Assessing the impacts of climate change on rainfed wheat production in Hamedan Province

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Abstract
Climate change is one of the greatest challenges in the 21st century and agriculture sector, particularly rainfed crops yields, may be very vulnerable to this phenomena. Since the wheat is the most important cereal crop in Iran, this paper aim to analyze the potential impact of climatic variables (temperature and precipitation) on rainfed wheat productivity in Hamedan Province, IRAN. For this purpose, we have used the generalized additive models to model yields of rainfed wheat based on climatic variables during 2004-2012. Then, based on sensitivity of rainfed wheat to temperature and precipitation in the this period we predict the potential effects of climate change on rainfed wheat yield under the SRES A1FI and B1 climate change scenarios. Results suggest that yields of rainfed wheat would decrease in all Hamedan's counties primarily because of decreasing of October to June precipitation (rainfed wheat-growing seasons) and higher temperature. As a result, it is predicted that the yield of rainfed wheat in Hamedan Province under the A1F1 and B1 scenarios falls by 41.3% and 20.6% respectively in the 2080s.
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Keywords: Climate change; Agriculture; Rainfed Wheat; Hamedan Province

1. Introduction

Climate change is one of the greatest challenges in the 21st century and agriculture may be particularly vulnerable to climate change (McCarthy et al., 2007, Keane et al. 2009, Brown and Funk 2008, IPCC, 2007, Khan et al. 2009, FAO, 2006, McIntyre et al, 2009, Audsley et al, 2009, Hille et al, 2012, Attri & Rathore, 2003) due to its dependence on natural weather patterns and climate cycles for its productivity. The impacts of climate change on agricultural production is both direct and indirect. Important direct effects will be through changes in temperatures, precipitation and radiation, more frequent extreme weather (like droughts, floods, and wind storms), atmospheric carbon dioxide concentration (Bannayan et al, 2005, Holden et al. 2003, Lobell et al, 2008, Rundgren, 2013, Morton, 2007, Ong and Monteith, 1985, Smith et al, 2007, Chiotti and Johnston 1995), length of growing season (Saarikko and Carter, 1996) and modifying evaporation, runoff, and finally soil moisture (Rosenzweig and Hillel, 1998). Indirect effects will include potentially deterministic changes in diseases, pests, weeds, sea Level rise (Kean et al, 2009) and the effects of which have not yet been quantified in most studies. All these factors and variables can change yield and agricultural productivity (Battisti and Naylor, 2009, Harry et al 1993). Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to have negative effect, threatening global food security. Predictions show that global agricultural productivity would fall by 15.9% in the 2080s if global warming continues unabated (Cline, 2007) and developing countries lying in the tropical and sub-tropical regions would face callous results (Morison, Morecroft, 2006, IPCC 2007b, Morton 2007, FAO, 2009a, Diaz et al. 2006).

Iran is one of these countries where agriculture after the service is the greatest sector of the economy and accounted for about 26% of GDP and 26 percent of non-oil exports. It also provides nearly 23% of the total country's employment, and 80% of food production(Dabiri et al, 2013). Nonetheless, Iran has arid or semiarid climates with long dry summers and low winter rainfall average annual precipitation around 250 mm and high potential evapotranspiration. Such climatic characteristics associated with relevant phenomena like desertification, drought, water table reduction and flooding increment and vulnerability of land resources (Momeni, 2003) become very vulnerable to climate change. Findings of recent studies confirmed and documented the occurrence of climate change (Masoudian, 2005, IRIMO, 2006a, 2006b, Rahimzadeh, 2006) and its rigorous potential future effects on Iran agriculture sector (see Valizadeh et al, 2014, Dehghanpour et al, 2014, Rosenzweig and Parry, 1994, Bolle, 2003, Koocheki and Nassiri 2008, Kiani and Houshyar, 2013, Dastorani and Poormohammadi, 2012). Since the rainfed agriculture is much more vulnerable to climate change (Fulco and Senthold, 2006, Trethowan and Pfeiffer, 1999, Boko et al, 2007) and the fact that wheat is the most important cereal crops in the Iran[1], Share of wheat in the daily energy supply is 47%, (Hosseini et al, 2007, Ministry of Agriculture Jahad of Iran, 2000) and since the demand for wheat is predicted to be over 20 million tonnes in 2020 (Zare Faiz Abadi et al, 2006, Sharifi 2001), we aimed at analyzing the impacts of climate change on rainfed wheat production in the Hamedan Province as one of the main wheat producer provinces in the country.

2. Materials and methods

2.1. Study area

The study was conducted at Hamedan province. This province covers an area of 19,543 km² and situated between 33° 59’ to 35° 44’ North latitude and 47° 47’ to 49° 28’ East Longitude and included 8 counties namely Hamadan, Malayer, Nahavand, Asadabad, Razan, Bahar, Kaboodarahang and Tuyserkan. Cultivable land of this province is 641168 ha and 59% of this area _384003 ha_ dedicated to the cultivation of wheat, about 80% allocated to the rainfed wheat and 20% to irrigated wheat (Fig. 1). Hamedan province is one of the important producers of wheat in the Iran_ production of wheat is about 528979 tons/year. The climate regime of this Province is cold and semi-arid. Average annual temperature is 11.3°C and the mean annual precipitation is 300 mm (IRIMO, 2006b), occurring mostly from March to April (Fig. 2).

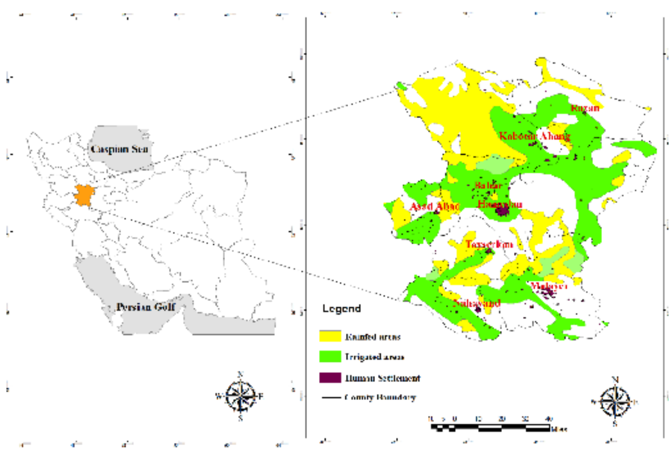

Fig. 1. Location of the study area within Iran (Left) and its Existing Land use/cover (right).

1- Wheat is one of the main cereal crops of Iran, accounting for 35% of the food grain production of the country (12 million tonnes in 2004). Rainfed wheat accounts for about 60 – 65% of the land area under wheat production in Iran and contributes 30 – 35% of wheat production in the country.

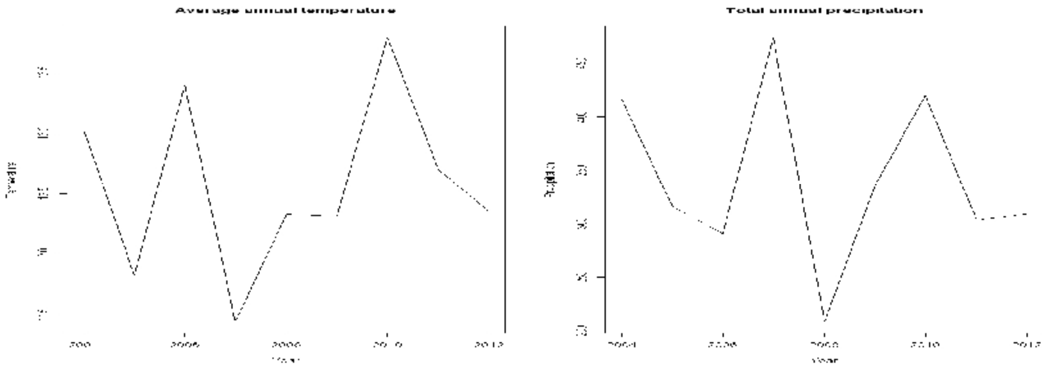

Fig. 2: Average temperature (C°) and the total precipitation (mm) for the period of 2004-2012 in Hamedan province.

2.2. Data set and climate model

Although radiation, soil moisture and carbon dioxide (CO_2) concentration are all important variables to determine wheat productivity and assessing potential impacts of climate change on it, but temperature and precipitation effects are more significant (Wang et al, 2009, Chiotti and Johnston 1995, Warrick 1988). For this reason, and also the lack of accurate information about other variables we used the temperature and rainfall data to analyze the effects of climate change on rainfed wheat production in Hamedan Province, for the currents and the future years. For this purpose, climatic data series (minimum and maximum temperature and precipitation) of synoptic stations of Hamedan Province were obtained for the period of 2004-2012 from Iran Meteorological Organization. Wheat production data series used in this study cover the same period _from 2004 until 2012_ and include data on cultivated areas, Production and Yield (tones/Ha) under rain-fed conditions. The choice of these period was justified by the availability of wheat productions statistics for the areas at those periods.

The SRES A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) climate scenarios for three time slices, namely 2020s (2010-2039), 2050s (2040- 2069) and 2080s (2070-2099) were chosen to evaluate climate change impacts (Table 1).

Season	2010-2039				2040-2069				2070-2099			
	T(C°)		P (%)		T(C°)		P (%)		T(C°)		P (%)	
	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1	A1F1	B1
DJF	1.26	1.06	-3	-4	3.1	2	-3	-5	5.1	2.8	-11	-4
MAM	1.29	1.24	-2	-8	3.2	2.2	-8	-9	5.6	3	-25	-11
JJA	1.55	1.53	13	5	3.7	2.5	13	20	6.1	2.7	32	13
SON	1.48	1.35	18	13	3.6	2.2	27	29	5.7	3.2	52	25

Table 1. Projected changes in surface air temperature and precipitation for west Asia, (12N- 42N; 26E-63E) pathways for three time slices, namely 2020s, 2050s and 2080s (IPCC,). DJF= Dec., Jan., Feb.; MAM= Mar., Apr., May; JJA= Jun, Jul., Aug.; SON= Sep., Oct., Nov. (°C) = Temperature; P (%) = Precipitation; A1FI= Highest future emission trajectory; B1= Lowest future emission trajectory

2.3. Generalized Additive Models (GAM)

While many researchers have evaluated the possible impact of climate change on crop yields using mainly indirect crop simulation models, there are relatively few direct assessments on the impact of observed climate change based on past crop yield and then prediction of future based on fitted trends. In this study we have used the Generalized additive models (GAMs) to model past climatic trends and its effects on rainfed wheat yield. Then, based on sensitivity of rainfed wheat to temperature and precipitation in the period of 2004-2012 we predicted the potential effects of climate change on rainfed wheat in Hamedan Province.

Generalized additive models (Hastie and Tibshirani, 1986) extend the well-known generalized linear models (GLMs) by allowing for non-linear covariate effects through the incorporation of additive non-parametric smooth functions. In the univariate case, assume the distribution of the response variable Y_i belongs to the exponential family and that its mean $\mu_i = E(Y_i)$ related to explanatory variables x_{1i}, x_{2i}, … through the use of a link function $g()$. GAMs are very flexible and there is no need for any assumption about the parametric form for the dependence of the response variable Y_i on variables x_{1i}, x_{2i}, …. When the mean relationships are complex and cannot be easily modeled by specific linear or non-linear functions, a GAM can be a natural choice. Due to their flexibility in model specification, GAMs have seen a variety of applications. GAMs have been widely used in environmental, biological, and ecological studies.

A GAM has the following general structure

$$g\left(E\left[Y|\mathbf{X}\right]\right) = f_0 + \sum_{j=1}^{p} f_j(X_j),$$

Where $f_j()$ are unknown smooth functions of the covariates x_{1i}, x_{2i}, … . The details of GAM fitting procedure can be seen in the book: Generalized Additive Model (Hastie and Tibshirani, 1990).

For our case study our response variable is Yield (tones/Ha), and our selected covariates are total October to June precipitation (mm), mean temperature of JFM, AMJ, JAS and OND. October to January is selected to calculate the precipitation because in Hamadan province commonly rainfed wheat cultivation began in early October and harvested in early Jane. In order to quantify the rainfed wheat effect of annual precipitation and temperature, precipitation and temperature are usually assumed to be linearly related to the indicators of wheat production in the literatures, but the relation to the calendar time and weather variables is not assumed to be parameterized. To take in to account the seasonal effect we also included the year as a covariate in the proposed model. Then the proposed model can be written as

Y = f(Year) + f(October to June precipitation) + f(JFM mean temperature) + f(AMJ mean temperature) + f(JAS mean temperature) + f(OND mean temperature) + ϵ,

where ϵ are the independent normally distributed measurement errors whit mean zero and variance σ^2. As can be seen in Figure 3 (specifically in 2008), October to June Precipitation is one of the main reason for Yield variation. We also studied the effect of Latitude and Longitude and Elevation of 8 counties of Hamadan province namely, Hamadan, Malayer, Nahavand, Asadabad, Razan, Bahar, Kaboodarahang, Tuyserkan but since they are not statistically significant we have removed them from the final model.

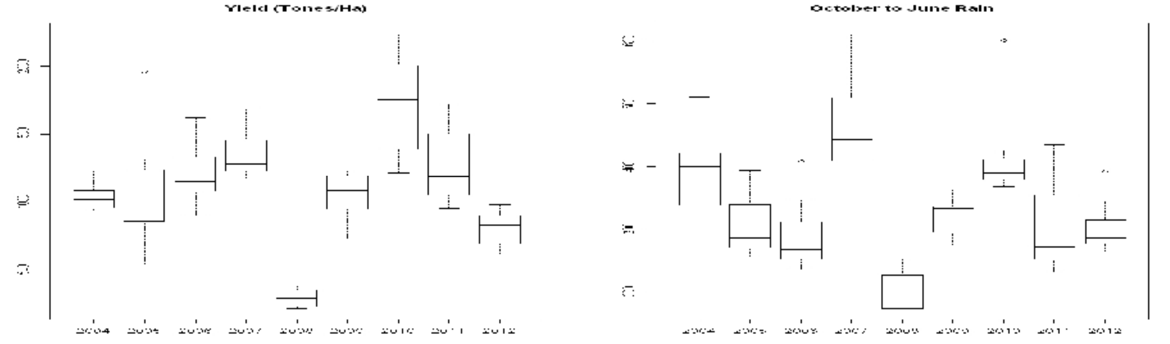

Fig. 3. Box plot of wheat yield and October to June precipitation for the period of 2004-2012 in Hamedan province.

3. Results and discussion

3.1. Fitting the Proposed Model

For proposed model fitting we used mgcv package in R statistical software. Figure 4 and 5 depict the effect of covariates in the Yield and describes the diagnostic plots for the fitted model which indicate that the proposed model is a reasonable model with normally distributed residuals. Based on the residual diagnostics (Q_Q plot, Histogram and scatter plots of residuals against the fitted value reported in the paper), residuals of the fitted model did not significantly violate the normality, equal variance, and independence assumptions. The seasonal relation of the Year and Yields is illustrated very well by the model. Most of the nonparametric terms in the fitted model were significant. The selection of predictors and the decision on their entry or exclusion was based on the GCV score, Akaike information criterion (AIC) and the total deviance explained. 67.4 % of variations of yield are well described by the fitted model. From the fitted model we concluded that if precipitation in October to June and mean temperature in JFM increases, the yield is also rises but with increasing OND mean temperature the wheat yield decreases.

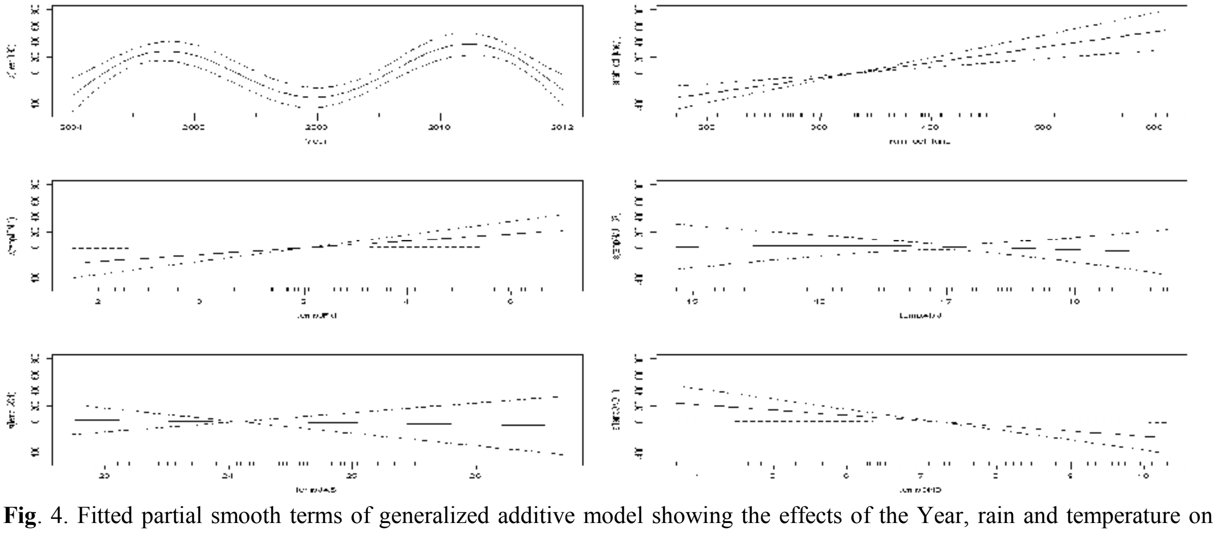

Fig. 4. Fitted partial smooth terms of generalized additive model showing the effects of the Year, rain and temperature on yield of Hamadan province from 2004 to 2012. The dotted curves are 95% confidence intervals of smooth functions.

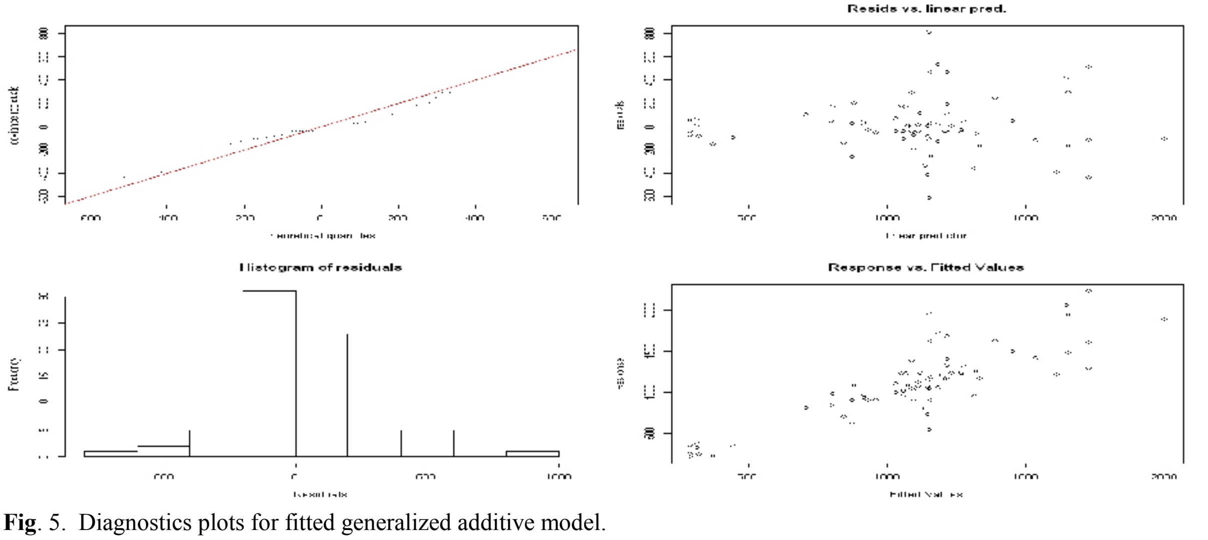

Fig. 5. Diagnostics plots for fitted generalized additive model.

3.2. Analyzing the Climate change impacts on wheat production

As we mentioned, Iran and especially its agricultural sector is facing the issues arising from climate change. The results of many researches has proven climate change in this country, so that, during the last half century, in many parts of the country higher mean temperatures and reduction in total annual precipitation has been observed. Accordingly, in this section we analyze the effects of climate change on rainfed wheat productivity based on the SRES A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) climate change scenarios and according to Hamedan rainfed wheat sensitivity to temperature and precipitation which described already during 2004 – 2012. Figure 6 indicates that, in each scenario, with increasing precipitation the yield will increase as well. However as we can see overall yield is decreasing in 2020s, 2050, and 2080s. Results presented in figure 6 based on our model predict that the yield of rainfed wheat in Hamedan Province under the A1F1 and B1 scenarios fall by 41.3% and 20.6% in the 2080s, respectively.

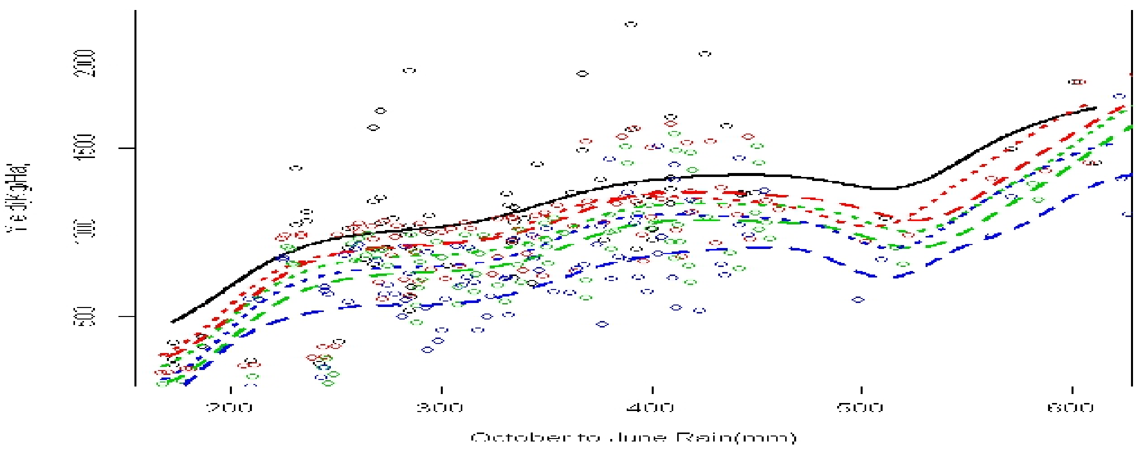

Fig. 6. Prediction for yield in Hamadan based on the data in table 1. Solid cure is recent trend. Red dashed cure is predicted trend for A1FI in 2020s. Red dotted cure is predicted trend for BI in 2020s. Green dashed cure is predicted trend for A1FI in 2050s. Green dotted cure is predicted trend for BI in 2050s. Blue dashed cure is predicted trend for A1FI in 2080s. Blue dotted cure is predicted trend for BI in 2080s.

4. Conclusions

The present study was designed to determine the impact of variation in temperature and rainfall on rainfed wheat in Hamedan Province. For this purpose, we have used the Generalized Additive Models to analyze past climatic trends and its effects on rainfed wheat yield. Generalized additive models provide a flexible method for uncovering nonlinear relationship between response variable and covariates in exponential family and other likelihood based regression models. In the case study given in this paper, the iterative method called the back-fitting algorithm was used to predict the unspecified smoothed function. The cublic spline smoother was applied to the covariates.
Then, based on sensitivity of rainfed wheat to temperature and precipitation in the period of 2004-2012 we predict the potential effects of climate change on rainfed wheat yield in Hamedan Province. To take in to account the seasonal effect we also included the year as a covariate in to the proposed model. For proposed model fitting we used mgcv package in R statistical software. The results derived from the analysis by R statistical software indicate that the proposed model is a reasonable model with normally distributed residuals. 67.4 % of variation of yield are well described by fitted model. Finally based on the SRES A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) climate change scenarios we analyzed the potential impacts of climate change on rainfed wheat in Hamedan Province. Results suggest that yields of rainfed wheat would decrease in all Hamedan`s counties primarily because of decreasing of October to June precipitation (rainfed wheat-

growing seasons) and higher temperature under the climate changes scenarios. Future research needs to take in to account the all important variables such as radiation, soil moisture and carbon dioxide (CO2) concentration to determine wheat productivity and assessing potential impacts of climate change in Hamedan Province.

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