Design a conceptual model of interaction between climate and non-climate factors affecting wheat yield

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(2019-2020)

Climate and weather factors

Climate and weather conditions are the most important factors influencing crop yields and production (Qiang et al., 2013; Bryant et al., 2000; Yinhong., 2009; Raymond and Wolfgang, 2005). Climate variables have a major effect on the average wheat yield and its distribution (Cabas et al., 2009). The length of the growing season, precipitation and temperature are three major variables of weather factors having a decisive role in the yield rate (Porter and Semenov, 2005; Almaraz et al., 2005). Noticeably, the length of the growing season can have a positive effect on the yield crop the most. In Ontario, the length of the growing season has been caused to increase wheat yield and has had the highest impact on increasing yield. So that every 10 % increase in the number of growing days has been able to add wheat yield, about 5% but the marginal effect reclines with the number of growing days (Cabas, 2009). Although the length of the growing season has had a positive effect on wheat yield, the other significant climate variables, temperature and precipitation, have impacted wheat yield negatively in Ontario over a period of 26 years (1981 -2006) (Weersink et al., 2010). In other words, Ontario has been a witness of a warming trend since 1980 by increasing hot days and temperature variation (McKeown et al., 2006). As well Increases in deviation of these climate variables from their averages has been caused by decrease wheat yield in Ontario (Weersink et al., 2010). However, precipitation and temperature are helpful for improving yield if they would happen at the right time. In other words, seasons and times as well as different stages of plant growth can influence the effects of weather variables on yield or modify them (Weersink et al., 2010) and the effects of climate variables on yield are dependent on the interaction between them (Philips et al., 1996). Overall, increasing temperature occurs in cold seasons such as autumn or spring leads to rising yield at a decreasing rate, by contrast, if it takes place in summer resulted in a reduction in wheat yield. In spring, cold and humid conditions can lead to reduced yields due to delayed cultivation or retarded plant growth (Carew et al, 2009). Plant growth stages are other important factors influencing and offsetting weather conditions. The number of humid leads to different yields in different stages of growth such as planting, flowering, and harvesting (Islam et al 1999). In Canadian prairies, the most critical stage for high green grain yield of wheat is early precipitation from seeding to anthesis. In other words, early precipitation (from May to July) has had a certain and great positive effect on wheat yield. In fact, year to year and place to place variation in spring wheat yield in Canada prairies especially in the rain-fed semiarid area of Canada prairies is basically associated with precipitation amount and time as well as soil type (Yong Hea et al., 2013). In Ontario, precipitation at the very beginning of the growing season and summer season causes to increase wheat yield at a decreasing rate, while it decreases yield around seeding and harvest months (Cabas et al., 2009). Also, In Manitoba (1996-2012), increasing in growing degree days in June and July and their combined effects not only has been caused lower yield, on hard red spring wheat but also, has increased yield variations in winter wheat and this signals a potential risk of total precipitation reduces yield while it rises yield variability (Carew et al., 2017). In fact, the precipitation and growing temperature have reduced marginal product in Manitoba (Carew et al, 2009). Increasing temperature leads to increase evaporation and therefore a reduction in the average spring wheat yield. Wheat yield in Manitoba was less than other years in 2005. The most reason was related to excess moisture in early spring. This situation resulted in 15% of the lands were not cultivable (Carew et al 2017).

Having a longer growing season can offset the negative impact of the precipitation variability and hot temperature and lets to higher average yields (Weerksink et al. 2010). In total, the length of the growing season and extreme events have an offsetting effect on wheat yield but the length of the growing season is dominant

(Weersink et al., 2010). It is expected to warmer the weather in future, but with more variability in temperature and precipitation. Although a longer growing season can partly offset variations in temperature and precipitation, especially in moisture areas and southwest Ontario, it is not helpful in the Semi-arid areas which suffer from more heat stress (Cabas et al., (2009).

The climate in bad years has a more negative effect on crop yield than good years (Jiang 2017). Overall, yield loss is willing to increase over time in the future and wheat yield will experience more volatility during the time in future. The research results suggested expected yield loss in 2023 was larger than that of 2018. This study forecasts that the crops in the studied provinces will be faced with increases in expected yield loss, but of different amounts. Wheat yield loss in Ontario is more than that of Saskatchewan. So that, the rate of wheat yield loss in Ontario is 8.02% compared to Saskatchewan which is 1.54%. Also is predicted that the expected wheat yield loss increase in the future decade, by 16.07% in Ontario (Horlick Ng, 2019).

Non-climate factors

Besides the climate factors, there are other factors influencing wheat yield and its variation. The most important non-climate factors consist of Plant growth environment, farmer decision-management, advanced technology and economic factors. These factors not only by themselves (direct effect) but also, by the interaction between them (indirect effect) can affect yield wheat and yield variation in Canada and Ontario.

Plant growth environment

Environmental conditions of plant growth, as well as the interaction between them, affect green yield and quality in wheat. Pests and disease, soil properties and Nitrogen rate have been three important environmental factors influencing yield wheat and its variation during the last decades in Canada and Ontario.

Pests and disease- Drought and wheat stem sawflies are one of the most popular pests influencing green wheat yield in Canada (Beres et al., 2005; Beres et al., 2013;

Knodel et al., 2009; Bekkerman et al., 2018). In this pet, the female insect lays eggs in the stem of the plant and its larvae begin to feed on the parenchyma and vascular tissues and leads to loss in the plant's photosynthetic abilities and reduce kernel weight and seeds (Holmes 1977; Mecedo et al., 2005). The pest moves easily in warm and dry climates and settles on the plant host (Ainslie, 1920). Studies in Canadian prairies (Beres et al., 2011), southern Canadian prairies (Beres et al., 2007) and west of Canada (Olfert et al., 2019) have shown that Drought and wheat stem sawfly are two main limiting factors of wheat yield that leads to loss yield. wheat stem sawfly damage causes an extreme reduction and predictable in wheat yield level. So that, each percent increase in wheat stem cutting will cause a loss Asof 2 kg/ha of yield. (B. L. et al., 2007).

Also, Fusarium head blight is one of the most important and dangerous diseases of wheat (Osborne and Stein, 2007; Xue et al., 2004) in worldwide (Wang et al., 2019) including north of America (Osborne and Stein, 2007, Wang et al., 2019). In Canada, Ontario has experienced prevalent epidemics of FHB from the 1970s on, every 5 years (Crippin et al., 2020). As well wheat-growing areas of Canada have seen this disease during the last decades (Wang et al., 2019). Among other crops, Wheat and Corn are the most susceptible to this infection (LUONGO et al., 2005). FHB negatively affects wheat yield and quality grain (Osborne and Stein, 2007; Xue et al., 2004; LUONGO et al., 2005). Mycotoxin contamination of the grain creates a head blight or ear infection in wheat and leads to loss of grain yield and its reduction (LUONGO et al., 2005). On the other hand, decomposed infected crop residues on the soil are the main pathogen inoculum and epidemic creation. In this disease, infective spores transfer to wheat from the previous crop in the same farm or they can spread or transport by the wind from nearby farms (Osborne and Stein, 2007; LUONGO et al., 2005). It is noteworthy, weather variables, plant growth stages and crop practice, and management by the farmer, as well as wheat varieties, are factors influencing FHB incidence and spread. Weather properties such as humidity, heat and continuous precipitation affect FHB and support pathogen proliferation and spread. Each of the FHB species, based on fungus type, favors special weather or environment. For instance, F. graminearum seen in Ontario and many other areas prefer the warm and wet environment, it is well adapted to a wide range of weather conditions though (Osborne and Stein, 2007). Also, sufficient moisture, precipitation especially in June has been caused to spread of the disease in Ontario (Crippin, 2019). The windy conditions help to spread spores and resulting reproduce disease as well (LUONGO et al., 2005). Crops in some of their growth stages are more vulnerable to this disease. The anthesis in wheat is the most critical and sensitive stage of growth to infection pollution (Osborne and Stein, 2007, LUONGO et al., 2005). Also, Farmer management or crop practices affect infection to spread. AS said above, remnants of the previous infectious crop on the soil are the most important factor to pathogen reproduce and spread the infection. Studies in North American have shown that residual FHB in straw and stubble can remain on the soil for 630 days (LUONGO et al., 2005). In this situation, rotation and no-tillage or reduced tillage contributes to the expansion and spread of the disease (LUONGO et al., 2005). In the US, due to using no-tillage and rotation has been spread this disease (Osborne and Stein, 2007). Also, in Ontario, crop residues, minimum tillage and rotation of wheat and maize with soybeans have caused to expansion and spread of this disease (Crippin et al., 2020). As well wheat varieties and cultivars influencing the spread of this disease. Resistant cultivars and appropriate fungicides and interaction between them are factors influencing the control of FHB in Canada (Amarasinghe et al., 2013).

Soil quality and properties- Soil as the plant growth bed have a considerable impact on wheat grain yield and quality. Soil type and quality have had a significant effect on wheat yield in Canadian prairies. In Southwest Ontario, the soil quality of a site has been an influencing important factor in yield over 26 years (Cabas et al., 2009). As well, in Manitoba, Higher soil quality is the only effective factor, certainly increasing wheat yield (Carew et al., 2009). Soil, with different properties and quality, has different effects on yield wheat. Grain yield in clay soil is higher than silt loam soil because the clay soil has a higher drought tolerance and capacity for holding water. On the other hand, the sites with sandy soil showed the lowest wheat yield (Cabas et al., 2009). Also, Soil type and properties can affect absorbing N fertilizer and increase or decrease it. In clay soil, because of having less nitrate leaching, N fertilizer has higher efficiency in increasing yield. (Yong Hea, et al., 2013). Besides the type of soil, soil water or moisture has a significant effect on wheat yield. The magnitude of soil moisture at planting is a matter and affects wheat yield and N effect as well. Interaction between soil water and precipitation during the growing season influences yield wheat. Exceeded moisture soil at planting causes delaying in planting time and as a result, decreasing yield wheat. In addition, excessive moisture prevents of effective action of N fertilizer to improve yield (Carew et al., 2017).

Nitrogen fertilizer- Nitrogen fertilizer is one of the most necessary plant nutrients used in crops and wheat. Generally, Nitrogen existing in the crop planting environment or soil is one of the needed elements for plant growth. Therefore, it is expected N could help to improve wheat yields. But various research has shown that the N effects is dependent on the other variable such as weather and environment condition and soil properties. B L et al (2004) have done research about the effect of interaction between environment and N fertilizer on Hard Red Spring wheat (HRSW) in the east of Canada from 1998 to 2000 in five areas among three provinces. The results showed that there is a significant crossover interaction between N and the environment. In general, more N use resulted in more yield except in some environments. In two of the five environments tested, higher nitrogen application did not produce higher yield rates in HRSW. This was due to the increase and spread of the diseases (Fusarium head blight and the other foliar diseases). In other words, the presence of diseases in these areas has caused a decrease in the yield of HRSW (B L et al., 2004). In another research in Manitoba (Carew et al.,2009), nitrogen fertilizer was identified as a factor that increases changes in wheat yield. On the other hand, the N effect depends on growth conditions such as soil quality and weather. If the growing conditions are favorable, N typically increases the wheat yield. But in growing heat and varied precipitations, its effect on yield is insignificant (Carew et al., 2009). In Ontario, researchers have studied soil properties and the N rate effect on crop yield. The result showed that crop yield and use rate of N depends on the balance between climate, N management and soil properties. Also, the result demonstrated that soil properties along with the N rate, affect marginal yield (Dong et al., 2019). As well, the study illustrated phases of crop growth can affect N fertilizer. This research studied the effect of the N rate and soil properties on crops yield, under various phases of crop growth. crop yield impressed severely by applying N before seeding. So that 10% increase in applying input increases wheat yield by about 1% on average (Cabas et al., 2009).

Advance of technology and breeding efforts

It could be said one of the most important non-climate factors influencing yield is advanced technology in Canada and Ontario (Cabas et al., 2009). The estimated effect of advanced technology on wheat yield is about 1% in Ontario. Some research has shown breeding efforts have had a positive effect on improving wheat yield. Based on a study in the west of Canada from 1885 to 2012 (Iqbal et al., 2016), the green yield has a positive correlation with days to maturity and kernel weight. Also, it has a negative correlation with the wheat high, loading and content of grain protein. Therefore, scientists have worked on these properties in order to improve crop yield. Studies in Canada have demonstrated that grain yield has raised in the western red spring (CWRS), and Canada prairie spring (CPS) class due to breeding efforts. CWRS had the earliest maturing and the latest maturing was related to CPS class. Delayed maturity in the CPS class led to 20% higher yields on average than CWRS class. This study showed that breeding efforts have had positive effects on increasing wheat yields in Canada during the last century. As well as in Saskatchewan, researchers have studied and compared the older cultivars (Neepawa and Marquis) with four new CWRS wheat cultivars in terms of yield in 2001. The results showed the new group yield was 34.3% and 5.9% higher than that of Marquis and Neepawa, on average, respectively (Wang et al., 2001). Other researchers in Manitoba have found that Plant Breeders' Rights (PBR) effect depends on soil quality and temporal diversity. PBR has a little positive effect in the best case, while it has increased wheat yield variance in this study (Carew et al., 2009). Another research in Ontario and Saskatchewan have illustrated that although technology changes increase crop yield over time, it can also increase or decrease yield volatility. The advance of technology acts differently in different situations. In other words, it improves yield average under good situations for growing but no in the bad situation. In other words, based on this research, the technology change rate is better in good years than bad years, therefore, it increases yield volatility over time (Horlick, 2019). Some study in Manitoba has shown that variety richness increases yield average and decreases its variance while protected varieties by PBR rises yield variations (Carew et al., 2017). Also in Ontario (Yuetian et al., 2017), the climate in bad years has a more negative effect on crop yield than good years. As well as innovation effects on yield volatility are increasing especially in bad years.

Economic, market and government politics

The other significant factors influencing wheat yield are economic and market factors. Although these factors cannot directly change crop yield, they have a considerable impact on crop yield through the other factors. In fact, they affect farmers' financial capacity for farm management practices in order to improve crop yield. In the perspective of Southwestern Ontario farmers (Reid and et al., 2007) economic and market variables influence their income average and therefore their ability to crop production. These variables include interest rates, commodity prices, the value of the Canadian dollar, input costs, price fluctuations, land values and global commodity production. An increase in interest rates, input costs, price fluctuations and global commodity production leads to a decrease in their income or purchase power. Therefore, they cannot employ sufficient inputs such as fertilizers and sprays or provide crop insurance or access to advanced technology. As well, decrease commodity prices the value of the Canadian dollar land values, after selling them, places them in unfavorable financial conditions for meeting needed facilities in farm management. Land price, after leave, can affect farmer purchase power as well. On the other hand, farmland values are dependent on the climate variables and Canadian farms would benefit from higher precipitation but not warmer temperatures (Mendelsohn and Reinsborough, 2007). In Manitoba planted areas of wheat suffered a decrease rate from 1.6 in 1996 to 1.2 in 2015 million hectares because of dropping in price during the 1990s and competition with other crops like soybean and pulse. As well as planted wheat in an area was only 878000 hector in 2011 because of extreme moisture (Carew et al., 2017). Price output towards input has been another economic factor affecting yield wheat in Southwestern Ontario over 26 years (Cabas, 2009). In other words, the price of output (wheat) to input has been noticed to input use and influenced it. It is noteworthy changes in input utilization under maximum profit conditions have had a positive effect on wheat yield. Considering the law of diminishing return, using input increases the average wheat yields, although not much, first, eventually cause to decrease in the yields after.

Government politics and programs affect farmers' ability to manage their farm and crop production, as well. In Ontario farmers' view, they have been influenced by some of these programs such as the supply-management system in Canada, International trade agreements and opening commodity markets. As well as the government in Canada has established some supporting programs such as crop insurance, disaster relief and income stabilization aimed to decrease market risks and improve farmers' income (Reid et al., 2007). Also, paying protein premiums (discounts) is one of the tools using in Canada in order to price stabilization or avoiding price variation in wheat production. This factor affects farmers' behavior and decision in farm management and using outputs. In other words, using input, Nitrogen, reduces wheat price variance if protein premiums (discounts) are applied. A decrease in variance in wheat price is due to the level of concentrated protein is close to or higher than the maximum premium paid. The optimal rate of N applied with premium payments is approximately 60% higher than without premium payments. Because there is a constant price over protein levels, high N apply cannot reduce benefit. This encourages farmers to use higher rates of nitrogen to increase wheat protein and thus higher prices. But it leads to increase wheat yields variance as well (Smit et al., 2003).

Farmers' decision and management

Farmer in Ontario applies farm management practice in order to increase yields and production. They use the strategies for raising their products as well as to deal with weather and environmental risks. In other words, they have their own practice strategies for managing the farms. In fact, they care about their current problems, such as economic problems rather than their future problems, such as climate change. Also, they prefer to use a cheaper strategy instead of more expensive technology. In Ontario, farmers do not adopt biotechnology for pest control and they choose crop rotation instead because they believe it is cheaper and includes premiums for identity-preserved (non- GMO) commodities. Also, they use resistant cultivators (Reid et al., 2007). The question is if the advance of innovation or technology can offset weather changes but do the farmers adopt and apply them or they prefer to use subsidized insurance?

Farmers can raise or maintain their benefit by increasing the planted area, as well. Farmers in Ontario have increased or allocated their planted area to the crop based on the expected income. In other words, the expected income is the most important factor which has affected farmer decision-making about farmlands allocation over a period of 26 years (1981 -2006) in Ontario. Expected income variation is influenced by its component or expected yield variation and expected price variation. In other words, farmers have decided to allocate their lands among the crops considering the future changes in price and yield (Weersink et al., 2010).

Increases in the planted area by farmers, in Southwest Ontario, over 26 years, resulted in decrease yield because of a drop in the marginal quality of the planted land. As well as less quality land causes more yield variations. Therefore, increasing planted area leads to not only decreases in wheat, so that 10% increase in planted area decrease wheat yield about 1% on average, but also increases in its variability (Cabas et al., 2009). Also,in Manitoba (Carew et al., 2009. 7.) allocating more land to plant wheat, has been led to reducing wheat yield because of reducing returns to scale.

The other variables which farmer can affect crop yields through them are spatial diversity and temporal diversity. Farmer's decisions and behave have affected spatial diversity and temporal diversity in Canada. Spatial diversity shows how much a specific geographical area is diverse in terms of planted crops and it influences crop yields in a negative way As well as temporal diversity demonstrates the weighted average age of planted crop varieties and it positively affects crop yields. Therefore, depends on farmers ‘decisions and management spatial diversity and temporal diversity change crop yields. In Manitoba, farmers who are used to applying old cultivars prevent them from increasing their crop yields. (Carew et al., 2009).

Interactions between weather, as a key factor, and the other factors

Obviously, wheat yields are influenced by a variety of factors that they are not separate from each other and act independently. In other words, climate and non-climate factors form an interactive system with a series of direct and indirect effects, although the climate factors is the head of factors. In this system, not only each factor has its own effect, a direct effect, but also it has an interaction effect, an indirect effect, on wheat yield. Among all the factors, climate and weather conditions are the key factor playing the main role in wheat yield or its variation (Yong Hea et al., 2013; Cabas et al., 2009). In other words, weather variables such as precipitation, temperature and the length of growing season affect the wheat production and yield the most (Qiang et al., 2013; Bryant et al., 2000; Yinhong., 2009; Raymond and Fgang, 2005). On the other hand, climate factors influence non-climate factors' effects and control their effects on wheat yield. Thus, many non-climate factors dependent on climate factors to impact in a good way. However, they need good and appropriate weather condition such as suitable heat, humidity and raining for positive effectiveness on yield wheat. The weather affects plant growth environment, including disease, soil and N, and strengthens or weakens their effects on crop yields. Some weather condition such as the wind, humidity, heat and conditions precipitation supports to produce and spread diseases (Osborne and stein, 2007; Luongo et al., 2005). Also, interaction between weather condition and soil water during the growing season is important and influences yield wheat. Heavy precipitation and exceeded moisture soil at planting cause delaying in planting time and as a result, decreasing yield wheat (Carew et al20017). As well, weather conditions influence N effectiveness for improving wheat yield. N fertilizer is unable to increase wheat yield in an unsuitable weather conditions. In the growing heat and varied precipitations condition N has no effect on wheat yield (Carew et al, 2009; Yuetian, 2017). In addition, excessive moisture prevents of effective action of N fertilizer to improve yield. (Carew et al., 2017). Similarly, the positive effects of technology on yield depend on the good years in terms of weather conditions. Therefore, it can be said, innovations effects not only cannot be helpful on yield wheat in the bad years but also, it can increase yield volatility (Horlick, 2019; Yuetian et al., 2017). A well as the weather conditions can affect farmers' economic situation and make it better or worse. Thus, suitable weather condition improves the yield and then the farmers' income. On the other hand, a good financial situation can offset bad weather conditions or extreme events effects (O'Brien and Leichenko 2000). Also, the farmland's value depends on the weather variables. So that, higher precipitation makes the farmlands more valuable and it is opposite, about the hot temperature (Cabas et al., 2009). Unsuitable weather condition such as extreme moisture leads to decrease of planted land of wheat by farmer, as well (Carew et al., 2017). Farmers' decision and behavior is the other important non-climate factor influenced by climate factor. One of the most important decisions of farmers about farm management is to decide on the allocation of the farmlands. However, farmers allocate their farmlands to crops considering the expected income. While the expected income is obtained through the expected yield and price. On the other hand, expected yield is severely influenced by the weather condition especially the length of the growing season. Therefore, farmers allocate their farmlands based on the weather condition (Weersink et al., 2010). Also, farmers react and respond to new climates or weather conditions. They adapt themselves to risky weather conditions through their strategies such as crop rotation to control disease and maintain quality of soil, using crop varieties, no-till practices and (Wandel and Smit's 2000) and disease-resistant cultivars (Amarasinghe et al., 2013).

Reciprocally, non-climate factors can moderate or offset the climate factor effects on crop production. Basically, the purpose of applying them is to support and improve wheat yield in unsuitable weather conditions. N fertilizer, healthy soil and no disease, advanced technology and genetic improvement (wang et al 2012), economic and financial resources, farmers' decisions and management (Reid and et al., 2007) are partly able to compensate for negative effects resulting from extreme events or risky climate conditions.

Not only interaction climate factors and non-climate factors affect production and yield but also, interaction among non-climate factors is significant. For instance, N fertilizer; use and efficiency, are influenced by the other non-climate factor. Good environmental condition in terms of soil properties (Carew et al., 2007) and no disease (B L et al., 2004) is needed for N effectiveness. Economic and financial situation and government politics can support farmers for using more N fertilizer to get a higher price. Management practices, by farmers, influence N effectiveness on yields since yields impressed severely by applying N before seeding (Dong, 2019) as well as the inclusion of legumes (such as peas, beans and lentils) reduce the amount of nitrogen required and increased yield in hard red spring wheat (HRSW) (Mervin et al 2015).

Figure 1 shows the conceptual model, drawing from the literature review. In this figure, factors affecting wheat yield and Interactive relationships, direct and indirect effects, are presented. According to figure 1, weather factors, as head of factors, have both direct effect and indirect effects, through the non-weather factors, on wheat yield. On the other hand, Non-weather factors (growth environment, advanced technology, economics, and government policies and farmers' decisions and managements) have their direct effects as well as indirect effects, through the other non-weather factors, on yield. Also, they can influence the weather effects and partly offset or moderate weather effects on yield.

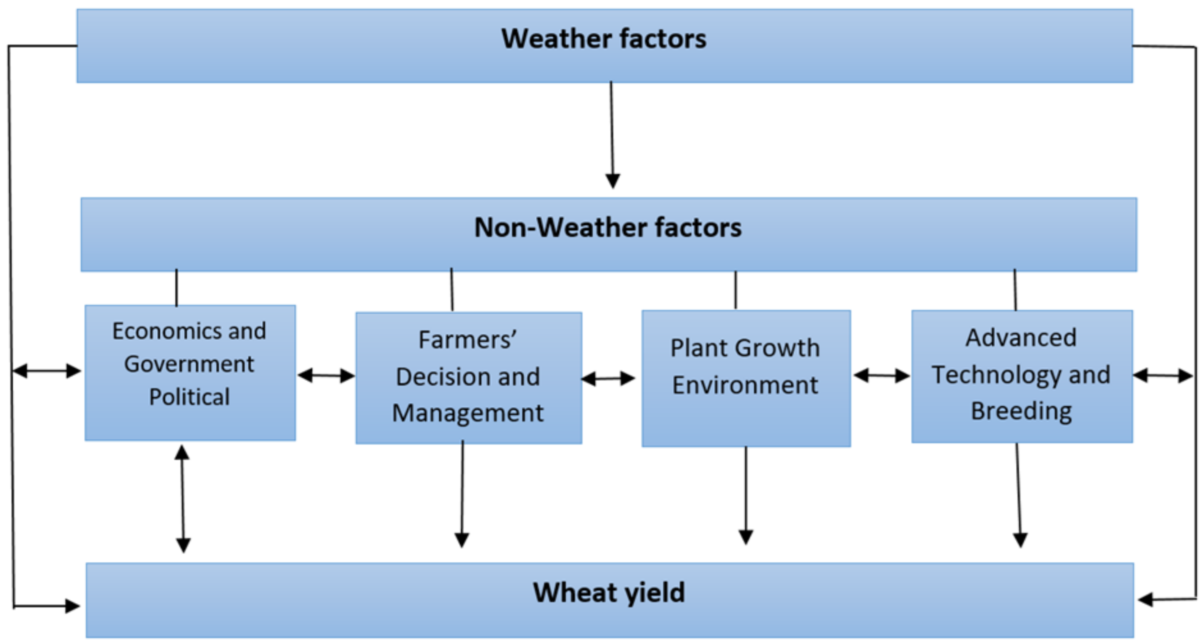

Figure: 1- Research conceptual model: Two-way arrows indicate interactive relationships.