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Preface

Praise be to the Almighty God who blessed us, with the efforts and perseverance of the editorial board, the journal staff, and the cooperation of the reviewers and editors, the Journal of Irrigation Sciences and Engineering (JISE) publishes the Vol.45 No.2 in English.

The JISE journal has a history about 43 years and The Ministry of Science, Research and Technology issued the license for this journal in 2009 as a scientific-research journal in present form. This journal is indexed on the ISC and Doaj international sites.

The editorial board of the JISE journal hopes that the esteemed colleagues in all universities, scientific and research centers by sending their valuable scientific and practical articles in specialties of water engineering, irrigation and drainage, water resources, hydraulic structures, sediment hydraulics, aquatic environment, watershed management, meteorology, hydrology, groundwater, water economics, and the related sciences cooperate with the JISE. Also we hope those people who are specialist in these fields of study assist us for the continuity of journal printing and publishing and providing more valuable researches of water sciences and engineering. We sincerely thank all the experts and reviewers of the articles who have played a role in improving the quality of the journal on various occasions by providing their valuable opinions.

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Shahid Chamran University of Ahvaz

Irrigation Sciences and Engineering (JISE)
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Original Paper

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Prediction of Transverse Shear Stress in a Rectangular Channel Using Shannon Entropy and Support Vector Regression

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Abstract

In open channel flow, determining the boundary shear stress and its distribution over the wetted perimeter is a significant problem. The shear stress distribution (SSD) is primarily affected by secondary flows, sediment transport rate, erosion or sedimentation, and geometry of the channels. The presented research uses Shannon entropy and support vector regression (SVR) approach to predict the SSD in rectangular channels (RCs). First, the entropy technique proposed by Sterling and Knight, (2002) is used to construct the probability density function of transverse SSD, and the constant coefficients of density are obtained by comparing experimental results in various aspect ratios. Second, to estimate the transverse SSD in a smooth RC, SVR methods have been used. According to the results of the sensitivity analysis, the aspect ratio B/H is the most essential parameter for SSD estimation. The SVR model performed better when the (b/B), (z/H), and (B/H) parameters were also used as input. For the aspect ratios (B/H) 2.86, 4.51, 7.14, and 13.95, the SVR model, with an average MAE of 0.044 in bed and 0.053 in wall, gives higher accuracy than the Shannon entropy, which has an average MAE of 0.062 in bed and 0.073 in wall for all flow depths. The Shannon entropy overestimates shear stress as compared to SVR. As a result, the costs of construction of channels may be significant.

Introduction

In open channel flow, determining the boundary shear stress and its distribution over the wetted perimeter is a significant problem. The SSD is primarily affected by secondary flows, sediment transport rate, erosion or sedimentation, and geometry of the channels. The SSD and flow resistance in simple and compound channels with smooth and rough surfaces were studied by many scholars Kartha and Leutheusser (1970), Yang and Lim (1997), Knight and Patel (1985a), Knight and Patel (1985b), Knight et al. (1994), Sheikh Khozani and Bonakdari (2016), Sheikh Khozani and Bonakdari (2018) and Lashkar-Ara et al. (2021).

It is plausible that the transverse SSD in wide and broad channels is not uniform. Kartha and Leutheusser (1970) conducted a series of experiments on the determination of SSD to design stable alluvial channels by tensile forces. Experiments were performed in a rectangular laboratory flume with smooth-wall in aspect ratios between 1 and 12.5. They measured shear stress by Preston tube. For calibration of the Preston tube, the indirect method was applied, and the law of the wall and velocity logarithmic distribution was used. At that time, they indicated that none of the available analytical techniques could calculate the shear stress for a proper design of alluvial channels.

Lashkar-Ara and Fatahi (2020) have been measuring transverse SSD in rectangular open channels bed and wall using the Preston tube with an optimal diameter. The study's results include two dimensionless relationships for estimating local shear stress in the bed and wall. The aspect ratio *B/H*, as well as the bed relative coordinates *b/B* in cross-section and *z/H* in sidewall, determine these relationships. The study found that the aspect ratio *B/H* has a significant impact on the dimensionless bed SSD. Ardiçlioğlu et al. (2006) did an experimental investigation for the SSD in a fully developed boundary layer area in both smooth and rough surfaces throughout the whole length of the cross-section of an RC. They conducted 48 tests by measuring flow velocity on both smooth and rough surfaces.

The logarithmic distribution of flow velocity was used to calculate mean transverse shear stresses for various aspect ratios *B/H* ranging from 4.2 to 21.6 and Froude numbers ranging from 0.12 to 1.23. Since experimental methods are difficult and time-consuming to calculate the SSD in channels, soft computing methods are suggested. Cobaner et al. (2010) utilized Artificial Neural Networks (ANN) to model boundary shear stress in a smooth RC.

Sheikh Khozani et al. (2018) employed a support vector machine (SVM) to estimate shear stress in a rough RC. To obtain new relationships for the velocity and SSD in open channels, Chiu (1987) proposed new hydraulic principles of maximum entropy and chance. The Shannon's entropy, which is the basis behind such analysis like the maximum entropy concept was further discussed by Chiu (1991) and similar studies by Shuyou and Knight (1996) have been used by Araújo and Chaudhry (1998) and Sterling and Knight (2002) to estimate open channel shear stress. Based on the work of Chiu (1991), Shuyou and Knight (1996), Araújo and Chaudhry (1998), and Sterling and Knight (2002) employed Shannon entropy theory to estimate SSD in open channels.

Sterling and Knight (2002) proposed a novel method for estimating SSD in open channels with a circular cross section. One pitfall of that study is the limitation that the model has to cover all extent of hydraulic behaviors of a channel, which in turn could overshadow the model's reliability. One reason is the difficulty behind the choice of parameter assumptions and the resulting sensitivity to estimate those parameters.

In this research, the efficiency of the Shannon entropy method in estimating SSD in a smooth RC has been evaluated. For this aim, first, the method presented by Sterling and Knight (2002) is implemented to derive the probability density function of shear stress transverse distribution, the constant coefficients of density are determined by examining the findings of the Lashkar-Ara and Fatahi (2020). In the second step, the support vector regression (SVR) function is investigated in the SSD estimation. Finally, the outcomes of these two approaches are compared to each other as well as the Lashkar-Ara and Fatahi (2020) experimental results.

The aim of the presented study was to use the entropy method of Shannon to estimate the SSD in a smooth RC. The outcome of the Shannon entropy method was compared with the SVR model and the experimental outcomes of Lashkar-Ara and Fatahi (2020). The result of the literature review shows that no document has been published on the use of Shannon entropy and SVR in the estimation of SSD in smooth RC's.

Methodology

Data Collection

Data were obtained from Lashkar-Ara and Fatahi (2020) experiments, which were conducted in 10-meter length flume with 60 cm width and 70 cm height. These experiments were carried out at the hydraulic laboratory of Jundi-Shapur University of Technology, Dezful, Iran. The flow rate ranged from 11.06 to 102.38 liters per second for all measurements. Flow rate variations cause changes in water depth from 0.043 m to 0.21 m, as well as changes in the aspect ratio (*B/H*) ranging from 2.86 to 13.95. Pressure transmitter device with a capacity of 0.2 bar and a 50 Hz measuring frequency were used to measure and evaluate the values of total pressure and static difference in various of *B/H*. A weir was added at the end of the flume to obtain uniform flow conditions. The experimental flume is shown in Fig. (1).

Based on previous experimental and field study results, the effective criterion for measuring the SSD throughout the wet perimeter of a channel may be described as follows:

$$f_1(\bar{\tau}_w, \varrho, \upsilon, g, V, H, S_w, S_o, B, z, K_s) = 0 \quad (1)$$

$$f_2(\bar{\tau}_b, \varrho, \upsilon, g, V, H, S_w, S_o, B, b, K_s) = 0 \quad (2)$$

where $\bar{\tau}_b$ is the mean bed shear stress, $\bar{\tau}_w$ is the mean wall shear stress, υ is the kinematic viscosity, ρ is the density, V is the velocity of flow, g is the gravity acceleration, H is the depth of flow, B is the bed width of flume, K_s is the height of roughness and S_w is the slope of water surface. As demonstrated in Eqs. (3) and (4), the Buckingham- π theorem was utilized to derive dimensionless parameters for wall and bed shear stress.

$$f_3\left(\frac{\upsilon}{VH}, \frac{K_s}{H}, \frac{gH}{V^2}, \frac{B}{H}, \frac{z}{H}, \frac{\bar{\tau}_w}{\varrho g H S_w}\right) = 0 \quad (3)$$

$$f_4\left(\frac{\upsilon}{VH}, \frac{K_s}{H}, \frac{gH}{V^2}, \frac{B}{H}, \frac{b}{B}, \frac{\bar{\tau}_b}{\varrho g H S_w}\right) = 0 \quad (4)$$

Equations (3) and (4) may be rewritten as (5) and (6) in the case of smooth channels:

$$\frac{\bar{\tau}_w}{\varrho g H S_w} = f_5\left(\mathrm{Re}, \mathrm{Fr}^2, \frac{B}{H}, \frac{z}{H}\right) \quad (5)$$

$$\frac{\bar{\tau}_b}{\varrho g H S_w} = f_6\left(\mathrm{Re}, \mathrm{Fr}^2, \frac{B}{H}, \frac{b}{B}\right) \quad (6)$$

Where (Fr) is the Froude number and (Re) is the Reynolds number. In a smooth RC with varying flow depths, 100 data of shear stress on wall τ_w and 160 data of shear stress on bed τ_b from Lashkar-Ara and Fatahi (2020) were selected for Shannon entropy and SVR models assessment. A total of 70% of the data was picked for training and 30% for testing. Table (1) contains a summary of the experiments.

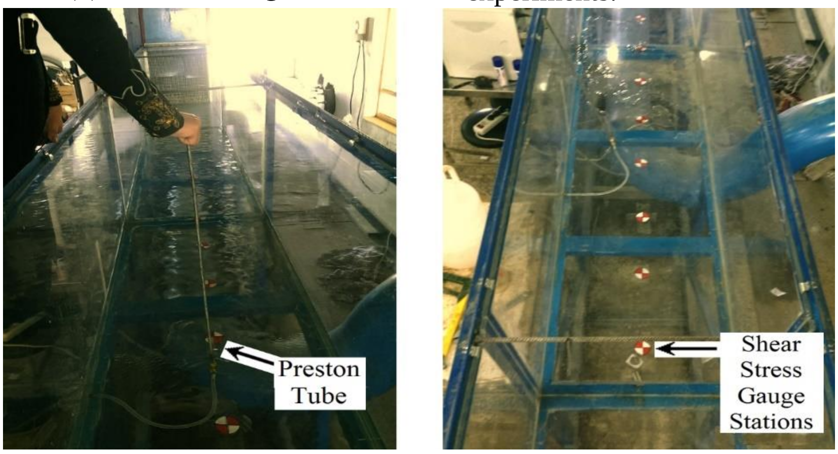

Fig. 1- Experimental setup (Lashkar-Ara and Fatahi, 2020)

Table 1- Summary of the experiment

Parameters	Variable	Min.	Max.	Mean
H (m)	Depth of flow	0.043	0.21	0.0928
B/H	aspect ration	2.86	13.95	7.98
Q (L/s)	Discharge	11.06	102.38	34.795
V (m/s)	Velocity	0.429	0.813	0.568
Fr	Froude number	0.66	0.566	0.618
$\mathrm{Re} \times 10^4$	Reynolds number	6.4	39.87	16.418
Re_*	Shear Reynolds	0.322	0.609	0.426
γHS	Total shear stress	0.442	2.162	0.955

Shannon entropy

The Lagrange coefficient was used by Sterling and Knight (2002) to maximize Shannon entropy and to provide an equation to estimate shear stress:

$$\tau = \frac{1}{\lambda}(1 + (e^{\lambda\tau_{max}} - 1)\frac{y}{L}) \quad (7)$$

Where τ is the shear stress of local boundary, τ_{max} is the maximum boundary shear stress, y is the transverse coordinate, L is half of the wet perimeter and the multipliers of the λ which can be calculated as:

$$\lambda = (\frac{\tau_{max} \quad e^{\lambda\tau_{max}}}{e^{\lambda\tau_{max}} - 1} - \rho gRS)^{-1} \quad (8)$$

Where ρ is the mass density, R is the hydraulic radius, g is the gravitational acceleration and, S is the channel's bed slope. This formula was used only in the cross-section of the circle. In a circular channel with a flatbed, the relationships between the wall and the bed must be defined as follows:

$$\tau_w = \frac{1}{\lambda_w}(1 + (e^{\lambda_w\tau_{max(w)}} - 1)\frac{2(y - y_w)}{P_w})y_w\langle y\langle\frac{P_w}{2} \quad (9)$$

$$\frac{1}{\lambda_b}(1 + (e^{\lambda_b\tau_{max(b)}} - 1)\frac{2(y - y_w)}{P_b})\frac{P_w}{2}\langle y\langle\frac{P_b}{2} + y_w \quad (10)$$

Where P is the channel perimeter, and λ are the Lagrange multiplier each corresponding to the channel bed and wall denoted by the subscript of *b* and *w*, respectively. It's worth to mentioning that before using the Eqs. (9), (10) and Eq. (7), we have to estimate the mean and maximum shear stresses.

A pair of mean and maximum shear stresses are required to calculate the SSD. For estimating the values of τ_{max} and $\bar{\tau}$, the results of the Lashkar-Ara and Fatahi (2020) studies were applied. They set the flume's bed slope at 9.58×10^{-4}. Aspect ratios of 2.86, 4.51, 5.31, 6.19, 7.14, 7.89, 8.96, 10.71, 12.24, and 13.95 were used to determine the shear stress distributed by the walls and bed. Preston tubes were used to measure the shear stress distribution. Assuming a completely turbulent and subcritical regime among all the experimental data, the best fit equation for τ_{max} and $\bar{\tau}$ separately for wall and bed in aspect ratio 2.89 < *B/H* < 13.95 was fitted.

Equations (11)– (14) demonstrate the relationships between the variables.

$$\frac{\bar{\tau}_w}{\rho gRS} = \frac{2.1007 + 0.0462\left(\frac{B}{H}\right)}{1 + 0.1418\left(\frac{B}{H}\right) + \left(\frac{B}{H}\right)^{-0.0424}} \quad (11)$$

$$\frac{\bar{\tau}_b}{\rho gRS} = \frac{2.0732 - 0.0694\left(\frac{B}{H}\right)}{1 - 0.146\left(\frac{B}{H}\right) + \left(\frac{B}{H}\right)^{-0.1054}} \quad (12)$$

$$\frac{\tau_{max\,w}}{\rho gRS} = \frac{2.5462 + 6.5434\left(\frac{B}{H}\right)}{1 + 6.34\left(\frac{B}{H}\right) + \left(\frac{B}{H}\right)^{-0.1083}} \quad (13)$$

$$\frac{\tau_{max\,b}}{\rho gRS} = \frac{3.157 + 0.8214\left(\frac{B}{H}\right)}{1 + 0.8535\left(\frac{B}{H}\right) + \left(\frac{B}{H}\right)^{-0.1401}} \quad (14)$$

The mean and maximum wall and bed shear stress are $\bar{\tau}_w \& \bar{\tau}_b$ and $\tau_{max\,w} \& \tau_{max\,b}$, respectively. As a result, based on *B/H* and S_o, the transverse SSD for an RC can be estimated.

Using the results of Lashkar-Ara and Fatahi (2020) and determining the values of $\bar{\tau}_w \& \bar{\tau}_b$ using Eqs. 11 to 14, the Lagrange coefficients were calculated by Eqs 9 and 10. The results are summarized in Table (2).

Support Vector Regression analysis

The fundamental basis of SVM has been developed by Vapnik (1998), which receives wide admiration among researchers because of having characteristics of a great empirical performance. This machine learning method works on the identification of a hyper-plane constructed in an infinite-dimensional space that separates two classes in a series of classification. An SVM has been used for classification, regression, or other similar tasks Ebrahimi and Rajaee (2017). Support vector machines have been known by two main categories: support vector classification (SVC) and SVR.

SVM is a method of a learning machine that uses a high dimensional space. This offers predictive functions that are built on a

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support vector subset. SVR relies only on a sub-set of training data, as the cost function for model construction is not concerned with training points beyond the margin Basak et al. (2007). The efficiency of the generalization of SVR is calculated by the calibration of the kernel function and parameters. C and π are SVR parameters and indicate the constant regularization and constant kernel function which control the complexity of the model prediction (regression), and the kernel function changes the input space dimensionality to perform the regression process more confidently, respectively. Due to its accuracy and reliable efficiency, RBF has become the researcher's option as the kernel function for SVR over the years Suryanarayana et al. (2014). SVM's regression subset, known as SVR, was applied to estimate the transverse SSD in a smooth RC. Therefore, the Radial Basis Function (RBF) is adopted in this study and is expressed as

$$k(x_i, x) = exp(\gamma \|x - x_i\|^2) \tag{15}$$

The estimation precision is determined by collecting of the three parameters of the SVR, namely C, γ, and ε. Using the trial and error method, these parameters are standardized, and results are shown in table (3).

Statistical analysis

The four statistical assessment metrics used to determine the Shannon entropy and SVR models performance are the Maximum Error (ME), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Nash–Sutcliffe Efficiency (NSE), which are calculated as follows (Willmott and Matsuura (2005) and McCuen et al. (2006)):

$$\text{ME} = \text{Max}|P_i - O_i| \tag{16}$$

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}|P_i - O_i| \tag{17}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}} \tag{18}$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(O_i - \bar{O})^2} \tag{19}$$

where O_i represents the observed parameter value, P_i represents the projected parameter value, $\bar{O}$ represents the mean observed parameter value, and N represents the number of samples.

Table 2- Summary of the results of Lagrange coefficients in the Shannon entropy model

b/h	Experimental shear stress		Lagrange coefficents	
	$\bar{\tau}_b$	$\bar{\tau}_w$	λ_b	λ_w
2.86	1.435	1.200	1.415	8.262
4.51	1.012	0.846	2.087	11.510
5.31	0.894	0.738	3.099	15.322
6.19	0.761	0.638	3.099	15.322
7.14	0.709	0.556	3.515	12.204
7.89	0.655	0.498	4.540	12.305
8.96	0.603	0.450	5.930	14.716
10.71	0.516	0.372	7.485	16.433
12.24	0.466	0.326	10.213	18.122
13.95	0.409	0.278	13.687	20.985

Table 3- Kernel constant after try and error

Kernel function	Kernel constants		
	C	γ	ε
RBF	100	0.1	1

Results and discussion

SVR modeling

The sensitivity of the SVR model to each input parameter is assessed in this section. Three models were developed for this purpose. SVR models implemented in the present study are described as:

For the bed:

$$SVM\ Model(1): \frac{b}{B}, \frac{B}{H}, Fr, \mathrm{Re}$$

$$SVMModel(2): \frac{b}{B}, \frac{B}{H}, Fr,$$

$$SVMModel(3): \frac{b}{B}, \frac{B}{H},$$

For the wall:

$$SVMModel(1): \frac{z}{H}, \frac{B}{H}, Fr, Re$$

$$SVMModel(2): \frac{z}{H}, \frac{B}{H}, Fr,$$

$$SVMModel(3): \frac{z}{H}, \frac{B}{H},$$

Different models were examined for every channel segment to examine the influence of each input parameter on the SVR model accuracy. The results of the simulation of the bed shear stress showed that the SVR model (1) consists of the input parameters (*b/B*, *B/H*, Fr, Re) had the lowest error (average RMSE = 0.055), and in wall shear stress modeling, SVR model (Model 2) with the inputs *z/H*, *B/H*, Fr had the lowest error (average RMSE=0.064). Among the SVR models with ternary variables of input, Model 3, with *b/B* and *B/H* as input variables with NSE value of 0.942, performed the best in modeling bed shear stress while Model 3 with *z/H* and *B/H* as input variables with NSE value of 0.832, performed the best in modeling wall shear stress. Therefore, *B/H* has a significant impact on the SVR model efficiency and validates the Model 3 performance. As a result of the sensitivity analysis, the Reynolds number can be ignored in Model 2 because the flow condition is fully developed. The statistical results of the SVR model with different input combinations are shown in Table (4).

Table 4- Evaluation results of the SVR model with various input cases

B/H	Input Variable	Bed				Input Variable	Wall			
		ME	MAE	RMSE	NSE		ME	MAE	RMSE	NSE
2.86	*b/B,B/H,* Fr, Re	0.1938	0.0495	0.0787	0.9589	*z/H,B/H,* Fr, Re	0.0617	0.0363	0.0516	0.8021
2.86	*b/B,B/H,* Fr	0.2045	0.0650	0.0885	0.9571	*z/H,B/H,* Fr	0.0343	0.0288	0.0450	0.8416
2.86	*b/B,B/H*	0.1443	0.0690	0.0789	0.9502	*z/H,B/H*	0.0383	0.0278	0.0424	0.8026
4.51	*b/B,B/H,* Fr, Re	0.5270	0.0176	0.0246	0.9951	*z/H,B/H,* Fr, Re	0.0668	0.0493	0.0546	0.9189
4.51	*b/B,B/H,* Fr	0.0619	0.0286	0.0335	0.9944	*z/H,B/H,* Fr	0.1402	0.0442	0.0545	0.9314
4.51	*b/B,B/H*	0.0650	0.0229	0.0301	0.991	*z/H,B/H*	0.1030	0.0388	0.0496	0.9095
7.14	*b/B,B/H,* Fr, Re	0.0489	0.0269	0.0294	0.9916	*z/H,B/H,* Fr, Re	0.0744	0.0614	0.0514	0.9216
7.14	*b/B,B/H,* Fr	0.0451	0.0255	0.0277	0.9922	*z/H,B/H,* Fr	0.0482	0.0501	0.0538	0.893
7.14	*b/B,B/H*	0.0425	0.0243	0.0266	0.9907	*z/H,B/H*	0.1037	0.0376	0.0501	0.8954
13.95	*b/B,B/H,* Fr, Re	0.1205	0.0677	0.0903	0.8318	*z/H,B/H,* Fr, Re	0.0720	0.0612	0.1045	0.6942
13.95	*b/B,B/H,* Fr	0.1219	0.0607	0.0878	0.8287	*z/H,B/H,* Fr	0.2400	0.0942	0.1061	0.7125
13.95	*b/B,B/H*	0.1678	0.0716	0.0978	0.8394	*z/H,B/H*	0.2092	0.1109	0.1246	0.7238
Average Model (1)		0.222	0.0404	0.055	0.944		0.068	0.052	0.065	0.834
Average Model (2)		0.108	0.044	0.059	0.943		0.115	0.054	0.064	0.844
Average Model (3)		0.105	0.047	0.058	0.942		0.113	0.053	0.066	0.832
Total Average		0.145	0.044	0.057	0.943		0.099	0.053	0.065	0.837

There is no significant difference when Reynolds number (Re) is left out of the input parameters, as indicated in the table. The influence of the Froude number may be ignored because all of the experiments were conducted at subcritical flow conditions; hence, the parameter Fr has been omitted from Model 3. The SVR model's performance was not much improved by omitting the Re and Fr parameters, and the SVR model appears to be sensitive to the *B/H* parameter. It is clear that the *B*/*H* ratio is essential in shear stress prediction, as this parameter plays an important role in the mentioned equations.

Therefore, Model 3 is chosen as the most suitable model for the bed and wall. Figures (2) and (3) show the estimated results of the SVR model plotted as scatter against the experimental data for the dimensionless parameter of bed and wall shear stresses. As seen in these figures, the regression analysis shows the results obtained by the SVR model have almost fitted against the experimental data for both the bed and wall shear stresses of the channel. The result of NSE is higher for the dimensionless bed shear stress (average NSE is 0.942) than dimensionless wall shear stress (average NSE is 0.832), and both models are shown to have better performance than the other SVR models implemented in this study.

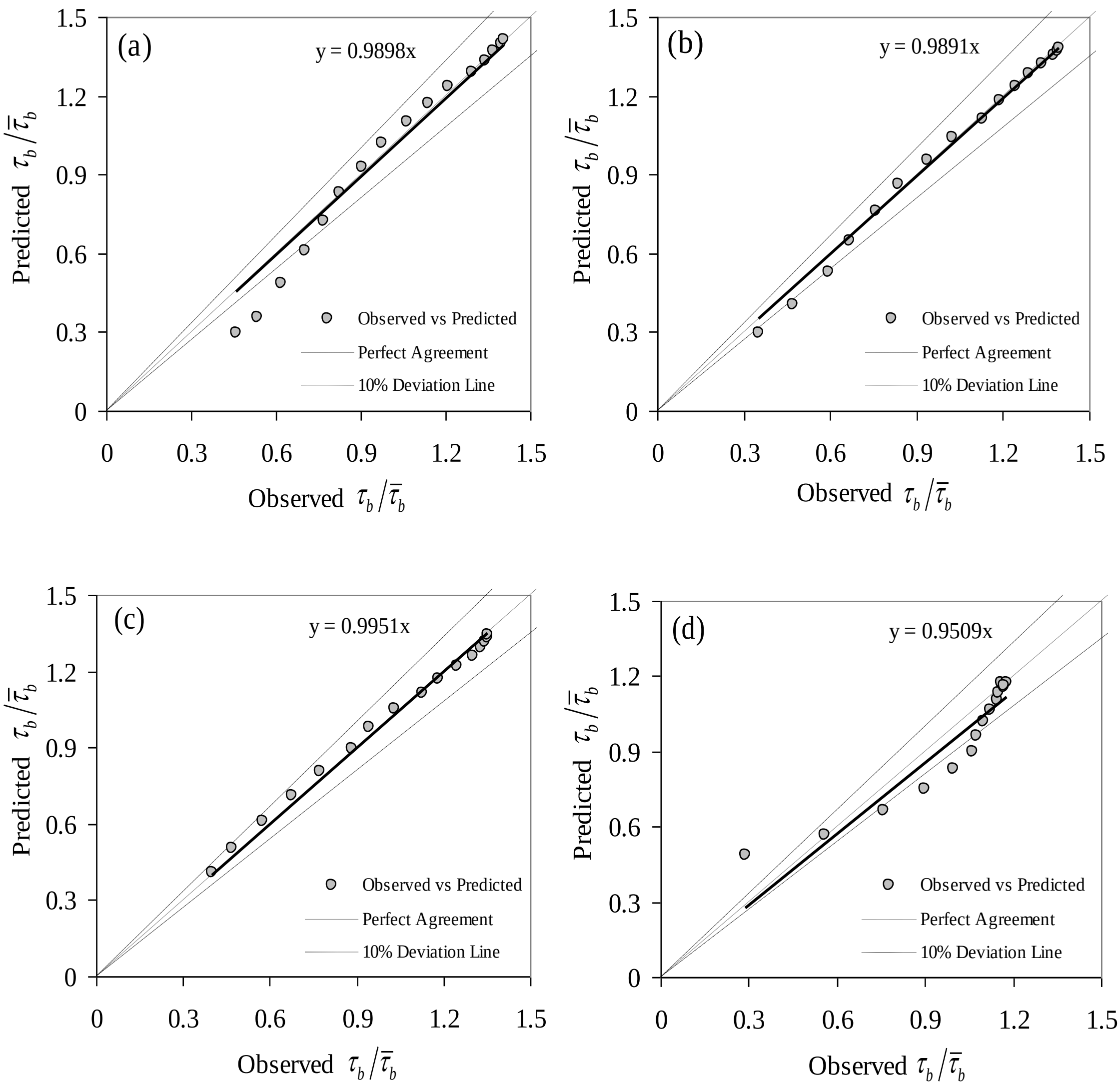

Fig. 2- Comparison SVR result in $\tau_b/\bar{\tau}_b$prediction versus laboratory observations at : (a) *B/H*=2.86, (b) *B/H*=4.51, (c) *B/H*=7.14, and (d) *B/H*=13.95.

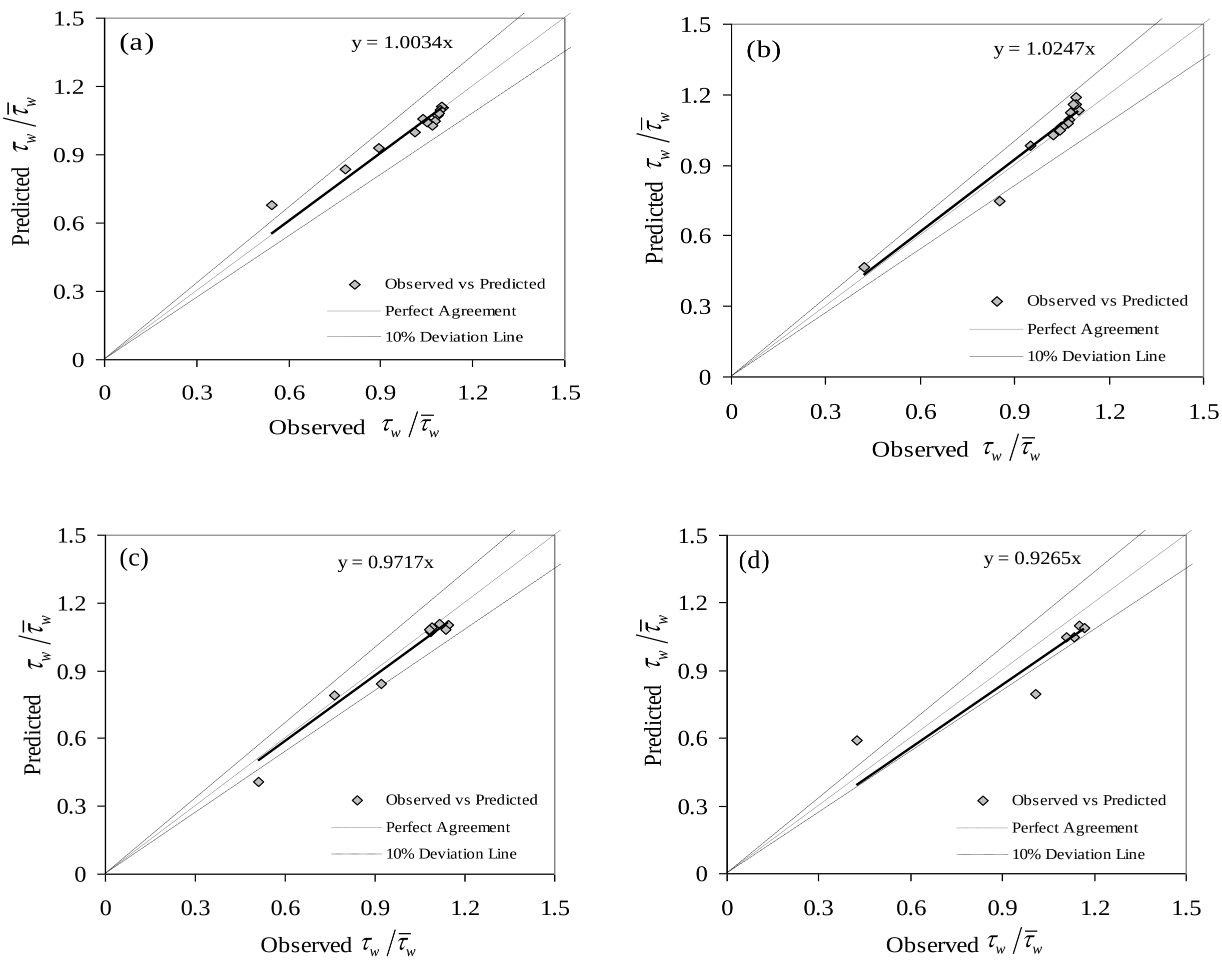

Fig. 3- Comparison SVR result in $\tau_w/\bar{\tau}_w$ prediction versus laboratory observations at : (a) *B/H*=2.86, (b) *B/H*=4.51, (c) *B/H*=7.14, and (d) *B/H*=13.95.

Model comparisons

In this part, the results of the best SVR models and Shannon entropy in predicting shear stress were compared to the observation of Lashkar-Ara and Fatahi (2020). Figures 4 and 5 show the laboratory results and SSD predictions with different models in a smooth RC for *B/H* equal to 2.85, 4.51, 7.14 and 13.95. In addition, Table (4) shows the Shannon entropy model's performance metric for estimating SSD.

All the test data utilized to model SSD using the SVR are well recognized as seen in these statistics. According to the statistical metric, all test functions used to estimate the SSD using the SVR were realized. 70% of total data was used for training and 30% was used for testing the SVR models for SSD estimation. The SVR model predicted bed shear stress better than the Shannon entropy model for all aspect ratios *B/H*, as shown in Figure 4. The SVR estimates the bed SSD better compared to Shannon entropy for *B/H*=2.86, 4.51, 7.14 (Fig. 4(a) to 4(c)) while the Shannon entropy model seems to be better than the SVR for *B/H*=13.95 (Fig. 4(d)). The SVR model predicted wall SSD better than the Shannon entropy model in Figures 5(a), 5(b), and 5(c) for *B/H* = 2.86, 4.51, and 7.14, respectively, while the Shannon entropy model predicted wall SSD more precisely in Figure 5(d). At increasing flow depth, the SVR model predicted bed and wall shear stress better than the Shannon entropy-based model.

When a model predicted higher shear stress values, it's obvious that channel design would be problematic. As a result, using the Shannon entropy technique to channel construction might be challenging. When the SVR model's observations became more precise, it could be utilized to more consistently design stable channels. As for one example, both methods ignore the effect of secondary flows; however, in the case of the SVR model, the results show improved performance. The results showed that the flexibility of the SVR model to estimate SSD is higher than the Shannon entropy and can overestimate the results when faced with a channel's most uncertain behaviors. The bed shear stress values are decreased in the center of the channel (Fig. 5), which varies from other cases. As demonstrated in Figures 2 and 3, the SVR model's fit line is closer to the best fit line than the other models, and its prediction is more accurate with a higher NSE value based on statistical metrics (Tables 4 and 5).

The SSD predictions based on SVR and Shannon entropy models exhibit the same tendency in evaluating the location of peak shear stress as the channel centerline, which is closer to the experimental results.

Table 5- Shannon entropy model statistical outcomes compared to experimental data

B/H	Bed				Wall			
	ME	MAE	RMSE	NSE	ME	MAE	RMSE	NSE
2.86	0.187	0.0611	0.0746	0.9332	1.3091	0.0678	0.0777	0.7907
4.51	1.338	0.0560	0.0655	0.9486	1.3091	0.0754	0.0830	0.7899
7.14	1.388	0.0620	0.0705	0.9419	1.660	0.0651	0.0787	0.8423
13.95	1.423	0.0685	0.0740	0.8665	0.9562	0.0846	0.1017	0.8548
Average	1.084	0.062	0.071	0.922	1.308	0.073	0.085	0.819

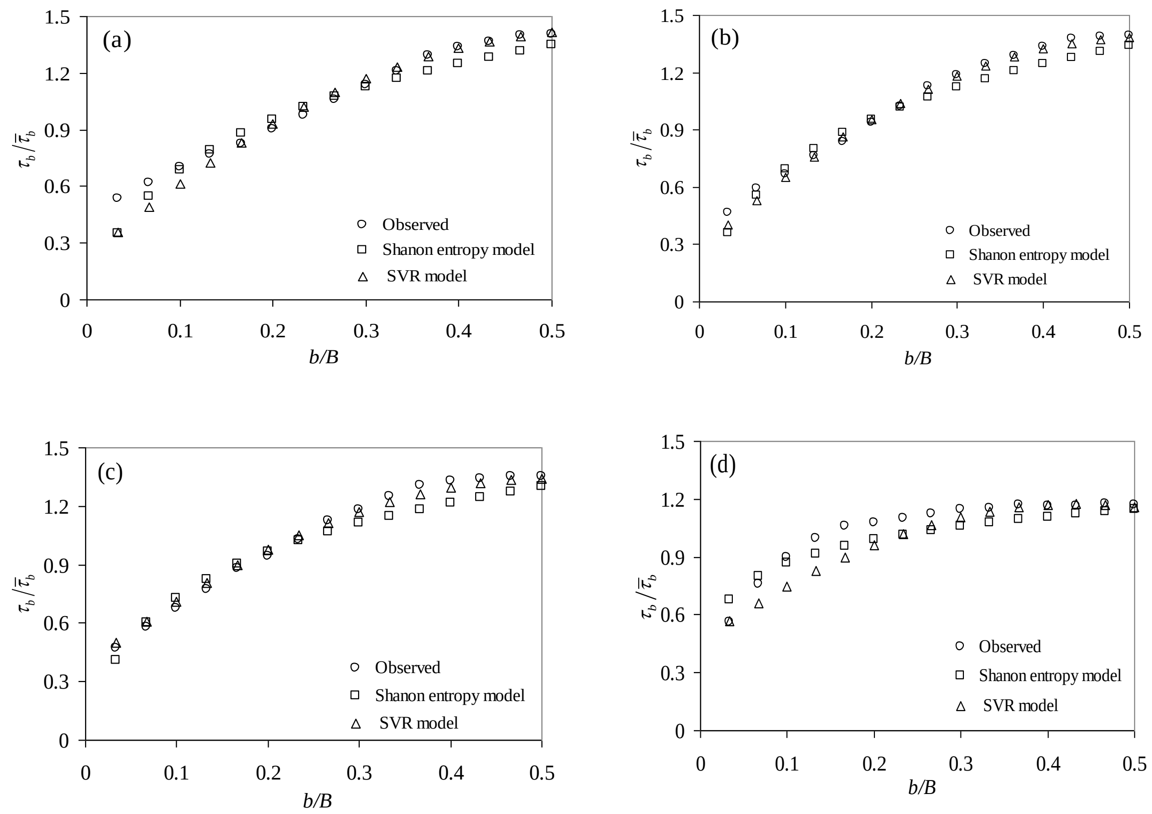

Fig.5- Comparison the prediction of $\tau_b/\bar{\tau}_b$ distribution by Shannon entropy model versus laboratory observations and SVR model at: (a) *B/H*=2.86, (b) *B/H*=4.51, (c) *B/H*=7.14, and (d) *B/H*=13.95.

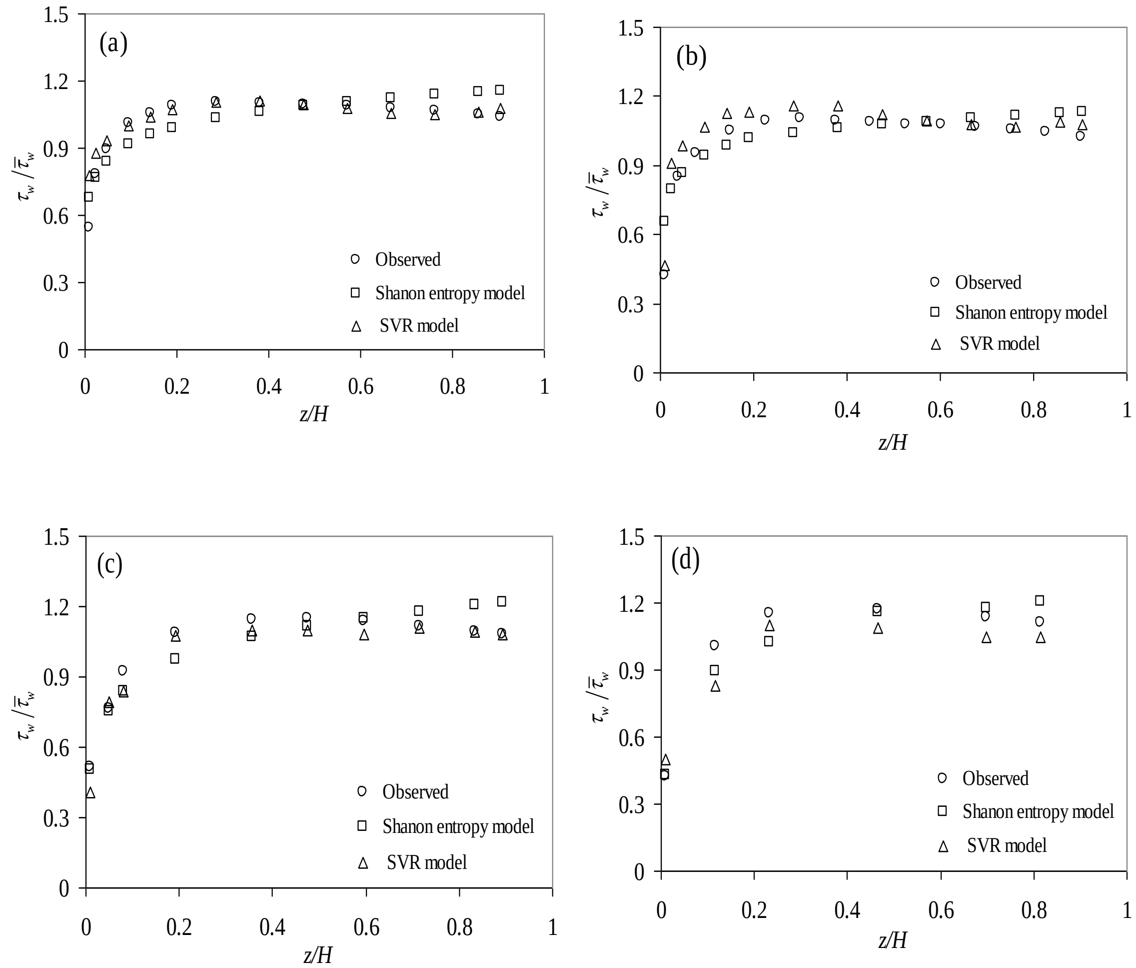

Fig. 6- Comparison the prediction of $\tau_w/\bar{\tau}_w$distribution by Shannon entropy model versus laboratory observations and SVR model at: (a) *B/H*=2.86, (b) *B/H*=4.51, (c) *B/H*=7.14, and (d) *B/H*=13.95.

Conclusions

The determination of SSD in open channels is an essential problem to be solved by engineers. This study examined the use of Shannon entropy and SVR method to predict the SSD in RC's. For this purpose, using the method presented by Sterling and Knight (2002) to derive the probability density function of shear stress transverse distribution, the constant coefficients of density are determined by comparing with the laboratory results of (Lashkar-Ara and Fatahi, 2020). Sensitivity analysis was applied, and three separate SVR models were used to evaluate the effective parameters on the SSD. The outcomes show that B/H is a sensitive parameter in estimating the SSD. Shannon entropy-based formula was compared with the SVR model in estimating SSD. For rising flow depths, both the SVR and the Shannon-based entropy formula provided well accuracy. The SVR, with an average RMSE of 0.057 and NSE of 0.943 performed superior to the Shannon entropy method with the RMSE of 0.074, NSE of 0.922 in bed SSD estimation for the aspect ratios (*B/H*) 2.86, 4.51, 7.14 and 13.95. In wall SSD estimation, also the SVR with the RMSE of 0.065 and NSE of 0.837 outperformed the Shannon entropy with the RMSE of 0.085 and NSE of 0.819 for the all aspect ratios. However, with increasing flow depth, the SVR model measures wall shear stress better than the entropy model. Channel design is known to incur higher costs when a model overestimates shear stress values. As a result, using SVR instead of Shannon entropy to estimate SSD in RC and design stable channels may be less risky and costly to implement.

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Effects of Using Agricultural Drainage Water on Chemical, Biological, and Physical Properties of Soil and Yield of Tomato in Moghan Plain, Iran

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Abstract

This study assesses the use of drainage water in agriculture by mixing irrigation water and agricultural drainage water to examine the effects of the mixture on soil properties and the yield of tomatoes in Moghan Plain, Iran. The experimental design was completely random, conducted with three irrigation treatments and four replications for two years. The treatments were the control treatment (only irrigation water) (T0), 50% drainage water +50% irrigation water treatment (T1), and only agricultural drainage water treatment (T2). The results showed the treatments had significant differences ($p \leq 0.05$) in terms of the microbial population, basal respiration, and substrate-induced respiration. There were also significant differences among the treatments in terms of soil pH and EC ($p \leq 0.01$). However, the soil organic matter, yield, bulk density, and chlorophyll content of tomatoes showed no significant differences among the treatments. The treatments did not differ significantly in terms of the saturated hydraulic conductivity (K_s) in the first year, whereas the K_s for the drainage water treatment differed significantly ($p \leq 0.05$) in the second year. No significant differences were observed in the parameters of van Genuchten (θ_s, θ_r, and α) among the treatments. Whereas the statistical results showed that there was a significant difference ($p \leq 0.01$) in the parameters of van Genuchten (n) between T0 with T1 and T2 treatments, there was no significant difference between T1 and T2 treatments. It can be concluded that the use of drainage water negatively affected soil pH, salinity, and biological properties; but it did not decrease the plant yield.

Introduction

Iran is among the countries affected by the water shortage problem. One strategy that could moderate water shortage is the re-use of agricultural drainage. In recent years, the conditions of water resources in Iran have urged national policies toward increasing the productivity of water resources (Ghazavi and Orst, 2017). Therefore, optimized use of current water resources, such as drainages, is among the fundamental tasks to be fulfilled by the custodians and consumers. The agricultural drainage water in the Moghan Plain of Iran is one of the largest water drainage systems in the country (Seshadri et al., 2016). The agricultural drainage water can be returned to the agricultural lands for irrigation by proper management, diminishing severe water short-use of drainage water should be evaluated in terms of the long-term and short-term effects on soil properties. The direct use of drainage water on the farmlands is usually conducted without mixing with fresh water (Al-Isawi et al., 2016; Norton-Brandao et al., 2013).

The leading cause of the adverse effect of drainage water is the high concentration of ions, which is referred to as salinity. One way for decreasing water salinity is the mixing of saline water with freshwater or less saline water so that its quality is improved for the irrigation of crops. There are some studies about the feasibility of drainage water re-use in agriculture (Rasoulzadeh and Nasiri, 2013; Beltrán, 1999; Abu-Rizaiza, Sarikaya, 1994; Sharma and Rao, 1998; Suyama et al., 2006; Barnes, 2014; Reinhart et al., 2019; El-Zawily et al. 2019; Liang et al., 2005). Using agricultural water drainage has a different effect on soil and the quality and quantity of crops. In this regard, Rasoulzadeh and Nasiri (2013) investigated the effects of re-using drainage on soil properties in the Moghan Plain. According to their findings, the use of drainage water mixed with a ratio of 50%, and 70% with irrigation water had no significant impact on the soil-water retention curve (SWRC) after one year. Nasiri and Rasoulzadeh (2011) assessed the effects of re-using drainage water on the chemical soil properties. According to their results, sodium concentration had a significant difference in the treatments, and the levels of SAR and ESP were significantly different in the treatments. Abu-Rizaiza, Sarikaya (1994) examined the biological, chemical, and physical quality of drainage water and reported that because of high salinity, this water resource is not appropriate for irrigation. In another study, Beltrán (1999) declared that low-quality water resources (e.g., drainage water, saltwater, and wastewater) could be used for irrigation due to the water shortage in arid and semi-arid areas. Using these water resources requires soil salinity to be controlled by the leaching or draining of the extra saltwater. Cetin and Kirda (2003) assessed temporal and spatial changes in soil salinity in cotton farms under low-quality irrigation water. According to their results, the risk of increased soil salinity was near zero for two years. In this regard, Sharma and Minhas (2005) evaluated the necessary measures for the management of saline/alkaline waters for efficient production in the agriculture section of southern Asia. Salinity, toxicity, sodicity, and water resources not only reduce production but also restrict the selection of crops. Choudhary et al. (2006) investigated the effect of irrigation with sodic and non-sodic water on the properties of soil and the yield of the sunflower plant. Since the sunflower has an average tolerance to salinity, its response to sodic water remains unclear. Their results showed that the continuous use of sodic water increased soil ESP and pH while reducing the relative permeability and yield of sunflowers. Therefore, it was concluded that sodic water could be used for irrigation only if it was mixed with non-sodic water in a specific proportion. In another study, Sharma and Rao (1998) assessed the possibility of the long-term use of drainage saltwater for agricultural irrigation in arid and semi-arid regions where the drainage outlets usually are saline. They used drainage saltwater with salinity levels of 6, 9, 18, 8, and 19 $dS.m^{-1}$ for the irrigation of wheat for seven years. The high salinity and sodicity of the drainage water increase the salinity and sodicity of the soil. They indicated that the use of low-quality drainage water for the irrigation of winter wheat showed no significant decline in plant yield and soil degradation. Reinhart et al. (2019) declared that quantifying nutrient load reductions and irrigation potential showed that drainage water recycling is a promising practice for the tile-drained landscape of the U.S. Midwest. Karimi et al. (2019) declared that the application of treated urban wastewater had a significant effect on the increase of tomato yields because these water resources contain nutrient elements (nitrogen, phosphorus, and other macro-and micro-nutrients). Aghajani Shahrivar et al.

(2020) assessed the effect of irrigation using recycled waters on soil pH and EC under Kikuyu grass production, and the result showed that compared to the initial EC of the soil, an increase recorded for EC of top soils irrigated with treated wastewaters. They indicated that Soil pH increased by about 1 unit under irrigation with treated wastewater. In another study, Smaoui et al. (2020) assessed the effects of raw and treated landfill leachate on the chemical properties of Tunisian soil. The result showed that the electrical conductivity of the soil increased significantly, but pH decreased due to the oxidation of organic compounds. Compared to irrigation water, the use of wastewater increases the electrical conductivity (EC) of the soil due to the containing of more ions (Tsigoida and Argyrokastritis, 2020). Although the long-term effects of saltwater use on the chemical and physical soil properties were investigated, limited research was conducted on soil biological properties in the Moghan Plain. This study aimed to assess the effects of using drainage water on the chemical, biological, and physical properties of soil and the yield of tomatoes in Moghan Plain, Iran. The present study could yield valuable data regarding the potential of using drainage outlet saltwater in irrigation, as well as its impact on the chemical and biological soil properties. In case the drainage outlet is usable, a vast area of the agricultural lands could be irrigated with these water resources, which prevents substantial loss of freshwater.

Materials and Methods

To evaluate the possibility of using agricultural drainage water in agriculture, incorporating normal water and saltwater was used. This study was carried out for two years (2015-2016) on a farm at Moghan Faculty of Agriculture, University of Mohaghegh Ardabili (UMA) in Pars Abad town which is in the north of Ardabil Province (Iran), in 39º 20´ to 39º 42´ east longitude and 47º 30´ to 48º 10´ north latitude (Figure 1). The mean rainfall in the studied area is 275 mm per year, with a maximum rainfall of 386 and a minimum of 111 mm per year. Maximum rainfall per month and day in the Moghan Plain was reported to be 124 and 94 mm, respectively. Also, the minimum and maximum temperature in the area was -15 and 41 Celsius, respectively. The average altitude of the area is 45 meters above sea level, with a humid and warm climate. The irrigation and drainage network of Moghan Plain was constructed to irrigate 70,000 hectares of agricultural lands. Its main canal is un-lining, with a capacity of 80 cubic meters per second. Its drainage network is subsurface drainage and discharges an average of about 220 million m^3 of drainage from the network annually.

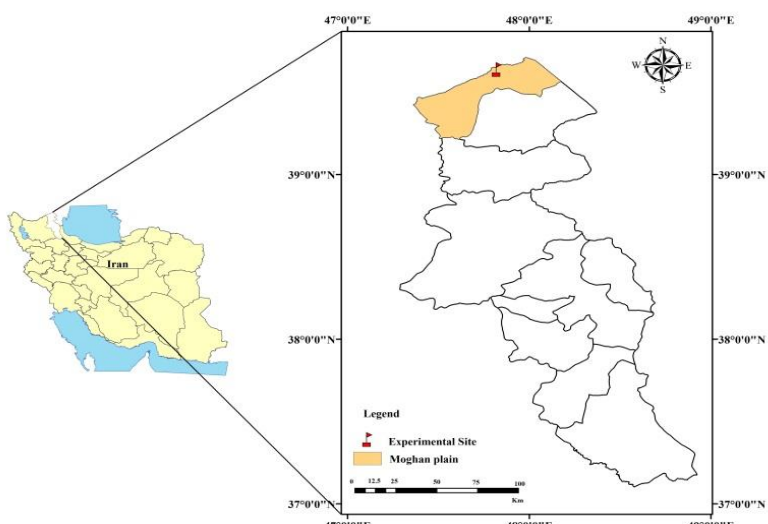

Fig. 1- Map of ran showing the location of the experimental site

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Table 1- Results of Chemical Analysis for Irrigation Water, Drainage Water, and Soil

Sources	Date	Concentration (meq/lit)							dS/m	-	-	-
		Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	$HCO3^{-}$	Cl^{-}	$SO4^{-}_{2}$	EC	pH	SAR	ESP
Water drainage	Oct 2015	4.95	3.15	20.50	0.24	4.00	7.60	17.24	2.89	7.69	10.2	12.11
	Jan 2016	2.75	3.30	16.18	0.27	4.20	6.30	11.99	2.26	7.65	9.3	11.08
	Apr 2016	2.45	1.95	12.40	0.25	3.90	4.70	8.45	1.71	7.62	8.36	9.97
Water irrigation	Oct 2015	1.35	1.65	5.10	0.24	3.80	2.80	1.75	0.84	7.79	4.16	4.65
	Jan 2016	1.5	1.65	4.02	0.24	3.80	2.90	1.72	0.75	7.75	3.20	3.34
	Apr 2016	1.6	1.65	4.83	0.24	3.80	3.00	1.43	0.84	7.72	3.79	4.15
Soil	-	3.6	1.53	14.38	4.50	3.86	-	-	1.77	7.77	5.71	6.68

Table 2- Average Monthly Temperature and Rainfall in the Study Area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Precipitation (mm)	15.7	23.4	30.8	31.8	31.1	14.8	7.1	12.4	26.7	33.5	25.4	18.4
Temperature ºC	4.1	5.8	9.9	15.7	20.9	25.3	27.1	25.2	20.1	13.8	8.1	4.6

Some quality characteristics of irrigation water, drainage water, and soil of the region, along with average monthly temperature and rainfall in the study area are shown in Tables (1) and (2), respectively. Treatments in this study were T0 (irrigation with water from the canal of Mil- o- Moghan dam), T1 (irrigation with 50% agricultural drainage water+50% water from the irrigation canal), and T2 (irrigation with agricultural drainage water only) at four replications in a completely random design. The 12 plots (3m×16m) were prepared to perform the treatments. For tomato irrigation, a furrow system was used. Three furrows were made inside each plot, and the width of each furrow was 0.75m.

A sampling of soil and plant were made from the middle furrow. Irrigation was performed based on the irrigation frequencies of the region every ten days. In the planting stage, the salinity was not applied until the plants were well established in the ground to increase the seedling resistance against salinity. Therefore, the plots were irrigated with irrigation water only in this stage. To apply treatments, the drainage water was first pumped into a tanker. Afterward, in an appropriate proportion, the irrigation water was added to the drainage water. In addition, 3 composite soil samples from different treatments were prepared, and some soil tests including the soil pH, electrical conductivity (EC) of the soil solution Gupta, (2009), soil texture Dane and Topp, (2002), organic matter Jones, (2001), basal respiration, and substrate-induced respiration Schinner, (2012) were carried out. Soil particle-size distribution was determined using a hydrometric method by four readings (Dane and Topp, 2002). Then, the soil texture was determined using the soil texture triangle. Moreover, basal and substrate-induced respiration was measured using the CO_2 emission method (Schinner, 2012; Anderson and Domsch, 1993). The EC and pH of the soil solution (water to soil ratio of 2:1) were measured using a pH meter and EC meter Gupta, (2009). Additionally, the absolute osmotic potential (OP), which directly shows the effects of salinity on plant growth (Mojalali, 1987), was obtained using equation (1):

$$OP = EC \times (0.36) \quad (1)$$

The undisturbed samples of soil were taken using 100 cm^3 stainless steel cylinders for measuring the bulk density. Soil samples were oven-dried at 105 ºC, and bulk density was obtained from cylinder volume and oven-dry soil mass. To obtain the Soil Water Retention Curve (SWRC), undisturbed (using 100 cm^3 stainless steel cylinders) and disturbed soil samples were used to measure less than one bar suction (1000 cm-water) and over 1 bar to 15 bar (1000 to 15000 cm-water), respectively. The undisturbed soil samples were saturated from below and after 24 hr.; they were dried down to different suction. For less than 100 and over 100 to 1500 cm-water suction, the hanging column apparatus and ceramic pressure plate extractors were used. The falling head method was used to measure the saturated hydraulic conductivity (Dane and Topp, 2002; Rasoulzadeh and Yaghoobi, 2014). The SWRC was fitted to the van Genuchten (1980) equation using WATREC software Rasoulzadeh, (2010) to obtain the parameters of the Van Genuchten equation.

In this study, to assess the impact of drainage water on soil hydraulic properties (SWRC), Van Genuchten (1980) function was used as follows:

$$\theta(h) = \theta_r + (\theta_s - \theta_r)(1 + |\alpha h|^n)^{-m} \quad (2)$$

Where h is the pressure head (cm-water) and $\theta(h)$ is the soil moisture at the h pressure head, θ_s and θ_r denote saturated and residual soil water content ($cm^3\ cm^{-3}$), respectively. The symbols α, n, and m=1-1/n are the shape parameters. The statistical design of this research was completely randomized blocks and ANOVA was conducted using SPSS 16.0 software, and the mean comparison was performed by Duncan's multiple range tests at the appropriate probability level (1% and 5%).

Results

The results showed that the percentage of soil particles (sand, silt, and clay) and soil texture were the same in all the treatments. The sand, silt, and clay made up were 24.6%, 32.4%, and 43% of the soil, respectively, and the soil texture was obtained from clay. Since the quality of the water in irrigation water and drainage outlets might differ at various irrigation times, the sampling from the drainage and irrigation water was carried out per each irrigation event, and each sample was analyzed in the laboratory for water quality (pH and EC) (Table 3). According to the results, the pH of drainage water and irrigation water was less than 7 in most irrigation events. The maximum and minimum EC of the drainage water was 2.531 and 0.98 $dS.m^{-1}$, respectively, which belonged to the ninth and fifth irrigations (during the first year of the study).

It is also noteworthy that the leading cause of low EC in the drainage water of the fifth irrigation was possible because of the rainfall and mixing of the surface runoff with the drainage water. In the classification of water resources, the EC of most drainage waters was within the range of 2-10 $dS.m^{-1}$, which is considered to be a medium salinity (Hasheminia et al. 1997). As observed in the results of the drainage water analysis in the Moghan Plain, the EC of these water resources also falls within the same range, classifying them as water resources with a medium salinity. These water resources are found abundantly in Moghan Plain and have a high potential for agricultural uses. This management practice is done during the shortage of water in Moghan (drainage water is returned to the main canal). According to Table 3, the quality of the irrigation water had a slight difference during the two years, with a similar trend. Evaluation of EC and pH in different months showed no changes. Therefore, it could be concluded that irrigation water had the same quality during the year in terms of these parameters. Due to salt leaching from the topsoil, drainage water has a higher ionic concentration and EC, compared to irrigation waters. In the present study, only a slight difference was observed in terms of pH in irrigation and drainage water.

Effects of Various Treatments on the Chemical Properties of the Soil

After applying the treatments, a chemical analysis of the soil was conducted in the laboratory. Results of ANOVA and the mean

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comparison using Duncan's multiple range tests are presented in Tables (4) and (5), respectively. According to the results, the replications had no significant differences. Therefore, it could be concluded that the soil properties of all four replications in each treatment were the same in both years of the study. Furthermore, the results of variance analysis indicated that at the probability level of 1%, the treatments had a significant effect on the EC and OP of the soil in both years of the study. In treatment T2, pH showed a significant difference compared to the T1 and T0 treatments in the first year of the research (2015). However, soil pH showed no significant differences in various treatments during the second year of the research (2016) (Table 4).

Table 3- Results of Chemical Analysis for pH and EC (dS/m^{-1}) of T0 (Irrigation water only), T1 (50% drainage water +50% irrigation water), and T2 (drainage water only) Treatments in Each Irrigation Event in the First (2015) and the Second Year (2016).

Irrigation event	pH			EC		
	T0	T1	T2	T0	T1	T2
			Year-2015			
1	6.83	6.58	6.72	0.80	1.62	2.19
2	6.52	6.70	7.03	0.84	1.95	2.45
3	6.84	6.75	6.84	1.30	1.47	2.25
4	6.54	6.60	7.20	0.84	1.83	2.36
5	6.60	6.53	6.60	0.74	0.90	0.98
6	6.71	6.78	6.58	0.84	1.50	2.25
7	6.45	6.66	6.85	0.84	1.29	1.77
8	7.02	6.67	7.03	0.83	1.64	2.48
9	6.82	6.71	6.87	0.83	1.71	2.53
10	6.70	6.66	6.85	0.87	1.66	2.14
			Year-2016			
1	6.80	6.66	6.58	0.70	1.58	2.35
2	6.82	6.69	7.10	0.85	1.85	1.87
3	6.84	6.59	6.84	0.97	1.92	2.45
4	6.52	6.70	7.23	0.88	2.24	2.36
5	6.59	6.78	6.51	0.75	1.65	1.98
6	6.70	6.53	6.58	0.78	1.32	2.01
7	6.56	6.66	6.72	0.87	0.90	1.95
8	6.71	6.69	7.12	0.89	1.49	1.68
9	6.62	6.71	6.70	0.88	1.89	1.97

Table 4- Variance Analysis of Treatment Effects on pH, EC, organic matter (OM), and Osmotic Pressure (OP) of Soil in the First (2015) and the Second year (2016)

Source of variation	df	Mean squares (Year-2015)			
		pH	EC	OM	OP
Replication	3	0.004^{ns}	0.039^{ns}	0.096^{ns}	0.005^{ns}
Treatment	2	0.049**	0.322**	0.091^{ns}	0.042**
Error	6	0.003	0.009	0.068	0.001
		Mean squares (Year-2016)			
Replication	3	0.000^{ns}	0.045^{ns}	0.017^{ns}	0.006^{ns}
Treatment	2	0.004^{ns}	0.874**	0.027^{ns}	0.113**
Error	6	0.014	0.007	0.008	0.001

ns and ** show the non-significant and significant at $P\leq0.01$, respectively.

Table 5-Means Comparison of the Effects of Using Drainage Water on pH, EC Organic Matter, and OP of Soil Solution in the First (2015) and the Second Year (2016)

Treatment	pH	EC ($ds.m^{-1}$)	OM (%)	OP (bar)
(Year-2015)				
T0	7.81^{a} (±0.033)	1.28^{a} (±0.053)	1.55^{a} (±0.130)	0.46^{a} (±0.019)
T1	7.83^{a} (±0.023)	1.43^{a} (±0.059)	1.67^{a} (±0.113)	0.52^{a} (±0.021)
T2	7.63^{b} (±0.032)	1.83^{b} (±0.089)	1.85^{a} (±0.169)	0.66^{b} (±0.032)
(Year-2016)				
T0	7.71^{a} (±0.058)	0.62^{a} (±0.040)	2.05^{a} (±0.040)	0.22^{a} (±0.014)
T1	7.76^{a} (±0.035)	1.24^{b} (±0.074)	2.14^{ab} (±0.046)	0.45^{b} (±0.021)
T2	7.70^{a} (±0.046)	1.54^{c} (±0.086)	2.23^{b} (±0.066)	0.55^{c} (±0.042)

Different letters in the same column denote significant differences ($P \leq 0.01$).

The results showed that the amount of indicators pH and OP of irrigation water had minor changes during the research period, but indicators EC and OM had more changes (Table 5). Change pH is proportional to the change in the type of ions in the water, which are not changed due to the constant of the river route, except by an external source or factor. But the changes of EC depend on the change of the sum of anions and cations in the water, in which the addition of impurities and evaporation increases. Measurement of EC in the current study showed with the higher concentration of drainage in the water resources of all the irrigation treatments, EC of the saturated soil mud significantly increases ($p \leq 0.01$). It could be attributed to the increased concentrations of calcium, magnesium, sodium, chlorine, and sulfate ions in the T2 treatment compared to the other treatments. According to the findings, the T2 treatment caused a significant increase in the EC and OP of the soil solution compared to the T1 and T0 treatments ($p \leq 0.01$) in both years (Table 5). On the other hand, the average value of EC and OP of the soil solution had no significant difference in the T0 and T1 treatments during the first year of the research (2015). While the difference was considered significant between these treatments in the second year (2016), therefore it could be concluded that the diluted drainage water did not increase the EC and OP of the soil solution in the first year of the study. It could increase these parameters compared to the T0 treatment after two years. It could be attributed to the quality of the irrigation water. Irrigation was performed with a higher proportion of the drainage water in the T1 and T2 treatment, which causes the cations and anions to enter the soil. Consequently, it leads to a significant increase in the EC of these treatments compared to the T0 treatment.

Effects of Various Treatments on the Biological Properties of the Soil

After the irrigation with T0 and T2 at the end of each year, some biological indices (basal and substrate-induced respiration, and the microbial population) were measured in the soil, and statistical results were presented in Tables (6) and (7). The results showed that there was a significant difference ($p \leq 0.05$) in the basal respiration between T2 with T0 treatments while there was no significant difference between T0 and T1 treatments as well as T1 and T2 at the end of the first year. Also, a significant difference ($p \leq 0.05$) was observed between all treatments in basal respiration at the end of the second year (Table 7).

Table 6-Variance Analysis of Treatment Effects on Basal Respiration, Substrate-Induced Respiration, and Microbial Population of Soil in the First (2015) and the Second Year (2016)

Source of variation	df	Mean squares (Year-2015)		
		Basal respiration	Substrate-induced respiration	Bacterial population
Replication	3	0.001^{ns}	0.000^{ns}	$5.3E+12^{ns}$
Treatment	2	0.002^{*}	0.000^{*}	$5.6E+12^{**}$
Error	6	0.000	9.9E-05	3.5E+12
		Mean squares (Year-2016)		
Replication	3	0.000^{ns}	0.000^{ns}	$5.3E+11^{ns}$
Treatment	2	0.005^{**}	0.001^{*}	$9.3E+12^{**}$
Error	6	0.000	0.000	10.1E+13

ns,*and ** show the non-significant, significance at $P\leq0.05$and $P\leq0.01$, respectively.

Table 7-Mean Comparison of Different Treatments in Terms of Basal Respiration, Substrate-Induced Respiration, and Microbial Population of Soil in the First (2015) and the Second Year (2016)

Treatment	(Year-2015)		
	Basal respiration (mg CO_2 g^{-1})	Substrate-induced respiration (mg CO_2 g^{-1})	Bacterial population (Number. g^{-1} dry Soil)
T0	0.2439^{a*} (±0.0293)	0.0965^{a*} (±0.0111)	$5.4E+06^{a**}$ (±5.2E+05)
T1	0.2137^{ab*} (±0.0149)	0.0935^{a*} (±0.0040)	$4.8E+6^{a**}$ (±1.3E+05)
T2	0.1987^{b*} (±0.0128)	0.0761^{b*} (±0.0030)	$3.1E+6^{b**}$ (±1.0E+05)
	(Year-2016)		
T0	0.2475^{a*} (±0.0031)	0.0790^{a*} (±0.0076)	$5.3E+06^{a**}$ (±1.5E+05)
T1	0.2122^{b*} (±0.0240)	0.0599^{b*} (±0.0029)	$3.9E+06^{b**}$ (±1.6E+05)
T2	0.1782^{c*} (±0.0110)	0.0528^{b*} (±0.0058)	$2.2E+06^{c**}$ (±8.9E+05)

Different letters in the same column along with asterisks denote significant differences at $P \leq 0.05$(*) and $P \leq 0.01$ (**).

Effects of Irrigation with Different Treatment Water Resources on soil physical properties

Variations of soil bulk density (BD) and saturated hydraulic conductivity (K_s) were shown in Figure 2. The treatments did not differ significantly in terms of the BD in 2015 and 2016 as well as the K_s in 2015, whereas the K_s for the T2 treatment differed significantly ($p\leq0.05$) in 2016 (Figure 2).

It is noticeable that with increasing the EC of irrigation water, the amount of Na ions increases. A higher concentration of Na can disperse soil aggregate and consequently decrease K_s. This result is in line with the results of Bagarello et al. (2006) who found that with increasing SAR in irrigation water, K_s decreases significantly in clay and sandy loam soils.

Effects of Irrigation with Different Treatment Water Resources on Plant Growth Properties

Tomato growth parameters, including the yield and chlorophyll content, after the first and the second year of irrigation with T0, T1, and T2 treatments were recorded, and the results are shown in Tables (8) and (9). According to the results of variance analysis Table (8), there were no significant differences among the treatments in terms of yield and chlorophyll content.

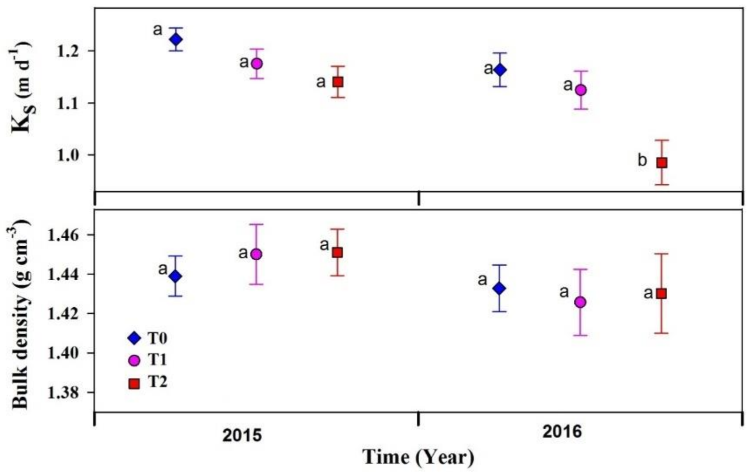

Fig. 2- Variation of bulk density and saturated hydraulic conductivity (K_s) (mean and ±SE values) for two years (the same letter indicates no significant difference (p≤0.05) (T0 (Irrigation water only), T1 (50% drainage water +50% irrigation water) and T2 (drainage water only) treatments)

Table 8- Variance Analysis of Treatment Effects on Tomato Yield and Chlorophyll in the First (2015) and the Second Year (2016)

Source of variation	df	Mean squares(Year-2015) Yield	Chlorophyll
Replication	3	1.551^{ns}	16.819^{ns}
Treatment	2	0.288^{ns}	0.528^{ns}
Error	6	0.784	7.461
		Mean squares (Year-2016)	
Replication	3	9.700^{ns}	1.551^{ns}
Treatment	2	0.048^{ns}	0.288^{ns}
Error	6	1.745	0.784

ns shows the non-significant.

Table 9- Mean Comparison of Different Treatments in Terms of Tomato Yield and Chlorophyll in the First (2015) and the Second Year (2016)

Treatment	(Year-2015) Yield (ton ha^{-1})	Chlorophyll
T0	13.61^{a} (±0.43)	49.97^{a} (±1.69)
T1	13.86^{a} (±0.73)	50.53^{a} (±0.64)
T2	14.14^{a} (±0.26)	50.65^{a} (±0.55)
	(Year-2016)	
T0	16.91^{a} (±0.75)	50.74^{a} (±1.57)
T1	17.10^{a} (±0.82)	50.86^{a} (±0.71)
T2	17.44^{a} (±0.47)	50.95^{a} (±0.57)

Different letters in the same column along with asterisks denote a significant difference at P ≤ 0.05.

Discussion

Although the acidity of irrigation water affects the pH of the soil, after changing the effect of acidity of irrigation water, the soil pH returns to its stable state immediately (Tsigoida and Argyrokastritis, 2020; Smaoui et al., 2020), so according to the acidity of irrigation water (T0) and drainage water (T2) used in this study Table (1), which differs slightly from soil pH, no change in soil pH was expected. Soil pH reaction is a prominent measurement method for the chemical properties of the soil (Mclean 1983). Soil pH not only determines the acidic or alkaline condition of the soil, but it also determines the availability of essential nutrients and toxicity of the other elements to plants (Thomas,1996). Soil pH declines typically by increasing the soil-to-water ratio or the presence of salts. Soil pH was measured in the saturated soil mud in the irrigation treatments with various proportions of saline drainage water. There was a significant difference ($p \le 0.01$) among the treatments in terms of soil pH, with the mean value estimated at 7.6, which is a healthy pH for most plants. Although there were minor changes in soil pH. The decrease in soil pH as an effect of the drainage water addition could be due to the higher concentration of soluble cations, which slightly releases exchangeable acidity (H+) (Neishabouri and Reyhani Tabar, 2010). Also, the increase in EC is due to the high mineral loads (Smaoui et al., 2020; Aghajani Shahrivar, 2020). Singh et al. (2017) stated due to the high levels of dissolved salts, and according to Tsigoida and Argyrokastritis (2020), using wastewater for irrigation increases soil EC. The boundary line between saline and non-saline soils is considered to be at the EC of 4 dS.m-1 for the saturated soil extract (Mojalali, 1987). Nevertheless, the risk of salinity is low in the treatments, which is expected only to affect highly sensitive plants. In this regard, many researchers have reported similar results. For instance, Choudhary et al. (2006) investigated the effects of alternative irrigation with sodic and non-sodic water on the properties of soil and yield of the sunflower plant and obtained similar results. Accordingly, constant use of sodic water increased soil EC, while decreasing the relative permeability and yield of the sunflower. Also, Suyama et al. (2006) evaluated the yield of the forage irrigated by sodic-saline drainage in the greenhouse, concluding that irrigation with sodic-saline water would significantly increase soil EC. In sum, current research showed that the application of T2 treatment significantly decreased soil pH compared to the T0 and T1 treatments in the first year. However, no significant difference was observed between the T0 and T1 treatments. Moreover, soil organic matter (OM) showed no significant difference among the treatments in the first year, while the OM in the T2 treatment was significantly ($p \le 0.01$) more than the one in T0 treatment in the second year (Table 4). A certain amount of OM likely enters the T2 treatment during the leaching process. As a result, the T2 treatment obtains some organic materials, which will enhance the organic content of the soil irrigated with the T2 in the long term. According to the results, irrigation with the T2 decreased OP in the soil, such that the absolute OP showed a significant increase in the T2 treatment compared to the other two treatments. It could be attributed to the higher concentrations of ions in the soil and the increased EC after irrigation with the T2. This increase might influence plants by affecting the water-soil potential (Mojalali, 1987). According to the results, the mean comparison of soil substrate-induced respiration indicated no significant difference between the T0 and T1 treatments at the end of the first year. However, a significant difference was observed between these two treatments and the T2. The same trend was observed in terms of the bacterial population at the end of the first year. The results showed a significant difference ($p \le 0.01$) between all treatments in the bacterial population at the end of the second year. There was a significant difference ($p \le 0.05$) in the soil substrate-induced respiration between T0 with T1 and T2 treatments while there was no significant difference between T1 and T2 treatments at the end of the second year (Table 7). The variation of Van Genuchten function parameters is illustrated in Figure (3).

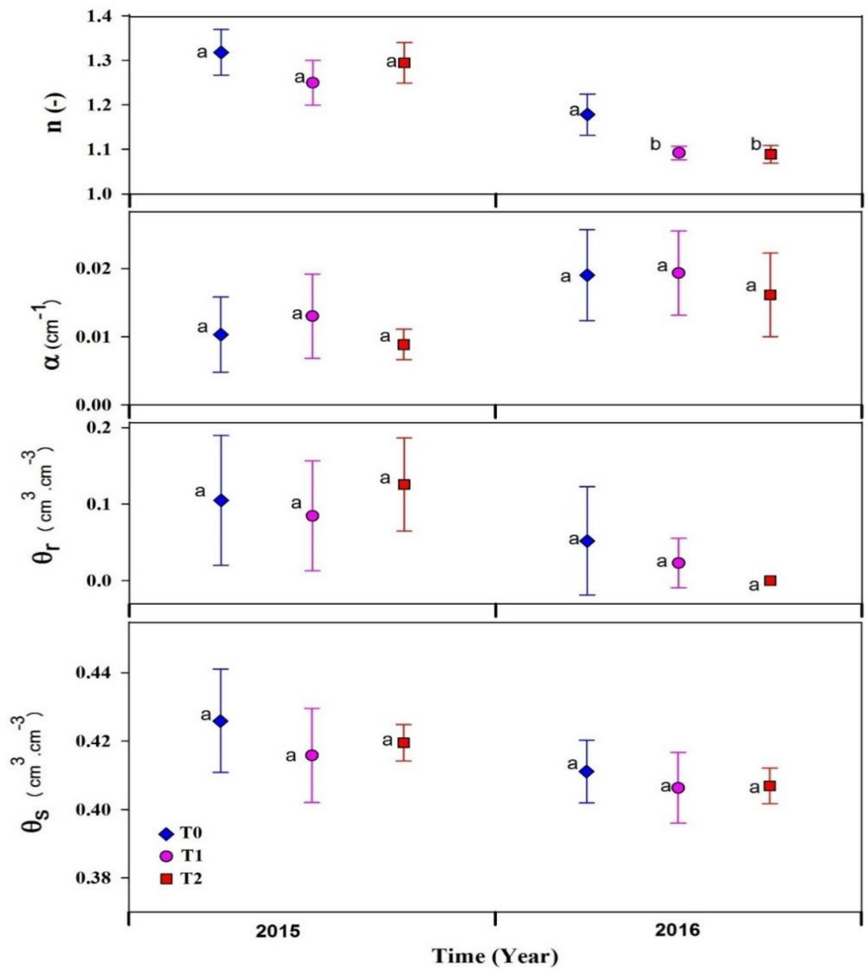

Fig. 3- Variation of van Genuchten's retention function parameters (mean and ±SE values) for two years (the same letter indicates no significant difference ($p \le 0.01$) (T0 (Irrigation water only), T1 (50% drainage water +50% irrigation water) and T2 (drainage water only) treatments)

No significant differences were observed in the parameters of van Genuchten (θs, θr, and α) in all the treatments. This finding can be because of the low salinity of the drainage water and the existence of the drainage system in the study area. Kiremit and Arslan (2016) reported that if appropriate leaching and drainage systems are applied, slightly saline water can be used for irrigation with little or no soil damage. There was a significant difference ($p \le 0.01$) in the n (the parameters of van Genuchten which is indicated the slope of the SWRC) between T0 with T1 and T2 treatments. While there was no significant difference between T1 and T2 treatments in the n. Furthermore, a comparison of the means of the yield and chlorophyll content in different treatments showed no significant differences in this regard (Table 9). Gatta et al. (2015) reported that irrigation with wastewater does not affect yield. But some studies have had different results (Karimi et al., 2019; Fereidoni et al., 2013) because irrigation with wastewater is effective if it contains so enough nutrients such as nitrate and phosphate. Irrigation with T2 compared to T0 treatment led to a 4% and 3% increase in the yield of tomatoes in the first and second years of the study, respectively. However, the increase was not considered statistically significant. Generally, the T2 treatment is high in nutrients because of fertilizer leaching from the soil column. Thus, the slight increase in tomato yield in irrigation with the T2 might be due to the possible nutrients in the T2 treatment, which enhanced the yield of the crops.

Conclusion

It is essential to use unconventional water resources, such as drainage water in the agricultural sector because of population growth and a freshwater shortage problem in the semi-arid regions. This study focuses on the effect of the re-using of drainage water in agriculture on soil chemical, biological and physical properties and the yield of tomatoes. The results showed that re-use of drainage water decreases pH and increases EC, OP, and OM of the soil solution. It is noticeable that the increase of OM in the effect of irrigation with drainage water probably is because of the leaching process. It is expected that due to the salinity of drainage water, irrigation with this water causes a decrease in the yield of tomatoes whereas it causes an increase in the yield. It can be justified by increasing OM. Results suggested that the use of drainage water decreased soil microbial population, basal respiration, and substrate-induced respiration. The application of the drainage water for two years significantly affected the soil's biological properties in all the treatments. In other words, in comparison with irrigation water, long-term use of drainage water has more clear adverse

effects on the biological properties of soil. The basal and substrate-induced respiration are expected to reduce because of the use of the drainage water so that the soil respiration would decrease because of the reduction in soil microbial population. Re-use of the drainage water increased soil salinity and OP, which adversely affected the microbial population, microbial activities, and soil respiration. Soil respiration and substrate-substrate-induced respiration are the sensitive indices for the determination of the effects of non-biological stress, such as salinity, on the microbial activities in the soil. Based on the results, re-use of the drainage water causes a decrease in saturated hydraulic conductivity and water content as well as an increase in bulk density. The reason for the lack of significant effect of the drainage water on the physical parameters is the presence of organic matter and the medium salinity of the drainage water. It can be concluded that re-use of the drainage water has no significant effect on the mentioned soil physical parameters. The effect of re-use of drainage water on the shape parameters of van Genuchten function (α, *n*) showed that only the *n* parameter was significantly ($p \leq 0.01$) affected by the re-use of drainage water in the second year of the experiment. It can be concluded that the organic matter in the drainage water is affecting α greater than *n*.

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Original Paper

A study on the effects of sugarcane bagasse hydrochar as an environmentally friendly fertilizer on bean plant and sandy loam soil characteristics

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Abstract

The present study investigated the effects of engineered sugarcane bagasse hydrochar on the soil properties of sandy loam and the growth parameters of bean plants. After preparing the optimal hydrochar, its physicochemical properties were determined through various analyses. The effects of different rates of hydrochar (0%, 1%, 2%, and 5% w/w) were then investigated on the bulk density, porosity, pH, organic carbon, nitrogen, and phosphorus content of the soil, as well as on plant height, lateral branch number, leaf number, and dry weight of aerial parts and roots. The results show that the addition of engineered sugarcane bagasse hydrochar at all levels improved the soil properties of sandy loam. However, an inverse effect was observed for the electrical conductivity (EC) parameter. The 5% hydrochar treatment resulted in a significant increase of 78.4% in organic carbon, while a minimal decrease of 0.4% was observed in pH. Regarding the growth parameters of bean plants, only the 1% engineered hydrochar treatment showed a positive effect on growth parameters.

Introduction

The increase in global population has led to an increase in agricultural production, which has had detrimental effects on water, air, and soil quality (De Jager et al., 2020). In recent years, the gradual decline in organic matter and the subsequent deterioration of soil quality have become significant global challenges (Parlavecchia et al., 2020). While ensuring food production safety, it is essential to maintain a healthy environment for plant growth. Declining soil fertility has compelled farmers to rely more on mineral fertilizers such as nitrogen and phosphorus to achieve higher yields (Chen et al., 2021). However, this practice results in the excessive accumulation of phosphorus and nitrogen in water sources, leading to water pollution. Water pollution disrupts the balance of aquatic ecosystems and imposes substantial costs for pollutant removal from water sources (Azimzadeh et al., 2021).

In addition, the mineral resources of fertilizers of nitrogen and phosphorus are limited and non-renewable. Therefore, finding sustainable solutions to address these challenges is crucial. One potential solution is the utilization of environmentally friendly materials that can effectively remove phosphorus and nitrate from aqueous solutions. These materials can then be further explored as slow-release fertilizers

(Azimzadeh et al., 2021). Indeed, the increase in greenhouse gas emissions resulting from agricultural activities has significant implications for climate change. It is imperative to adopt sustainable agricultural practices that not only ensure stable agricultural systems but also minimize the environmental impact and reduce production costs. In recent years, the production of biochar from agricultural residues has significantly contributed to their recycling. As a result, global concerns regarding the increase in greenhouse gases from the composting of agricultural residues have been partially addressed.

Biochar is a porous, cost-effective, and carbon-rich material that possesses various beneficial properties. It has the capacity to effectively remove contaminants from water, enhance soil fertility by increasing carbon reserves, stabilize soil nutrients, promote aggregate formation and stability, improve soil porosity, and enhance plant growth. However, challenges associated with the utilization of dry agricultural residues and the generation of hazardous gases, such as carbon monoxide (CO), and methane (CH_4) in during biochar production have prompted researchers to explore alternative approaches (Fang et al., 2015). One of the alternative methods is the production of hydrochar. Hydrochar is a specific type of biochar that is generated through the hydrothermal carbonization process. This process involves subjecting the biomass to high temperature and pressure conditions within a stainless steel autoclave, typically in the range of 180 to 260 °C (Liu et al., 2018). The hydrothermal process and the resulting hydrochar are known for their environmentally friendly mechanisms. However, the outcomes of hydrochar application on soil and plant systems are influenced by various factors, including the characteristics of the raw materials used, the temperature and duration of the hydrothermal process, the texture of the soil, the quantity of hydrochar applied, and the specific plant species involved. These factors collectively determine the effectiveness and impact of hydrochar application. It is crucial to consider and optimize these variables to achieve desired outcomes when using hydrochar in soil and plant management practices (Bento et al., 2019; Islam et al., 2021). Studies on the effect of hydrochar on soil and plants showed that the presence of oxygen-containing functional groups and the porous structure of hydrochar can be a factor in the success of nutrient stabilization (Xia et al., 2020; Yu et al., 2020). The researchers also expressed that hydrochar prevents soil degradation, increases soil porosity, enhances soil water holding capacity, and improves the stability of soil aggregates (Abel et al., 2013; De Jager et al., 2020; Islam et al., 2021). Schimmelpfennig et al. (2014) stated that plant growth decreased with the application of hydrochar, particularly in the first year of the experiment. Fang et al. (2015) stated that seed germination significantly increased with the addition of hydrochar. Puccini et al. (2018) observed the germination of lettuce decreased after using hydrochar. Baronti et al. (2017) observed a significant increase in biomass production of poplar trees after 2 years.

Hydrochar's behavior in the soil and its effect on different plant systems is still unclear due to the above. To avoid negative effects on soil and plants, their use should be carefully tested before large-scale use (George et al., 2012). The aim of this study was to examine the utilization of engineered hydrochar derived from sugarcane bagasse, following the adsorption of nitrate and phosphate, as an organic fertilizer for soil and its impact on bean characteristics. Sugarcane bagasse, which is a by-product of the sugar industry obtained after extracting water from sugarcane, is typically disposed of by burning, resulting in environmental pollution. However, due to the presence of cellulose, hemicellulose, and lignin in sugarcane bagasse, it possesses a porous surface, high mechanical strength, and the potential to serve as a biosorbent. By utilizing engineered hydrochar derived from sugarcane bagasse and enhancing its adsorption capacity for nitrate and phosphate, it can be repurposed as an organic fertilizer, thereby reducing waste and environmental pollution while providing beneficial effects for soil and bean growth (Feng et al., 2020). Therefore, the use of sugarcane bagasse is not only environmentally valuable but also is a suitable option for producing valuable and new products on a large scale.

Material and methods

Synthesis of sugarcane bagasse hydrochar

The present research was conducted at the Faculty of Water and Environmental Engineering, Shahid Chamran University of Ahvaz (2020-2021). To prepare the hydrochar, sugarcane bagasse obtained from the Amir Kabir agriculture and industry was used. It was then washed multiple times with distilled water to remove dust and impurities and dried at a temperature of 80 °C. 10 g of sugarcane bagasse, were mixed with 60 ml of deionized water and added to a stainless steel autoclave with a capacity of 100 ml. The autoclave was then placed at a temperature of at 220 ° C for 4 h. After the specified time, the autoclave was cooled to room temperature, and its contents were washed with deionized water to stabilize their pH. Subsequently, they were dried at a temperature of 50 °C for 24 hours, and the resulting solid products were introduced as sugarcane bagasse hydrochar (HCSB). To achieve particle homogeneity of the obtained sugarcane bagasse hydrochar, the product was passed through sieve number 10.

To increase the efficiency, the prepared hydrochars were placed on a stirrer at room temperature with a 1:1 weight ratio of magnesium chloride solution. After 24 hours, the solid phase was separated from the liquid and washed with deionized water to remove residual chemicals. The activated hydrochars were dried at a temperature of 100 °C for 24 hours. Finally, the obtained product was introduced as engineered sugarcane bagasse hydrochar.

Characterization of engineered hydrochar of sugarcane bagasse

The surface structure of engineered sugarcane bagasse hydrochar was examined using a scanning electron microscopy (SEM, Leo 1455 VP model, made in Germany). Fourier transform infrared spectroscopy (FTIR, Spectrum GX, and Perkin- Elmer) was used to identify different functional groups in engineered sugarcane bagasse hydrochar. The percentage carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) was determined using the elemental analyzer (CHNOS, Vario ELIII, Elementary, made in Germany). The X-ray fluorescence (XRF) was used to determine the percentage and type of metal oxides of the prepared engineered sugarcane bagasse hydrochar. The pH of the point of zero charge ($pH_{(pzc)}$) of engineered sugarcane bagasse hydrochar was determined with sodium chloride solution method (Hafshejani et al., 2016).

Soil

The soil samples used in this study were collected from a depth of 0-30 cm in the research field of the Faculty of Agriculture at Shahid Chamran University of Ahvaz, Iran. The soil samples were air dried until reaching a constant weight. After drying, the soils were crushed and passed through a 2 mm sieve to ensure uniformity. The soil properties such as bulk density by cylinder method, soil texture by hydrometer method were analyzed (Gee & Or, 2002), organic carbon by Walkley and Black method (Nelson & Sommers, 1996), total nitrogen was measured by Kjeldahl method, total phosphorus was measured by Olsen method (Kuo, 1996), cation and anion exchange capacity was measured by sodium nitrate replacement by hydrochloric acid and potassium chloride, and pH and EC in soil saturated extracts were measured. The physical and chemical properties of the soil are presented in Table (1).

Table 1- The physical and chemical properties of soil used in present study

Soil			
Property	Value	Property	Value
pH	7.48	Bulk density (g. cm^{-3})	1.56
EC (ds. m^{-1})	2.93	Porosity (%)	42.5
Soil texture	Sandy loam	Phosphorus (mg. Kg^{-1})	7.23
Nitrogen (%)	0.03	Organic carbon (%)	0.51

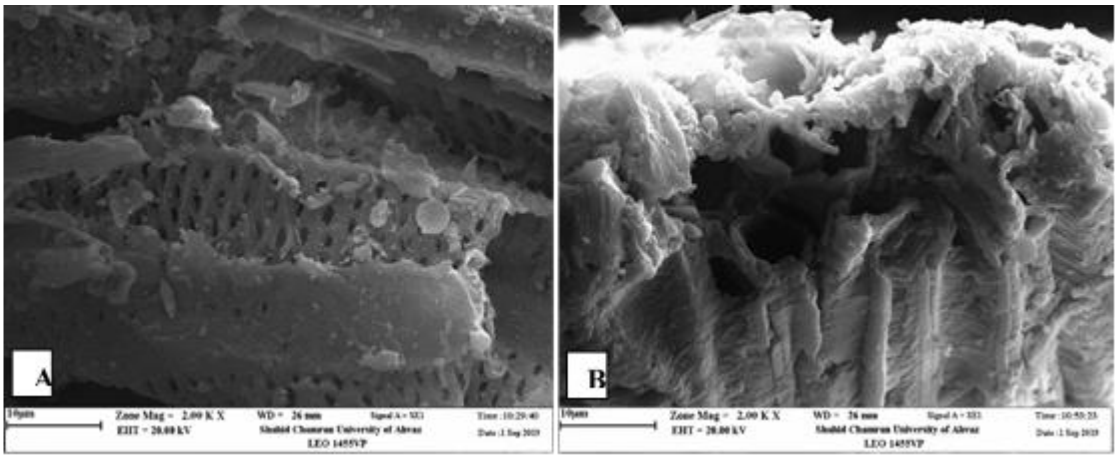

Fig 1- SEM image of sugarcane bagasse hydrochar (A), engineered sugarcane bagasse hydrochar (B)

Preparation of test pots

This study was conducted in a randomized complete block design with three replications and four engineered sugarcane bagasse hydrochar treatments (0% (control), 1%, 2% and 5% w/w). Air-dried soil was passed through a 2 mm sieve. Considering the bulk density of farm soil (1.56 g. cm^{-3}) and the volume of the pots (1020 cm^3), 1591 g of soil was needed to fill each pot. The amount of sugarcane bagasse hydrochar required for each treatment level was calculated. For example, a treatment of 1% (10 grams of hydrochar per kilogram of soil) required 15.91 grams of hydrochar. The soil and hydrochar mixed were transferred to the pots. After adding half of the soil into each pot, 3 bean seeds were placed, and the remaining soil and hydrochar mixed were added to the pot again. Then the pots were placed in water to be saturated from below. It should be noted that bean seeds were sterilized in 3% sodium hypochlorite for 3 minutes before planting and then washed several times with deionized water to remove the effect of sodium hypochlorite. Water with an average EC of 0.91 dS / m and an average pH of about 7.13 was used to irrigate pots during the growth period (35 days).The determination of field capacity moisture time was by placing the probes of the TDR device at a depth of 8 cm from the top of the soil columns. Finally, plants were harvested and plant height, number of leaves, number of lateral branches, fresh weight of roots, and shoots were measured. Then, to measure the dry weight of shoots and roots, these parts were dried in an oven at 70 ° C for 72 hours. After harvesting the plants, as investigating the effect of hydrochar on different soil properties (organic carbon, total nitrogen, absorbable phosphorus, acidity, electrical conductivity, bulk density, true bulk density, and total porosity) were measured for each pot. Then, the study data were analyzed at a significance level of 0.05 using SPSS software version 23. Duncan's multi-range test was used to investigate the effects of applying different levels of hydrochar on soil and plant properties. In addition, a one-way ANOVA was used to determine the difference between treatments. Charts were also drawn with Excel software.

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Results and discussion

Characteristics of soil and engineered sugarcane bagasse hydrochar

The SEM analysis results of the hydrochars are shown in Fig (1 (A-B)). The presence of longitudinal pores on the sugarcane bagasse hydrochar indicates pyrolysis at low temperatures. (Fig (1- A)). By modifying the hydrochar with magnesium chloride (engineered sugarcane bagasse hydrochar), the surface impurities that had blocked the pores were removed, revealing the porous structure of the engineered hydrochar honeycomb (Fig (1-B)). Li et al. (2020) reported that the activation of hydrochar with magnesium ions resulted in an increased degree of carbonization. Furthermore, the surface of the activated hydrochar appeared more spongy and exhibited a higher number of pores compared to its original state (Li et al., 2020). As a result, this hydrochar has a greater capacity for retaining nutrients in the soil. Similar findings to those obtained in the current study have been reported by other researchers (Li et al., 2020; Qiao et al., 2019). The results of the functional groups on hydrochar are shown in Fig (2). According to the Fig. 2, the existence of groups O-H, C-H, C-O and C = C was confirmed within the wave range 3400, 2900, 1050-1180 and 1600cm^{-1}, respectively. The presence of these functional groups on the hydrochar confirms the presence of carbon in the structure of the synthesized hydrochar. These functional groups, characterized by their positive and negative charges, are predicted to have a high potential for retaining nutrients in the soil.

The results of determining the elements in the hydrochar sample before (sugarcane bagasse hydrochar) and after activation (engineered sugarcane bagasse hydrochar) are shown in Table (2).

According to Table (2), magnesium oxide (MgO) in sugarcane bagasse hydrochar was 0.43% while in engineered sugarcane bagasse hydrochar increased to 1.28. This change in sugarcane bagasse hydrochar, due to the positive charge of magnesium, can increase the retention of negatively charged nutrients in the soil. Also, by converting sugarcane bagasse to hydrochar and activated hydrochar, the amount of carbon (C) increased from 44.4% to 49.54 and 47.48%, respectively. On the other hand, the amounts of hydrogen, oxygen, oxygen to carbon ratio and hydrogen to carbon in the hydrochar are lower than raw sugarcane bagasse. This can be due to the processes of dehydration, decarboxylation and dehydrogenation and indicates carbonization in during the hydrothermal process (ZHANG et al., 2014).The point of zero charge ($pH_{(pzc)}$) engineered sugarcane bagasse hydrochar was obtained at 5.59 which indicates that this material in soils with pH lower than 5.59, has a greater ability to retain nutrients with a Negative charge. Also engineered hydrochar of sugarcane bagasse at pH above 5.59, has a greater ability to retain positively charged nutrients.

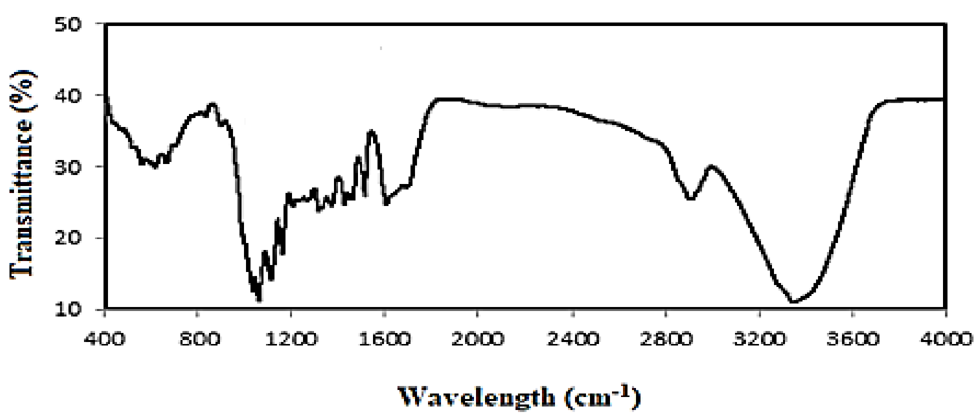

Fig 2- FTIR spectrums of engineered sugarcane bagasse hydrochar

Table 2- The elements and metal oxides of sugarcane bagasse, hydrochar sugarcane bagasse and engineered hydrochar sugarcane bagass

Product	Sugarcane bagasse	Sugarcane bagasse hydrochar	Engineered sugarcane bagasse hydrochar
C/H	1.61	1.39	1.45
C/O	0.75	0.59	0.6
S	0.24	0.47	0.19
O	44.44	38.88	39.05
H	5.98	5.78	5.99
C	44.4	49.54	49.25
N	0.95	1.13	0.92
MgO	0.42	0.43	1.28

The effect of engineered sugarcane bagasse hydrochar on physical and chemical properties of sandy loam soil

At the end of the growth season, the results of applying various levels of sugarcane bagasse hydrochar (0% (control), 1%, 2%, and 5% w/w) on the physical and chemical properties of the soil were evaluated, and the findings are presented in Table (3) ($p < 0.05$). The application of treatments 1%, 2% and 5%, resulted in an increase in soil organic carbon to 12.16%, 48.65%, and 78.38% respectively. Hydrochar contains stable carbon and nutrients that enhance soil quality and facilitate carbon storage within the soil (Bento et al., 2019). The results of research conducted Song et al (2018), demonstrated that the addition of hydrochar to the soil leads to an increase in soil organic carbon content. However, some researchers have suggested that hydrochar may have a lower capacity for long-term carbon storage compared to biochar, as biochar contains higher levels of polyaromatic carbon, which is more stable (Busch & Glaser, 2015). Hydrochar, being a porous material with a high carbon content, has the potential to enhance soil organic carbon levels (Bahcivanji et al., 2020; Taskin et al., 2019).

The use of fertilizers with high levels of organic matter clearly enhances the internal and external bonds of soil aggregates, leading to improved soil structure. In the present study, the application of engineered sugarcane bagasse hydrochar at 1%, 2%, and 5% concentrations resulted in significant increases in total nitrogen content compared to the control: 8.99%, 15.73%, and 43.82%, respectively. The presence of carbon compounds in hydrochar stimulates microbial activity in the soil, thereby promoting nitrogen stabilization (Bento et al., 2019). Chu et al. (2020) also observed in their study that the low pH of hydrochar and the presence of carboxyl groups contribute to nitrogen retention in the soil.

Furthermore, the application of sugarcane bagasse hydrochar in the soil led to an increase in soil phosphorus content. As shown in Table (3), the phosphorus content changed from 7.37 mg/kg in the control to 7.67 mg/kg (1%), 8.38 mg/kg (2%), and 10.03 mg/kg (5%). Hydrochar may enhance phosphorus levels in the soil through mechanisms such as pH reduction, phosphorus adsorption, and the adsorption of phosphorus-stabilizing cations (e.g., calcium, iron, and magnesium). Similar findings have been reported by other studies that observed an increase in soil phosphorus following hydrochar application (Bahcivanji et al., 2020).

pH plays a crucial role in improving soil conditions as it can affect nutrient availability and potential toxicity. The pH level can range from acidic to alkaline, and extreme values can limit nutrient accessibility. Hydrochar typically exhibits acidic pH due to the presence of organic acids in its structure or the removal of alkaline elements during production. However, in the current study, after activating the hydrochar with magnesium chloride, its pH slightly increased due to the presence of the alkaline earth metal magnesium.

The results indicated that treatments of 1%, 2%, and 5% engineered sugarcane bagasse hydrochar decreased soil pH by 0.40%, 0.54%, and 1.34% compared to the control, respectively. The reduction in soil pH following hydrochar application may be influenced by the initial pH of the hydrochar and its impact on enhancing soil microbial activity. Previous studies have also attributed the decrease in soil pH to the acidic nature of hydrochar and the presence of carboxylic groups in its structure (Ren et al., 2017; Bento et al., 2019). Additionally, the decrease in soil pH after organic fertilizer application can be attributed to the decomposition of organic matter and the production of carbonic acid and organic acids.

According to the findings of the present study, the application of 1%, 2%, and 5% hydrochar treatments significantly increased soil electrical conductivity (EC) by 33.29%, 51.83%, and 81.82% compared to the control, respectively. The elevated EC in the soil can be attributed to the higher EC of the hydrochar compared to the soil itself.

In Table (3) results showed a significant reduction in soil bulk density following the addition of sugarcane bagasse hydrochar. The decrease in bulk density was observed to be 4.86%, 11.26%, and 16.34% for the 1%, 2%, and 5% treatments compared to the control. This decrease in bulk density can be attributed to the incorporation of lower-density materials into the soil and the increase in soil organic matter resulting from hydrochar application. The presence of soil organic matter promotes the formation of soil aggregates and enhances soil structure stability (Song et al., 2015). Mau et al. (2020) also reported a decrease in soil bulk density associated with the use of hydrochar, which can be attributed to the low density of hydrochar itself. Similarly, other researchers have reported a reduction in bulk density following the application of different types of hydrochar (Abel et al., 2013).

The results of comparing the means showed that the increase of hydrochar at all levels led to a significant increase in soil porosity compared to the control. Soil porosity of 10.6%, 19.39%, and 26.54%, respectively increased in treatments of 1, 2, and 5%. The increase in soil porosity after the application of hydrochar is due to its porous structure. Also, the bulk density in effect the application of hydrochar decreased and it can be an effect on increasing porosity. Abel et al. (2013) attributed the increase in soil porosity to the high specific surface area and porosity of hydrochar (Abel et al., 2013). Shao et al. (2020) stated that hydrochar as a material with a high specific surface area and a porous structure can be used to improve the characteristic soil (Shao et al., 2020).

The results of the mean comparisons revealed a significant increase in soil porosity with the application of hydrochar at all levels compared to the control. The treatments of 1%, 2%, and 5% hydrochar resulted in soil porosity increases of 10.6%, 19.39%, and 26.54%, respectively. This increase in soil porosity can be attributed to the porous structure of hydrochar. Furthermore, the decrease in bulk density resulting from the application of hydrochar can also contribute to the increase in porosity. Abel et al. (2013) attributed the increase in soil porosity to the high specific surface area and porosity of hydrochar. Shao et al. (2020) stated that hydrochar, with its high specific surface area and porous structure, can be utilized to enhance soil characteristics. Mau et al. (2020) mentioned that the addition of hydrochars to the soil increases the presence of secondary pores. Additionally, hydrochars produced at lower temperatures exhibit a greater ability to increase soil porosity. Similar findings have been reported by other researchers regarding the increase in soil porosity following the application of hydrochar (Eibisch et al., 2015).

The effect of sugarcane bagasse hydrochar application on bean plant characteristics

The results from Table (4) indicate that the application of various treatments of engineered sugarcane bagasse hydrochar had a significant impact on the height of the bean plants.

Table 3- Effects of different levels of engineered sugarcane bagasse hydrochar on physical and chemical properties of sandy loam soil ($p < 0.05$)

Parameter	Treatments			
	0% (control)	1%	2%	5%
Bulk density	1.55[c]	1.44[b]	1.34[b]	1.26[a]
Organic carbon	0.25[a]	0.28[a]	0.38[b]	0.44[c]
Nitrogen	0.030[a]	0.034[ab]	0.035[b]	0.042[c]
Porosity	42.54[a]	47.05[b]	50.80[cb]	53.84[c]
Phosphorus	7.37[a]	7.67[a]	8.38[b]	10.03[c]
pH	7.45[b]	7.42[a]	7.41[a]	7.35[a]
EC	2.82 [a]	3.76[b]	4.29[c]	5.13[d]

Table 4- Effects of different levels of engineered sugarcane bagasse hydrochar on bean plant properties ($p < 0.05$)

Parameter	Treatments			
	0% (control)	1%	2%	5%
Plant height (cm)	23.5[b]	25.6[b]	20.2[a]	18.1[a]
Lateral branches number	3.7[a]	4.0[a]	3.7[a]	3.3[a]
Leaf number	9.7[a]	10.0[a]	9.3[a]	8.7[a]
Dry weight of aerial parts (g)	3.5[a]	3.63[a]	3.44[a]	3.32[a]
Root dry weight (g)	0.564[b]	0.615[c]	0.529[ab]	0.523[a]

The highest plant height of 25.6 cm was observed with the application of 1% hydrochar, while the application of 2% and 5% hydrochar resulted in a significant decrease in plant height by 14.02% and 23.08%, respectively, compared to the control.

As mentioned, the application of the 1% hydrochar treatment resulted in increased growth parameters of beans. However, higher application of hydrochar in the soil, specifically the 2% and 5% treatments, caused toxicity to the plants and resulted in decreased growth parameters of beans. Melo et al. (2019) also reported similar findings of reduced growth with increased hydrochar application. They observed that the use of hydrochar at a rate of 0.5% improved bean growth, but higher application rates led to plant toxicity.

Fang et al. (2015) conducted a study to investigate the effect of sugarcane bagasse hydrochars produced at different temperatures (200, 250, and 300 °C) on plant height. Their results showed that the application of hydrochars produced at temperatures of 250 and 300 °C resulted in a decrease in plant height (Fang et al., 2015). In the present study, magnesium chloride salt was used to activate hydrochar, which increased its electrical conductivity (EC). As a result of its application to soil, it increased soil salinity. As bean is sensitive to salinity and tolerates soil salinity less than 2 ds/m, its growth parameters were reduced by increasing the dose of hydrochar (Parande et al., 2014). The application of hydrochar at a 1% concentration led to a non-significant increase of 9.09% in the number of lateral branches of the bean plant compared to the control. On the other hand, the application of 5% hydrochar in the soil resulted in a reduction of 9.1% in the number of lateral

Interestingly, the 2% treatment had no significant effect on the number of lateral branches. It was initially expected that the increase in nutrients and improvement in soil properties due to hydrochar application would promote the growth and yield of bean plants. However, this positive effect was observed only at the 1% concentration. It can be inferred that the enhanced water and nutrient retention in the soil, coupled with a high concentration of elements, might have disrupted the nutrient balance in the soil, thereby negatively affecting the growth of bean plants. Furthermore, Bento et al. (2019) mentioned that hydrochar has the ability to release certain toxic compounds such as organic acids and phenols into the soil, which can harm plant growth. Therefore, it is necessary to conduct further studies to determine the optimal and most beneficial dosage of hydrochar for different applications.

Mau et al. (2020) also reached a similar conclusion in their study, stating that although hydrochar positively affects soil moisture and enhances water retention, this factor alone cannot account for the improved growth of lettuce. They stated that hydrochar likely exerts its effects on plant growth through other mechanisms. In terms of leaf number, no significant difference was observed between the effects of the 2% and 5% hydrochar treatments. These treatments resulted in a slight decrease in leaf number (3.45% and 10.34%, respectively). On the other hand, the application of 1% hydrochar led to a 3.45% increase in the number of bean leaves compared to the control. Bargman et al. (2014) conducted a study on spring barley and French beans and identified optimal doses of hydrochar ranging from 2% to 4%. They reported that increasing the hydrochar dosage to 10% resulted in a reduction in plant growth.

The 1% treatment resulted in a 3.8% increase in the dry weight of aerial parts. On the other hand, the addition of hydrochar at 2% and 5% led to a decrease of 1.82% and 5.15%, respectively, in the dry weight of aerial parts compared to the control. Rillig et al. (2010) also found that the addition of hydrochar produced from beetroot residues at a volume of 4% did not significantly impact plant growth, while doses above 10% inhibited plant growth. However, some researchers have reported positive effects of hydrochar on plant growth and performance, attributing it to increased soil nitrogen (Chu et al., 2020). Melo et al. (2019) stated in their research that doses of 10 mg and 60 mg of hydrochar per hectare had the greatest effect on the dry weight of beans and rice, respectively, and further increasing the application dose had a negative correlation with biomass dry weight.

Based on the results presented in Table (4), the application of 1% hydrochar treatment resulted in the highest root dry weight of 0.615 g. This increase in root dry weight was found to be statistically significant compared to both the control group and the other treatments. However, the application of 2% and 5% hydrochar treatments significantly reduced the root dry weight by 6.521% and 7.33%, respectively. Fang et al. (2015) also observed that although hydrochar did not have a significant effect on seed germination, it had a positive impact on root growth. Melo et al. (2019) suggested that the response of biomass to hydrochar application in the soil varies depending on the dosage and type of hydrochar. Long-term field studies are necessary to investigate the interaction between hydrochar, soil properties, and plant growth. The appropriate application of hydrochar as a soil amendment needs to be determined through further research.

Conclusions

The extensive research conducted on the application of hydrochar for soil and plant improvement has demonstrated its positive effects. However, it is important to consider various factors such as biomass type, production temperature, soil type, and application rate of hydrochar, as these variables can influence the outcomes obtained. A comprehensive study that examines the impact of these variables is necessary to determine the most beneficial results. In this particular study, activated hydrochar, obtained after nitrate and phosphate adsorption, was applied to enhance soil and plant growth. The results indicated that the engineered hydrochar had a positive influence on soil parameters, including bulk density, porosity, pH, organic carbon, nitrogen, and phosphorus, thereby improving the physical and chemical conditions of the soil. Consequently, hydrochar can be considered a crucial factor for farmers when selecting fertilizers, as it acts as a soil conditioner. However, when discussing the use of hydrochar as an organic fertilizer for bean plant growth, the expected results were not achieved, most likely due to the use of high doses. Nonetheless, positive effects were observed when applying the hydrochar treatment at 1% concentration.

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Comparison of open and combined closed hydroponic system on water productivity, nutrient use efficiency yield and fruit quality of cucumber

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Abstract

One of the greatest challenges currently facing society is the production of high-yield and high-quality foods due to population growth and the need to increase food production. In this study, the effect of two hydroponic systems on water productivity, nutrient use efficiency yield and fruit quality of three greenhouse cucumber cultivars have been investigated. This experiment is in the form of split plots in a randomized complete block design, with the treatment of cucumber cultivars (Strong, Yalda, and RY) and type of hydroponic cultivation system (open and combined closed) in which 3 replicates were implemented at Shahid Chamran University of Ahvaz. The studied traits included water productivity, nutrient use efficiency, crop yield, fruit length and diameter, fruit volume, fruit firmness, fruit dry weight, fruit carotenoids, phenolic compounds, total soluble solids, titratable acidity were measured. The highest fruit length, fruit diameter, yield, water productivity and nutrient use efficiency were obtained in the combined closed system. The highest fruit firmness, total soluble solids, phenolic compounds were obtained in the open system. The combined closed system increased crop yield, water productivity and nutrient use efficiency by 22.63%, 80.81% and 81.92 % respectively, as compared to the open system. The highest phenolic compounds, fruit length, yield and water productivity were calculated in the RY cultivar. The RY cultivar increased phenolic compounds by 56.30% and 71.98% respectively, as compared to the Strong and Yalda cultivars. Based on the results, Fruit diameter had a significant correlation with fruit length (0.47^*) and crop yield (0.55^*). According to the results of this study, combined closed system and RY cultivar have the highest quality characteristics of fruit and yield, therefore they can be recommended for greenhouse production.

Introduction

Due to the high demand for water resources and the consequent supply of food, many new trends have evolved in innovative farming methods that involve a complex system of agricultural production. Greenhouses play an essential role in reducing water consumption, food supply, and the farmer's economy due to their ability to control environmental factors and enable the production of off-season crops (Miller et al, 2020). The hydroponics cultivation system is the production of a crop using the nutrient solution, which is divided into open and closed systems. In this system provide water and nutrients to the plant as a nutrient solution and in the open system (about 25%) is drained from the system as water, causing environmental pollution (Fayezizadeh et al, 2021; Maucieri et al, 2018; Savvas and Gruda, 2018). In the closed system, the nutrient solution is returned to the main tank after passing through the pot and is rotated uniformly and continuously in the system during the day and night (Maucieri et al, 2018). In the closed system nutrients are absorbed by the plant, to regenerate the nutrient solution nutrients and water are added to it with a certain percentage. The high efficiency of the nutrient solution in the closed system for the production of crops such as leafy vegetables, tomatoes, cucumbers, and peppers are among the advantages that can encourage greenhouse growers to grow products in this system (Fayezizadeh et al, 2021). Khafajeh et al. (2020), in a study of a closed hydroponics cultivation system (Aqua Crop) on the morphological characteristics and yield of greenhouse cucumber, concluded that the closed system produced the highest yield and biomass with the least evapotranspiration. In a study to determine the effect of wick systems (closed) and drip (open) on the yield and quality of tomato fruit, the results showed that the wick system increased of fruit firmness, ascorbic acid, soluble solids and yield, as compared to the drip system (Kaur et al, 2018). Abd-Elmoniem et al. (2006) in the study of closed and open systems in lettuce cultivation reported, the yield in the closed system was 5% higher than the open system in lettuce cultivation, and closed system reduced water and nutrient consumption. Fayezizadeh et al. (2023), in a study on the effect of open and closed hydroponics systems on the quality characteristics and yield of tomato reported, the highest fruit length and fruit firmness were obtained in the open irrigation system and the total soluble solids, lycopene, fruit carotenoids were obtained in the closed irrigation system (NFT) and also the irrigation systems were not significantly different in terms of crop yield. Rodriguez Ortega et al. (2019) in the study of the effect of three hydroponics systems (DFT, perlite, and NFT) on the quantitative and qualitative characteristics of tomatoes concluded that the NFT system increased total soluble solids and titratable acidity and fruit quality. Fayezizadeh et al. (2023), reported, water productivity in a closed system (about 55%) was higher than open system, and closed irrigation system decreased nutrient solution consumption by up to 96% and fertilizer consumption by up to 97% compared to the open system.

Cucumber (Cucumis sativus L.) is listed among the top four important vegetable crops after *Solanum* lycopersicum, *Brassica oleracea*, and Allium cepa (Ghani et al., 2022), in addition, its nutritional contribution and nutraceutical properties have positive impacts on health, especially in people with diabetes, hypertension, cardiovascular, and Alzheimer’s disease. Moreover, it is also a high source of fiber, carbohydrates, proteins, magnesium, iron, vitamin B and C, flavonoids, phenolic compounds, and antioxidants (Yuan et al, 2019; Uthpala et al, 2020).

The innovation of this research is the use of integration of several combined irrigation systems included drip irrigation system, aeroponics system, wick system, and deep water culture system. The combination of these systems in cucumber cultivation caused the water productivity in this system to be calculated at about 72 kg/m^3 while the open system was measured at 39 Kg/m^3. Also, no droppers were taken in this system. Environmental pollution is at a minimum. The energy required for irrigation was generated using the earth's gravity, and only small pumps carried water from the sewage collection containers to the main tank. Therefore, the purpose of the current study was comparison of open and combined closed hydroponic system on water productivity, nutrient use efficiency yield and fruit quality of cucumber at Shahid Chamran University of Ahvaz.

Materials and methods

This experiment was carried out in the autumn and winter of 2021 in the greenhouse and qualitative analysis laboratory of the Department of Horticultural Sciences, the Shahid Chamran University of Ahvaz in the form of split plots in a randomized complete

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block design with three replications. Experimental treatments include two types of open and closed hydroponics systems and 3 cucumber cultivars (Strong and Yalda from Rijk Zwaan Company in the Netherlands, and RY cultivar was bred at the Shahid Chamran University of Ahvaz). The temperature and humidity in the greenhouse were recorded daily by a digital device (Termo hygrometer-Germany made in Germany) (Figure1). The culture medium in the open hydroponic system was (50% cocopeat+50% perlite); however, the combined closed hydroponic system was without any culture medium (Figure 2). After preparing the nutrient solution, the EC and pH of the nutrient solution in both the combined closed and the open hydroponic system were measured using a manual digital conductivity meter and a pH meter. The EC of the nutrient solution was adjusted to 1.7 (dS m^{-1}) in the open system and ranged from 1.2 to 2.5 (dS m^{-1}) in the combined closed system. After resetting the EC of the nutrient solution in the combined closed hydroponic system, the pH of the nutrient solution was measured and adjusted using H_2SO_4 or NaOH in the range of 5.8–6.0 as required. In the open hydroponic system, the nutrient solution was transferred to the plant by pipes and drippers using a digital timer. Irrigation was done in the open system from 8 am to 6 pm during the day and in the combined closed hydroponic system, irrigation was done by gravity and the nutrient solution was transferred to the pots. The drainage water was collected and returned to the tank by using a pump and P.V.C pipe. The nutrient solution had a constant volume in the pots and flowed consistently during the day and night. A Resh nutrient solution was used to feed the plants (Resh, 2013) (Table 1). After preparing the nutrient solution, the electrical conductivity and pH of the nutrient solution were measured in two systems using a manual digital conductivity meter and a pH meter (Phantong et al, 2018).

Fig. 1- Combined closed hydroponic system (A), Open hydroponic system (B).

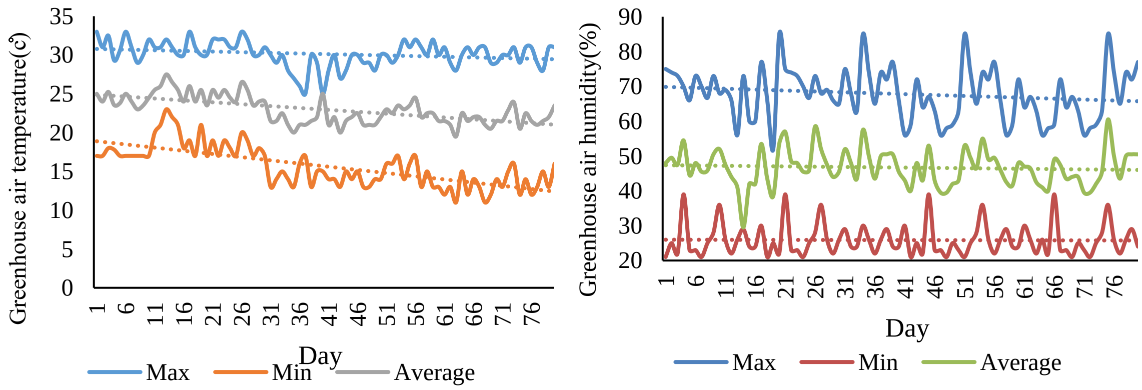

Fig. 2- The above figure: greenhouse temperature graph, the below figure: greenhouse humidity graph.

Table 1- Nutrient solution of Resh (2013)

High Consumption elements	Elements Consumption (ppm)	Low Consumption elements	Elements Consumption (ppm)
N	140	Mn	0.8
P	50	Cu	0.07
K	325	Zn	0.1
Mg	50	B	0.3
Ca	180	Mo	0.03
S	168	Fe	2

The pH of the nutrient solution was adjusted in two systems in the range of 5.8 - 6.0 and the electrical conductivity in the open system was 1.7 (dS m^{-1}) and the combined closed system was in the range of 1.2-2.5 (dS m^{-1}).

Measured variables

Normally, the cucumbers were harvested every 1–2 days, with the yield recorded each time, and all fruits harvested during the week were added together as the total yield in grams. Fruit length (cm) and fruit diameter (mm) after each harvest were recorded using a ruler and a caliper, respectively. Fruit volume was measured by fluid transfer (weight change). The amount of total soluble solids (Brix°) was measured with an Atago digital refractometer, A-PAL-1 (Voca et al., 2007). Total acidity in terms of percentage of malic acid was determined by titration method with 0.1 N sodium hydroxide solution until pH = 8.1 (Voca et al, 2007). The percentage of fruit dry matter was measured by a standard drying method in an oven at 70 ° C. Fruit firmness (N/mm) was measured by the Santam STM-1 hardness tester with a 0.8 mm probe at a speed of 20 m/s. The total carotenoid of the fruit (mg/100gr FW) at a wavelength of 450 nm was calculated (Arnon, 1967).

Carotenoids= (1000(A470)–1.8(chl a)–58.2(chl b)) /198 (1)

The total phenolic contents of the cucumber extracts were evaluated using the procedure explained by Benzie and Strain. (1996). The absorbance of the samples was read at 725 nm. The concentration of phenolic compounds (mg/kg) was calculated using the standard of gallic acid (Y=0.0095X-0.0502, R^2 = 0.9606). In this study, water productivity in two open and combined closed hydroponics systems was measured and recorded during planting from the beginning to the end of the experiment. Irrigation in the open system was adjusted based on the water drainage (20-25%) from the pots. In order to measure nutrient use efficiency, the volume of nutrient solution applied per plant was recorded on daily basis and the concentration of each nutrient in the applied nutrient solution was known (Fayezizadeh et al, 2021; Singh et al, 2019).

$$\text{Water Productivity: } \frac{\text{Yield (kg plant}^{-1})}{\text{Water applied (m}^3\text{ plant}^{-1})} \quad (2)$$

$$\text{Nutrient Use Efficiency: } \frac{\text{Yield (g plant}^{-1})}{\text{Nutrient applied (g plant}^{-1})}$$

Statistical analyzes were performed using MSTAT-C (analysis of variance) and SPSS (correlation between trait) software and graphs were drawn by Excel software.

Results and discussion

Fruit diameter and length

The effect of the hydroponics cultivation system had a significant difference on fruit diameter at 1% level. But the effect of cultivar and the interaction of cultivar and hydroponics system on fruit diameter was not significant. The effect of the hydroponics system on fruit length at 5% level and the effect of cultivar on fruit length at 1% level had a significant difference. The interaction effect of hydroponics system and cultivar on fruit length was not significant (Table 2). The highest and lowest fruit diameters were measured in the combined closed system (32.16 mm) and in the open system (30.97 mm). The highest and lowest fruit lengths were measured in RY cultivar (15.19 cm) and

Strong cultivar (14.73 cm), respectively. The highest and lowest fruit lengths were measured in the combined closed system (15.12 cm) and in the open system (14.89 cm) (Table 3). The findings are consistent with the results of Maboko et al, (2012). They stated that the length and diameter of fruits in the combined closed hydroponics system are more than open system. Cardoso et al. (2017), showed that increasing the concentration of potassium in the nutrient solution in the closed system increases the fruit diameter. Probably the longer length of the fruits of the RY cultivar is also a genetic characteristic of this cultivar. Fruit diameter had a significant correlation with fruit length (0.47*) and crop yield (0.55*) (Table 4). By increasing the diameter and length of the cucumber fruit, the weight of single fruit and ultimately the yield of the whole crop increases (Ahirwar et al, 2017).

Fruit volume and firmness

Based on the results, the effect of the hydroponic system, the cultivar and the interaction of the hydroponic system and the cultivar on fruit volume was not significant (Table 2). The effect of the hydroponics system and the effect of cultivar on fruit firmness showed a significant difference at the 5% level. The interaction of hydroponics system and cultivar did not have a significant on fruit firmness (Table 2). The highest and lowest fruit firmness were obtained to the open system (65.50 N/mm) and combined closed system (60.54 N/mm), respectively (Table 3). The highest and lowest fruit firmness were obtained in Strong cultivar (65.87 N/mm) and Yalda cultivar (58.47 N/mm), respectively (Table 3). The results of this study are consistent with the results of Fayezizadeh et al. (2023) and Saito et al. (2008), they concluded that increasing the concentration of the nutrient solution in the closed system is an important factor influencing the firmness of the fruit by reducing the absorption of calcium (Ca^{2+}). The calcium is non-moving in the plant and mainly moves in the plant by water in the phloem. Therefore, with increasing the concentration of the nutrient solution, the osmotic potential of water decreases, and the transfer of water to the fruit decreases. Genetic factors in different cultivars can make a significant difference in fruit quality traits such as fruit firmness between cucumber cultivars. Fruit firmness had a significant correlation with fruit diameter (0.489*) (Table 4). The growth process of cucumber fruit affects the firmness and composition of the cell wall. The fruit firmness of all cucumber decreased with increasing fruit diameter. This decrease in firmness is mainly due to the activity of some endogenous enzymes related to the destruction of the cell wall, which increases during the fruit growing season. In addition, changes in fruit firmness are associated with the degradation of the middle layer of parenchymal cells, leading to a significant increase in pectin dissolution (Shehata et al., 2021).

Titratable acidity, dry matter and fruit carotenoids

The effect of the hydroponic system, the cultivar and the interaction of the hydroponic system and the cultivar on titratable acidity, percentage of dry matter and fruit carotenoids were not significant (Table 2).

Phenolic compounds

The effect of hydroponics cultivation system, the effect of cultivar, and the interaction effect of hydroponics cultivation system and cultivar on phenolic compounds of fruit made a significant difference at a 1% level (Table 2). The highest and lowest levels of phenolic compounds were measured in the RY cultivar (2191.13 mg gallic acid/gr FW) and Yalda cultivar (1232.16 mg gallic acid/g FW), respectively (Table 5). Also, the highest and lowest concentration of phenolic compounds were obtained in the combined closed system (1811.78 mg gallic acid/gr FW) and in the open system (1374.26 mg gallic acid/gr FW), respectively (Table 5). The findings are consistent with the results of Antolinos et al. (2020). They stated that different concentrations of nutrient solution in the NFT system increased fruit phenol content in vegetables. Kumaric acids, ferulic acid, and caffeic acid are among the main phenolic compounds in cucumber (Ongena et al, 2000).

Total Soluble solids

The effect of hydroponic system on the total soluble solids was significantly different at the level of 1% (Table 2). The effect of cultivar and the interaction of the hydroponic system and cultivar on the total soluble solids did not show a significant difference. The highest and lowest of soluble solids were obtained in a combined closed system with average (3.00° Brix) and open system with average (2.50° Brix), respectively (Table 5). The findings are consistent with the results of with the results of Kaur et al. (2018). The combined closed system had higher values and better quality in terms of ascorbic acid and soluble solids in the fruit. Schmautz et al. (2016), stated that plants can regulate themselves osmotically, because with increasing the concentration of the nutrient solution, the amount of sugars, organic acids, and mineral salts increases and osmotically negatively affects and ultimately prevents the deficiency of various tissues. The yield had a significant correlation with TSS (-0.489) (Table 4). The increase in TSS may due to be the dissolution of cellulose and hemicellulose in the cell wall or water loss. Therefore, considering that about 97% of cucumber fruit is water, with increasing sugars and loss of fruit juice, crop yield will decrease (Shehata et al., 2021).

Crop yield

Based on the results of the analysis of variance, the effect of the hydroponics cultivation system and the effect of cultivar on the fruit yield of cucumber showed a significant difference at a 1% level. The interaction effect of hydroponics cultivation system and cultivar on yield was not significant (Table 2). The highest and lowest fruit yields were obtained in the combined closed system with an average (4043.11 g) and in the open system with an average (3296.88 gr), respectively (Table 5). The RY cultivar with average (3858.00 g) and Yalda cultivar with average (3421.66 g) had the highest and lowest fruit yields, respectively (Table 5). The findings are consistent with the results of Roza-Rodriguez et al. 2020 and Fayezizadeh et al. (2021). They concluded in an experiment to determine the efficiency of water consumption and tomato fertilizer in greenhouse conditions under both open and closed hydroponic systems. The closed hydroponic system (recirculation of nutrient solution) 13.50 kg more fruit compared to open system (with non-circulating nutrient solution) produced. The yield of cultivars in different hydroponics systems is different and this can be the result of diversity and genetic characteristics that exist between different cultivars under different cultivation conditions (Fayezizadeh et al. 2023).

Water productivity

The effect of the hydroponic systems at the 1% level on water productivity were significantly different, while the effect of the cultivar and the interaction of the hydroponic system and cultivar did not cause any significant difference (Table 2). The highest water productivity occurred in the combined closed hydroponic system with an average consumption of 72.05 kg/m^3, whereas the lowest water productivity occurred in the open hydroponic system with an average of 39.82 kg/m^3 (Table 5). The combined closed hydroponic system showed an increased water productivity by 80.93% in this system. The findings in this study correspond with those of Verdoliva et al. (2021), and Al-Shrouf, (2017), that they compare water and fertilizer use efficiency in open and closed hydroponic systems and conclude that closed irrigation systems reduce water loss and increase water use efficiency compared to open systems. Therefore, closed hydroponic systems are more efficient in terms of water consumption efficiency and are also able to produce higher quality products.

Nutrient use efficiency

Based on the results, the amount of fertilizer consumed in the open system and in the combined closed system was 9.26 gr $plant^{-1}$ and 5.09 gr $plant^{-1}$ respectively, and the combined closed system increased nutrient use efficiency by 81.92% compared to the open system. These results are due to the recirculation of the nutrient solution in a combined closed system since this allows reducing the water and fertilizers used. Nutrient uptake by plants is affected by several factors, such as ionic concentration in the nutrient solution, pH, the selectivity of the roots, and oxygen concentration of the nutrient solution, climate, and plant development stage (Lopez et al. 2011;

Kempen et al. 2017). The uptake of nutrients is affected by the balance existing among them, which in closed systems is the main factor to maintain optimal plant nutrition (Moreno-Perez et al. 2015). The findings in this study correspond with those of Fayezizadeh et al. (2021) and Rosa-Rodríguez et al. (2020), which reported in the closed hydroponic system the amount of fertilizers decreased during the tomato crop cycle, in comparison to the open system and this was because of the recirculation of the nutrient solution.

Table 2- Variance analysis for studied traits as a function of cucumber (C) cultivars and Hydroponics systems (H)

		Mean Squares					
Source of variance	DF	Fruit length	Fruit diameter	Fruit volume	Fruit firmness	Fruit dry weight	Fruit carotenoids
Replication	2	0.078 ns	0.165 ns	37.389ns	24.833 ns	0.284 ns	0.132 ns
H	1	0.229*	6.349**	6.722 ns	110.558*	0.344 ns	0.041 ns
Error	4	0.107	0.402	104.222	25.663	0.060	0.785
C	2	0.356**	0.299 ns	321.056 ns	95.014*	0.151 ns	1.076 ns
H×C	2	0.060 ns	0.097 ns	132.056 ns	34.800 ns	0.224 ns	0.165 ns
Error	6	0.027	0.445	79.944	13.788	0.203	0.342
(%) CV		1.09	2.11	7.93	5.89	14.94	18.13
Source of variance		Phenolic compounds	Total soluble solids	Titratable acidity	Water productivity		Crop yield
Replication	2	0.008 ns	0.245 ns	8.877 ns	0.489 ns		13388.667 ns
H	1	0.167 **	1.125*	22.894 ns	4672.222**		2505814.222**
Error	4	0.039	0.138	3.271	1.153		30784.833
C	2	0.438 **	0.095 ns	31.304 ns	75.608**		301960.667**
H×C	2	0.439 **	0.195 ns	48.124 ns	8.136ns		61333.556 ns
Error	6	0.019	0.080	56.534	2.227		16649.778
(%) CV		5.13	10.70	19.52	29.37		3.51

Note. **, *, ns: significant effect at 1%, 5%, and no significant effect, respectively.

Table 3- Comparison of the mean of the physical characteristics of fruit with Duncan test.

Treatment	Fruit firmness (N/mm)	Fruit volume (cm^3)	Fruit diameter (mm)	Fruit length (cm)
Hydroponic system				
Closed system	60.54b	112.00a	32.16a	15.12a
Open system	65.50a	113.22a	30.97b	14.89b
Cultivar				
Strong	65.87a	104.16a	31.48a	14.73b
Yalda	58.47b	116.66a	31.82a	15.10a
RY	64.72a	117.00a	31.40a	15.19a
System× Cultivar				
Open× Strong	68.91a	105.33a	31.03bc	14.73b
Open× Yalda	58.31b	121.66a	31.19abc	14.90ab
Open× RY	69.27a	112.66a	30.71c	15.05ab
Closed× Strong	62.82ab	103.00a	31.93abc	14.73b
Closed× Yalda	58.64b	111.66a	32.46a	15.30a
Closed× RY	60.17b	121.33a	32.10ab	15.33a

Treatments with at least one common letter are not have a significant difference.

Table 4- Correlation coefficient* between studied characters.

	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	-0.313	1									
3	0.594**	-0.081	1								
4	-0.126	0.400	-0.203	1							
5	-0.193	0.017	0.085	-0.299	1						
6	0.382	-0.123	0.012	-0.228	-0.309	1					
7	-0.372	0.558*	-0.105	0.416	0.302	-0.169	1				
8	-0.489*	0.130	-0.448	0.121	0.358	-0.210	0.226	1			
9	-0.299	0.296	0.078	0.337	0.222	-0.325	0.139	0.473*	1		
10	-0.114	-0.121	-0.489*	0.413	0.087	-0.050	-0.074	0.555*	0.280	1	
11	-0.084	-0.541*	0.424	0.168	-0.28	0.018	0.686**	0.380	0.926**	-0.313	1

**: Correlation is significant at the 0.01 level, *. Correlation is significant at the 0.05. N=12, 1- Fruit firmness(N/mm), 2- fruit volume(cm^3), 3- Total soluble solids content(Brix◦), 4- Phenolic compounds (mg galic acid/kg), 5- Titratable acidity (mg Citric acid/100gr Fw), 6- Fruit dry matter (%), 7- Fruit Carotenoids (mg/100gr Fw), 8-Fruit diameter (cm), 9- Fruit height(cm), 10- Yield (gr), 11- Water productivity (kg/m^3).

Table 5- Comparison of the mean for total soluble solids (TSS, Brix◦), Phenolic compounds (PC, mg galic acid/kg), titratable acidity (TA, mg Citric acid/100gr Fw), fruit carotenoids (FC, mg/100gr Fw), fruit dry weight (FDW, g), yield (Y, g) **and water productivity (WP, Kg/m^3) with Duncan test**

	TSS	PC	TA	FC	FDW	Y	WP
Hydroponic system							
Closed system	3.00^{a}	1811 ^{a}	39.63^{a}	4.48^{a}	2.87^{a}	4043^{a}	72.0^{a}
Open system	2.5^{b}	1374. ^{b}	37.33^{a}	4.38^{a}	3.15^{a}	3296^{b}	39.8^{b}
Cultivar							
Strong	2.63^{a}	1355.78^{b}	36.73^{a}	3.95^{a}	3.16^{a}	3730^{a}	56.0^{b}
Yalda	2.73^{a}	1232.16^{b}	41.08^{a}	4.76^{a}	2.84^{a}	3421^{b}	52.3^{c}
RY	2.88^{a}	2191.13^{a}	37.70^{a}	4.58^{a}	3.02^{a}	3858^{a}	59.4^{a}
System× Cultivar							
Open× Strong	2.83^{ab}	1555.59^{b}	36.73^{a}	3.96^{a}	3.51^{a}	3462^{c}	41.2^{c}
Open× Yalda	2.83^{ab}	1203.01^{b}	36.73^{a}	4.85^{a}	2.81^{a}	2952^{d}	35.1^{d}
Open× RY	3.33^{a}	1364.20^{b}	38.66^{a}	4.35^{a}	3.12^{a}	3476^{c}	43.1^{c}
Closed× Strong	2.43^{b}	1155.97^{b}	36.73^{a}	3.95^{a}	2.81^{a}	3998^{ab}	70.9^{b}
Closed× Yalda	2.63^{ab}	1261.31^{b}	45.43^{a}	4.67^{a}	2.88^{a}	3891^{b}	69.4^{b}
Closed× RY	2.43^{b}	3018.05^{a}	36.73^{a}	4.81^{a}	2.92^{a}	4239^{a}	75.7^{a}

Treatments with at least one common letter are not have a significant difference

Conclusions

Knowing the methods for increasing water productivity, nutrient use efficiency, and the quality of the product in a controlled environment is very important. One of the new methods that increased the efficiency of water, fertilizer consumption, yield, and TSS in cucumber was the combined closed system consisting of several different closed hydroponic systems. This system was able to increase water productivity (80.81%), nutrient use efficiency (81.92 %), and yield (22.63%) of greenhouse cucumber, compared to the usual drip irrigation method. The highest yield and quality of fruit such as length, diameter, and TSS were obtained in the combined closed system. The RY cultivar produced by the Shahid Chamran University of Ahvaz improved fruit quality and yield compared to other cultivars. It seems that this efficiency could be increased because, by increasing temperature and decreasing humidity in the greenhouse, evaporation and transpiration are reduced. By using the environmental management system (EMS), it is possible to better control the environment for increasing photosynthesis, yield, and water productivity. In future research, the integration of humidity control, temperature, carbon dioxide, and new irrigation methods with the use of an intelligent climate control system can control many environmental stresses.

Ethical approval

Not applicable.

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Consent to participate

Consent was obtained from all individual participants included in the study.

Consent to publish

The participant has consented to the submission of the case report to the journal.

Credit authorship contribution statement

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Hossein Darai and Naser Alemzadeh Ansari. The first draft of the manuscript was written by Hossein Darai and Naser Alemzadeh Ansari and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of Competing 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.

Data Availability

Data will be made available on request.

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Evaluation of some Estimation methods of Evapotranspiration to determination of yield for Maize and Wheat using AquaCrop

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Abstract
AquaCrop model was developed to simulate crop response to water consumption and irrigation management. The model is easy to use, works with limited input, and has acceptable accuracy. On the other hand, there are different methods for estimating evapotranspiration, whose performance is different in various climatic conditions. The purpose of this research is to investigate the effect of different methods to estimate evapotranspiration of the reference plant in various climates of Iran on estimating the yield of maize and wheat using AquaCrop. To fulfil the experiment, 40-year meteorological data (1980-2020) of five cities of the country (Urmia, Mashhad, Rasht, Qazvin, and Yazd) were used. First, evapotranspiration was estimated using the FAO-56 and five temperature and radiation methods daily. Then, the yield value of these two plants was simulated by AquaCrop and compared with the FAO-56 by error statistical criteria determination coefficient (R^2), normal root means square error (NRMSE) and Nash-Sutcliffe index (NS). According to the results, among the two temperature methods Blaney-Criddle method with the NRMSE is in the range of 0-20%, R^2 and Nash-Sutcliffe are, close to the optimal value of one for maize and wheat in parameter simulation are acceptable. About radiation methods, the Priestley-Taylor and the Turc methods in simulation of maize yield. Also about radiation methods for wheat, the Turc and the Makkink method for simulation of yield are desirable.

Introduction

The severe reduction of water resources, climate changes and the subsequent policies to reduce the water allocated to the agricultural sector have made the management of water consumption in this sector of special importance. Water management use in agriculture is impossible without paying attention to the relationship between water, soil and plants. Because field experiments require spending time, money and energy, and also due to the limitation of these experiments to the physical conditions of the farm, the short duration of the experiment, and the limitation in the number of scenarios that are examined by the experiment, the use of models and software in water and soil relations have been developed (Russo and Bakker, 1986). The AquaCrop model is a plant model that is developed by FAO.

Also, evapotranspiration is one of the main components of the hydrological cycle. The correct estimation is more important for the design and management of irrigation systems, studies of water resources, and other similar cases. Due to the importance of evapotranspiration and its various applications in different sciences, calculating its amount, especially potential and actual evapotranspiration, are of great importance. In the field of calculating evapotranspiration and the effect that different calculation methods have on yield, biomass, and net irrigation water requirement, many studies have been conducted in the world including Iran. Based on the results of a study conducted by Safari et al. (2022) to calibrate and modify the coefficients of the equation for estimating evapotranspiration on four synoptic stations in Iran with arid, semi-arid, humid, and semi-humid climates, the Blaney-Criddle method was selected as the superior method for calculating ET at all four climates. In another study, three methods (Blaney-Criddle, Thorent-White, and Hargreaves-Samani) were compared to estimate the potential ET in Omidieh city. Standard error with the FAO-56 method was more accurate in estimating potential evapotranspiration (Asareh and Davoudi, 2014).

Abdollahzadeh et al. (2019) determined the actual evapotranspiration rate and net irrigation water requirement of wheat, barley and maize in Moghan plain by the AquaCrop model and compared the results with the CropWat and the NetWat models. Based on the results, evapotranspiration and water requirement of the AquaCrop model are lower compared to the CropWat and the results are higher than the NetWat for wheat and maize and less for barley. In a study, Meban et al. (2013) confirmed the effectiveness of the AquaCrop model on maize in Pennsylvania, they reported that the AquaCrop model overestimated for simulation of evapotranspiration of maize and the reason for this overestimation is related to errors in estimating hydraulic factors included FC and WP. Also in simulation of evapotranpiration of maize with the AquaCrop under different texture and soil fertility conditions was reported that the model had moderate efficiency in this field. The efficiency of the model in simulation of evapotranspiration of maize in loam soil was better than the two textures of silty-clay-loam and sandy-loam and the efficiency of the model decreased with the application of fertility stress (Ghorbanian Kurd Abadi et al., 2015). Also, the AquaCrop model for sunflower in Khuzestan province was studied and the results showed that this model simulates crop yield with high accuracy (Haydarinia et al., 2012). This model for maize in Qazvin region was calibrated by Rahimi Khoob et al. (2014). Based on their results, the average model error was determined to be about 10%.

In a study conducted by Jorenush et al. (2019) to simulate wheat yield and determine the date of cultivation in Fars province by the AquaCrop, the results showed that the model has high accuracy in simulation of canopy cover, biomass and grain yield of wheat. The results of a study in Delhi, India showed that the AquaCrop model has acceptable accuracy in simulation of grain yield, biomass and water use efficiency in cultivars of resistant and non-resistant wheat to salinity. In this study, it was found that the ability of the model to simulate performance is more than the other two parameters (Kumar et al., 2014).

The purpose of this research is to evaluate the AquaCrop model in the simulation of maize and wheat yield and to investigate the effect of different estimation methods of evapotranspiration in this simulation. Considering that limited studies have been conducted in this regard in the world, the evaluation of the AquaCrop model, as a plant model, in the climatic conditions of Iran is one of the innovations of this research.

Materials and Methods

In this research, Iran was classified into 4 different climates based on the Köppen climate classification (arid, humid, semi-arid and semi-humid) and the cities of Yazd, Rasht, Mashhad, Qazvin and Urmia as the representatives of this climate, respectively, selected and their meteorological data were used. The characteristics of meteorological stations are presented in Table (1).

The equations used to estimate of reference evapotranspiration in this study are from temperature groups: Hargreaves-Samani (H.S) and Blaney-Criddle (B.C) and the radiation group: Priestley-Taylor (P.T), Turc (T) and Makkink (Mak) were selected. The original form of the equations is presented in Table (2).

Reference evapotranspiration data as model inputs are required to run the AquaCrop model. For this purpose, meteorological variables received: maximum and minimum air temperature, maximum and minimum relative humidity, sunny hours, rain and wind speed at a height of two meters above the ground from Urmia, Rasht, Qazvin, Mashhad and Yazd stations from 1980/1/1 to 2020/12/31 and reference evapotranspiration was calculated by the methods mentioned in the table above (Tables 3).

Due to the insufficiency of lysimetric data, the FAO-Penman-Monteith (FAO-56) method, due to its high accuracy in estimation of reference evapotranspiration, is used to estimate observatory data and validation.

Introducing the AquaCrop model

The basis for estimating crop performance in the AquaCrop model is the Doorenbos-Kassam relationship, which is presented in issue 33 of the Food and Drainage Journal of the Wirld Food Organization (FAO). Modifications such as the separation of actual evapotranspiration (ET) evaporate from the soil surface (Es) and transpiration (Ts), as well as yield to biomass (B) and harvest index (HI) have been inferred (Raes et al., 2012):

$$\left(1-\frac{Y}{Y_x}\right)=K_y\left(1-\frac{ET}{ET_x}\right) \quad (1)$$

Where Y_x: maximum yield, Y: actual yield, ETx: maximum evapotranspiration, ET: actual evapotranspiration, and Ky is the ratio between the relative decrease in yield and evapotranspiration. Model inputs include four categories of meteorological, plant, management, and soil information.Table (4) shows the required data for each section.

Table 1- Details of meteorological stations studies

Station	Climate	Latitude	Longitude	Elevation (m)
Urmia	semi-humid	37° 40´	45° 3´	1328
Rasht	humid	37° 19´	49° 37´	-8.6
Mashhad	semi-arid	36° 16´	59° 38´	999.2
Qazvin	semi-arid	36° 16´	50° 0´	1279.1
Yazd	arid	31° 54´	54° 17´	1237.2

Table 2- Equations used in research

Number	name of Eq.s	Equation form	Reference
1	FAO-56	$ET_O=\frac{0.408\Delta(R_n-G)+\gamma(\frac{890}{T+273})U_2(e_a-e_d)}{\Delta+\gamma(1+0.34U_2)}$	Allen et al., 1998
2	Hargreaves-Samani	$ET_O=0.0023R_a\sqrt{T_{max}-T_{min}}(T_{mean}+17.8)$	Hargreaves and Samani., 1985
3	Blaney-Criddle	$ET_O=a+b(P(0.46T_{mean}+8.13))$	Blaney and Criddle., 1950
4	Priestley-Taylor	$ET_O=1.26(\frac{\Delta}{\Delta+\gamma})(\frac{R_n-G}{\lambda})$	Priestley and Taylor., 1972
5	Makkink	$ET_O=0.61\left(\frac{\Delta}{\Delta+\gamma}\right)\left(\frac{R_s}{2.45}\right)-0.12$	Makkink, .1957
6	Turc	$ET_O=0.013\frac{(23.89R_s+50)T_{avg}}{(T_{avg}+15)}$	Turc., 1961

Table 3- Average of 40-years data climate in each stations

Station	Tmax (°C)	Tmin (°C)	Wind speed (m/s)	Rain (mm)	Umax (%)	Umin (%)	Sunny hours (hour)
Urmia	18.01	5.29	1.88	293.36	78.72	39.40	7.99
Rasht	21.05	12.51	1.25	571.67	96.13	65.75	4.70
Mashhad	22.09	8.70	2.33	148.96	70.58	33.33	8.02
Qazvin	21.45	7.09	5.93	226.11	75.02	31.49	5.78
Yazd	27.24	17.43	2.42	25.22	43.61	17.53	9.09

Table 4- AquaCrop model input data.

AquaCrop model inputs			
Soil data	Management data	Crop data	Climate data
Soil profile	Irrigation management	Fixed parameters	Precipitation
Groundwater	Field management	User specific parameters	Minimum temprature
			Maximum temprature
			Daily potential evapotranspiration (ET_P)
			Concentration of carbon dioxide in the atmosphere (CO_2)

The most important climatic data required for the model are minimum, maximum and average daily temperature, reference plant evapotranspiration (ET_o) and precipitation. The model uses maximum and minimum daily temperature data to calculate the degree of growth day to moderate biomass crop due to frost damage. Data on daily temperature, daily precipitation and all the information needed to calculate ET_o from data of 1980-2020 in Qazvin, Rasht, Urmia, Mashhad and Yazd stations and ET_o Calculated by the methods mentioned in Table (2).

Statistical evaluation criteria

In this study, the results of the scenarios with the data of the mentioned stations for two maize and wheat crops, by error statistical criteria including determination coefficient (R^2), normal root mean square error (NRMSE) and Nash-Sutcliffe index (NS) were compared.

Explanation coefficient is one of the most important criteria for evaluating the relationship between two variables x and y, which is displayed dimensionless. This coefficient is directly related to the correlation coefficient. In this way, by taking the square root of the determination coefficient, the correlation coefficient between the two series can be obtained. As with the correlation coefficient, the closer the value of the coefficient of explanation is to one, the stronger the relationship between the two variables. If the determination coefficient is multiplied by 100, the value obtained represents the variance of the variable x, described by the variable y. The Pearson coefficient classification is given in Table (5) (Joinior et al., 2017).

Excel software was used to calculate the explanation coefficient. The NRMSE index indicates the level of estimation. The NRMSE classification by Jamieson et al. (1991) is given in Table (6) (Jamieson et al., 1991).

$$\mathrm{NRMSE} = \frac{1}{\bar{O}}\sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}} \quad (2)$$

Table 5- Classificatin of Pearson coefficient.

R^2	0.1>	0.1-0.2	0.2-0.5	0.5<
Estimation result	Not correlated	Weak	Moderate	Strong

Table 6- Classification of simulation results based on NRMSE

NRMSE (%)	0-10	10-20	20-30	>30
Estimation result	Excellent	Good	Moderate	Weak

The Nash-Sutcliffe coefficient is one of the most common indicators used to evaluate the performance of hydrological models (Nash and Sutcliffe, 1970). This standard state index is a function of the least-squares error:

$$NS = 1 - \frac{\sum_1^N (ET(Sim) - ET(Obs))^2}{\sum_1^N (ET(Obs) - \overline{ET(Obs)})^2} \quad (3)$$

The range of changes of this index is from -1 to +1 and the optimal value of this index is one. Based on various studies in this field, as the studies of Gassman et al. (2007), if the value of the Nash-Sutcliffe coefficient is higher than 0.5, it has a good simulation model.

Results and Discussion

In this study, yield of maize and wheat were simulated with the AquaCrop model and the effect of different methods of estimation of ET on this parameter was evaluated. In the following, the statistical study of these two parameters in wheat and maize are discussed separately.

Maize

The results of evaluating the yield of datasets with synoptic stations from 1980 to 2020 for maize are presented in Figures (1) to (5). Based on the results of the temperature methods, Blaney-Criddle method in Urmia station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Rasht station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Mashhad station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Yazd station with R^2 equal to 0.98, excellent NRMSE and Nash-Sutcliffe index of 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 are the priority for simulation and evaluation of the yield of maize. About the radiation methods, the Turc method in Urmia station with R^2 equal to 0.99, excellent NRMSE (0.49) and Nash-Sutcliffe index of 0.99 and Rasht station with R^2 equal to 0.99, excellent NRMSE (0.2) and Nash-Sutcliffe index of 0.99 are the priority for simulation yield of maize. Priestley-Taylor method in Mashhad station with R^2 equal to 0.99, excellent NRMSE (1.28) and Nash-Sutcliffe index of 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE (2.89) and Nash-Sutcliffe index 0.99 is the priority. Also, the Turc method in Yazd station with R^2 equal to 0.97, excellent NRMSE (2.46) and Nash-Sutcliffe index 0.99 is the priority for simulation and evaluation yield of maize.

According to a study evaluated radiation and humidity methods for estimation of reference evapotranspiration in Golestan province, showed that Makkink, Turc, Jensen-Haise and radiation methods, respectively, have a good daily estimation of ETo and humidity methods will have good results if they are corrected (Sharifian et al., 2005). As a result of the research conducted in India with the accuracy of AquaCrop, it was reported that the acceptable model simulated biomass, grain yield and water consumption efficiency of maize in different regimes of irrigation water and nitrogen fertilizer. The best prediction of the model was made in the treatment of full irrigation and consumption of 150 kg/ha of pure nitrogen (Abedinpour et al., 2012). Also, in another study in the center of Portugal, this model predicted maize evapotranspiration, soil water balance, biomass, and yield in fully irrigated and under-irrigated conditions with high accuracy (Paredes et al., 2014).

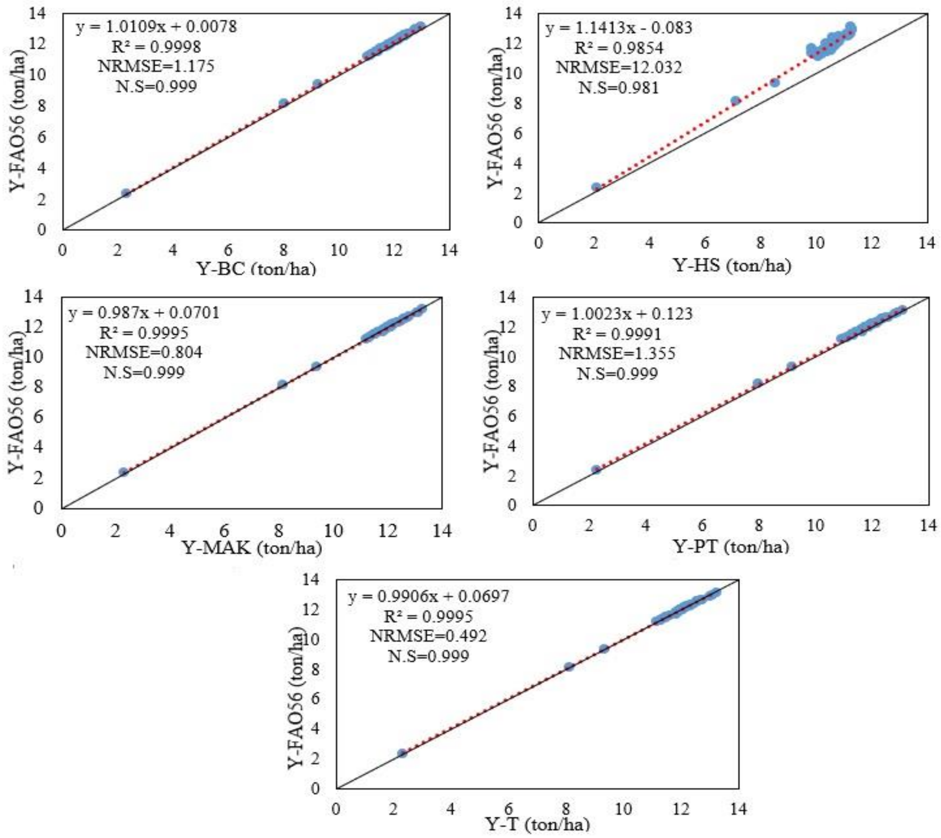


Fig. 1- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Urmia station.

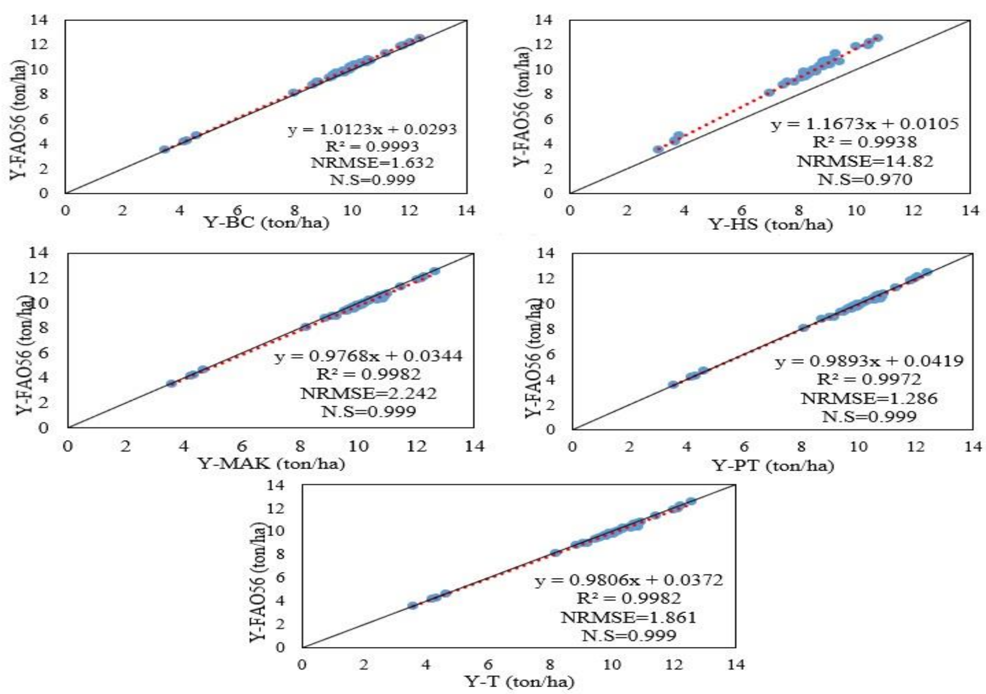


Fig. 2- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Mashhad station.

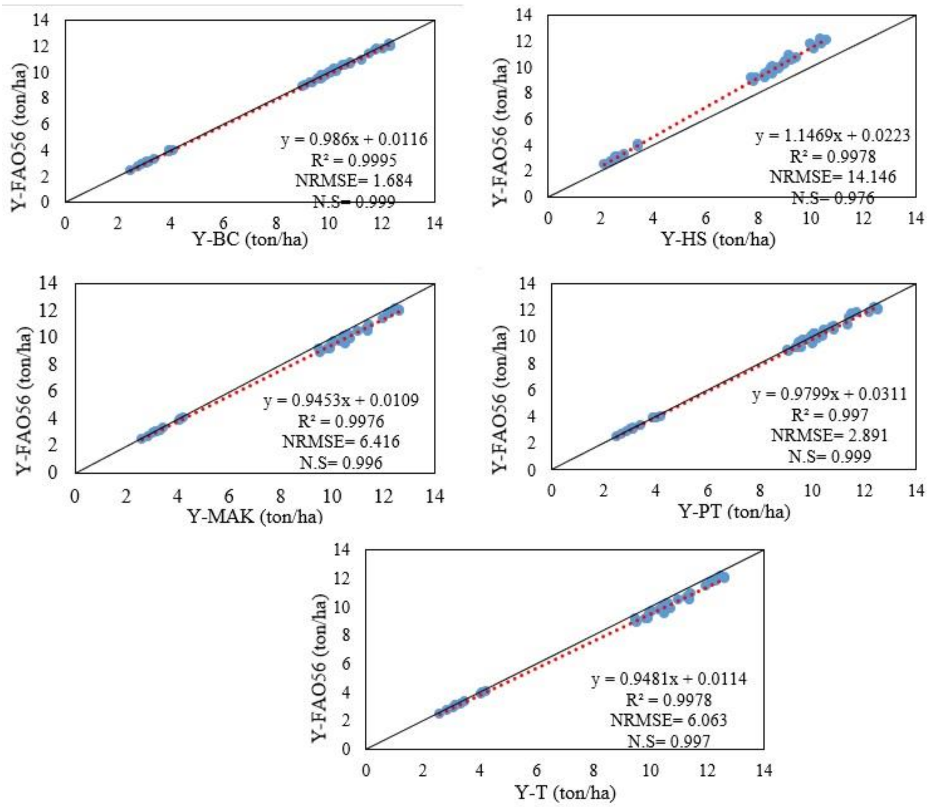
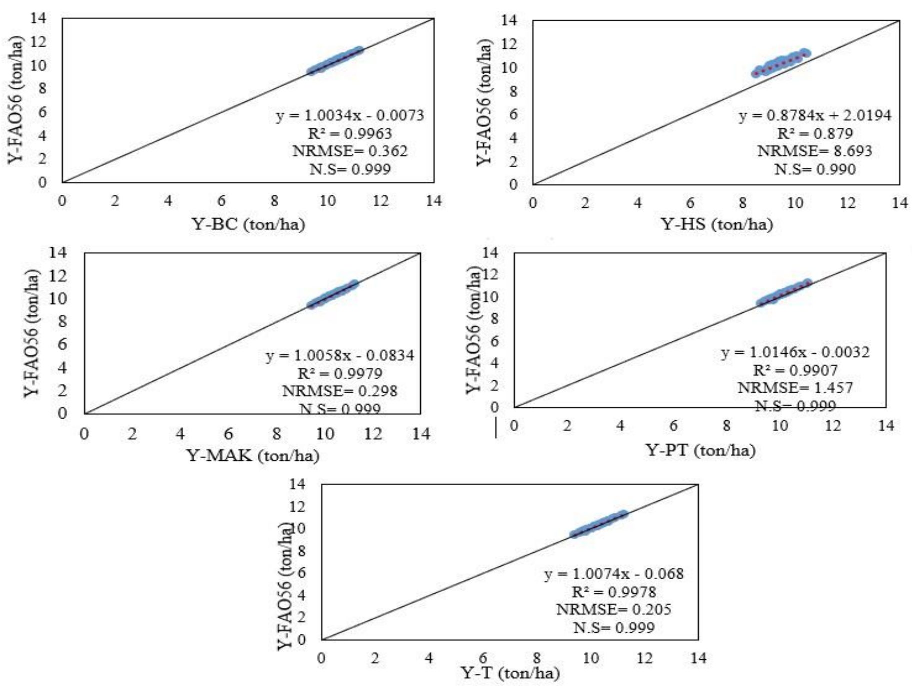


Fig. 3- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation



of ET in Qazvin station.

Fig. 4- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Rasht station.

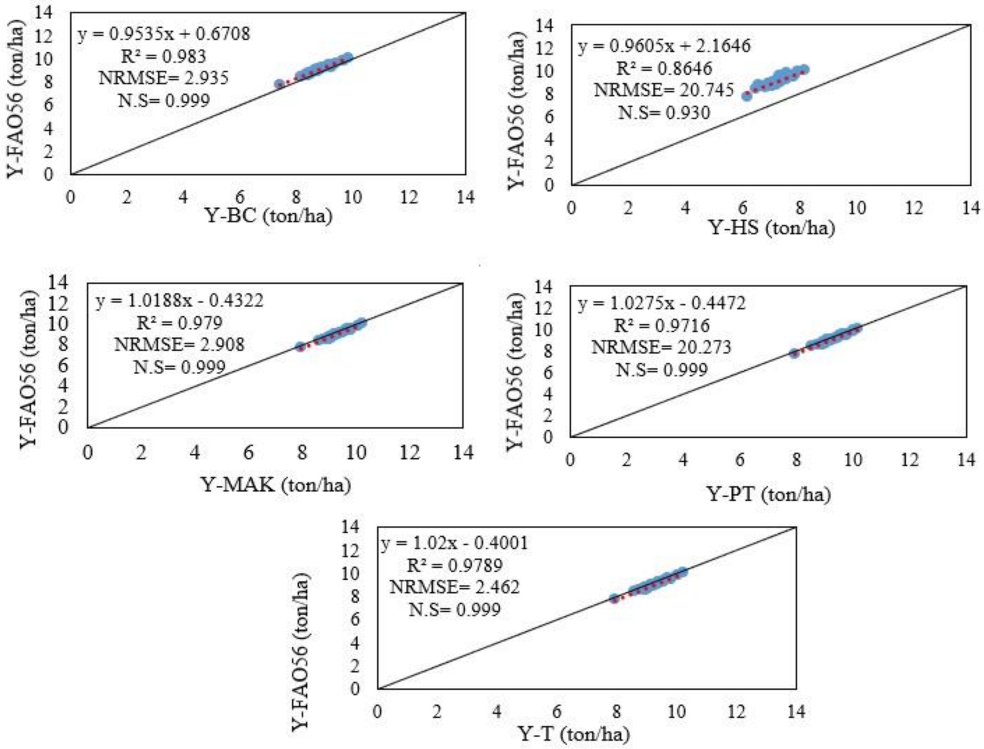


Fig. 5- Comparison of maize yield simulated by the FAO-56 method and different methods of estimation of ET in Yazd station.

Wheat

The results of evaluating the yield of datasets with synoptic stations from 1980 to 2020 for wheat are presented in Figures (6) to (10). Based on the results of the evaluation of wheat, among the temperature methods, the Blaney-Criddle method in Urmia station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Rasht station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99, Mashhad station with R^2 equal to 0.98, excellent NRMSE and Nash-Sutcliffe index of 0.99, Yazd station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 is the priority for simulation and evaluation of yield of wheat.

Among the radiation methods, the Turc method in Urmia station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 and Makkink method in Rasht station with R^2 equal to 1, excellent NRMSE and Nash-Sutcliffe index of 1 is the priority for simulation of the yield of wheat. Makkink method in Mashhad station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index 0.99 and in Qazvin station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index 0.99 is the priority. Furthermore, the Turc method in Yazd station with R^2 equal to 0.99, excellent NRMSE and Nash-Sutcliffe index of 0.99 is the priority for simulation and evaluation of the yield of wheat. In general, the Blaney-Criddle is a good method for the simulation of yield. Also, about radiation methods, Makkink and Turc methods are suitable for the simulation of yield of wheat in all the investigated stations.

Pashakhah et al. (2014) examined the reference evapotranspiration by the Blaney-Criddle, Hargreaves and Thorent-White methods for different climates of Iran based on the UNESCO climate in comparison with the FAO-56 standard method. Their results showed that the Blaney-Criddle method has the best estimation in arid, semi-arid and humid climates. The results of this study remarked that in the studied climates, due to the lack of access to the required data, it is not possible to estimate the reference evapotranspiration by the FAO-56 method, using the calibrated equations can be made similar estimates.

Iqbal et al. (2014) calibrated the AquaCrop version 1/3 of the winter wheat crop in the North China Plain. The results showed that the biomass yield under different irrigation conditions is estimated with appropriate accuracy by the model. The AquaCrop model has been evaluated for several products and some regions of Iran. This model provided acceptable results for predicting wheat and soybean yield in low irrigation conditions in Karaj region (Alizadeh et al., 2010; Babazadeh and Sarai Tabrizi, 2012). The results of a study conducted in Zahedan synoptic station showed that methods based on mass transfer had showed the statistically weakest performance compared to other methods with the standard method of the FAO-56; But temperature and radiation methods such as Turc, Jensen-Haise, Hargreaves and Blaney-Criddle methods can be a good alternative to the relatively complex FAO-56 hybrid method for the hot and dry climate of Zahedan (Kahkhamoghadam, 2017). Based on these studies, the results obtained in this research can be mentioned.

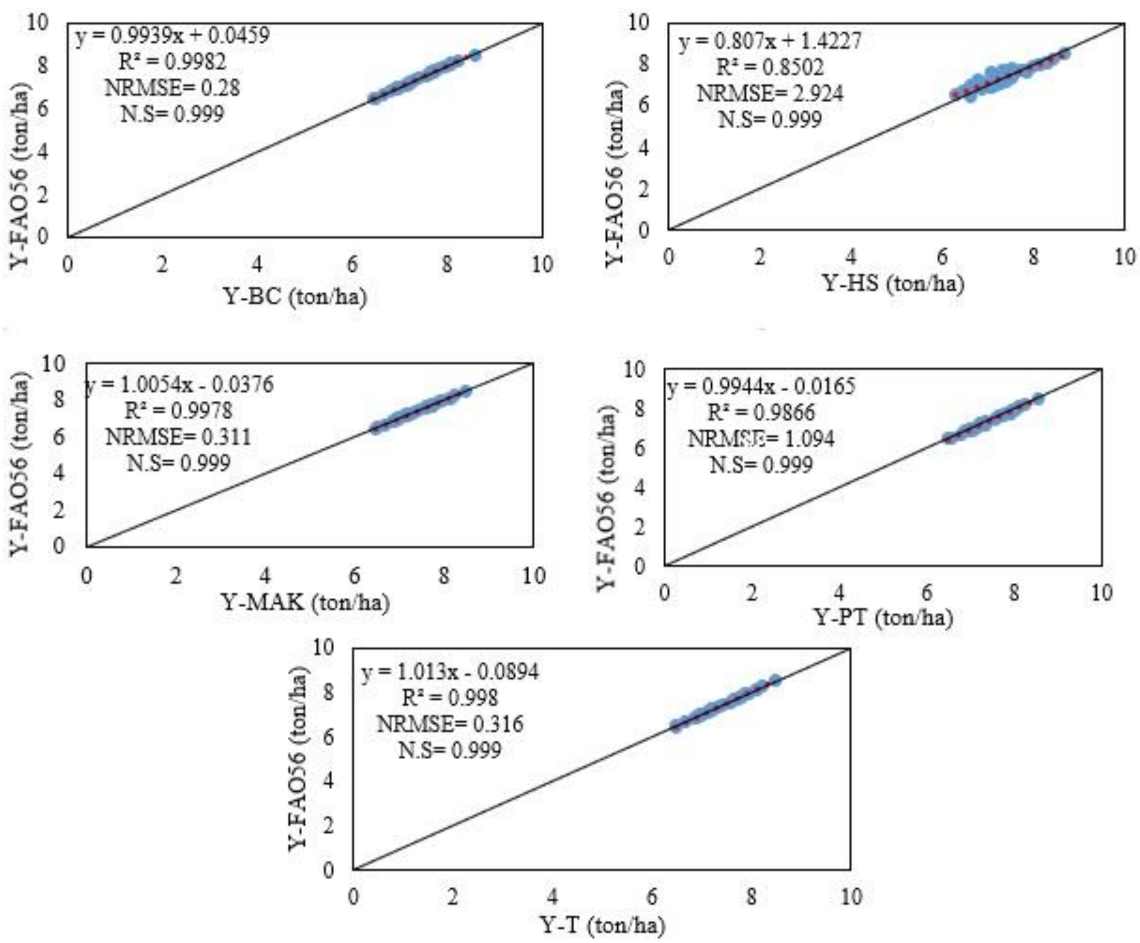


Fig. 6- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Urmia station.

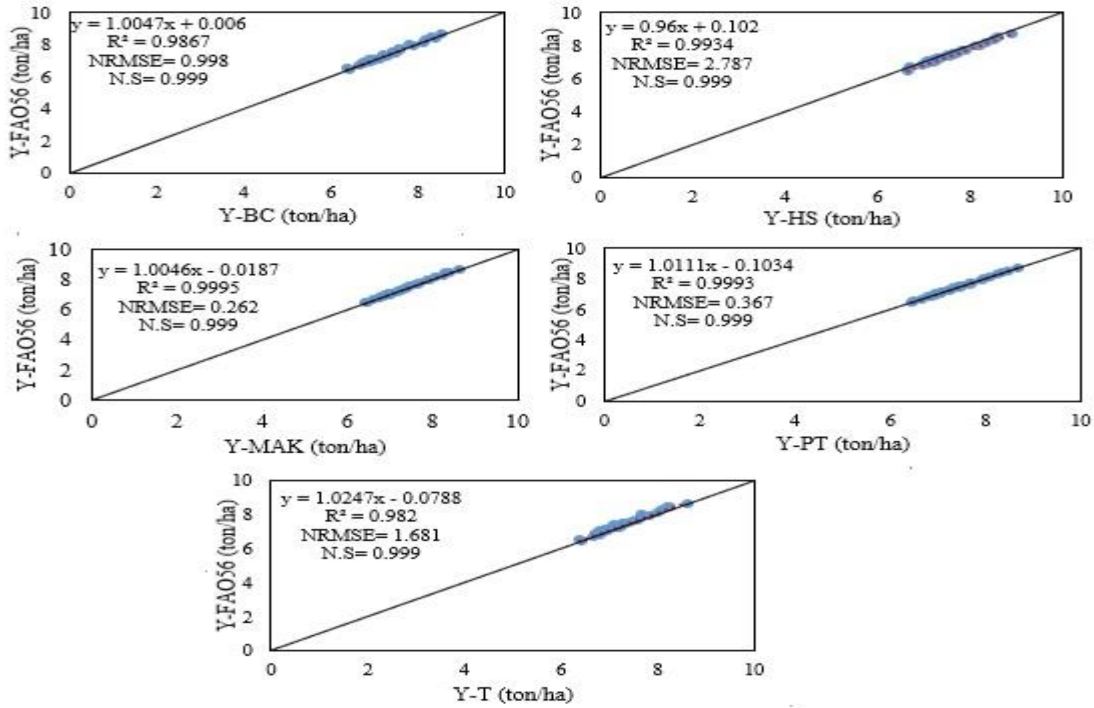


Fig. 7- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Mashhad station

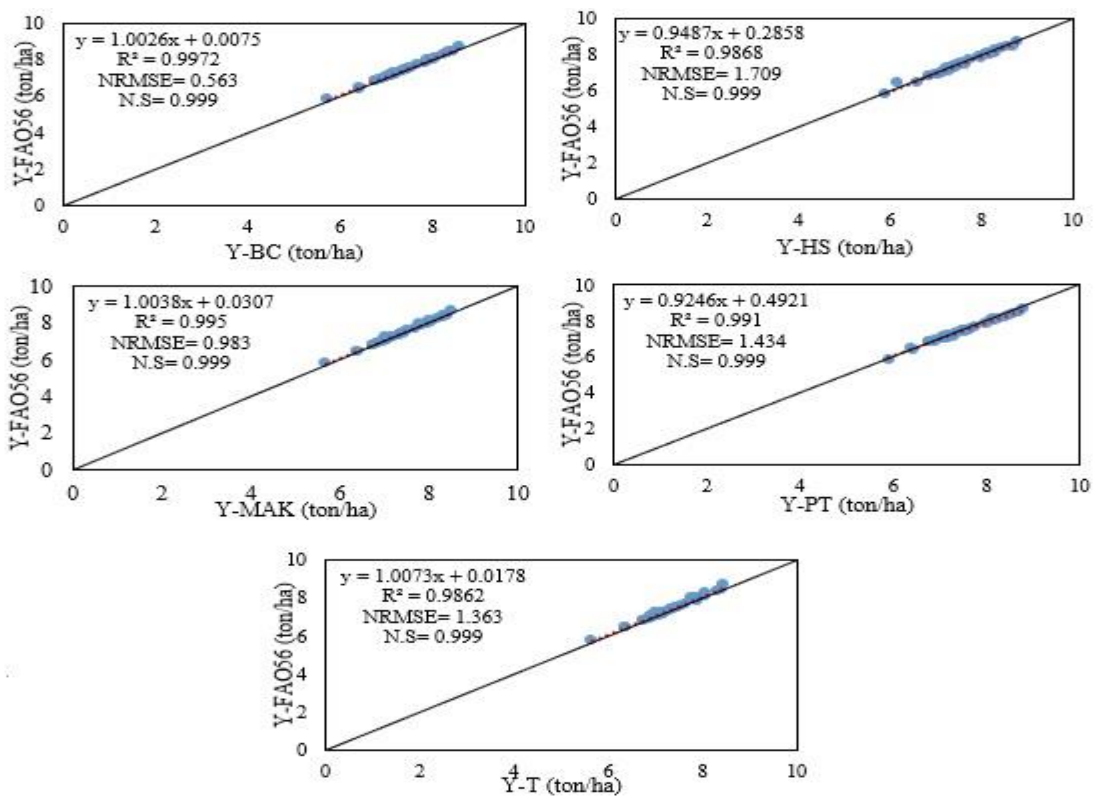


Fig. 8- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Qazvin station.

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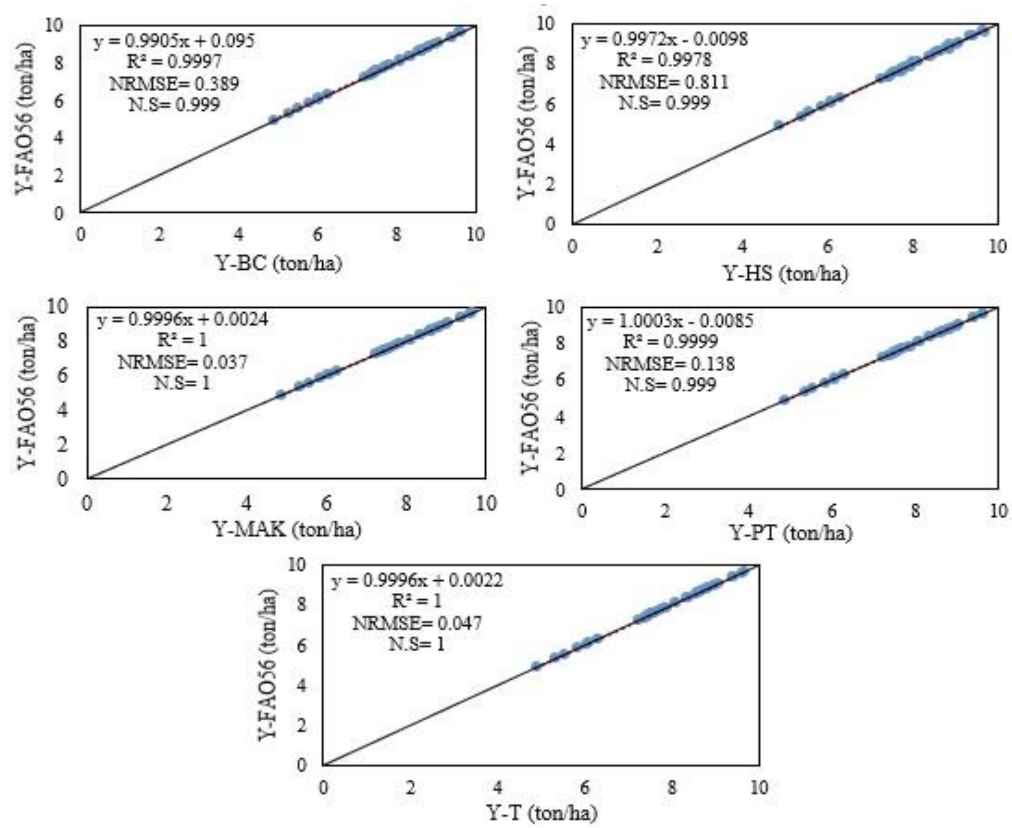

Fig. 9- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Rasht station.

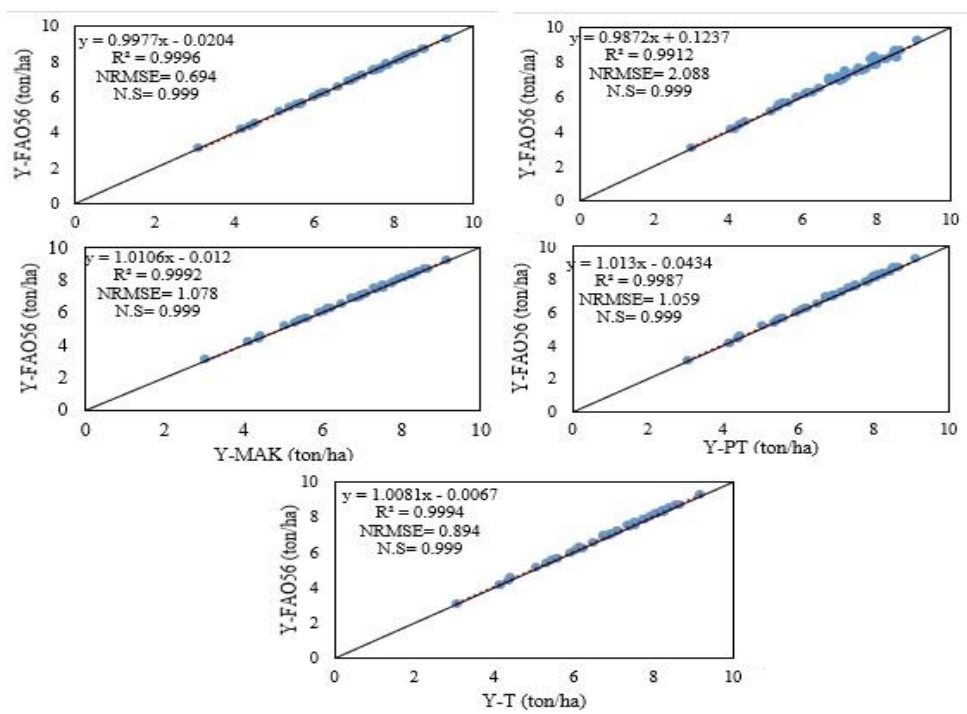

Fig. 10- Comparison of wheat yield simulated by the FAO-56 method and different methods of estimation of ET in Yazd station.

Conclusion

Evaluation of the AquaCrop model for common plants in a region plays an important role in comparing crop yield in different conditions. Wheat and maize are important crops in Iran. In this research, the ability of the AquaCrop model to simulate wheat and maize yields and the effect of different methods of evapotranspiration estimation in five cities of Iran were investigated. Based on the results of model accuracy to simulation, between the two temperature methods Blaney-Criddle method with the NRMSE is in the range of 0-20%, R^2 and Nash-Sutcliffe are close to the optimal value of one for maize and wheat in parameter simulation are acceptable. About radiation methods, the Priestley-Taylor and the Turc methods in simulation of maize yield. Also about radiation methods for wheat, the Turc and the Makkink methods for simulation of yield are desirable.

In general, among the investigated methods, the Blaney-Criddle method as a temperature method and the Turc method as a radiation method are suitable for simulating yield in these areas and provide acceptable results.

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Effect of rotational tillage regimes on water-use efficiency and yield of wheat under corn–wheat cropping system (Case Study: North China Plain)

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Abstract

Tillage practices have been widely acknowledged to play a critical role in optimizing water use efficiency (WUE) for winter wheat production in the Northern China Plain (NCP) where drought is a critical limiting factor. Therefore, the WUE of wheat as influenced by annual rotational tillage under the corn–wheat cropping system during 2016–2018 has determined. The tillage regimes in the corn season were either N: no–tillage or SR: sub–soiling with rotary tillage). One of three regimes, sTR: strip rotary tillage; R: rotary tillage; and SR: sub–soiling with rotary tillage) were the tillage practices in the wheat seasons. Thus, making a total of 6 treatments. N–SR markedly decreased the penetration resistance, while the soil water storage was enhanced in the 60-100 cm layer during the wheat season, over both years. On the other hand, the use of SR during the wheat-growing season increased evapotranspiration. Compared with other tillage practices, the photosynthesis rate enhanced under the N–SR. As a result, the highest yield and WUE of wheat were recorded in the N–SR regime. Our findings suggest that no–tillage in the corn season and sub–soiling with rotary tillage in the succeeding wheat season can improve wheat yield by promoting deep soil water, enhancing the leaves photosynthesis rate and increasing WUE.

Introduction

The North China Plain occupies nearly 20% of China's total cropland and produces about a quarter of all grain output (Zhao et al., 2013). It contributes massively to China's food security and is a key area for winter wheat production (Wang and Li, 2018). However, the annual precipitation of 90 mm to 300 mm is insufficient to meet the water needs of the crop (Wu et al., 2006). The high water demand of wheat cropping systems and the inadequate rainfall put enormous pressure on the irrigation system making the cultivation of wheat in the NCP even more challenging (Zhang et al., 2017).

In the NCP, winter wheat production is threatened by drought. One important management practice for ameliorating the impact of drought on wheat production is tillage practices (Shi et al., 2016). Because tillage practices have profound impacts on the soil properties, it has strong implication for the conservation of soil water and productivity of crops, particularly in drought-prone regions (Garcia-Franco et al., 2015; Latifmanesh et al., 2016; Shi et al., 2016). Generally, no-tillage and reduced tillage practices are commonly suggested for the protection of the soil structure and enhancement of soil fertility (Su et al., 2007; Sun et al., 2016; Wang et al., 2006). Meanwhile, sub-soiling tillage can boost soil properties, water and fertility statuses of croplands, compared with conventional tillage practices (Su et al., 2007). Under arid conditions, Li et al. (2006) and Zheng et al. (2014) recommended no-tillage and sub-soiling tillage for water conservation, improving the chlorophyll contents of flag leaves, net photosynthetic rates and consequently higher crop yield. By reducing the seasonal evapotranspiration, no–tillage and reduced tillage and mulching can improve WUE (Jemai et al., 2013; Sainju et al., 2011; Verhulst et al., 2011) while as much as 90% of rainfall can be retained in soil following by deep tillage (Wang et al., 2002).

In the NCP, several studies have reported the impacts of tillage on soil characteristics, crop productivity and resource use efficiency. Soil sub-soiling and ridge tillage were found to have improved soil moisture, facilitate root development and photosynthesis, enhance resilience of maize to extreme temperature, and increase grain output (Tao et al., 2013). Following plow tillage in the corn season, root parameters and water use efficiency improved while penetration resistance and soil bulk density were reduced (Guan et al., 2015). However, these reports have focused mainly on single cropping systems or one of multiple cropping cycles (Guan et al., 2015; Tao et al., 2013). Less has been documented on the additive impact of corn and wheat season tillage regimes on the productivity of the wheat in the succeeding season. Considering that the NCP contributes about 50% to China's total wheat production (Fang et al., 2010a), it is beneficial to understand how the choices of tillage practices in corn and wheat season impact wheat yield. Accordingly, the objective of this study is to determine the effects of corn season tillage practices on: (i) soil penetration resistance, (ii) soil water storage, (iii) evapotranspiration, (iv) photosynthetic rate, (v) WUE, and (vi) yield of wheat.

Materials and Methods

Site Description

The experiment was carried out at the Institute of Agricultural Science of Dongping County near the Dongping Lake, Dongping (35°54′30″N 116°18′00″E, 35.937°N 116.470°E) (fig. 1), stands 377 meters above sea level, in the southwestern part of Tai'an, in the west of Shandong Province, China. Here, the traditional cropping pattern is corn- wheat cropping with no–tillage and rotary tillage regimes in the corn season and wheat seasons, respectively. The precipitation amounts to 609.2mm annually and the wettest months are between April and August. Meanwhile, the average annual temperature is about 14.4 °C. During the 2016–2017 and 2017–2018 growing cycle of wheat, the total precipitation was 156.9 and 104.9 mm, respectively. The soil is categorized as cumulated irrigated fluvo–aquic soil according to the classification system of the United States Department of Agriculture (USDA) (Soil Survey Staff 1999). At initial total N, available N, soil organic matter, available potassium and available phosphorus of the soil at the depth of 0–20 cm were 1.2 g kg^{-1}, 104.9 mg kg^{-1},18.6 g kg^{-1}, 108.7 mg kg^{-1} and 40.5 mg kg^{-1}, respectively.

Experimental Design and Management

The field experiment was first set up in the 2012–2013 cropping season. In the wheat season of 2012, three tillage practices i.e. strip rotary tillage (sTR), rotary tillage (R), and sub–soiling with rotary tillage (SR), were designed. Meanwhile, two additional tillage regimes, i.e. no–tillage (N) and sub–soiling with rotary tillage (SR), were established in the succeeding corn season in the next year. In all, our treatments were: N–sTR; N–R; N–SR; SR–sTR; SR–R; and SR–SR for the entire corn-

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wheat cropping. Each of the plots, including the three replications of each treatment, had a dimension of 55 m × 5.2 m, and was arranged in a completely randomized design.

Each year, the straw obtained after the harvest of wheat and corn were returned into the soil as described (Table 1). Jimai 22 was the wheat cultivar of choice for this experiment. The planting dates of the wheat was October 10th, 2016 and 2017, harvesting dates was June 15th, 2017 and 2018. We applied 60% of the nitrogen fertilizer (135 kg N ha−1) as basal fertilizer while the rest (90 kg N ha−1) was applied as top dressing at the jointing stage. In the case of the potassium and the phosphorus fertilizers all the allocated quantities, 77 kg K2O ha−1 and 130 kg P2O5 ha−1, respectively, were applied at once as basal fertilizer.

Fig. 1- Digital elevation model (DEM) of Dongping County

Table 1- Operational procedure of different tillage treatments during corn and wheat seasons

	Corn planting tillage practices		Wheat planting tillage practices	Treatments
N	Returning wheat straw to the field, base fertilizer spread and seeding with common seeder without any soil disturbance.	sTR	Returning corn straw to the field, the strip rotary tillage only on wheat sowing row (15 cm in depth) and base fertilizer spread simultaneously one time.	N-sTR
		R	Returning corn straw to the field, base fertilizer spreading, completely rotary tillage two times for wheat season (15 cm in depth), seeding with common seeder.	N-R
		SR	Returning corn straw to the field, base fertilizer spreading, sub-soiling once (35 cm in depth) followed completely rotary tillage two times (15 cm in depth), seeding with common seeder.	N-SR
SR	Returning wheat straw to the field, base fertilizer spreading, sub-soiling once (35 cm in depth) followed completely rotary tillage two times (15 cm in depth), seeding with common seeder	sTR	Returning corn straw to the field, the strip rotary tillage only on wheat sowing row (15 cm in depth) and base fertilizer spread simultaneously one time.	SR-sTR
		R	Returning corn straw to the field, base fertilizer spreading, completely rotary tillage two times for wheat season (15 cm in depth), seeding with common seeder.	SR-R
		SR	Returning corn straw to the field, base fertilizer spreading, sub-soiling once (35 cm in depth) followed completely rotary tillage two times (15 cm in depth), seeding with common seeder.	SR-SR

Fig. 2- SC-900 Field Scout Digital Soil Compaction Meter (Digital Penetrometer)

Soil penetration resistance

The soil penetration resistance (PR, MPa) was determined in the second year of the experiment. We used a digital handheld cone–tipped penetrometer (Field Scout, SC 900 Soil Compaction Meter; Spectrum Technologies, Inc., Plainfield, IL, USA) (Fig. 2) of 6.4 mm radius to measure the PR at six different points in each plot from 0–45 cm at 2.5 cm interval (Mu et al., 2016).

Soil sampling for water content

We estimated the soil water content (%) at different stages of wheat growth at a depth of 140 cm and an interval of 20 cm. Firstly, a sampling tube was used in collecting six cores (diameter: 5 cm). Then, the oven–drying approach was employed in determining the soil water content by instantaneously weighing a portion of the fresh soil, and reweighing after it attained a constant weigh following oven-drying at 105 ◦C for 48 h. We estimated the changes in the stored soil water (ΔS) by finding the difference in stored soil water in the upper 140 cm soil layers at the sowing and maturity stages. We calculated the soil water storage (SWS, mm) based on the formula given by Xu et al. (2016).

$$SWS = MWC \times \gamma \times H \quad (1)$$

where MWC represents the mass water content (g g–1), γ (g cm–3) stands for the soil bulk density, and the thickness of the soil layer is given as H (mm).

SET was calculated using the water balance equation (Wang et al., 2009) as follows:

$$SET = (RG + I + SG) - D - ROFF - \Delta S \quad (2)$$

Where:
RG is the growing seasonal rainfall (mm)
I is the irrigation amount (mm)
SG is the groundwater contribution to the plant's available water (mm)
D is the downward drainage out of the root-zone (mm)
ROFF is the surface runoff (mm), and
ΔS (mm) is the change in stored soil water in the upper 140 cm of the soil between the sowing and maturity phases.
Noteworthy, SG, D and ROFF were all negligible or insignificant because the depth of groundwater in the experiment was about 10 m below the surface, and the experimental plots were designed in such a way any entry of runoff was blocked.

Photosynthetic characteristics

The flag leaf, which is known to contribute immensely to photosynthesis was tested for the net photosynthetic rate (Pn) by using the LI-COR 6400 portable photosynthesis system (LI-COR, Inc., Lincoln, Nebraska, USA). To prevent errors caused by variation in sunlight intensity on different days, we conducted all the measurements on sunny days between 8:00 am and 11:00 am. The CO2 concentration in the leaf chamber and the light intensity of red blue light emitting diode (LED) of LI-6400 were set at 400 µmol

mol−1 and 1500 photons µmol m−2 s−1, respectively.

Grain yield

The grain yield was determined from a 2 m2 undisturbed subplot of each of the six replicate plots and was reported at moisture of 17%.

2.7. WUE

WUE was calculated using the following equation (Fang et al., 2010b):

$$WUE = Y/SET \quad (3)$$

where Y is the grain yield (kg ha−1).

Data analysis

SAS 9.2 statistical package (SAS institute Inc., Cary, NC, US) was used to carry out statistical analysis while Microsoft Excel 2010 (Microsoft Corporation, New Mexico, USA) and sigma plot Ver.12.5 (Systat Software Inc., Chicago, IL, USA) was used to make the figures. The statistical analysis of variance (ANOVA) was employed to test for differences among the treatments while the least significant difference (LSD) test used to compare the means of the treatments at $P < 0.05$.

Results

Soil penetration resistance (PR)

In 2017–2018, the PR in the 0–45 cm soil layer at the revival stage of winter wheat illustrated significant difference (Fig. 3). Under no-tillage in corn, the lowest and highest PR were observed in N-SR and N–sTR, respectively. Meanwhile, the PR of SR–sTR in the 0-33 cm soil depth was 77.5% and 94.6% higher when compared with SR–R and SR–SR, respectively.

No significant difference was noted between N–SR and SR–SR, while SR–R had 4.7% higher PR than N–SR at the 0-45 cm soil layer. The average PR of N–sTR soil was 11.2 % and 11.4% higher than SR–sTR treatment in the 0-33 cm and 0–45 cm soil depths, respectively (Fig. 3).

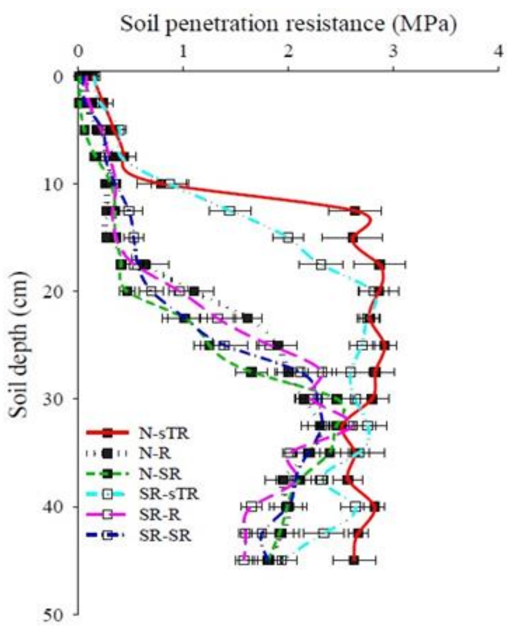

Fig. 3- Effect of different tillage practices on soil penetration resistance in 0–45 cm soil depth at revival stage of wheat season 2017–2018, N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.

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Soil water content

In both 2016–2017 Fig. (4a) and 2017–2018 Fig. (4b) wheat growing seasons, the soil water contents was significantly different in the 0–140 cm soil layers at the different wheat growing stages. At the sowing stage of both years, the top 40 cm layers of soil had higher water content under the use of no–tillage in corn and was 6.9%, 5.4%, and 6.2% higher under N–sTR, N–R and N–SR compared with SR–sTR, SR–R, and SR–SR, respectively. On the contrary, the water content in the 40–140 cm layers at the same stage, was higher under SR–tillage in corn by 6.7%, 2.2%, and 6.3% under SR–sTR, SR–R, and SR–SR, in comparison with N–sTR, N–R, and N–SR tillage practices, respectively.

At revival stage of the first year, the water content at the 0–40 cm depth was 3.3% higher in those treatments under no–tillage in the corn season, while no difference was detected in 40–140 cm. N–sTR had 15.7% higher water content at 0–20 cm soil, compared with SR–sTR but there was no difference at 40–140 cm between these two treatments. Generally, the water content at the 0–140 cm depth of the revival stage, was higher under N–sTR, N–R, and N–SR by 3.8%, 5.7% and 3.9%, compared with SR–sTR, SR–R, and SR–SR, respectively. There was no marked difference in water content noted in the second year among N–sTR and N–SR, compared with SR–sTR and SR–SR, but N–R had 2.1% and 4.4% higher water content at 0–40 and 40–140 cm, compared with SR–R, respectively.

At jointing stage in the first year, the soil moisture content of N–sTR, N–R, and N–SR were significantly higher in the 0–40 cm soil layer by 4%, 4.8% and 11.8%, compared with SR–sTR, SR–R, and SR–SR, respectively but no marked difference was seen at the 40–140 cm depth among the treatments. In the second year, we observed an insignificant reduction in the soil water content at 0–40 cm in all treatments compared with the previous year.

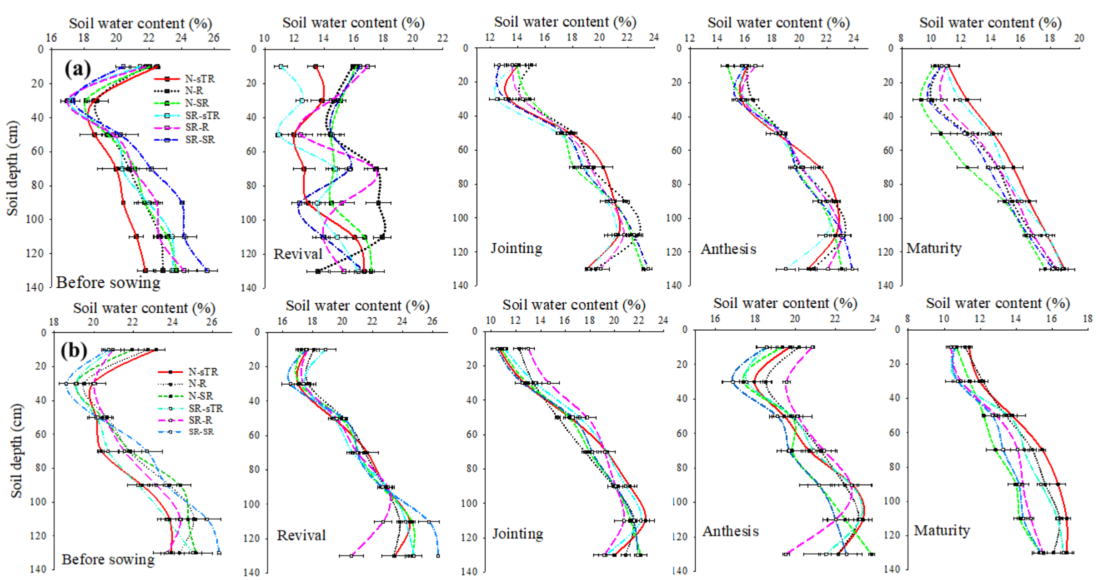

Fig. 4- Soil water content at different stage of the wheat growing season in 2016–2017 (a), and 2017–2018 (b); N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.

On comparing the treatment at the anthesis stage, no significant differences were found among them in both years but in the first year, N–sTR showed 4.3% lower water content in 40–140 cm while in the second year 4.2% higher water content compared with SR–sTR. Furthermore, in first year N–SR showed lower water content by 2.7% and 1.4%, but second–year water content was higher by 3.6% and 2.4% in 0–40 and 40–140 cm depths, in comparison to SR–SR respectively.

At maturity, both years exhibited a similar trend of water content across all the treatments. In the 0–140 cm soil depth, the highest and lowest water content were observed in N–sTR and N–SR, respectively. The moisture content of SR–SR and SR–R were higher by 5.0% and 4.9%, at the 0–40 cm layer, and also by 5.5% and 1.2% at the 40–140 cm soil layer, compared with N–SR and N–R, respectively. Overall, the water content in the 0–140 cm depth under N–sTR, SR–R, and SR–SR tillage at the maturity stage were 2.1%, 2.0%, and 5.4% more than those under SR–sTR, N–R, and N–SR, respectively (Fig. 4).

Apparent ΔS in different soil layers

In the wheat season, there were noticeable variations in the ΔS at the 0–140 cm soil layers among all six treatments (Fig. 5a & b). The ΔS in the 0–40 cm depth was 12.6%, 5.2% and 5.4% higher in the treatments N–sTR, N–R and N–SR, as against SR–sTR, SR–R and SR–SR, respectively. Elsewhere, reverse was the case at the soil depth of 40–140 cm where SR–sTR, SR–R and SR–SR were 12.3%, 33.0% and 0.8% higher than N–sTR, NR and N–SR, respectively. Together, N and SR in the corn-growing season combined with sub–soiling with rotary tillage in the wheat-growing, i.e. N–SR and SR–SR, promoted the use of the soil water resident in the deeper soil layers (60 – 140 cm) by winter wheat.

Evapotranspiration (ET) during the wheat season

The ET in the six treatments were between the range of 372.9 mm and 435.6 mm during both cropping years (Fig. 6). There was no marked difference between N–sTR and SR–sTR in the first and second year while SR–sTR was higher than N–sTR in both years. The highest ET was observed under the sub-soiling with rotary tillage in the wheat-growing season under both N and SR during the corn season, while sTR recorded the least ET in both years. Together, we can deduce that the sub–soiling with rotary tillage improved the water consumption of winter wheat in both years.

Water use efficiency (WUE)

The range of values for the WUE was between 20 kg ha−1mm−1 and 25.4 kg ha−1mm−1 (Fig. 7). Under both N and SR–tillage in the corn season, SR in wheat recorded the highest WUE, in comparison with other treatments. N–SR achieved the highest WUE at 24.3 and 25.4 kg ha−1mm−1 in the 2016–2017 and 2017–2018 growing seasons, respectively ($P<0.05$). Averagely, in both years N–sTR and SR–sTR had the lowest WUE compared with those practices under N–SR tillage, respectively. In this experiment, a strong positive relationship ($R2=0.86$– 0.90) was observed between WUE and grain yield (Fig. 8).

Fig. (9) depicts the relationship of WUE and grain yield with ΔS using regression. We found a positive correlation between grain yield and ΔS and between WUE and ΔS in the wheat-growing seasons of 2016–2017 and 2017–2018, respectively (Fig. 9).

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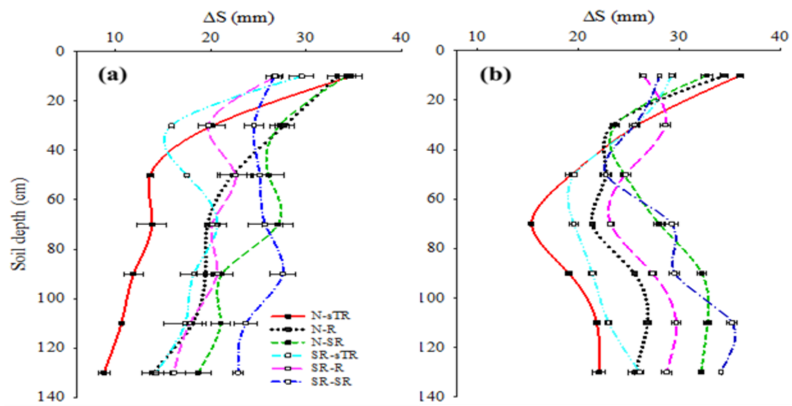

Fig. 5- Change in soil water storage (0–140 cm) under different tillage practices during wheat growing season in 2016–2017 (a) (Latifmanesh et al., 2018), and 2017–2018 (b); N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.

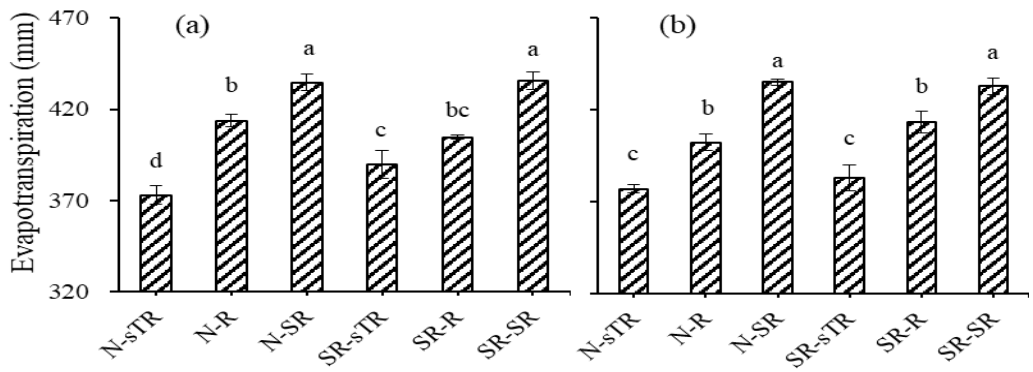

Fig. 6- Evapotranspiration during the wheat season 2016–2017 (a), and 2017–2018 (b); N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.

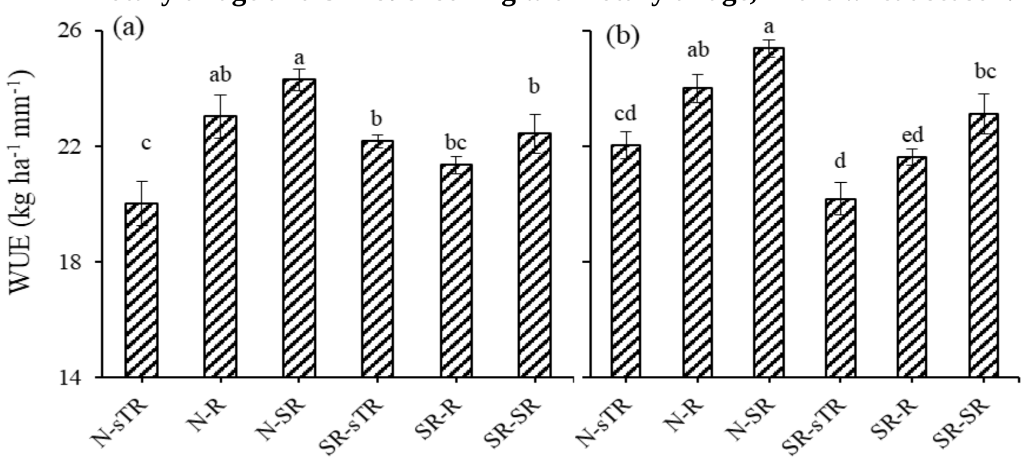

Fig. 7- Water use efficiency during the wheat season 2016–2017 (a), and 2017–2018 (b).

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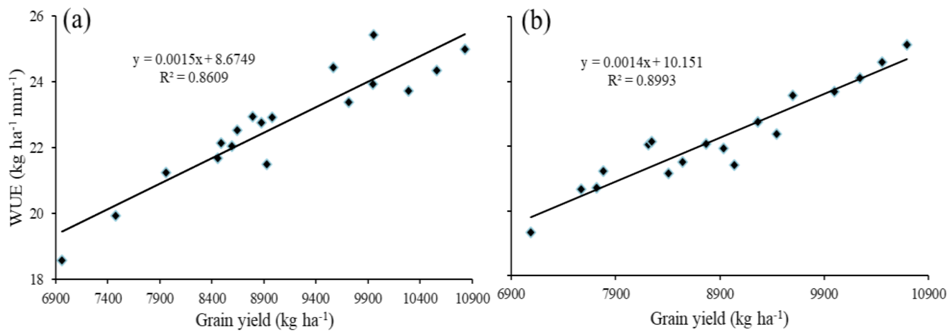

Fig. 8- Linear relationship between WUE and grain yield of wheat growing season in 2016–2017 (a), and 2017–2018 (b).

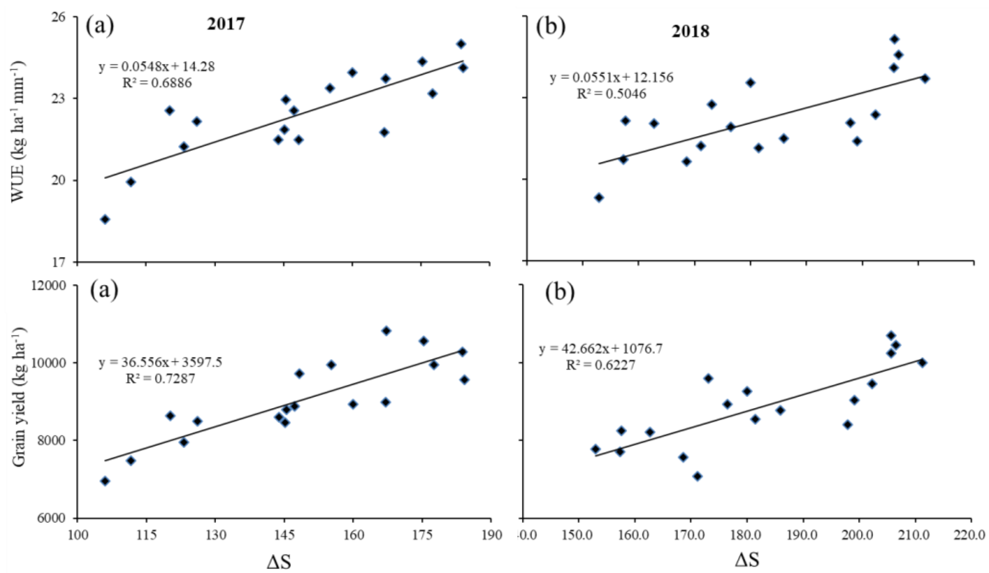

Fig. (9) Regression (polynomial) relationship between WUE and grain yield with ΔS in wheat growing season 2016–2017 (a), and 2017–2018 (b)); N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.

Consumption of different water resources of ET

In the 2016–2017 growing season, the irrigation supplied amounted to 102.4 mm with an RG of 156.9 mm while in 2017–2018 growing season, 101.3 mm was recorded with an RG of 104.9 mm (Table 2).

ET irrigation ratios in the N–SR and SR–SR were similar in both years and were the lowest among those treatments in N and SR in the corn season, respectively. This implies that SR in the wheat season can decline soil water consumption. On average, ΔS at the 0–140 cm soil depth was higher by 54.4% and 13.6% under the treatment N–SR in the first year and by 29.4% and 14.6% in the succeeding year, compared with N–sTR and N–R, respectively. Similarly, SR–SR had the highest ΔS which was higher than that under SR–sTR and SR–R by 35.0% and 21.2% in the first year and 24.3% and 8.4% in the second year, respectively.

Table 2- Effects of tillage practices on different water resources consumption amount and their ratio on ET.

Year	Tillage practices	R_G		Irrigation		ΔS	
		Amount (mm)	Ratio (%)	Amount (mm)	Ratio (%)	Amount (mm)	Ratio (%)
2016–2017	N–sTR	156.9	42.1	102.4	27.5	113.6	30.5
	N–R	156.9	37.9	102.4	24.7	154.5	37.3
	N–SR	156.9	36.1	102.4	23.6	175.5	40.4
	SR–sTR	156.9	40.2	102.4	26.3	130.6	33.5
	SR–R	156.9	38.8	102.4	25.3	145.4	35.9
	SR–SR	156.9	36.0	102.4	23.5	176.3	40.5
2017–2018	N–sTR	104.9	28.7	101.3	27.7	159.2	43.6
	N–R	104.9	27.2	101.3	26.3	179.7	46.6
	N–SR	104.9	25.5	101.3	24.6	205.9	50.0
	SR–sTR	104.9	28.3	101.3	27.3	164.2	44.3
	SR–R	104.9	26.6	101.3	25.7	188.4	47.7
	SR–SR	104.9	25.6	101.3	24.7	204.2	49.8

Abbreviation: N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.
RG: growing season rainfall (mm); ΔS: apparent change of soil water storage (mm).

Table 3- Effects of tillage practices on photosynthetic rate (*Pn*)

Year	Tillage practices	*Pn* (μmol CO_2 m^{-2} s^{-1}) DAA		
		0	10	20
2017–2018	N–sTR	21.9 b	19.2 d	18.2 c
	N–R	23.8 ab	21.3 bc	20.3 ab
	N–SR	25.6 a	23.4 a	21.7 a
	SR–sTR	21.7 b	19.9 cd	18.7 c
	SR–R	22.2 b	20.3 bcd	19.6 bc
	SR–SR	23.9 ab	21.6 b	20.9 ab

Means of each column followed by similar letters are not significantly different (5%).
Abbreviation: N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season.
DAA is days after anthesis.

Leaf photosynthetic rate (Pn)

Pn values from anthesis to twenty days after anthesis (DAA), were significantly higher under N–SR and SR–SR treatments, in comparison with other tillage practices under N and SR in the corn season ($P<0.05$). The results showed that the Pn of N–SR was markedly higher at anthesis, ten DAA, and twenty DAA by 17%, 21.6% and 18.6% compared with N–sTR, respectively. Meanwhile, the Pn under SR–SR was higher by 10% at anthesis, 8.2% at ten DAA, and 11.5% at twenty DAA, compared with SR–sTR (Table 3).

The flag leaf Pn at anthesis, ten and twenty DAA were higher by 6.9%, 8.6% and 4.0% under N–SR than SR–SR, and by 7.2%, 5.0% and 3.3% under N–R as against SR–R, respectively. We found no significant difference in the flag leaf Pn between N–sTR and SR–sTR.

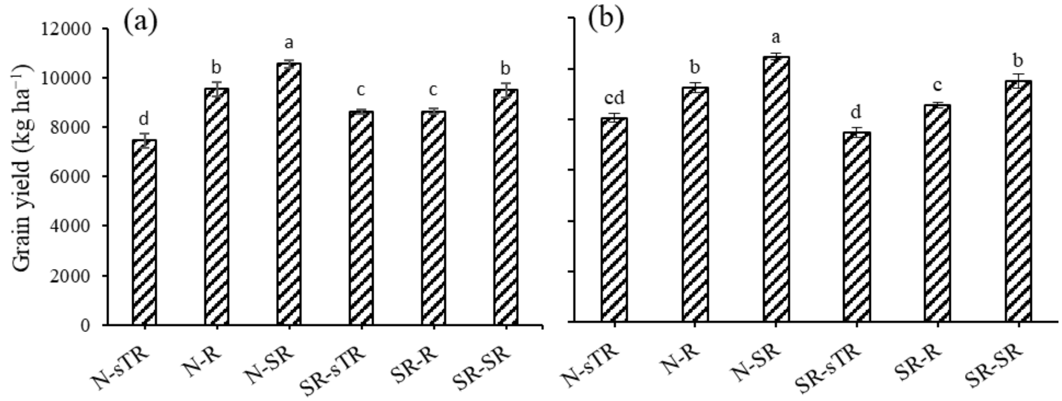

Fig. 10- Wheat grain yield 2016–2017 (a), and 2017–2018 (b)); N= no–tillage and SR= sub–soiling with rotary tillage, in the corn season; sTR= strip rotary tillage, R=rotary tillage and SR=sub–soiling with rotary tillage, in the wheat season

Tillage impacts on yield

In comparison with SR–SR and SR–R, the use of N–SR and N–R significantly increased grain yield by 10% and 9.9% in the first year and by 10.2% and 8.1% in the second year, respectively. On the contrary, there was a 6.4% decrease in grain yield under N–sTR, compared with SR–sTR tillage in the first year but increased by 7.8% in the second year (Fig. 10). On comparing the tillage practices during the wheat season under no–tillage and SR–tillage in the corn, the higher grain yield recorded under N–SR by 41.5% and 10.8% in the first year, and 29.8%, and 12.9% than N–sTR and N-R in the second year, and by 9.9% and 10% in the first year, and 27% and 10.7% in the second year under SR–SR than SR–sTR and SR–R, respectively.

Discussion

Effects of tillage practices on soil penetration resistance

Tillage practices have a notable effect on soil penetration resistance (Suci et al., 2021). In no–tillage systems, improvement in soil structure has been reported (Cavalieri et al., 2009) but long-term continuous use results in soil surface compaction leading to increase in penetration resistance (Kuhwald et al., 2020). More so, soil compaction in deeper layers restricts lateral root growth, therefore limiting the ability of plants to access the water and nutrients in the subsoil (Guan et al., 2014). In this study, the adverse impact of the no-till on penetration resistance was annulled by sub-soiling with rotary tillage in the wheat season; the effect of which could last up to 2 years before the reappearance of the plow pan (Wang et al., 2020). The better performance of sub-soiling with rotary tillage over strip rotary can be linked to its ability to impact soil properties in the deeper soil layers. Following sub-soiling with rotary tillage in the wheat season, improvement in bulk density caused the penetration resistance to decrease (He et al., 2019). Hence, the soil water supply was better regulated and the vertical distribution of nutrients was more balanced (Li et al., 2019; Pengcheng et al., 2019).

Effects of tillage practices on soil water and ΔS

Tillage practices affect the soil's physical properties resulting in changes in water cycling in the soil-plant-atmosphere continuum (Dalmago et al., 2004). In our study, the practice of no-tillage in the corn season increased soil moisture in the top 40 cm layer than sub-soiling with rotary tillage. This corroborates with the report of Li et al. (2020) in the Arid Loess Plateau in China and can be attributed to the role of corn straw as mulch; thereby, preventing the loss of soil water by evaporation and promoting water infiltration. Meanwhile, the reverse effect in the 40-140 cm layer was because the sub-soiling with rotary tillage fostered the accumulation of water in deeper soil layer while the benefit of water retention in no-tillage systems were restricted to the upper layer of the soil (Huang et al., 2012). Thus, sub-soiling with rotary tillage in winter wheat promoted water conservation in deeper layers much more than strip rotary tillage, which restricts the infiltration of water into this layer due to the hard pan of the subsoil (He et al., 2019). Sub-soiling with rotary tillage promoted water retention in this layer due to its capacity to improve infiltration by disintegrating the hardpan of the soil without disturbing the top soil (Chen et al., 2005; Rathinavel, 2020). The impact of the tillage practices was predominant and significant in the sowing stage, compared to other growth stages because the changes in the soil must have benefited the early growth of wheat which has high water demand (Noor et al., 2022).

Effects of tillage practices on WUE and photosynthesis

Variations in evapotranspiration and WUE as a result of tillage practices have been reported (Noor et al., 2022). In this study, we observed there was no notable difference in the evapotranspiration when strip tillage was applied in the wheat season regardless of the tillage practice in the corn season. Thus, the lack of residual effect of corn tillage practices on the wheat season under strip tillage infers that strip tillage without sub-soiling is unsuitable for winter wheat cultivation, particularly in Arid climates (He et al., 2019). However, when sub-soiling with rotary tillage was carried out in the wheat season, evapotranspiration was higher than strip rotary tillage. This can be linked to the potential of sub-soiling to reduce runoffs, ensuring that more water available for the wheat plant and consequently, increasing evapotranspiration and WUE (Jiao et al., 2017).

The no-tillage in corn season ensures that water is available in the topsoil and used by the crop during the early growth stages of the wheat season whereas sub-soiling in the wheat season promoted the availability of water in the deeper layer of the soil, and its utilization at the later growth stages of wheat rather than the moisture-depleted top soil (Zheng et al., 2014). By so doing, the combination of no-till in the corn season and sub-soiling with rotary tillage in the wheat season promoted water conservation, increased WUE and reduced irrigation water requirements. Meanwhile, strip rotary tillage causes the soil to loosen such that soil water is easily lost. It has been demonstrated that strip rotary as a tillage practice that is not suited to arid agroecosystems or water-deficient soils (He et al., 2020). Moreso, wheat performs poorly in loose soil due to poor contact with roots (He et al., 2020).

Since water is a raw material for photosynthesis, tillage indirectly influences the rate of photosynthesis. The no-tillage in corn season, which had the higher moisture content than sub-soiling in the top 40 cm layer, equally recorded the higher photosynthesis rate. Also, the no-tillage in corn season and sub-soiling with rotary tillage in the winter wheat ensured the diversification of water use, higher WUE, and higher rate of photosynthesis, as against sub-soiling in both seasons. This finding conforms with previous work that tillage practices, like no-tillage, promote leaf photosynthesis in wheat due to increased soil water availability (Buczek et al., 2021).

Effects of tillage practices on yield

The availability of water drives wheat production and yield in the North China Plain. Therefore, we observed significant positive correlation relationship between WUE and grain yield. Meanwhile, wheat performs poorly in soil under strip rotary tillage without sub-soiling owing to the high risk of erosion and water loss (He et al., 2020). In addition, a double sub-soiling with rotary tillage does not allow for diversification of water sources because only the water in the deeper layers is conserved while the top isn't optimized. However, the combination of no-tillage in the corn season and sub-soiling in the wheat season complement each other by ensuring the conservation of soil water in the topsoil when temperature is relatively higher in the corn season, while during a period of water scarcity, sub-soiling with rotary ensure that the top soil remains unturned, the hardpan of the subsoil is loosened and water from the deeper layer of the soil is accessible for the wheat (Qin et al., 2008). Thus, the most significant yield improvement were observed in the no-tillage and sub-soiling with rotary tillage.

Conclusion

Optimal grain production in the corn-wheat system of the NCP require that tillage practices are implemented in such a way that it benefits the succeeding crop. In this study, implementing no-tillage or sub-soiling with rotary in the corn season reduced penetration resistance in the wheat season under sub-soiling with rotary but not under rotary or strip rotary. However, treatments under no-tillage in corn had more water in the 0-40 cm soil layer while those under sub-soiling saved more water in the 40-140 cm layer. Together, the combination of no-tillage in the corn season and sub-soiling with rotary in the wheat season recorded the highest WUE efficiency and leaf photosynthetic rate due to the capacity to utilize the water in the upper and deeper layers of the soil at different stages of wheat growth. Hence, the application of no-tillage in the corn season and sub-soiling in the wheat season improved wheat yield, and it is therefore recommended for sustainable wheat production in the NCP.

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Original Paper

Investigating the effects of different amounts of A200 hydrogel and vermicompost on wheat crop under deficit irrigation

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Abstract
The intensification of drought and water stress caused by climate change is a major factor in yield and productivity reduction in the agricultural sector in arid and semi-arid environments. Agricultural lands are often sorely affected by water tension caused by scarce and low precipitation. This research evaluated the effect of different amounts of water, vermicompost and hydrogel used to save the soil water content on wheat grain and biomass yield. Hence, an experiment was conducted at the research farm of Kashmar higher education institute to evaluate the effects of different amounts of hydrogel and vermicompost on wheat biomass and grain yield. Experimental treatments were included: four levels of A_{200} hydrogel (i.e. 0(S_0), 0.1(S_1), 0.2 (S_2) and 0.3 (S_3) wt. %) plus four levels of vermicompost (0(V_0), 7(V_1), 10(V_2) and 15(V_3) tons per hectare) and three levels of irrigation water (60(W_1), 80(W_2) and 100(W_3) percent of wheat water requirement). The experiment was carried out in a randomized completely block design (RCBD) in a factorial arrangement as a pot experiment in 144 pots. The results showed that the highest amount of biomass and grain yield was obtained in $S_3V_3W_3$ treatment amounting of 81.7 and 35 grams per pot, respectively. Also, the lowest biomass and grain yield was achieved in $S_0V_0W_1$ treatment at the rate of 35 and 10.2 gram per pot, respectively. Furthermore, grain and biomass yield were significantly affected ($P \leq 0.05$) by different amounts of hydrogel and vermicompost under varying irrigation water levels. However, application of hydrogel and vermicompost compounds was not significant on the wheat yields. Overall, the best economic value for achieving the highest amount of grain yield was observed in (S_2, 0.2%) of A_{200} hydrogel and (V_2, 10 ton/ha) of Vermicompost. Similarly, the highest amount of biomass was obtained in the (S_3, 0.3%) treatment of A_{200} hydrogels and 15 ton/ha (V_3) of vermicompost. Based on the results, the application of moisture absorbents can be effective in increasing wheat yield in water deficit conditions in the arid and semi-arid environment.

Introduction

Half of global wheat production occurs in irrigated cropping regions that face increasing water shortages. Wheat (Triticum aestivum L.) crop supplies a fifth of food calories and protein to the world's population. It is the most widely cultivated crop in the globe, cultivated on 217 million ha annually (Erenstein et al., 2022). Today, the cultivated area of irrigated and rainfed wheat in Iran is approximately 2 and 4 million hectares, respectively. Iranian people consume 12.5 million tons of wheat annually and the per capita consumption of wheat is c 141 kg (Shokati et al., 2023). The lack of surface water sources for irrigating the rapidly expanding wheat cultivation area has triggered a massive exploitation of groundwater resources; as a consequence, water levels have decreased and environmental problems have developed. Agriculture is thus faced with the challenge of ensuring global food security by increasing yields, while minimizing environmental problems. Therefore, water saving agricultural techniques must be applied to prevent further overexploitation of groundwater resources and increase the yields of essential crops (Mao et al., 2017).

Water scarcity is becoming the important determinant problem in agricultural crop production in arid and semi-arid areas (Rivero et al., 2007; Pourgholam-Amiji et al., 2020). Soil amendments have been widely used for crops and ornamental plants to mitigate the damage caused by water shortage in arid and semi-arid areas (Bhardwaj et al., 2007). It is indisputable that both synthetic polymer and natural soil amendments can provide beneficial effects on crop growth in terms of germination, root growth and nutrient uptake by improving soil physical, chemical and biological properties (Xu et al., 2015). To sustain or increase the productivity of wheat system, it is important that soil status must be perfect the level of organic matter in soil should be enough and overall, the soil must be without any constraints. Some of the secretions of worms and associated microbes act as growth promoter along with other nutrients. It has attracted the attention not only of scientists but also of farmers worldwide. Since, it is a natural organic product which is eco-friendly, it does not leave any adverse effects either in the soil or in the environment (Kumar et al., 2017). Compost is one of organic product for the soil moisture retention by increasing the soil porosity and aeration, which positively affect beneficial soil microorganisms. Other practical and commercially available products to help retain soil moisture are available, especially soil amendments containing cross-linked copolymers (Pedroza Sandoval et al., 2017). Certain metabolites produced by earthworms may also be responsible to stimulate the plant growth. Vermicompost also helps in preventing plant diseases (Rao, 2001). The mucus associated with the cast being hygroscopic absorbs water and improve water holding capacity (Kumar et al., 2017). One of the special advantages of vermicompost over other organic fertilizers is, existing large amount of humus in it and its humus-making process speed (Claudio, 2009). Vermicompost application has been known to improve physical, chemical and biological properties of soil (Kansotia et al., 2016). By using vermicompost and accession of humus to the soil, clays and silts are generally compounded with humus and adhesive materials and make up small units of soil. These small units cling to each other by adding organic materials to the soil make aggregate and shape soil structure. Aggregates clinging, causes to improve moisture retention capacity, water penetration, drainage and climate exchange in the soil and its intensity is reduced (Bagheri and Afrasiab, 2013).

Super absorbent polymers are extensively studied cross-linked macromolecules with segments of hydrophilic groups which are capable of absorbing and retaining large volumes of water (Fernández et al., 2005). Hydraulic super absorbent polymers have a quite different structure from vermicompost that found special place in new agriculture in order to reinforce nutritional and moisture status of the plant. In fact, the main objective of polymers in soil is to increase water retention (Bagheri and Afrasiab, 2013). These materials can reduce the effects of water stress on the plant and lead to increased yield in arid and semiarid regions.

Biri et al. (2016) conducted a field experiment during the main cropping season of 2013 with an objective to study the effect of different levels of nitrogen and vermicompost application on Striga infestation, growth and yield of sorghum at Fedis agricultural research center, eastern Ethiopia. The treatments consisted of three rates of nitrogen (0, 46, 92 kg/ha) in the form of urea and five rates of vermicompost (0, 0.5, 1, 1.5, 2 t/ha) in the form of organic fertilizer. The results of this study revealed that application of vermicompost significantly increased soil organic carbon, total nitrogen, available phosphorus, and exchangeable potassium contents. Nitrogen and vermicompost interacted to significantly ($P < 0.01$) influence the number of Striga per hectare.

Yang et al. (2017), performed a field-based pot experiment with maize plants was conducted to examine the effect of combined folic acid (FA) and super-absorbent polymer (SAP) on leaf gas exchange, water use efficiency, and grain yield under soil water deficit. SAP (45 kg hm^{-2}) was applied to the topsoil at sowing. Plants were well-watered (80% field capacity), but subjected to water deficit (50% field capacity) from tassel stage to grain-fill. FA solution (2 g L^{-1}) was sprayed onto plant leaves at 2 and 9 days after imposing water deficit. Under water deficit, SAP and FA application did not affect evapotranspiration, but increased leaf abscisic acid and decreased leaf transpiration rate with a little change in photosynthesis, thus improving instantaneous water use efficiency. Applying SAP and FA under water deficit also increased grain yield by 19% and grain water use efficiency by 24%, largely attributed to an increase in kernel number. In contrast, under well-watered condition the two chemicals increased stomatal conductance, leaf transpiration, photosynthesis and chlorophyll content, but did not change kernel number and were relatively less effective in respect to water use efficiency compared to water-stressed condition. This study showed that application of foliar FA and soil SAP had little effect on evapotranspiration but maintained high photosynthesis and kernel number, and improved water use efficiency under soil water deficit.

Hao et al., (2015) demonstrated that proper selection of drought tolerant hybrids can increase corn yield and WUE under water-limited conditions. Mahajan et al., (2015) suggested that breeding for traits of high yield potential and improved weed-suppressive ability for dry direct-seeded rice would lead to strengthened integrated crop management strategies.

Kohansal et al. (2014), to determine whether technology has a positive or negative effect on production variation. To achieve this aim, a stochastic frontier production function with a heteroske-dastic error structure has been used. A 10-year panel dataset from 8 provinces (Azarbayjan-e-sharghi, azarbayjan-e-gharbi, Ardebil, Kurdestan, Kermanshah, Lorestan, Zanjan, Eilam) in northwest of Iran was used to estimate different functional specifications. The results indicated that Potash fertilizer and technological change have positive and significant impact on wheat production risk; as well land and labour have a positive effect on wheat production risk but these coefficients are not statically significant. Plus, using phosphate and nitrogen fertilizer and seed have negative and significant impact on wheat production risk.

Carew et al. (2009) used Just-pope production function to examine the relationship among fertilizer inputs, soil quality, biodiversity indicators, cultivars qualified for Plant Breeders’ Rights (PBR), and climatic conditions on the mean and variance of spring wheat yields in Monitabo Canada, and the main result showed nitrogen fertilizer, temporal diversity, and PBR wheat cultivars were associated with increased yield variance.

Gardebroek et al. (2010) compared the production technology and production risk of organic and conventional arable farms in the Netherlands. Just–Pope production functions have been estimated for Dutch organic and conventional farms. The result showed that organic farms face more output variation than conventional farms. Manure and fertilizers are risk-increasing inputs on organic farms and risk-reducing inputs on conventional farms. Labour is risk increasing on both farm types; capital and land are risk-reducing inputs.

Saseendran et al. (2014), Crop water production functions (CWPFs) are often expressed as crop yield vs. consumptive water use or irrigation water applied. CWPFs are helpful for optimizing management of limited water resources, but are site-specific and vary from year to year, especially when yield is expressed as a function of irrigation water applied. Designing limited irrigation practices requires deriving CWPFs from long-term field data to account for variation in precipitation and other climatic variables

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at a location. However, long-term field experimental data are seldom available. We developed location-specific (soil and climate) long-term averaged CWPFs for corn (Zea mays L.) using the Root Zone Water Quality Model ($RZWQM_2$) and 20 years (1992–2011) of historical weather data from three counties of Colorado. Mean CWPFs as functions of crop evapotranspiration (ET), ET due to irrigation (ETa–d), irrigation (I), and plant water supply (PWS = effective rainfall + plant available water in the soil profile at planting + applied irrigation) were developed for three soil types at each location. Normalization of the developed CWPF across soils and climates was also developed. A Cobb–Douglas type response function was used to explain the mean yield responses to applied irrigations and extend the CWPFs for drip, sprinkler and surface irrigation methods, respectively, assuming irrigation application efficiencies of 95, 85 and 55%, respectively. The CWPFs developed for corn, and other crops, are being used in an optimizer program for decision support in limited irrigation water management in Colorado.

The Kashmar city has a moderate desert climate with an average annual rainfall of 210 mm. Agricultural production in Kashmar is affected by the shortage of water resources and the occurrence of successive droughts. One of the effective solutions to deal with drought and lack of water resources is deficit irrigation and a solution to increase the water holding capacity in the soil. Therefore, the present experiment was conducted with the aim of the effect of different amounts of water along with soil moisture absorbents (natural and artificial) on wheat grain yield and biomass.

Materials and methods

This experiment was performed at the research farm of Kashmar higher education institute at Kashmar city in Khorasan Razavi province, north-east of Iran. The experimental field is located at 35°16´ 01" N latitude, and 58° 28´ 24" E longitude at 1110 meters altitude. A location map of Kashmar city is presented in Fig. (1). In the study area of research farm, the mean annual temperature recorded at a nearby observatory was 35°C with June being the hottest month (*i.e.* mean maximum temperature of 45°C) and January was the coldest (*i.e.* mean minimum temperature of 7°C). The mean annual rainfall based on 32 years' record (1989-2022) was 210 mm.

Estimation of the ombrothermic curve of this city based on precipitation and long-term temperature (1989-2022) of the meteorological station of Kashmar indicates that it is considered to be dry months of Kashmar from late May to late January (Fig. 2). Therefore, the city of Kashmar has a lack precipitation of 8 months and experiences dry weather. Meteorological information of the area including monthly rainfall, monthly average of temperature, relative humidity (RH), and reference evapotranspiration (ET_o).

Fig. 1- Location of study area

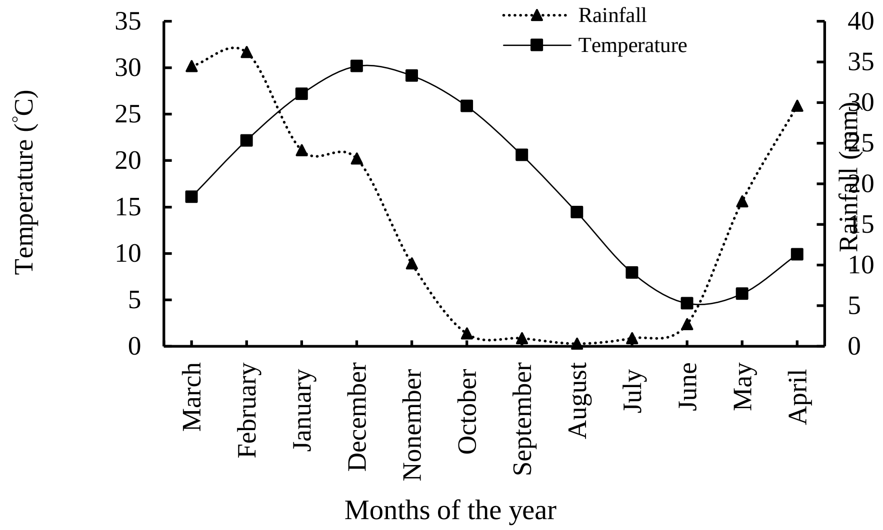

Fig. 2- Ombrothermic curve of Kashmar city based on long-term rainfall and temperature data of the area (1989-20222018)

Table 1- Experimental treatments

S	Different amounts of A_{200} Hydrogel	V	Different amounts of Vermi compost	W	Different amounts of Water Requirements
S_0	No A_{200} Hydrogel	V_0	No Vermi compost	W_1	60% water requirement
S_1	0.1 %wt of A_{200} Hydrogel	V_1	7 ton/ha Vermi compost	W_2	80% water requirement
S_2	0.2 %wt of A_{200} Hydrogel	V_2	10 ton/ha Vermi compost	W_3	100% water requirement
S_3	0.3 %wt of A_{200} Hydrogel	V_3	15 ton/ha Vermi compost		

In order to evaluate the effects of different amounts of hydrogel and vermicompost on biomass and grain yield of wheat, a field experiment was conducted at the research farm at Kashmar higher education institute in a factorial arrangement under completely randomization designs with three replications. The first factor consists of 16 different levels of artificial adsorbent (A_{200} hydrogel in four levels 0, 0.1, 0.2 and 0.3 weight percent, and vermicompost at four levels of 0, 7, 10 and 15 tons per hectare). The second factor consists of three levels of irrigation water (i.e. 60, 80 and 100% of the wheat water depth). The experiment was carried out in 144 black plastic pots (the height of 35 cm, upper diameter of 30 cm, and lower diameter of 25 cm). To illustrate the values of A_{200} hydrogel (S), vermicompost (V) and irrigation (W), the acronyms were used, as described in Table (1).

The irrigation water quality was good and classified in the C1S1 class. The irrigations were applied two weeks after planting. To fill the pots, 24 kg of homogenous soil was mixed with specified ratios of A_{200} hydrogel and vermicompost (the values given in Table 1). After preparing the pots, 15 wheat seeds of *Alvand* cultivar were cultivated in depth of 2cm from the top soil, in each pot. Soil moisture content of 10cm of soil depth and up to crop root zone were monitored periodically for irrigation scheduling *i.e.* deciding the date and quantity of irrigation water during the crop growth period. The date of irrigation was decided when the soil moisture of the root zone reached 50% of the total available water (TAW) *i.e* when half the moisture between the field capacity (FC) and permanent wilting point (PWP) gets depleted. The quantity of irrigation water for each treatment was calculated based on the soil moisture content before irrigation and root zone depth of the plant using the Eq. (1) (Azimi et., (2018).

$$SMD = (\theta_{FC} - \theta_i) \times D_{rz} \times f \qquad (1)$$

Where:

SMD is soil moisture deficit (mm), Θ_{FC} is soil moisture content at field capacity (*vol*,

%), Θ_i is the amount of moisture corrected at irrigation time, (*vol*, %), D_{rz} is root effective depth, (mm), and *f* is coefficient of irrigation treatment (0.6, 0.8 and 1).

For measurement of soil water content, the *PMS-714* moisture meter was used. Grain yield was measured as weight of harvested grain with 3% grain moisture in each pot and converted to kg ha^{-1} unit for each treatment. Biomass yield was determined by taking the weight of above ground plant parts including the grain. After harvesting and drying of wheat plants, harvest operations were performed on 22/May. For measurement the yield, the plants in each pot (10 wheat plants) were cut from the soil surface and recorded by digital scale as biomass.

The optimal production function was selected based on the statistical analysis. The production function coefficients were estimated using OLS and SPSS 16 software. The model coefficients for determining the grain yield, the coefficient of determination (R^2) and standard error for the comparison of production functions (Sankhayan, 1988).

Linear:

$$Y = a_0 + a_1 w + a_2 v + a_3 s \quad (2)$$

Cobb-Douglas:

$$Y = a_0 w^{a1} v^{a2} s^{a3} \quad (3)$$

$$\rightarrow \mathrm{Ln}\,(Y) = ln(a_0) + a_1 ln(w) + a_2 ln(v) + a_3 ln(s)$$

Quadratic:

$$Y = a_0 + a_1 w + a_2 w^2 + a_3 v + a_4 v^2 + a_5 s + a_6 s^2 + a_7 wv + a_8 ws + a_9 vs \quad (5)$$

Transcendental:

$$Y = a_0 w^{a1} v^{a2} s^{a3} \exp(a_4 w + a_5 v + a_6 s) \quad (6)$$

$$\rightarrow \mathrm{Ln}(Y) = ln(a_0) + a_1 ln(w) + a_2 ln(v) + a_3 ln(s) + a_4 w + a_5 v + a_6 s \quad (7)$$

Results

Statistical Analysis

The results showed that wheat grain yield and biomass were significantly affected at ($P \leq 0.01$) level by different amounts of irrigation and hydrogel. Also, wheat grain and biomass yield were significantly affected at ($P \leq 0.05$) level by different amounts of vermicompost. The interaction effect of hydrogel with irrigation water levels on the biomass and grain yield was significant at 5% probability level. It was indicated that, increasing water amount resulted in a relatively higher yield, since water deficit was main yield-limiting factor. The effects of different amounts of irrigation water in interaction with hydrogel on biomass and grain yield was significant at the 5% probability level. Increasing the amount of A_{200} hydrogel caused increasing of biomass and grain yield. Also, the interaction effect of A200 hydrogel with vermicompost on the measured parameters was not significant. The results of variance analysis were presented in Table (2).

The result of Table (3) shows that, there is a significant difference between different amounts of irrigation water (60, 80 and 100% WR) on grain yield and biomass. The maximum and minimum grain yield was obtained at full irrigation (W3) and 60% of applied water (W_1) treatment at the rate of 27.97 and 14.16 g pot^{-1}, respectively. Similarly, the maximum and minimum of biomass was achieved in the highest applied water (W_3) treatment at the rate of 47.74 and 64.27 g pot^{-1}, respectively.

Table 2- Analysis of variance of different parameters

Variables	df	Biomass	Grain Yield
Hydrogel	3	1509.49^{**}	148.05^{**}
Vermicompost	3	586.34^{*}	97.93^{*}
Irrigation	2	10.57^{**}	6.05^{**}
Hydrogel × Vermicompost	9	3372.05^{ns}	2291.94^{ns}
Hydrogel × Irrigation	6	41.26^{*}	9.51^{*}
Vermicompost × Irrigation	6	41.03^{*}	4.05^{ns}
Hydrogel × Vermicompost × Irrigation	18	21.05^{ns}	3.49^{ns}
Error	96	1416.67	326.71

*,** and ^{ns} are significant at 5% probability level, significant at 1% probability level and no significant, respectively.

Table 3- Comparison of the average biomass and grain yield for different treatments

Factor	Level	Biomass (gr)	Grain Yield (gr)
Water requirement	60	47.71^{c}	14.16^{c}
	80	58.23^{b}	20.63^{b}
	100	64.27^{a}	27.97^{a}
A200 Hydrogel	0	48.47^{d}	18.54^{c}
	0.1	55.28^{c}	19.96^{b}
	0.2	59.58^{b}	22.28^{a}
	0.3	63.61^{a}	22.90^{a}
Vermicompost	0	51.25^{d}	18.76^{c}
	7	56.39^{c}	20.61^{b}
	10	58.75^{b}	21.75^{a}
	15	60.55^{a}	22.56^{a}

In each column and for each treatment, the values followed by at least one common character are not statistically different at 0.05 probability level.

According to table (3), there is not significant difference between 0.3 (S_3) and 0.2 (S_2) wt% of A200 hydrogel on grain yield and biomass. But there is a significant difference between 0.3 (S_3) and 0.2 (S_2) wt% of A200 hydrogel with 0.1 (S_1) and 0 (S_0) wt% on grain yield and biomass. The maximum and minimum grain yield was obtained at (S_3) and 0 wt% of applied hydrogel treatment at the rate of 22.9 and 18.54 g pot^{-1}, respectively. Similarly, the maximum and minimum of biomass was achieved in the highest and lowest hydrogel rates (S_3 and S_0) treatment at the rate of 63.61 and 48.47 g pot^{-1}, respectively.

Similar results were obtained for vermicompost, which there was not significant difference between 15 (V_3) and 10 (V_2) wt% of vermicompost on grain yield and biomass. But there is a significant difference between 15 (V_3) and 10 (V_2) t ha^{-1} with 7 (V_1) and 0 (S_0) t ha^{-1} of vermicompost on grain yield and biomass. The maximum and minimum grain yield was obtained at (V_3) and 0 t ha^{-1} of applied vermicompost treatment at the rate of 22.56 and 18.76 g pot^{-1}, respectively. Similarly, the maximum and minimum of biomass was achieved in the highest and lowest vermicompost amounts (V_3 and V_0) treatments at the rate of 60.55 and 51.25 g pot^{-1}, respectively.

The highest amount of biomass was observed at 100% of water requirement (W_3) in interaction with 0.3% weight of A_{200} hydrogel. The lowest amount of biomass was obtained at 60% of water requirement (W_1) in interaction with non-applied hydrogel treatment (S_0). Also, the highest amount of grain yield was related to 100% water requirement (W_3) and 0.3% weight of A_{200} hydrogel treatment which had no significant difference with 100% water requirement and 0.2% weight of A_{200} hydrogel treatment.

The interaction effect of vermicompost levels with the levels of irrigation water requirement was significant on the biomass at 5% probability level. Increasing amount of irrigation water depth and vermicompost caused to increased biomass. The highest amount of biomass was obtained at 100% water requirement (W_3) in interaction with 15 ton/ha vermicompost amount, which had a significant difference with (W_3) in interaction with 7 ton/ha vermicompost.

Table (4) shows the estimation of production function of water-hydrogel-vermicompost with simple linear functions, Cobb-Douglas, quadratic and transcendental. The determination coefficient values of each function were obtained amounting of 0.897, 0.06, 0.91 and 0.894, respectively. The results showed that the quadratic, linear and transcendental functions were fit well on the data. With Comparing the determination coefficients and standard error, it was found that the quadratic function was better than other functions. Also, comparison of coefficients shows that changes in irrigation water amounts was more effective on wheat grain yield than A_{200} hydrogel and vermicompost treatments. In addition, the effect of A_{200} hydrogel was greater than vermicompost on wheat yield.

Table 4- Wheat water-hydrogel- vermicompost production coefficients using simple linear functions, Cobb Douglas, quadratic, and transcendental

Variables	Linear	Cobb-Douglas	Quadratic	Transcendental
intercept	-5.443**	1.027**	3.023**	1.027**
SE	0.248	0.037	0.056	0.012
W	0.026**	-	0.797**	0.278**
SE	0.001	-	0.024	0.009
V	0.039**	-	0.209**	0.073**
SE	0.005	-	0.024	0.009
S	2.231**	-	0.249**	0.088**
SE	0.222	-	0.024	0.009
Ln (W)	-	-0.01ns		-0.014*
SE	-	0.017		0.006
Ln (V)	-	-0.01ns		-0.003ns
SE	-	0.031		0.01
Ln (S)	-	-0.026 ns		-0.026ns
SE	-	0.049		0.016
W^2	-	-	0.028**	-
SE	-	-	0.033	-
V^2	-	-	-0.01**	-
SE	-	-	0.026	-
S^2	-	-	-0.046**	-
SE	-	-	0.029	-
WV	-	-	0.036**	-
SE	-	-	0.024	-
WS	-	-	0.043**	-
SE	-	-	0.024	-
VS	-	-	0.079**	-
SE	-	-	0.024	-
R^2	0.897	0.006	0.910	0.894
SE	0.088	0.104	0.080	0.011

Discussion

According to results, decreasing of irrigation water had negative effect on wheat yields. By decreasing of irrigation water, biomass and grain yield were reduced. Also, by increasing of hydrogel and vermicompost, biomass and grain yield were increased compared to the lack of using it. This result consistent with the result of Fazeli Rostampour et al. (2011), Allahyari et al. (2013) and Darvishi et al. (2013). Mao et al. (2017) applied three precision planting patterns (single row, alternating single and twin rows and twin row) and three irrigation treatments (0 mm (I0), 90 mm (I90) and 180 mm (I180)). Compared with I0 and I90 irrigation treatments increased yield by 19.3%. They showed that in water scarce regions, 90 mm of irrigation has a greater potential to increase winter wheat production than 180 mm. A significant decrease in wheat yield under water deficit conditions suggests that the identification and development of drought mitigation strategies to not only improve yield in drought prone areas but to also bring the arid and desert regions of the world under cultivation is of prime importance (Nawaz et al., 2016). Tollenaar and Lee (2002) believed that the most drought stress effect on during grain filling was on grain weight that grain weight decreased by drought stress. Yield reduction by drought stress due to reduced number of grains per ear and grain weight in response to

decreased leaf relative water content and increased cell membrane stability reported by Majidian and ghadiri (2002).
In different studies, the addition of small amounts of organic matter to the soil increases its capacity to retain water because of the positive correlation among the organic matter content, available water and yield (Julca-Otiniano et al., 2006). A positive effect of vermicompost application on yield attributes and yield of various crops had been reported by Vasanthi and Kumaraswamy (1999), Ranwa and Singh (1999). Dussere (1992) reported that vermicompost helps to improve and protect fertility of top soil and also helps to boost up productivity by 40% with 20 to 60% lower inputs, it also enhances the quality of end products and thereby creating significant impact on flexibility in marketing as well as increases the storage time. Vermicompost contain 30 to 50 percent substance which help in the stimulation of plant growth, particularly that of roots, also the nutrients present in vermicompost are readily available (Kumar et al., 2017). In addition, the application of compost increases the soil organic matter content and improves some of its physical characteristics, such as the amount of hydrostable aggregates, bulk density, and porosity, which promote the flow of air and water and plant root development (Tits et al., 2014). Kizilkaya et al. (2012) reported that vermicomposted organic wastes by supplying more nutrients for wheat than non-vermicomposted organic wastes can enhance wheat growth. Vermicomposted organic wastes may be a potential source of plant nutrients for sustainable crop production.

Grain yield of wheat crop varied from 51.25 to 60.55. A significant effect of A200 hydrogel application on wheat grain yield was observed. A similar effect was observed for maize production by Pedroza Sandoval et al. (2017). They showed that the production of fresh forage increased from 19.5 t ha^{-1} in the control to 77.6 and 81.6 t ha^{-1} when the hydrogel was applied at rates of 12.5 and 25 kg ha^{-1}, respectively. The application of the hydrogel increased the soil moisture content by 20.8% compared to the control, facilitating increased photosynthetic activity and other physiological variables and therefore resulting in increased biological yields. Kosterna et al. (2012) investigated the effect of different irrigation methods (no irrigation, irrigation by means of a drip tape) and method of AgroHydroGel application (control, AgroHydroGel applied to seedlings, AgroHydroGel applied to plants in the field, half of the AgroHydroGel applied to seedlings, the other half to plants in the field) on the yield level and quality of celeriac grown in the field. In the irrigated treatments, the highest yield was obtained in the plots where hydrogel was applied to plants in the field. Irrigation increased the total celeriac plant weight by 34% as compared to the non-irrigated plots. Simultaneously, irrigation and hydrogel application in a split proportion increased total sugar content as compared to the plants in which the hydrogel was only applied to the seedlings. Khadem et al. (2010) stated that 1000-seed weight, grain and biological yield increased by using animal manure and superabsorbent polymer together as maximum grain yield was obtained by using 65% animal manure and 35% superabsorbent polymer.

The positive effect of super absorbent polymers in increasing yield in the tomato (El-Hadi and Camelia, 2004), sunflower (Nazarli et al., 2010) and soybean (Yazdani et al, 2007) reported it and it was consistent with these findings. By applying super absorbent polymers, humidity fluctuations were reduced, irrigation intervals were increased and plant growth was increased. Yazdani et al. (2007) reported that using super absorbent polymers in drought stress and water shortage conditions can increase the yield of soybean and found that using adequate amount of super absorbent polymers not only under irrigation conditions but also under water stress can compensate its purchase costs and gain profit and increase yield. Also, the positive effect of super absorbent polymers in reducing the bad effects of drought stress was reported in corn (Islam et al. 2011) and sunflower (Nazarli et al. 2010). Pourpasha et al. in 2011 stated that A200 hydrogel has a positive effect on wheat yield and yield components.

Conclusions

The highest amount of biomass and grain yield were obtained in $S_3V_3W_3$ treatment at the rating of 81.7 and 35 grams in the pot, respectively. Also, lowest biomass and grain yield were obtained in $S_0V_0W_1$ treatment amounting of 35 and 10.2 gram in the pot, respectively. In general, it can be concluded that wheat biomass and grain yield was increased with application of A_{200} hydrogel and vermicompost. The highest grain yield can be achieved with application of 0.2% weighing of A_{200} hydrogel and 10 ton/ha of Vermicompost in interaction with W_2 treatment. However, comparison of coefficients reveald that changes in irrigation water depths was more effective on wheat grain yield than A_{200} hydrogel and vermicompost treatments. In addition, the effect of A_{200} hydrogel was greater than vermicompost on wheat yield. Nevertheless, the use of moisture absorbents in water shortage conditions, especially in arid and semi-arid regions, is recommended to obtain more agricultural productions.

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Original Paper

Spatiotemporal Investigation of Maroon dam effects on water quality by multivariate statistical Analysis

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Abstract

Maroon River is a valuable aquatic ecosystem in Iran. The purpose of this research was to investigate the lasting impacts of the Maroon dam on river water quality (RWQ), particularly downstream, and determine those factors affecting the optimal management of the RWQ. The modified Mann-Kendall and Sen's slope estimator tests were employed to investigate the variation trend of qualitative parameters. Then, multivariate statistical analyses, including correlation assessment, cluster analysis, T-test, and factor analysis of spatiotemporal pattern, are applied to recognize factors affecting the effects of dam construction. Results showed that the total hardness and the calcium, chlorine, and sulfate concentrations significantly increased in downstream at a level of 5% confidence. The cluster analysis indicated that dam construction probably did not affect the upstream; however, the increased dissolution rates of calcium and sulfates downstream illustrated the presence of the Gachsaran formation in the river path and the dissolution of rock gypsum in the water. The factor analysis determined three and two main components before and after dam construction with 84.8% and 71.6% variances, respectively. These components and the correlation between chloride-sodium and calcium-sulfate ions could show the Sodium Chloride dissolution and the effects of the dissolution of gypsum mid-layers from the Gachsaran formation after the dam construction. The strong relationship between the magnesium and chlorine contents in the Cham Nezam station might result from the salt/detergent-contained household and urban wastes entering the river. According to the results of various tests, the dam has changed the quality of the river downstream. Still, Wilcox and Schoeller's indices demonstrated that dam construction did not significantly affect the RWQ used for drinking and agriculture.

Introduction

The growing population and water demands, industrialization, and development of different sectors are reasons for dam construction. Constructing dams across rivers results in hydrologic changes and alteration of physical processes, such as stream and sediment transport, and consequently, water quality. On the other hand, dam construction and surface water storage may lead to increase water evaporation, water stagnation resulting in thermal stratification in the reservoir, suspended particle deposition, nutrient enrichment, and changes in the physical, chemical, and biological properties of water (Ding et al., 2018). Recognizing aquatic mediums of dams in terms of physical and chemical properties is helpful for different applications. It is often realized through evaluating the temporal and spatial variation of water quality downstream and upstream of the dam (Amiri et al., 2021; Allia et al., 2022; Alsubih et al., 2022).

Most studies have focused on environmental investigation and finding the pollution reasons in dam basins. Achieving ecological goals requires determining applied pressure, current water quality, and trends based on records and basin characteristics. Thus, evaluating water resources conditions will be easier, developing solutions for raised issues and taking necessary actions to attain determined environmental goals (Arslan, 2013; Yenilmez, 2022). The evaluation of temporal and spatial changes of water contamination in the Akkaya Dam watershed indicated that the main reasons for water contamination are agricultural activities and household and urban wastewater imposed on the system while either not treated or treated insufficiently. Korkanç et al. (2017) claimed that the contamination problem in Akkaya can only be resolved through consistent studies and prevention at the basin scale (Korkanç et al., 2017). The water quality of the Latyan dam (2014-2017) as the drinking water resource was investigated by Mohseni-Bandpei et al. (2018) that indicating the suitability of this water. However, the authors believe that the precise and continuous evaluation of water quality is essential because of variations of the nitrate and phosphorus and the high eutrophication extension (Mohseni-Bandpei et al., 2018).

Different methods have been developed to upgrade water quality management, including mathematical models, optimization algorithms, and integrated decision support systems (Huang and Xia, 2001; Taner, Üstün, and Erdinçler, 2011). Multivariate statistical analysis is one of the methods used to study several parameters simultaneously that may have different units (Shaw, 2009). Also, investigating the correlation between parameters by principal component analysis (PCA), factor analysis (FA), and cluster analysis (CA) are other tools for this goal (Parinet et al., 2004; Yenilmez et al., 2011; Wang *et al.*, 2019). These methods find a group or a set of variables with similar features and simplify their observations by finding structures or patterns in the presence of numerous data (Ragno, et al., 2007). The investigation of water quality parameters of the Karacaören-II dam by the FA method showed that the most effective quality parameters are nitrogen, phosphorus, pH, temperature, precipitation, and evaporation. In addition, the Mann-Kendall test for examining trends of qualitative data of this dam indicated the increased values of total phosphorus (TP) and total nitrogen (TN) (Yenilmez, 2022). Using PCA, FA, and analysis of variance (ANOVA) for clustering and examining water quality data in four stations in the Coruh basin (Turkey), Bilgin (2015) found that there was a statistically significant in terms of water quality difference between the upstream of released wastewater by the Black Sea copper companies and it's downstream. The water quality comparison of the Murgul and Borcka Dams did not show a statistically significant difference. The Factor analysis determined five factors explained 81.3 % of the total variance. The results showed that domestic, industrial, and agricultural activities, in combination with physicochemical properties, were the factors affecting the water quality in the Coruh Basin (Bilgin, 2015). Studying the water quality in 2008 and 2015 (before and after the three dam construction on the Geum River) indicated increased EC, decreased TP, decreased total particulate phosphorus (TPP), and no significant difference in suspended solids (SS) (Shim et al., 2018).

In the upstream station before dam construction, the results showed parameters of Ca^{2+}, Cl^{-}, HCO_3^{-}, Mg^{2+}, and SO_4^{2-} proportionate to the first principal component and K^{+} with the second main component. Although, after the dam construction, only two parameters of Ca^{2+} and Cl^{-} commensurate to the first principal component and SO_4^{2-} with the second main component. The survey of downstream data before dam construction illustrated that three parameters of Ca^{2+}, Mg^{2+}, and SO_4^{2-} were proportionate to the first main component, and EC and HCO_3^{-} were symmetric with the second principal component. After constructing the Jare dam, the result of water quality analysis downstream showed that the HCO_3^{-} and Na^{+} created the first principal component, and Mg^{2+} and pH the second main component. Neissi et al. (2019) claimed the flow of the Zard River on different formations causes solute more transportation downstream of the dam. Regarding increased hardness and pollution of surface water, control of upstream agricultural activities is essential before changing the water quality needed in the long term for irrigation (Neissi et al., 2019).

Rahimi Shahid et al., (2023) showed that groundwater quality in the construction site of Shahid Dam in the south of Shahid village in Semirom County is suitable for agricultural production. Based on hierarchical clustering analysis, different types of groundwater were classified into three groups.

The study conducted on the nematode population in the Ba Lai River in Vietnam, both upstream and downstream of the dam, revealed distinct disparities in the communities. The non-uniform distribution of nematode communities indicates the influence of dam construction on the river. This could potentially lead to increased sedimentation and eutrophication, ultimately transforming the area into a methane-rich zone, as predicted based on the impact on nematodes (Quang, N. X. et al., 2022).

Maroon is a hydroelectric pebble dam with a clay core constructed on the Maroon River in the southeastern part of Khuzestan province. The reservoir of this dam has a capacity of 1200 million m^3 of water and a length of 30 kilometers. This dam is used for electricity generation and irrigation of 55000 hectares of agricultural lands in Behbahan, Jayezan, and Shadegan. This area is environmentally valuable and includes Rich biodiversity and extensive farming lands. Therefore, due to water quality's vital role in this region, it is essential to investigate the dam construction effects on the water quality in the Maroon River. However, in the review of sources, no complete study was found to investigate the significant effect of this dam on upstream and downstream water quality. This study aims to examine the variation trend of water quality downstream and upstream of the dam in two pre- and post-construction periods. Also, the principal components and factors affecting water quality were determined using PCA, FA, and CA. Finally, water suitability was evaluated for agricultural and drinking usage.

Methods and materials

Study area

The Maroon-Jarrahi catchment, with a surface area of 24310 km^2, is located in southwestern Iran. About 9802 km^2 of this catchment basin (40.3%) is mountainous, and about 14508 km^2 is composed of plains and sloped lands. Based on the stratigraphy of the study area, those sediments located in the development region of the Maroon River belong to Eocene-Oligocene, Miocene, Pliocene, and Quaternary. Formations in the Maroon basin include Sarvak-Pabdeh, Gurpi, Asmari, Mishan-Aghajari, Gachsaran, and Alluvial rocks (Gholamhaydari et al., 2021). Maroon River, with a basin area of 7385.8 km^2, is located between Karun and Zoherh rivers and originates from the Shuroum mountains in the southern part of Lordegan. Maroon Reservoir dam was constructed across the Maroon River at a 19 *km* distance in northeastern Behbahan with a total volume of 1274 million m^3 between the years 1368 and 1378. Its impoundment started in 1380 (Fig. 1).

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This pebble dam with clay core was designed and constructed for agricultural activities, flood control, drinking water supply for Behbahan, and producing hydroelectric energy.

To accurately evaluate water quality variation in the Maroon River, two stations of Idanak and Cham Nezam upstream and downstream of the Maroon dam were considered (Table 1). For this purpose, qualitative data (1981-2018) from these two stations provided by the Water and Power Organization of Khuzestan Province were employed.

After initial evaluations, eight parameters, including electrical conductivity (EC), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, and SO_4^{2-}, were selected for statistical analysis. Unfortunately, the water pollution data had not been measured in these years. The degree of accuracy and validity of data was determined by calculating the Charge Balance Error (CBE) of ions (Freeze and Cherry, 1979) using Eq. (1). In this study, all data have CBE lower than 5%.

$$RE = \frac{\sum Cation - \sum Anions}{\sum Cation + \sum Anions} \times 100 \quad (1)$$

Investigation of variation trend

The modified non-parametric Mann-Kendall test, eliminating the effect of all significant autocorrelation coefficients, and Sen's slope estimator test (SSET) for examining the variation trend of water quality parameters in the Maroon River were used in this study.

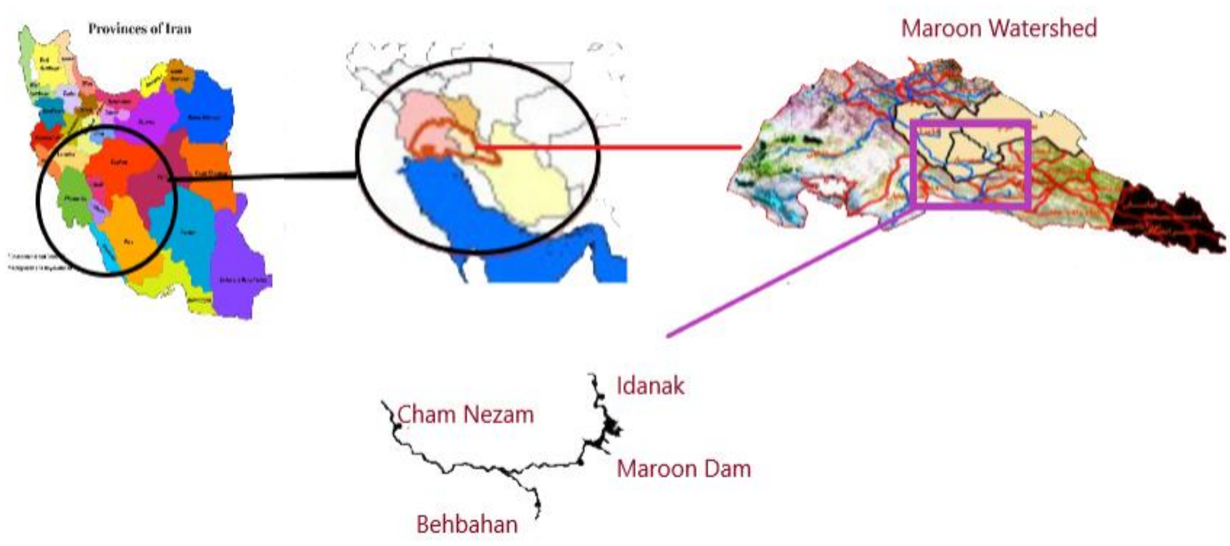

Fig. 1- The location of the Maroon dam and the studied hydrometric stations

Table 1- Characteristics of Hydrometric station in the study region

Station	Estabilished Year	Area (km^2)	River	Height	Longitude	latitude
Idanak	1969	2.2735	Maroon	560	444282	3424207
Chamnezan	1977	8.5384	Maroon	190	396307	3402397

The Mann-Kendall test is utilized for finding trends in hydrologic, climatic, and other related data. In this test, each value in the time series is compared with different values continuously and consecutively. The Statistic S and standardized statistic Z in the Mann-Kendall test are calculated using Eqs. (2) and (3), where n is the number of observations, x_i is the ith rank of observations ($i = 1, 2, 3, \ldots, n-1$), and x_j is the jth rank of observations ($j = i+1, 2, 3, \ldots, n$) (Mann, 1945; Kendall, 1948; Pirnia *et al.*, 2019).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad (2)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > \circ \\ \circ & S = \circ \\ \frac{S+1}{\sqrt{Var(S)}} & S < \circ \end{cases} \quad (3)$$

The necessary condition to use the Mann-Kendall test is the lack of autocorrelation in time series data. However, data may have significant autocorrelation. The modified Man-Kendall test (MMKT) utilizes modified variance $V(S)^*$ instead of $V(S)$ (Eq.4) to altogether deleted the effect of significant autocorrelation coefficients (Hamed and Rao, 1998). Eq. (5) calculates the modified variance.

$$V(S)^* = V(S).\frac{n}{n^*} \quad (4)$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2).r_i \quad (5)$$

Where r_i is the autocorrelation coefficient with the delay i at a 10% significance level and can be calculated as follows (Kumar et al., 2009; Yue and Wang, 2004).

$$r_k = \frac{\frac{1}{n-k}\sum_{i=1}^{n-k}(x_i-\bar{x})(x_{i+k}-\bar{x})}{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad (6)$$

Sen's slope estimator

A helpful index in the Mann-Kendall test is the trend line slope or Sen's slope, which shows the magnitude of a uniform trend. The trend line slope is estimated using Eq. (7) (Sen, 1968).

$$\beta = Median\left(\frac{x_j - x_i}{j-i}\right) \qquad \forall i < j \quad (7)$$

Where β is the slope estimator of a trend line, x_i and x_j are the ith and jth observational values, respectively. The β positive values indicate an increasing trend while negative values show a decreasing trend.

Hierarchical cluster analysis

Hierarchical CA is the most conventional approach for CA. This analysis starts by placing each case in an individual cluster, and then groups join each other until only one collection remains, which is usually shown by a dendrogram (McKenna Jr, 2003). In this study, hierarchical CA is executed on a normalized dataset using Ward's method with squared Euclidean distance as the similarity measure. Ward's method evaluates the distance between clusters by ANOVA to minimize the sum of squared distances between each pair of groups in every step (Murtagh & Legendre, 2014). According to Eq. (8), the Ward function minimizes the sum of members' squared distances from the cluster's center of gravity.

$$W=\sum_{k-1}^{K} \sum_{j-1}^{m} \sum_{j-1}^{N_K} (Y_{iy}^{k} - Y_{wj}^{k}) \quad (8)$$

Where K is the number of available clusters, m is the number of variables, N_k is the number of members belonging to each cluster Y_{wj}^k is the dimensionless mean value of the jth variable in set k, Y_{iy}^k is the dimensionless value of the jth variable related to the ith member in cluster k. Eq. (9) is used to make variables dimensionless.

$$Y_{ij} = \frac{W_j}{\sigma_j}\left[f(x_{ij})\right] \quad (9)$$

Where x_{ij} is the value of the jth variable related to the ith member, $f(x_{ij})$ is the transformation function, Wj is the weight considered for the jth variable, σ_j is the standard deviation, and Y_{ij} is the nondimensionalized value of the ith variable.

Factor analysis and principal component analysis

The FA is a statistical method to describe the integrity between observed and correlated variables in terms of a few potential unobserved variables named factors. FA is performed in R-mode or Q-mode. In the first case, the relationships between variables, and in the second, the relationships between samples are examined (Reghunath et al., 2002). In this study, R-mode FA is used. Deriving the principal components in FA is conducted in six steps: 1) preparing the information matrix, 2) deriving the correlation coefficient matrix between variables, 3) deriving eigenvalues and eigenvectors of variables and observations from the correlation matrix, 4) determining the number of factors using fundamental metrics, 5) rotating the factor axes to simplify the structure of factor loadings, and 6) determining the factor ranking matrix (Mondal et al., 2010). By using the FA method, the affected factors on water quality could be estimated.

PCA is also a robust statistical method where some correlated variables are converted to a smaller set of uncorrelated variables or factors describing the main variations in a dataset. Reduction is achieved by altering the dataset to a new set of variables (principal components) that are orthogonal or uncorrelated relative to each other (Arslan, 2013; Jeong et al., 2014). For PCA, eigenvector calculations can be performed using a covariance matrix (Petersen et al., 2001). Factor analysis is carried out using R languages in this study.

Average comparison using paired T-test

The paired T-test was applied to compare the average of different parameters before and after the dam construction. This method determines the difference between every pair of observations and infers the differences in average values in the population. When the difference between pre-and post-construction values is calculated, a single value is obtained for every two values existing for every observation. So, the problem becomes similar to a one-sample T-test. If the goal is to examine the equality of average values pre and post-construction, the zero assumption of the test is that the difference between observations is zero.

Examining the water quality in stations in terms of agricultural and drinking indices

The water quality in the intended stations was examined through the Wilcox index during the years before the dam construction (1981-1999) and years after the dam construction (2000-2018) to supply agricultural water. In addition, the suitability of this water for drinking was examined using the Schoeller index pre and post-construction.

Results and discussion

Idanak and Cham Nezam stations are located respectively upstream and downstream of the Maroon dam. Table (2) presents some brief statistics of these two stations. Based on statistics between 1981 and 2018, the river flow rate variation in Idanak (upstream) and Cham Nezam (downstream) stations indicate that the maximum flow rate relates to 1986 and 1987 before the dam construction (215.44 m^3/s and 140.74 m^3/s is Idanak and Cham Nezam, respectively). The flow rate has experienced a descending trend in both stations. However, this trend is more extreme in Cham Nezam (Fig. 2). Land use is an essential factor affecting runoff, evapotranspiration, surface erosion of the basin, and, consequently, the flow rate. Motlagh et al. (2018) indicated that changing the land use in Idanak during the past four decades caused the reduction of permeability and hydraulic conductivity of the surface and deep aquifers and subsurface flow.

For examining the trend of qualitative data and the significance of their variations during the evaluated years, MMKT and SSET were used. Table (3) shows that the results obtained from these two tests. The mean EC is 0.941 *dS/m* for Idanak and 2.28 dS/m for Cham Nezam. Based on the system of water quality classification, total dissolved solids (TDS) lower than 1000 *mg/l* denotes fresh water, and TDS between 1000 and 10000 *mg/l* marks

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brackish water (Carroll, 1962). Therefore, the upstream station has fresh water, and the downstream has brackish water.

Water quality variation in the Maroon River upstream and downstream of the dam indicates that EC and TDS have been increased in both stations. However, the intensity of this increase is more significant in the downstream stations. Increased EC may be because of the river feed reduction after the dam construction (Shim et al., 2018). Based on the MMKT, the significance level is 5% for EC and TDS in Idanak, and in Cham Nezam, it is 5% for TDS and 10% for EC (Table 3). The probable reasons for this increase are human factors, like agricultural and industrial drainages, and geological salinization agents. Other studies have also indicated this increase (Zalaki Badili et al., 2013; HaRa et al., 2020).

Table 2- Summary of statistics in Idanak and Cham Nezam stations (1981-2018)

No.	Station	Parameter	Unit	Min	Max	Ave.	S.E	Skweness
1	Idanak	Flow discharche	*m^3/s*	10.90	215.44	56.55	43.61	1.83
		EC	*µS/cm*	692.67	1802.14	941.44	208.06	2.52
		pH	-	7.33	8.35	7.87	0.27	-0.73
		SO_4^{2-}	*meq/l*	1.44	5.95	2.95	0.76	1.31
		HCO_3^-	*meq/l*	2.05	3.68	2.79	0.42	0.28
		Cl^-	*meq/l*	1.99	4.99	3.37	0.75	-0.13
		Ca^{2+}	*meq/l*	2.66	6.13	4.31	0.69	-0.01
		Mg^{2+}	*meq/l*	0.98	2.23	1.61	0.28	-0.11
		Na^+	*meq/l*	1.09	4.93	3.17	0.75	-0.25
2	Cham Nezam	Flow discharche	*m^3/s*	0.00	140.74	56.91	32.39	0.53
		EC	*µS/cm*	1783.00	2757.25	2282.93	246.72	-0.02
		pH	-	7.53	8.27	7.90	0.17	-0.02
		SO_4^{2-}	*meq/l*	5.97	21.57	10.39	2.51	2.18
		HCO_3^-	*meq/l*	1.80	3.12	2.42	0.31	0.26
		Cl^-	*meq/l*	8.14	14.08	11.02	1.76	0.13
		Ca^{2+}	*meq/l*	6.68	12.25	9.31	1.40	0.04
		Mg^{2+}	*meq/l*	2.13	4.82	3.23	0.70	0.65
		Na^+	*meq/l*	8.36	14.04	11.01	1.66	0.21

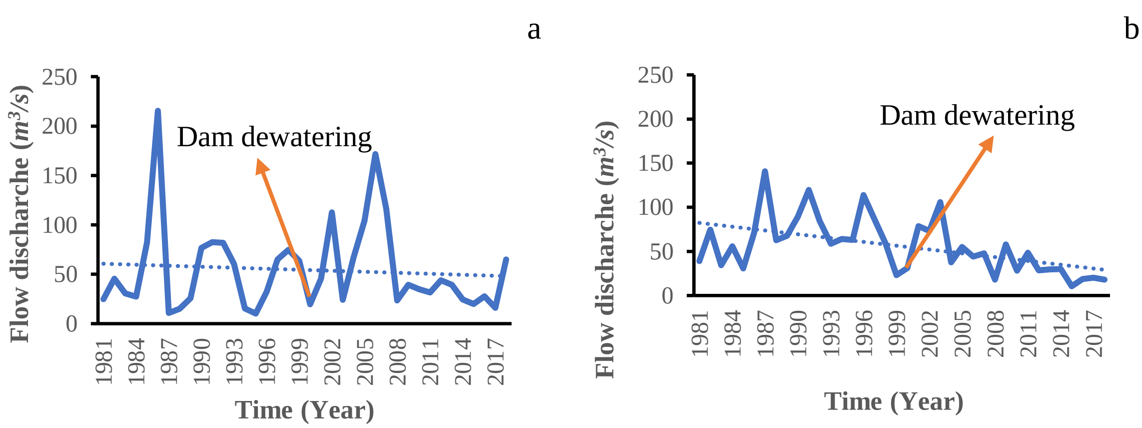

Fig. 2- Flow rate variations: a) Idanak, b) Cham Nezam station

Sodium is one of the effective cations in water quality evaluation. Upstream the river, Na^+ has insignificantly increased to a small extent; however, in Cham Nezam, it has shown a statistically insignificant decreasing trend. These observations are in contrast to the EC trend. Of course, all dissolved salts influence EC. In both stations, Ca^{2+} has increased, and its increasing trend in Idanak has a lower slope than in Cham Nezam. The variation of Ca^{2+} is at a significance level of 5% in both stations. Mg^{2+} has increased during the evaluation years, especially downstream; however, these changes have been insignificant in both stations. The dominance of Ca^{2+}, Na^+, and K^+ in Idanak demonstrates that the river has probably passed through layers of dolomitic limestone and salt (Zalaki Badili et al., 2013). Gachsaran formation in the study area is dominant and affects the water quality in the Maroon Dam (Rezaei et al., 2016).

The water's temporary and total hardness has been increased in both stations. The temporary hardness variation has no significant difference between upstream and downstream. However, the water's total hardness in Cham Nezam station is lower than upstream. The total hardness variation has a significance level of 5% in both stations.

The reason for increased temporary hardness in these stations is probably the increase in the HCO_3^- content. HCO_3^- shows an increasing but statistically insignificant trend in both stations. Indeed, the maximum HCO_3^- observed at downstream stations is lower than in the Idanak station. As presented in Table (3), the trend of SO_4^{2-} in Idanak is relatively constant, but it has an increasing trend in downstream stations during the study years. The maximum amount of SO_4^{2-} had occurred in Cham Nezam in 2015 (after the dam construction), which can be one of the reasons for the escalation of total hardness in this station. The increasing trend of SO_4^{2-} in Cham Nezam has a significance level of 5% (Table 3). It can be said that the dissolution of rock gypsum from the Gachsaran formation caused TDS and SO_4^{2-} to increase in surface and groundwater, decreasing water quality. The exceeding withdrawal of groundwater and decreasing water table level could be led to an increased dissolution rate of gypsum rocks (Mohammadian et al., 2015). Gholamhaydari et al. (2021) illustrated that the Gachsaran formation and gypsum karstification in the plain have destructive effects on the roads, utilities, agricultural lands, residential buildings, and Maroon Dam's reservoir (Gholamhaydari et al., 2021).

The variation of Cl^- indicates little growth in Idanak and negative growth in Cham Nezam, which are insignificant. Based on the Piper diagram, Zalaki Badili et al. (2013) showed that the water has a hydro-chemical face of Ca-HCO_3-Cl.

The content of K^+ increases from upstream to downstream (10% significance level in both stations), and the maximum amount of K^+ is observed in Cham Nezam. In addition, pH has a descending trend in all stations, and the water is alkaline. However, the alkalinity level has been increased after the dam construction. Concerning the increasing trend of HCO_3^- during post-construction years, the rising trend of alkalinity is natural.

T-test

The test of compare means was conducted in Idanak and Cham Nezam on critical parameters in two periods before and after the Maroon dam construction to evaluate and validate the variation of these variables statistically. The results shows that the variation in Idanak was not significant. Table (4) shows the results of this test for Cl^-, SO_4^{2-} and EC for example. As can be seen, the p-value is higher than 5% in Idanak, and there is no statistically significant change in these parameters mean before and after the dam construction. Since Idanak is located upstream of the dam, this result is not far-fetched.

In Cham Nezam, all parameters experience considerable and significant changes pre-construction and post-construction (at a significance level of 1% for Cl^- and SO_4^{2-} and a significance level of 5% for EC). Therefore, it can be illustrated that SO_4^{2-}, Cl^-, and EC have significant variation trends. After the dam construction, they escalate due to the geology formation dissolution and contaminant discharge into the Maroon River. Examining the Third Gorges Dam's environmental impact on the chemistry of the water in the Yangtze River indicated that the concentration of all ions, except HCO_3^-, was increased after TGD construction (at a significance level of 1%). Researchers of this study considered the increased load of dissolved silicate due to the water-induced erosion and the role of the dam lake as the main reasons for these variations (X. Wang et al., 2018).

Box plot comparison before and after the dam construction

For more investigation, the Idanak and Cham Nezam stations were considered as representative of river conditions before and after the dam construction, and the box plot was drawn. Fig. (3) shows the box plot for variations of two parameters in Cham Nezam stations before and after the dam. The midline of each box represents the median value; the lower part shows the third quartile (75th percentile), and the upper part shows the first quartile (25th percentile). The maximum and minimum values are connected to the box using vertical lines. As can be seen, the parameters exhibit an increasing trend after the dam, and average concentrations have considerably increased before and after the dam. Investigation of the hydrology and biochemistry variation of nitrogen before and after dam construction was done in southern Ontario. Using box plots, researchers showed that the amount of dissolved oxygen in coastal groundwater reduced after the dam construction. In spring and autumn, nitrate nitrogen concentration decreased relative to pre-construction. However, ammonium nitrogen concentration increased (Hill & Duval, 2009).

Table 3- Results of MMKT and SSET

Station	MMKT	TDS *(mg/l)*	EC *µS/cm*	pH	HCO_3^- *meq/l*	Cl^- *meq/l*	SO_4^{2-} *meq/l*	Ca^{2+} *meq/l*	Mg^{2+} *meq/l*	Na^+ *meq/l*	K^+ *meq/l*	Temporary Hardness	Total Hardness
Idanak	Z	2.03	2.15	-1.46	1.25	1.60	-0.39	2.76	0.61	1.52	1.88	1.31	2.09
	Sen	2.761	4.753	-0.015	0.019	0.025	-0.002	0.037	0.001	0.021	0.000	0.963	1.870
Cham Nezam	Z	2.260	1.812	-1.498	1.372	-0.190	2.320	2.296	1.247	0.009	1.969	1.273	2.316
	Sen	9.506	10.847	-0.010	0.018	-0.006	0.106	0.111	0.014	0.002	0.001	0.832	6.326

The z value at significance levels of 10%, 5%, and 1% is 1.64, 1.96, and 2.33, respectively.

Table 4- Independent T-Test results in two station

Station	Parameter	t	df	Sig	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Upper	Lower
Idanak	CL^-	-1.797	51	0.083	-0.399	0.222	-0.846	0.046
Cham Nezam		-4.466	41	0.000	-2.02	0.45	-2.94	-1.11
Idanak	SO_4^{2-}	-0.433	51	0.667	-0.085	0.196	-0.479	0.309
Cham Nezam		3.079	41	0.004	1.50	0.49	0.52	2.49
Idanak	EC	-2.005	51	0.053	-67.845	33.835	-135.772	0.082
Cham Nezam		-2.476	41	0.037	-38.77	81.51	-203.38	125.84

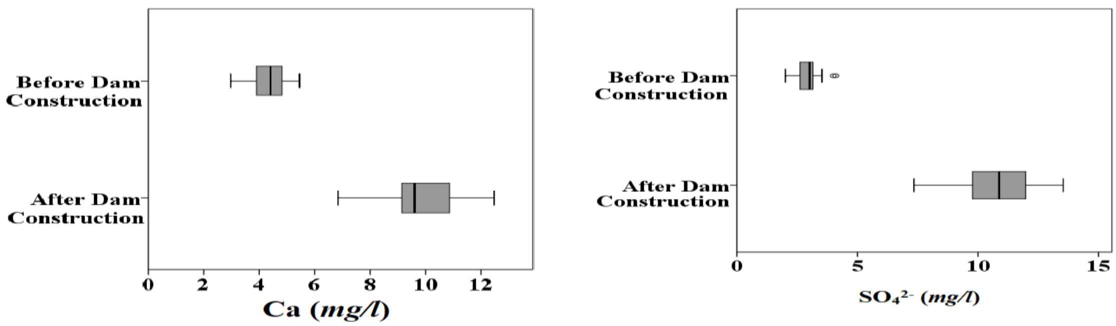

Fig. 3- Box plot of qualitative parameters in Cham Nezam after and before the dam construction

Cluster analysis of qualitative parameters in Idanak and Cham Nezam stations

The tree diagram shows the clustering process, cluster images, and their proximity with a considerable reduction of initial data dimensions. This diagram was drawn for the water quality parameters of the Idanak and Cham Nezam stations before and after the dam construction (Figs. 4 and 5). Based on Fig. (4), EC, TDS, Cl, and Na are placed in the same cluster before and after the dam construction, and their variations correspond. It is observed that the distance between Ca^{2+} and SO_4^{2-} is similar in both diagrams, and the ascending trend due to the $CaSO_4$ dissolution cannot be seen. HCO_3^- has the farthest distance from other parameters. However, in the second diagram, after the dam construction, the increased spread of HCO_3^- from 25 to 17 indicates the rising of this parameter. Generally, how the qualitative parameters are classified in this station upstream of the dam is the same as pre-and post-construction. It seems that the dam did not affect the parameters in this station.

As can be observed in Fig. (5), there is no significant difference between the two diagrams. However, the similarity of Ca^{2+} and SO_4^{2-} parameters is significantly increased after the dam construction (Table 5), which can be seen in the shortening of Euclidean distance along the horizontal axis of the diagram. The distance index of these parameters decreases from 5 to 2.5, indicating the increasing dissolution rate for these parameters along the river path after the dam. Results illustrate that the presence of Gachsaran formation on the way to the river and dam probably causes the dissolution of gypsum rock and increment of Ca^{2+} and SO_4^{2}. Red circles in Fig. (6) related to post-construction have moved upward, which confirms the increased dissolution rate and concentration. Indeed, the strong correlation between these parameters (Fig. 6) authorizes the effect of gypsum dissolution from the Gachsaran formation (Mohammadian et al., 2015; Gholamhaydari et al., 2021). Parameters of Na^{+}, Cl^{-}, and EC have no significant variation.

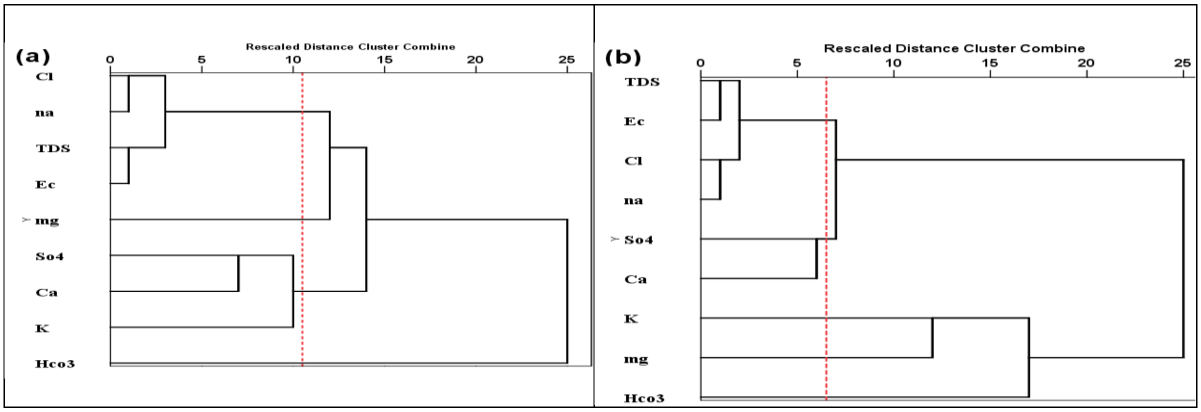

Fig. 4- Dendrogram of Idanak station: a) pre-construction, and b) post-construction

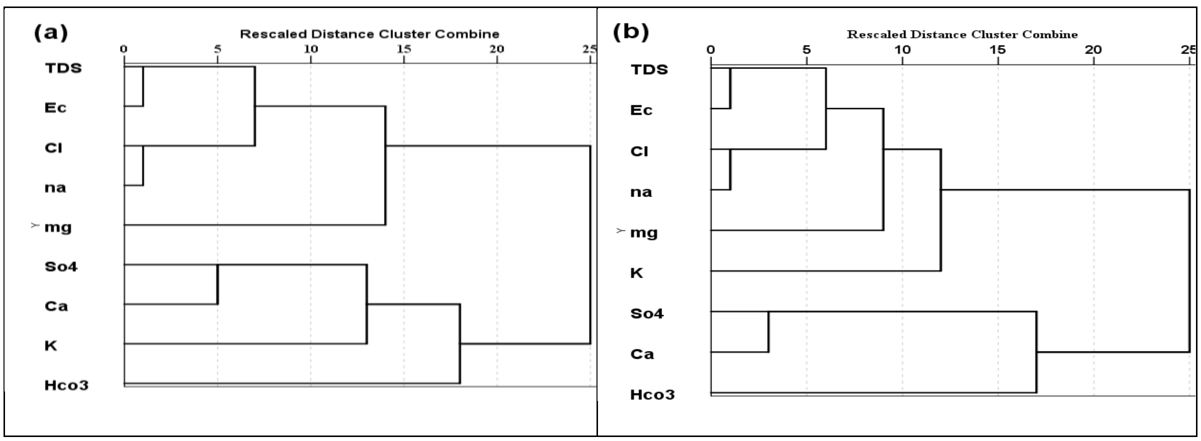

Fig. 5- Dendrogram of Cham Nezam station: a) pre-construction, and b) post-construction

Table 5-levation of Ca and SO_4 parameters in Cham Nezam before and after the dam construction

Parameter	SO_4^{2+}		Ca^{2+}	
	Before Dam	After Dam	Before Dam	After Dam
Mean	9.74	11.61	8.70	10.89
Min	1.19	4.79	2.50	3.70
Max	23.28	21.17	23.65	17.63
Variation	22.09	16.38	21.15	13.93

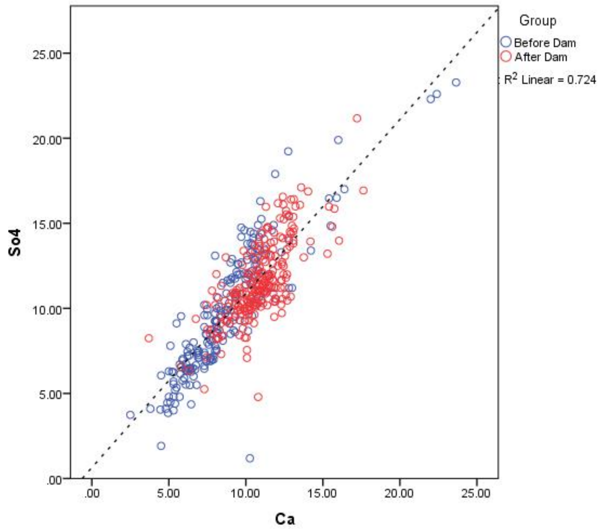

Fig. 6- Correlation diagram between SO_4^{2-} and Ca^{2+} in Cham Nezam station before and after the dam construction

Correlation between parameters in Idanak and Cham Nezam stations

The Pearson correlation coefficient can measure the strength of the linear relationship between parameters and determine the relationships between different elements to recognize origination and how it transfers in the medium under similar conditions. The correlation values vary between -1 and +1. Zero value shows that variables are independent (Hauke & Kossowski, 2011). According to Fig. (7a), the correlation between Ca^{2+} and SO_4^{2-} (at the Idanak station with r=0.64, P<0.01) is lower than at the Cham Nezam station downstream of the dam (Fig. 7b). In addition, HCO_3^{-1} and K parameters have the lowest influence. Fig. (8) (for Idanak statoin) shows the linear chart between Ca^{2+} and SO_4^{2+} with a higher dispersion and lower r with blue color. These parameters increased in the Cham Nezam station, where their linear relationship is shown in purple (Fig. 9). Also, in the Cham Nezam station, the strong correlation between EC and primary ions, including Na^+ (r=0.87, p>0.01), Cl (r=0.87, p<0.01), and SO_4^{2-} (r=0.71, p<0.01), indicate the outstanding contribution of each ion in the water salinity in Cham Nezam downstream of the dam. The correlation between Cl^- and Na^+ ions (r=0.95, p<0.01) may reveal the dissolution of NaCl. Indeed the dissolution of salt formations in the water releases Na^+ and Cl^- ions. Regarding the formations in the study area, the correlation between Ca^{2+} and SO_4^{2-} (r=0.85, p<0.01) may represent the dissolution of gypsum mid-layers from the Gachsaran formation. In Fig. (9), the purple line nicely shows the strong correlation and mutual effects of parameters Ca-Na and SO_4-Mg. HCO_3^- and K^+ exhibit a weaker correlation than other parameters. The strong correlation between Mg^{2+} and Cl^- may be due to the discharge of household garbage and urban waste containing salts and detergents that they have $MgCl_2$. In addition, the moderate correlation between Mg^{2+} and SO_4^{2-} may be attributed to using organic and chemical fertilizers.

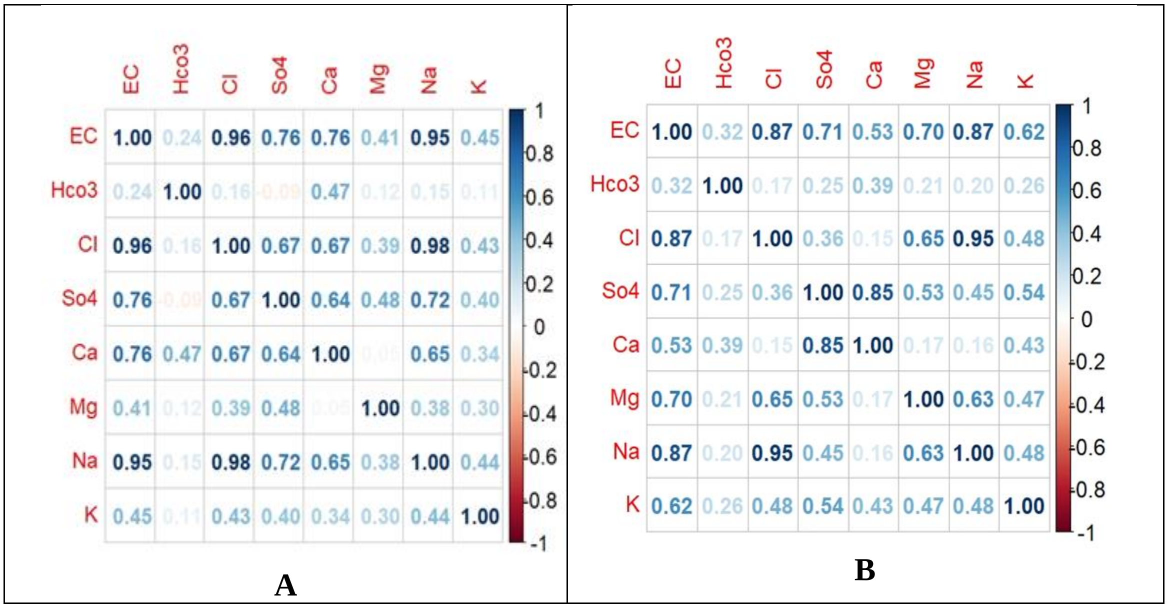

Fig. 7- Correlation between water quality parameters: a)Idanak station, and b)Cham Nezam station

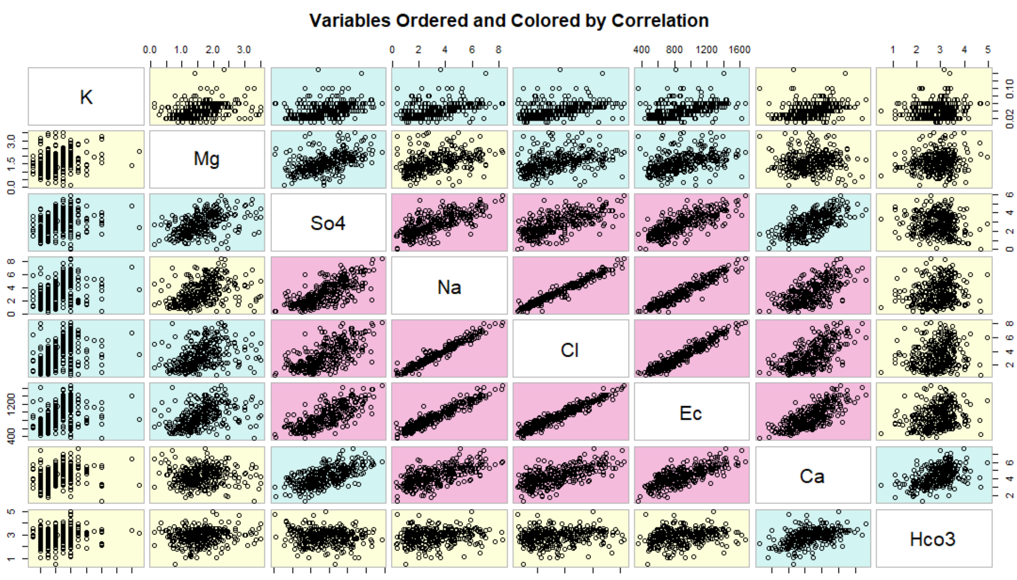

Fig. 8- Linear relationship between qualitative parameters in Idanak station based on the correlation between parameters

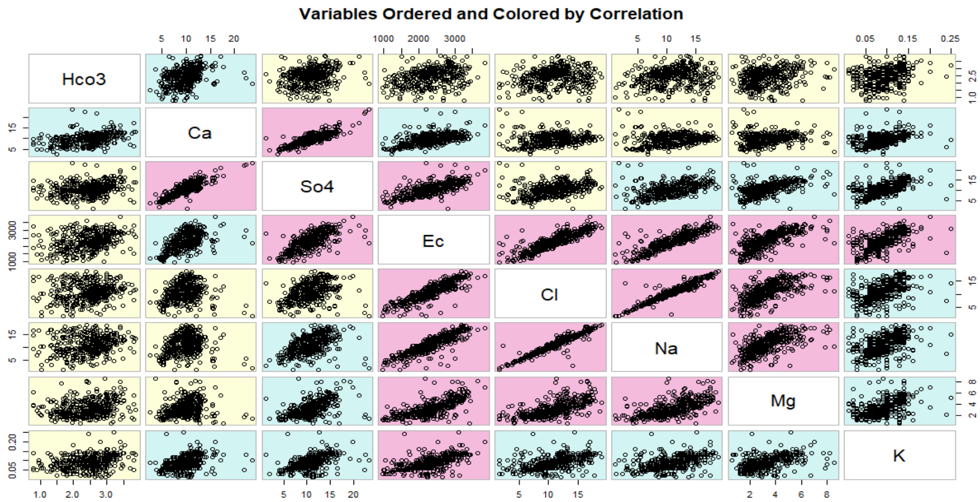

Fig. 9- Linear relationship between qualitative parameters in Cham Nezam station based on the correlation between parameters

Determining the main parameters affecting water quality in two stations

In the next stage, the FA and PCA were performed in both stations for all study years. Results showed two principal factors with total variances of 72.68% (Idanak) and 68.01 (Cham Nezam) (Table 6). The results indicate that the dam construction had affected the water quality in Cham Nezam. For determining the most influential parameters, optimal components, and the number of factors affecting the Cham Nezam water quality evaluation (before and after the dam construction), the Scree plot was produced. The Scree plot is a two-dimensional graph that can determine the contribution of each variable in total variance estimation and the optimal number of components (Fig. 10).

According to Fig. (10a), it is observed that from the third factor onward, the variation of eigenvalues becomes lower than one. Therefore, the first two factors can be derived as the principal factors with the highest contribution to the data variance estimation and can be introduced as the most influential factors in the period before the dam construction. Principal component analysis results in three components with a total variance of 84% (Table 7). Values higher than 0.75% are assumed as strong factor loading, between 0.5 and 0.75 as moderate factor loading, and between 0.3 and 0.5 as weak factor loading (Liu et al., 2003). The first factor contributing 45% of the variance and high factor loading of parameters TDS, EC, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, and Na^+ introduces the natural flows and wastewater from the agriculture sector. This factor is attributed to different geochemical processes (dissolution, sedimentation, and ion exchange) because most anions and cations have high factor loading. Naturally, these elements in surface waters originate from geologic and sedimentation effects in groundwater and surface water flows and local geographical conditions (Menció and Mas-Pla, 2008; Hamil et al., 2018). The third factor has a factor loading of 0.5 exclusively for Ca^{2+} and SO_4^{2-} parameters, which is a moderate factor loading and should be compared with the value after the dam construction (Table 7). After the dam construction, two principal components are selected according to the Scree plot (Fig. 10b). The first component contributes 60% of the total variance and the high factor loading in most primary anions and cations. It also mentions the effects of natural flows (Table 7). The second component contributing to 24% of the total variance demonstrates the effects of Ca^{2+} and SO_4^{2-} with high factor loading. The factor loading of Ca and SO_4 in the first component is lower than before the dam construction (Table 7).

Spatial analysis of Idanak and Cham Nezam upstream and downstream of the dam was performed using biplots, which are two-dimensional graphs of the set of components of the first factor (F1) on the second factor (F2). The position of each ion point indicates the ion-increasing direction in samples, and the closeness of each engagement to the factor axis shows the level of correlation between the ion and that factor. In the Idanak station, EC, TDS, Na^+, and Cl^- parameters are positioned near the horizontal axis (first factor), indicating the significant influence of these parameters on the first factor (Fig. 11a). In addition, compared to Cham Nezam, the distance between Ca^{2+} and SO_4^{2-} in Idanak shows the close correlation of these parameters and an increase in their concentrations downstream of the dam. As shown in Fig. 11b, K^+ and HCO_3^- parameters are placed close in Cham Nezam. This situation, which is not seen in Idanak (upstream of the dam), implies the effects of agricultural drainages and associated pollution in the Maroon river and represents the effects of expanding agricultural lands downstream of the dam. With regard to the dissolution of bedrock and formations in the area affected by the dam, it is observed that EC and TDS are not merely susceptible to Na^+ and Cl^-. In Cham Nezam, increasing the distance between the points associated with these two parameters and the horizontal axis (first factor) reveals the contribution of other ions, such as SO_4^{2-}, Ca^{2+}, and K^-, to the TDS value. When points are placed in opposite directions against each other denotes the inverse correlation. As shown in Fig. (11a), the ends of pH and HCO_3^- are positioned against each other, meaning that HCO_3^- with positive factor loading in the proximity of the vertical axis (Second component) has placed against pH with negative factor loading (the lower part of diagram denote negative values). This situation shows that HCO_3^- does not affect pH, which is justifiable concerning the type of water upstream of the Maroon River (i.e., $CaCL_2$ type). However, after the dam construction, the increasing value of HCO_3^- and pH variation toward being alkaline in the Cham Nezam diagram, as well as going far away from the vertical axis (second factor) and decreasing distance with water-soluble elements indicate the susceptibility of this parameter than the pre-construction conditions.

Table 6- Main factors in Idanak and Cham Nezam stations

Idanak			Cham Nezam		
Parameter	PC1	PC2	Parameter	PC	PC2
TDS	0.949	0.221	TDS	0.794	0.499
EC	0.948	0.247	EC	0.888	0.388
pH	-0.029	-0.831	pH	0.259	-0.600
HCO_3^-	0.035	0.865	HCO_3^-	0.379	0.435
Cl^-	0.924	0.197	Cl^-	0.925	-0.011
SO_4^{2-}	0.872	-0.095	SO_4^{2-}	0.491	0.702
Ca^{2+}	0.662	0.568	Ca^{2+}	0.149	0.899
Mg^{2+}	0.527	-0.127	Mg^{2+}	0.704	0.024
Na^+	0.932	0.170	Na^+	0.915	0.061
K^+	0.547	0.047	K^+	0.508	0.457
Eigenvalues	5.301	1.967	Eigenvalues	4.339	2.462
Variance %	53.009	19.673	Variance %	43.388	24.627
Cumulative %	53.009	72.681	Cumulative %	43.338	68.009

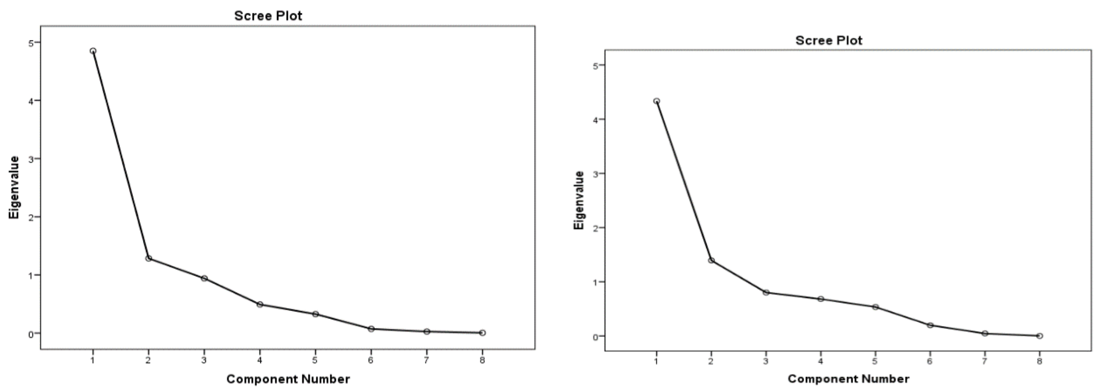

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Fig. 10- Scree plot for determining the number of principal factors in Cham Nezam: a) pre-construction, and b) post-construction

Table 7- Main factors in Cham Nezam before and after the dam construction

Before Dam				After Dam		
Parameter	PC1	PC2	PC3	Parameter	PC1	PC2
TDS	0.98	0.011	0.051	EC	0.803	0.529
EC	0.979	0.079	-0.038	HCO_3^-	0.372	0.428
HCO_3^-	0.267	-0.632	-0.53	Cl^-	0.935	0.123
Cl^-	0.875	0.303	-0.305	SO_4^{2-}	0.307	0.839
SO_4^{2-}	0.808	-0.273	0.463	Ca^{2+}	-0.057	0.949
pH	0.015	0.774	0.355	Mg^{2+}	0.709	0.144
Ca^{2+}	0.634	-0.513	0.54	Na^+	0.900	0.212
Mg^{2+}	0.831	0.191	-0.133	K^+	0.385	0.607
Na^+	0.877	0.276	-0.297	Ca^{2+}	0.803	0.529
K^+	0.735	-0.07	0.062	HCO3	0.372	0.428
Eigenvalues	4.557	2.487	1.436	Eigenvalues	3.216	2.515
Variance %	45.568	24.875	14.361	Variance %	60.197	11.436
Cumulative %	45.568	70.443	84.804	Cumulative %	60.197	71.633

a b

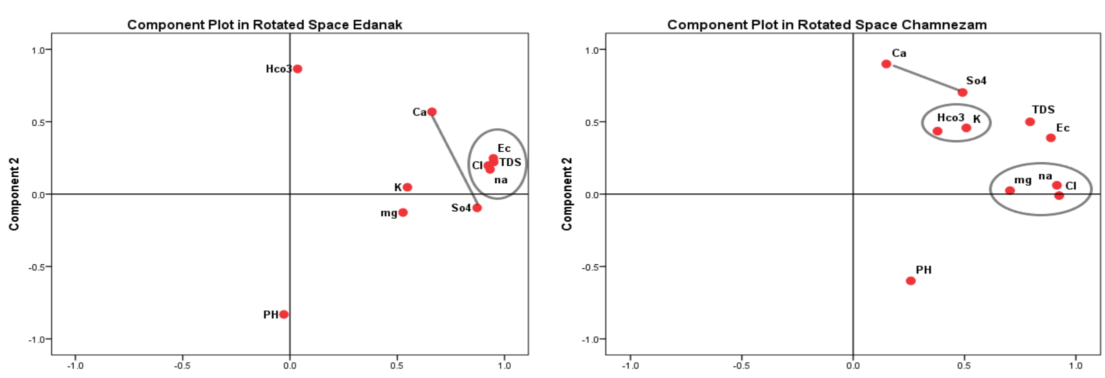

Fig. 11- Biplot obtained from factor analysis: a) Idanak, and b) Cham Nezam station

Evaluating the suitability of water quality for agricultural and drinking use in both stations

Finally, the water quality was examined in both stations before and after the dam construction for agricultural and drinking use. Wilcox classification shows that the water quality has no change after the dam construction for agricultural purposes and is still classified as C3S1. However, the EC has increased. Based on the Wilcox index, the agricultural water quality in Cham Nezam is often classified as C3S1 and C3S2 before and after the dam construction.

Schoeller index, as an index for potable water quality, was examined. After the dam construction, the water quality in terms of drinking use is suitable to acceptable in Idanak. However, water TDS increases to the medium range after the dam construction. In Cham Nezam, the water is in the acceptable range for drinking.

Conclusion

Water quality data (1981-2018) was studied to investigate the effect of the Maroon Dam construction on river water quality upstream (Idanak station) and downstream (Cham Nezam station) of the dam. Over these years, the river's flow rate has reduced in two stations, and the EC has increased. Downstream of the dam, Ca^{2+}, total hardness, and CaSO4 significantly have increased at a 5% significance level. The cluster analysis reveals the increased dissolution rate of Ca^{2+} and SO_4^{2-} along the river after the dam construction. The authors believe that the gypsum rock is dissolved from the Gachsaran formation along the river and dam, so this causes increases in the Ca^{2+} and SO_4^{2-} concentrations downstream. The CA shows EC, TDS, Cl^-, and Na^+ are placed in the same group in the Idanak station before and after the dam construction. Cluster analysis reveals that upstream regions may not be affected by the dam construction.

Downstream of the dam, there is a strong correlation between EC and some ions (Na^+, Cl^-, and SO_4^{2-}), indicating each ion's high contribution to Cham Nezam water salinity. In the Cham Nezam station (downstream), the correlation between Cl^- and Na ions can signify NaCl dissolution. The correlation between Ca^{2+} and SO_4^{2-} can demonstrate the effect of the dissolution of gypsum mid-layers from the Gachsaran formation after the dam construction. The discharge of household garbage and urban wastes containing salts and detergents (including $MgCl_2$) is the main reason for the highly-correlated Mg^{2+} and Cl^- in Cham Nezam. In addition, the moderate correlation between Mg^{2+} and SO_4^{2-} can be related to using organic and chemical fertilizers. The dam construction has no statistically significant effect on Schoeller and Wilcox indices.

Acknowledgments

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