Hindawi
International Journal of Agronomy
Volume 2017, Article ID 5353648, 8 pages
https://doi.org/10.1155/2017/5353648

Research Article

Linear Optimization Model for Efficient Use of Irrigation Water

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Received 8 May 2017; Accepted 27 June 2017; Published 26 July 2017

Academic Editor: David Clay

The implementation of innovative and efficient irrigation techniques is among the greatest challenges facing agriculture. In this regard, a linear programming model is presented in order to optimize water use. The idea behind this model is to assess the effectiveness or ineffectiveness of precipitation to determine the amount of irrigation water required to optimize water use. To achieve this idea, the "knapsack" problem decisional form was used, and the combination of the linear programming and the above-mentioned form proved satisfactory. Field experiments were conducted in Algeria. Based on calculated budgets a model using linear programming was developed. A comparison between the model results and the field findings suggests that the model could reduce water consumption by 28.5%.

1. Introduction

Irrigation is the most used means of agricultural intensification and will stay a cornerstone in the domain of food security policies towards climatic variability [1]. It can be defined as artificial implementation of water in agriculture and is regarded as a very significant constituent of agrarian activity [2].

In most countries, water is used for irrigating land more than for any other purpose, and any decrease in water supply can cause production and yield to decrease.

In order to reduce water consumption without compromising agricultural yield as an economic mainstay, various studies have been carried out by researchers, who had different visions on the subject.

Some researchers attempted to estimate evapotranspiration to determine water needs and hence to optimize the use of irrigation water. A neural network approach was proposed by Laaboudi et al. [3] to estimate the reference evapotranspiration and resolve the problem of the high number of climatic parameters needed to use Penman Montheith equation. Takakura et al. [4] used the energy balance equation to measure evapotranspiration. Takakura et al. proved in their study the simplicity and suitability of their method for irrigation.

For the same purpose, support vector machine method was used by Yao et al. [5] and artificial neural networks technique was used by King et al. [6]. Extraterrestrial radiation, air temperature, and humidity were used in [7] to estimate potential evapotranspiration and to assess future climate change effects on the vegetation.

Other researchers insist on the necessity of considering the economic factors [8, 9], to decide about irrigation depths and select crop zones for economic benefit; Kuo & Liu [8] developed a customized genetic algorithm. For the same purpose, the exact optimization methods were also used, to mention but a few, linear programming [10–12], nonlinear programming [13], quadratic programming [14], and dynamic programming [9].

Many authors used real time monitoring applications [15] by means of wireless sensor networks (WSNs). These networks make possible a timely and minute irrigation application according to the existing environmental conditions, resource availability, and weather forecasts [16, 17]. The potential applications of WSN in irrigation cover a large set of scenarios and applications [18]. For instance, a real time intelligent irrigation controller has been conceived in order to detect the optimal irrigation time [19]. For the same purpose, a wireless data acquisition network was implemented and applied to control drip irrigation of dwarf cherry trees [20]. Angelopoulos et al. [21] minimized the study area and proposed a smart home-irrigation system. This system is managed to maintain soil humidity levels and cover the different watering needs. Ant Colony Algorithm was also combined with a wireless sensor network to identify areas which are relatively arid and avoid water wastage [22]. Another implementation of WSN for two kinds of soil and six different crops was performed by Kumari et al. [23]. Gao et al. [24] combined WSN with a fuzzy control system in an intelligent water-saving irrigation system in their research to achieve remote on-line monitoring and control.

To highlight the impact of WSN use in irrigation, a comparison study between automated drip irrigation system and non-automated drip irrigation systems was done by Soorya et al. [25]. This study proved that the automated system exhibited more promising results compared to the other system. However, WSNs consist of battery-powered nodes known for limited energy capacity [26]; as a result, several studies about solar powered nodes in irrigation were proposed as a solution to the energy constraint [20, 27].

Among the various approaches presented, the linear programming model is considered as the most heavily used technology in resource management, such as the problem posed in this study. Therefore, this model has been selected in order to ensure an integrated irrigation management.

The new feature in this proposal is to take advantage of the knapsack optimization problem, which dates back to more than a hundred years to solve a contemporary problem, which is water shortage. The object of this proposal is to develop an approach which uses the right amount of water and replace the traditional strategies of regular irrigation whether the plants need it or not.

Besides the discussion of previous works performed in water optimization, this study comprises five sections; the first presents factors that affect plant water needs, the second deals with the model description followed by model formulation using linear programming, next a numerical study will be done using Matlab R2015a Software to validate the performance of the proposed model, and the last section concludes the work.

2. Materials and Methods

2.1. Experimental Setting. The study of cereals was conducted in the meteorological station of Ain Skhouna; municipality of Zarma was selected; it is located 23 Km east of the city of Batna in Algeria. The variety of the sample crop (winter wheat) used was sown on November 20th and harvested on June 10th. The climate is semiarid with an annual average rainfall of 327 mm, insufficient for the cereals, due to a dry period of 06 months from May to November, and thus requiring irrigation (see Figure 1). The soil is not saline and is rich in limestone with a slightly basic pH (7.1), in a fine clay-loam texture [28].

2.2. Determining Plant Irrigation Needs. Determining the timing and amount of necessary water for irrigation (plant irrigation needs) can be a complex process that takes into consideration factors such as the following.

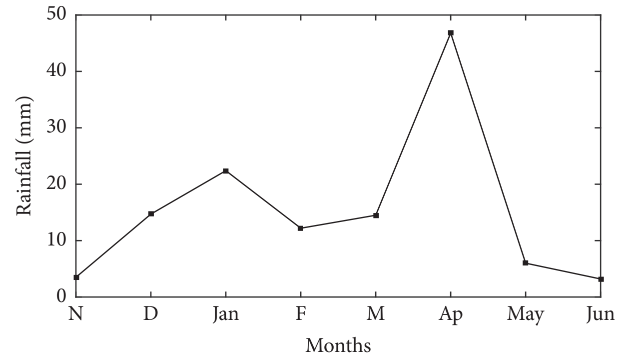

Figure 1: Monthly changes of rainfall in the study field.

2.2.1. Climatic Conditions Prevailing in the Region. The effect of weather on plant water needs is given by the reference crop evapotranspiration "ET0" which can be defined as the rate of evapotranspiration from a wide surface of 8 to 15 cm tall, green grass cover of identical height, actively growing, completely shading the ground, and not short of water. It is expressed in mm per day [29]. ET0 is calculated using (1), which takes into account the climatic parameters of temperature, solar radiation, wind speed, and humidity. This equation was estimated from the Penman-Montheith formula given in (2).

$$\mathrm{ET0} = \frac{0.408\Delta\left(R_n - G\right) + \gamma\left(900/\left(T + 273\right)\right) u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)}, \quad (1)$$

$$\lambda\mathrm{ET} = \frac{\Delta\left(R_n - G\right) + \rho_a c_p\left(\left(e_s - e_a\right)/r_a\right)}{\Delta + \gamma\left(1 + r_s/r_a\right)}, \quad (2)$$

where ET0 is the reference evapotranspiration [mm day^{-1}], R_n is the net radiation at the crop surface [MJ m^{-2} day^{-1}], G is the soil heat flux density [MJ m^{-2} day^{-1}], T is the mean of daily air temperature at 2 m height [°C], u_2 is the wind speed at 2 m height [m s^{-1}], e_s is the saturation vapour pressure [kPa], e_a is the actual vapor pressure [kPa], $e_s - e_a$ is the saturation vapor pressure deficit [kPa], Δ is the slope vapor pressure curve [kPa °C^{-1}], γ is the psychometric constant [kPa °C^{-1}], λET is the latent heat flux [MJ kg^{-1}], ρ_a is the mean air density [g m^{-3}], c_p is the specific heat of the air [MJ kg^{-1} °C^{-1}], r_a is the aerodynamic resistance [s m^{-1}], and r_s is the bulk surface resistance [s m^{-1}] [30, 31].

2.2.2. Plant Type and Stage of Growth. Different plants require specific amounts of water at various stages of their growth, and as mentioned in [32], the crop evapotranspiration ET$_c$ is calculated by multiplying the reference evapotranspiration ET$_0$ and the agricultural coefficient "k_c" which

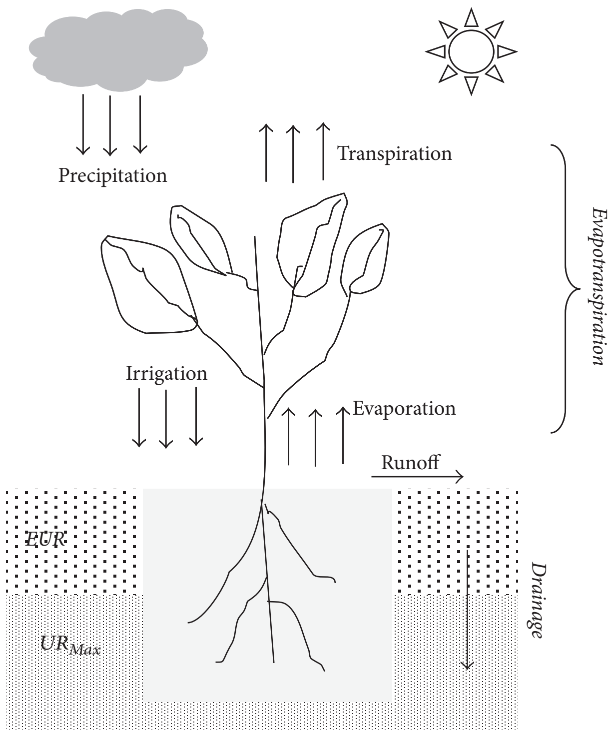

Figure 2: Water balance model.

is different from one plant to another, and from one growth phase to another.

$$\mathrm{ET}_c = k_c \times \mathrm{ET}_0. \quad (3)$$

2.2.3. The Properties of the Soil. The type of soil plays a major role in determining the plant water balance. The soil water content is mainly due to its texture, which is determined uniquely by a combination of three variables, sand percentage, silt, and clay content of the soil [33].

Water retention capacity depends on the composition and compaction of the soil. Crops sown in sandy soils need more water because of higher infiltration rate. Likewise, surface soils need more water compared to deeper soils [34].

2.2.4. Irrigation Method. To select a convenient irrigation strategy, it is necessary to be aware of the benefits and shortcomings of these strategies. The agriculturer has to be able to decide about the best strategy to use according to local conditions. However, it is often difficult to find the best option since any strategy has benefits and shortcomings [35].

The choice of the irrigation strategy, that is, using surface, sprinkler, or drip irrigation, is mainly based on natural conditions, the kind of plant, the available techniques, prior experience, the available labour force, and the cost function [36].

2.3. Model Description. There are different sources of water to meet the needs of plants (see Figure 2).

First, rain, which is a natural source significantly affecting the amount of water to be added to the plant, is efficient when rainfall exceeds a threshold $T1$ and is less than $T2$, or when the amount of rainfall of three consecutive days exceeds a threshold $T3$ (see Table 1). If not, the rain is qualified as isolated and therefore not useful for the plant. These threshold values vary depending on the climate and soil of the agricultural zone; for example, any isolated rain less than 10 mm or any episode where the amount of rain over three days is less than 15 mm. Similarly, the excessive volume of rain stored out of the reach of the roots cannot be considered [37].

Table 1: Thresholds value.

$T1$	$e_i - s_i - i_i + d_i$
$T2$	$ur_i - s_i - i_i + d_i$
$T3$	$T1 \leq T3 \leq T2$
$T4$	$e_i - r_i - i_i + d_i$
$T5$	$ur_i - r_i - i_i + d_i$
$T6$	$e_i - r_i - s_i + d_i$
$T7$	$ur_i - r_i - i_i + d_i$

Another source is the soil reserve which plant roots can reach.

Since soil oxygen is essential for root function, the growth of plants depends on the H_2O content and oxygen movement within the soil [38].

Water in the soil can be classified as available or unavailable water, based on the amount held in the soil between retention point and wilting point; water volume can vary from a small percentage to more than 50 percent [39]. The amount of available water depends on the soil textures and the rooting system of the crop.

According to Tiercelin and Vidal [37], the useful water content θu is given by

$$\theta u = \theta cr - \theta pf, \quad (4)$$

where θu is useful water content and θcr is Retention point, that is, water content in the retention capacity. If θu equals θcr, there is an excess of water; θpf is wilting point, or water content capacity of wilting. If θu equals θpf, there is a lack of water.

It is also possible to calculate θu using the equation of useful water reserve:

$$\mathrm{UR} = (\theta cr - \theta pf) \times Z, \qquad \theta u = \frac{\mathrm{UR}}{Z}, \quad (5)$$

where UR is useful water reserve and Z is depth of soil reached by the roots.

And the most important resource is the water provided by the agriculturer, which is generally a limited resource which must be used with precaution.

This resource represents the difference between the total amount of water needed by the plant and the water provided by rainfall and the soil.

In addition to the discussed resources, plant water needs include all losses such as evapotranspiration, which is expressed by (1), and losses during irrigation, expressed in terms of drainage water and represented by "D" in the proposed model.

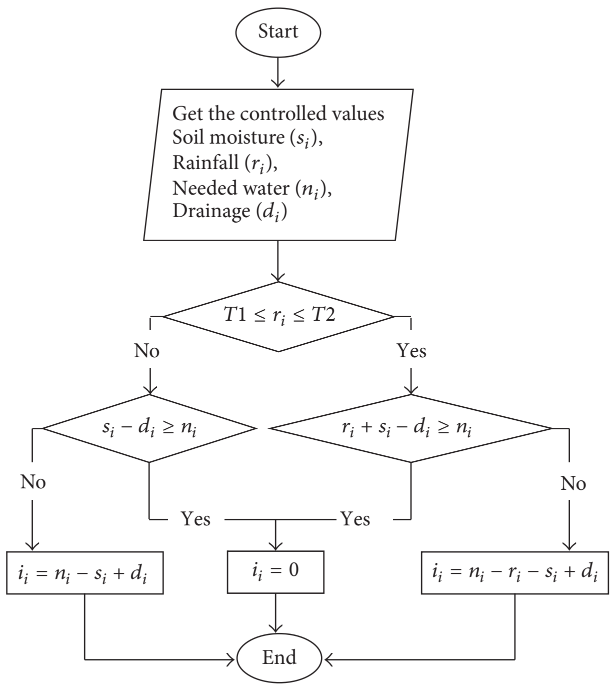

Figure 3: Flow chart of the proposed model.

The design of the model suggested in this work is generally based on the flowchart illustrated in Figure 3. The idea of the system is to take advantage of all available water resources to determine the optimal quantity of irrigation water, and as noted in Figure 3, the system handles all conditions that may be faced by the agriculturer during the irrigation process:

Case 1. When there is no rainfall and the soil moisture is insufficient to cover the lost water, the irrigation water provided by the agriculturer will be equal to the difference between plant water requirement and soil water content.

Case 2. If the soil moisture is equivalent to the plant water needs either with or without rainfall, in this case, the irrigation water will take the value 0.

Case 3. If rain and soil moisture are not effective, and there is a lack of coverage of the plant water needs, the value of irrigation water will be equal to the difference needed to cover this lack.

An analysis of the efficiency or inefficiency of precipitation and soil moisture will be discussed in the next section.

2.4. Model Formulation. In this study, a linear programming model is used. A set of techniques and methods is inferred from mathematics and other sciences, which was developed during World War II, and it is continually applied by researchers to improve management decisions [40].

The formulation process model contains

(i) the identification of the decision variables,

(ii) the formulation of the objective function,

(iii) the identification and the formulation of the constraints.

Let $P = [t, t+1, t+2, \ldots, T]$ be planting period, and it varies from one plant to another and can be measured with any usual temporal unit, in which "t" is the planting time and "T" is the harvest time. $\mathrm{NW} = [n_i, n_{i+1}, n_{i+2}, \ldots, n_T]$ is needed water, and it refers to the water lost through evapotranspiration, $R = [r_i, r_{i+1}, r_{i+2}, \ldots, r_T]$ is efficient rain, $\mathrm{UR}_{\mathrm{Max}} = [ur_i, ur_{i+1}, ur_{i+2}, \ldots, ur_T]$ is maximal useful water reserve, $\mathrm{EUR} = [e_i, e_{i+1}, e_{i+2}, \ldots, e_T]$ is easily used water reserve, $S = [s_i, s_{i+1}, s_{i+2}, \ldots, s_T]$ is soil moisture, and $I = [i_i, i_{i+1}, i_{i+2}, \ldots, i_T]$ is irrigation water. These values are the decision variables of the linear optimization model. $D = [d_i, d_{i+1}, d_{i+2}, \ldots, d_T]$ is drainage water, in which

$$\frac{\delta n}{\delta t} = \frac{\delta r}{\delta t} + \frac{\delta s}{\delta t} + \frac{\delta i}{\delta t} - \frac{\delta d}{\delta t}. \tag{6}$$

2.4.1. Identification of the Objective Function. The aim of the proposed model is to minimize the quantity of water required for irrigation using soil humidity and rain, as explained in

$$\mathrm{Min} \sum_{i=t}^{T} \alpha_1 r_i + \alpha_2 s_i + i_i. \tag{7}$$

$\alpha_1 = 1$ for $r_i \in R$ and $\alpha_2 = 1$ for $ur_i \in \mathrm{UR}$.

2.4.2. Identification and Formulation of the Constraints

(1) Limits of Efficient Rainfall

$$\begin{gathered} r_i \in R \longrightarrow r_i \geq 0, \\ T1 \leq r_i \leq T2, \quad \forall i \in [t, \ldots, T], \\ \sum_{t=i}^{i+2} r_i \geq T3, \quad \forall i \in [t, \ldots, T-2]. \end{gathered} \tag{8}$$

(This condition applies just when there is successive rainfall.)

(2) Limits of Useful Reserve

$$\begin{gathered} ur_i \in \mathrm{UR}_{\mathrm{Max}} \longrightarrow ur_i \geq 0, \\ \theta pf < ur_i < \theta cr \quad \forall i \in [t, \ldots, T]. \end{gathered} \tag{9}$$

The same conditions remain valid for the EUR, given that the latter is less than $\mathrm{UR}_{\mathrm{Max}}$.

(3) Limits of Soil Humidity

$$\begin{gathered} s_i \in s \longrightarrow s_i \geq 0, \\ T4 \leq s_i \leq T5 \quad \forall i \in [t, \ldots, T], \\ s_{T+1} = 0. \end{gathered} \tag{10}$$

Table 2: Summary of monthly results during the development cycle (January–June).

Month	Jan	Feb	Mar	Apr	May	Jun
Rooting depth (cm)	12–17	18–21.5	22–35	36–45.5	46–53	53
EUR (mm)	42.87	55.17	72.50	112.50	141.33	50.17
R (mm)	22.4	12.2	14.5	46.8	6.0	3.2
S (mm)	21.43	27.58	36.25	56.25	70.67	25.08
D (mm)	45.25	46.25	35.5	102.25	85.0	42.0
UR_{Max} (mm)	64.3	82.75	108.75	168.75	212.0	75.25
NW (mm/month)	42.1	45.07	91.5	113.92	133.25	33.25

Table 3: Usual and estimated irrigation water from January to June (mm).

Month	Jan	Feb	Mar	Apr	May	Jun	Total
Usual irrigation water	75.25	212	168.75	108.75	82.75	64.30	711.80
Estimated irrigation water	63.89	149.66	113.12	76.25	61.64	44.29	508.85

(4) Limits of Available Irrigation Water

$$\sum_{i=t}^{T} i_i \leq I, \quad i_i \in I \longrightarrow i_i \geq 0, \quad T6 \leq i_i \leq T7. \tag{11}$$

Threshold values vary from one agricultural zone to another, according to climatic conditions. These values are computed as illustrated in Table 1.

Therefore, the problem was reduced to the following linear program:

$$\text{Minimize} \quad Z = \sum_{i=t}^{T} \alpha_1 r_i + \alpha_2 s_i + x_i \tag{12}$$

$$\text{Subject to} \quad \sum_{i=t}^{T} x_i \leq I, \tag{13}$$

$$x_i \geq e_i - r_i - s_i + d_i, \tag{14}$$

$$x_i \leq ur_i - r_i - s_i + d_i, \tag{15}$$

$$r_i \geq e_i - x_i - s_i + d_i, \tag{16}$$

$$r_i \leq ur_i - x_i - s_i + d_i, \tag{17}$$

$$s_i \geq e_i - r_i - x_i + d_i, \tag{18}$$

$$s_i \leq ur_i - r_i - x_i + d_i, \tag{19}$$

$$r_t + s_i + x_i - d_i \geq n_i, \tag{20}$$

$$s_{T+1} = 0, \tag{21}$$

$$\alpha_1, \alpha_2 \in [0, 1], \tag{22}$$

$$x_i, e_i, r_i, s_i, ur_i, d_i, n_i \geq 0 \quad \forall i \in [t, \ldots, T]. \tag{23}$$

In this model

(i) the objective function (12) with constraints (13), (14), (15), and (20) minimizes the quantity of irrigation water,

(ii) constraints (16) and (17) are used to check rainfall efficiency,

(iii) constraints (18) and (19) are used to check the efficiency of the soil reserve in water (soil moisture),

(iv) constraint (21) is used to ensure that at the end of the planting season the soil reserve is fully used; thus it is well exploited in order to optimize irrigation water.

3. Results

In order to highlight the necessity of using a linear programming model for irrigation water optimization, it is necessary to first determine the values of each term of the proposed model as described in Section 2.4.

Results in Table 2 illustrate the monthly variables over the experimental study field, used to resolve the optimization problem.

In order to check the validity of the proposed model, the obtained results will be compared with the usual amount of water, used for irrigation during the experimental period. These values are based on traditional methods. The usual and estimated irrigation water distribution from January to June is presented in Table 3.

4. Discussion

In the presented proposal, a linear programming model was combined with the "Knap sack" problem decisional form to evaluate water use efficiency, by studying the effectiveness or ineffectiveness of rainfall and soil water content.

To resolve the optimization problem, the linear programming function of MATLAB R2015a software is used. The obtained results indicate that the total irrigation water measured using the proposed model is less than the total usual quantity with 202.95 mm, and this is also confirmed

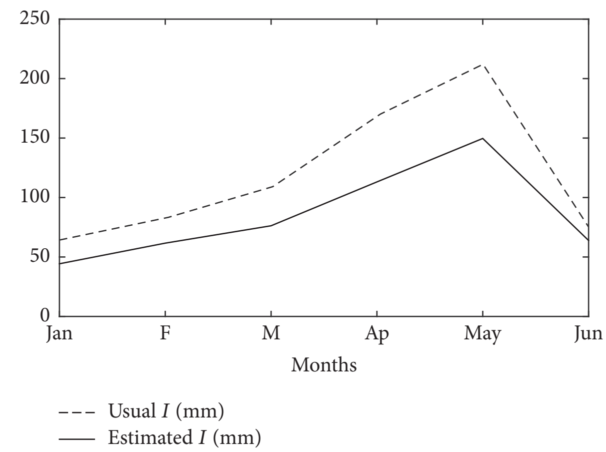

Figure 4: Usual and estimated irrigation water.

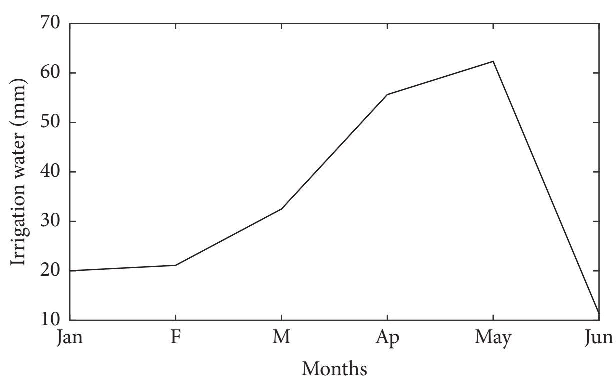

Figure 5: Monthly difference of estimated and usual irrigation water.

in Figure 4, which shows the difference between usual and estimated irrigation water during different plantation periods, and this has to do with the full use of all available water resources, either in the soil or as rainfall, as described in the system constraints.

Figure 5 shows the monthly difference of estimated and usual irrigation water from January to June. It can clearly be seen that there has been a positive difference between usual and estimated irrigation water. This difference increases to reach the highest value in the month of May, which is estimated at 62.34 mm, and then decreases until the month of April to 11.36 mm, and this is a logical decrease because rainfall in this period reaches the lowest levels as shown in Figure 1.

According to the system constraints, the lowering in the value of i_i means more economy in water as a source of irrigation. Moreover the increase of this value which is due to inadequate r_i and s_i to cover the plant's needs means that there is a renewal of soil water, which helps prevent the phenomenon of underground water pollution.

Moreover, by looking at Figure 6, it can be noted that there is a direct proportion between rainfall and the difference between the losses due to the evapotranspiration and drainage on the one hand, and the estimated irrigation water on the other, which means that there is a decrease in the amount of irrigation water accompanied with increase in rainfall, which proves that there is an optimized use of rain water as an alternative resource for irrigation, and this is one of the most important features of the proposed model.

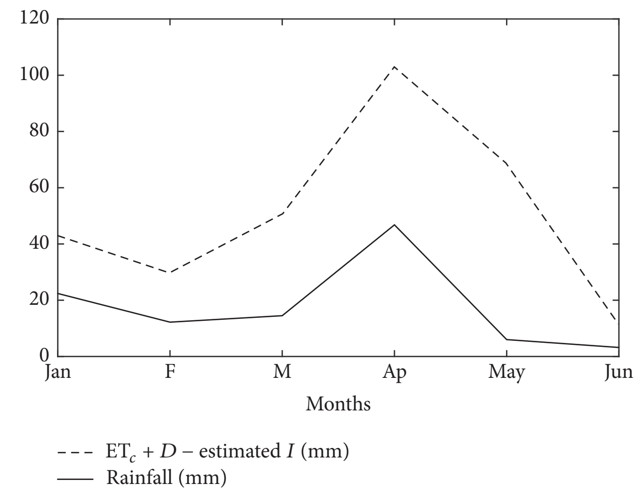

Figure 6: Relation between ($ET_c + D -$ estimated I) and Rainfall.

The results of this study have revealed the importance of irrigation water management, especially in arid and semi-arid regions, under extreme climatic conditions. The study takes advantage of the positive impact of precipitation and soil water content to improve the efficiency of water use.

5. Conclusion

The present paper attempted to develop a linear programming model that improves water use efficiency based on weather and soil conditions.

The model in its structure is based on the use of simple equations, which makes it attractive to use by a wide variety of agriculturers.

As shown in this study, the model can be used for agricultural purposes, and the experimental results demonstrate that, by applying the proposed optimization model, it is possible to reduce water consumption by 28.51%.

Furthermore, excessive irrigation can lead to ground water pollution and to salinization of this resource. Hence, this method can reduce these effects through rational use of water.

In addition to that this model is feasible to apply in any area; the difference lies only in the threshold values characterizing each zone.

It is worth mentioning that this system should be further developed, so that it will have more features and can be combined with recent technological advances like the Internet of things in order to monitor and schedule irrigation water.

Moreover, this system could be developed for use inside greenhouses, where it is possible to control external factors such as relative humidity, temperature, wind speed, and sunshine duration, and also in order to enrich the system with other parameters that might be the subject of further investigation.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] FAO water reports, *Climate change, water and food security*, Food and Agriculture Organization of the United Nations, Rome, Italy, 2011.

[2] Aqeel-ur-Rehman et al., "A review of wireless sensors and networks' applications in agriculture," *Computer Standards Interfaces*, vol. 36, pp. 263–270, 2014.

[3] A. Laaboudi, B. Mouhouche, and B. Draoui, "Neural network approach to reference evapotranspiration modeling from limited climatic data in arid regions," *International Journal of Biometeorology*, vol. 56, no. 5, pp. 831–841, 2012.

[4] T. Takakura, C. Kubota, S. Sase et al., "Measurement of evapotranspiration rate in a single-span greenhouse using the energy-balance equation," *Biosystems Engineering*, vol. 102, no. 3, pp. 298–304, 2009.

[5] Y. Yao, S. Liang, X. Li et al., "Improving global terrestrial evapotranspiration estimation using support vector machine by integrating three process-based algorithms," *Agricultural and Forest Meteorology*, vol. 242, pp. 55–74, 2017.

[6] D. A. King, D. M. Bachelet, A. J. Symstad, K. Ferschweiler, and M. Hobbins, "Estimation of potential evapotranspiration from extraterrestrial radiation, air temperature and humidity to assess future climate change effects on the vegetation of the Northern Great Plains, USA," *Ecological Modelling*, vol. 297, pp. 86–97, 2015.

[7] V. Z. Antonopoulos and A. V. Antonopoulos, "Daily reference evapotranspiration estimates by artificial neural networks technique and empirical equations using limited input climate variables," *Computers and Electronics in Agriculture*, vol. 132, pp. 86–96, 2017.

[8] S.-F. Kuo and C.-W. Liu, "Simulation and optimization model for irrigation planning and management," *Hydrological Processes*, vol. 17, no. 15, pp. 3141–3159, 2003.

[9] Z. X. Fang, B. Voron, and C. Bocquillon, "Dynamic programming: a model for an irrigation reservoir," *Hydrological Sciences Journal*, vol. 34, no. 4, pp. 415–424, 1989.

[10] J. Auriol et al., "Optimization of catchment devices for simulation irrigation on mathematical models and linear programming," in *Proceedings of the Paper presented at the 9th World Congress of the ICI*, Moscow, 1975.

[11] Z. Zhenmin, "Optimization of water allocation in canal systems of ChenGai irrigation area," in *Proceedings of the Paper presented at CEMAGREF-IIMI International Workshop on The Application of Mathematical Modeling for the Improvement of Irrigation canal Operation*, Montpellier, France, 1992.

[12] A. Singh and S. N. Panda, "Optimization and Simulation Modelling for Managing the Problems of Water Resources," *Water Resources Management*, vol. 27, no. 9, pp. 3421–3431, 2013.

[13] V. Azimi et al., "Optimization of deficit irrigation using non-linear programming (Case study:Mianeh region, Iran)," *International journal of Agriculture and Crop Sciences*, vol. 6, no. 5, pp. 252–260, 2013.

[14] S. Hong et al., "Optimization of irrigation scheduling for complex water distribution using mixed integer quadratic programming (MIQP)," in *Proceedings of the the 10th International Conference on Hydroinformatics*, Hamburg, Germany, 2012.

[15] P. Upadhyay et al., "Evaluating seed germination monitoring system by application of wireless sensor networks: a survey," *Advances in Intelligent Systems and Computing*, vol. 411, pp. 259–266, 2016.

[16] K. R. Thorp, D. J. Hunsaker, A. N. French, E. Bautista, and K. F. Bronson, "Integrating geospatial data and cropping system simulation within a geographic information system to analyze spatial seed cotton yield, water use, and irrigation requirements," *Precision Agriculture*, vol. 16, no. 5, pp. 532–557, 2015.

[17] D. Levy, W. K. Coleman, and R. E. Veilleux, "Adaptation of potato to water shortage: irrigation management and enhancement of tolerance to drought and salinity," *American Journal of Potato Research*, vol. 90, no. 2, pp. 186–206, 2013.

[18] J. M. Barcelo-Ordinas, "A survey of wireless sensor technologies applied to precision agriculture," in *Precision agriculture 13*, J. V. Stafford, Ed., Wageningen Academic Publishers, 2013.

[19] Dassanayake et al., "Water saving through smarter irrigation in Australian dairy farming: Use of intelligent irrigation controller and wireless sensor network," in *Proceedings of the Paper presented at the 18th World IMACS / MODSIM Congress*, Cairns, Australia, 2009.

[20] M. Dursun and S. Ozden, "A wireless application of drip irrigation automation supported by soil moisture sensors," *Scientific Research and Essays*, vol. 6, no. 7, pp. 1573–1582, 2011.

[21] C. M. Angelopoulos, S. Nikoletseas, and G. C. Theofanopoulos, "A Smart system for garden watering using wireless sensor networks," in *Proceedings of the 9th ACM International Symposium on Mobility Management and Wireless Access, MobiWac'11, Co-located with MSWiM'11*, pp. 167–170, usa, November 2011.

[22] S. Sutar et al., "Irrigation and fertilizer control for precision agriculture using wsn: energy efficient approach," *International Journal of Advances in Computing and Information Researches*, vol. 1, no. 1, 2012.

[23] R. N. Kumari et al., "Microcontroller based irrigation using sensor [a smart way for irrigation]," *International Journal of Research in Engineering & Advanced Technology*, vol. 2, no. 2, pp. 1–3, 2014.

[24] L. Gao, M. Zhang, and G. Chen, "An intelligent irrigation system based on wireless sensor network and fuzzy control," *Journal of Networks*, vol. 8, no. 5, pp. 1080–1087, 2013.

[25] E. Soorya et al., "Smart drip irrigation system using sensor networks," *International Journal of Scientific & Engineering Research*, vol. 4, no. 2, pp. 2039–2042, 2013.

[26] Y. T. Hou, Y. Shi, and H. D. Sherali, "Rate allocation and network lifetime problems for wireless sensor networks," *IEEE/ACM Transactions on Networking*, vol. 16, no. 2, pp. 321–334, 2008.

[27] P. Alagupandi, R. Ramesh, and S. Gayathri, "Smart irrigation system for outdoor environment using Tiny OS," in *Proceedings of the 3rd IEEE International Conference on Computation of Power, Energy, Information and Communication, ICCPEIC 2014*, pp. 104–108, ind, April 2014.

[28] R. Bourkouche, "La consommation en eau du blé water consumption of wheat," *Revue Agriculture*, pp. 205–209, 2016, http://revue-agro.univ-setif.dz/documents/numero-special/session5/bourkouche.pdf.

[29] M. Beg, "Prediction of crop water requirement: a Review," *International Journal of Advanced Technology in Engineering and Science*, vol. 2, no. 1, pp. 727–734, 2014.

[30] A. Laaboudi et al., "Conceptual reference evapotranspiration models for different time steps," *Pet EnvironBiotechnol*, vol. 3, no. 4, pp. 1–8, 2012.

[31] FAO document, *Crop evapotranspiration - Guidelines for computing crop water requirements*, Natural Resources Management and Environment Department, http://www.fao.org/docrep/X0490E/x0490e08.htm.

[32] R. G. Alen et al., *albakhr nutah lilmahasil : dalil taqdir alaihtiajat almayiya " Crop Evapotranspiration : Guidelines for Computing crop Water Requirement "tarjama F.Aawad w M.alssueud, alnnashr aleilmi w almutabie- jamieat almalik seud, almamlakat alearabiat alssaeudia*, 2006.

[33] B. J. Cosby, G. M. Hornberger, R. B. Glapp, and T. R. Ginn, "A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils," *Water Resources Research*, vol. 20, no. 6, pp. 682–690, 1984.

[34] Raghav, "5 Important Factors Affecting the Demand of Water for Crops," http://www.geographynotes.com/articles/5-important-factors-affecting-the-demand-of-water-for-crops/650.

[35] W. L. Powers and M. P. lewis, "Irrigation Requirement of Arable Oregon Soils, Oregon State College," 1941, http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/15005/StationBulletin394.pdf.

[36] C. Brouwer et al., *Irrigation Water Management: Irrigation Methods,Training manual no 5*, FAO Land and Water Development Division, 2001.

[37] J. R. Tiercelin and A. Vidal, *Traité d'irrigation "Irrigation treaty"*, 2nd edition, 2006.

[38] J. T. Ritchie, "Soil water balance and plant water stress," in *Understanding Options for Agricultural Production*, vol. 7 of *Systems Approaches for Sustainable Agricultural Development*, pp. 41–54, Springer Netherlands, Dordrecht, 1998.

[39] C. M. K. Gardner et al., *Soil physical constraints to plant growth and crop production*, FAO Land and water development division, 1999.

[40] M. S. Lord, "Linear Programming Optimizing the Resources," *Interdisciplinary Journal of Contemporary research in business*, vol. 4, pp. 701–705, 2013.