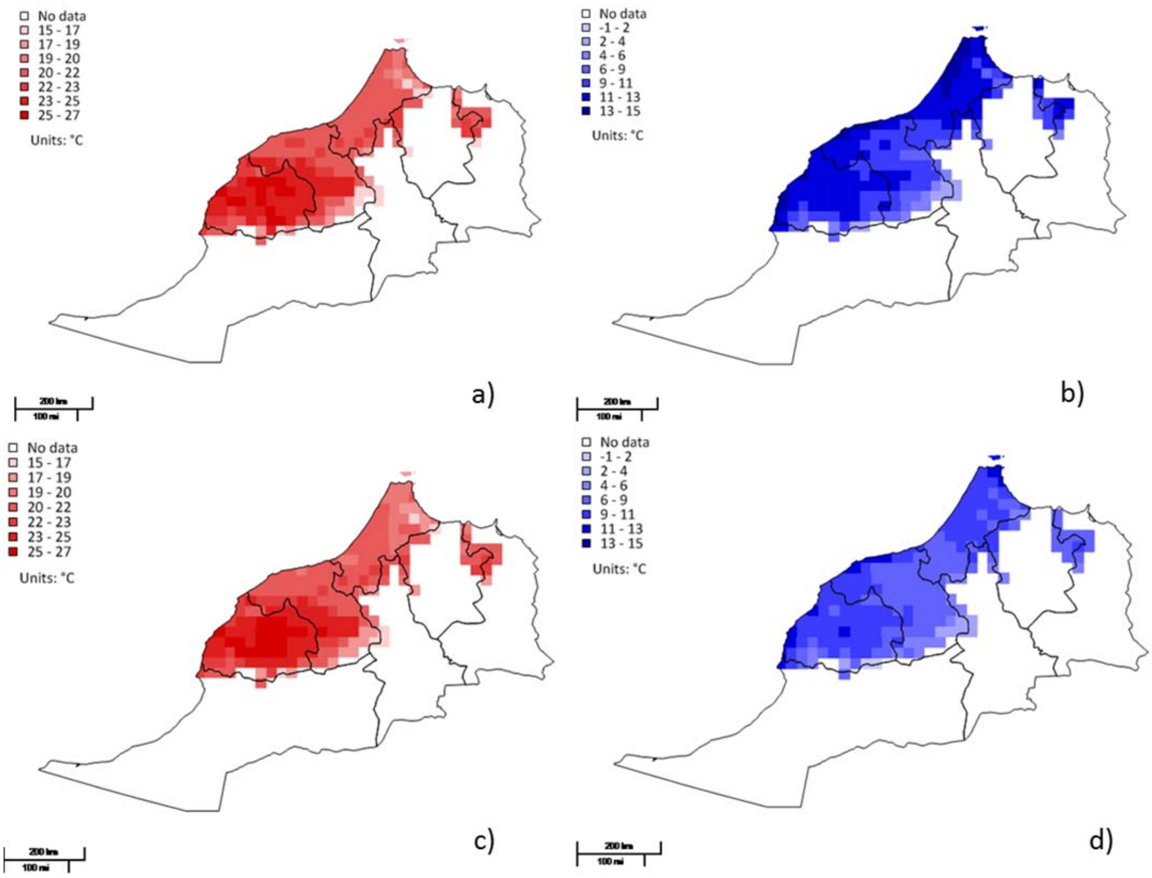

Figure 3 Daily maximum (a) and minimim (b) temperature averaged out from December 2009 to June 2010; Daily maximum (c) and minimim (d) temperature averaged out from December 2011 to June 2012.

Most of wheat in Morocco is not irrigated, thus rainfall can be considered as the main water source and it regulates the plant development and growth. The driest (i.e., 2011-2012) and the wettest seasons (i.e., 2009-2010) of the time series analysed were selected to study the effect of rainfall on plant growth and development. Figure 4 represents the cumulated rainfall during the wheat growing period. The figure shows that the rainfall pattern is the same for the two studied years, with higher values in the northern regions, where solar radiation and maximum temperatures were lower. Cumulated rainfall decreased moving at south. The values of cumulated rainfall were completely different in the two wheat growing periods, thus different intervals were chosen to represent the variable: in 2009-2010 rainfall values ranged from 225 mm to 1450 mm (Figure 4a), whereas in 2011-2012 values ranged from 70 mm to 250 mm (Figure 4b). In 2009-2010 precipitations were more abundant, thus the cloudy sky shielded sun rays and led to lower values of solar radiation.

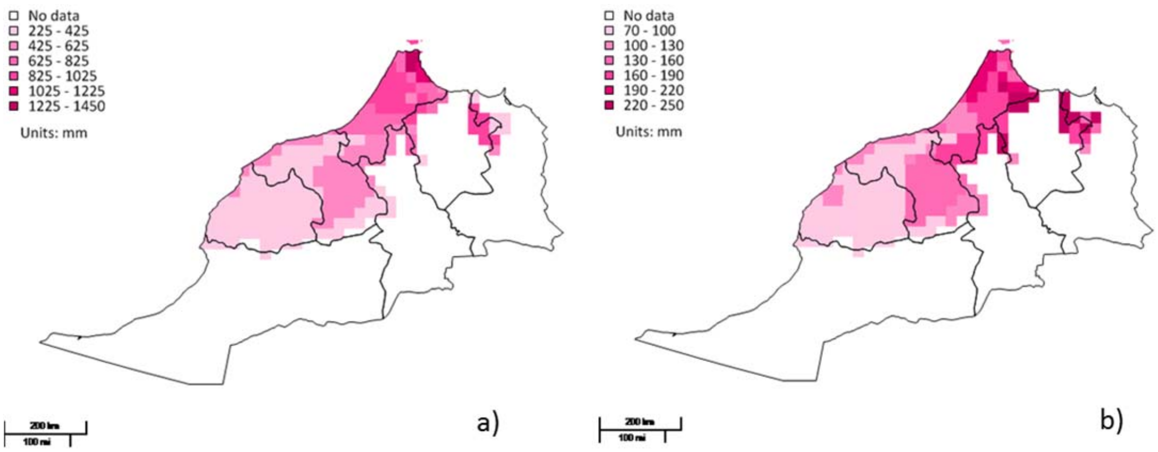

Figure 4 Cumulated rainfall from December 2009 to June 2010 (a) and from December 2011 to June 2012 (b).

3.2. Aboveground biomass spatial simulations

Spatial simulations of wheat AGB were performed under both water limiting and potential conditions, although irrigation is rarely used in Morocco. During the calibration activity, wheat varieties cultivated in Morocco were divided in three classes (i.e. durum wheat, soft wheat – high potential and soft wheat – low potential) and each one was separely calibrated. Spatial simulations were carried out for each of the parameters sets obtained for the three variety classes. The results obtained by the simulations of CropSyst and WOFOST are presented in the following sections.

3.2.1. Potential conditions

3.2.1.1. CropSyst simulations

Figure *5 Maximum value of aboveground biomass of the durum variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under potential conditions*
, Figure 6 and Figure 7 show the AGB pattern simulated by CropSyst referred to durum, soft - high potential and soft - low potential wheat, respectively. In each figure the driest and the wettest years are compared. Figures show that AGB patterns for the three groups of varieties and the two studied years follow the same north-south gradient discussed for maximum temperature and global solar radiation: the maximum AGB values were reached at the southern part of the cropped region and gradually decreased moving to the northern area.

In the 2009-2010 growing season, the AGB values for durum and soft - high potential wheat were similar and ranged from 12000 kg ha^{-1} at the extreme north to 22000 kg ha^{-1} at the extreme south of the area. AGB values of soft low – potential wheat were lower and ranged from 10000 kg ha^{-1} to 20000 kg ha^{-1}. In the 2011-2012 growing season, solar radiation was higher and more favourable to plant biomass accumulation. For durum and soft - high potential wheat, AGB exceeded the value of 22000 kg ha^{-1} in some grid units placed at southern part of the cropped region, whereas the minimum value was 14000 kg ha^{-1} in northern areas. Soft low – potential wheat was characterized by low productivity and the aboveground biomass never overcame the value of 22000 kg ha^{-1}.

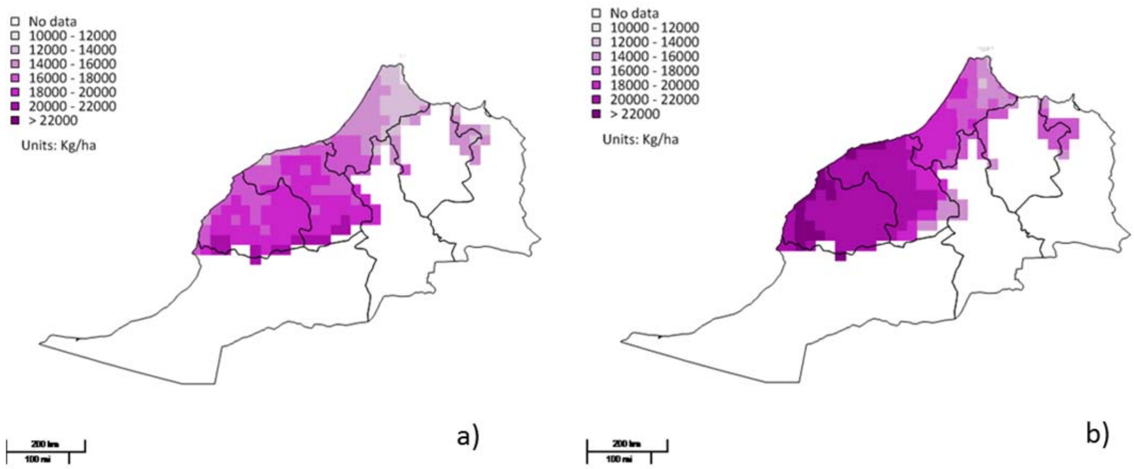

Figure 5 Maximum value of aboveground biomass of the durum variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under potential conditions

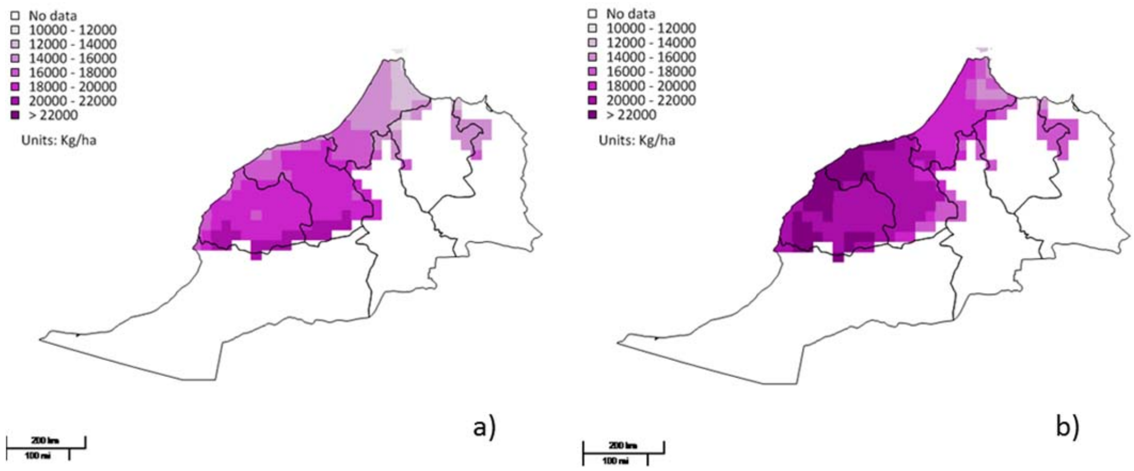

Figure 6 Maximum value of aboveground biomass of the soft high variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under potential conditions

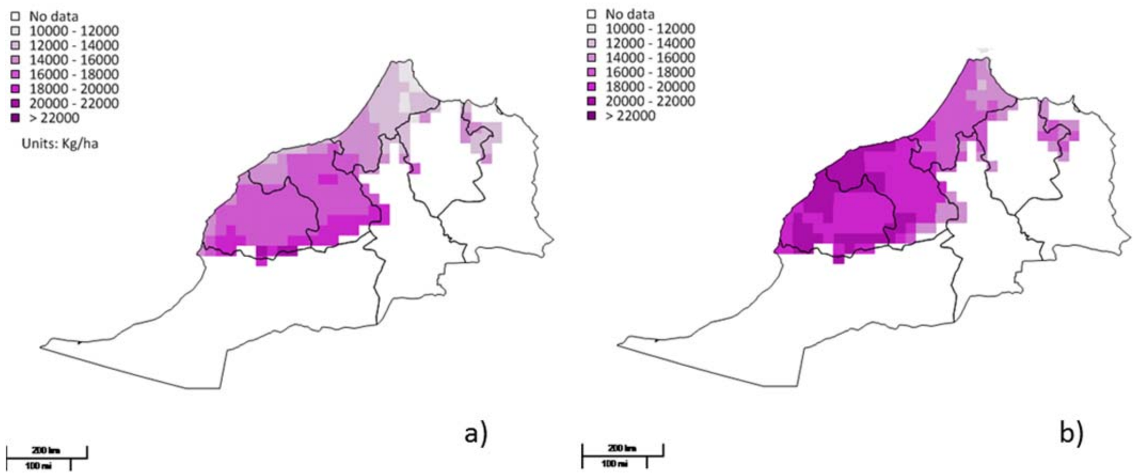

Figure 7 Maximum value of aboveground biomass of the low variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under potential conditions.

3.2.1.2. WOFOST simulations

Figure 8, Figure 9 and Figure 7 show the AGB trends simulated by WOFOST referred to durum, soft - high potential and soft - low potential wheat, respectively.
In the 2011-2012 season, AGB values were higher than 2009-2010, as shown for CropSyst, thanks to higher values of solar radiation. Durum and soft - high potential wheat presented the best performances, as shown for CropSyst. If AGB values simulated by WOFOST are compared to the CropSyst ones, two main differences can be underlined:

- At the northern part of the moroccan cultivated region, AGB values simulated by WOFOST were higher than those simulated by CropSyst for all the groups of varieties. WOFOST simulated the same class of AGB in most of the northern cells and a decreasing trend moving to extreme north was not shown. As an example, in the 2009-2010 seasons for soft – high potential wheat, the AGB class simulated by WOFOST in all the northern grid cells was 16000-18000 kg ha^{-1}, whereas CropSyst AGB ranged from 12000-14000 kg ha^{-1} to 14000-16000 kg ha^{-1}. This is probably due to the values chosen during the calibration activity for some WOFOST parameters involved in plant biomass accumulation. For the calibration and evaluation of CropSyst and WOFOST, field observations collected in the central-western part of the cultivated region were used. Although the two models showed comparable performances during calibration and validation under the weather conditions explored in the experimental sites (see deliverable D34.3), WOFOST simulated higher productions when applied at the northern part of the region.
- At the southern part of the cultivated region, AGB values simulated by WOFOST were lower than the Cropsyst ones. The accumulation of biomass simulated by WOFOST was even lower than values simulated in the northern grid cells by the same model. This is due to the different response of CropSyst and WOFOST to temperature. The response function to temperature adopted by CropSyst is a linear one, assuming values from 0 (base temperature) to 1 (optimum temperature), without a decreasing phase for high temperature values. For this reason the accumulation of biomass simulated by CropSyst increased at south where temperatures were higher. On the contrary, the accumulation of biomass simulated by WOFOST is reduced with temperature higher than the optimum one. Moreover, the plant growth simulated by WOFOST is also influenced by respiration, not accounted by CropSyst which simulates net-photosynthesis. The reduction of AGB accumulation is more marked for soft – high potential and soft – low potential wheat. For durum wheat in 2010, the southern AGB values fluctuated between 16000 kg ha^{-1} and 22000 kg ha^{-1}, which are the same values simulated by CropSyst. In 2012, AGB values simulated by WOFOST ranged from 18000 kg ha^{-1} to 22000 kg ha^{-1} and those simulated by CropSyst from 20000 to values higher than 22000 kg ha^{-1}. These values confirm that the performances of the two models are comparable under these conditions. For soft - high potential wheat, the southern AGB values simulated by CropSyst in 2010 were about 16000-18000 kg ha^{-1} and in 2012 overcame 22000 kg ha^{-1}, whereas WOFOST AGB values fluctuated from 14000 kg ha^{-1} to 18000 kg ha^{-1} in both the studied years. The same differences between the two models can be observed for soft – low productivity wheat. This is due to different

values given to the parameter Reduction Factor of Maximum Leaf CO_2 Assimilation. This parameter was differently calibrated for the three groups of varieties: for durum wheat if the mean air temperature rises above 34°C, the accumulation of biomass decreases, whereas for soft wheat the reduction of AGB accumulation begins at 29 °C.

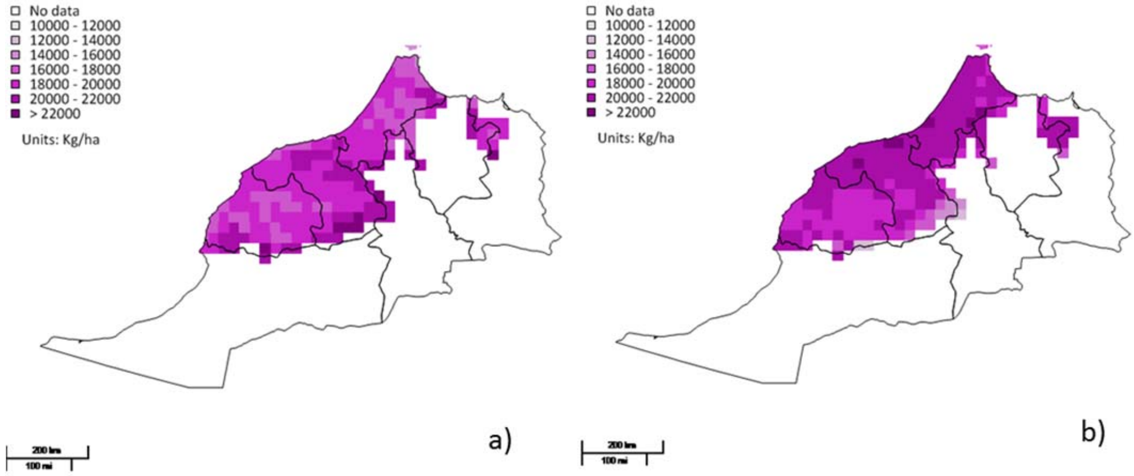

Figure 8 Maximum value of aboveground biomass of the durum variety simulated by WOFOST in: a) 2010 growing season; b) 2012 growing season, under potential conditions.

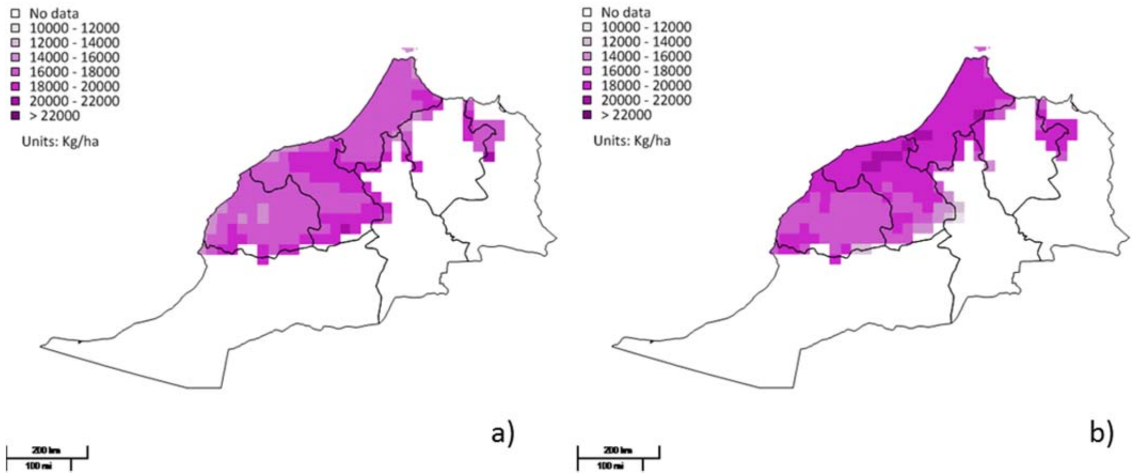

Figure 9 Maximum value of aboveground biomass of soft high variety simulated by WOFOST in: a) 2010 growing season; b) 2012 growing season, under potential conditions.

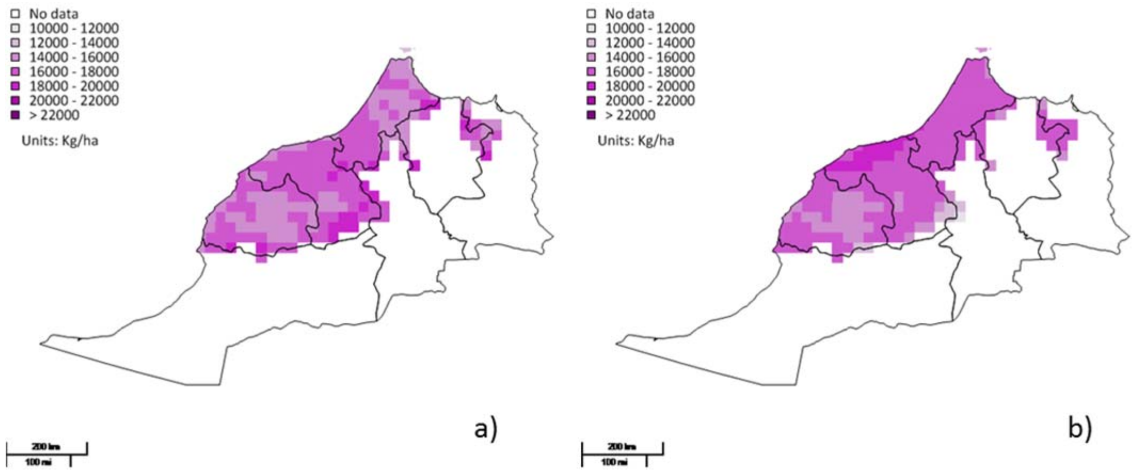

Figure 10 Maximum value of aboveground biomass of the low variaty simulated by WOFOST in: a) 2010 growing season; b) 2012 growing season, under potential conditions.

3.2.2. Water limiting conditions

The simulated wheat biomass under water limiting conditions is lower than for the potential ones. The maximum value reached was 12500 kg ha^{-1}, against 22000 kg ha^{-1} attained in unstressed conditions. Meteorological variables which influence plant growth are temperature, radiation and rainfall. 2009-2010 is the wettest year of the time series analyzed, 2011-2012 is the driest one. The trend of rainfall in the two years is represented and discussed in paragraph 3.1.

3.2.2.1. CropSyst simulations

In the wettest year (20009-2010), the most productive variety group was soft - high potential wheat, which reached in some grid units values of 12500 kg ha^{-1}, followed by durum wheat, whose maximum AGB value was 10500 kg ha^{-1}. The less productive was soft – low potential wheat, which did not overcome the AGB value of 8500 kg ha^{-1}.

For all the groups of varieties, AGB does not follow a north-south pattern, like that presented for potential conditions. Similar rates of biomass accumulation were simulated at northern and southern regions, and this is due to the opposite behaviour of the meteorological variables (temperature-radiation and rainfall). At the northern part of the area precipitations were abundant and did not limit plant growth, but temperatures and solar radiation were not optimal for wheat growth. On the other hand, precipitations during wheat growing season were low in the southern areas and drought caused a decline in growth rates, although temperature and solar radiation were favourable for accumulation of biomass. For this reason the final value of AGB is similar in southern and northern areas. It can also be noted that cells placed inland in the southern part of the cropped area where all meteorological variable were unfavourable (temperature, radiation and rainfall reached the minimum values) presented AGB values belonging to the lowest class (500-2500 kg ha^{-1}).

In the driest year of the time series, rainfall highly influenced wheat growth. At south, rain volumes ranged from 70 to 100 mm, against 225-425 mm of 2011-2012. For this reason, biomass accumulation was highly limited and for all the groups of varieties did not overcome the value of 4500 kg ha^{-1}. Moving to centre and north of the cultivated region, rainfall increased and biomass accumulation reached values of 4500-6500 kg ha^{-1} and even, in few grid cells, 6500-8500 kg ha^{-1}.

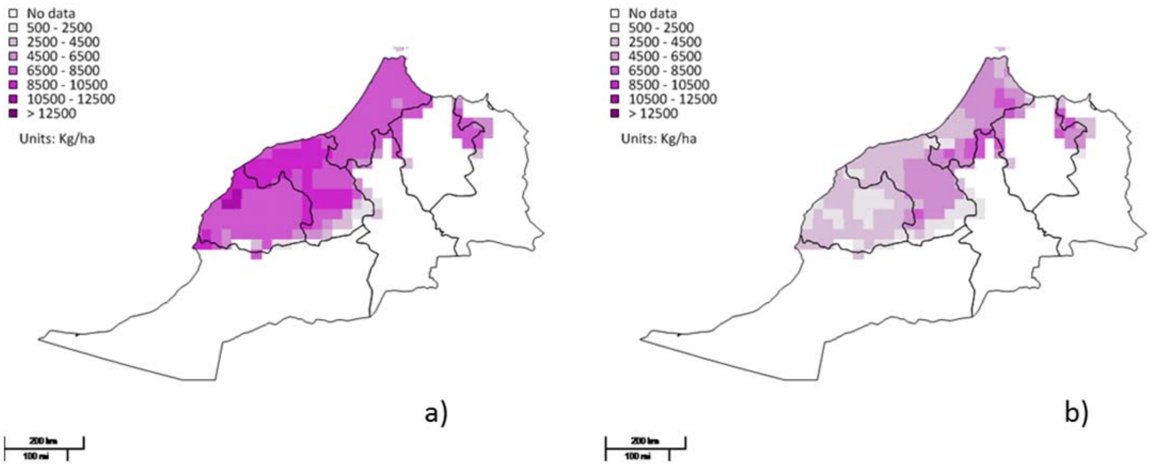

Figure 11 Maximum value of aboveground biomass of the durum variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under water limited conditions.

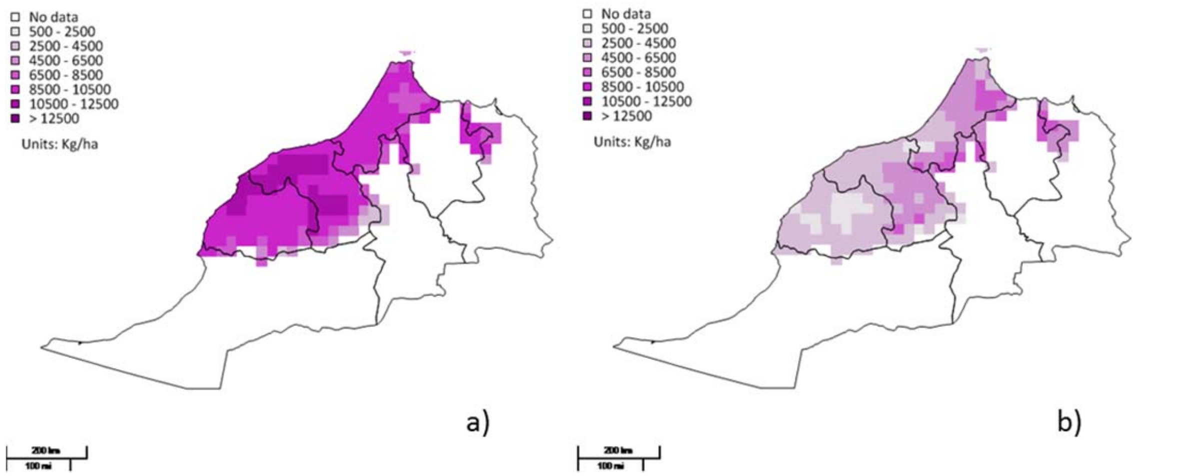

Figure 12 Maximum value of aboveground biomass of the soft high variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under water limited conditions.

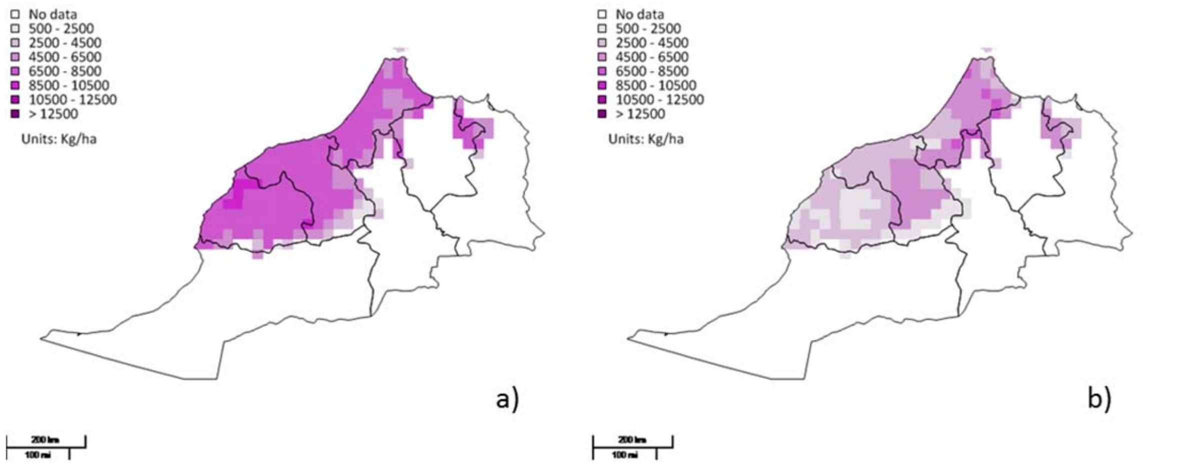

Figure 13 Maximum value of aboveground biomass of the soft low variety simulated by CropSyst in: a) 2010 growing season; b) 2012 growing season, under water limited conditions.

3.2.2.2. WOFOST simulations

AGB values simulated by WOFOST are higher than those simulated by CropSyst for reasons explained in paragraph 3.2.1.2. In the wettest season (2009-2010), the most productive variety groups were durum and soft – high potential, which reached at the northern part of the region AGB values of 12500 kg ha^{-1}. As discussed in paragraph 3.2.1.2., WOFOST biomass accumulation is limited by high temperatures. For this reason, under water limiting conditions AGB values were not constant at north and south, as discussed for CropSyst. At the northern area, thanks to abundant rainfall, AGB ranged from 8500 kg ha^{-1} to 12500 kg ha^{-1} for durum and soft – high potential wheat and from 6500 kg ha^{-1} to 10500 kg ha^{-1} for soft – low potential wheat. In the southern part of the cultivated region, where precipitations were insufficient and temperatures higher, AGB accumulation was lower: for durum and soft – high potential, values ranged from 6500 kg ha^{-1} to 10500 kg ha^{-1}, whereas for soft – low potential, the range was 4500-8500 kg ha^{-1}. In 2011-2012, the simulation of WOFOST is similar to that obtained with CropSyst, for the severe limitation caused by the scarce rainfall.

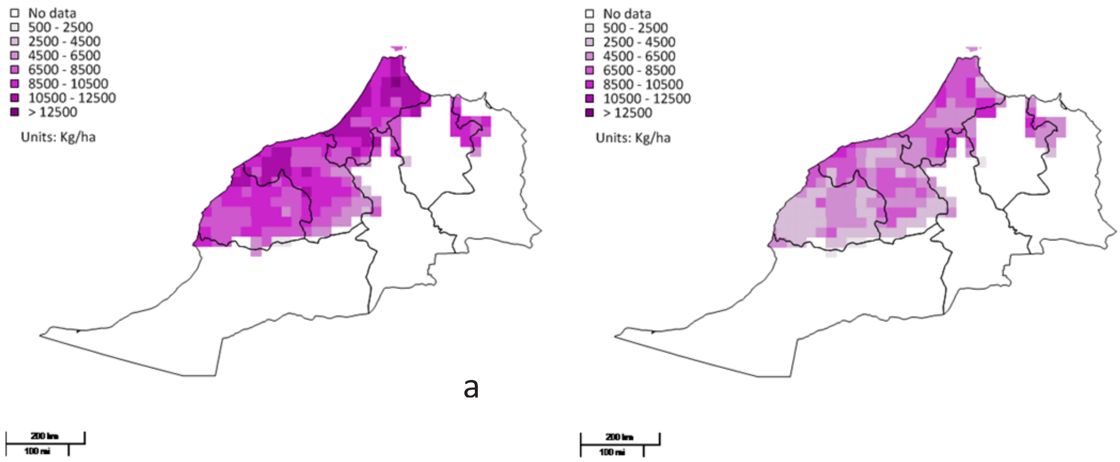

Figure 14 Maximum value of aboveground biomass of the durum variety simulated by WOFOST in: a) 2010 growing season; b) 2012 growing season, under water limited conditions.

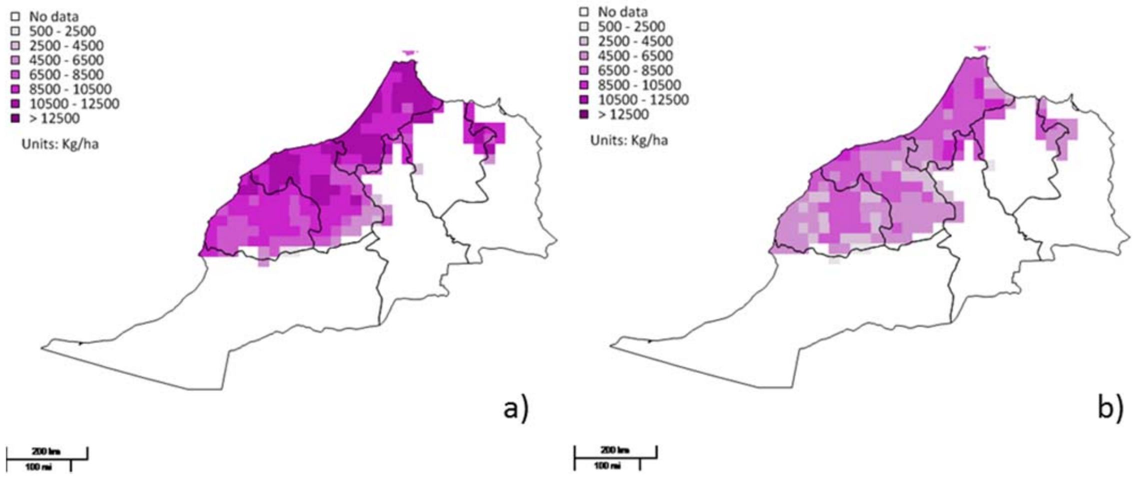

Figure 15 Maximum value of aboveground biomass of the soft high variety simulated by WOFOST in: a) 2010 growing season; b) 2012 growing season, under water limited conditions.

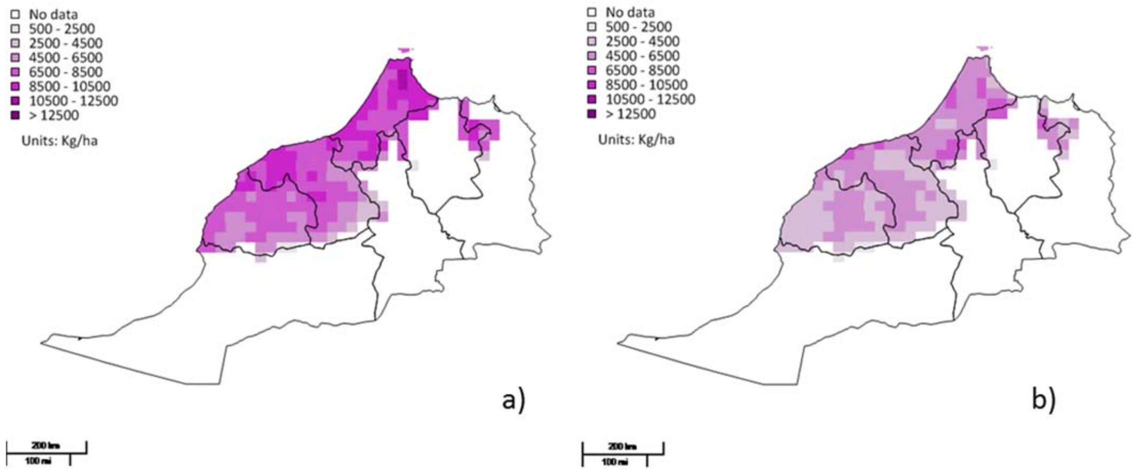

Figure 16 Maximum value of aboveground biomass of the soft low variety simulated by WOFOST in: a) 2010 growing season; b) 2012 growing season, under water limited conditions.

4. Conclusions

The spatial simulations of Aboveground Biomass were performed using the models CropSyst and WOFOST under potential and water limiting conditions. The simulations were separately carried out for the three groups of varieties grown in Morocco (i.e., durum, soft – high potential and soft – low potential). It was chosen to study the differences between AGB accumulation simulated in the wettest and driest year of the 2000-2012 time series to analyse the effect of rainfall on crop growth, considering that most of wheat in Morocco is not irrigated.

The analysis revealed that under both potential and water stressed conditions, durum and soft – high potential wheat were the most productive. Under potential conditions, accumulated biomass ranged from 10000 kg ha^{-1} to 22000 kg ha^{-1}, whereas in stressed conditions the maximum value of AGB accumulated was 12500 kg ha^{-1}.

Under potential conditions, global solar radiation and air temperature were the meteorological variables which mostly influenced wheat growth: both WOFOST and CropSyst simulated lower accumulation of biomass in 2009-2010 then in 2011-2012 because radiation values were lower in the first growing season. AGB pattern simulated by CropSyst exactly followed the gradient of meteorological variables, with higher values reached at the southern part of the region. WOFOST simulated higher values of biomass in the northern areas, but the biomass accumulation was limited in the south by air temperatures above the optimum for photosynthesis.

Under water limiting conditions, rainfall highly influenced wheat growth in the dry season. In the wet one, precipitations at south were lower than in the north, but they did not stress the plant in a relevant way. In the dry year, the volume of rainfall was very low in the wouthern areas and this highly influenced the accumulation of biomass (which declined to 500-4500 kg ha^{-1}).

5. References

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