International Journal of Plant Production
https://doi.org/10.1007/s42106-022-00199-z

RESEARCH

How the Economic Risk Management Influence Sugar Beet Production Methods in Different Irrigation Regimes and Plant Densities in Iran?

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Received: 15 December 2021 / Accepted: 30 April 2022
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Abstract

Under water shortage conditions, the farmers are faced with risk and uncertainty in decision making. The main objectives of this study are to selecting the well-managed deficit irrigation, the optimum plant density and appropriate planting method in order to decrease the sugar beet yield risk and water consumption risk. The gross margin (GM) and economic water productivity (EWP) are two main economic criteria, which are affected by yield and water consumption; therefore, they can be considered as risky parameters. This study uses Stochastic Dominance with Respect to a Function (SDRF) and stoplight graphs to evaluate the GM and EWP in three levels of irrigation regimes (100% (II), 75% (I2), and 50% (I3) of full irrigation), four plant densities (180,000 (P1), 135,000 (P2), 90,000 (P3), and 45,000 (P4) plants ha^{-1}) and two planting methods (direct seeding (D) and transplanting (T)) in sugar beet cultivation experiment, conducted in a split-split plot arrangement. The results from the SDRF method for GM and EWP analysis show that for lower risk aversion farmers, the I2 irrigation level and for upper-risk aversion farmers, the I1 irrigation level are the most preferred options. However, for both upper and lower risk aversion farmers, the P3 plant density and transplanting method are the most preferred options. By considering the interaction effects of irrigation regimes, plant densities, and planting methods on EWP, the I2P3T treatment is the most preferred treatment followed by I2P2T and I3P3T for both lower and upper-risk aversion farmers based on the SDRF method. The results showed that by using the deficit irrigation strategy in the same level of probability, the higher GM and EWP can be achieved as compared to the full irrigation strategy. The stoplights graph also indicated that the irrigation level of I2, plant density of P3, and transplanting method can increase the value of EWP to a higher level as compared to other treatments. Therefore, under condition of water deficit, combining these treatments can be helpful for obtaining the optimum GM and EWP in sugar beet cultivation.

Keywords Stochastic dominance · Risk management · Water consumption · Economic water productivity · Sugar beet

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Introduction

Irrigated sugar beet *(Beta vulgaris)* has been produced in last one century in Iran. Nowadays, about 32% of sugar supply is obtained from sugar beet, (Draycott, 2006), which is usually cultivated under arid and semi-arid environments. In 2018, approximately 2 million tons of sugar beet were produced in Iran from a total irrigated area of 23,000 ha (Zamani et al., 2019). The Iranian government has persuaded the farmers to produce sugar beet by a guaranteed price due to the fact that the farmer decision-making is related to gross margin (GM) achieved from sugar beet cultivation. Obtaining certain GM is not possible for farmers, because GM is related to the risky variables such as yield and production costs. While most farmers tend to be risk averse, attitude concerning risk is not fixed. Degree of risk aversion is deferred for farmers so risk management is an important process.

Sugar beet production, with an average of 13,000 m^3 ha^{-1} of water requirement (Khozaei et al., 2020), consumes more water as compared to many crops. Therefore, the shortage of water leads to the risk of water availability that is the most important challenge for increasing sugar beet yield in Iran, where water scarcity is the most important problem in the irrigated agriculture. (Oweis et al., 2011).

In sugar beet cultivation, different irrigation regimes, various plant densities and planting methods (transplanting and direct seeding) influence the GM and economic water productivity (EWP). It is noted that obtaining the maximum yield and consequently maximum GM are the desired objectives for farmers. However, in the condition of limited water resource, using the deficit irrigation strategy lead to achieving the optimal yield in comparison to spite of the full irrigation; therefore, the economic water productivity (EWP) can be increased. The EWP is affected by yield, production cost and water consumption that all of them are risky parameters for farmers.

Sugar beet planting method including transplanting and direct seeding influence water consumption, crop yield, and production cost; therefore, EWP and GM will be affected by these parameters. Transplanting method can be considered as an effective way for saving irrigation water, increasing water productivity and also decreasing the irrigation water cost in agricultural practice (Khozaei et al., 2020). Also, in this method, the risk of access to water resource is reduced due to eliminating the large amounts of irrigation water in the early growing season (Khozaei et al., 2020). In addition, the crop yield reduction in direct seeding is higher than that in transplanting method in late planting situation that affect the yield risk and consequently farmer's income (Haghighikhah et al., 2016; Dehghani et al., 2015; Rahnema and Bakhshande, 2005). The results of Khozaei et al. (2020) showed that in high plant density the transplanting method is more efficient than direct seeding method in sugar beet production. Plant density is an important agronomic parameter due to its effects on the light interception of leaves during the photosynthesis process and also influencing many aspects of cultural practices including susceptibility to pathogens, water and fertilizer requirements (Dai et al., 2014; Haghverdi et al., 2017; Jin et al., 2017; Khozaei et al., 2020; Thapa et al., 2019).

The profitability associated with planting methods and deficit irrigation under different plant densities can also be helpful in describing the adopted patterns. Despite of decreasing water cost in deficit irrigation, decrease in sugar beet yield in this irrigation strategy and increase in the production cost in transplanting methods, and also changes in root yield, water and fertilizer costs in different levels of plant density can affect overall risk of farmer profit. Therefore, the economic efficiency of combining these parameters should be evaluated to recognize the programs' overall effects on field profitability.

The effects of different levels of deficit irrigation, various plant densities and planting methods on quantity and quality of sugar beet yield and also on physiological parameters of sugar beet were investigated on different studies such as Khozaei et al. (2020), Haghverdi et al. (2017) and Abyaneh et al. (2017). Although many researches have investigated the trade-offs between water consumption and economic goals such as the study of Khozaei and Sepaskhah (2018) on economic analysis of the optimal level of supplemental irrigation for rain-fed figs. Khozaei et al. (2020) also reported the results on economic analysis of supplemental irrigation for rain-fed grape vine under drought condition. Banda et al. (2019) investigate economic analysis of deficit irrigation in sugarcane cultivation. The above-mentioned studies have only focused on certainty conditions, and risk management has not been considered. While, the present study investigated the risk management of the effects of different field managements in sugar beet production by considering farmer's attitude in uncertainty conditions. Management of sustainable production of sugar beet is impossible without taking into account economic and water consumption risks. The risk efficiency approaches are often used for agricultural risk management. In this case, the cultivation risk managements were investigated by Kadigi et al. (2020) for effect of different plant densities and nitrogen fertilizer on maize cultivation, Salassi et al. (2013) for rotation farming, Monjardino et al. (2015) for using fertilizers in production process, and Fathi et al. (2020) for environmental and economic risk management of maize production in different province of Iran, while some of the researchers investigated the water risk management in agricultural practices such as Lien et al. (2007) and Zuniga et al. (2001) and Walker and Schulze (2006), who indicated that agronomic practices have a significant influence on decreasing risk in agricultural systems.

Due to limited water resource in Iran and high-water consumption in agricultural section, the farmers have to use the agricultural management strategies, which are led to low water consumption with no adverse effects on obtained yield, such as selecting the optimum level of deficit irrigation and plant density, and also choosing the efficient planting method based on current situations and available facilities.

The present research aims to determine the status of different cultivation treatments in sugar beet production considering economics based on GM and EWP, that are both the risky parameters, because these are affected by the risky factors such as yield and water consumption, while crop yield and water consumption are also affected by different field management strategies such as irrigation water level, planting method and plant density. Therefore, the goal of current study is to use the risk efficiency approaches, that combine gross margin and water consumption data in different levels of deficit irrigation, plant densities and planting methods including direct seeding and transplanting in sugar beet cultivation. In this regard, the stochastic dominance with respect to a function (SDRF) are used based on GM and EWP, which then it is allowed for the selection of optimum practice patterns from a set of outcome distributions. The results of selecting and ranking the practice patterns help policy maker to support management of economic and water consumption risk for different farmers' risk attitude.

Material and Methods

The material is structured as follows: Firstly, in each treatment the amounts of water use and root yield were determined. Secondly, GM and EWP were simulated for each treatment for two years based on risky variable components on GM and EWP, sugar beet water consumption, and yield, Thirdly, the probabilities of GM and EWP in different treatments considered by stoplight analysis and compared by average of farmer GM and EWP. Finally, the sugar beet production in different treatments were ranked according to risk level preferences based on SDRF. Figure 1 shows the flowchart of this study.

Experimental Site

The field experiments were conducted at the Experimental Station of School of Agricultural, Shiraz University with 29°56′ N, 52°02′ E and at 1810 m above mean sea level with semi- arid climate, during the two-growing seasons of 2017 and 2018 by average annual rainfall of 386 mm, annual average air temperature of 13.4 °C, and relative humidity of 52.2%.

The soil texture at the experimental site is silty clay loam with pH = 8, EC = 0.36, bulk density of 1.43 (g cm^{-3}), field capacity (FC) of 0.32 (m^3 m^{-3}) and permanent wilting point (PWP) of 0.19 (m^3 m^{-3}).

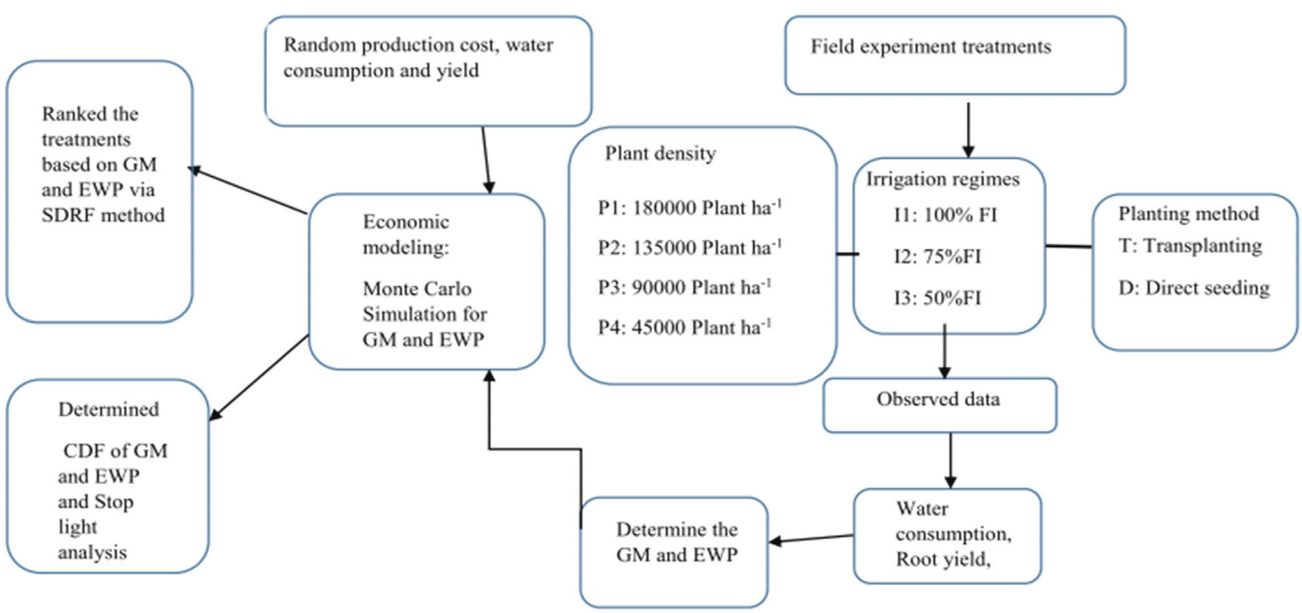

Fig. 1 Flowchart of present study

Experimental Design and Treatments

The field trials comprised a split-split plot experiment with a complete randomized block design under three levels of irrigation, 100% of full irrigation (FI), 75% FI and 50% FI namely: I1, I2 and I3 respectively, four levels of plant densities, 180,000 plant ha^{-1} (very high plant density), 135,000 plant ha^{-1}, 90,000 plant ha^{-1} and 45,000 plant ha^{-1} (very low plant density) namely: P1, P2, P3 and P4, respectively, and two planting method including transplanting (T) and direct seeded (D) methods. Table 1 describes the treatment definitions and properties of each treatment. Each plot had 4 m^2 of area with five rows and the distance between each plot was 1.0 m. The sugar beet seeds (Shokoofa cultivar) were hand sown on 11th and 4th of April in 2017 and 2018, respectively in direct seeding method. In the transplanting method, the seeds of sugar beet were sown in paper pots in the greenhouse on 15th and 8th of April in 2017 and 2018, respectively. The sugar beet seedlings were transplanted when they had about 6 true leaves on 30th May, 2017 and 24th May, 2018. After the plant's establishment, the I1 treatments were irrigated with 100% of full irrigation, while for treatments I2 and I3 the irrigation was applied at the levels of 75% and 50% of full irrigation, respectively. Phosphorus at level of 150 kg ha^{-1} as triple-superphosphate and before sowing the seeds was applied to each plot for two years of growing seasons, and nitrogen as urea was applied to the field when the plants reached 8 true leaves at the level of 250 kg ha^{-1} via broadcast method. On 29th October, 2017 in the first year and 22th October, 2018 in the second year, the sugar beets were harvested.

At harvest, three inner rows of the plots were hand harvested. The storage roots and plant leaves were separated below the green leaf scars and were individually weighed in each plot, then the subsamples of storage roots and plant leaves were dried at 70 °C for 72 h.

Water Consumption

To calculate the depth of irrigation water which is required for I1 treatment the volumetric soil water content was measured at 0.3, 0.6, 0.9 and 1.2 m of soil depth with neutron meter (model CPN 503 DR) with the interval of seven days. The water content balance of soil in the root zone was calculated as follows:

$$d = \sum_{1}^{n} 1000\left(FC_i - \theta_{vi}\right) \times \Delta zi \tag{1}$$

In which d is the depth of irrigation (mm), FC_i is the soil water content in field capacity ($cm^3\ cm^{-3}$), Θ_{vi} is the soil water content before each irrigation event ($cm^3\ cm^{-3}$) at nth layer of soil and Δzi is the thickness of soil layer (m).

Raes et al. (2016) presented the following equation to calculate the crop root depth in various growing stage:

$$Z = Z_{ini} + \left(Z_x - Z_{ini}\right) \sqrt[n]{\frac{GDD - \frac{GDD_0}{2}}{GDD_x - \frac{GDD_0}{2}}} \tag{2}$$

In which Z is the depth of root (m), z_{ini} is the minimum and z_x is the maximum depth of root as 0.1 and 1.8 (m), respectively (Draycott, 2006). n is the shape coefficient (1.8), GDD is the sum of growing degree days until present day, GDD_0 is the growing degree days from the first day of planting until seeds germination, GDD_x is the cumulative growing degree days from the first day of planting until maximum depth of root. Growing degree days (GDD) was calculated by following equation (McMaster and Wilhelm, 1997):

$$GDD = \sum_{0}^{n} \frac{T_{\max} + T_{\min}}{2} - T_b \tag{3}$$

where T_{max} and T_{min} are the maximum and minimum air temperature (°C), respectively and T_b is the base temperature, which was considered as 5 (°C) for sugar beet.

Stochastic GM and EWP

The gross margin (GM) as an economic criterion (Nash et al., 2013) was affected by different variables such as the real unit price of sugar beet root (P_{it}), the amounts of sugar beet root yield per hectare (Y_{it}), and total production costs per hectare (TVC_{it}). Some of the fixed and variable costs for sugar beet production are presented in Table 2. The value of GM_{it} for the treatment i Table 1 in the period of t was calculated as follow:

$$\tilde{GM}_{it} = P_{it}\tilde{Y}_{it} - TVC_{it} - P_W w\tilde{a}ter_{it} - PD_i P_{PDi} \tag{4}$$

where ~ shows the risky variable that distribution functions could define for them. GM_{it} is the value of gross margin in treatment i in the period of t (Rial ha^{-1}) that it is the function of the risky variables such as $\tilde{Y}_{it}$ and $w\tilde{a}ter_{it}$. Multivariate empirical probability distribution (MVEPD) is used for the GM_{it}. P_W is the price of water (Rials m^{-3}), $w\tilde{a}ter_{it}$ and $\tilde{Y}_{it}$ are the amounts of water use and sugar beet root yield, respectively in treatment i and period of t, which both of them are the risky variables. PD_{it} is the plant density and P_{PDit} is the cost for planting sugar beet in each plant density per hectare.

Economic water productivity (EWP_{it}) defined as the ratio of GM_{it} and amounts of water consumption per hectare ($w\tilde{a}ter_{it}$) (Pereira et al., 2012), which is affected by production cost, the amounts of root yield and the selling unit price and also the amounts of irrigation water, which is used for sugar beet cultivation. The value of EWP was calculated for each treatment as follows:

Table 1 The properties of different sugar beet treatments

Treatments	FI				Plant ha^{-1}			Method cultivation	
	100%	75%	50%	180,000	135,000	90,000	45,000	Direct Seeding	Transplanting
I1	✓								
I2		✓							
I3			✓						
P1				✓					
P2					✓				
P3						✓			
P4							✓		
D								✓	
T									✓
I1P1D	✓			✓				✓	
I1P2D	✓				✓			✓	
I1P3D	✓					✓		✓	
I1P4D	✓						✓	✓	
I1P1T	✓			✓					✓
I1P2T	✓				✓				✓
I1P3T	✓					✓			✓
I1P4T	✓						✓		✓
I2P1D		✓		✓				✓	
I2P2D		✓			✓			✓	
I2P3D		✓				✓		✓	
I2P4D		✓					✓	✓	
I2P1T		✓		✓					✓
I2P2T		✓			✓				✓
I2P3T		✓				✓			✓
I2P4T		✓					✓		✓
I3P1D			✓	✓				✓	
I3P2D			✓		✓			✓	
I3P3D			✓			✓		✓	
I3P4D			✓				✓	✓	
I3P1T			✓	✓					✓
I3P2T			✓		✓				✓
I3P3T			✓			✓			✓
I3P4T			✓				✓		✓

$$\tilde{EWP}_{it} = \frac{\tilde{GM}_{it}}{\tilde{water}_{it}} \quad (5)$$

$i = i' = I1, I2, I3, P1, P2, P3, P4, D, T, I1P1D, I1P2D, \ldots, I3P3T, I3P4T$; $t = 2017, 2018$.

Ranking the Treatments by Stochastic Dominance with Respect to a Function (SDRF)

Producing the sugar beet under different irrigation levels, planting densities, and planting methods are considered as risky options from the two economic criteria including GM and EWP. One of the models, which is usually used under risky and uncertain conditions for decision-making, is the expected utility hypothesis (Schoemaker, 1982), which is calculated by the probability distribution function (PDF) of the results and risky preferences of decision-makers (Moss, 2010).

Stochastic dominance rules have an important role in the research on choice under the condition of uncertainty. It can be used effectively when it is not possible to estimate the risk preference accurately. In this way, the risk activities ranked in the case of efficiency and inefficiency. Therefore, the PDF was selected after calculating the GM and EWP of sugar beet production in different treatments of cultivation during

Table 2 Some of costs for sugar beet production in different planting methods

	Costs Direct seeding	Planting method Transplanting
Land renting cost (Million Rial ha.$^{-1}$)	90	90
Initial field preparation (Million Rial ha.$^{-1}$)	8	8
Fertilizer (Million Rial ha.$^{-1}$)	1	1
Pesticides (Million Rial ha.$^{-1}$)	5	1.9
Paper pot seedling cost (Rial -1000 unit.$^{-1}$)	0	600,000
Seed/seedling preparation (Rial -1000 unit.$^{-1}$)	480,000	800,000
Seed / seedling planting (Rial- 1000 unit.$^{-1}$)	28,000	110,000
Water price (Rial m.$^{-3}$)	5,70	570

2017–2018. Probability distribution related to the variables of GM and EWP were estimated by a multivariate empirical probability distribution (MVEPD) in order to maintain the correlation between the risk variables. Simulation of PDF was developed by Monte Carlo simulation with 1000 iteration (Tables 3 and 4). Afterward, the treatments were ranked based on the lower and upper risks aversion farmers in terms of GM and EWP using stochastic dominance with respect to a function (SDRF), which was introduced by Meyer (1977).

In this study the SDRF models was used to rank the sugar beet production in different treatments under various irrigation levels, planting density and planting method in accordance with EWP and GM criteria by using the following equations:

$$\int_{-\infty}^{x} f_i(x)dx = F_i(x) \tag{6}$$

x= GM, EWP

$$\int_{-\infty}^{x} \left[F_i(x) - F_{i'}(x)\right] U'(x)dx \tag{7}$$

$i = i' = I1, I2, I3, P1, P2, P3, P4, D, T, I1P1D, I1P2D, \ldots, I3P3T, I3P4T$; x = GM, EWP

$$r_1(x) < r_a(x) < r_2(x) \quad where; \quad r_a(x) = -\frac{U''(x)}{U'(x)} \tag{8}$$

$$U(x) = 1 - exp(-ax)a > 0. \quad r_a(x) = a \tag{9}$$

As shown in Eq. (7), the cumulative distribution functions (CDF) is a result of integration for distribution functions ($f_i(x)$) of two variables of GM and EWP.

The absolute risk aversion ($r_a(x)$) is obtained in Eq. (8) in SDRF model, and changes between $r_1(x)$ and $r_2(x)$. The $r_1(x)$ and $r_2(x)$ are the upper and lower range of risk aversion levels.

The treatments with CDF of $F_i(x)$ is dominance over $F_{i'}(x)$ when the utility function U (x) becomes negative with respect to Eq. (6). The negative exponential function [(Eq. (9)] with constant absolute risk aversion (CARA) is used for convenience in most practical applications (Hardaker et al., 2004; Moss, 2010). The U′(x) is the first derivative of U(x). In this study, the risk aversion constant coefficient is changed between 0.0 to 0.01 to rank the options more accurately for lower risk aversion (LRA) and upper risk aversion (URA) (Fathi et al., 2020) using Simetar software (Richardson, 2008).

The Stoplight

The CDF results of the model for GM and EWP were also presented using the Stoplight chart. The Stoplight chart is a function in Simetar used to develop ranking probabilities. The results of Stoplight graphs show the probabilities of each treatment being less than the lower cut-off value and greater than that cut-off value. The probabilities of economic indicators of each treatment exceeding the upper cut-off value are presented numerically and it is shown in green. The yellow segments represent the probability of values that fall between the lower and upper cut-off values, and the red segment presents the probability of the value that is below the lower cut-off (Clarke et al., 2017; Bizimana and Richardson, 2019; Kadigi et al., 2020). The minimum and the maximum target values of GM and EWP are set based on the average value of GM and EWP per ha in Iranian sugar beet farms (MAJ, 2019).

Results and Discussion

The Experimental Results

Table 5 presents the root yield and gross margin values for sugar beet in different treatments during 2017 and 2018. The maximum values of root yield and gross margin were obtained from treatment I1 and decreased by about 9% and 28% by decreasing the irrigation water from I1 to I2 and I1 to I3, respectively in average for both growing seasons. The maximum values of root yield and gross margin

Table 3 Summary statistics of the GM simulation model of sugar beet

Variables	Mean	StDev	CV	Min	Max
D	196,482,737	72,278,129	37	39,981,176	360,043,256
T	185,865,718	138,606,849	75	– 129,742,354	476,093,507
P1	167,190,014	90,595,919	54	– 40,432,269	359,757,694
P2	195,139,460	101,880,686	52	– 34,234,133	437,581,475
P3	229,485,782	123,484,485	54	– 38,324,651	492,724,655
P4	175,573,468	98,019,689	56	– 42,537,409	389,670,265
I1	219,273,362	116,410,514	53	– 54,366,231	476,259,533
I2	198,512,713	108,680,287	55	– 35,899,858	443,542,622
I3	156,519,536	84,371,057	54	– 42,689,650	354,623,666
I1P2D	163,150,961	31,237,742	19	71,953,716	257,726,782
I1P3D	176,373,284	8,837,591	5	154,174,380	205,180,120
I1P2T	151,117,891	34,971,138	23	55,041,074	248,388,256
I1P3T	158,543,340	19,359,692	12	103,565,162	223,930,950
I2P2D	132,457,568	56,770,278	43	– 34,261,203	322,855,762
I2P3D	165,353,004	80,937,091	49	– 153,512,858	429,483,551
I2P2T	138,264,730	222,828,525	161	– 568,845,125	838,947,792
I2P3T	146,487,839	149,478,156	102	– 413,286,212	525,684,732
I3P2D	96,831,557	72,425,809	75	– 144,002,351	338,817,070
I3P3D	133,922,533	83,213,648	62	– 132,506,869	355,435,522
I3P2T	100,901,504	129,459,867	128	– 309,401,504	466,508,941
I3P3T	137,165,138	157,866,062	115	– 255,160,796	655,397,021

were obtained from treatment P3 and decreased by either increasing or decreasing plant density. Transplanting method resulted in saving irrigation water in average for two years by about 19.5%, while decreasing the gross margin by about 4%. Decreasing the gross margin in transplanting method is due to the higher production costs in this method as

Table 4 Summary statistics of the EWP simulation model of sugar beet

Variables	Mean	StDev	CV	Min	Max
D	12,163	964	8	9310	14,936
T	15,195	2063	14	8975	22,001
P1	11,904	141	1	11,666	12,142
P2	14,141	231	2	13,740	14,542
P3	16,438	191	1	16,109	16,768
P4	12,713	201	2	12,372	13,056
I1	11,828	445	4	10,589	13,243
I2	14,196	1915	13	6433	19,174
I3	15,472	4157	27	1423	28,002
I1P2D	11,757	1610	14	6161	16,796
I1P3D	12,707	1116	9	9641	17,050
I1P2T	14,061	3279	23	2554	23,963
I1P3T	14,740	9565	65	– 11,969	39,622
I2P2D	12,484	7963	64	– 9968	39,649
I2P3D	15,578	5822	37	268	33,167
I2P2T	17,005	7090	42	– 3466	36,765
I2P3T	18,023	6350	35	– 1658	40,293
I3P2D	12,342	3450	28	569	21,861
I3P3D	17,028	3604	21	5176	26,136
I3P2T	17,592	7938	45	– 3214	39,782
I3P3T	23,899	8003	33	1671	46,243

compared to the direct seeding method. The average gross margin of all treatments and both years is 127 million Rials ha^{-1}, in which the treatments I1P3D and I3P1T have the maximum (176 million Rials ha^{-1}) and minimum (80 million Rials ha^{-1}) values, respectively. These results are due to higher root yield in I1 irrigation level and P3 plant density as compared to that obtained in I3 irrigation level at very high plant density (P1), and also the higher production cost in transplanting than direct seeding method.

Figures 2 and 3 show the values of GM and EWP under different water costs for the transplanting and direct seeding methods. The results show that the value of GM in the direct seeding method is higher than that obtained in transplanting method until the water cost reached up to 1250 (Rials m^{-3}). However, in water costs more than 1250 (Rials m^{-3}) the GM value in the transplanting method is higher than direct seeding method; therefore, the transplanting method is more economical for sugar beet cultivation (Fig. 2).

The values of EWP in the transplanting method in all water costs are higher than those in direct seeding method (Fig. 3) due to the lower water consumption in the transplanting method as well as higher root yield in the transplanting method in the same level of irrigation (Table 5). Therefore, in the regions with limited water resources, by using the transplanting method the net income per unit of water can be increased, and this method is more suitable for sugar beet cultivation.

Table 5 The sugar beet yield, gross margin (GM) and water consumption in different treatments over two growing seasons

Treatments	2017		2018	
	Yield (ton $ha.^{-1}$)	GM (million Rials $ha.^{-1}$)	Yield (ton $ha.^{-1}$)	GM (million Rials $ha.^{-1}$)
I1	84.62	143	86.41	147
I2	78.02	133	77.51	132
I3	62.23	106	61.43	103
P1	64.52	109	65.01	112
P2	77.42	133	74.30	128
P3	89.15	152	90.11	152
P4	68.73	117	71.06	120.8
D	72.26	130	73.18	131
T	77.65	125	77.06	123
I1P1D	71.26	127	77.56	138
I1P2D	92.00	166	89.09	160
I1P3D	98.00	177	97.27	175
I1P4D	76.78	137	80.39	144
I1P1T	71.48	114	76.67	129
I1P2T	93.45	150	91.67	151
I1P3T	98.79	159	98.00	157
I1P4T	75.16	120	80.67	121
I2P1D	67.25	121	68.77	123
I2P2D	73.88	133	72.77	131
I2P3D	89.26	162	92.75	168
I2P4D	71.00	128	67.48	121
I2P1T	73.33	118	73.67	122
I2P2T	85.65	138	79.33	137
I2P3T	92.13	149	92.67	143
I2P4T	71.67	115	72.67	112
I3P1D	46.83	92	45.73	82
I3P2D	54.10	97	53.29	96
I3P3D	72.37	131	74.63	135
I3P4D	54.42	98	58.47	105
I3P1T	56.95	84	47.67	76
I3P2T	65.45	106	59.67	95
I3P3T	84.38	137	85.33	136
I3P4T	63.33	102	66.67	107.33

The Modelling Results

GM and EWP Cumulative Distribution Function

The cumulative probability distribution (CDF) of GM and EWP were obtained for different treatments using Monte Carlo simulation. Bizimana and Richardson (2019) and Rezende and Richardson (2015) also used Monte Carlo simulation method to investigate the economic feasibility of different field managements in the agricultural sector. The summary statistics of simulation models for GM and EWP were presented in Tables 3 and 4.

The CDFs for GM in different irrigation regimes, planting densities and planting methods are shown in Fig. 4a–c, respectively. The results show that the curves related to irrigation levels I1 and I2 lie more to right than the treatment I3 (Fig. 4a), while the difference between I1 and I2 is not significant, which indicates that by using deficit irrigation strategy the acceptable GM can be attained by almost the same probability. In this case Vico and Porporato (2011) indicated that the deficit irrigation results in higher yield variability as compared to full irrigation strategies, while deficit irrigation has less water consumption and lower production costs. Rajsic et al. (2009) and Finger (2012) investigated the effects of N-fertilizer and irrigation strategy on profitability and profit variability. The results showed that decreasing in irrigation and N fertilizer are both a potential risk mitigation strategy, which should be traded off appropriately.

The CDFs curves related to P3 plant density lies more to right, which indicated that this treatment is preferred to other density treatments due to higher GM value in this treatment in all probability levels (Fig. 4b). Also, the results showed that the GM values of lower than 200 million Rials ha^{-1} and probability levels of lower than 54%, the direct seeding method is the dominance option, while for GM value of higher than 200 million Rials ha^{-1} the transplanting method is the preferred option (Fig. 4c).

Figure 5a–c shows the CDFs for EWP in different irrigation regimes, plant densities and planting methods. The I2 treatment in the probability level of lower than 0.31 and EWP value lower than 13,000 (Rials m^{-3}) is the dominance irrigation level, while in the probability level higher than 0.31 and EWP higher than 13,000 (Rials m^{-3}), the I3 irrigation level is preferred to the other treatments at each level of probability. As the results show, the curve related to I1 lies further to the left than the other irrigation levels (Fig. 5a), and indicates that this treatment is the least preferred option due to obtaining the lowest EWP in this treatment at the same level of probability.

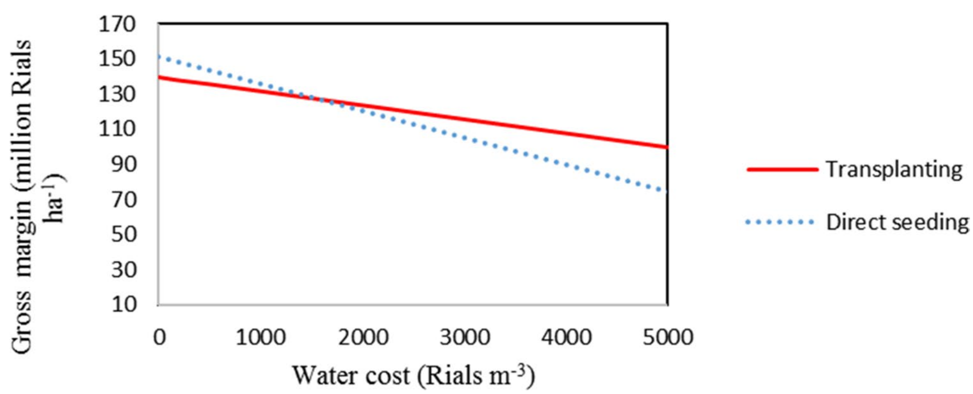

Fig. 2 The certain values of GM in different water costs for the transplanting and direct seeding methods

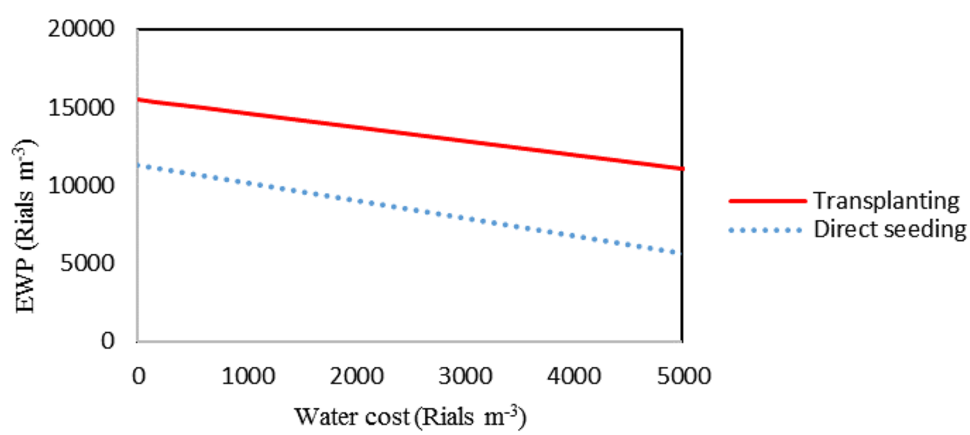

Fig. 3 The certain values of economical water productivity (*EWP*) in different water costs for the transplanting and direct seeding methods

Similar to the results which are obtained for GM, the treatment P3 is preferred to the other density treatments followed by P2, P4, and P1 in the case of EWP. This is due to obtaining the highest level of EWP in this treatment as compared to other treatments in the same level of probability (Fig. 5b). Decreasing the GM and EWP in high plant density is due to the fact that by increasing the plant density over the standard level, the competition between crops increased and therefore, the crop growth and yield decreased (Chaudhari et al., 2015).

The CDFs of GM and EWP criteria by considering the combined effects of different treatments are shown in Fig. 6a, b. The treatments I2P3T, I2P2T and I3P3T are the three dominance treatments in the case of GM. This is

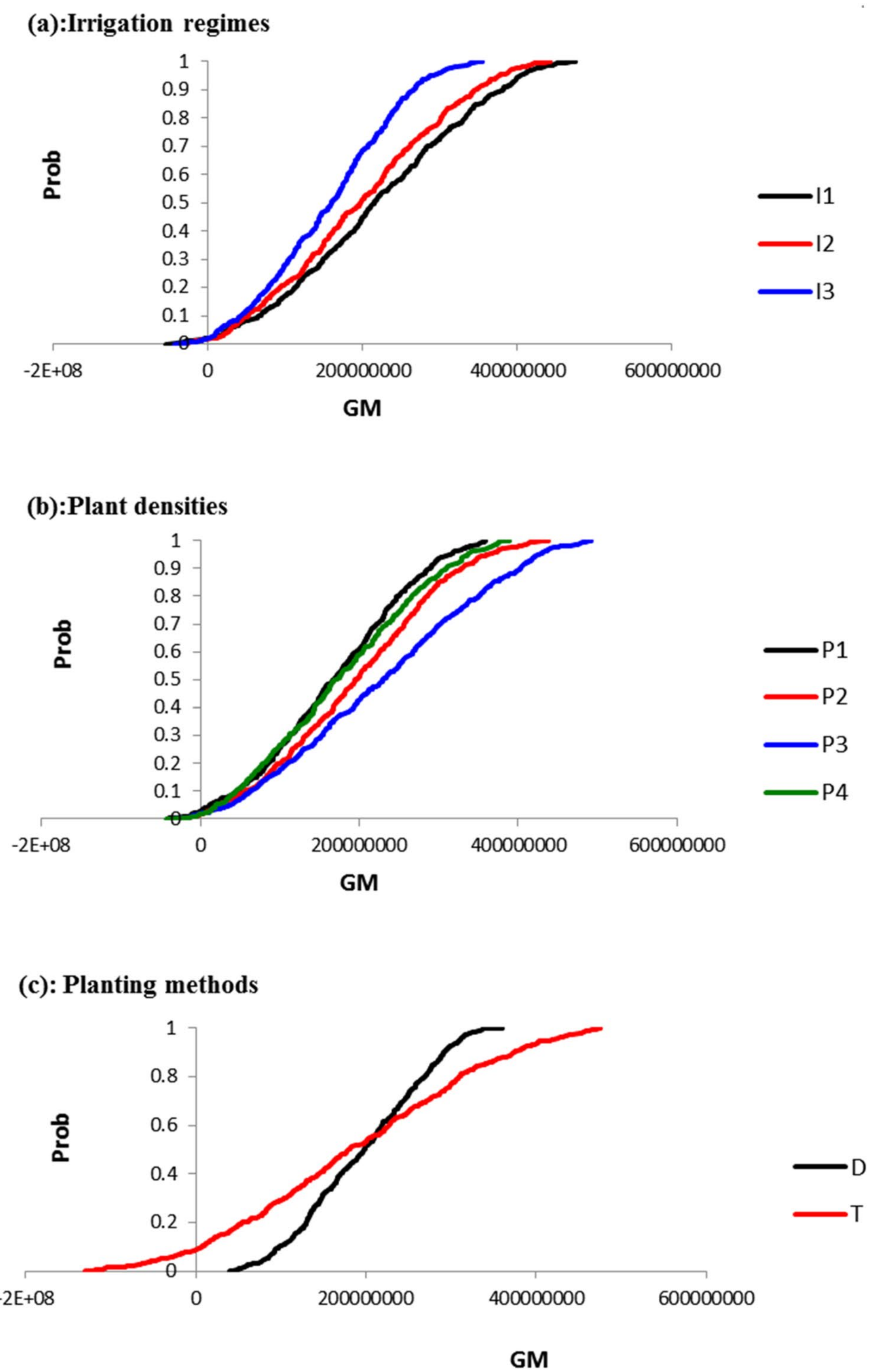

Fig. 4 Cumulative Distribution Function of GM for different irrigation regimes (**a**): I1 (100% FI), I2 (75% FI) and I3 (50%FI), (**b**): Plant densities: P1 (180,000 plant ha^{-1}), P2 (135,000 plant ha^{-1}), P3 (90,000 plant ha^{-1}) and P4 (45,000 plant ha.$^{-1}$), (**c**): Planting methods: D (direct seeding) and T (transplanting)

because of obtaining higher GM in these treatments in levels of probability higher than 0.56 (Fig. 6a), while for EWP the treatment I3P3T is preferred over other treatments for the same reasons (Fig. 6b). It is noted that when the CDF lines cross each other, it is necessary to rank the options based on expected utility principles such as stochastic dominance. Therefore, the next part explains ranking of this treatment by SDRF.

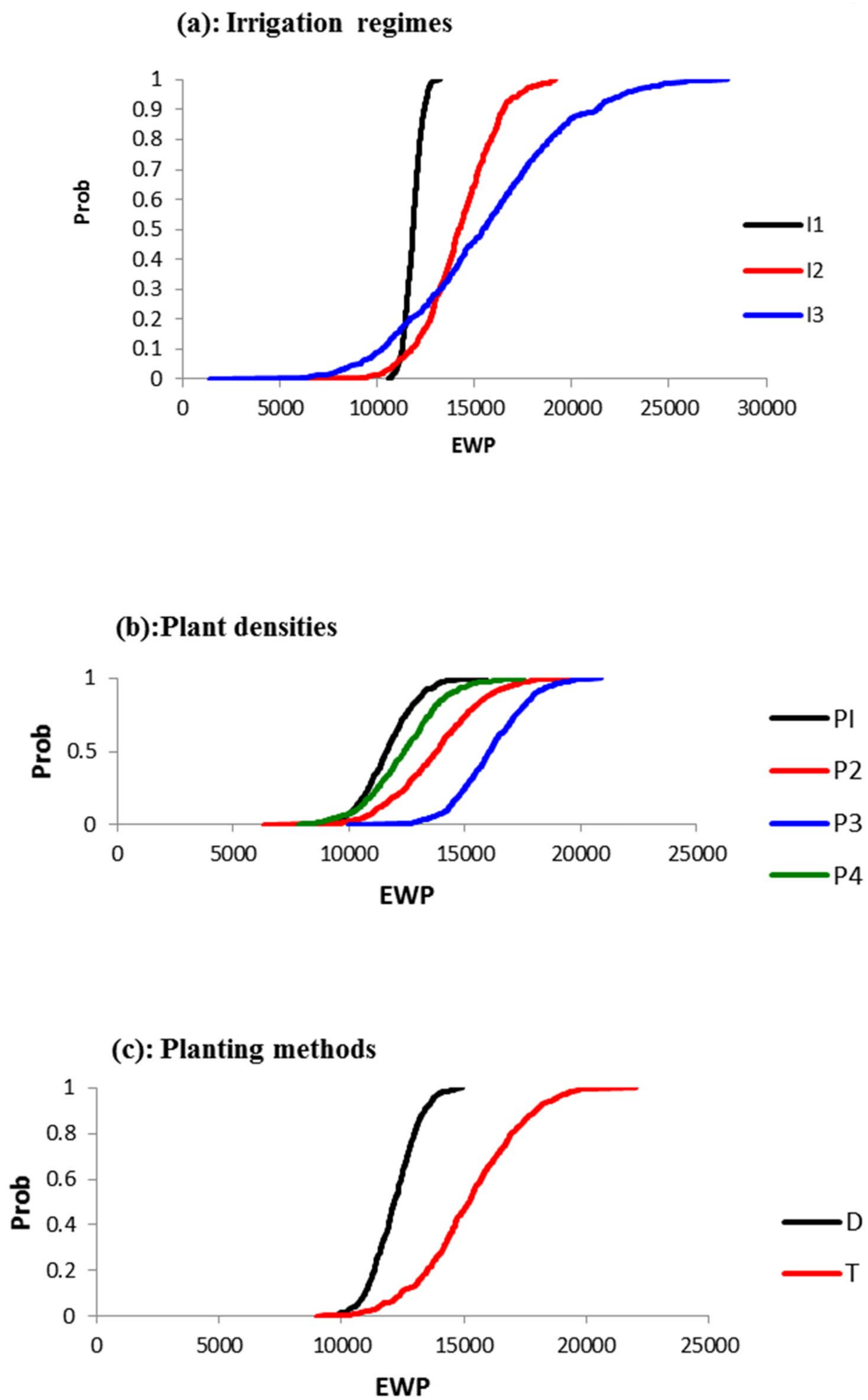

Fig. 5 Cumulative Distribution Function of EWP for different irrigation regimes, (**a**): I1 (100% FI), I2 (75% FI) and I3 (50%FI), (**b**): Plant densities: P1 (180,000 plant ha^{-1}), P2 (135,000 plant ha^{-1}), P3 (90,000 plant ha^{-1}) and P4 (45,000 plant $ha.^{-1}$), (C): Planting methods: D (direct seeding) and T (transplanting)

Ranking Different Treatments of Sugar Beet Cultivation by SDRF

Maximizing GM and EWP is the objective regardless of variance for risk-neutral farmers. However, most farmers and also Iranian farmers are risk-averse (Hardaker, 2004; Fathi et al., 2020). To account for farmers' aversion to risk, the results were analyzed using the SDRF framework. Table 6 presented the results obtained from a ranking of different treatments based on GM and EWP via the SDRF method for LRA and URA farmers. If farmers just considered the water consumption in field management, the full irrigation treatment (I1) ranked first for URA farmers followed by I2 and I3. This is because for URA farmers obtaining the maximum yield and consequently maximum GM in short-run is more important than saving water. For LRA farmers, 75% of full irrigation (I2) treatment ranked first followed by I3 and I1 for both GM and EWP criteria. This is because water saving and increasing the EWP are more important for LRA farmers. The results from Table 6 showed that by applying the 75% of full irrigation (I2), decreasing in root yield is about 8%, but saving in water is about 25%, while in I3 irrigation treatments, the sugar beet root yield decreases by about 26%, while the irrigation water is saved by about 50%. Therefore, the EWP increased in these treatments as compared to I1 irrigation level. These results can be favorable for LRA farmers, which they accept the risk of obtaining lower yield versus higher water saving. The presented results are similar to the study of Grove et al. (2006), which indicated that by using stochastic efficiency analysis, the risk-aversion farmers preferred deficit irrigation strategies when they had to save water in wheat and maize cultivation. Peak et al. (2016) indicated that the deficit irrigation for wheat cultivation in larger areas was more risk-efficient and profitable than the full irrigation strategy in smaller areas. Ali et al. (2007) showed that the highest water productivity and net financial return were achieved in alternate deficit irrigation for wheat cultivation.

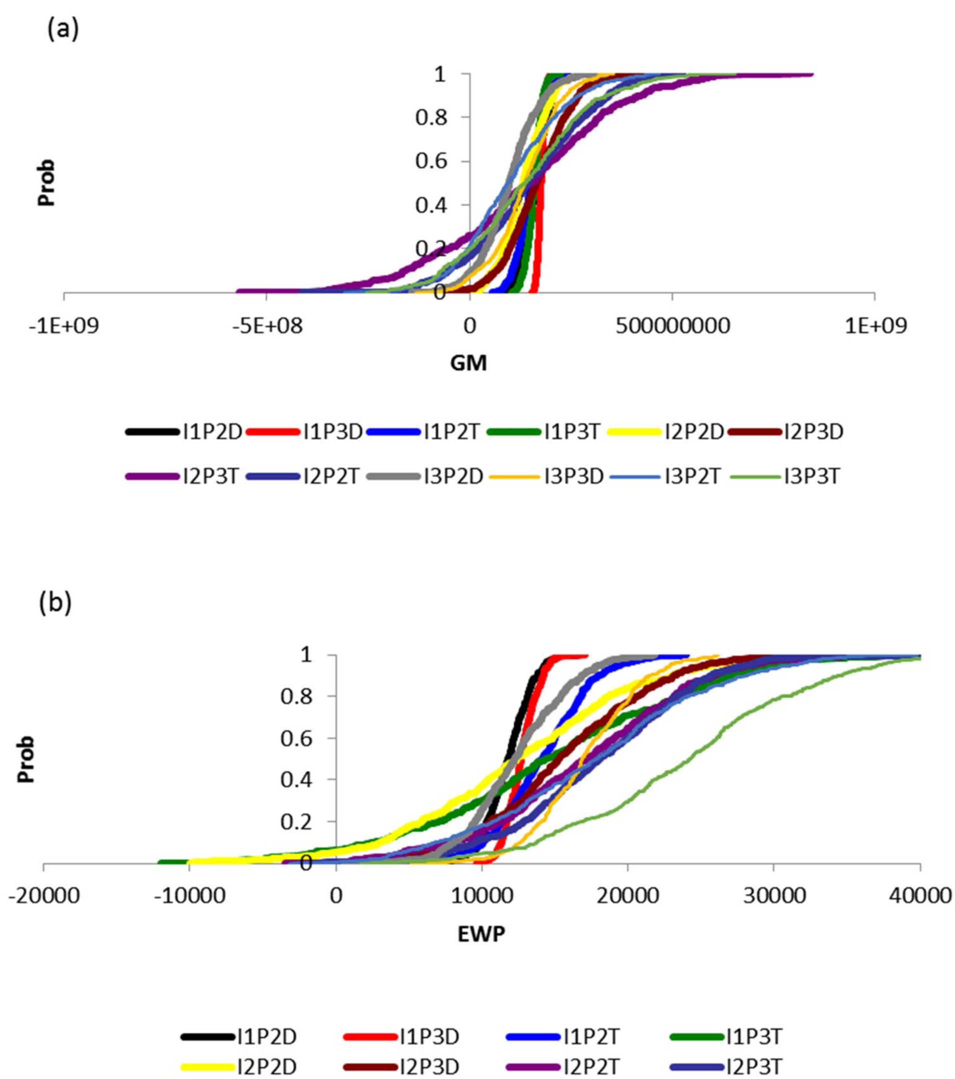

Fig. 6 Cumulative Distribution Function of (**a**): GM and (**b**): EWP, for different irrigation regimes: I1 (100% FI), I2 (75% FI) and I3 (50%FI), four plant densities: P1 (180,000 plant ha^{-1}), P2 (135,000 plant ha^{-1}), P3 (90,000 plant ha^{-1}) and P4 (45,000 plant ha.$^{-1}$) and two planting methods: D (direct seeding) and T (transplanting)

Table 6 Treatment's ranking based on SDRF method for GM and EWP

Treatments	Ranking based on:				Average of experimental water consumption (m^3 $ha.^{-1}$), for 2017–2018	Average of experimental GM, for 2017–2018
	EWP		GM			
	Lower Risk aversion (LRA)	Upper Risk aversion (URA)	Lower Risk aversion (LRA)	Upper Risk aversion (URA)		
I1	3	1	3	1	12,142.0	145.0
I2	1	2	1	2	9406.0	132.5
I3	2	3	2	3	6766.0	104.5
P1	4	4	4	4	9833.0	110.5
P2	2	2	2	2	9506.0	130.5
P3	1	1	1	1	9250.0	152.0
P4	3	3	3	3	8159.0	117.0
D	2	2	2	2	10,178.0	130.5
T	1	1	1	1	8196.0	124.0
I3P3T	1	3	3	3	5561.0	136.5
I2P3T	2	4	1	1	8019.0	146.0
I3P2T	3	2	4	4	5758.0	100.5
I2P2T	4	1	2	2	8153.0	137.5
I3P3D	5	6	11	11	7689.0	133.0
I2P3D	6	9	5	5	10,481.0	165.0
I1P3T	7	7	6	6	10,572.0	158.0
I1P2T	8	10	7	7	10,750.0	150.5
I1P3D	9	12	9	9	13,183.0	176.0
I2P2D	10	8	8	8	10,612.0	132.0
I3P2D	11	5	12	12	7880.0	96.5
I1P2D	12	11	10	10	13,883.0	163.0

With respect to the values of GM and EWP, the results from Table 5 indicated that the plant density of 90,000 plant ha^{-1} (P3) ranked in the first order, followed by P2, P4, and P1 for both LRA and URA farmers. By increasing the plant density over the optimum level (90,000 plant ha^{-1}), the competition between the plants over the water and nutrient absorption increases. Therefore, the root yield decreases (Haghverdi et al., 2017; Khozaei et al., 2020; Marchiori et al., 2014; Watanabe et al., 2003), and all of these factors lead to reduce EWP and GM. It is noted that very low plant density as 45,000 plants ha^{-1} (P4) cannot produce the acceptable sugar beet yield and it is not considered as a desirable plant density by farmers (Khozaei et al., 2020). With respect to the GM and EWP criteria, the transplanting method can be considered as an alternative planting method to direct seeding for both LRA and URA farmers, and farmer's attitude is not important for selecting cultivation methods (Table 5). The transplanting method increased root yield due to protection of the sugar beet crop from pests and control the environmental parameters in the early growing season. On the other hand, the transplanting method reduced water consumption, which is applied in large quantities, in general, at the direct seeding method for germinating the seeds (Khozaei et al., 2020). All of these factors resulted in increasing EWP and GM and decreased the risk of EWP and GM in the transplanting methods. In this case, Ahmad et al. (2018) indicated that the transplanting method increased the water productivity of cotton as compared to the direct seeding method.

The results from the combined effects of different treatments on GM and EWP are shown in Table 5. Based on EWP criteria and for LRA farmers, the I3P3T is the most preferred option, followed by I2P3T and I3P2T, while for URA farmers the I2P2T ranked in the first order followed by I3P2T and I3P3T (Table 5). For GM criteria, the treatment I2P3T for both LRA and URA farmers is the most preferred option. Therefore, in order to obtain the highest GM and also the acceptable EWP, the I2P3T treatment is the preferred option as compared to other treatments.

GM and EWP Stoplight Analysis

The stoplight charts for GM are shown in Fig. 7a–c for different treatments. These Figures show the probabilities of GM on ranges of less than 80 (million Rials ha^{-1}), between 80 (million Rials ha^{-1}) and 176 (million Rials ha^{-1}) as well as greater than 176 (million Rials ha^{-1}) that were achieved by farmers. The minimum and the maximum target values

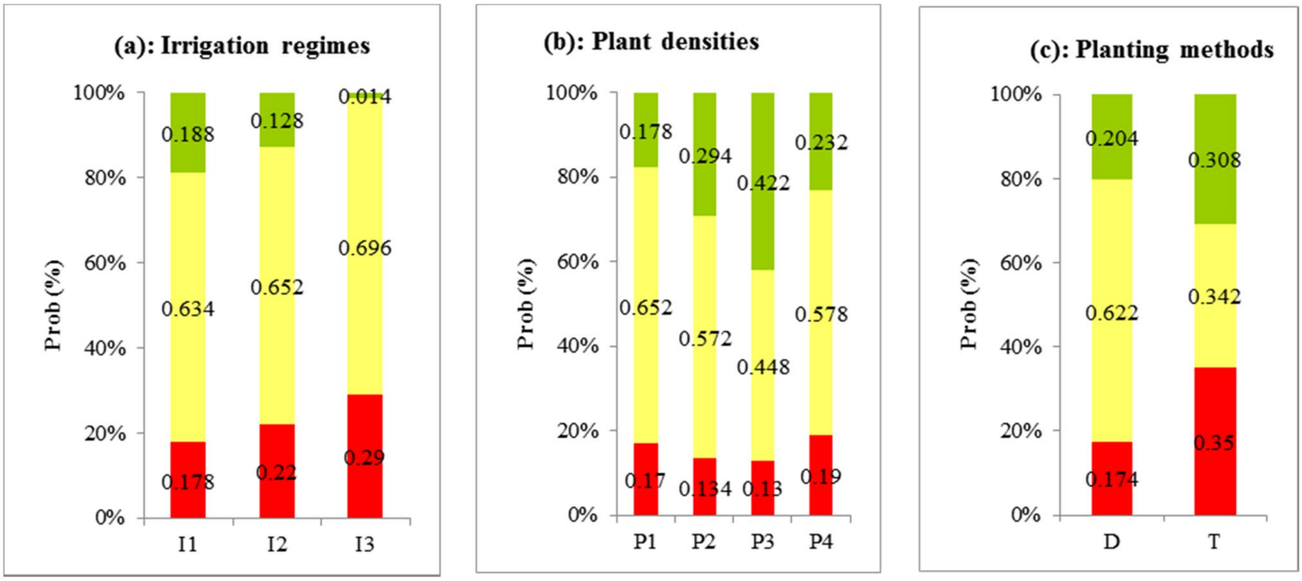

Fig. 7 Stoplight chart of GM for probabilities less than 80 and greater than 176 (million Rial ha-1) (**a**): Irrigation regimes, (**b**): Plant densities and (**c**): Planting methods

are set based on the average values per ha in Iranian sugar beet farms (MAJ, 2019).

The results from Fig. 7a showed that for I1 irrigation level, there is a 17.8% chance (red) that GM is < 80 (million Rials ha^{-1}), 63.4% chance (yellow) that GM is between 80 to 176 (million Rials ha^{-1}) and 18.8% chance (green) that GM is > 176 (million Rials ha^{-1}). For I2 irrigation treatment, there is 22% chance that GM to be less than 80 (million Rials ha^{-1}), 12.8% probability to exceed over 176 million (million Rials ha^{-1}), and 65.2% of probability to be in the range of 80 to 176 (million Rials ha^{-1}), respectively. For I3 irrigation treatment, there is 69.6% chance that GM to be in the range of 80 to 176 (million Rials ha^{-1}), while only 1.4% probability is to exceed over 176 (million Rials ha^{-1}). These results indicated that in no water stress condition, applying the full irrigation level can increase the GM over the maximum value of the acceptable range (176 million Rials ha^{-1}) by higher probability than deficit irrigation treatments.

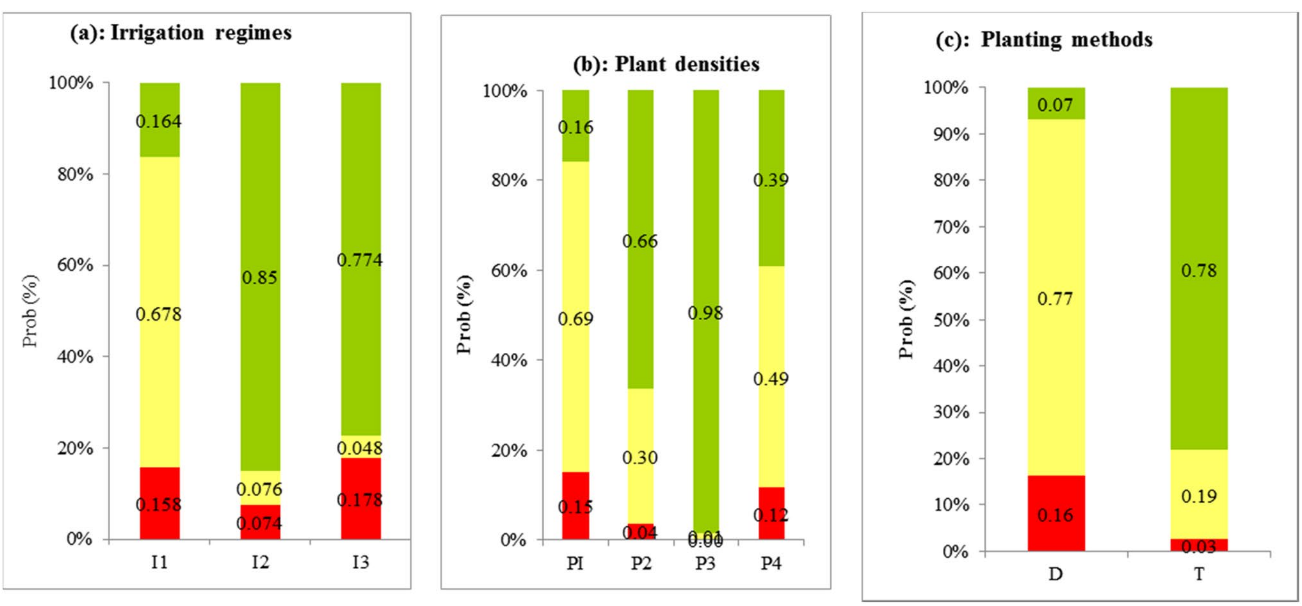

Fig. 8 Stoplight chart of EWP for probabilities less than 11,000 and greater than 15,000 (Rials m.$^{-3}$) (**a**): Irrigation regimes, (**b**): Plant densities and (**c**): Planting methods

However, due to no remarkable differences between full and deficit irrigation strategies for attaining the GM in the acceptable range of 80 to 176 million Rials ha^{-1}, the deficit irrigation can be considered as a useful strategy in water shortage condition.

In plant densities of P2 and P3 (common plant densities), there are 57.2% and 44.8% chances that GM to be in the range of 80 to 176 (million Rials ha^{-1}), respectively, while 29% and 42% chances are to increase the GM value over 176 (million Rials ha^{-1}), respectively (Fig. 7b). Therefore, the P3 plant density (90,000 plant ha^{-1}) for sugar beet cultivation can be suggested as an optimum plant density due to increasing the GM over the maximum value of acceptable range with higher probability than other density levels. In this case, Kadigi et al. (2020) used CDFs and Stoplight charts to investigate the effect of plant density on profitability of Maize cultivation. The results of their study showed that increasing in plant population over the 33,000-plant ha^{-1} enhanced the risks of main return.

Figure 7c showed that in the direct seeding and transplanting method, there are 17.4% and 35% of probability that GM is less than 80 (million Rials ha^{-1}), while there are 20% and 31% of probability that GM exceed over 176 (million Rial ha^{-1}) as well as 62% and 34% of probability that GM being between 80 and 176 (million Rial ha^{-1}), respectively. As it is mentioned before, the transplanting method increased the production costs in some cases (Table 2); however, due to the decreases in irrigation water cost, this method can increase the GM value over the 176 (million Rials ha^{-1}) by more probability (30%) than direct seeding method (20%). However, in the water shortage condition, achieving the higher EWP is more important than gaining the high value of GM, and this should be taken into account by farmers.

The Stoplights graphs for EWP showed that there is 67.8% probability that EWP would be in the range of 11,000 to 15,000 (Rials m^{-3}) in treatment I1, while there are 85% and 77.4% chances to exceed 15,000 (Rials m^{-3}) in I2 and I3, respectively (Fig. 8a). In P3 plant density there is 98% chance that EWP exceeds 15,000 (Rials m^{-3}) (Fig. 8b). In the transplanting method there are 78% chance for EWP to exceed 15,000 (Rials m^{-3}), 19% chance to be in the range of 11,000 to 15,000 (Rials m^{-3}), and there is only 3% probability it would fall less than 11,000 (Rials m^{-3}), while in the direct seeding method, there is 77% chance that EWP would be in the range of 11,000 to 15,000 (Rials m^{-3}) and only there is 7% chance to exceed 15,000 (Rials m^{-3}).

The overall modelling results indicated that using 75% of full irrigation level, P3 plant density and the transplanting method is the most economical strategy to obtain the acceptable GM and consequently optimum EWP, and can be considered at water shortage condition in arid and semi-arid regions.

Conclusion and Recommendation

The main objective of this study is to investigate the effect of different irrigation regimes, various plant densities as well as the direct seeding and transplanting method on GM and EWP with considering the risk analysis due to the fact that the farmer's decision making in many times is under uncertainty and risky conditions. Regarding the present study, the risk attitude was considered for economic objectives in order to manage the suitable production of sugar beet cultivation.

The experimental results showed that the two-year average values of the maximum root yield and gross margin were obtained from treatment I1 and decreased by about 9% and 28% by decreasing the irrigation water from I1 to I2 and I1 to I3, respectively. The maximum values of root yield and gross margin were obtained from treatment P3 and decreased by either increasing or decreasing plant density. The transplanting method resulted in saving irrigation water, in average for two years, by about 19.5%, while decreasing the gross margin by about 4%. Decreasing the gross margin in the transplanting method is due to the higher production costs in this method as compared to the direct seeding method.

The results from ranking the different treatments via the SDRF method and Stoplight graphs showed that in the case of GM and EWP criteria, for LRA farmers the irrigation level of 75% full irrigation (treatment I2) is the most preferred option followed by 50% (I3) and 100% full irrigation (I1). URA farmers preferred the full irrigation level (I1) followed by I2 and I3. However, for both LRA and URA farmers the P3 plant density and the transplanting method are the most preferred options. Based on cumulative distribution function, the treatments I2P3T, I2P2T and I3P3T are the three dominance treatments in the case of GM as compared to other treatments, while for EWP, the treatment I3P3T is preferred over other treatments. The overall results indicated that the moderate deficit irrigation along with the transplanting method under optimum plant density as 90,000 plant ha^{-1} are suggested in order to decrease the risk of GM and EWP, which can be helpful for optimal and economical sugar beet cultivation in the water shortage condition.

Since sugar beet is a strategic crop, more attention can be paid to the cultivation method to optimal water consumption through reducing economic risk. In this regard, policies such as training the farmers to use the optimum irrigation regime, plant density, and cultivation method for increasing the productivity of water consumption are suggested. In addition, policies such as paying subsidies to farmers to apply the transplanting method for cultivation to decrease the production cost, reduce GM risk and strengthen income insurance to decrease economic risk are suggested.

This study can be continued for different fertilizer levels and irrigation regimes in sugar beet cultivation to minimize the risk of adverse environmental impacts and economic aspects.

Acknowledgements The authors would like to thank the Center of Excellence for on-Farm Water Management and the Center of Drought Research, Shiraz University and the Iran National Science Foundation (INSF). Also, we would like to acknowledge Dr. Davar Khalili and Yasmine Kamgar Haghighi for their help to English editing the manuscript, Dr. Ali Reza Yazdani and Dr. Vliallah Yousef-abadi for their help to prepare the sugar beet seedlings and Dr Mohsen Bazrafshan for his help to prepare the seed of sugar beet. This research did not receive any specific funding.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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