Man vs. nature: investigating factors affecting the winter wheat production in Tibetan area

Abstract

Global warming seriously threatens agriculture in the Tibetan Plateau (TP), bringing about unpredictable seasons and latent pests and diseases. Despite these threats, the yield of winter wheat (*Triticum aestivum* L.), one of the most important staple food crops, is gradually increasing on the TP over the past few decades. With a simple linear regression model, it was found that compared to environmental variables, anthropogenic factors have a more significant impact on the wheat yield. The study is expected to provide guidelines for exploring agricultural adaptation against ever-worsening climate change on a global scale.

Introduction

The Tibetan Plateau (TP), known as the "Third Pole", is an important region of multi-sphere interactions with high climatic sensitivity (Hua *et al*., 2019). Global warming has significantly affected this sensitive plateau for the last few decades. Records have witnessed an annual temperature rise of 0.37 °C per decade from 1961 to 2017, which is greater than anywhere else in China (Xiao *et al*., 2015).

Among all socioeconomic sectors, agriculture is considered as the most sensitive and vulnerable one regarding climate change, threatened by unpredictable seasons, water imbalance and potential diseases (Meng *et al*., 2016). Against all these threats, winter wheat production is rising while the mechanism remains unclear. Herein, both anthropogenic factors, i.e., farmer population, sum of chemical usage, sum of agricultural machinery and environmental factors (temperature and precipitation) were investigated to explain the production increase. Previous studies suggested that wheat yield is expected to decrease by 1.0 to 10.0% per degree of warming without proper agricultural adaptation, with more frequent weather extremes reducing yield stability in North America (Zhang *et al.*, 2022). Thus, compared with environmental factors, anthropogenic factors matter more in increasing winter wheat production in the TP.

Method

Environmental data were collected from the [KNMI Climate Explorer]. Specifically, winter temperature and precipitation data were obtained as the mean values of December, January and February (DJF) over the TP (25 °N – 40 °N and 74 °E - 104 °E), averaged over 2 ° latitude by 2 ° longitude grid boxes. The winter wheat yield and anthropogenic factor data from 1978 to 2018 were obtained from the China National Bureau of Statistics, including annual winter wheat yield (in ten thousand tons), annual winter wheat planting area (in thousand hectares), annual sum of agricultural machinery power (in megawatt), annual fertilizer usage (in ten thousand tons), annual pesticide usage (in ten thousand tons), annual farmer population (in ten thousand people), annual DJF mean temperature (in degrees Celsius) and annual DJF mean precipitation (in mm/month). The response variable is the 41-year annual winter wheat yield, and the explanatory variables are year, planting area, machinery power, fertilizer usage, pesticide usage, farmer population, DJF mean temperature and DJF mean precipitation. All the data and R scripts are available at the EECMaster-mini-project repository.

All statistical analyses were performed in R 4.2.0 (R Core Team, 2022) using the IDE RStudio desktop 2022.12.0+353 (RStudio, Inc., MA, USA). Two simple linear regression (LM) models were fitted with *lm* function and then compared through computing analysis of variance (ANOVA) tables (package *stats* 4.2.0, R Core Team, 2022). I fitted all the explanatory variables into the first model; and for the other one, I excluded variables with high collinearity using the Variance Inflation Factor (VIF) test (package *usdm* 1.1-18, Naimi *et al*., 2014) with a threshold value of 3, and thus, variables of year and fertilizer were removed. I also z-standardized all the explanatory variables using *scale* function in both models, so the slope coefficients were comparable. Diagnostic plots of the LM models were checked and no violation of the assumptions were found.

Results

The differences between the LM model with all the variables (Model 1) and the LM model with the exclusion of high collinear variables (Model 2) were examined using ANOVA. In Model 2, the removal of year and fertilizer variables does make the model significantly worse: the p-value is less than 0.05, indicating significant differences between the models, and the residual sum of squares (RSS) increased from 332.80 to 495.22, which is statistically significant.

The above results suggests that the LM with all the variables is a better model. The results of Model 1 are shown in Table 1. A significant linear regression equation was found (F-value = 8.246, df = (8, 32), p-value < 0.01) with an adjusted R^2 of 0.59. The slope coefficients (Table 1) were significantly different between each variable. For instance, for every one standard deviation increase in annual fertilizer usage, annual winter wheat production increased by 7.19, while for every one standard deviation increase in DJF mean temperature, annual winter wheat production decreased by 1.97.

Table 1. Coefficients of the simple linear regression models.

Coefficient	Estimate ± SE	t-value	p-value
Intercept	17.06 ± 0.50	33.88	< 0.01
z-standardized year	-0.52 ± 2.71	-0.19	0.85
z-standardized annual planting area	2.25 ± 0.54	4.17	< 0.01
z-standardized annual fertilizer usage	7.19 ± 2.32	3.10	< 0.01
z-standardized annual machine power	-3.43 ± 1.71	-2.01	0.053
z-standardized annual pesticide usage	-0.56 ± 0.73	-0.78	0.43
z-standardized annual farmer population	0.31 ± 0.86	0.36	0.72
z-standardized annual DJF precipitation	-1.97 ± 0.63	-3.15	< 0.01
z-standardized annual DJF temperature	-1.24 ± 0.93	-1.33	0.19

The obtained results are in line with the hypothesis: compared to environmental factors, human agricultural practices affect winter wheat production in the TP more. Figure 1 shows an obvious negative relationship between winter wheat yield and environmental variables, DJF temperature and precipitation. On the contrary, area and fertilizer are in a positive trend with the winter wheat yield: annual fertilizer usage is the most influential factor, with the highest positive estimate value, and the annual winter wheat planting area ranked second.

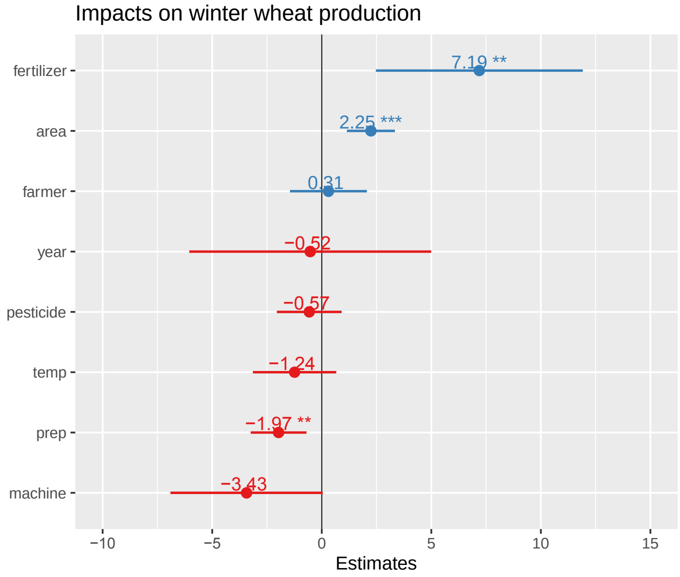

Figure 1. Schematic illustration of Model 1 estimates. The error bar indicates the standard error for each variable. The black line of 0 indicates whether the effect is negative (red) or positive (blue). The * is the

significant code: *** indicates the p-value is greater or equal to 0 and less or equal to 0.001; ** indicates the p-value is greater than 0.001 and less or equal to 0.01; * indicates the p-value is greater than 0.01 and less or equal to 0.05; while no * indicates the p-value is greater than 0.1 and less or equal to 1.

Discussion

The findings that anthropogenic factors have a more significant effect on winter wheat production are in accordance with previous studies. Over the past few decades, enhanced agricultural management practices, including improved irrigation infrastructures, elevated chemical fertilizers and pesticides application contributed to a 50% increase in the crop yield per unit area all over China (Xiao *et al*., 2015). The historical findings, along with the current study results, affirms the mainstay role of agricultural management practices for crop production under the climate change.

Apart from increasing planation area and fertilizer usage mentioned in this project, more human practices improving the winter wheat production should be noted. Some feasible approaches to facilitating wheat adaptation to climate change include early sowing and better water irrigation (Kothari *et al.*, 2019). Specifically, early sowing of winter wheat allows for the early establishment and timely flowering, thus, this practice not only increases flowering time stability, but also yield stability. Advanced strategies include the replacement of higher-yield winter wheat type and precise nitrogen application, which enhances the nitrogen use efficiency. However, climate change will likely outpace the progress made in wheat yield improvements. Under future climate scenarios, yields of winter wheat in North America are modeled with a clear declining trends even with advanced planation strategies such as the replacement of wheat types (Zhang *et al*., 2022). Thus, it is important to adapt the winter wheat growing strategies with changing climates.

Limitations still exist. The annual winter wheat data was obtained as the mean winter wheat production all over the TP, where variations between different planting locations were not taken into consideration. Also, NAs and the relatively small data size affect the robustness of the results.

Overall**,** a simple linear regression model examines the effects of environmental and anthropogenic factors on winter wheat production over the TP. Results have revealed that compared to winter temperature and precipitation, anthropogenic factors, including fertilizer usage and planting area, affect the winter wheat production more, emphasizing the significant role of agricultural management practices for crop yield. For the future studies, more crop types and more plantation areas need to be investigated to study the global patterns of agricultural adaptation to climate change.

Reference

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Self-reflection essay

The mini-project provided me with a chance to sharpen my statistical analysis ability in practice. I found that I spent most of the time figuring out which model I should use. My confusion over this, to some extent, pushes me to review the statistical lectures and deepens my understanding of the differences between models. At first, I thought that I cannot fit my data into a simple linear regression model, since the response variable, winter wheat production, is not normally distributed. Instead, I tried to fit the data into the generalized linear model. The similar model results indicated that the more complex models were unnecessary. What matters more is the ecological meaning behind the model. During my model interpretation process, I learnt that one of the most useful materials is the scientific articles. Although the content may vary due to different requirements of the publisher, the articles provide me with examples for how to think and write in a scientific way, especially sometimes when I was struggling to write down what I had in my mind.

I managed my time quite well. I finished the essay part during the weekends ahead of the deadline and left plenty time to check the writing, write down this self-reflection essay and prepare for the presentation. Rather than sitting in front of my laptop doing nothing, I prefer to take a break and have a short self-reflection of what I need to do and what I did not do well. Also, I kept a log of every thought and question I had during the whole process in Notion. I will use these techniques in the main project since they are so useful to me.