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Original Article

A model-based evaluation of farmers' income variability under climate change (case study: autumn crops in Iran)

Uma avaliação baseada em modelo da variabilidade da renda dos agricultores sob mudança climática (estudo de caso: culturas de outono no Irã)

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Abstract

The study strives to analyze the potential variations of farmers' income under climate change by using Ricardian approach. The case study was Mazandaran province of Iran and three autumn crops, i.e. wheat, barley and canola were considered as the investigated crops. The Long Ashton Research Station Weather Generator (LARS-WG) model was selected to downscale the climate data. Three climate variables were downscaled for the years 2020-2080 under three climate scenarios: optimistic (RCP2.6), medium (RCP4.5), and pessimistic (RCP8.5). The Ricardian approach was also employed to predict the economics of climate change. Accordingly, the mean monthly temperature of the province is projected to have an upward trend under all climate scenarios, however, the rainfall pattern would be varied. The results of economic impacts of climate change also approved that the net income of investigated crops would be different trends under climate change scenarios. Accordingly, the variations of air temperature and rainfall would lead that the net income increases for wheat and barley, while it decreases for canola.

Keywords: climate change, agriculture, net income, Ricardian approach.

Resumo

O estudo se esforça para analisar as variações potenciais da renda dos agricultores sob a mudança climática usando a abordagem Ricardiana. O estudo de caso foi a província de Mazandaran do Irã e três culturas de outono, ou seja, trigo, cevada e canola foram consideradas como as culturas investigadas. O modelo Long Ashton Research Station Weather Generator (LARS-WG) foi selecionado para reduzir a escala dos dados climáticos. Três variáveis climáticas foram reduzidas para os anos 2020-2080 em três cenários climáticos: otimista (RCP2.6), médio (RCP4.5) e pessimista (RCP8.5). A abordagem ricardiana também foi empregada para prever a economia das mudanças climáticas. Assim, projeta-se que a temperatura média mensal da província tenha uma tendência ascendente em todos os cenários climáticos, no entanto, o padrão de chuvas seria variado. Os resultados dos impactos econômicos das mudanças climáticas também aprovaram que a renda líquida das lavouras investigadas seria de tendências diferentes em cenários de mudanças climáticas. Nesse sentido, as variações da temperatura do ar e da pluviosidade fariam com que a renda líquida aumentasse para o trigo e a cevada, enquanto diminuía para a canola.

Palavras-chave: mudanças climáticas, agricultura, renda líquida, abordagem Ricardiana.

1. Introduction

Climate is one of the vital structures of the earth which has numerous influences on different parts of human life. The effect of human activities on the earth has caused that the climate variables such as temperature and rainfall are influenced by ever-increasing of greenhouse gas emissions and these changes will influence human life and their environment later on (Zarakani et al., 2014). Such climate changes can lead to a fundamental evolution in the agriculture sector and thus cause the application of new management policies to cope with these sector changes (Todisco and Vergni, 2008). The role of changing in climate variables in the agriculture sector has appeared as changes in the patterns of temperature, precipitation, and evapotranspiration, and on the other hand, it finally results in some economic outcomes such as changes in crops yield, crops prices, and supply and demand degree, and consequently changes in income distribution for both consumers and producers (Kompas et al., 2018; Pequeno et al., 2021). Since agricultural products highly depend on the climate condition, so climate change may affect significantly on economic aspects of agriculture (Shamsipur et al., 2012; Parhizkari et al., 2017). This phenomenon causes some changes in the regional climate patterns and it has been shown that making more changes

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in rainfall and increasing drought is its main outcome (Burke and Brown, 2010). The importance of climate change has made it necessary to identify the climate change trend in different regions and to find the appropriate management strategies to lessen the impacts of climate change.

The consequences of climate change in different agricultural sectors have been investigated mostly through modeling techniques. One of the methods that has been currently applied to investigate the economics of climate change in agriculture is the Ricardian approach which was first introduced by David Ricardo (Ricardo, 1817) and then extended by Vaseghi and Esmaeili (2009). In this regard, in examining how climate change would affect the farmers' income in Vietnam by applying the Ricardian approach, the results showed that it led to rising temperature and rainfall, and consequently reducing farmers' income, however, application of the adaptation scenarios can compensate for some losses (Huong et al., 2019). In another research in Italy on the impact of global warming potential by using data of 16000 farmlands, the results of the Ricardian model indicated that the net income was significantly affected by seasonal changes of temperature and rainfall, and the land value was affected by the climate variables (Bozzola et al., 2018). Evaluating of climate change effect on land rental prices of six farm types in Germany by using the Ricardian model approved that the farms with permanent crops in the areas with higher annual temperatures are more affected compared with fodder and mixed farms in areas with higher annual rainfall (Chatzopoulos and Lippert, 2015). In another research, the effect of climate change on optimal crop management practices, i.e., the required amount and applying time of nitrogen fertilizer and irrigation, in producing wheat and maize in Switzerland was examined. The results showed that maize needs to be irrigated in all regions, while for wheat, irrigation isn't considered an optimal management practice. Furthermore, climate change in both crops leads to a decrease in the amount of required nitrogen fertilizer (Lehmann et al., 2013). The Ricardian model was also applied to analyze the consequences of climate change in Nepalese agriculture. The results suggested that the studied variables significantly affected the farm's net income per hectare; and also the relative decreasing of rainfall and rising of temperature had positive effects on farms' income during springs and autumns (Thapa and Joshi, 2010). In studying the climate change effects on wheat yield in seven counties of Khuzestan province, Iran, the results showed that among studied regions, the seed yield, biomass, and wheat leaf area index have a rising trend and the growing season length have a dropping trend. It was also claimed that the highest wheat yield under climate change in the future will be related to Izeh and Ramhormoz counties with 7691 and 6595 kg ha^{-1}, respectively (Farshadi et al., 2017). Parhizkari et al. (2017) also assessed the climate change effects on agricultural products and farmers' income at the regional level and in the studied areas of the downlands of Taleghan dam. The findings revealed that based on the studied scenarios, the yield of irrigated barley, maize, sugar beet, and alfalfa increases 14.9, 19.1, 17.4, and 13%, respectively, while the yield of irrigated wheat, tomato, and canola decreases 21.4, 16.5 and 26.2%, respectively. The farmers' total gross return also decreases by 5.16% compared to the baseline year.

Mazandaran province is known as one of the major provinces in agriculture in Iran. In Mazandaran, about 413,000 hectares of agricultural products are annually cultivated among which wheat (54,000 hectares), barely (34,300 hectares), and canola (13,550 hectares) are the main autumn crops. Regarding the importance of improving farmer's income and yield of such crops per unit area, study the role of climate change on producing the crops would be of great essential.

A comprehensive study on how climate change would influence agriculture can lead to significant results to predict the economic aspects of crop production, and consequently, improve management policies to adopt the cropping patterns under climate scenarios. Accordingly, in the current study, first, the climate variables of temperature and rainfall in the province were projected through downscaling the GCM's outputs using a weather generator, i.e., LARS-WG, under three RCPs, i.e., RCP2.6, RCP4.5, and RCP8.5. Then, the Ricardian approach was employed to assess the economics of climate change on autumn crops in Mazandaran province, Iran. Next, the effect of climate variables on determining the net income of autumn crops in the province was investigated under climate scenarios.

2. Materials and Methods

2.1. Data collection

To study the climate change effects on autumn crops in Mazandaran province, three crops, i.e. wheat, barley, and canola were selected because they are the major crops cultivated in the regions. The studied climate variables were minimum and maximum air temperatures and monthly rainfall during 2000-2020 which were acquired from Iran Meteorological Organization. The studied regions were considered as seven synoptic stations in Mazandaran province, i.e. Amol, Babolsar, Qara Kheyl, Nowshahr, Ramsar, Sari, and Siah Bisheh (Figure 1).

The farmers' annual net income of each crop was computed from the difference between the gross income and production costs. For this purpose, first, the temperature and rainfall in the investigated stations were predicted under climate change scenarios. Then, the impact of the climate variables on farmers' net income was determined through the Ricardian approach, by using Matlab and Minitab statistical software. The flowchart of the procedure of the study is represented in Figure 2.

2.2. Downscaling and simulating weather data

The LARS-WG (Long Ashton Research Station Weather Generator) was employed to downscale the effects of climate change on climate variables, i.e. minimum and maximum temperature and rainfall for 2020-2080 (Semenov and Barrow, 2002) under different scenarios. In its fifth report, International Panel of Climate Change (IPCC) introduced some scenarios based on the amount of greenhouse gas emissions, i.e., RCP8.5, RCP6, RCP4.5,

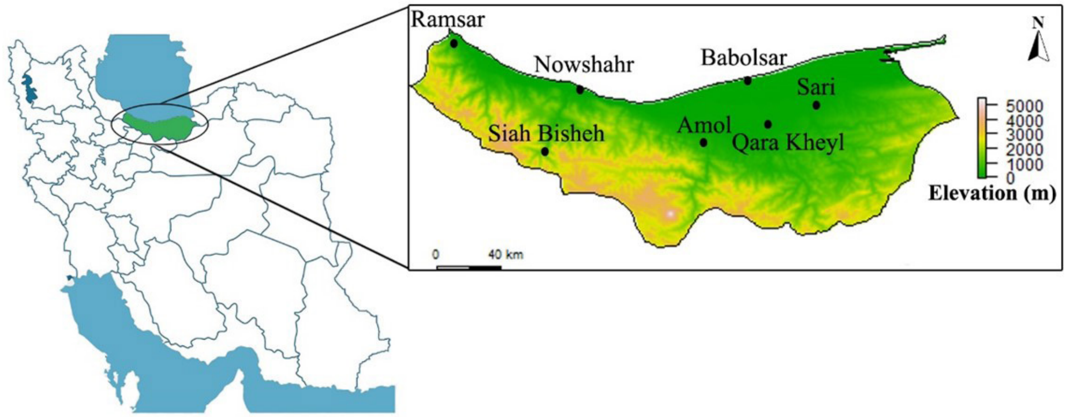

Figure 1. The map of the investigated synoptic stations in Mazandaran province, Iran based on elevation [retrieved from GADM (2021)].

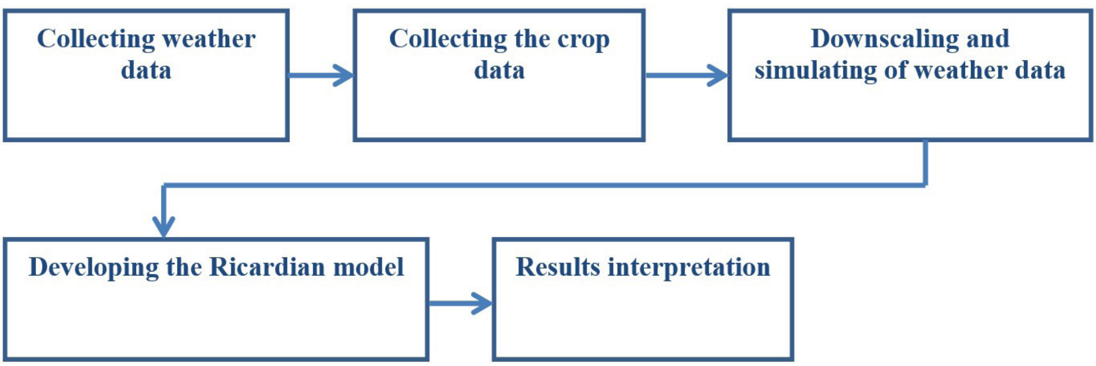

Figure 2. Flowchart of the procedure to investigate climate change impact on farmers' net income in Mazandaran province, Iran.

and RCP2.6 (Wayne, 2013). RCPs are the pre-determined pathways for determining the concentration of aerosols and greenhouse gases with some land-use changes which are matched with a set of wide climate outputs using in climate modeling society. In the current research, the effect of three climate change scenarios (RCP8.5, RCP4.5, and RCP2.6) was studied on the economic index of autumn crop production, i.e., net income per unit area.

2.3. Application of the Ricardian approach

Ricardian approach was introduced to study the economics of climate change in the agricultural sector; and due to its performance, it has been used widely in several studies (Mendelsohn and Reinsborough, 2007; Eid et al., 2007; Chatzopoulos, 2015). The Ricardian approach considers the value of land per unit area (hectare) (V_i) equals to the present value of future net incomes resulted from agricultural practices (Equation 1) (Bozzola et al., 2018):

$$V = \int_t^{\infty} [\sum MO(X,G,Z) - I'X] e^{-\varphi t} dt \tag{1}$$

Where *i* refers to the farm index. *M* is the vector of crop price *i*, and *O* is the output of crop *i*. *X, C, S,* and *G* are the vectors of purchased inputs (except land), the variables which are constant during the studied period (e. g. climate), and the control variables that change during the period (i.e. income), respectively. Finally, *I* is the inputs price vector and *t* and ϕ are time and relevant discount rate. A farmer selects some outputs for production and also considers the inputs *X* for maximizing the value of lands at given prices, climate conditions, and other socioeconomic conditions.

It is assumed that for maximizing Equation 1, the output and purchased inputs should be selected such that the value of lands per unit area becomes maximized. Therefore, the Ricardian model refers to the relationship between the land's maximum value and the variables which cannot be changed by farmers (Equation 2) (Bozzola et al., 2018).

$$V = f(G, Z, \mathrm{M}, \mathrm{I}) \tag{2}$$

In the current research, the climate variables of temperature and rainfall during the crop year and the growing period (i.e. from planting to harvesting) were considered to examine the climate change impacts on farmers' net income (Equation 3), as follows:

$$V = c_0 + c_1 T_c + c_2 T_a + c_3 R_c + c_4 R_a + c_5 T_c^2 + c_6 T_a^2 + c_7 R_c^2 + c_8 R_a^2 + c_9 T_c R_c + c_{10} T_a R_a \tag{3}$$

Where V is the net income per unit area, T_a and T_c are the mean monthly temperature during the crop year and growing period (ºC), respectively. R_a and R_c are also the total monthly rainfall (mm) during the crop year and growing period (mm), respectively. The coefficients of C_i *(i= 0,1,2,…,10)* also refer to the regression coefficients of the proposed model.

The regression coefficients of the Ricardian model were determined through Quantile Regression methodology (Benhin, 2006; Mano and Nhemachena, 2007; Huong et al., 2019). Using quantile regression can help to determine the distribution shape of the dependable variable of the model at different levels (Leite et al., 2021; Lu et al., 2021). Furthermore, this method is able to remove the limitations related to Ordinary least squares (OLS) regression models such as outlier data, limited forecast errors, and variance variability (Huong et al., 2019).

Next, marginal impacts of the studied climate variables were obtained through Equations 4-7 (Bozzola et al., 2018; Huong et al., 2019):

$$[\partial \hat{V}_i / \partial T_c] / \hat{V}_i = c_1 + (2c_5 T_c) \tag{4}$$

$$[\partial \hat{V}_i / \partial T_a] / \hat{V}_i = c_2 + (2c_6 T_a) \tag{5}$$

$$[\partial \hat{V}_i / \partial R_c] / \hat{V}_i = c_3 + (2c_7 R_c) \tag{6}$$

$$[\partial \hat{V}_i / \partial R_a] / \hat{V}_i = c_4 + (2c_8 R_a) \tag{7}$$

Finally, the climate change impact on land's value was calculated for each farm as a difference between land value under future temperature and rainfall conditions (T_f, R_f) and temperature and rainfall conditions at baseline period (T_0, R_0). Thus, net income change per unit area was obtained as a measure of land's value change under climate change conditions (Equation 8) as follows (Bozzola et al., 2018):

$$\hat{\Delta} V_i = \sum_{i=1}^{N} [\hat{V}_i(T_{i,f}\ R_{i,f}) - \hat{V}_i(T_{i,0}\ R_{i,0})] \tag{8}$$

3. Results and Discussion

3.1. Downscaling the GCMs outputs

3.1.1. LARS-WG performance analysis

In this study, three climate variables, i.e., minimum and maximum monthly temperature, and total monthly rainfall under the baseline period (2000-2020) were downscaled and simulated by using LARS-WG under three scenarios of RCP2.6, RCP4.5, and RCP8.5 within the period of 2020-2080. The results of the mean comparison test for data probability distributions of observed and simulated climate variables in the studied stations are represented in Table 1. Accordingly, there was not a significant difference between observed and simulated data in all three investigated variables. Therefore, the LARS-WG model was able to simulate the climate variables with high accuracy in the studied stations.

To more deeply comparison between observed and simulated data in the studied stations, the variation diagram of the studied climate variables for each station is presented in Figure 3. Accordingly, the observed and LARS-WG-simulated values in the studied stations during the baseline period of 2000-2020 were not different significantly.

3.1.2. Temperature and rainfall under the baseline period

The mean monthly temperature and total monthly rainfall of Mazandaran province were estimated from the values obtained from seven studied stations. The variations in mean temperature and total rainfall are illustrated in Figures 4-5, respectively. According to Figure 4, during the baseline period, Mazandaran had the highest mean temperature in July with 26.2 ºC, while the lowest mean temperature occurred in January with 7.1 ºC, on average. According to Figure 5, the highest and the lowest values of rainfall in Mazandaran province are observed in October with 153.74 mm and in May with 26.6 mm, respectively, on average.

Studying Mazandaran's total annual rainfall under the baseline period indicated that the mean annual rainfall was 870.6 mm. Assessing the trend of annual rainfall in Mazandaran province also revealed a declining gradient of rainfall trend line during the baseline period as an indicator for decreasing the annual rainfall in the province (Figure 6).

3.1.3. Climate change impacts on temperature and rainfall

After evaluating the proposed model performance during the baseline period and studying the trends of temperature and rainfall changes during this period in Mazandaran province, the future mean monthly temperature and total monthly rainfall were predicted by using the LARS-WG model. The simulated values of the temperature and rainfall in Mazandaran province for three periods of 2020-2040, 2021-2060, and 2061-2080 under three scenarios of RCP2.6, RCP4.5, and RCP8.5 were represented in Figure 7-8. According to Figure 7, the LARS-WG model indicates an upward trend for mean

Table 1. The results of the mean comparison test (base on P-value) for data probability distributions of observed and simulated monthly maximum temperature and the total monthly rainfall in seven studied synoptic stations.

station	p-value		
	Maximum temperature	Minimum temperature	rainfall
Amol	0.952	0.996	0.916
Babolsar	0.961	0.998	0.930
Qara kheyl	0.941	0.982	0.950
Nowshahr	0.958	0.995	0.918
Ramsar	0.96	0.994	0.919
Sari	0.951	0.980	0.997
Siah bisheh	0.979	0.943	0.945

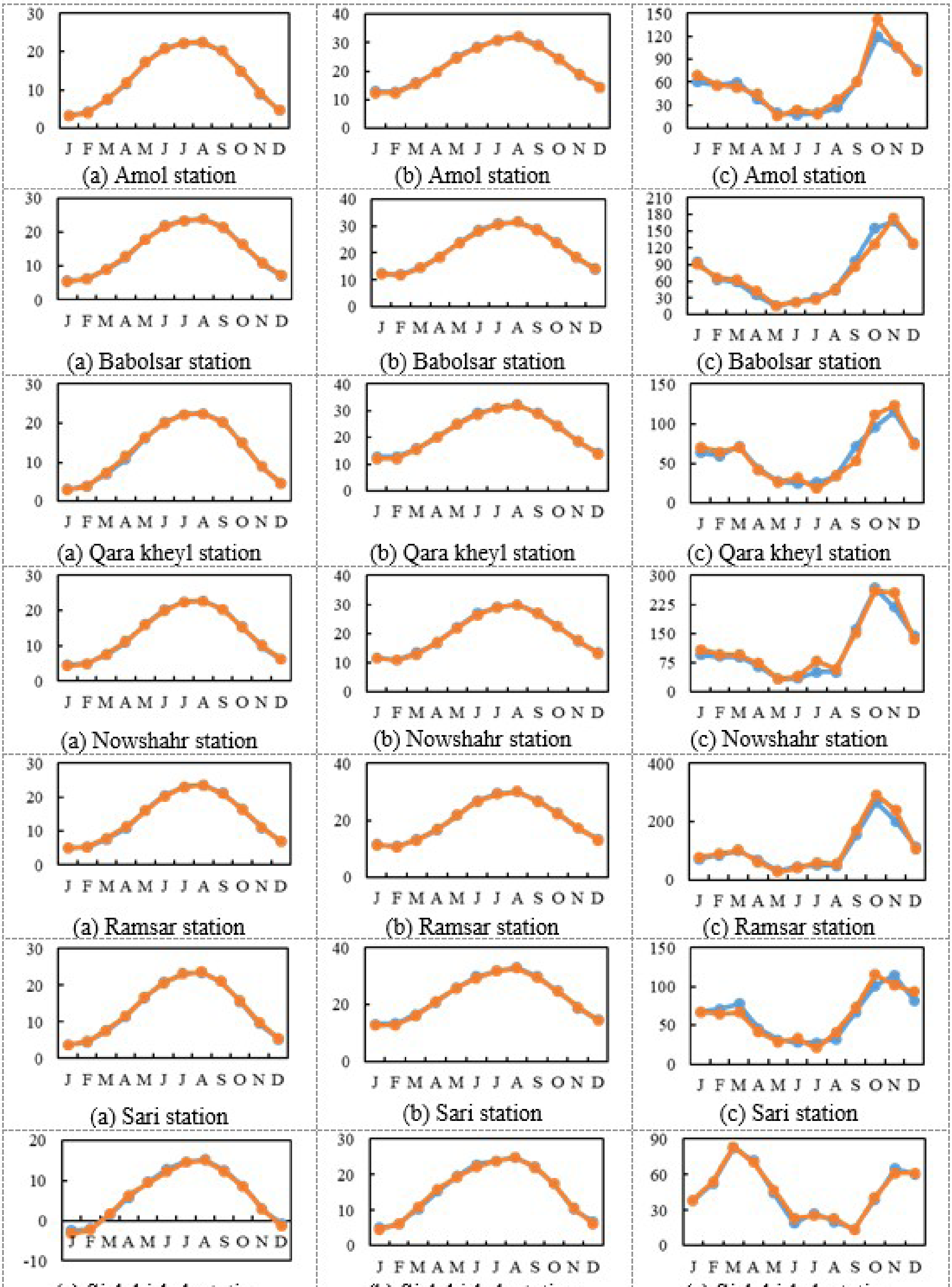

Figure 3. Comparison between the observed (blue line) and LARS-WG-simulated values (orange line) in the studied stations for the climate variables: a) monthly minimum temperature, b) monthly maximum temperature, c) total monthly rainfall (horizontal line).

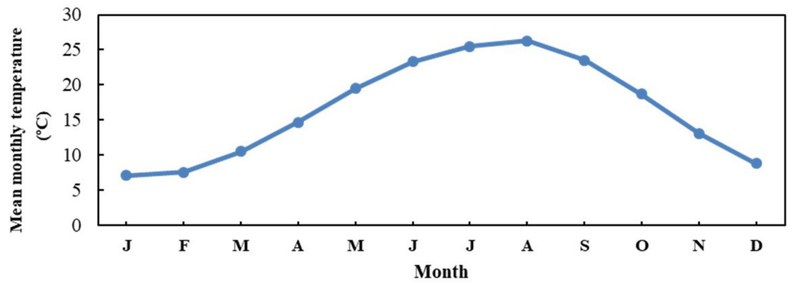

Figure 4. The mean monthly temperature in Mazandaran province under the baseline period (2000-2020).

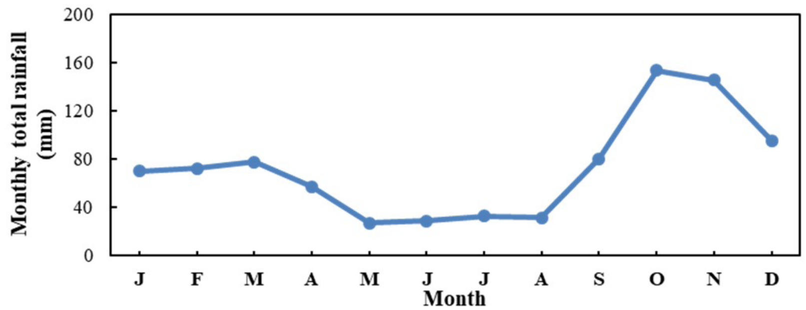

Figure 5. The monthly total rainfall in Mazandaran province under the baseline period (2000-2020).

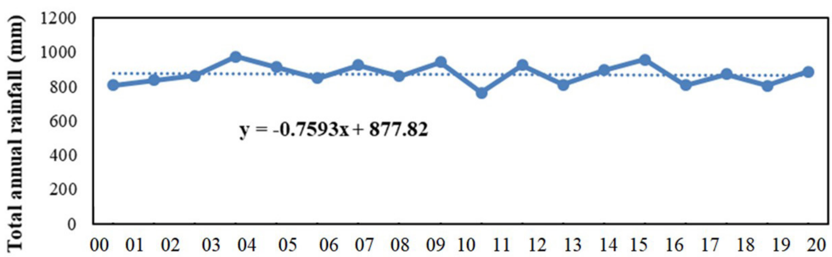

Figure 6. The total annual rainfall in Mazandaran province during the baseline period (2000-2020).

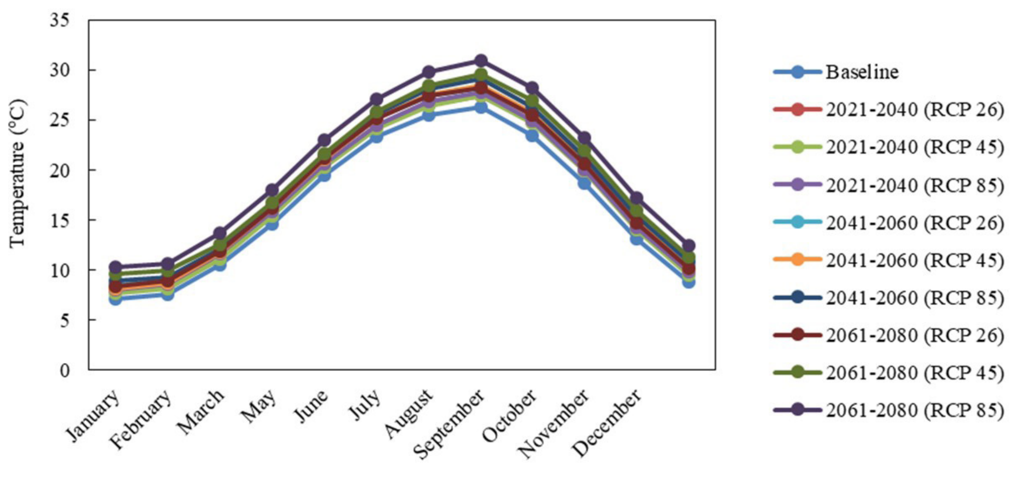

Figure 7. The mean monthly temperature changes in Mazandaran province under the baseline period and climate change scenarios during 2020-2080.

monthly temperature in future periods. The highest and the lowest values of simulated temperature belonged to August and January, respectively. Examining the rainfall trend in Figure 8 also claimed that the rainfall pattern had different behaviors in Mazandaran province and the highest and the lowest values of predicted rainfall were related to November and August, respectively.

3.2. Development of Ricardian model

3.2.1. Descriptive statistics

In order to develop the Ricardian model, the baseline period for all three crops was considered from 2005 to 2016, in accordance with the available economics data for the study. Accordingly, Table 2 indicates the descriptive statistics of all studied variables in the Ricardian model for autumn crops in Mazandaran province, including mean, maximum, minimum, standard deviation, and the coefficient of variation (CV) of temperature and rainfall during the growing period from 2005 to 2016, on average. Since the growing period of the three crops of wheat, barley, and canola are the same, from the early autumn to the early summer, the mean monthly temperature and total monthly rainfall during the growing period of the crops are considered to be equal. According to Table 2, the mean monthly temperature during the crop year (T_a) and growing period (T_c) was 16.2 ºC and 13.7 ºC, respectively. Also, the total monthly rainfall during the crop year (R_a) and growing period (R_c) was 290.3 and 285.1 mm, respectively.

3.2.2. Model parameters estimation

In this study, the quantile regression method was used to find the best coefficients for the Ricardian model. Since the OLS regression model may be involved in some problems such as variance, multi-collinearity, and autocorrelation, the results may be faced with some degree of errors. Therefore, the quantile regression method was employed to determine the regression coefficients (Huong et al., 2019). In this regard, the results of determining the regression coefficients of Ricardian models for the studied crops are presented in Table 3. Accordingly, regression results claimed that most regression terms had a significant effect on net income per unit area at 1%, 5%, and 10% levels in all studied crops.

Table 3 indicates that the mean absolute error (MAE) of the regression model in predicting the net income of wheat was 2.45 and the Pseudo R^2 was also assigned to 56.4%. Also, according to results, the temperature of growing period (T_c), squared temperature of crop year (T_a^2), squared rainfall of growing period (R_c^2), and squared rainfall of crop year (R_a^2) had negative impacts on net income, while the effects of the temperature of crop year (T_a), rainfall of growing period (R_c), rainfall of crop year (R_a), and squared temperature of growing period (T_c^2) on net income were positive. Finally, the interaction of temperature and rainfall of growing period ($T_c \times R_c$) and the interaction of temperature and rainfall of crop year ($T_a \times R_a$) did not affect the net income.

Table 2. Descriptive statistics of the variables of the Ricardian model for studied crops in Mazandaran province.

Variable	mean	maximum	minimum	Standard deviation	CV
T_a (ºC)	16.2	16.3	15.6	0.08	0.01
T_c (ºC)	13.7	14.1	13.4	0.15	0.01
R_a (mm)	290.3	329.4	263.7	16.9	0.06
R_C (mm)	258.10	304.80	232.30	17.76	0.07

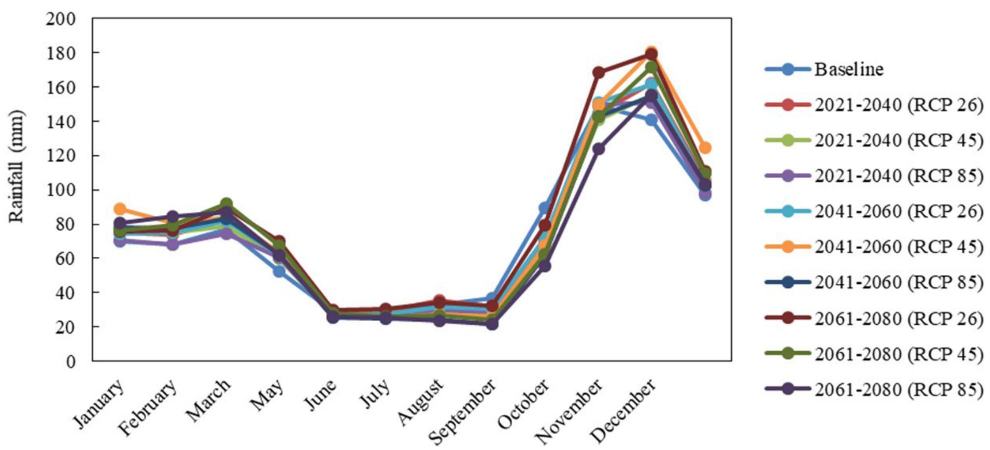

Figure 8. The total monthly rainfall changes in Mazandaran province under the baseline period and climate change scenarios during 2020-2080.

Table 3. The regression results of the Ricardian model for wheat, barley, and canola in Mazandaran province.

Term	Wheat	Barley	Canola
Intercept	-2647225821(-5.888)**	-939102262 (-5.578)**	-2208575663 (-10.047)*
T_c	-226101048 (-6.020)*	-27459585.5 (-2.015)^{ns}	-60116936.7 (-3.273)**
T_a	93843133.11 (3.615)**	24982821.69 (2.653)^{ns}	226606196.1 (17.854)*
R_c	9248609.75 (8.626)*	731885.87 (1.882)^{ns}	4515823.05 (8.614)*
R_a	12974392.07 (7.429)*	4989840.14 (7.875)*	3330450.03 (3.900)**
T_c^2	10358713.48 (7.046)*	1562667.22 (2.930)***	4123117.59 (5.736)**
T_a^2	-3938181.37 (-3.795)**	-999346.37 (-2.655)***	-10136040.4 (-19.978)*
R_c^2	-16049.29 (-8.198)*	-1144.93 (-1.612)^{ns}	-7601.364 (-7.941)*
R_a^2	-20724.82 (-7.370)*	-7986.94 (-7.830)*	-4279.896 (-3.113)***
$T_c{\times}R_c$	0	0	0
$T_a{\times}R_a$	0	0	0
Pseudo R^2	0.564	0.573	0.762
MAE	2.45	0.94	1.26

Values in parenthesis are t-statistic. ^{ns}: Not Significant. *Significance at 1% level. **Significance at 5% level. ***Significance at 10% level.

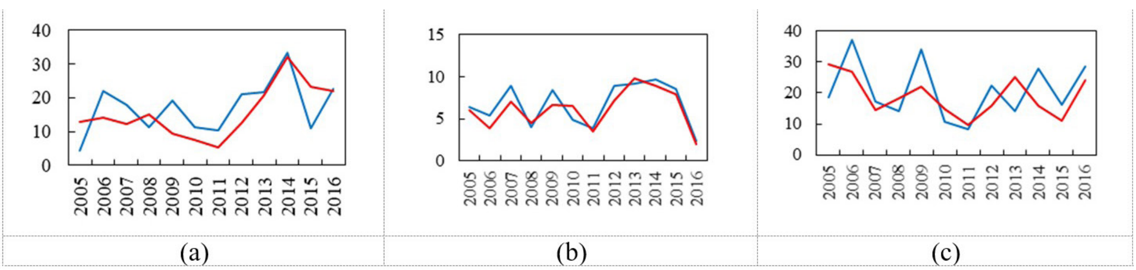

Figure 9. Regression model performance in determining the net income (blue line) compared to the observed value (red line) for (a) wheat, (b) barley, and (c) canola (vertical axis shows the net income).

In barley production, the MAE of the proposed model was obtained as 0.94 and the Pseudo R^2 was estimated at 57.3% (Table 3). According to the results, the temperature of growing period (T_c), squared temperature of crop year (T_a^2), squared rainfall of growing period (R_c^2), and squared rainfall of crop year (R_a^2) had a negative impact on net income. However, the temperature of growing period (T_c), rainfall of growing period (R_c), rainfall of crop year (R_a), and squared temperature of growing period (T_c^2) lead to an increase in net income. The regression coefficients of ($T_c{\times}R_c$) and ($T_a{\times}R_a$) were determined to be zero in the model.

According to Table 3, the value of MAE and Pseudo R^2 was determined as 1.26 and 76.2%, respectively. Regression results also claimed that the temperature of growing period (T_c), squared temperature of crop year (T_a^2), squared rainfall of growing period (R_c^2), and squared rainfall of crop year (R_a^2) had a negative impact on net income. In contrast, the impact of the temperature of crop year (T_a), rainfall of growing period (R_c), rainfall of crop year (R_a), and squared temperature of growing period (T_c^2) on net income were positive. Like wheat and barley, the terms of ($T_c{\times}R_c$) and ($T_a{\times}R_a$) did not affect the net income.

Figure 9 presents the performance of the proposed regression models through the Ricardian approach to predict the net income compared to the observed values for the studied crops, i.e., wheat, barley, and canola in 2005-2016. Accordingly, the proposed models had an acceptable performance in predicting the trend of net income changes during the studied years.

According to the regression results, the Pseudo R^2 of the models developed for the studied crops, i.e. wheat, barley, and canola was calculated as 56.4%, 57.3%, and 76.2%, respectively. Huong et al. (2019), who also used the quantile regression model for modeling Vietnamese farmers' net income using the Ricardian model, reported Pseudo R^2 of the regression model to be 18.37% for the non-adaptation model. In other similar studies, this index was obtained to be 18.71% (Mano and Nhemachena, 2007) and 16.99% (Benhin, 2006). It can be seen that the performance of the proposed models in the present study outweighs other similar studies. Regarding the high uncertainty of agricultural net incomes resulting from uninterpretable variables, the determined values can be acceptable (Ouedraogo et al., 2006). The regression analysis of predicting agricultural net income revealed that in all proposed models, the effects of temperature during the production period, monthly temperature squared, monthly rainfall squared and rainfall squared during the production period on net income were negative. In similar research, the effects of temperature during the dry season and rainfall coefficients during dry and wet seasons on net income were reported to be negative (Huong et al., 2019). Mahmood et al. (2021) also found that the effect of different mean monthly temperatures on the gross income of wheat farmers was negative. In examining the economic impacts of climate change on wheat in Iran, Khan et al. (2020) claimed that the effect of temperature was negative, while the effect of rainfall was positive on net income.

3.3. Marginal impacts of climate on net income

The marginal impacts of climate were determined to study how a slight change in temperature and rainfall would affect the farmers' net income from autumn crops in Mazandaran province (Table 4). The results indicated that the increasing temperature of growing period led to an increase in net income of all three crops. In other words, per 1ºC increase in temperature of growing period, the net income of wheat, barley, and canola would increase 20.72, 3.13, and 8.25, respectively. Accordingly, the net income of wheat was influenced higher than two other crops. However, the impact of the temperature of crop year on the net income of all investigated crops was negative. On the other hand, per 1ºC increase in the temperature of crop year, the net income of wheat, barley, and canola decreased 7.88, 2.00, 20.27, respectively that for canola, the impact was higher than two other crops. In a study examining the marginal impact of temperature during dry and wet seasons, Huong et al. (2019) showed that increasing temperature during the dry season led to a decrease in net income while increasing temperature during the wet season led to an increase in farmers' net income.

Analyzing the marginal impact of rainfall of growing period indicated that per 1 mm increase in rainfall of the period would result in a decrease in net income of all three crops by 0.03, 0.002, and 0.02, for wheat, barley, and canola, respectively (Table 4). Similarly, the marginal impact of increasing rainfall of crop year on farmers' net income of all investigated crops was negative. On the other hand, per 1 mm increase in monthly rainfall, the net income of wheat, barley, and canola could decrease by 0.04, 0.02, and 0.01, respectively. Huong et al. (2019) found that as rainfall increased during dry and wet seasons, the Vietnamese farmers' net income would increase.

3.4. Economics of climate change

After proposing the Ricardian model for the investigated crops, the climate change impact on net income was examined under different climate scenarios. In this regard, mean monthly temperature and total monthly rainfall for 2020 and 2080 were projected by using the LARS-WG model under different RCPs, i.e., RCP2.6, RCP4.5, and RCP8.5. Then, the climate impacts under the scenarios on the farmers' net income were investigated (Table 5). Accordingly, it can be seen that variations in temperature and rainfall during the crop year and growing period would increase the net income of wheat. In other words, compared to the baseline period, in 2050, the net income of wheat agro-systems in Mazandaran province under the scenarios of RCP2.6, RCP4.5, and RCP8.5 is projected to increase about 24.5, 28.1, and 30.0%, respectively. Similarly, in 2080, the projected net income of the agro-systems under the studied scenarios

Table 4. Marginal impact of climate variables on farmers' net income.

Term		wheat	barley	Canola
Temperature (ºC)	Growing period	20.72	3.13	8.25
	Crop year	-7.88	-2.00	-20.27
Rainfall (per mm)	Growing period	-0.03	-0.002	-0.02
	Crop year	-0.04	-0.02	-0.01

Table 5. The impact of climate change on net income.

Year	Climate scenarios	Temperature (ºC)		Rainfall (mm)		Net income, (USD)		
		Growing period	Crop year	Growing period	Crop year	Wheat	Barley	Canola
Baseline	-	13.7	16.2	258.9	290.3	425.2	150.1	475.0
2050	RCP2.6	15.4 (12.4)	18.9 (16.7)	257.1 (-0.7)	284.0 (-2.2)	542.7 (24.5)	198.8 (30.2)	432.3 (-16.4)
	RCP4.5	15.5 (13.1)	19.0 (17.3)	254.3 (-1.8)	278.5 (-4.1)	550.0 (28.1)	230.2 (36.8)	425.0 (-18.0)
	RCP8.5	15.7 (14.6)	19.1 (17.9)	252.0 (-2.6)	261.2 (-10.0)	550.3 (30.0)	232.3 (39.2)	399.9 (-23.6)
2080	RCP2.6	15.3 (11.7)	19.0 (17.3)	254.2 (-1.8)	280.3 (-3.5)	547.9 (27.5)	225.1 (35.8)	350.5 (-29.9)
	RCP4.5	16.3 (19.0)	19.8 (22.2)	240.1 (-7.3)	267.7 (-7.8)	22.4 (30.3)	227.9 (36.8)	338.5 (-34.8)
	RCP8.5	17.5 (27.7)	20.3 (25.3)	210.0 (-19.0)	247.4 (-14.7)	23.6 (37.7)	232.3 (39.0)	325.1 (-36.8)

The values in parentheses show the change percentage of the variable.

increase 21.9, 22.4, and 23.6%, respectively compared to the baseline.

According to Table 5, climate change leads to an increase in the projected net income of barley. Therefore, under three scenarios of RCP2.6, RCP4.5, and RCP8.5, compared to the baseline period, the net income of barley would enhance about 30.2, 36.8, and 39.2%, respectively in 2050, and 35.8, 36.8, and 39.0%, respectively in 2080.

Table 5 also indicates that increasing monthly temperature and decreasing monthly rainfall under climate change scenarios had a negative impact on the net income of canola. On the other hand, in comparison with the baseline period, net income of canola under scenarios of RCP2.6, RCP4.5, and RCP8.5 in 2050 is projected to decrease about 16.4, 18.0, and 23.6%, respectively, and in 2080 about 29.9, 34.8, and 36.8%, respectively.

Generally, the results of studying the economic impacts of climate change in 2050 and 2080 under three scenarios of RCP2.6, RCP4.5, and RCP8.5 for different crops in Mazandaran province indicated different trends of net income. In other words, increasing temperature and decreasing rainfall lead to the net income of wheat and barley increase. Since increasing temperature with sufficient rainfall can cause to increase in net income (Fezzi and Bateman, 2012), so the projected increase may result from sufficient rainfall in addition to a temperature increase. In contrast, climate change would decrease the net income of canola. In a study on the climate change impacts on the crops of rainfed wheat, rainfed barley, irrigated cotton, and irrigated soybean in Golestan province, Iran, Mojaverian et al. (2015) found that the average net income per hectare (land value) in the years 2050 and 2100 would decrease 21.14 and 38.26%, respectively. In another study, it was revealed that the gross income of agricultural products will decrease by 32% within the next 60 years (Karimi et al., 2018). Huong et al. (2019) mentioned that the net income of Vietnamese farmers would decrease 17.7 and 21.28% in the years 2050 and 2100.

4. Conclusion

The growing trend of gas greenhouse emissions has caused that climate change becomes to one of the main challenges of human life. Regarding the dependence of agriculture on climate conditions, the necessity of examining the climate change effects on the agricultural economy is of great importance. Therefore, the goal of this study was to evaluate the economics of climate change on autumn crops, i.e., wheat, barley, and canola in Mazandaran province under three scenarios of RCP2.6, RCP4.5, and RCP8.5. In this regard, the impact of changes in two climate variables of temperature and rainfall of crop year and growing period was determined on the net income per unit area in 2050 and 2080 compared to the baseline period. The results showed that for all studied crops, the variables of the temperature of growing period squared temperature of crop year, squared rainfall of growing period, and squared rainfall of crop year had a negative impact on net income, while the effect of temperature of crop year, squared temperature of growing period, rainfall of crop year and rainfall of growing period on net income was positive. According to Pseudo R^2 obtained from quantile regression, the proposed Ricardian models were able to predict climate variables-based changes in net income in the studied region. Examining the marginal impacts of climate variables indicated that increasing temperature during the growing period would enhance the net income, while, increasing the temperature of crop year would result in a decrease in net income of all investigated crops. The variables of rainfall of crop year and growing period had negative effects on the net income of all crops. Finally, examining the effects of climate change for the years 2050 and 2080 under three scenarios of RCP2.6, RCP4.5 and RCP8.5 revealed that the possible changes in the climate variables of temperature and rainfall affect the net income of the studied crops in different ways. Accordingly, increasing temperature and decreasing rainfall led to an increase in the net income of wheat and barley and a decrease in the net income of canola. Finally, it can be concluded that regarding possible climate changes in the future years, the amount of profitability in the agricultural sector would be affected, and therefore it may need to change the cropping pattern to mitigate the potential economic consequences.

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Erratum

ERRATUM: A model-based evaluation of farmers' income variability under climate change (case study: autumn crops in Iran)

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