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Minimizing Climate Change-Induced Food Insecurity Through Land Suitability Predictions and Preemptive Breeding of Climate Change Resilient Crops

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Introduction

In 2011, 16% of households across Canada experienced some form of food insecurity (Tarasuk et al. 2022), while 10% of the global population endured chronic hunger (World Health Organization 2022). Upwards of a 70% increase in global food productivity is required by 2050 to feed the projected population (Hannah et al. 2020). Should food production not meet the need of the growing population, the number of families facing food insecurity is expected to grow over the coming decades. Meeting future global food demands is a significant challenge because there is a consensus that climate change is likely to diminish crop yields in mid-latitude countries, where temperatures are already near crop tolerance levels (Mendelsohn 2008; Neufeldt et al. 2018). In fact, the Lancet medical journal has deemed nutritional deficits due to the anticipated impacts of climate change on food security as this century's greatest threat to public health and that a response to this threat could be "the greatest global health opportunity of the 21st century" (Watts et al. 2018).

High latitude countries are projected to experience both positive and negative effects on agricultural production due to changes in climate, with Canada and Russia holding 56% of the world's anticipated new arable lands (Anderson et al. 2020; Hannah et al. 2020). Hence, if climate change reduces crop yields in mid-latitude countries, then Canada may need to play a more prominent role in ensuring global food security. Canada's ability to leverage the positive effects of climate change on agricultural production while mitigating the negative effects will have significant implications on not only global food security, but also the nation's GDP. If Canada is to retain it's position as a leading producer in the agri-food industry and help to minimize food insecurity, it is essential that potential negative impacts be identified and where possible, proactively addressed.

Much of Canada's viable farm land and thus, agricultural productivity, occurs in the southern latitudes of the country. Due to climate change, these areas are ex- pected to experience higher rates of drought and heat stress over the coming decades(King et al. 2018; Palomo 2017). This change in the environment is expected to neg-atively impact the agricultural output of these regions. However, increasing temper-atures will open new land in the northern latitudes to agricultural development. It is projected that approximately 1.85 million km^2 of currently unviable Canadian land will become suitable for farming by 2080. While developing this land would work to offset climate change-induced reductions in agricultural productivity, it would release an estimated 15 gigatonnes of carbon, further intensifying climate change (KC et al. 2021). As such, the most sustainable approach to increasing crop yields across Canada may be intensifying agricultural productivity at preexisting farms. This paper looks to estimate how agricultural productivity in Canada may change due to the effects of climate change over the coming decades and provide evidence based policy solutions to counter these effects to sustain the growing population.

Future Land Suitability Projections

Several studies, such as those by Anusha et al. 2023; Everest et al. 2021; Han et al. 2021, have attempted future land suitability projections for different regions of the world. However, these projections lack a data-driven approach and merely offer binary indicators, determining whether the land is suitable or unsuitable for specific crop cultivation. The binary nature of the projections is limiting as there is no indication of the extent of *how* suitable the land is for each crop. In the preceding research of Bhullar et al. 2023, we developed a novel framework for producing a continuous measure of agriculture land suitability based on climate and soil variables labelled Deep Simultaneous Suitability Scoring ($DeepS^3$). $DeepS^3$ is a multi-layer perceptron model which leverages historic Canadian soil, climate, landscape, and crop yield data to predict land suitability for six major commodity crops: barley, peas, spring wheat, canola, oats, and soy. From our knowledge, it is the first and only data-driven land suitability algorithm for Canada. It was found that $DeepS^3$ is capable of producing up to a 2.82 fold reduction in mean absolute error relativeto the common single crop models.

Climate projections based on RCP 4.5 and 8.5 scenarios were used to predict how land suitability would change by year 2050 and 2100. RCP projections were obtained from the NEX-GDDP dataset using the IPSL-CM5A-MR climate model (Thrasher et al. 2012). Scenario 4.5 is considered a medium stabilization scenario where the globe takes some action to address climate change and scenario 8.5 is a worst-case scenario where emissions are left unchecked (Van Vuuren et al. 2011). The generation of the maps in Figure 1 involved the utilization of DeepS[3] to create suitability maps for both present and future conditions, followed by subtracting the two to derive the final output.

Figure 1 displays crop specific maps showing the predicted percent change in agriculture land suitability. We found that the yields of barley and oats are generally expected to increase where the diurnal air temperature increases and the region is flat, but decrease where the precipitation increases. For peas, spring wheat, canola, and soy, the opposite relationship is found and little to no change in land suitability is projected for the norther latitudes suggesting that developing these areas for agriculture may not be an effective method for offsetting the reduction in yield. The trends exhibited by Figure 1 should also be assessed with the assumption that agriculture does not expand outside of where it is done now (Table 1). We see that Oats are expected to see the largest increase in production followed by Barley. Conversely, canola is expected to see the largest loss of productions followed closely by peas, spring wheat, and soy. This potential decrease in production presents a significant threat to the Canadian agri-food industry, as Canada is a top 5 exporter of the mentioned crops. Additionally, this implies that Canada will fall short of achieving the 70% production increase target if conditions remain unchanged. These results suggest that more focus should be placed on improving the genetic quality of canola and pea cultivars to minimize the impact of climate change on these crops whereas less emphasis needs to be places on oats and barley.

Preemptive Breeding

From our analysis, we gain insights into the crops that are expected to face the greatest adverse effects from climate change and the reasons behind it. This knowledge enables us to take proactive measures in minimizing the impact of climate change on crop yields. Enhancing crop yields can be achieved through two primary approaches: improving genetics and management techniques. Historically, genetic gain has been found to be the more significant factor in improving crop performance (Mackay et al. 2011; Rijk et al. 2013). However, as the breeding cycle for many crops can take over

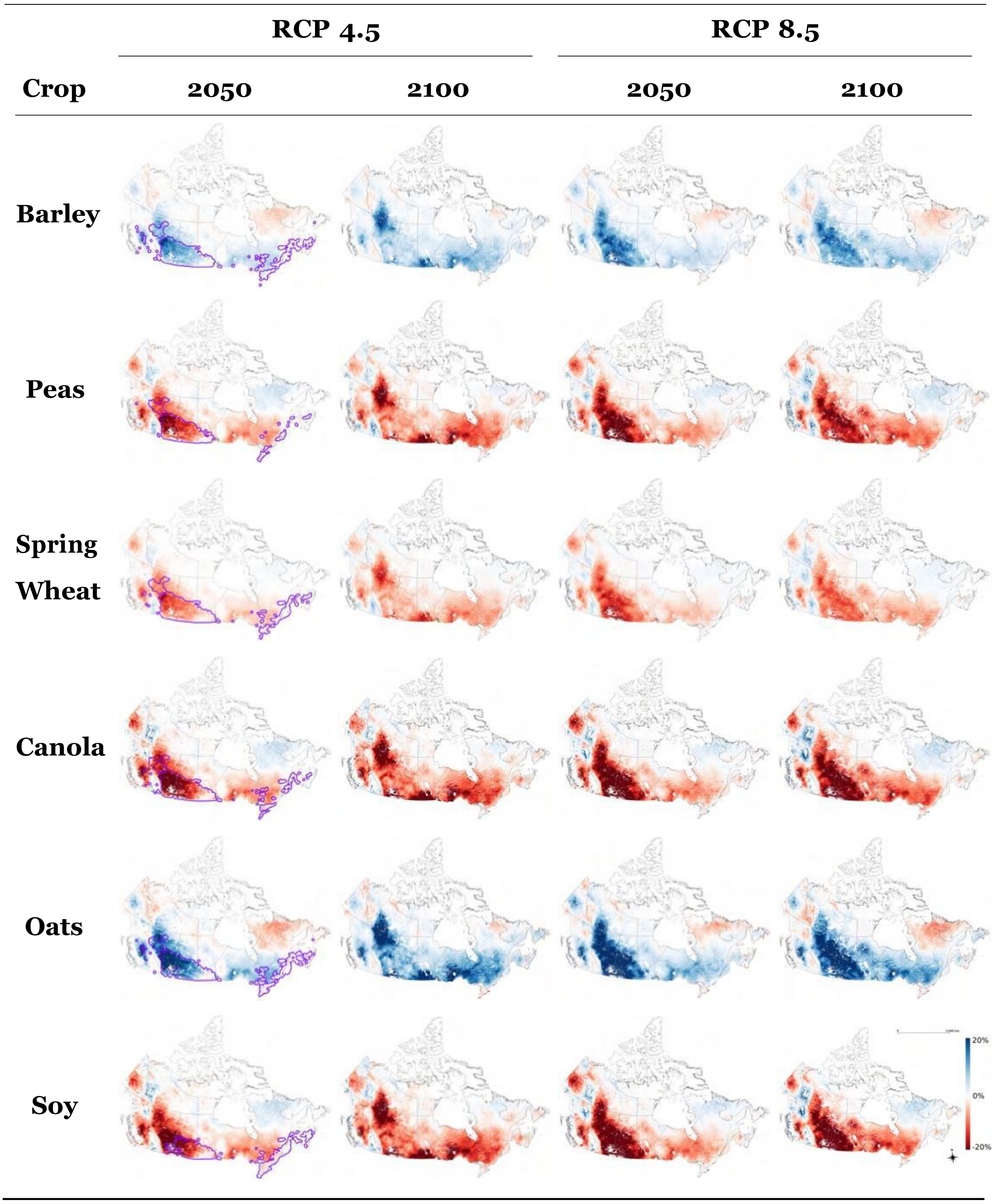

Figure 1: Regions in Canada that are expected to have higher crop yields (blue),and lower crop yields (red) relative to the 2010s. Specifically, white represents a relative crop yield increase of 0%, the darkest blue represents a relative crop yield increase of 20%, and the darkest red represents a relative crop yield decrease of 20%. The purple border in column one coarsely depicts where the respective cropwas cultivated throughout the growing seasons from 2013 to 2020. QGIS version 3.30.0 (http://www.qgis.org) was used to create the figure (QGIS Association n.d.).

	Current	Projected			
	Avg Production	RCP 4.5		RCP 8.5	
Crop	**(2013-2020)**	**2050**	**2100**	**2050**	**2100**
Oats	241,280	+11%	+11%	+16%	+17%
Barley	412,727	+10%	+6%	+13%	+10%
Soy	233,943	-2%	-10%	-5%	-6%
Spring Wheat	880,088	-8%	-7%	-13%	-10%
Peas	148,128	-14%	-10%	-21%	-16%
Canola	851,620	-16%	-14%	-24%	-20%

Table 1: Expected percent change in nationwide crop production relative to the current time (2013-2020). The current average production is in bushels, sourced from Statistics Canada Statistics Canada 2021, and allows for the percentage to be converted into bushels. The projections assume that agriculture does not expand to lands outside of where the crops were cultivated between 2013-2020

a decade to produce a market ready cultivar, it is essential that the breeding process for climate change resiliency is started preemptively (Fugeray-Scarbel et al. 2021).

The proposed framework for this methodology is to obtain a dataset of multi-environment crop performance trials with genotyped cultivars, analyze this data along with climate variables to capture genotype by environment interactions, and finally predict the performance of modern cultivars under climate change scenarios to identify potentially climate change resilient varieties. With this, we can quantify the relationship between a cultivars performance and the environment in which its grown. This analysis can also provide insight into which genes are responsible for resiliency to different stressors. From here, these top cultivars can be used as parentalgermplasm to begin breeding for cultivars with improved climate change resistance. As many provinces have affiliations with official bodies which conduct cultivar variety registration trials such as the Ontario Cereals and Crops Committee, a large amount of data on the performance of modern cultivars is internally available. However, as cultivars are typically highly adapted to specific geographic areas, climate change resilient cultivars must be bred for all major crop producing areas. This presentsa large amount of work which is beyond the scope of this research. It is vital thatthe government of Canada introduces policy to begin funding research for proactive climate change resilient crop breeding research if Canada is to proactively address the issues facing the nation's agri-food industry and global food security.

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