Modelling of berseem (*Trifolium Alexandrinum*) growth and biomass yield under different levels of water stress in Tadla, Morocco

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Abstract

This work compares the performance of PILOTE, an operative crop model developed by IRSTA Montpellier France, with that of well established model, CropSyst, in simulating berseem (*Trifolium Alexandrinum* L.) growth under different water regimes in the semi-arid climate of Tadla (Morocco). Both based on Beer's law via the intercepted potential active radiation (IPAR) regarding dry matter accumulation, the models differ in the level of complexity describing crop development, biomass growth, root water uptake principle and consequently, in the number of input parameters. The models were calibrated on an unstressed irrigation treatment in 2009/10, and were validated on other stressed and unstressed treatments in 2009/10 and 2010/11. Although PILOTE required fewer input parameters and data than CropSyst, it performed similarly better when simulating both biomass and soil water balance. The use of different numbers of parameters and crop growth modules by the tested models did not influence substantially the simulation results. Therefore, for management purposes and in conditions of limited input information, the use of simpler models should be encouraged.

Keywords: Crop models, berseem, PILOTE, CropSyst, water stress, Morocco.

Résumé

Ce travail compare les performances de PILOTE, un modèle opérationnel développé par IRSTA de Montpellier-France, avec celles d'un modèle plus élaboré, CropSyst, dans la simulation de croissance du bersim (*Trifolium Alexandrinum* L.) conduit sous différents régimes hydriques au Tadla (Maroc). L'accumulation de la matière sèche selon la loi de Beer via la radiation potentielle active interceptée (IPAR) constitue le point commun des deux modèles. Ils diffèrent par le niveau de complexité relative à la description du développement et la croissance de la culture, le principe d'absorption de l'eau par les racines et par conséquent le nombre d'input. Les deux modèles ont été calés sur le régime hydrique non limitant en 2009/10, puis validés sur les autres traitements de 2009/10 et de 2010/11. Bien que PILOTE nécessite moins de paramètres, il s'avère comparable à CropSyst dans la simulation de la biomasse et du bilan hydrique. L'utilisation d'un nombre différent de paramètres et de modules par les deux modèles testés n'a pas influencé sensiblement les résultats de la simulation. Par conséquent, dans un objectif limité à la gestion de l'eau et dans des conditions de manque de paramètres culturaux, l'utilisation de modèles plus simples devrait être encouragée.

Mots clés: Modèle de culture, bersim, PILOTE, CropSyst, stress hydrique, Maroc

INTRODUCTION

In Mediterranean environments, where water resources are limited, it is fundamental to optimize irrigation management, to maximize economic water use efficiency and at the same time, to reduce waste.

The verification of the optimal time and amount of irrigation requires long and expensive field experiments. Furthermore, it is impossible to test all the situations deriving from the combination of time, frequency and seasonal amount of irrigation water. It is also necessary to replicate the experiments over time in order to assess the yearly variability. The overall irrigation scheduling can change significantly depending on sowing time, nitrogen fertilization, and the irrigation system in use.

A more dynamic tool for planning the scheduling of irrigation, taking into account the above mentioned needs, is represented by mathematical simulation models. Once calibrated and validated on experimental data, they can help farmers to choose irrigation strategies either before sowing or during the crop cycle, taking into account the multiple interactions between soil, climate, genotype and crop management (Rizzo et *al.*, 1992).

Among the growth simulation models that can be used for this task, a distinction has to be done between more elaborate models, which simulate main processes of crop growth (leaf area growth, biomass production and its partitioning) and their interaction with all the agricultural practices (irrigation, fertilisation, tillage, residues ….)

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and those simulating crop growth and yield mainly for improving the irrigation management. The first category refers to models such as for instance CERES-maize (Jones and Kiniry, 1986), CropSyst (Stockle *et al.*, 1994), EPIC (Williams *et al.*, 1984), STICS (Brisson *et al.*, 1998) while the second one refers to models such as PILOTE (Mailhol *et al.*, 1997; Khaledian *et al.*, 2009). PILOTE model simulates the effects of water stress on leaf area index considered as a visible indicator of potential production of the plant over its growth.

However, in contrast to PILOTE, these crop models usually differentiate between the effects of water stress on photosynthesis (biomass production), leaf area index, and harvest index (Villalobos *et al.*, 1996; Reddy *et al.*, 1997; Cabelguenne *et al.*, 1999) according to a functional approach at the opposite of that of PILOTE which is somewhat empirical. Consequently, the performance of these crop models should be theoretically less dependent of environmental conditions than models such as PILOTE.

Moreover, due to the lower number of input parameters and the simplifications of some processes, PILOTE model is easier to apply under contexts where the availability of crop parameters is limited. Thus, PILOTE has been successfully applied in environmental contexts far from Lavalette (Montpellier SE of France), the experimental site where it was developed and tested on different crops. The model showed more particularly satisfactory results for maize and durum wheat in Mediterranean context (Mailhol et *al.*, 2004; Khaledian et *al.*, 2009, Bouazzama, 2013) even for other crops such as sugar beet in North west of Morocco (Taky *et al.*, 2009) and in the North of France (Bouarfa *et al.*, 2011).

The present study was carried out with the main objective to evaluate and to compare a crop growth simulation models PILOTE and CropSyst in their ability to simulate berseem growth and biomass yield under different level of water stress in Tadla, Morocco.

MATERIAL AND METHODS

Field experiments

This study was carried out during the growing periods of 2009 - 2011 at the experimental station of Tadla (X = 32.3; Y = 6.31'; Z = 450 m) of the National Institute of Agronomic Research (INRA) (Morocco). The soil was classified as loamy-silt. The climate of this area is semi-arid with a great irregularity of rains. Average annual precipitation is about 268 mm, average temperature is 18 °C with a maximum in August which often exceeds 45°C and a minimum in January of approximately 0 °C.

The climatic variables for growing periods during experimental years are given in Table 1. The climatic data were collected from a local meteorological station. According to Table 1, the growing period of berseem (September-April) includes the rainy period in the region of Tadla (December-March). This period is characterized by relatively low temperatures may be around 0 ° C in January. The rainfall is abundant and often imposed stopping irrigations. The years 2009, 2010 and 2011 during which the experiment took place offer contrasts in climate conditions especially in terms of rainfall.

Before the experiment started, soil samples were collected from soil layers 0-30, 30-60 and 60-120 cm for analyses.

Table 1: Climatic data of the experimental station in the growing periods of 2009-2011

Months	Mean Tmax (°C)		Mean Tmin (°C)		Total precipitation (mm)		ET_0 (mm)	
	2009/10	2010/11	2009/10	2010/11	2009/10	2010/11	2009/10	2010/11
Sept	29.6	33.8	16.4	18.4	17.5	0.0	128	124
Oct	31.9	26.1	14.1	13.3	5.1	51.1	101	83
Nov	25.4	22.0	9.2	9.1	5.0	35.5	60	51
Dec	20.0	20.2	7.0	7.0	82.3	83.8	39	44
Jan	17.4	20.0	5.8	3.7	114.4	29.6	39	46
Feb	19.0	19.9	8.9	3.6	109.8	0.0	49	61
Mar	21.9	21.2	9.8	6.1	63.3	74.5	78	87
April	26.4	27.6	12.0	11.6	19.0	21.6	114	123

Table 2: Some physical and chemical properties of the experimental field soil

Horiz. (cm)	Soil particle size* (%)					FC %	WP %	AD	Calc. Total (%)	MO (%)	P_2O_5 Assim. (ppm)	K_2O Exha. (ppm)	pH	CEps
	A	LF	LG	SF	SG									
0-30	28.1	4.2	48.6	11.8	7.3	33.5	16.4	1.32	14.8	1.91	20.01	1120	7.92	1.04
30-60	43.1	15.6	3.1	12.2	26.2	39.1	20.4	1.44	5.9	1.08	5.14	350	8.09	0.43
60-120	46.7	17.2	20.1	12.3	3.8	41.0	25.1	1.52	12.3	0.76	6.78	224	8.23	0.49

*Soil particle size: A (< 2µm), LF (2µm à 20 µm), LG (20 µm à 50 µm), SF (50 µm à 0,2 mm) et SG (0,2 mm à 2 mm)

FC: Field capacity, WP: wilting point, AD: Apparent density, MO: Organic matter

Some physical and chemical properties of the soil were determined. Undisturbed samples of soil were taken for determining the characteristics of soil water contents. The measurements were performed in the laboratory through pressure pots (method of Richards). Bulk density measurements were carried out in situ by the method of the cylinders. Results obtained are presented in Table 2.

The experiment was laid out in a total randomized design with three replications. The studied factor is irrigation treatment. According to the local irrigation practices, the devices of irrigation are traditional basins of 60 m^2. According to the basin irrigation technique, a flow rate of 12 L/s was applied on one side of the basin until it was fully filled. Spaces of 10 m were considered between plot's treatments in order to minimize the risk of water transfer between compared treatments. Four irrigation regimes were established on the basis of coefficients affecting maximal evapotranspiration (MET) of berseem. Irrigation treatments were 100 %, 80 %, 60 % and 40 % MET for T1, T2, T3 and T4 respectively. The experimental plot area was 2600 m^2.

As crop material, a variety *INRA 6454* was used. This variety is *Miscaoui* type and obtained in Morocco. The seeds were sown by seed drill on 16 September 2009 and on 14 September 2010. The seeding rate was at 32 kg ha^{-1}. Before sowing, 30 kg/ha N, 120 kg/ha P_2O_5 and 80 kg/ha K_2O were applied to all plots. After emergence, treatments of insecticides were applied to limit the effect of the ravagers.

Theoretic water deficit (TWD, mm) for each treatment was calculated by:

$$TWD = Kc.ajst.\ ET_0.\ k_{rc} \qquad (1)$$

Where Kc.ajst is adjusted crop coefficient using methods given in FAO paper n°56, ET_0 is the reference evapotranspiration (mm day^{-1}), in that case MET = Kc.ajst. ET_0. The reduction coefficient K_{rc} defines the irrigation treatments. It was set to 1, 0.8, 0.6 and 0.4 for T1, T2, T3 and T4 respectively. ET_0 was calculated using the FAO Penman Monteith (Allen *et al.*, 1998).

Because of its relatively shallow root system, irrigation was applied for each treatment when cumulative TWD reached 35 mm. This value corresponds to the easily usable soil water reserve for upper 50 cm of soil profile. However, due to the cracking phenomenon, high irrigation durations are required especially during the 5th cycle. Under such conditions, intervals between irrigation events and water amounts vary between treatments (Table 3). Water was supplied by a dam reservoir located at 20 km away. It is of high quality with an electrical conductivity of 0.4 dS/m and a pH of 7.2.

Observations on plants at each treatment were carried out in the middle and at the end of each growth cycle. On the center of each elementary plot, plants samples of an area of 9 m^2 were cut to measure fresh yield for each treatment. To determine dry yield, crop samples were weighed after oven-drying at 80 °C for 72 h. The leaf area index (LAI) was measured by a LAI-2200 plant canopy analyser. This instrument contains the necessary electronics to measure, record and compute the final results of LAI in the field.

Change in the soil water content was measured 2 or 3 times a cycle, before each irrigation event and at each cut. Conventional oven dry (gravimetric) method was used to evaluate soil water content at soil layers 0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm. Other measures of soil water content were performed only under T1 from the beginning of the 2nd cycle of growth in 2010 using a soil moisture probe capacitive sensor (ECH2O-5).

Models description

CropSyst

CropSyst (Stockle *et al.*, 1994, 2003; Stockle and Nelson, 2000) is a multiyear, multi-crop, daily time step crop growth simulation model, developed with emphasis on a friendly user interface, and with a link to GIS software and a weather generator. CropSyst uses the same approach to simulate the growth and development of all herbaceous crops. To reach this aim, simplifications have been introduced to describe some processes, e.g., monolayer canopy; constant specific leaf area (SLA), absence of daily assimilates partitioning. This makes CropSyst easier to calibrate with a reduced set of crop parameters as compared to other models like the CERES (Ritchie *et al.*, 1985; Jones and Kiniry, 1986) model which is very detailed in describing crop physiology requiring more number of crop parameters. These aspects and the

Table 3: Length of cycle (day) and irrigation water amounts applied (mm) in different treatments

Growing year	Treatment		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
2009/10	Length of cycle		61	55	43	36	31
	Water applied (mm)	T1	448	93	0	0	256
		T2	328	141	0	0	207
		T3	215	173	0	0	106
		T4	158	150	0	0	0
2010/11	Length of cycle		62	43	42	41	29
	Water applied (mm)	T1	408	118	102	192	260
		T2	326	106	97	90	211
		T3	219	0	0	101	125
		T4	215	0	0	0	0

possibility of simulating rotations make CropSyst a useful tool for large scale simulations (Confalonieri and Bechini, 2004). The use of a large number of input parameters (about 40 crop input parameters to simulate the production rate of biomass) may improve the modelling results for specific purposes. However, this could require many years of experimental work for adequate calibration and validation of all parameters.

Crop development is simulated on the basis of the accumulated thermal time required to reach each vegetative stage. The model accounts for four potential limiting factors to crop growth: radiation interception, water and N uptake, and temperature. Daily crop growth is based on two different approaches: (i) the radiation dependent biomass growth, based on the photosynthetically active radiation intercepted by the crop, and (ii) the transpiration dependent biomass growth, relying on the estimate of potential crop transpiration. According to the first approach, CropSyst simulates daily above ground biomass production by using the following equation (Monteith, 1977):

$$AGB_{IPAR} = RUE \times IPAR \times T_{lim} \qquad (2)$$

Where AGB_{IPAR} is the daily above ground biomass growth dependent on the intercepted photosynthetic active radiation; RUE is the light to above ground biomass conversion factor or radiation use efficiency; T_{lim} is the temperature limitation factor; and IPAR is the intercepted photosynthetically active radiation. According to the second approach, CropSyst simulates daily aboveground biomass production by using the following equation (Tanner and Sinclair, 1983):

$$AGB_T = T_{act} \times BTR/VPD \qquad (3)$$

Where AGB_T is the transpiration dependent growth; T_{act} is the actual transpiration; BTR is the above ground biomass-transpiration coefficient; and VPD is the daily mean vapor pressure deficit, used to normalize BTR.

Therefore in CropSyst, the production rate of biomass is simulated by capture of either radiation or water, depending on the most limiting factor among them. Transpiration is assumed to be equal to crop water uptake, which is a function of soil and leaf water potential, and root conductance.

The soil water budget of CropSyst includes precipitation, irrigation, runoff, water infiltration and redistribution in the soil profile, crop transpiration, and soil evaporation. Water redistribution in the soil can be simulated by a simple cascading approach or a numerical solution of the Richard's equation to determine soil water fluxes. The numerical solution corresponds to a finite difference scheme, similar to that introduced by Campbell (1985) and refined by Ross and Bristow (1990) for layered soils. Reference evapotranspiration is estimated either by the Penman-Monteith approach (Allen *et al.*, 1998) or by the Priestley-Taylor equation (Priestley and Taylor, 1972) depending on the availability of weather data.

Root growth in CropSyst is described in terms of root depth and root density. Crop water uptake and actual crop transpiration are considered equal, so crop water storage is assumed negligible. For crop water uptake estimation, the soil profile is divided into layers, and the water uptake of each layer is calculated from the water potential difference between the soil and the plant xylem, multiplied by plant conductance (mainly determined by root conductance).

The soil conductance is assumed to be large compared to root conductance so that water uptake is not limited by water movement towards the roots. Water uptake in ((kg/m²)/day), from each soil layer i is given by:

$$WUi = K \cdot Ci/1.5 \cdot (\Psi si - \Psi l) \qquad (4)$$

Where Ψsi (J/kg or m²/s²) is the soil water potential of soil layer i. Ψl (J/kg or m²/s²) is the leaf water potential. Ci is the layer root conductance. K (86 400) is the number of seconds per day. The total water uptake WU is the sum of the uptake from each soil layer.

Water-limited growth is calculated using parameters that directly limit biomass accumulation, including the ratio of actual to potential evapotranspiration, leaf water potentials that induce stomatal closure and wilting, and phonological sensitivities to water stress (Stockle and Nelson, 2000; Stockle *et al.*, 2003). Water-limited yield is calculated by using parameters that affect the yield through the limitation of assimilate translocation, like sensitivity to water stress at flowering and at maturity.

Crop yield is calculated by multiplying total biomass at harvesting by the unstressed HI (Stockle and Nelson, 2000). In CropSyst, HI is determined using as a basis an unstressed HI, modified according to stress intensity (water and N) and crop sensitivity to stress during flowering and grain filling.

In the case of folder crops harvested several times as berseem, biomass yield may be determined based on a percentage of the dry biomass accumulated in the day of cutting or as a function of a quantity of biomass to be removed from the biomass the day of the cutting. To ensure regrowth after cutting, the model defines for each cycle a minimum green leaf area index (GAI).

PILOTE

PILOTE simulates soil water balance and crop yield at a daily time step by association of a soil module and a crop module, assuming that water is the only limited condition. The soil module consists of a three-reservoir system (Mailhol et *al.,* 1996*,* 1997) covering surface layer until the maximum rooting depth. The reservoir with shallow depth of 10 cm rules the water balance at the soil surface, in which evaporation is governed by current LAI acting on the partitioning coefficient between transpiration and evaporation. The following reservoir R_2 accounts for root section, so its capacity increases with root growth. Before the potential root area is totally taken by the second reservoir, the third reservoir represents the remaining part. Water is first taken from the shallow reservoir until total depletion by evaporation and plant then, from the second one by plant only. On the basis of field capacity (Fc) and wilting point (Wp), the soil water balance among reservoirs is thus calculated. Maximal evapotranspiration (MET), and actual evapotranspiration

(AET) are involved in the water stress index (WSI) calculation. MET is derived from MET = Kc.ET_0, where ET_0 is the reference evapotranspiration (Allen *et al.*, 1998) and Kc, the crop coefficient as a function of LAI. Under water stress conditions, that occur when the easily usable water reserve derived from the ratio Kr of Doorenbos and Kassam, (1979) is depleted, AET linearly decreases from MET with the depletion level of R_2. Then, WSI, obtained accordingly to this lumped plant uptake approach, is exported to the crop module as environment coefficient.

The crop module is based on the LAI simulation according to Eq (5) and its response to WSI associated to λ a parameter governing the sensitivity to water stress. This simulation involves two shape parameters (α which changes into γ after the LAI peak was reached and β) calibrated on a full irrigated treatment, and a vegetative stage parameter (t_p) corresponding to the temperature sum when the maximum LAI (LAI_X) is reached.

$$LAI(j) = LAI_x \left[\left(\frac{\sum_{k=1}^{j} TT - ts}{t_p} \right)^{\beta} \exp\left\{ \frac{\beta}{\alpha} \left(1 - \left(\frac{\sum_{k=1}^{j} TT - ts}{t_p} \right)^{\alpha} \right) \right\} - \left(1 - WSI^{\lambda} \right) \right] \quad (5)$$

With TT= Tm-Tb, Tm = daily average temperature, Tb = the base temperature. t_p and LAI_X can be derived from the literature or measured in the field for a specified plant density. Total dry mater (TDM) for a given day j is calculated based on Beer's Law and formulated as in Mailhol and Merot (2008):

$$TDM(j) = RUE.\ Rg(j).WSI^{\lambda}.\ [1-\exp(-kLAI(j)] \quad (6)$$

Where Rg is global radiation (J/m^2), WSI is a water stress index calculated as the ratio between actual transpiration and potential transpiration, k = min (1.0, 1.43.LAI $^{-0.5}$), the extinction coefficient. As CropSyt, grain yield is evaluated at the end of the cropping cycle by the product of TDM by a harvest index (HI). The latter is set to a potential value if average LAI from the stage 'grain filling' to the stage of ''pasty grain' (for instance in the case of a field crop) is greater than a threshold value (a model parameter), otherwise, to account for a water stress impact, it linearly decreases (Mailhol *et al.*, 2004; Khaledian *et al.*, 2009). The required daily climatic data are precipitations, global radiation, average temperature and ET_0.

In the PILOTE adapted version for Crau hay which used in this work for berseem, the daily accumulation of dry matter (MST) is calculated according to (Mailhol and Merot, 2008):

$$MST(j) = MST(j-1) + RUE.Rg(j).R_P(j)(1-\exp(-k.LAI^*(j)) \quad (7)$$

Where LAI* is the value of LAI without stress. R(j)=CLAI/CLAI* is the relationship between two cumulative values of LAI of three days preceding the day j. This ratio is calculated within a critical period defined by two temperature thresholds that allow the correction of the potential biomass between two cuts.

Models performance evaluation

The validations were based on the comparison between simulated and observed data for all treatments other than those used in model calibration: T2, T3 and T4 treatments in 2009/10 and all the treatments in 2010/11. The following parameters were analyzed: (i) biomass growth over each growing cycle and final biomass (ii) leaf area index evolution over the growing cycle and (iii) soil water reserve (SWR) calculated as:

$$SWR = \int_0^{R\max} \theta(z)dz$$

from 0 to Rmax, maximal root depth. In addition to graphical comparisons, there are several statistical indices to compare between predicted and observed values. The model results were evaluated using two performance criteria: the root mean square error (RMSE) and the coefficient of efficiency (Ce) of Nash-Sutcliffe (ASCE, 1993; ASCE: American Society of Civil Engineers). These indices take the following form:

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} (P_i - O_i)^2 \right]^{0.5} \quad (8)$$

And

$$Ce = \left[1 - \left[\sum_{i=1}^{n} (P_i - O_i)^2 / \sum_{i=1}^{n} (P_i - \overline{O_i})^2 \right] \right] \quad (9)$$

Where, n is the number of cases, O is observed value, $\overline{O}$ is mean of observed values and P is predicted value.

RESULTS AND DISCUSSION

Calibration of the models

The models were calibrated on the full irrigated treatment T1 in 2009/10. Initially, soil, weather, and irrigation files were prepared similarly for the two models. Thereafter, measured and estimated crop parameters from experimental results were inserted in the models. More specifically for CropSyst, the final phase of calibration consisted in the refinement of other parameters so that simulated values fit well with observed data. In fact, the parameters were changed manually around the default values until the best fitting with measured data was achieved.

CropSyst

Only biomass-transpiration coefficient (BTR) and extinction coefficient for solar radiation were determined by calibration, since the model was very sensitive to these parameters under Tadla conditions. Specific leaf area (SLA) was determined using regression analysis of leaf area versus leaf weight.

In CropSyst, the cuts can be automatic by setting a cumulative biomass threshold or specified at fixed dates. In this study, the cuts are made at the times when the plants berseem under the water regime T1 reaches a height of about 40 to 50 cm.

Considering a base temperature (Tb) of 3 °C, the accumulated thermal time necessary for germination was maintained at 100 °C. The field observations have confirmed that over 50% of germination occurs 3 to 4 days after first irrigation of sowing. Temperature values set at 3 °C for T_b and 22 °C for T_{cutoff} were seem reasonable because of the growing period of the crop positioned largely in winter (September to April) who knows relatively low temperatures (Table 1). According to Bounjemate (1997), the berseem prefers areas with mild winter and no freezing. Its growth is optimal when the temperature is between 12 and 25 ° C.

Root profiles made in late April 2010 under T1 regime showed that the roots reach 80 cm as the maximum depth and are very dense in the upper 50 cm of the profile. Monitoring of LAI using LICOR 2200 plant canopy analyzer during all growth cycles in 2010/11 has set the LAI_X at 5.21 $m^2.m^{-2}$. This value was recorded at the end of the 2nd cycle with a density of 350 plants per m^2. The maximum value of LAI measured by Naranda et *al*. (2003) in India for the berseem sown in a weighing lysimeter is registered in the 5th cycle to 3.9 for a variety native to Egypt. The maximum crop coefficient (Kcmax) was calculated for the berseem taking the value proposed by Allen et *al*., (1998) and then adjusted to the climatic conditions of Tadla as described in the FAO bulletin No. 56. A value of 1.20 was assigned to this parameter.

Specific leaf area (SLA) and stem/leaf partition coefficient (SLP) were measured from samples of plants berseem taken at various dates during the five cycles in 2009/10. A relationship was established between leaf area measured using a leaf area meter (LI COR 3100) and leaf dry weight. The value of this parameter was set at 27.9 $m^2.kg^{-1}$ (Bouazzama, 2013). This value is slightly lower than the measured value (28.2 $m^2.kg^{-1}$) by Antolin et *al*., (1995) for alfalfa under water and nitrogen comfort. The ratio SLP was calculated from the determined field values. The value considered for the model is the average of the values obtained under T1 which is 1.87 with a CV of 11.3%.

Maximum water uptake of berseem in Tadla was derived from monitoring of water balance at lysimeter drainage. The maximum daily average consumption was recorded at the end of the last cycle on 19 April; it is 7.1 mm / day (Bouazzama, 2013). This value is similar to that measured by Naranda et *al*. (2003) in India which found 6.9 mm / day in the 5thcycle (ie 25 weeks after sowing) of berseem conducted in a lysimeter weigh.

The coefficient of transpiration biomass was calibrated at 5.5 $kPa.kg.m^{-3}$. This value is slightly higher than the default value, which is 5 $kPa.kg\ m^{-3}$. The value recommended by Stanhil (1986) for C3 crops is 3 $kPa.Kg.m^{-3}$. Concerning the extinction coefficient, the value that improves the simulations; is set to 0.60. This value is slightly higher than the measured value for alfalfa by Sheehy and Popple (1981) witch varies between 0.42 and 0.57. Solar radiation efficiency is set to the default option for alfalfa (2.25 $g.MJ^{-1}$). This value exceeds that measured by some researchers for the same crop well maintained and irrigated (eg 1.71 $g.MJ^{-1}$ by Duru and Langlet, 1989; 1.72 $g.MJ^{-1}$ by Duran et al., 1989; 2 15 $g.MJ^{-1}$ by Whitfield et al., 1986).

Since the initial leaf area index varies after the first cut (new buds emission phenomenon), this parameter was calibrated to 0.021 m^2 / m^2 to improve the simulation of leaf area index. Graves et *al*. (1996) reported that the expansion and growth of the basal plate and regeneration of new buds contribute much to the variation of the biomass produced after the first cut.

PILOTE

For PILOTE, calibration focused first on the shape parameters of LAI. The three parameters are changed manually around the defaults value. LAIx value was fixed at 5.21, which is measured in field immediately before the cutting of the 2nd cycle.

For simulating LAI and dry matter yield under water stress, the value of λ was set at 1.25 as the value generally adopted for field crops (Khaledian et *al*., 2009). Due to the lack of measured values for berseem, the starting value of RUE was set at 0.6 which corresponds to that measured by several authors for alfalfa. A calibration of this parameter was performed subsequently to improve simulations of biomass yield. The characteristics of the soil (WP and Fc) were set to averaged values for the three soil layers corresponding to the three reservoir simulation of the water balance. Kr parameter was set to 0.5 according to the values proposed by Doorenbos and Kassam (1979). Kcmax has been adjusted to the conditions of Tadla through the method proposed in the FAO bulletin No. 56 and was set at 1.20. This value does not differ much from that obtained through the lysimeter drainage that is 1.21 measured at the final phase of the 5th cycle in 2010/11. The maximum rooting depth measured at the profile under T1 is 0.80 m. Root rate growth was set at 0.015 m / day.

The crop parameters used in this study are given in Tables 4 and 5 for CropSyst and PILOTE respectively. The values are classified in the tables as to weather they were default data, or were calibrated data derived manually by changing the default value, or were data estimated from the available information and in-field measurements and observations. Parameters given in the previous two tables were used to simulate growth, LAI and soil water reserve under unstressed irrigation treatment T1 (2009/10). The results are shown in figures 1, 2, and 3 for CropSyst and figures 4, 5 and 6 for PILOTE model.

According to the results presented in figures 1.a and 4.a, the quality of biomass simulation is satisfactory for both models. Statistical indices are almost equal and confirm these performances (low RMSE and high Ce). Regarding biomass yield at cuts, CropSyst overestimated the value obtained in 2nd cycle and underestimated slightly the value obtained in first and 5th cycle while PILOTE overestimated measured value in the 1st cycle and underestimated biomass yield measured in the 4th cycle. Considering the total annual of biomass obtained under T1 (14.1 t / ha), both models showed a slight underestimation with more accuracy for PILOTE (PILOTE simulates 13.8 t/ha while CropSyst simulated 13.7 t/ha). The representation of the simulated biomass versus measured (graph 1: 1) illustrated by figures 1.b and 4.b confirms the performance of both models.

Model simulation of LAI showed more accurately for CropSyst with an overestimation of value measured in the 2nd cycle, while PILOTE underestimated especially values at ends of cycles 2, 3 and 4. Based on the statistical indices, LAI predictions of both models are satisfactory. Values of Ce are 0.78 and 0.89, while those of RMSE are 0.55 and 0.42 for PILOTE and CropSyst respectively. PILOTE performance is significant in view of the effects of temperature on leaf growth, which are not simulated by the model. Simulated values by the models plotted against experimental data shows the level of point's dispersion around the bisector.

Regarding soil water reserve on root profile (0-80 cm), prediction throughout the growing season under treatment T1 in 2009/10 by both models (Figure 3 and 6) are satisfactory with more accurately in favor of PILOTE. Simulation accuracy is better when considering values measured by gravimetry than those obtained using the capacitive sensors. Considering SWR calculated from moisture values measured by gravimetric analysis, statistical indices obtained are 0.8 and 0.9 for Ce and 14.0 and 8.2 mm for RMSE for CropSyst and PILOTE respectively. SWR evolution is well reproduced by models in a situation of high water contents with slight overestimation in water stress (4^{th} and 5^{th} cycle).

Table 4: CropSyst crop parameter values used for berseem (M: measured, Cal: calibrated, L: extracted from the literature or D: default value)

Parameters	Source	Value
Biomass transpiration coefficient, kPa.kg.m^{-3}	Cal	5.5
Light to biomass conversion, g.MJ^{-1}	D	2,5
At/Pt that limits root growth	D	0.5
Optimum mean daily temperature for growth	D	20
Xylem critical water potential, J.kg^{-1}	D	-900
Xylem wilting water potential, J.kg^{-1}	D	-1600
Maximum root depth, m	M	0.80
Initial green leaf area index, m^2.m^{-2}	Cal	0.021
LAIx	M	5,21
Green LAI at physiological maturity	D	1
Specific leaf area, m^2.kg^{-1}	M	27.9
Stem/leaf partition coefficient	M	2.6
Leaf duration, degree days	D	800
Extinction coefficient	Cal	0.60
Maximal value of the crop coefficient	M	1.20
GDD sowing-emergence	M	100
GDD maximum root depth	D	1040
GDD leaf duration		9999
GDD end of vegetative growth		9999
GDD begin flowering		9999
GDD begin filling		9999
Base temperature	L	3
Cut-off temperature	L	22

Table 5: PILOTE crop parameter values used for berseem

Parameters	Source	Value
Efficiency of solar radiation (g. MJ^{-1})	L	0.6
GDD sowing-flowering (°C j)	M, L	700
Aversion coefficient to water stress	L	1.25
Shape parameters: α, β, γ	Cal	2.2, 0.5, 2.5
GDD sowing-emergence (°C j)	L	80
Base temperature (°C)	L	3
Maximum root depth (m)	M	0.8
RFU/RU	L	0.5
Root growth rate (m/j)	L	0.015
GDD installation of root system (°C j)	L	150
LAIx	M	5.21
LAI after cut	Cal	0.4
Kcmax	M	1.20

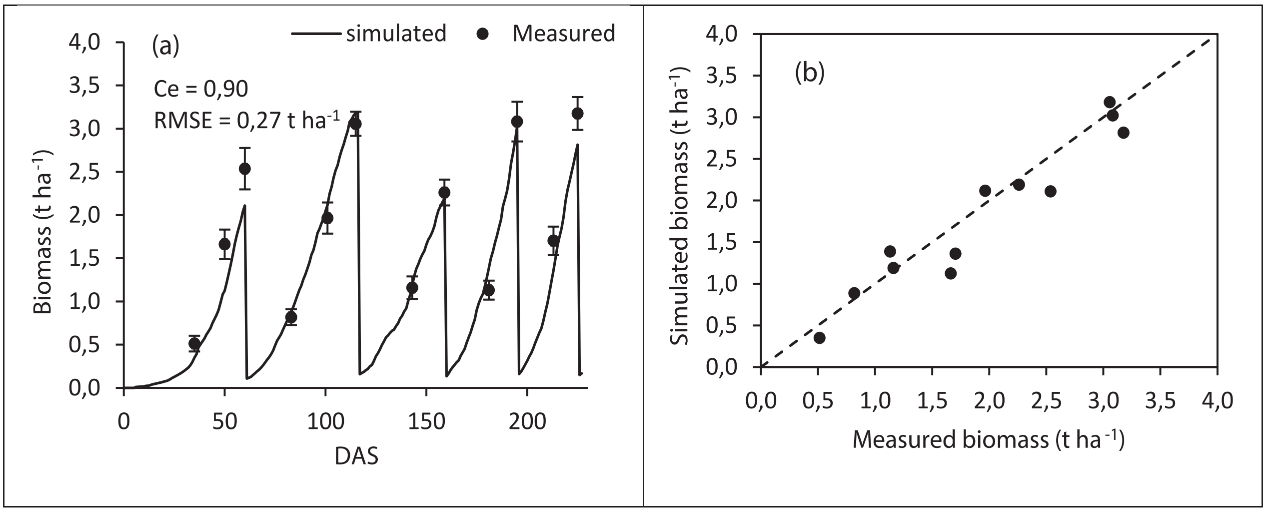

Figure 1: (a) Measured and simulated biomass growth by CropSyst for the unstressed irrigation treatment T1 (calibration) in 2009/10 and (b) on (1/1) graph

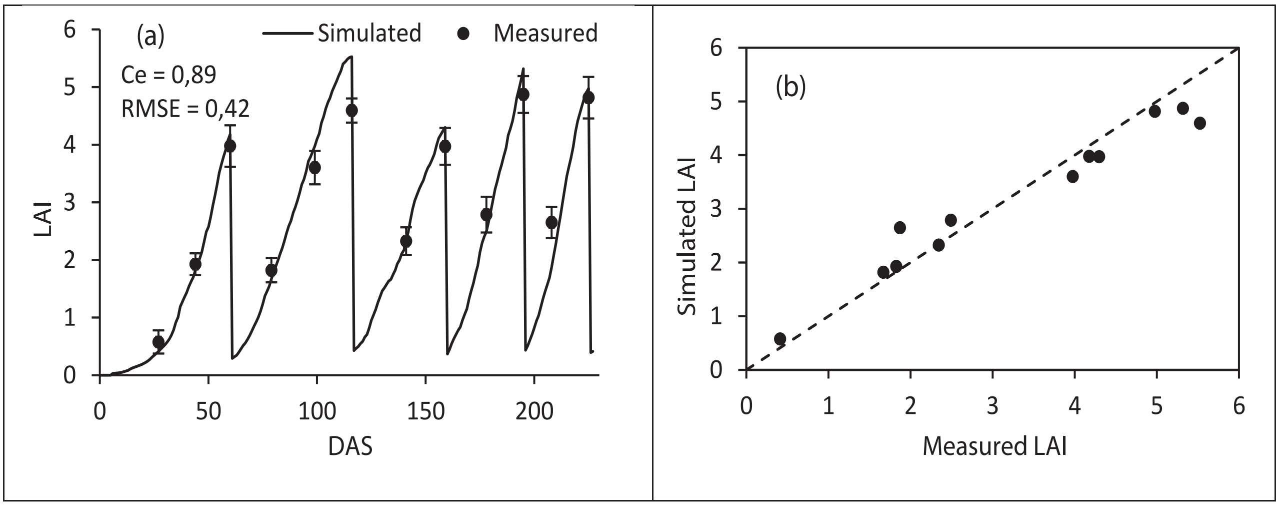

Figure 2: (a) Measured and simulated leaf area index by CropSyst for the unstressed irrigation treatment T1 (calibration) in 2009/10 and (b) on (1/1) graph

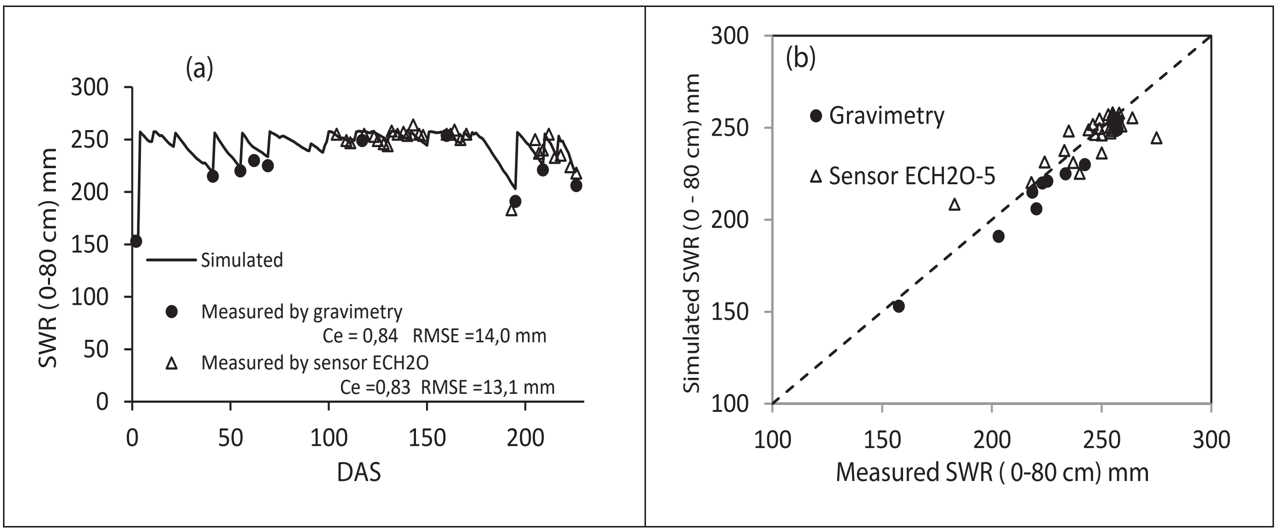

Figure 3: (a) Measured and simulated SWR by CropSyst under the unstressed irrigation treatment T1 (calibration) in 2009/10 and (b) on (1/1) graph

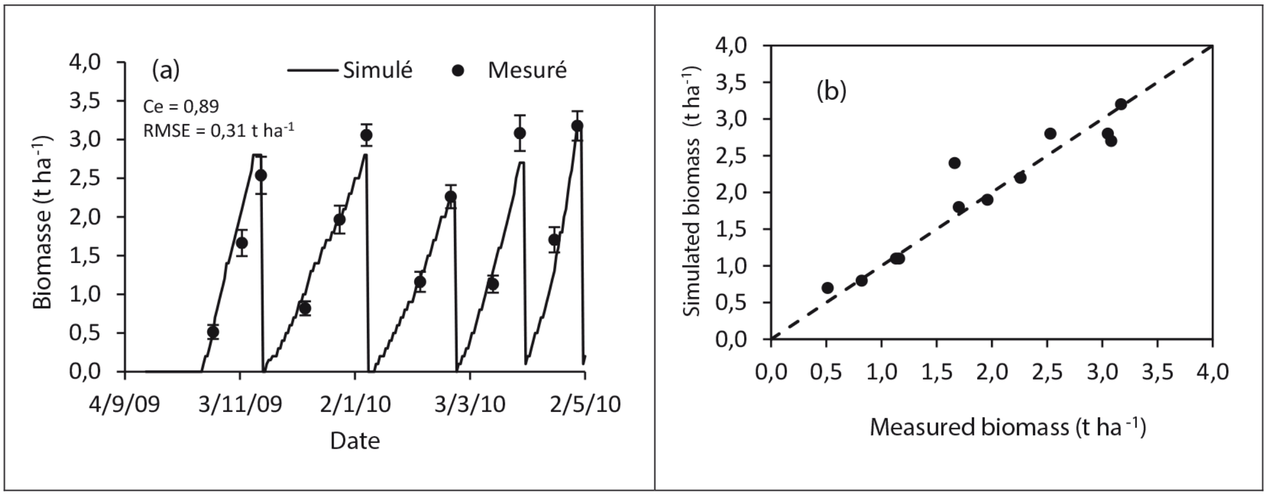

Figure 4: (a) Measured and simulated biomass growth by PILOTE for the unstressed irrigation treatment T1 (calibration) in 2009/10 and (b) on (1/1) graph

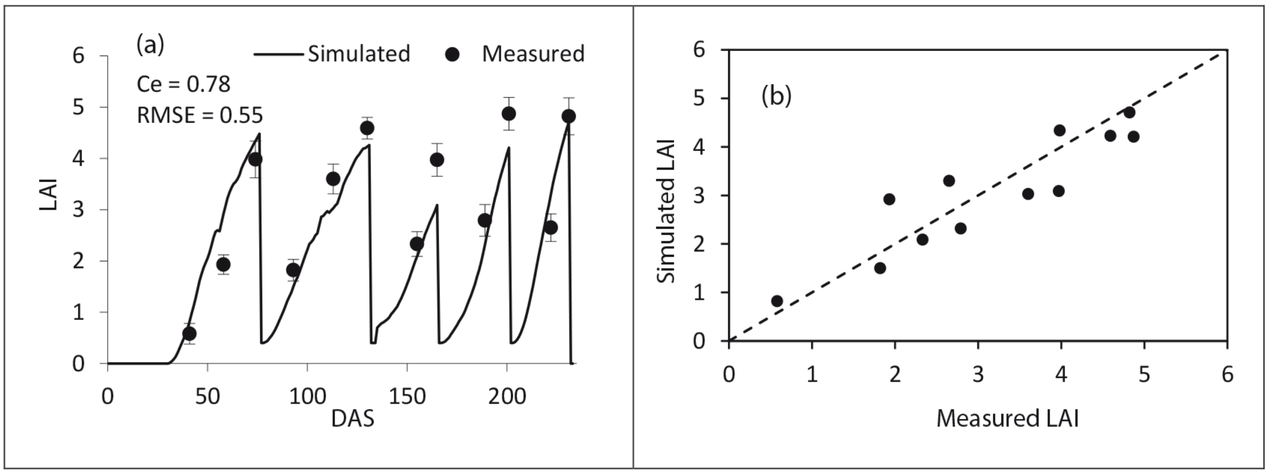

Figure 5: (a) Measured and simulated leaf area index by PILOTE for the unstressed irrigation treatment T1 (calibration) in 2009/10 and (b) on (1/1) graph

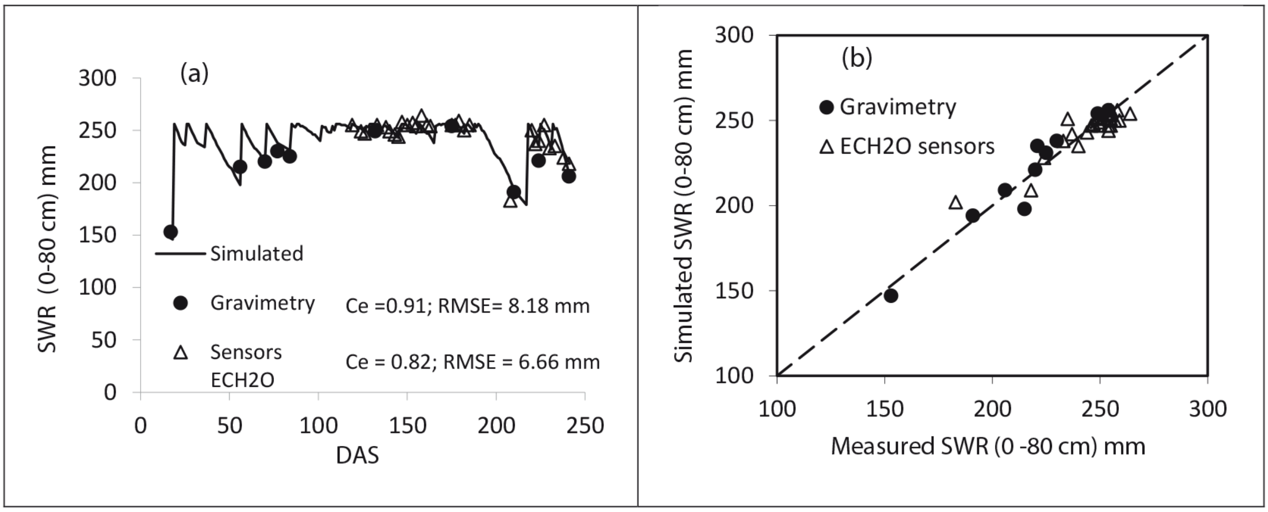

Figure 6: (a) Measured and simulated SWR by PILOTE under the unstressed irrigation treatment T1 (calibration) in 2009/10 and (b) on (1/1) graph

Validation of the models

The parameters derived from calibration were used for validation and performance evaluation of PILOTE and CropSyst by using data from three irrigation regimes in 2009/10 (T2, T3 and T4) and the four treatments in 2010/11. The performance of models reported in Table 6, are given separately for each treatment, accounting for biomass growth (intermediate and at cut) and also for the whole of the treatments.

According to the results presented in Table 6, overall biomass simulations are almost satisfactory for the two models and for all treatments with more performance for CropSyst. The predictions of biomass growth during the season were slightly better for 2009/10 (year of calibration) than for 2010/11. Note that the weather conditions, which affect the production potential of biomass, are quite different between the two considered seasons, more rain and less evapotranspiration in 2009/10 than in 2010/11, which affects the production potential of biomass. For both growing years, the results show that the growth of biomass is better simulated under water stress regimes (T3 and T4). A general tendency to under estimate the growth of biomass models is recognized under non-stressed systems.

Considering all the treatments used for validation, we can confirm that both models reproduce well the evolution of biomass. The CropSyst model seems more accurate than PILOTE, since the values of the statistical indices are 0.287 and 0.263 t / ha for RMSE and 0.81 and 0.87 for PILOTE and CropSyst respectively.

The performance of the models on the simulation of biomass was also evaluated by considering biomass yield at cuts for all regimes used in validation (table 7). The RMSE and Ce values were 0.187 t/ha 0.73 respectively for PILOTE while the same indices become 0.24 t ha^{-1} and 0.81 respectively in the case of CropSyst.

Regarding LAI, we notice more accuracy for PILOTE model. Indeed, RMSE and Ce values are 0.49 and 0.81 for PILOTE and 0.54 and 0.77 for CropSyst respectively. The accuracy of predictions increases slightly with water stress and is better for year calibration 2009/10. The RMSE values range from 0.52 under T1 (2010/11) and 0.41 for T4 regime (2009/10). The efficiency coefficient ranges from 0.85 for T4 to 0.78 under T1 (2010/11).

In some situations, the delay in implementing the cuts after rain induced downpour of berseem associated with rotting plants in ground contact and consequently a reduction in yield. This phenomenon is not simulated by the model and partially overestimates yields frequently observed in 2nd cut (early January). Variations in the residual biomass from one cycle to another (winter and spring cycle) may lead to under or overestimation of LAI and therefore biomass at the end of the cycle. In CropSyst model, this problem is partially limited since the model specifies the residual biomass at the beginning of each cycle.

Referring to the predictions of soil water reserve on the soil depth exploited by roots (0-80 cm) under all water regimes (table 8), the quality of the simulations is satisfactory for both models under all treatments. The PILOTE predictions are more accurate than those of CropSyst. The RMSE and Ce values are 8.43 mm and 0.89 for PILOTE and 12.6 mm and 0.83 in the case of CropSyst respectively. Simulations

Table 6: Statistical indices derived for evaluating the performance of the PILOTE and CropSyst models in predicting biomass growth for each treatment used for model validation

Growing Year	Treatment	PILOTE		CropSyst	
		RMSE (t/ha)	Ce	RMSE (t/ha)	Ce
2009/2010	T2	0.341	0.81	0.234	0.89
	T3	0.293	0.79	0.219	0.88
	T4	0.261	0.86	0.208	0.88
	T2, T3, T4	0.284	0.82	0.226	0.89
2010/2011	T1	0.314	0.77	0.307	0.83
	T2	0.283	0.84	0.303	0.87
	T3	0.251	0.84	0.232	0.89
	T4	0.287	0.82	0.247	0.88
	T1, T2, T3, T4	0.282	0.81	0.274	0.87
All treatments (2009/10 and 2010/11) All treatments		0.287	0.81	0.263	0.87

Table 7: Comparing indices between simulated and measured values at cuts of biomass, LAI and soil water reserve

Model	Model output	RMSE	Ce	Slope	Intercept	R^2
CropSyst	Biomass	0.239 t/ha	0.81	0.86	0.291 t/ha	0.81**
	SWR	12.6 mm	0.83	0.99	-7.03 mm	0.89***
	LAI	0.57	0.78	0.80	0.34	0.77*
PILOTE	Biomass	0.20 t/ha	0.73	0.91	0.269 t/ha	0.72*
	SWR	11.3 mm	0.84	1.01	-18.3 mm	0.92***
	LAI	0.31	0.78	0.68	1.33	0.84**

in 2009/10, which is the year of calibration, are better than those of the 2nd growing year. In 2010/11, the performances of the models are better under water stress regimes than that most irrigated. The number of limited irrigations under T4 compared to T1 implies a better estimate of water content in soil profile.

Table 8: Statistical indices derived for validation of PILOTE and CropSyst models in predicting soil water reserve (SWR)

Growing year	Treatment	PILOTE		CropSyst	
		RMSE (mm)	Ce	RMSE (mm)	Ce
2009/2010	T2	5.81	0.95	11.1	0.89
	T3	8.24	0.96	13.8	0.88
	T4	9.91	0.92	14.7	0.88
	All treatments	8.11	0.93	11.5	0.89
2010/2011	T1	9.83	0.82	13.7	0.83
	T2	7.76	0.89	12.7	0.87
	T3	10.2	0.92	11.6	0.89
	T4	8.41	0.94	11.4	0.88
	All treatments	9.14	0.88	10.3	0.87
All treatments (2009/10 and 2010/11)		8.43	0.89	12.6	0.83

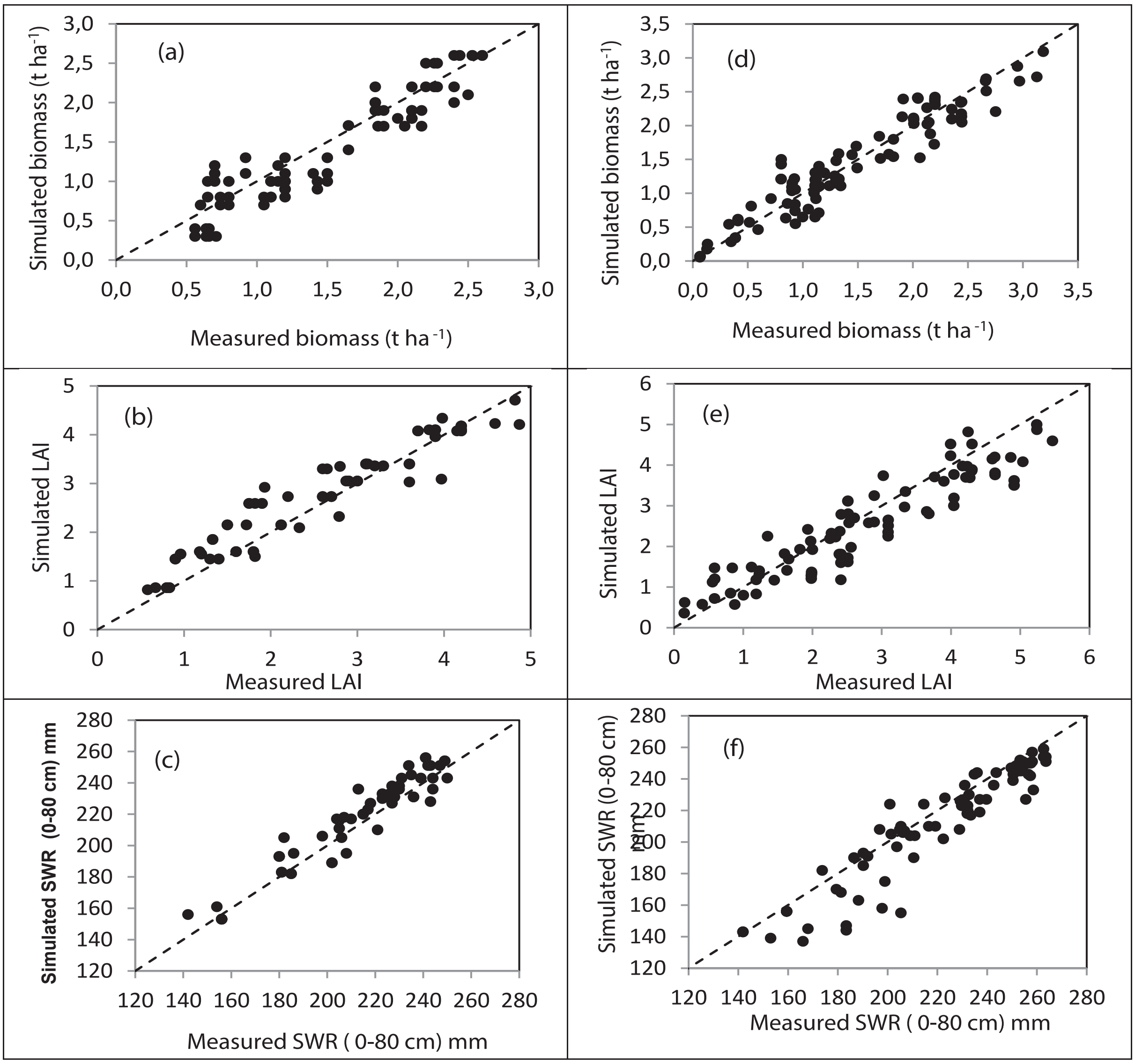

Figure 7: Observed and predicted final biomass, LAI and SWR by PILOTE (a, b, c) and CropSyst (d, e, f) for all the treatments of the two years

In the case of soil water reserve (SWR) the poor performance of the models can be explained in part by the effect of soil cracks that appear with the drying of up soil layers. Indeed, the appearance of cracks from the 4th cycle accentuates consequently the dryness of the soil on the whole profile and also involves additional water percolation during irrigation. These losses are not simulated by models that consider only percolation permitted by soil characteristics (hydraulic conductivity). Performance models are better in most cases with less irrigation compared to the situation where the water is much made. It should be noted that measurements of soil moisture and consequently the water reserve are also affected by distribution uniformity at the field, which increases models uncertainties. Finally, despite the multiple sources of uncertainty, we can confirm that the three outputs considered are simulated correctly by both models as shown in Table 7 and Figure 7.

CONCLUSION

Parameters set obtained from models calibration based on the experimental results under full irrigation in 2009/10, allowed to correctly simulating the evolution of biomass and yields of berseem for all water regimes under two different climatic conditions. The predictions of biomass by CropSyst seem to be more accurate than those of PILOTE model. Considering the predictions of soil water reserve over roots depth (0-80 cm) in all water regimes, the quality of the simulations is satisfactory for both models with more accuracy for the PILOTE model.

The PILOTE model introduces notable simplifications and requires fewer input parameters than CropSyst, without affecting negatively its performances in terms of biomass yield and soil water reserve, except that CropSyst simulated biomass much better under limited water supply. However, the simplifications adopted in PILOTE could be a limiting factor when severe water stress conditions need be analyzed. This is particularly due to a lack of a more complex plant physiological submodel to account for water stress impact on biomass growth.

The crop parameters calibrated for the two models under full irrigation in 2009/10 were shown to be mostly conservative enough to be used in all other simulations regardless of the water regimes and weather in 2 year under study. However, the predictions of biomass growth during the season were slightly better for 2009/10 (year of calibration) than for 2010/11. This means that slight modifications of crop growth parameters for 2009/10 could improve the simulation results by all models.

Therefore, for management purposes and in conditions of limited input information, the use of simpler models should be encouraged.

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