Optimization of irrigation water allocation to reach the maximum net benefit using Genetic algorithm (Case Study: Hamidiya irrigation network)

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Abstract: Two optimization models were created in this study. The first one is to minimize the error in yield reduction estimation under deficit irrigation situation, and the second one is to maximize total net benefit in Hamidiya irrigation network. Results from yield estimation error minimization model indicates that the yield reduction is 112.5% for beans, 195.5% for rice, 102.5% for canola and sesame, 135% for tomato, 105% for cucumber, and 170% percent for vegetables under applying 50% deficit irrigation in all growth stages using the K_{yi} values proposed by former studies, while yield reduction is 57.5% for beans, 54.9% for rice, 40% for canola and sesame, 54.8% for tomato, 46.8% for cucumber, and 49.7% for vegetables under applying 50% deficit irrigation in all growth stages using the modified K_{yi} values proposed by this study. Results from the optimal allocation of irrigation water model indicates that the consumed water is reduced by 12%, while the total cultivation area and total net benefit is increased by 17.3% and 25%, respectively. As a result, genetic algorithm has proved to be an effective tool in the models created in this study.
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1. Introduction:

Proper water management in all uses is necessary due to scarcity of water resources. Water is used mostly by the agriculture sector, so proper water management is dependent to optimal irrigation water allocation. The optimization technique has been previously used by many studies. Nazarifar et al. (2012) evaluated 3 deficit irrigation scenarios (10, 20, and 30%) applied in the crops cultivated in Shahid Chamran irrigation network. Results indicated that the cropping pattern with 10% deficit irrigation applied to beans, 20% deficit irrigation applied to potato and sunflower, and 30% deficit irrigation applied to wheat is with the most value of net benefit. Azimi et al. (2013) allocated irrigation water to Mianeh region using non liner programming method. Results indicated that irrigation water consumption is reduced by 13 MCM, while net benefit is reduced by 0.51 million Dollars. Garg and Dadhich (2014) allocated water to Khairpur east canal of the lower Indus basin using non-linear programming. Results showed that the overall net benefit and the cropping area in increased by 72.9% and 109.7%, respectively. Another study by Garg and Dadhich (2014) was conducted to minimize yield reduction estimation using inverse formulation method by modifying K_{yi} values of the crops that were planted in lower Indus basin and applying deficit irrigation in all of crops growth stages. Results indicated that yield reduction under deficit irrigation using FAO-proposed K_{yi} values for main growing crops of lower Indus basin (cotton, oilseed, rice, sorghum, gram, mustard, wheat, and sugarcane) varies from 7.2% to 121.2%, however, yield reduction of more than 100% is not logic and acceptable while the modified K_{yi} values have less yield reduction estimation error and they are recommended to estimate the actual yield under deficit irrigation. Isik and Kalin (2014) used dynamic programming to allocate water in Turkey. As a result, net benefit is 22.8, 22.96, and 13.8 million Dollars in wet, dry, and normal weather conditions, respectively. Khanjari Sadati et al. (2014) allocated water to downstream agricultural lands of Doroodzan dam in Fars province of Iran using genetic algorithm (GA). Results indicated that net benefit under deficit irrigation is 37 billion Rials more than full irrigation in wet weather condition. Furthermore, net benefit under deficit irrigation situation is 19 billion Rials more than full irrigation situation in normal weather condition. Habibi Divajni et al. (2016) Allocated water to central desserts of Iran. Results indicated that 1096 jobs is created under optimal water resources allocation.

Furthermore, net benefit increases from 73 billion Rials to 112 billion Rials. A model was created to optimally allocate irrigation water to Hamdiya irrigation network crops using genetic algorithm with the purpose of maximizing net benefit. Another model was also created to minimize yield reduction estimation error under deficit irrigation situation.

2. Materials and methods

Hamidiya county is located in Khuzestan province of Iran. The altitude of the city is 21 meters with longitude of 31˚ 29′ North and latitude of 48˚ 11′ East. Hamidiya plain is between 31˚ 28′ and 31˚ 47′ North. It is also located between 48˚ 10′ and 48˚ 27′ East. Agriculture is prosperous due to Karkheh river existence. Hamidiya irrigation network is in Hamidiya plain with total cultivable area of 13500 hectares. Planting is possible in fall and summer. Beans, rice, vegetables and sesame is planted in summer, while wheat, barely, cucumber, tomato, canola and cabbage is planted in fall. Table 1 includes information about the crops planted in Hamidiya irrigation network in 2015-2016 water year which is taken from Hamidiya county agriculture bureau. Constant expenses include planting expenses, growing expenses, and harvest expenses.

Table 1. Information about the crops planted in Hamidiya irrigation network in 2015-2016

Crop	Constant expenses (million Rials/hectare)	Water expense (million Rials/hectare)	Crop price (Rials/Kg)	Yield (Kg/ha)	Area (ha)
Wheat	18	1.2	13000	3200	8200
Beans	26	1.8	28000	1300	500
Barely	17	1.1	11000	2800	800
Rice	20	2.8	17000	3500	1800
Vegetables	70	7	5000	45000	1900
Cucumber	60	3.8	6000	15000	700
Tomato	120	4.7	2500	40000	1500
Cabbage	80	1.2	6000	45000	300
Canola	12	1.2	2800	2000	250
Sesame	9	1.2	50000	1100	700

Crop response factors modification model

Dorenboos and Kassam (1979) proposed the following equation to estimate yield reduction under deficit irrigation which is as follows:

$$1-\frac{Y_a}{Y_m}=K_y(1-\frac{ET_a}{ET_m})$$

Where K_y is seasonal crop response factor, Y_a is actual yield (Kg/ha), Y_m is potential yield (Kg/ha), ET_a is actual evapotranspiration and ET_m is potential evapotranspiration.

The additive method of yield reduction estimation could also be used to estimate yield reduction under deficit irrigation which is as follows (Steward et al., 1977):

$$1-\frac{Y_a}{Y_m}=\sum_{i=1}^{n}K_{yi}(1-\frac{ET_{ai}}{ET_{mi}})$$

Where K_{yi} is crop response factor in the i_{th} crop growth stage, ET_{ai} and ET_{mi} are actual and potential evapotranspiration in ith crop growth stage, respectively (steward et al., 1977).

Both K_{yi} and K_y are proposed for each crop in the former studies (Garg and Dadhich, 2014; faghihi et al., 2015; Dorenboos and Kassam, 1979). Table 2 includes K_y and K_{yi} values for each crop. K_{yi} values are the ones specified for each crop growth stage. Stage 1 is the interval between planting and the time that 10% of farm is covered, Stage 2 is the interval between 10% land cover and 100% land cover, Stage 3 is the interval between 100% land cover and flowering, and Stage 4 is the interval between flowering and harvesting.

Table 2. K_y and K_{yi} values of crops proposed by former studies

Crop	Wheat	Bean	Barely	Rice	Canola	Seesame	Cabbage	Tomato	Cucumber	Vegtables
Stage 1	0.20	0.20	0.20	1.00	0.30	0.30	0.20	0.40	0.30	0.80
Stage 2	0.60	1.10	0.60	1.09	0.55	0.55	0.40	1.10	0.50	0.40
Stage 3	0.50	0.75	0.50	1.32	0.60	0.60	0.45	0.80	0.70	1.20
Stage 4	0.60	0.20	0.40	0.50	0.60	0.60	0.60	0.40	0.60	1.00
Seasonal	1.00	1.15	1.00	1.10	0.80	0.80	0.95	1.05	0.77	1.00

The estimated value of crop yield reduction under deficit irrigation applied in all growth stages using stagewise crop response factors is different from the estimated yield reduction under deficit irrigation applied in different growth stages using seasonal crop response factors. According to Garg and Dadhich (2014), yield reduction under deficit irrigation applied in all growth stages using K_{yi} values of crops could be estimated more than 100% under applying 50% deficit irrigation to them which is not possible. This indicates an estimation error, and there is a need to obtain the K_{yi} values under field conditions for Hamidiya county, but planting all of the crops mentioned in table 1 and obtaining the correct K_{yi} values of them needs a vast and longtime research, so a model was created to minimize yield estimation error under deficit irrigation using K_{yi} values. Genetic algorithm (GA) optimization method is used in this model. The objective function is as follows (Garg and Dadhich, 2014):

$$E = \sum_{j=1}^{ND}[\{\sum_{i=1}^{n} K_{yi.adj}(1-\frac{ET_{aij}}{ET_{mi}})\} - (1-\frac{Y_{aj}}{Y_{mi}})]^2$$

Where E is yield reduction estimation error, ND is deficit level number, $K_{yi.adj}$ is the modified stagewise crop response factor in the ith crop growth stage, ET_{aij} is the actual evapotranspiration in the ith growth stage under j_{th} deficit irrigation level, ETm_i is the potential evapotranspiration in the ith growth stage under j_{th} deficit irrigation level, Y_{aj} is the actual yield under jth deficit irrigation level which is obtained using K_y values, and Y_m is the potential yield. Deficit irrigation levels are 10,20,30,40 and 50% and deficit irrigation is applied to all crop growth stages in this model.

Decision making variables are $K_{yi.adj}$ values in this model. As no field research was conducted to determine which stage is more sensitive than the other, the sensitivity trend of crops growth stages were considered according to previously-proposed K_{yi} values by former studies. In other words, the stage with K_{yi} values that was proposed by former studies is more sensitive, so this stage must have a bigger $K_{yi.adj}$ value.

Model results assessment

In order to compare the results with the pre-proposed K_{yi} values, RMSR is calculated for each crop using its $K_{yi.adj}$ and K_{yi} values. The values with lower RMSR value is more suitable to be used in yield reduction estimation (Garg and Dadhich, 2014).

$$\text{RMSR} = \text{SQRT}\left(\frac{SSR}{N}\right)$$

Where RMSR is the root mean square residual, SSR is sum of square residuals, and N is the number of deficit irrigation levels (Garg and Dadhich, 2014).

$$SSR = \sum_{i=1}^{N}\left(M_i - S_i\right)^2$$

Where M_i is the seasonal yield reduction, and S_i is the relative yield reduction using the stagewise crop response factors. For obtaining RMSR value of K_{yi} values of each crop, SSR should be obtained by substituting them in the additive yield estimation equation. Furthermore, to obtain RMSR value of $K_{yi.adj}$ values of each crop, SSR should be obtained using K_{yi} and modified K_{yi} values.

Results verification

Particle swarm optimization method (PSO) was used to verify the results obtained by GA, so PSO was also used in the model to compare the results obtained using either one of the mentioned optimization methods results after 20 independent runs. Both GA and PSO parameters were set according to Akbaripour and Masehian (2013) based on Vikor index. $K_{yi.adj}$ values of each crop are decision making variables of this model, so the number of variables are 4. In GA optimization method, population=40, crossover percent=70, mutation probability percent=30, mutation rate=3, and iteration number=200. In PSO method, particle number=40, social factor=2.5, cognitive factor=2.5, constriction factor=0.38, maximum inertia weight=0.9, minimum inertia weight=0.4, and iteration number=200. The mentioned values are the set values of parameters of GA and PSO method that should be tuned.

Optimal irrigation water allocation model

A model was created to optimally allocate irrigation water to Hamidiya irrigation network using GA optimization method. The objective of this model is to maximize the total net benefit which is described as follows (Lalehzari et al., 2015):

$$\text{NB} = \sum_{P=1}^{K}\left(B_p \times Y_{ap} - C_p - I_p C_w\right) \times A_p$$

Where NB is the total net benefit, K is the crop number, B_p is crop price (Rials), C_p is constant expenses consisting of planting, growing and harvest expenses (Rials), I_p is the gross irrigation depth (mm), C_w is water price (Rials/m^3), and A_p is the crop cultivation area (hectares). Note that the mentioned equation could also be used to calculate the net benefit of a crop when K=1 or A_p =1. Water expenses data taken from Hamidiya agriculture bureau are based on crop area, so the mentioned data should be converted to (Rials/m^3). In order to do that, the volume of gross water needed per hectare were calculated considering 47.8% as application efficiency for each crop and the price was divided by gross water requirement volume to be converted to Rials/m^3. The actual yield was obtained using the additive method of yield reduction estimation.

The 2015-2016 water year was divided by 36 periods. The irrigation depth in each period for each crop is a decision making variable, so the model consists of 155 variables. Potential evapotranspiration value of the crops for each 10-day period were calculated using Penman-Monteith method by Cropwat 8.0 software according to Allen et.al (1998). Furthermore, the actual evapotranspiration of crops for each 10-day period is calculated using the following equation (Reddy and Kumar, 2007):

$$\text{ETa?} = \frac{ET_m(\text{SM}_t - \text{PWP})}{(1-\text{p})(\text{FC}-\text{PWP})}$$

Where p is maximum allowed deficit (MAD), FC is the soil moisture in field capacity situation, and PWP is the soil moisture in permanent wilting point. The values of FC and PWP are 360 and 230 mm/m, respectively. The mentioned values are extracted from Allen et al. (1998). SM□ is the soil moisture depth in the t_{th} period which is determined as follows (Reddy and kumar,2007):

$$\text{SM}_{t+1}D_{t+1} = \text{SM}_t D_t + RF_t + q_t - ET_{at} + SM_{max}(D_{t+1} - D_t) - DP_t - SR_t$$

Where t is the period number, D_t is root depth in the t_{th} period, RF_t is effective rainfall, q_t is irrigation depth, DP is deep percolation, SR is surface runoff, SM□□□□□ is the saturated soil moisture depth which is 478 mm/m according to Tarboton (2003). The soil moisture amount is assumed equal to the amount of moisture in field capacity point crop planting day in this model. D_t, DP_t, SR_t, and p were calculated according to Allen et al (1992). Furthermore, effective rainfall is calculated according to USDA method using Cropwat 8.0 software. Note that if $\text{SM}_t > [PWP + (1-p)(FC-PWP)]$, Eta is equal to ET_m. ET_m is equal to zero if soil moisture depth is less than PWP (Reddy and Kumar, 2007).

There are some constraints considered in this model. Planting in Hamidiya irrigation network is conducted in fall and summer, so total cultivated area should not exceed 13500 hectares in each season. Determining cultivation area of each crop is subject to so many policies which is not considered in this model, so maximum area change is considered 30%. For any crop, the stage with K_y value of more than 0.5 should at least take half of crop water requirement in that stage to prevent severe water stress situation (lalehzari et al., 2015). Yield estimation using equations 1 and 2 is valid up to 50% percent according to Kipkorir and Raez (2002), so no more that 50% deficit irrigation should be applied to the crops. SM_t is also one of the constraints added to the model, and soil moisture depth must not be less than the soil moisture depth in permanent wilting point which is equal to 230 mm/m considering soil texture in Hamidiya county and according to Allen et al. (1998). Furthermore, soil moisture depth should not exceed the soil moisture depth under saturation situation. The allocated water should not exceed the network available water in every 10-day period which is 17.1 million cubic meters.

Results verification

Particle swarm optimization method (PSO) was used to verify the results of GA, and to compare the results obtained using either one of the mentioned optimization results after 20 independent runs. Similar to the previous model, Both GA and PSO parameters were set according to Akbaripour and Masehian (2013) based on Vikor index. Irrigation depths of each crop in every 10-day period are the decision making variable of this model, so the number of variables are 155. In GA optimization method, population=310, crossover percent=70, mutation probability percent=30, mutation rate=1, and iteration number=400. In PSO method, particle number=500, social factor=1.5, cognitive factor=3.5, constriction factor=0.9, maximum inertia weight=0.9, minimum inertia weight=0.3, and iteration number=500. The mentioned values are the set parameters values of GA and PSO.

3. Results

Table 3 includes the results of the stagewise crop response factors modification model obtained by either GA method or PSO method. Results were obtained after 20 independent runs. According to table 2, the minimized values of estimation error for each crop using GA are close to the minimized values of estimation error using PSO, so Results obtained by GA are verified. The mean and standard deviation values obtained by PSO method are less than those of GA. This shows better performance of PSO in this model in comparison to GA.

Table 4 includes the modified K_{yi} values. They are significantly less than the K_{yi} values proposed by former studies (Faghihi et al., 2015; Garg and Dadhich, 2014; Dorenboos and Kassam, 1979). Table 5 includes RMSR values for both K_{yi} and modified K_{yi} values. Considering the values, RMSR values for modified K_{yi} values are much lower than RMSR values for K_{yi} values. Furthermore, figures 1 to 10 indicate crop yield reduction using different types of

K_y values. The yield reduction estimated using K_{yi} values by applying 50% deficit irrigation in all growth stages exceeded 100% percent in Rice, Bean, sesame, canola vegetable, cucumber and tomato. The amount of yield reduction under 50% deficit irrigation for other crops is near to 100%, but these amount of yield reduction is not logic and acceptable, however, yield reduction is 57.5% for beans, 54.9% for rice, 40% for canola and sesame, 54.8% for tomato, 46.8% for cucumber, and 49.7% for vegetables under applying 50% deficit irrigation in all growth stages using the modified K_{yi} values proposed by this study. As a result, the modified K_{yi} values are recommended to estimate yield reduction under deficit irrigation situation. Garg and Dadhich (2014) also concluded that the K_{yi} values proposed by FAO is not suitable to be used in yield reduction estimation and the modified K_{yi} values are more suitable, so the findings of this research is in agreement with Garg and Dadhich (2014).

Table 3- Comparison of the minimized values of yield estimation error for each crop

		Wheat	Bean	Barely	Rice (with hulls)	Canola	Sesame	Cabbage	Tomato	Cucumber	Vegetables
Genetic algorithms	Best	9.3×10^{-9}	1.4×10^{-9}	1.6×10^{-9}	6.9×10^{-11}	1.1×10^{-9}	4.4×10^{-9}	1.1×10^{-8}	7.2×10^{-8}	1.1×10^{-6}	1.2×10^{-15}
	Worst	5×10^{-6}	1.18×10^{-6}	1.3×10^{-6}	1.3×10^{-5}	4.1×10^{-5}	3.14×10^{-7}	3.14×10^{-7}	6.5×10^{-6}	6.5×10^{-6}	6.7×10^{-6}
	Mean	8.7×10^{-7}	3.5×10^{-7}	5.6×10^{-7}	4.8×10^{-6}	4.8×10^{-6}	1.35×10^{-7}	5.12×10^{-7}	3.72×10^{-7}	48×10^{-6}	2.24×10^{-6}
	Standard deviation	1.57×10^{-6}	3.2×10^{-7}	1.2×10^{-6}	4.5×10^{-6}	1.6×10^{-5}	1.17×10^{-7}	5.66×10^{-7}	1.96×10^{-7}	1.41×10^{-6}	2.44×10^{-6}
Particle swarm optimization	Best	3×10^{-33}	3×10^{-33}	1.8×10^{-32}	3.8×10^{-33}	1.9×10^{-34}	4.6×10^{-33}	0	3.32×10^{-33}	3.8×10^{-33}	9.2×10^{-33}
	Worst	2.6×10^{-6}	5.4×10^{-11}	6×10^{-8}	1.2×10^{-9}	3.5×10^{-14}	1.8×10^{-17}	5.5×10^{-22}	10^{-22}	3×10^{-15}	1.09×10^{-18}
	Mean	5.2×10^{-7}	1.08×10^{-11}	1.2×10^{-8}	4.2×10^{-10}	7×10^{-15}	3.6×10^{-18}	1.1×10^{-22}	2×10^{-23}	6×10^{-16}	2.18×10^{-9}
	Standard deviation	1.04×10^{-6}	2.16×10^{-11}	2.4×10^{-8}	8.4×10^{-10}	1.4×10^{-14}	7.19×10^{-18}	2.2×10^{-22}	4×10^{-23}	1.2×10^{-23}	4.36×10^{-9}

Table 4- The modified stagewise crop response factors (modified K_{yi} values)

	Wheat	Bean	Barely	Rice	Canola	Sesame	Cabbage	Tomato	Cucumber	Vegetables
Stage 1	0.02	0.05	0.01	0.017	0.06	0.06	0.04	0.01	0.02	0.05
Stage 2	0.48	0.63	0.53	0.25	0.07	0.07	0.09	0.56	0.19	0.03
Stage 3	0.17	0.43	0.35	0.57	0.37	0.37	0.34	0.28	0.53	0.68
Stage 4	0.35	0.04	0.12	0.11	0.31	0.31	0.48	0.25	0.19	0.24

Table 5- RMSR values for K_{yi} and modified K_{yi} values

Crop	Wheat	Bean	Barely	Rice	Canola	Seesame	Cabbage	Tomato	Cucumber	Vegtables
K_{yi}	0.3505	0.3330	0.5982	1.3403	0.5962	0.5962	0.3339	0.7870	0.4932	0.8899
Modified K_{yi}	0.01	0	0	0	0	0	0	0.02	0.06	0

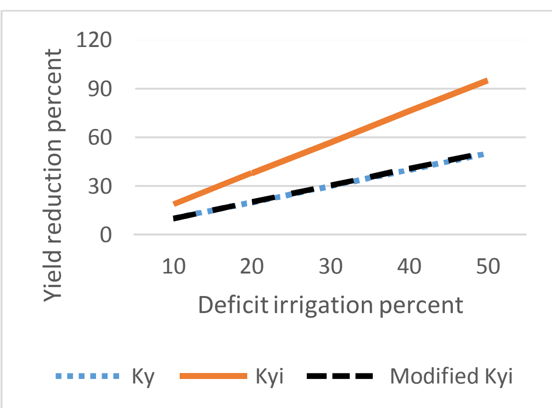

Figure 1. Comparison of wheat yield reduction estimation using different K_y types

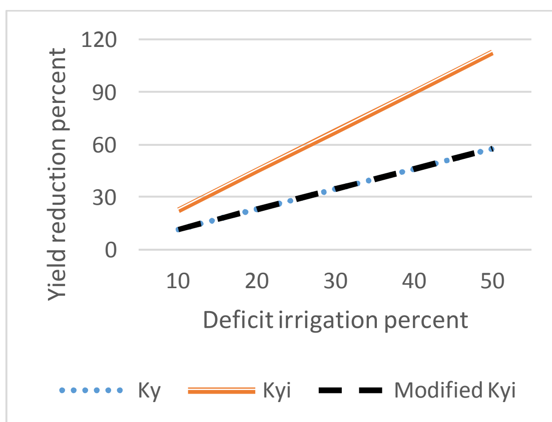

Figure 2. Comparison of bean yield reduction estimation using different K_y types

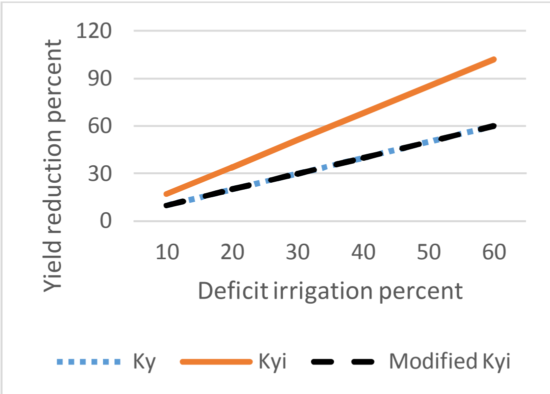

Figure 3. Comparison of barely yield reduction estimation using different K_y types

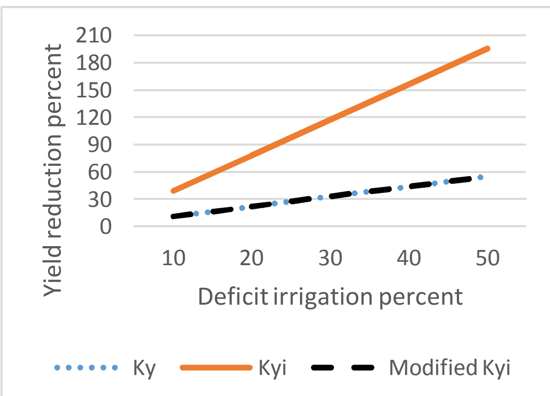

Figure 4. Comparison of rice yield reduction estimation using different K_y types

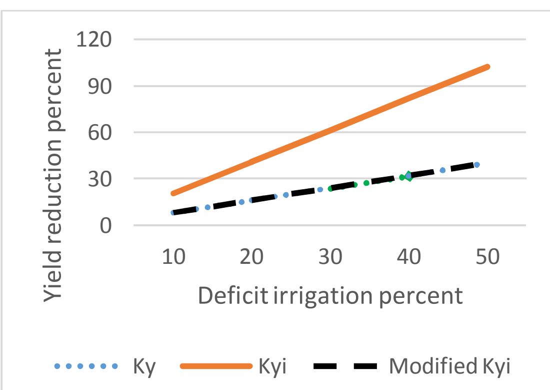

Figure 5. Comparison of canola yield reduction estimation using different K_y types

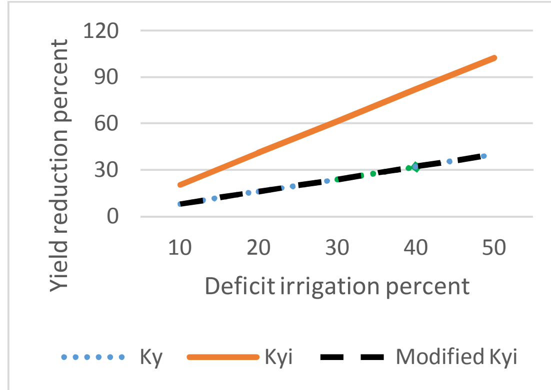

Figure 6. Comparison of sesame yield reduction estimation using different K_y types

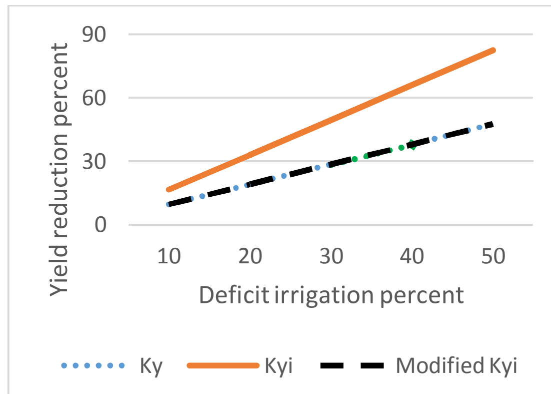

Figure 7. Comparison of cabbage yield reduction estimation using different K_y types

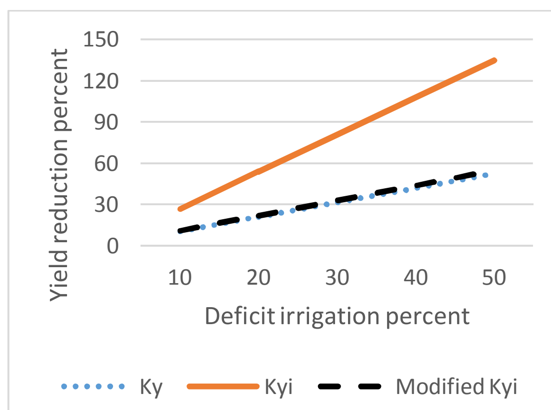

Figure 8. Comparison of tomato yield reduction estimation using different K_y types

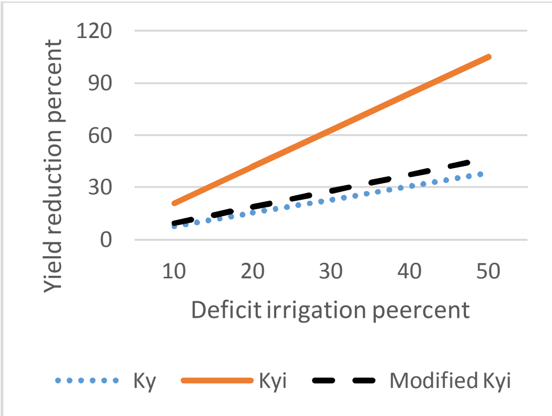

Figure 9. Comparison of cucumber yield reduction estimation using different K_y types

In order to verify the obtained results, PSO optimization model was also used to optimally allocate irrigation water to Hamidiya irrigation network. Either GA or PSO results were obtained after 20 independent runs. Table 6 shows the maximized value of net benefit (in Rials) under optimal irrigation water allocation situation which were obtained after 20 independent runs. The values obtained using GA and PSO are approximately close, however, mean value in PSO is bigger than mean value in GA method. Furthermore, standard deviation value in PSO results is lower than standard deviation of GA results, so PSO have a better performance than GA optimization method, but this shows that the results of GA are verified.

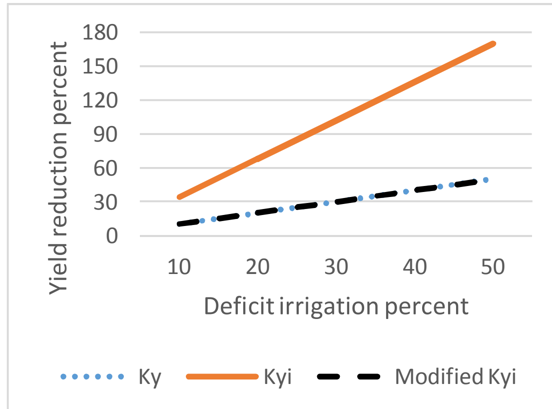

Figure 10. Comparison of vegetables yield reduction estimation using different K_y types Optimal irrigation water allocation model

Table 6- Results of maximizing the total net benefit in GA and PSO method

	Genetic algorithms	Particle swarm optimization
Best	7.8×10^{11}	8×10^{11}
Worst	6.4×10^{11}	6.8×10^{11}
Mean	7×10^{11}	7.29×10^{11}
Standard deviation	4.65×10^{10}	3.9×10^{11}

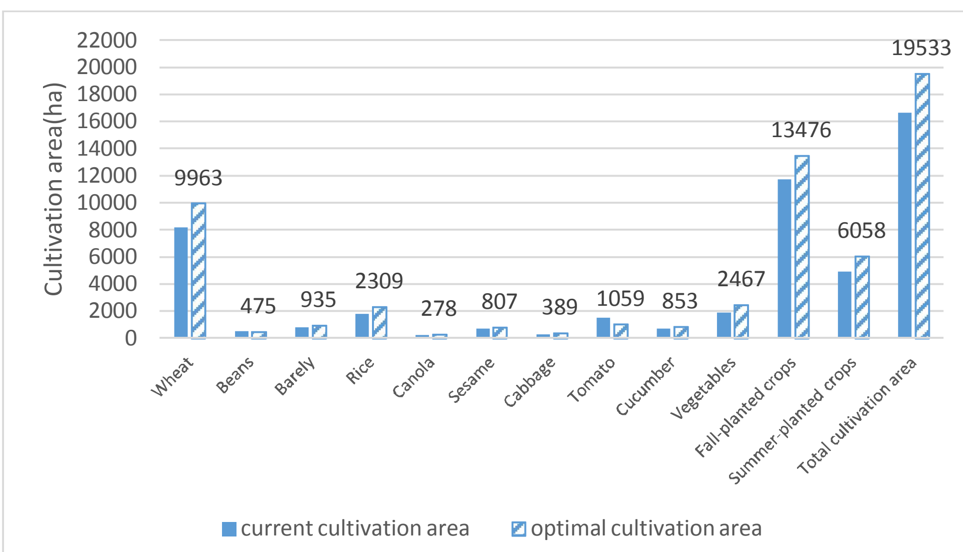

Figure 11. Current and optimal area of the Hamidiya irrigation network crops

A model was created to optimally allocate irrigation water with the purpose of net benefit maximization. Irrigation depth in every 10 day period of a crop growth stage is a decision making variable in this model. Figure 11 shows the crops cultivation area in both the current situation and the optimal irrigation water allocation situation. Results indicated that the network fallow area is reduced by 2883 hectares. In other words, the cultivation area of the crops planted in fall is increased by 1726 under optimal irrigation water allocation situation, and also the summer-planted crops cultivation area is increased by 1158 hectares which causes increase in the total cultivation area by 2883 hectares. The cultivation area of tomato and beans were decreased by 441 and 25 hectares, respectively. This is because growing beans is with low net benefit and growing tomato is without net benefit and causes loss. Vegetables have the most increase in the cultivation area while canola has the least. Rice cultivation area is also increased by 509 hectares. Khanjari sadati et al. (2014) reported an increase amount of 1642 hectares in the total cultivation area under optimal irrigation water allocation under wet weather condition. Garg and Dadhich (2014) also reported increase in the total cultivation area by 109%, so the results of this study is in agreement with the mentioned studies.

Table 7 shows the supplied water requirement percent of the crops in both the current and optimal irrigation water allocation situation. According to the table, the water requirement of wheat, vegetables, tomato and canola is fully supplied under optimal irrigation water allocation situation. Tomato water requirement is fully supplied in order to decrease the economic loss, but vegetables water requirement is fully supplied in order to increase the total net benefit. Wheat water requirement is also fully supplied because most of network area is under wheat cultivation and applying deficit irrigation will affect the net benefit. Deficit irrigation is not applied to canola because its water requirement amount is low and most of its water requirements is supplied by rain. Deficit irrigation is applied to the crops under optimal irrigation water allocation situation which the highest level of deficit irrigation is applied to beans.

Table 7- Current and optimal water requirement supplement percent in the current and optimal irrigation water allocation situation

	Current situation	Optimal water allocation situation
Wheat	100	100
Bean	100	71.3
Barely	100	100
Rice (with hulls)	100	73.6
Vegetables	100	100
Cucumber	100	89.2
Tomato	100	100
Cabbage	100	99
Canola	100	100
Sesame	100	83.2

Table 8 shows the amount of total net benefit and water consumption in both the current and the optimal irrigation water allocation situation. According to the table, total net benefit is increased by 154.8 billion Rials in the optimal irrigation water allocation situation in comparison to the current situation. Furthermore, water consumption in decreased by 47.7 MCM in comparison to the current situation, so it can be concluded that total net benefit is increased under optimal irrigation water allocation while water consumption is significantly decreased. The results also show effectiveness of GA to be as a tool to solve water management problems.

Table 8- Net benefit and consumed water in current and optimal situation

	Current situation	Optimal water allocation situation	Difference
Total net benefit (billion Rials)	624	778.8	154.8
Water consumption (MCM)	400	352.3	-47.7

4. Discussions

Two optimization models were created in this study. The first one is to minimize the yield reduction estimation error which the results of the model show that the previously-proposed K_{yi} values are not suitable to be used in yield reduction estimation under deficit irrigation, because the amount of yield reduction is more than 100% in wheat, tomato, cucumber, canola, rice, and sesame if 50% level of deficit irrigation is applied to them in all growth stages while yield reduction is 57.5% for beans, 54.9% for rice, 40% for canola and sesame, 54.8% for tomato, 46.8% for cucumber, and 49.7% for vegetables under applying 50% deficit irrigation in all growth stages using the modified K_{yi} values proposed by this study. Another model was also created to optimally allocate irrigation water to Hamidiya irrigation network. Results indicated that under optimal irrigation water allocation situation, total net benefit is increased by 25% while water consumption is reduced by 12% in comparison to the current situation. As a result, GA is highly effective to be used in optimization problems of water management.

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