ICIC Express Letters ICIC International ©2019 ISSN 1881-803X
Volume **13**, Number **5**, May **2019** pp. 349–356

AG-CASU: AN ALGORITHM TO GENERATE IRRIGATION PARAMETERS AND CROP MANAGEMENT STRATEGIES FOR THE AQUACROP MODEL

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Received October 2018; accepted December 2018

Abstract. *This paper presents an algorithm to generate the irrigation policies and crop management configuration files for the agroclimatic risk model AquaCrop. The software determines the parameters to be modified by a stochastic method. The AG-CASU algorithm takes account of the limits determined for each variable. The algorithm can be configured to determine the number of scenarios, the number of simulations, the feasibility of each of the parameters, the initial seed file and the compliance with the AquaCrop agroclimatic risk model. In general, the agroclimatic risk models use data and information referring to climate, soil composition, temperature, rainfall, availability of water resources and characteristics of the crops to estimate the productivity of a given crop. The genetic algorithm for calculating fitness is connected to the AquaCrop simulator, which, given a set of parameters that represent an irrigation policy, generates an estimate of biomass productivity. The algorithm was validated through a case study in special coffee crops of the Sierra Nevada de Santa Marta, Colombia. The proposed algorithm automatically obtains the files corresponding to irrigation policies and cultivation strategies of the AquaCrop model, with coverage of the domain of the variables and with compliance to the AquaCrop software.*
Keywords: Algorithm, AquaCrop, Models of agroclimatic risks, Special coffees, Monte Carlo method

1. **Introduction.** Nowadays, according to the Food and Agriculture Organization (FAO) [1] the sudden changes in the climate environment affect in a decisive way the agriculture. Therefore, the production levels of the crops are very changeful. Agroclimatic risk models are an alternative to understand the impact of climate on crops productivity. Agroclimatic risk models study the relationship between variables such as temperature, rainfall, altitude, sun light, soil, characteristics of the crop and its management. Moreover, one of the aspects to consider in the agroclimatic model application is the form as they are configured according to the conditions of the different crops.

In the literature review, different approaches are presented to configure the agroclimatic risk model AquaCrop [1]. Specifically, Stricevic et al. [2] evaluated the AquaCrop model and the impact of drying the crops fields, to determine if irrigation policies should be implemented, through the use of methods like root mean square error (RMSE), index

DOI: 10.24507/icicel.13.05.349

of agreement (d), irrigation water use efficiency (IWUE) by means of combination of historical data and measured facts in the field. The study by Paredes et al. [3] used the RMSE for the calibration of the curve of the canopy green cover, required for the AquaCrop model. Likewise, Hassanli et al. [4] performed the optimization by simulating cornfields with saltwater irrigation, using the three models of agroclimatic risk estimation: AquaCrop, SALTMED and SWAP in Iran, via the coefficient of determination (R^2).

In another order of ideas, Flores et al. [5] simulated cornfields, in the north of Sinaloa, Mexico, by the agroclimatic risk model AquaCrop, and the authors considered the RMSE and the d. In another context, Iqbal et al. [6] interpreted the optimization of the AquaCrop model for cereal production in North China, thinking RMSE and d. The authors Abedinpour et al. [7] carried out the calibration and validation of agroclimatic risk models in corn crops under different irrigation policies and nitrogen fertilizer regimes in New Delhi, using the RMSE, R^2 and mean absolute error (MAE). Alternatively, Akumaga et al. [8] validated the AquaCrop model to simulate grain fields for different levels of soil fertility in northern Guinea, and the Nigerian savannas. They use as statistical optimization methods: R^2, d, RMSE, MAE, and normalized root mean square error (NRMSE).

Additionally, Wang et al. [9] evaluated the ability of the AquaCrop model to simulate the performance of winter wheat under deficit of water conditions in the Loess Plateau in China, by R^2 and RMSE. In addition, Kim and Kaluarachchi [10] proposed an efficient and low-cost approach to validate the AquaCrop model through an optimization using satellite Landsat image (remote sensing estimates) instead of soil studies in the corn, barley and alfalfa crops. The authors concluded that the estimates made become good replacements of the ground measurements for the validation and calibration of the models.

This paper is based on the hypothesis proposed by agroclimatic risk models, which indicate that climatic variability generates instability in the productivity of crops, due to water availability. This article proposes an algorithm that determines the configuration parameters of the AquaCrop agroclimatic risk model, validated in special coffee crops at the Sierra Nevada de Santa Marta, Colombia. The present work is organized as follows. Initially, a review of the agroclimatic risk models is carried out to determine the different methodologies used for the configuration of the variables. Next, the materials and methods used are described. Finally, the results and conclusions of the paper are discussed, as well as proposals for future research.

2. **Materials and Methods.** This section describes data, information and tools used to develop this research. The AquaCrop agroclimatic risk model is formed by five modules: climate data, soil data, crop data, crop management strategies and available water resources. The AquaCrop agroclimatic risk model, proposed by the FAO [1], includes 25 variables. They are used to estimate the crop field subject to specific conditions. Thus, the set of variables constitutes a huge search space, and the estimate of crop productivity corresponds to a stochastic process. Then, the AquaCrop model allows to establish the duration and scope of each variable according to the availability of the corresponding data individually. Therefore, the data origin was specified depending on the individual needs of each variable. Data sequences were obtained from measurements made in the field, for example, temperature and rainfall. Other data are taken by default, due to their difficulty of obtaining or complexity of analysis, for example, evapotranspiration or CO_2. Hence, the configuration problem with multiple objectives is to find the *optimum* combination of irrigation policies and farming strategies that maximize productivity. Initially, for the modeling of special coffee crops, the climate data of Colombia was taken, in the Sierra Nevada region of Santa Marta, municipality of Pueblo Bello, Colombia. Figure 1 shows the sequence of rainfall in the region during the last fifty years. This variable allows us to establish a climate behavior tendency and estimate future results.

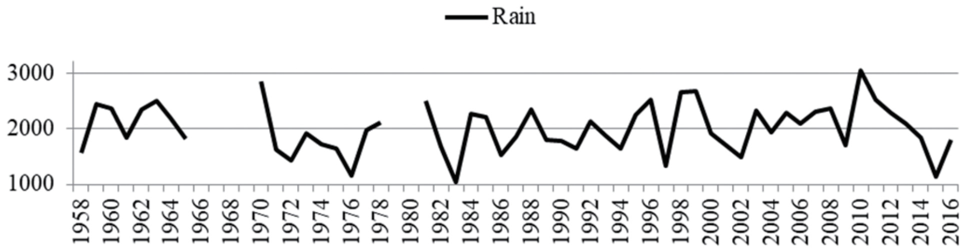

Figure 1. Rain historical data [11]

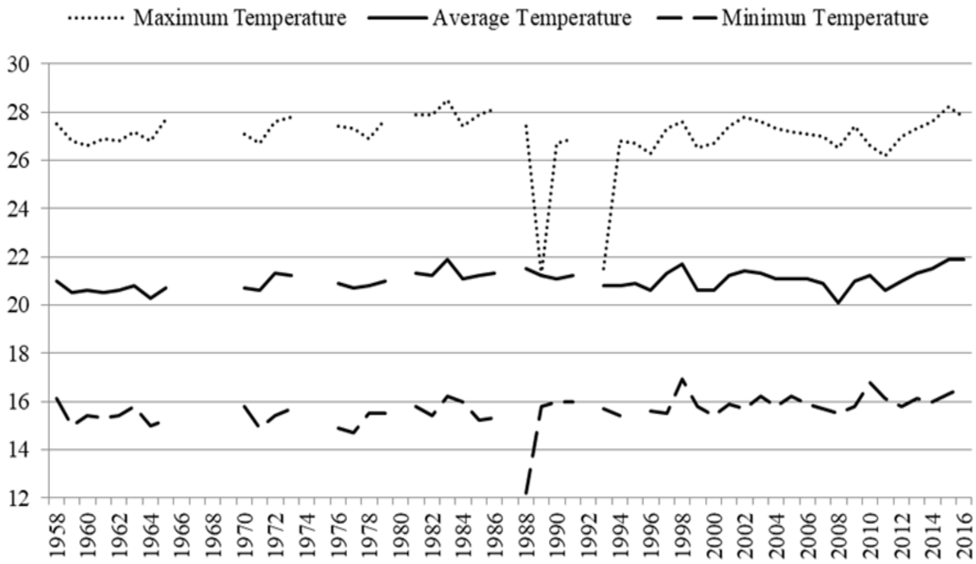

Figure 2. Historical temperatures measured in the region [12]

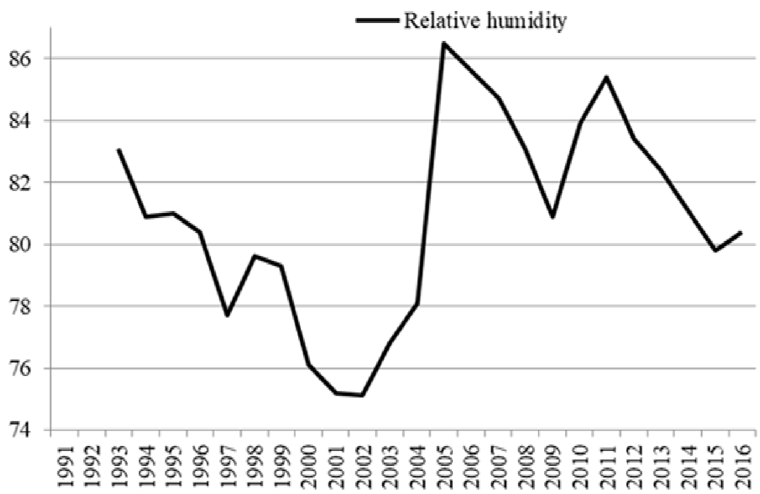

Figure 3. Relative humidity measured in the region [12]

Figure 2 shows the average temperatures per year, measured in the region. Also, Figure 3 shows the relative humidity in the region under study, with data from 1993 to 2016.

The data presented in Figures 1, 2 and 3 were included in the climate module of the AquaCrop agro climatic risk model software. On the other hand, the data corresponding to evotranspiration (ETo) were taken from the database by default in the AquaCrop software. The CO_2 data was taken from the standard FAO Geographical Information System [13].

On the other hand, the soil data were taken from specific analyses carried out in a crop field (farm) in the region. The Geographical Institute Agustín Codazzi (IGAC) made the soil tests, in December 2017. The analyses determined the humidity at different pressures, real density, field humidity and soil characterization that includes chemical composition, the present nutrients, type soil texture and saturation base. The data of the crop module, like canopy cover, rooting depth, crop transpiration, water resources, were taken from technical bulletins of the National Federation of Coffee Growers of Colombia (FNC), CENICAFE [12], and information, like altitude, crop density, harvesting, from an organic coffee association of the Sierra Nevada de Santa Marta (SNAM), Colombia.

Additionally, for the validation of the proposed algorithm in the organic coffee crops of the Sierra Nevada, the following phases were developed. First, the AquaCrop software is supplied with climate, soil, crop and water resources data. Second, the configuration files for irrigation policies and farming strategies are generated. Third, simulations are performed with the set of generated scenarios. Finally, the algorithm AG-CASU selects which are the best configurations from results generated by the AquaCrop simulator.

The algorithm uses an approximation of Monte Carlo method and genetic algorithms inspiration. Initially, AG-CASU seeks to establish irrigation policy configurations and crop management strategies. Second, each variable is activated individually depending on the approach chosen (exploration or exploitation). Third, the activated variables are generated, from an initial seed file, by a pseudo-random method according to domain, rank, and singularities. Fourth, once a set of configuration files is generated they are supplied to the AquaCrop simulator through an automated program. Fifth, the results obtained from the simulator are evaluated according to the generated biomass variable, which is used like a fitness function. The configurations with the highest biomass are selected as seed candidates for the next step of the optimization process. Finally, the process is repeated several times to let the search and optimization method. The algorithm developed tolerates the activation of each variable, the generation of parameters according to their individual characteristics, the configuration of the number of iterations and the automatic call of the AquaCrop software. AG-CASU executes 10000 times each seed configuration and selects the best fifty percent (50%) of individuals to pass to next iteration. The algorithm was developed in C/C++ language in the DEV C++ 5.11 environment. The simulations were carried out on an Hp Envy computer, with Intel Core I7 processor, and 4GB RAM and Microsoft Windows 10 like operating system.

3. **Results and Discussion.** We modeled the behavior of coffee crops in the Sierra Nevada of Santa Marta based on the data collected. Next, an algorithm inspired by the Monte Carlo method was designed, which will look for the configurations of the variables related to the crop management strategies and irrigation policies, in such a way that the best conditions are determined to increase the productivity of the crop farms. The model of the case study defines that the climate module was configured using the data obtained from IDEAM [11]. The soil module was configured with the studies developed in the project. The variables corresponding to the crop module were instantiated based on the information related to coffee supplied by the National Federation of Coffee Growers and CENICAFE [12]. Finally, the variables corresponding to the availability of water resources were adjusted according to the information provided by an association of organic coffee producers in the region under study. In this way, in order to estimate the productivity of the crops in this geographical area, and under the conditions established by the farms, it is necessary to determine the irrigation policies and the appropriate crop management strategies to improve productivity. The AG-CASU algorithm is composed by 4 modules, that is, 1) irrigation policy generator, 2) generator of crop management strategies, 3) scenario generator, and 4) execution of the simulations.

3.1. **Irrigation policy generator.** The irrigation policy generator algorithm takes a source file to create the different possible configurations; this file is called seed (.IRR). The seed file must be complete and must comply with the structure determined by the AquaCrop software, and in this way, the resulting files will be accord with the same structure. Algorithm 1 reads the seed file and generates a new scenario according to the configuration determined by the variation or not of each parameter.

Algorithm 1

```
Procedure AG_CASU_Irrigation (File τ.IRR)
if (¬τ.IRR)
            Exit() // τ.IRR file must comply
else
     if (IrrigationMode is Active) // 5-Surface irrigation 1 sprinkler irrigation
            WriteNewIrrigationType()
     if (Percentaje is Active) // porcentaje of field irrigation 0 to 100
            WriteNewPercentaje()
     if (Scheduling is Active) // scheduling mode: daily, 10 days or monthly
            WriteNewScheduling()
     if (TimeMode is Active) // Time to be simulated 0-100
            WriteNewTimeSimulation ()
     if (Depth is Active) // Irrigation depth 1-100
            WriteNewDepthMode()
end procedure
```

The irrigation policy configuration file includes 5 parameters: type of irrigation could be aspersion or flood; percentage of coverage of the area of crop field could be between 0 to 100; depth of penetration of irrigation in the field could stand by 0 to 100; an irrigation schedule according to the relative dates of planting, the schedule could be daily, each 10 days or monthly and a time horizon to be simulated. The algorithm changes each of the possible combinations of the variables, exploring the search space based on a Monte Carlo method. Figure 4 shows an example of the irrigation policy configuration file.

```
6.0    : AquaCrop Version (March 2017)
   4      : Surface irrigation: Furrow
  80      : Percentage of soil surface wetted by irrigation
   1      : Irrigation schedule

 Day     Depth (mm)    ECw (dS/m)
 ===================================
32      30      1.5
33      45      1.5
--
Generation of irrigation schedule (sprinkler - 80% RAW depletion - back to FC)
   4.0    : AquaCrop Version (March 2012)
   1      : Sprinkler irrigation
 100      : Percentage of soil surface wetted by irrigation
   2      : Generate irrigation schedule
   3      : Time criterion = allowable fraction of RAW
   1      : Depth criterion = back to FC

  From day     Depleted RAW (%)    Back to FC (+/- mm)        ECw (dS/m)
=======================================================================
      1             80                   0                    0.0
```

FIGURE 4. Example of the irrigation policy configuration file

3.2. **Generator of crop management strategies.** The strategies of crop management are composed by: the land percentage covered with weeds during the crop growth time, from 0 to 100; percentage of reduction of soil evaporation due to weeds present in the crop, data from 0 to 100; limitation of soil fertility between 0 to 100; height in meters of the ground boundaries; percentage of the surface of the soil not affected by the cleaning practices on the surface, from 0 to 100; relative coverage of the plant surface with herbs, a percentage between 0 and 100; relative increase in mid-season weed cover; percentage of expansion of weed cover, from 0 to 100. Algorithm 2 shows the generation of management strategies.

Algorithm 2

Procedure AG_CASU_Management (File $\boldsymbol{\tau}$.MAN)
if (¬$\boldsymbol{\tau}$.MAN)
  Exit() //τ.MAN file must comply
else
if (SurfaceOrganicMulches is **Active**) //percentage (%) of ground surface covered by mulches in growing period 0-100
  WriteNewOrganicMulches()
if (MulchesSoilEvaporation is **Active**) //(%) of mulches on reduction of soil evaporation 0-100
  WriteNewMulchesSoilEvaporation()
if (SoilFertility is **Active**) //Non-limiting soil fertility 0-100
  WriteNewSoilFertility()
if (SoilBunds is **Active**) //height (m) of soil bunds
  WriteNewSoilBunds()
if (SurfaceRunoff is **Active**) //surface runoff NOT affected by field surface practices
  WriteNewSurfaceRunoff()
if (CompletelyPrevented is **Active**) //N/A (surface runoff is not affected or completely prevented)
  WriteNewCompletlyPrevented()
if (CoverCanopy is **Active**) //relative cover of weeds at canopy closure (%) 0-100
  WriteNewCompletlePrevented()
if (CoverofWeeds is **Active**) //increase of relative cover of weeds in mid-season (+%) 0-100
  WriteNewCoverofWeeds()
if (CCexpansion is **Active**) //shape factor of the CC expansion function in a weed infested field
  WriteNewCCexpansion()
end procedure

The "AG-CASU" algorithm takes an initial configuration file (seed) of the variables of this type (.MAN) and it generates a set of scenarios based on the variability of each one of the parameters. Figure 5 shows an example of configuration file of crop management strategies.

3.3. **Scenario generator for the AquaCrop software.** This module, implemented as shown in Algorithm 3, is in charge of configuring the AquaCrop software project files (.PRO) according to the files generated by the previous modules. Additionally, it is in charge of controlling the number of possible scenarios according to the needs of the user. The module seeks to make the coverage of the search space by generating a large number of scenarios and making a combinatorial between the possible candidate files.

```
0  100 % surface organic mulches
1      6.0        : AquaCrop Version (March 2016)
2     100         : percentage (%) of ground surface covered by mulches IN growing period
20     50         : effect (%) of mulches on reduction of soil evaporation
31     0         : Non-limiting soil fertility
36     0.00      : height (m) of soil bunds
43     0         : surface runoff NOT affected by field surface practices
53     0         : N/A (surface runoff is not affected or completely prevented)
64     0         : relative cover of weeds at canopy closure (%)
74     0         : increase of relative cover of weeds in mid-season (+%)
85    -0.01      : shape factor of the CC expansion function in a weed infested field
```

FIGURE 5. Example of configuration file of crop management strategies

Algorithm 3

Procedure AG_Scenario
integer i ← 0
while i < NUMGENERATIONS
Activate (IrrigationParameters (IrrigationMode, Percentaje, Scheduling, TimeMode, Depth))
Activate (ManagmentParameters (SurfaceOrganicMulches, MulchesSoilEvaporation, SoilFertility, SoilBunds, SurfaceRunoff, CompletelyPrevented, CoverCanopy, CoverofWeeds, CCexpansion))
AG_CASU_Irrigation (τ.IRR)
AG_CASU_Management (τ.MAN)
UpdateProject (τ.PRO)
i ← i + 1
end procedure

3.4. **Execution of the simulations.** This module is responsible to automatically "call" the AquaCrop software plug-in to complete the simulations and be responsible for execution of the performance evaluation of each of the scenarios. The simulation software creates an output file according to the configuration of each scenario. The answers are analyzed from the biomass generated according to each configuration. Lastly, combinations of irrigation policies and crop management strategies that allow the best estimate of biomass production are selected to support the decision-making.

4. **Conclusions.** This paper explains the use of an algorithm as a tool for the automatic generation of irrigation policies configuration parameters and crop management strategies of the AquaCrop agroclimatic irrigation model. This algorithm supports the decision process in the planning and administration of organic coffee crops in the Sierra Nevada de Santa Marta. Finally, the Monte Carlo approach determines the opportunity to perform an exhaustive exploration of the search space to find the right solution for the complexity of this problem. This algorithm corresponds adequately to the restricted nature, with real values and non-deterministic behavior of the stochastic variables associated with the agroclimatic risk models. In summary, the problem is simplified to the selection of the appropriate combinations of crop management strategies and irrigation policies. In this project, it has been specified that the evaluation (fitness) function corresponds to the output of the AquaCrop simulator referring to the biomass estimated of the production of a coffee crop with a set of well-defined climatic conditions. From the results of the present paper, as future work, we would propose, for example, a mechanism to read and acquire data in real time using the Internet of things (IoT) and the coffee growers should improve the decision-making process with Ambiance Intelligence (AmI).

Acknowledgment. The authors gratefully acknowledge support by Universidad de Santander (UDES), Pontificia Universidad Javeriana, ASOPROKIA and COLCIENCIAS for funding this project.

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