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Climate Warming and Long-Term Trends in Saskatchewan Hay Yield

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Abstract: Adaptation to climate warming is a key strategy for sustainable agriculture. Analysis of long-term trends in the provincial average hay yield in Saskatchewan from 1967 to 2011 has reported a decline since the 1970's and changing agronomic and economic variables were only partially effective in explaining the trend. In this paper, I examined the relationship between Global temperature difference and hay yield in Saskatchewan. Collinearity was determined by regression and principal component analysis. The beef cow number, fertilizer price, hay hectares, CO_2 concentration, and Global temperature difference are generally increasing with time in the dataset and exhibited collinearity with time. The residuals from the hay yield predicted from April, May and June (AMJ) precipitation were regressed on Global temperature difference. The significant ($P < 0.001$) relationship indicates that precipitation is becoming less effective (water use efficiency is declining) as global temperatures increase. Future hay crops must become better adapted to warming temperatures to reverse this trend.

Key words: climate change, precipitation use efficiency, adaptation, forage crops

1. Introduction

Analysis of long-term decline in Saskatchewan average hay yield has been associated with rising fertilizer prices, increasing beef cattle herd numbers and increasing hay hectares [1] or to changing crop rotations that reduced stored soil water for deep-rooted perennial forage crops [2]. As both reports noted, the problem of long-term trend analysis is that of collinearity of other variables that are also changing over time. Jefferson and Selles (2007) reported no long-term temperature trend in Saskatchewan spring (April, May and June) temperatures. However, climate change research has reported long-term global temperatures increasing over time [3]. The objective of this analysis was determine if global temperature change was associated with long-term change in Saskatchewan hay yield.

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2. Materials and Methods

The data base for this project was reported previously [1, 2]. Briefly, provincial average hay yield was obtained from a Saskatchewan Ministry of Agriculture database. Weather data from 16 weather stations representing the agricultural regions of Saskatchewan was obtained from the Environment Canada Historical Weather Database [4]. April, May, and June (AMJ) monthly precipitation, maximum temperature, mean temperature and minimum temperature by month was summed or averaged as appropriate to represent the growing conditions for the hay crop. Producers in Saskatchewan typically harvest one hay cutting per year and summer regrowth is either grazed or left to ensure good winter survival of the legume species. Data from the years 1967 to 2011 were included in this analysis which was 2 additional years compared to the previous study [2]. For more details on agronomic and economic variables examined in this report, the reader is referred to Jefferson and Selles (2007) [1] and Jefferson and Larson (2014) [2].

Analysis was done with JMP Software (SAS Inc. Cary NC USA). Probability for significance in regression analysis was set at P = 0.05. Principal Component Analysis was used to examine the relationships among all the variables studied. Collinearity among variables was reported previously [1] and PCA was done to identify groups of variable that are associated with each other and to avoid collinearity in the analysis.

Global temperature difference data was obtained from the United Kingdom Meteorological Centre, Hadley England [3]. The data used global temperature data based on the change from the 1960 to 1990 baseline average global temperatures. The values in the global temperature difference data range from -0.212°C in 1974 to +0.509°C in 2005. There is a significant time-trend in the data ($R^2 = 0.82$, $P < 0.001$) over the period of this analysis (1967 to 2011).

3. Results and Discussion

The first and second principal components combined to explain 69% of the association among the variables. Year, Global temperature difference, Fertilizer Price Index, Beef Cow number, and Hay hectares were grouped together with positive values ranging from 0.296 to 0.389 for PC1 while Summerfallow hectares exhibited as different variable with -0.383 eigenvector value (Table 1). The values for hay yield (-0.526) and AMJ precipitation (-0.483) were grouped together contrasted with a temperature group of variables for April Maximum temperature (0.310), May Maximum temperature (0.538) and June Maximum temperature (0.233) in the second PC.

The PCA results also indicated that the collinearity in the dataset is associated with the variables that generally increasing over the time period, such as year, CO_2, Fertilizer Price Index, Beef cow numbers, and Hay hectares contrasted with the variable that is declining during the period, summerfallow hectares.

Table 1 Principal component analysis eigenvectors for component 1 and component 2.

Variable	PCA Component 1	PCA Component 2
Year	0.386	0.043
Summerfallow hectares	-0.383	-0.067
Hay yield kg ha^{-1}	-0.124	-0.526
Global temperature difference °C	0.361	0.112
April Maximum temperature °C	0.057	0.310
May Maximum temperature °C	-0.073	0.538
June Maximum temperature °C	-0.128	0.233
Fertilizer Price Index	0.364	0.038
AMJ precipitation mm	0.104	-0.483
Beef Cow number	0.296	-0.153
Hay hectares	0.385	-0.062
Atmospheric CO_2 ppm	0.389	0.023

The positive association between hay yield and precipitation and a negative association with temperature that was previously reported [1] was confirmed in the results of the second principal component.

As previously reported [1], there was a relationship between AMJ precipitation and Saskatchewan hay yield (Fig. 1a). While the previous report suggested a linear relationship, this analysis indicated a reciprocal of precipitation equation was the best fit to the expanded database. An examination of the data points suggested that years earlier in the data base (1967 to 1990) tended to appear above the regression and later years (1990 to 2011) tended to appear below the regression line. The residuals from the regression equation were regressed on the Global Temperature Difference variable (Fig. 1b). The linear regression was significant ($R^2 = 0.29$, $P < 0.001$) indicating that as global warming has occurred the residuals about the precipitation/hay yield equation tend to become more negative. In other words, the same precipitation early in the study period tended to produce more hay than later in the period. For example 89 mm of AMJ precipitation in 1969 was associated with 3113 kg ha^{-1} hay yield, but 89 mm in 2001 was associated with 1724 kg ha^{-1} hay yield. In another example, 100 mm was associated with 3136 kg ha^{-1} in 1987 but 99 mm was associated with 2016 kg ha^{-1} in 2009. A stepwise regression analysis indicated that AMJ precipitation and Global temperature difference explained 54% of the variation in Saskatchewan hay yield (P = 0.10). As the global temperatures warm, less hay is produced per mm of precipitation in Saskatchewan. This supports the earlier report that precipitation use efficiency for Saskatchewan's hay crop has declined [2] although that report also linked the decline to changing crop rotations. Cannell et al. (2003) reported declining summer hay yields in the UK due to increasing summer temperatures [5].

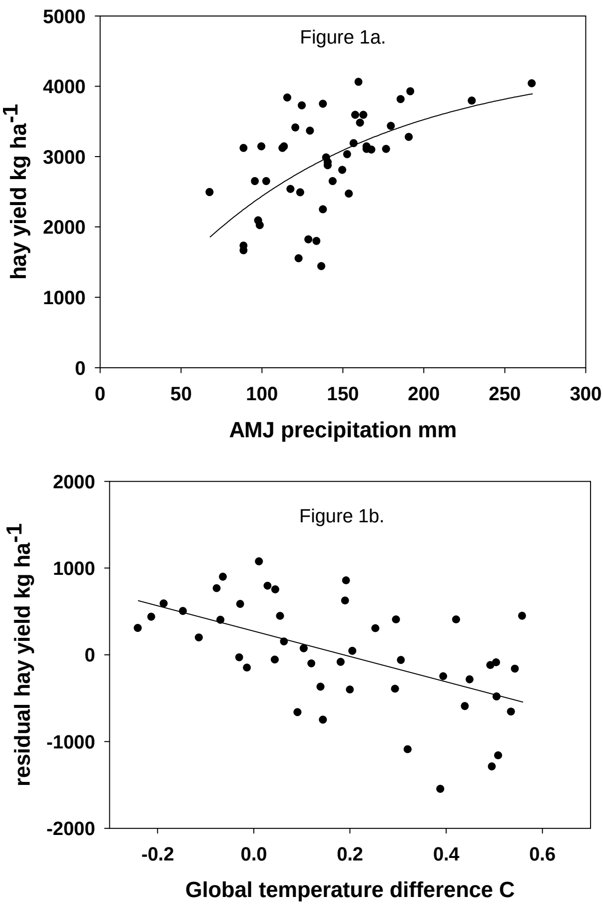

Fig. 1 Saskatchewan hay yield from 1967 to 2011 as correlated to annual spring (AMJ) precipitation with fitted reciprocal regression (Fig. 1a. R^2 = 0.24, P < 0.001) and residuals from that regression fitted to Global temperature difference with linear regression (Fig. 1 b. R^2 = 0.29, P < 0.001).

This new observation can be explained by the physiology of photosynthesis. Gas exchange between the atmosphere and plant tissues occurs through the leaf stomata with CO_2 entering the leaf to be absorbed by photosynthetic reactions in the mesophyll cells and H_2O vapour exiting the leaf. Water lost in this manner contributes to latent heat loss (cooling) of the leaf tissue. Optimum temperature for photosynthesis for C3 plants is 21°C. As air temperature increases, the amount of water lost to latent heat per g of carbon fixed increases. In water limited or semiarid environments, such as Saskatchewan, stomatal conductance to CO_2 and H_2O exchange is regulated to optimize both photosynthesis and water use efficiency. Water stress (drought) and high temperatures result in low stomatal conductance, low growth rate and reduced water loss. In Saskatchewan, perennial forage crops are primarily C3 plants so precipitation use efficiency will be reduced by higher temperatures.

Other crops, such as wheat, barley and canola, have reported yield increases during the same period of time [2]. In other words, these crops have demonstrated adaptation to increasing global temperatures while the hay crop has not. One difference between these crops is the rate of technology adoption. In wheat, for example, new cultivars are released from plant breeding programs continuously and are replaced by newer improved cultivars within a decade. In contrast, hay producers in Saskatchewan continue to use cultivars that were developed in the 1960s (Beaver and Algonquin alfalfas for example) because the cost of seed of new cultivars is higher and the perceived advantages are not apparent to producers. This suggests that slow technology adoption in hay crops may contribute to declining hay crop yield. Older forage crops (10 years or more since establishment) are common in Saskatchewan and may also contribute to poor precipitation use efficiency [6].

3. Conclusions and Implications

Hay yield and precipitation use efficiency of hay is declining in Saskatchewan. The responsiveness of the hay crop to spring precipitation is declining and this appears to be associated with global temperature increases. This suggests that the Saskatchewan livestock industries will experience more hay shortages in the future as the global temperatures are predicted to continue to rise. Further research on precipitation use efficiency and high temperature adaptation in the breeding of new hay cultivars should be undertaken.

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