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The effect of various irrigation technologies and strategies on water resources management

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ERRATUM

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The name, the ORCID, and the affiliation of the second author were inserted by a mistake in the original PDF version of this article published on 27th Jun 2022. These have been removed from the PDF version published on 16th Sep 2022. The other elements remain unchanged.

Abstract: Today, the uncontrolled abstraction of surface water and groundwater resources has created adverse consequences, which include: extinction of living organisms, land subsidence, salinity of coastal aquifers, increased pumping energy. Therefore, the need to manage available water resources is felt more than ever. Among the various water uses (agriculture, drinking, and industry), agriculture accounts for the bulk of water consumption. Due to the climate change and the growing population, determining the appropriate strategy and technology for irrigation is necessary. In the current study, a simulation model is used to numerically simulate the dynamics of daily soil moisture during the potato crop growing season and to estimate crop production and economic benefits. For climatic data, daily observations of a meteorological station have been used. Results and analyses have been presented for all cases of micro and traditional irrigation methods and agricultural management strategies of non-stress irrigation, low irrigation, and rainfed cultivation. The results showed that in the non-stress irrigation method, crop production and net profit are almost equal in both traditional and micro methods. In the low irrigation method, microtechnology has made crop production and net profit 1.75 times more than traditional technology, which indicates the impact of irrigation technology on crop production.

Keywords: groundwater, irrigation technology, soil moisture, surface water, water consumption

INTRODUCTION

Today, climate change and the mismanagement of surface and groundwater resources have created severe water crises [Afshar *et al.* 2021; Hanjra, Qureshi 2010; Oki, Quiocho 2020; White, Howe 2004]. Studies have shown that choosing the right method and strategy for irrigating agricultural products can effectively reduce water consumption while maintaining economic benefits [Rathnayaka *et al.* 2016; Wang *et al.* 2020].

Types of irrigation methods are divided into three types: 1) traditional surface irrigation methods [Shareef *et al.* 2019], 2) modern surface irrigation methods (strip and furrow) [Jia *et al.* 2020], and 3) pressure irrigation methods (sprinkler, micro) [Konstantinidi *et al.* 2017].

Cretaceous and flood irrigation are a variety of traditional irrigation methods [Gu *et al.* 2019]. In Cretaceous irrigation, agricultural land is divided into different sizes. Each of these parts is called a plot. There is a water atmosphere between the plots in which water circulation to the plant is performed by circulating water. Flood irrigation is a method in which water enters the ground permanently or intermittently and permanently floods the soil [Elshaikh *et al.* 2018].

Among the various modern irrigation methods, we can mention strip and furrow irrigation methods [Graterol *et al.* 1993]. In strip irrigation, the field is taped. The purpose of this work is to penetrate the water at the same time as the water advances inside the strips. In the furrow irrigation method, water is introduced into the furrows created between the two rows of crops [Mateos *et al.* 1991].

In general, pressurized irrigation systems are methods that distribute water through pipes and under pressure above atmospheric pressure on the farm surface [Neissi *et al.* 2020; Valipour 2017]. Pressure irrigation is divided into sprinkler and micro (drip) irrigation. In sprinkler irrigation, water enters the pipes with pressure by the pump motor and is sprayed on the product in the form of raindrops by a sprinkler. Drip irrigation (micro) is a method in which low-pressure water is poured out of the hole or a device called a dropper and poured in drops at the foot of the plant [Abedinpour 2017; Li 2018].

As mentioned before, in addition to the proper choice of irrigation method, irrigation strategy including stress-free, low-irrigation and rainfed irrigation is one of the effective factors in water resources management in the agricultural sector. Stress-free irrigation strategy increases water consumption and increases the farmer's economic profit. On the other hand, a low irrigation strategy reduces water consumption and reduces economic benefits. Therefore, in management plans, a compromise between water consumption and economic benefits should always be considered [Abdelraouf *et al.* 2021; Hamdan *et al.* 2021].

This study aims to obtain the actual evapotranspiration and potential evapotranspiration during the crop growth period for the potato plant through traditional irrigation methods and micro-irrigation and considering different irrigation management strategies (irrigation without stress, low irrigation, rainfed). The amount of product produced and the economic benefits for a variety of strategies and technologies are obtained. The optimal method and strategy for planting this crop will be obtained by comparing the types of irrigation methods and strategies. This plant is to be planted in Bajestan city (Iran), which is considered a hot and dry region. CROPWAT 8 software has been used to calculate the water requirement of the plant. The results of this study can provide a comparison of appropriate irrigation strategies and technologies for managers and decision-makers.

MATERIALS AND METHODS

GENERAL INFORMATION

In this study, the water requirement of the product was first calculated using CROPWAT software. Information and data input to this software include meteorological data, effective rainfall, plant conditions and soil characteristics, which will be mentioned in detail below. After calculating the water requirement of the potato plant, the simulation model will be prepared to calculate the total water requirement of the crop and economic benefits in the simulation time horizon for various irrigation strategies and technologies.

REQUIRED METEOROLOGICAL DATA

These data include minimum and maximum air temperature, sunny hours in the area, wind speed and direction, and relative humidity percentage at the station. At the end of this step, the value of ET_o is calculated in terms of mm per day due to weather conditions. The wind speed is taken at a distance of 10 m from the ground (v_{10}). Since velocity is required to calculate the rate of evaporation of plant transpiration at a distance of 2 m from the ground, Equation (1) has been used:

$$v_2 = v_Z \frac{4.87}{\ln(67.8Z - 5.42)} \tag{1}$$

where: Z = a distance of 10 m from the ground.

Therefore, according to the above equation, the velocity at the level of 2 m above the ground is calculated from Equation (2):

$$v_2 = 0.75 v_{10} \tag{2}$$

DETERMINING THE AMOUNT OF EFFECTIVE RAINFALL

In this section, the fix percentage method is used to calculate the effective precipitation (applying the leaf effect), and the effective precipitation of 80% of the precipitation is considered.

DETERMINING PLANT CONDITIONS

The initial stage, dev stage, mid-season, harvesting of potato take 25, 30, 30, and 30 days, respectively. Plant coefficient (K_c) is determined by the FAO-56 guideline (Fig. 1).

DETERMINING SOIL CHARACTERISTICS

The amount of relative soil moisture in the root zone of the plant can be considered in more detail to study water stress in the root zone of the plant at four levels: saturation capacity (S_{sat}), field capacity (S_{fc}), leaf threshold closure threshold (S_h) and plant wilting point (S_w). The S_{fc}, S_h, S_w and S_{sat} values of sandy loam are 0.56, 0.14, 0.18, and 0.46, respectively.

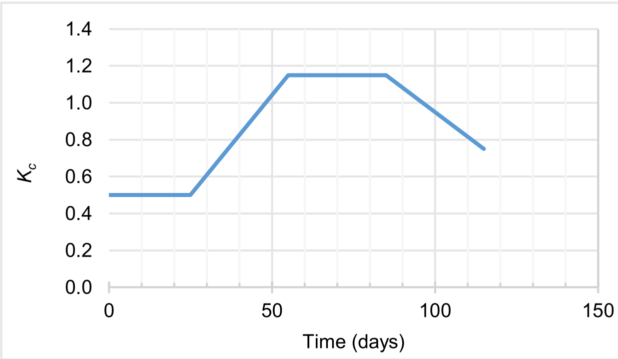

Fig. 1. Plant coefficient's (K_c diagram of potato during the plant growth time; source: own elaboration

Equation (3) is used to calculate the total available water:

$$T_{aw} = 1000(S_{fc} - S_w)Z_r \tag{3}$$

where: Z_r = plant root depth (60 cm).

The coefficient of water stress (K_s) is considered to be approximately 0.8.

CALCULATION OF POTENTIAL EVAPOTRANSPIRATION (ET_P)

The ET_p value for decades of crop growth must now be calculated and obtained. After calculating the potential evapotranspiration of plant, according to the type of irrigation technology and agricultural irrigation management strategies, the crop's amount of production and net profit can be obtained.

ECONOMIC DATA

In this study, the values of the cost of production per unit area of the crop (c), the uniform annual cost of operation of irrigation and drainage networks per unit area (c_2), the area under crop (A), p (the price of the crop), the sensitivity coefficient of crop water stress (K_y), and the maximum expected yield (Y_p) are USD2701 per ha, USD0.61 per mln m^3, 10 ha, USD0.33 per kg, 1.1, and 30,000 kg·ha^{-1}, respectively.

RESULTS AND DISCUSSION

The amount of required irrigation for potato crop in different decades of growing time was obtained as a graph in Figure 2.

After calculating the evapotranspiration potential of the potato crop, according to the type of irrigation technology (traditional and micro) and irrigation management strategies (rainfed, stress-free, and low-irrigation), the amount of production and net profit of this crop can be obtained. Note that crop production is a function of the amount of water given to the plant. Therefore, whenever the amount of rainfall or irrigation is less than the required moisture of the plant, the plant will suffer from stress and will not grow enough. Therefore, the rate of growth reduction is proportional to the rate of water shortage [Madramootoo, Morrison 2013]. It is logical that with the increase in the amount of potatoes produced, the cost of production per unit area, the amount of water consumption, the amount of operation of irrigation and drainage networks increases. On the other hand, more product production increases gross income. Therefore, in producing the quantity of the product, a compromise between costs and revenues must be considered [Liao *et al.* 2019].

In the rainfed irrigation method, the amount of crop is equal to 8,032 Mg, and the amount of net profit is –$503,703. A negative plus for net profit means that the cost of planting the crop is higher than the income from selling the potato crop. Therefore, this method of irrigation is not cost-effective and has no economic justification. Also, rainfed planting is recommended only when there are not enough water resources to meet the nutritional needs of the growing population. Figure 3a shows a diagram of soil moisture during rainfed cultivation.

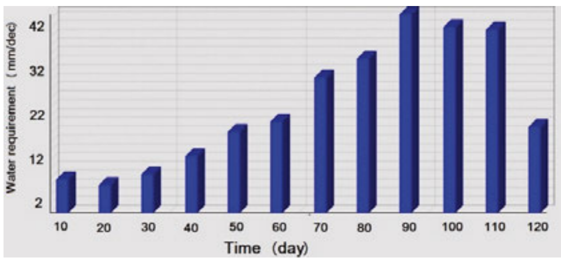

Fig. 2. Comparison of water requirements in decades of crop growth; source: own study

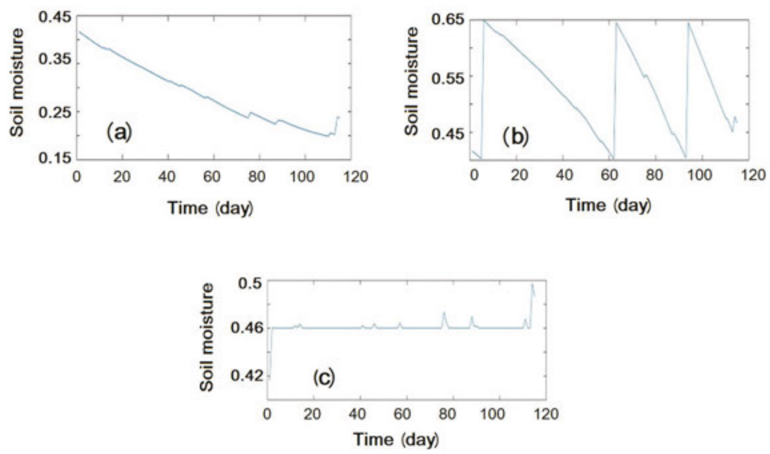

Fig. 3. Diagram of soil moisture by day with different cultivation methods/strategies: a) rainfed method, b) traditional irrigation strategy, c) stress-free strategy with microtechnology; source: own study

As you can see in Figure 3a, soil moisture is declining during the growing season. This can happen for two reasons: 1) decreased rainfall during the growing season; 2) increased potato crop demand during the growing season. As mentioned earlier, at the end of the growing season, water demand increases. According to the diagram in Figure 3a, the amount of soil moisture is much lower than in the first decades of growth. Therefore, it seems that the product has been under water stress in the last two months, and this has reduced the product. So negative net profit seems to be happening because of this.

In the low irrigation strategy with traditional irrigation technology, the yield is 29.21 Mg, and the net profit is USD69,391. Therefore, this type of irrigation method has economic justification and is recommended. It should be noted that the target humidity is considered to be 0.65, and irrigation will be cut off for higher humidity. Also, the humidity in which irrigation takes place is equal to 0.4. Management is done in such a way that soil moisture is never less than 0.4. Figure 3b shows a diagram of soil moisture during planting in a low-irrigation strategy with traditional technology. As mentioned before, in this method, irrigation is done whenever the soil moisture reaches the minimum moisture (0.4) until the soil moisture reaches the target point (0.65). This process continues until the end of the growth period.

In the stress-free irrigation strategy with micro-irrigation technology, the yield is 29.51 Mg, and the net profit is $70,384. Therefore, this type of irrigation method has economic justification and is recommended more than the traditional irrigation method. It should be noted that the target humidity is considered to be 0.46. Since irrigation is stress-free, the irrigation policy is such that the $S < S_{sat}$ condition is not violated. Figure 3c shows a diagram of soil moisture during planting in a stress-free irrigation strategy with microtechnology.

Finally, in order to better compare the different planting methods, Table 1 has been set up. As you can see in the table, the following methods are recommended for potatoes planting in the study area: 1) low irrigation strategy with micro-irrigation technology, 2) stress-free irrigation strategy with traditional irrigation technology, 3) stress-free irrigation strategy with micro-irrigation technology, 4) low irrigation strategy with traditional irrigation technology, and 5) rainfed cultivation of the crop.

Table 1. The amount of product produced and net profit for various technologies and irrigation management strategies

Type of cultivation	Product amount (Mg)	Net profit (USD)
Rainfed cultivation of the crop	8.032	–503.7
Low irrigation strategy with traditional irrigation technology	29.21	69,391
Low irrigation strategy with micro-irrigation technology	50.99	141,260
Stress-free irrigation strategy with traditional irrigation technology	29.976	71,912
Stress-free irrigation strategy with micro-irrigation technology	29.51	70,384

Source: own study.

CONCLUSIONS

In the current study, a comparison of different planting methods of potato with traditional and micro technologies and strategies of rainfed irrigation, low irrigation, and stress-free irrigation has been done. Concepts for each of the types of planting methods are presented. The water requirement of the potato crop has been calculated with CROPWAT software. In order to compare each of the different planting methods, production amount and economic profit are presented.

The results showed that in stress-free irrigation methods, crop production and net profit are almost equal in both traditional and micro methods. So, technology will have little impact on this strategy. The results indicated that the low-irrigation method of micro technology had made crop production and net profit much higher (1.75 times) than traditional technology. This issue will indicate the impact of irrigation technology on crop production. It is also observed that rain-fed crop cultivation is not economically viable, and crop production reaches a minimum.

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