

ASSESSING OPTIRRIG MODEL PERFORMANCE FOR IRRIGATION OPTIMIZATION IN SEMI-ARID CONDITIONS OF NORTHEAST TUNISIA

ÉVALUATION DES PERFORMANCES DU MODÈLE OPTIRRIG POUR L'OPTIMISATION DE L'IRRIGATION DANS LES CONDITIONS SEMI-ARIDES DU NORD-EST DE LA TUNISIE

Yacoubi S¹., Slatni A¹., Cheviron B²., Wittling C²., Hermassi T¹., Ben Abdallah Ma¹. and Pouget L³.

ABSTRACT

Under water scarcity conditions and imbalance between water supply and demand, appropriate management and control of irrigation water is becoming a major interest. Because they offer a wealth of data for planning and managing water and irrigation systems, simulation models are being used in agriculture more and more frequently. Optirrig model is a software tool developed by INRAE for generating, analyzing and optimizing irrigation scenarios. This paper investigated Optirrig model performance for a potato crop under the semi-arid conditions of Cap Bon region in the northeast of Tunisia. Field experiments were performed on two potato plots located at the Boucharray irrigated district in order to calibrate and validate the model. The validated model was used to assess potato crop response to water under different water availability conditions based on irrigation quota, relative crop evapotranspiration and relative yield loss. Simulations were performed for the climatic conditions of the average year estimated from a time series of 37 years (1984-2020). For both calibration and validation process, results indicated a very good agreement between measured and simulated Leaf Area Index (LAI) values. Based on the experimental data, the validation process proved that the model adequately predicts potato crop yield. Simulation results indicated that potato maximum yield is achieved with net season irrigation of 280 mm under average climatic conditions. When water availability is limited, the simulated results indicate that it is possible to revise yield objectives according to water supply strategies. If the objective is to keep the relative yield reduction below a threshold of 12 %, the irrigation quota must be greater than 120 mm. Applying a water depth equal to 21.4 % of the optimal irrigation quota would result in a relative yield loss of about 42% making adoption of deficit irrigation more difficult particularly under limited water availability.

Keywords: Optirrig model, Calibration, Validation, Irrigation quota, Potato crop, Relative yield loss.

RÉSUMÉ

Dans un contexte de pénurie d'eau et de déséquilibre entre l'offre et la demande, la gestion et le contrôle appropriés de l'eau d'irrigation deviennent un enjeu majeur. Parce qu'ils fournissent une grande quantité de données utiles à la planification et à la gestion des systèmes hydriques et d'irrigation, les modèles de simulation sont de plus en plus fréquemment utilisés en agriculture. Le modèle Optirrig est un outil logiciel développé par l'INRAE pour générer, analyser et optimiser des scénarios d'irrigation. Cet article évalue les performances du modèle Optirrig pour une culture de pomme de terre dans les conditions semi-arides de la région du Cap Bon, au nord-est de la Tunisie.

1 National Research Institute for Rural Engineering, Water and Forestry (INRGREF), Laboratory of Rural Engineering GR, University of Carthage, Rue Hédi El Karray El Menzah IV-BP N° 10, Ariana 2080, Tunisia, Email: samir.yacoubi@ingref.ucar.tn; slatni.adel@gmail.com; taoufik.hermassi@ingref.ucar.tn; benabdallah_medali@yahoo.fr

2 National Research Institute for Agriculture, Food and Environment (INRAE), UMR G-Eau – Campus Lavalette 361, rue Jean François Breton 34196 Montpellier, France, Email: bruno.cheviron@inrae.fr; claire.wittling@inrae.fr

3 Water Technology Center (Cetaqua Barcelona), Ctra. d'Esplugues, 75, 08940 Cornellà de Llobregat, Barcelona, Spain Email laurent.pouget@cetaqua.com

Des expériences de terrain ont été menées sur deux parcelles de pommes de terre situées dans le périmètre irrigué de Boucharray afin d'étalonner et de valider le modèle. Le modèle validé a servi à évaluer la réponse de la culture de pomme de terre à l'eau sous différentes conditions de disponibilité hydrique, en fonction du quota d'irrigation, de l'évapotranspiration relative de la culture et de la perte relative de rendement. Les simulations ont été réalisées pour les conditions climatiques d'une année moyenne, estimées à partir d'une série chronologique de 37 ans (1984–2020). Pour les phases d'étalonnage comme de validation, les résultats ont montré une très bonne concordance entre les valeurs mesurées et simulées de l'indice foliaire (LAI). À partir des données expérimentales, la validation a confirmé que le modèle prédit correctement le rendement de la pomme de terre. Les simulations indiquent que le rendement maximal de la pomme de terre est obtenu avec une irrigation saisonnière nette de 280 mm dans des conditions climatiques moyennes. Lorsque la disponibilité en eau est limitée, les résultats simulés montrent qu'il est possible de revoir les objectifs de rendement en fonction des stratégies d'approvisionnement en eau. Si l'objectif est de maintenir la réduction relative du rendement sous un seuil de 12 %, le quota d'irrigation doit être supérieur à 120 mm. L'application d'une lame d'eau égale à 21,4 % du quota d'irrigation optimal entraînerait une perte relative de rendement d'environ 42 %, ce qui rend l'adoption de l'irrigation déficitaire plus difficile, en particulier lorsque la disponibilité en eau est limitée.

Mots-clés : Modèle d'Optirrig; Calibration; Validation; Quota d'irrigation; Culture de pomme de terre; Perte relative au rendement.

1. INTRODUCTION

In arid and semi-arid regions, water availability is a determining factor in agricultural production. Under these conditions, optimal irrigation management aims to save water, increase yields and income for the farmer as well as preserve the environment. Adoption of appropriate irrigation management allows to (i) to improve crop yield and the farmer's income, (ii) to save water while reducing the negative impact of irrigation on the environment and (iii) ensuring the viability of irrigated agriculture (Smith et al., 1996).

The current imbalance between water demand and supply in agriculture has driven the search for new equilibria through adopting modern technologies and management tools to optimize irrigation water use (Pereira et al., 2009; Pereira, 2017; Javonovic et al., 2020). Irrigation scheduling and management is an important theme both at the plot level and at the level of collective water distribution networks. At the plot level, water management is a determining factor in yield from both a quantitative and qualitative point of view. On the other hand, the aggregation of individual irrigation scheduling programs determines the water demand and therefore the operating conditions of collective water distribution networks.

Numerous irrigation scheduling simulation models have been produced and made available to support irrigation decision-making since the 80's as reported in various international conferences (Pereira et al., 2020). Crop irrigation models often combine a water balance module and an agronomic module relating to the crop based upon crop evapotranspiration and yield-water relations (Doorenbos and Kassam, 1979). Among the available models, Optirrig model (Cheviron et al., 2016) is a simplified crop model turned towards the generation, analysis and optimization of irrigation scenarios, hence focusing on appropriate management of the available water resources and not on the thorough description of crop physiology. Crop growth stages are calculated from predefined crop-specific "thermal times" but water stresses hamper crop development by affecting crop growth dynamics when soil evaporation or crop transpiration demands cannot be fully met.

As regards soil properties, Optirrig is a reservoir model assuming the existence of a shallow reservoir followed by a root-zone reservoir that deepens with root growth throughout crop expansion phase. In accordance, roots are supposed to reach the maximum depth allowed at the same time crop canopy (its leaf area index) reaches its maximum extension.

Soil water status is deemed to control both the actual evaporation and transpiration values, that is the overall answer of the soil-plant system to the climatic demand, arising from the reigning conditions of wind, air humidity, air temperature and solar radiation. As only rain and irrigation are able to provide the needed water amounts, irrigation has to be decided so as to complement rain to meet the dynamics of crop water needs, whenever possible. Alternatively, in situations of recurrent water scarcity, deficit irrigation should provide a compromise between local water consumption for crop production and the scaled-up impact on the regional water resource, either managed or not.

Although designed for the plot scale and possibly used at the farm scale, Optirrig effectively allows connecting scales and addressing issues at the scale of the irrigated perimeter, provided hypotheses may be made on the dominant crops and irrigation practices on a given territory. Such studies at local or enlarged scales are made possible by the way irrigation choices (triggering criteria, decision rules) and constraints (e.g. water turns, restrictions, quotas) are described and combined on purpose in Optirrig. This opens way for a large set of ex-post, ex ante or real-time uses of the model, whose transfer and dissemination strategy is currently constructed between its development team (INRAE Montpellier) and the "INRAE Transfert" subsidiary of INRAE.

The objectives of this study were: 1) to calibrate and validate a crop soil-water-yield simulation model (Optirrig) under the local, climatic, soil and agronomic conditions of the Cap Bon Region and 2) to use the validated Optirrig model to explore the impact of water supply restriction on water use and yield under average climatic conditions of the study area in the Cap region of Tunisia.

2. MATERIALS AND METHODES

2.1 Experimental site

Field experiments were carried out at the public irrigated district of Boucharray located at Nabeul in the North east of Tunisia (Lat. 36°39'43.01"N, Long. 10°32'3.16"E, Alt. 22 m). The irrigation district of Bocharray covers 2314 ha. Irrigation water comes from dams in the north of the country through the Medjerda-Cap Bon Canal. The study area is characterized by Mediterranean semi-arid climate with yearly average precipitation of 415 mm. The seasonal distribution of rainfall presents the typical Mediterranean pattern with minima in summer, the period of maximum crop water requirements. The average reference evapotranspiration (ET₀) estimated by the Penman Monteith method (Allen, et al., 1998) is around 1350 mm/year. The soils of Cap Bon region are varied, consisting mainly of sandy, light sandy-loam, clay, red and brown forest soils.

2.2 Experimental setup

The experimental trials to assess Optirrig model performance were conducted on two farmer's potato plots in the Boucharray irrigated district hereinafter designated plot A and plot B (**Figure 1**). Plot A with an area of 2 ha was used for the calibration of Optirrig model while plot B (1,5 ha) was reserved for validation. For both plots, according to the USDA classification, soil texture is predominantly silty clay and bulk density is 1.5 g.cm⁻³. For plot A Soil water depth at field capacity and wilting point were 330 mm.m⁻¹ and 210 mm.m⁻¹, respectively, as determined using pressures plates. For plot B, the readily available water is 130 mm m⁻¹ (soil water depth at field capacity = 360 mm.m⁻¹ and soil water depth at wilting point = 230 mm.m⁻¹). Both plots are equipped with trickle irrigation system. For model calibration experiments, early potato crop (cv, Amani) was planted on January 25, 2022 with a tuber spacing of 0.8 m x 0.25 m. Likewise, for model validation, season potato crop (cv. Spunta) was planted in March 07, 2022, at a density of 4.17 plants.m⁻² (with a square spacing of 0.8 x 0.3 m). Harvest was performed in May 10, 2022 and 30 June, 2022, respectively, for plot A and plot B.

2.3 Optirrig model description

Optirrig is a process-based crop growth and irrigation model [7] devoted to generating, analyzing, and optimizing irrigation scenarios. This is a derived version of the PILOTE model (Mailhol et al., 2018). It is based on a simplified description of plant growth according to the evolution of water and nitrogen

resources in the soil. It compares the merits of different irrigation strategies according to different constraints (water quota, periods of limited availability, prefectural decrees, water and energy costs), for operational objectives at the plot, farm or territory level (Cheviron et al., 2020). **Figure 2.** illustrates the model version for field crops used in this study (Hamze et al., 2023; Cheviron et al., 2016).



Figure 1. Study area location of Boucharray irrigated district: experimental field (plots A and B) are shown in white

Optirrig simulates soil water balance, crop growth and yield using daily climatic data and coupling a soil module to a crop module. In this version of Optirrig model, water is considered as the unique limiting factor. The required daily climatic data are: precipitation (P), mean air temperature (T), potential evapotranspiration (ET₀), and total global solar radiation (R_g). Applied irrigation (I) is considered as a management parameter. As reported by Hamze et al. (2023), crop growth is characterized by the leaf area index (LAI), which is determined by the thermal time (TT) and potential water stress (Sw), as indicated in Figure 1. The crop coefficient (K_c) and partition coefficient (C_p) are derived from the LAI. The actual transpiration (T_p) and evaporation (E_s) are computed based on available water reserves. Total dry matter (TDM) is determined by radiation interception taking into account the impact of water deficit on the biomass. The crop yield (Y) is estimated using the harvest index (HI) and the total dry matter. Additional details regarding the soil, crop, temperature and management parameters involved in the Optirrig model are presented by [7,11].

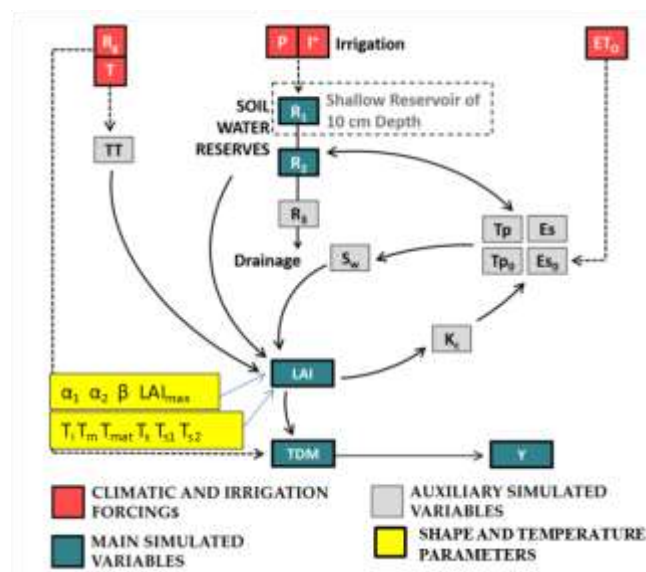


Figure 2. Schematic representation of the structure and principle of the Optirrig model

2.4 Model calibration and validation

Calibration and validation were carried out using experimental data obtained respectively on plot A and B (Yacoubi et al., 2023). Model calibration is based on the calculation of Leaf Area Index (LAI) dynamics, based on phenological thermal time parameters associated with crop development stages

to ensure reliable dynamic predictions for model variables calculated (harvest index H_i , crop yield Y and total dry matter (TDM). Temperature ($^{\circ}\text{C}$) parameters for model calibration are: T_i , T_m , T_{mat} , T_{s1} , T_{s2} where:

T_i : Temperature sum for root installation, T_m : Temperature sum to reach the maximum LAI, T_{mat} : Temperature sum for crop maturity, T_s : Temperature sum for crop emergence, T_{s1} : Temperature sum for the 1st critical stage and T_{s2} : Temperature sum for the 2nd critical stage. In addition to the input temperature parameters, calibration process requires the determination of LAI_{max} and the shape LAI curves parameters α_1 , α_2 , and β .

A validation phase completes the process. In this phase, data from experiments performed on plot B are used to establish the predictive capacity of the model.

The Optirrig model calibration and validation process require the following data:

- Meteorological daily data: Effective precipitation P (mm), global solar radiation R_g (J/cm^2), averaged air temperature T ($^{\circ}\text{C}$) and reference evapotranspiration ET_0 (mm) determined according to the FAO-Penman-Monteith method [8]
- Crop data, including the duration of the different crop stages, temperature parameter's, LAI crop coefficients K_c , root depth z (m), crop height (m) and crop yield ($\text{Tonne} \cdot \text{ha}^{-1}$). LAI measurements were performed using the SunScan plant canopy analyzer system.
- Management data: irrigation applied depth (mm), Soil water depth ($\text{mm} \cdot \text{m}^{-1}$)

3. RESULTS AND DISCUSSIONS

3.1 Model Calibration

The results of the first step of the model calibration process are presented in **Figure 3**. It should be highlighted that the LAI parameters were calibrated under optimal water supply conditions with an applied water depth was 320 mm during the irrigation season. Also, seasonal actual crop evapotranspiration ET_a was close to the maximum crop evapotranspiration ET_{max} (190 mm). **Figure 3** exhibits a fair agreement between measured and predicted LAI indicating that the model appropriately describes the LAI along the entire crop season.

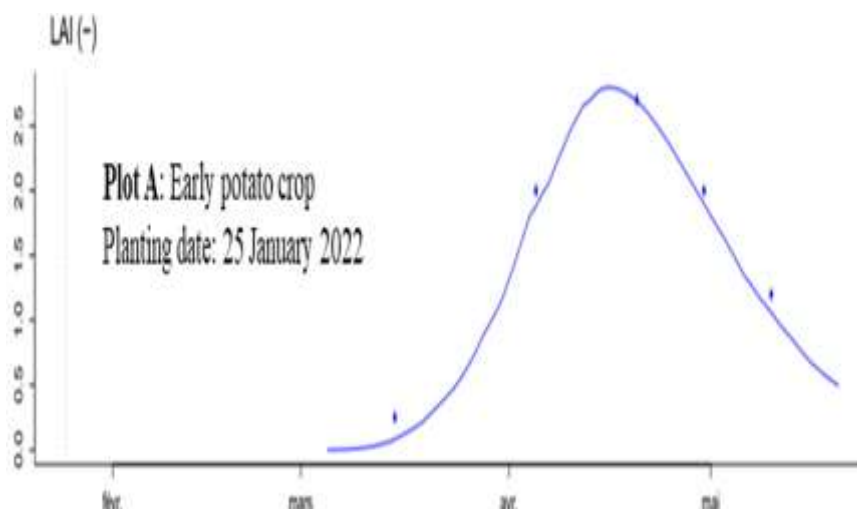


Figure 3. Optirrig model calibration: Observed (nodes) vs. simulated (line) LAI

3.2 Model validation

Optirrig model validation was performed by comparing the leaf area index observed in the field (Plot B) with those simulated by the model (**Figure 4.**). Results confirm the predictive capability of the model in the local conditions. For the validation conditions, irrigation depth amounts to 240 mm while ET_a and ET_{max} were 255 and 290 mm respectively. Also, results indicate that the model adequately predict the yield with values of simulated potato yield equals 31,5 T/ha and observed crop yield of 29 T/ha.

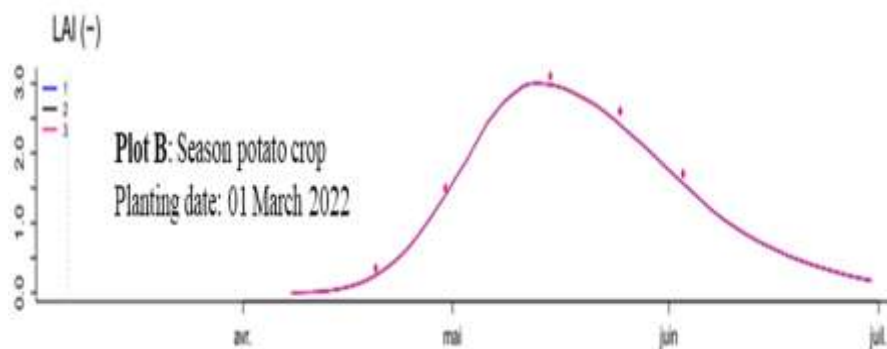


Figure 4. Observed (nodes) vs. simulated (line) LAI under validation conditions

3.3 Optirrig crop water-yield simulations

The validated Optirrig model was used to simulate the potato crop response to irrigation under different water availability conditions. Simulations were performed for the climatic conditions of the average year estimated from a time series of 37 years (1984-2020). The Optirrig irrigation simulations were performed for season potato crop based on the agronomic, and soil data of the plot B case study.

For the average year conditions, seasonal rainfall was about 100 mm. The values of seasonal reference evapotranspiration ET_0 and maximum crop evapotranspiration ET_{max} were 524.6 and 342 mm respectively. **Table 1.** presents the crop response to irrigation water application for irrigations strategies corresponding to full ET_{max} , 70% of ET_{max} and 50% of ET_{max} .

Table 1. Potato crop response to irrigation for the average year climatic conditions

Irrigation quota (mm)	ET_a (mm)	ET_a/ET_{max} (%)	Relative yield loss* (%)
280	340	99.4	-
120	238	70	11.7
60	172	50	41.7

* Relative Yield Loss, $RYL = 1 - Y_a/Y_{max}$ expressed in % Y_a is the actual yield, Y_{max} is the maximum yield

Simulation results indicated that potato maximum yield Y_{max} (38 T/ha) is achieved with net season irrigation of 280 mm under average climatic conditions. When adopting irrigation quota restriction, Optirrig simulations of crop water response indicate that it is possible to adjust potato crop yield objectives according to water supply strategies. If the objective is to maintain the relative yield reduction below a threshold of 12%, the irrigation quota must be greater than 120 mm. Result of simulation indicate that for an irrigation water supply of 60 mm (approximately 21.4% of the optimal quota), the relative yield loss would be approximately 41.7%. In this case, adoption of deficit irrigation should be avoided under limited water availability.

CONCLUSION

In this work, Optirrig model performances in water management and yield response to irrigation were assessed based on field experimental trials under the local conditions of Nabeul in the northeast Tunisia. The adopted methodology represents a contribution to the use of crop model in irrigation management. The model was successfully calibrated and validated for the leaf area index which is a key parameter in the model simulation of crop growth and crop yield. Although the model predictive capacity was established under average climatic conditions, further investigations regarding the use of the model as a tool leading to appropriate irrigation management are needed particularly under high and very high water demand conditions. In addition to the simulated water management options, the socio-economic implications need to be assessed to improve farmer income and water productivity.

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