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MY SIRR: Minimalist agro-hYdrological model for Sustainable IRRigation management—Soil moisture and crop dynamics

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ABSTRACT

The paper introduces a minimalist water-driven crop model for sustainable irrigation management using an eco-hydrological approach. Such model, called MY SIRR, uses a relatively small number of parameters and attempts to balance simplicity, accuracy, and robustness. MY SIRR is a quantitative tool to assess water requirements and agricultural production across different climates, soil types, crops, and irrigation strategies. The MY SIRR source code is published under copyleft license. The FOSS approach could lower the financial barriers of smallholders, especially in developing countries, in the utilization of tools for better decision-making on the strategies for short- and long-term water resource management.

Code metadata

Current code version	3.0
Permanent link to code/repository used of this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-15-00079
Legal Code License	GPL (GNU General Public License) v. 3.0
Code versioning system used	Revision 3
Software code languages, tools, and services used	Python (v. 2.7)
Compilation requirements, operating environments & dependencies	Matplotlib and numpy packages
If available Link to developer documentation/manual	https://github.com/raffalba/MYSIRR/blob/master/README.md
Support email for questions	raffaele.albano@unibas.it

1. Motivation and significance

Water supply is becoming more and more critical to meet current and foreseeable water demands [1,2]. With vast regions already experiencing water shortages, it is becoming imperative to manage sustainably the available water resources, especially in relation to agriculture. Globally, irrigated agriculture is the primary user of freshwater, accounting for nearly 85% of total water consumption [3], and providing about 40% of the total food production [4]. Higher pressures on water for food production may be expected to develop because large segments of the populations in the emerging countries will tend to raise their living standards [5]. Hence, irrigation is projected to increase in face of climate change, population growth and increased food requirements. Therefore, there is an increasing need to optimize water allocation in order to maximize production and farm revenue. Hence, strategic choices are needed to preserve productivity and profitability while ensuring a sustainable water management, a nontrivial task given rainfall unpredictability. In this context, it is particularly important to develop simple, widely applicable agro-hydrological tools that inform farmers for short- and long-term water-related agricultural management. This is of particular importance given that agricultural production systems are inextricably linked to the hydrologic systems they rely upon (i.e. agro-hydrology). The on-farm agricultural management decision-support tools should synthetically provide the key irrigation quantities (volumes, frequencies, etc.) for different irrigation schemes as a function of soil type, crop, and climatic features. On one hand, significant progress has also been made in developing models for optimal water allocation for

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Nomenclature

$R(t)$	rainfall
λ	mean frequency of rainfall events
$I(s(t))$	irrigation input to soil water balance
T_{mean}	daily mean temperature
n/N	daily relative sunshine duration
p	mean daily percentage of annual daytime hours
e_a	mean daily ambient vapor pressure
c_n	the numerator constant for the reference crop type and time step
Δ	slope of the saturated vapor pressure curve
Z_r	active soil depth
$ET(s(t))$	soil water losses through evapotranspiration
s^*	point of incipient stomatal closure, when plant transpiration is reduced
s_w	wilting point, corresponding to irreversible damages to plants
s_1	soil moisture level at which deep percolation and runoff losses take place
$\tilde{s}$	soil moisture "intervention point" triggering an irrigation application
ET_{seas}	total evapotranspiration over the growing season
Y	crop yield
a_{EMP}	steepness parameter the of the seasonal evapotranspiration-yield function
a_{DIC}	Crop-specific response to water limitation
$\rho(s(t))$	maximum normalized evapotranspiration loss rate
$g(s(t))$	simplified rate of crop biomass change
EW	effective use of water
$b(t)$	crop biomass
WP	water productivity
α	mean depth of rainfall events
T_{seas}	length of the growing season
ET_0	reference evapotranspiration
RH_{min}	minimum daily relative humidity
U_d	daily mean wind speed
R_n	Net radiation flux
e_s	mean saturated vapor pressure
c_d	the denominator constant for the reference crop type and time step
ET_{max}	evapotranspiration rate under well-watered conditions
n	soil porosity
E_A	irrigation application efficiency coefficient
s_{fc}	soil field capacity, i.e. soil moisture level at which deep percolation and runoff losses take place, above which deep percolation is non negligible
$s(t)$	relative soil moisture ranging from 0 (perfectly dry soil) to 1 (soil saturation)
$R_{tot} = \alpha\lambda t_{seas}$	total rainfall over the growing season
$\hat{s}$	"Target level" to which soil moisture is replenished by an irrigation application
$\eta = ET_{max}/(nZ_r)$	maximum normalized evapotranspiration loss rate
$Et_{seas50\%}$	total seasonal evapotranspiration corresponding to $Y_{max}/2$
Y_{max}	maximum crop yield
WF	Water footprint
$\zeta(t)$	plant water stress
$b_0 = b(t=0)$	crop biomass at the beginning of the central part of the growing season
g_+	crop development rate under well-watered conditions
$Y = h \cdot (b(t = T_{seas}))$	crop yield, as a function of crop biomass at the end of the central part of the growing season
K_c	crop coefficient

agricultural management at spatial scales ranging from the single field level to regional scales [6–9]. On the other hand, smallholders need reliable, parsimonious and flexible tools to support them to decide the management strategy more useful for their needs. At on-farm level, the tool complexity should be set into relation to the effort required to apply that model and should reflect farmers' flexibility in coping with uncertainty to maximize yields and profit.

A (FOSS) free and open source approach could lowering the financial barriers of smallholders to utilize tools and software that can lead to better decision-making especially in developing countries [10,11]. FOSS tool could promote leanings generate a guided discovery for the smallholders that can examine and experiment with software. Moreover, these tools are typically published for free and their source code is open with end-user rights to run the program for any purpose, to study how the program works, to adapt it, and to redistribute copies including modifications. The availability of the source code and the right to modify it is very important. It enables the unlimited tuning and improvement of a software product. It also makes it possible to port the code to new hardware, to adapt it to changing conditions, and to reach a detailed understanding of how the system works.

2. MY SIRR model

In this paper, we present a decision support tool at farm scale, called MY SIRR (Minimalist agro-hYdrological model for Sustainable IRRigation management), based on the description of the soil water balance and crop development, explicitly accounting for the randomness in the hydro-climatic forcing and the essential nonlinearities of the soil–plant–atmosphere system. This tool incorporates simple and widely applicable formulae with parsimonious inputs clearly showing the effects of climate, irrigation strategy, crop, and soil features on agro-ecosystems. The relatively few, physically based parameters make MYSIRR suitable for designing and assessing the feasibility of new agricultural initiatives and investigating the effect of climate change on existing agricultural practices. MY SIRR is based on the methods developed by stochastic ecohydrology [12] in order to realize a simple, widely applicable agro-hydrological tool designed to inform farmers, especially from the developing countries or smallholders, for water-related agricultural management. The ecohydrological approach, traditionally focusing on natural ecosystems, has the potential to offer a quantitative tool to assess and compare agricultural enterprises across climates, soil types, crops, and irrigation strategies, accounting for nonlinear interactions and temporal stochasticity, while smoothing out spatial heterogeneities through spatially lumped representations. In this manner, MYSIRR hopes to achieve predictions that are robust to parameter uncertainties and are easily transferable to future climatic conditions. On one hand, MYSIRR have similar functions to other available software, such as CROPWAT [13], that can be used to predict water availability and crop response to current and future agro-climatic conditions. On the other hand, in this respect, MYSIRR has the peculiarity to developing optimized irrigation schedules, maximizing Water Productivity, (that is considered, according to [14], the inverse of Water Footprint), for different climate scenarios carrying out future climate scenario analyses. This could help drive strategic action toward sustainable, efficient and equitable water use with reference to water productivity, yields, water requirements, and their variability (a crucial element for food security and resource allocation planning).