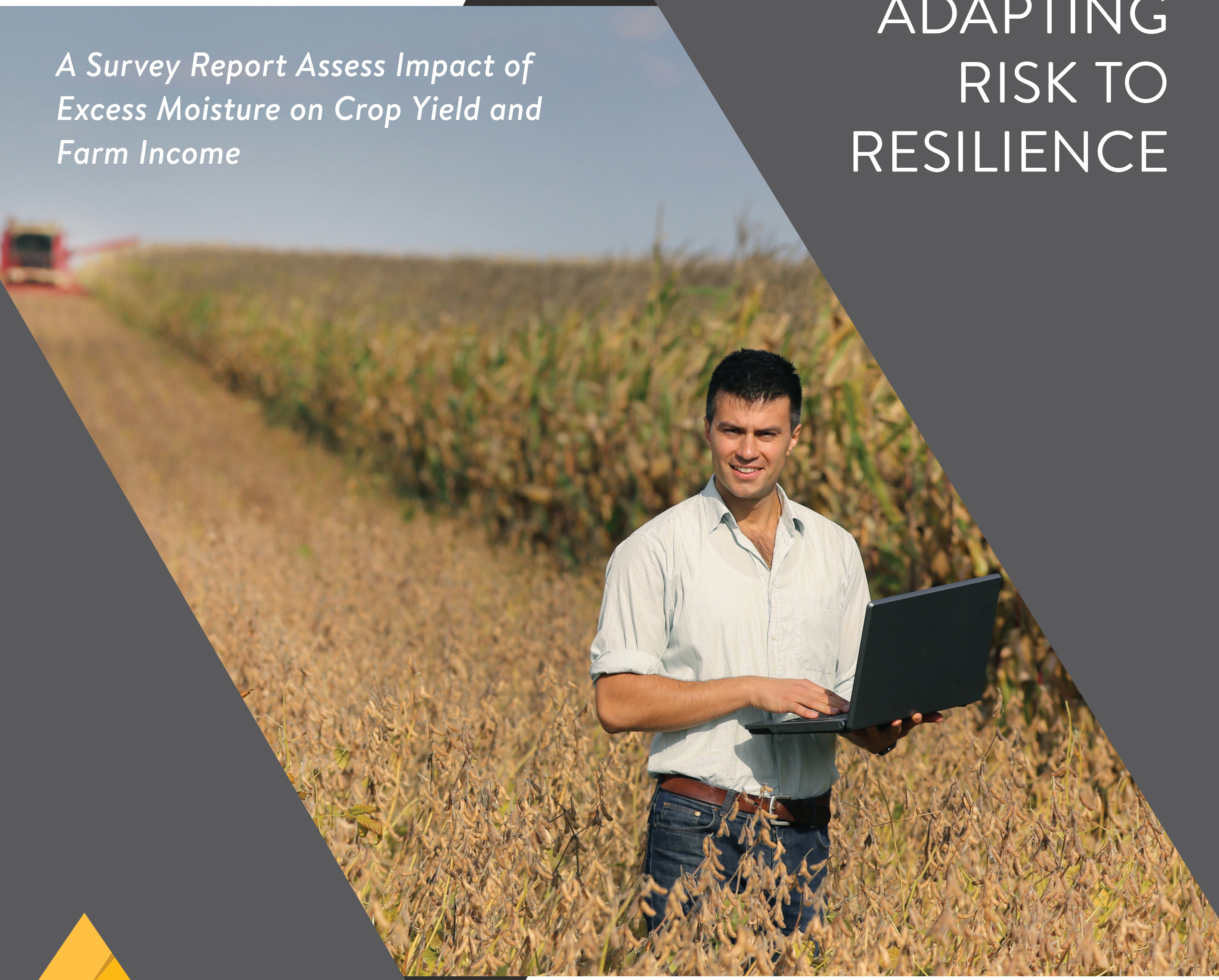
RURAL DEVELOPMENT INSTITUTE

PHASE 2

ADAPTING RISK TO RESILIENCE

A Survey Report Assess Impact of Excess Moisture on Crop Yield and Farm Income



RURAL DEVELOPMENT INSTITUTE

BRANDON UNIVERSITY

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It is important to recognize that the land on which we're gathered is the traditional and ancestral lands of the Dakota, Anishinabe, Inninewak, Oji-Cree, Dene and Metis peoples. We respect the treaties that were made on these lands and acknowledge that Brandon University is located on Treaty 2 Lands. We at Brandon University acknowledge and respect the history, land and the people of this area.

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RURAL DEVELOPMENT INSTITUTE

Rural Development Institute

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The Institute has diverse research affiliations, and multiple community and government linkages related to its rural development mandate. RDI disseminates information to a variety of constituents and stakeholders and makes research information and results widely available to the public either in printed form or by means of public lectures, seminars, workshops and conferences.

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Foreword

Manitoba's rapidly changing climate conditions are characterized by increased frequency and intensity of extreme moisture events. For instance, four of the top ten Assiniboine River floods and five of the top ten Red River floods took place during the last 25 years. In addition to these spring floods, other extreme moisture events include prolonged or intense periods of rain. Generally, from an ag-producer's perspective, these events result in soil moisture in extreme of field capacity for a period sufficient to significantly inhibit crop production.

Moreover, the impacts of such events can be local or regional as well as downstream. For producers, the impacts may be short-term, prolonged or persistent depending on the locale, previous moisture mitigation strategies, and the local and regional water infrastructure. These extreme water events harm farm livelihoods as well as the well-being of all downstream rural municipalities and urban centres having to deal with the social, economic and environmental costs due transportation interruptions, property damage, and agricultural run-off impacts on surface and ground water quality.

There are several longer term strategies producers can invest in to manage extreme moisture in their fields. Reducing the risk of crop loss or reductions in yield and quality are generally the main reasons why producers make such investments. Others at the local and regional levels may also benefit from these water management practices as well (e.g., reduced peak flows). This project aims to provide agricultural producers at the early stage of long-term planning with critical factors in estimating socio-economic costs and benefits of different on-farm extreme moisture practices, along with identifying other stakeholder considerations.

To achieve that goal, this project consists of three main activities and took place in two distinct phases. The focus of Activity 1 was to provide producers with an on-farm costs and benefits framework to help evaluate different investment strategies for managing extreme moisture. Activity 2 focused on using farm models to provide information on the impact on yield and farm income due to extreme moisture. Lastly, Activity 3 focused on identifying the downstream impacts and costs of extreme moisture events with a particular focus on the 2011 Assiniboine River flood. For each activity, Phase 1 consisted of gathering and synthesizing academic and other publicly available information and data. Phase 2 of the project sought to get feedback from producers and other stakeholders in an effort to validate the findings of the Phase 1 activities. Overall, the 2 phases of the 3 activities of this project resulted in the completion of 6 reports which are outlined in Figure 1.

Summary of the 6 reports indicating the main objectives for each phase and activity

	ACTIVITY 1	ACTIVITY 2	ACTIVITY 3
	Economic Costs and Benefits Analysis of Excess Moisture Investments	**Impacts of Excess Moisture on Crop Field and Farm Income**	**Downstream Effects of Excess Moisture in Manitoba**
PHASE 1	1. Identify farm investment options for excess moisture management. 2. Identify of on- and off-farm costs and benefits of investment options. 3. Quality costs and benefits of investment options and select suitable proxies for qualitative costs and benefits. 4. Develop a framework to assess costs and benefits of excess moisture investment options.	1. Identify, calibrate and adapt a farm model that could be simulating the impact of excess moisture events in southern Manitoba's field conditions.	1. Identify the physical and socio-economic impacts of excess moisture 2. Identify the direct the indirect costs excess moisture losses. 3. Identify the downstream economic impacts of excess moisture.
PHASE 2	1. Validate the economic cost-benefit framework of proposed investment options of farm-level extreme moisture management. 2. Determine what extreme moisture management strategies are currently being use. 3. Evaluate the willingness of producers to adapt their farm using proposed extreme moisture management strategies. 4. Conduct a Manitoba local market survey to validate cost estimations used in the development of cost-benefit framework.	1. Identify current yield forecasting tools available and being used by stakeholders at different scales of operations. 2. Evaluate the willingness of producers and other stakeholders in crop yield forecasting models.	1. Validate the completeness and accuracy of the physical and socio-economic impacts of excess moisture. 2. Assess the relevance and usefulness of the information for the procedures and stakeholders. 3. Identify other effects, outcomes, and strategies that producers and stakeholders considered in response to the 2011 Assiniboine River Flood

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Executive Summary

Global agricultural production is vulnerable to climate change. Understanding climate change impacts on agricultural production, especially extreme (excess and insufficient) moisture, is critical if producers, policymakers, researchers, and crop breeders are to ensure global food security. Prolonged extreme moisture conditions cause negative effects on agricultural operations that can result in loss of crop yield, quality, and farm income. It is increasingly becoming necessary for Manitoba producers to use yield forecast tools in order to understand the scope of extreme moisture events influencing crop yield, and quality. This information would allow producers to respond appropriately in order to overcome the extreme moisture events. Moreover, crop yield forecasts are important for determining the difference between potential and actual yields aiding government and producer organizations in the development of export-import policies, food security policies, and efficient land management practices. Traditional crop yield estimates, conducted through farm surveys or by experts based on their evaluation of crop conditions, are somewhat subjective, time-consuming and often unrepresentative due to small sample sizes. Farm simulation models assess the impacts of weather/climate on agricultural production to forecast crop yields and offer several benefits over traditional methods, including precision, reduced costs and the elimination of human-related biases and errors. Simulated farm models assess crop yield gaps (quantified as the difference between potential and actual farm yields), impact of climate change on future crop yields, and land-use change. Several farm models are available to measure the effects of climate extremes on crop yields. However, these models are calibrated in different climatic zones with region specific crop characteristics. Assessment of impacts and adaptability to climate change at Southern Manitoba's local scale necessitates parameterization of models to incorporate Manitoba's local conditions and management practices.

The overall aim of this project is to assist Manitoba producers in better understanding on-farm investments to manage extreme moisture and to catalogue downstream impacts of such events. In the phase-1 of this project activity, Rural Development Institute (RDI) calibrated the AquaCrop farm model using Manitoba's 30-year historical climatic data (1990 – 2019) and simulated local crop characteristics in the model interface to analyze the potential impacts of projected climate change scenarios on crop yield variability in southern Manitoba. This farm model has the ability to simulate extreme moisture scenarios and can be of use to many including producers, farm production consultants, planners, and economists to make business-informed decisions in their areas of expertise at the targeted spatial scale. In phase-2 of this project, RDI organized a series of surveys to receive feedback from targeted stakeholders involved in this study in terms of how yield forecasting models might be useful to their decision making.

The participants in this survey included agricultural producers/farmers, government analysts, and agricultural businesses, and enterprises delivering services at farm, regional and national level. This baseline survey of targeted stakeholders provided a valuable and unique insight into the current yield forecasting tools available and being used by stakeholders at different scales of operations, and willingness of survey participants in using crop yield forecasting models. Diverse feedback was received from the survey participants about current crop yield forecasting methods they are using at their targeted scale of operation. All producer participants recognized the importance of crop simulation models in yield forecasting and a profound interest was observed in the yield forecasting model calibrated by RDI for the southern Manitoba conditions to track impact of weather extremes with a focus on extreme moisture events on crop yield. All producers were in agreement that the consideration of historical climatic data in yield forecasting provides accurate, precise, and reliable yield

estimations. Additionally, all producers acknowledged that use of mathematical models in farm planning is a very important decision support tool and it can make farm operations more efficient and effective. However, the major challenge associated with the use of complex crop simulation models are the requirement of an extensive model operating knowledge, expertise in advanced model coding languages, and highly detailed input data. Participant producers were in agreement that a moisture response yield forecasting model with the user-friendly interface along with more reasonable crop and soils data inputs would allow them to estimate potential farm losses (including crop yield and property) under extreme moisture events. A participant producer also recommended the development of a user manual of AquaCrop model with all essential information for the user and step-by-step procedure for the model access and use. Given the interest of producers, a user-friendly manual of AquaCrop model has been developed by RDI researchers. This manual includes a description of the model functions and capabilities, contingencies and alternate modes of operation. The open access software program of AquaCrop model and a detailed user manual is available at the RDI website.

The aim of this report is to focus the objectives of Activity – 2 by developing a pro-active and fiscally responsible approach to mitigating the effects of excess moisture in Manitoba's metrological conditions. The ultimate goal of developing this risk management approach is that Manitoba's agricultural producers have access to, and are able to use a farm model to manage risk associated with excess moisture, and are therefore more prepared and less vulnerable to farm flooding situations.

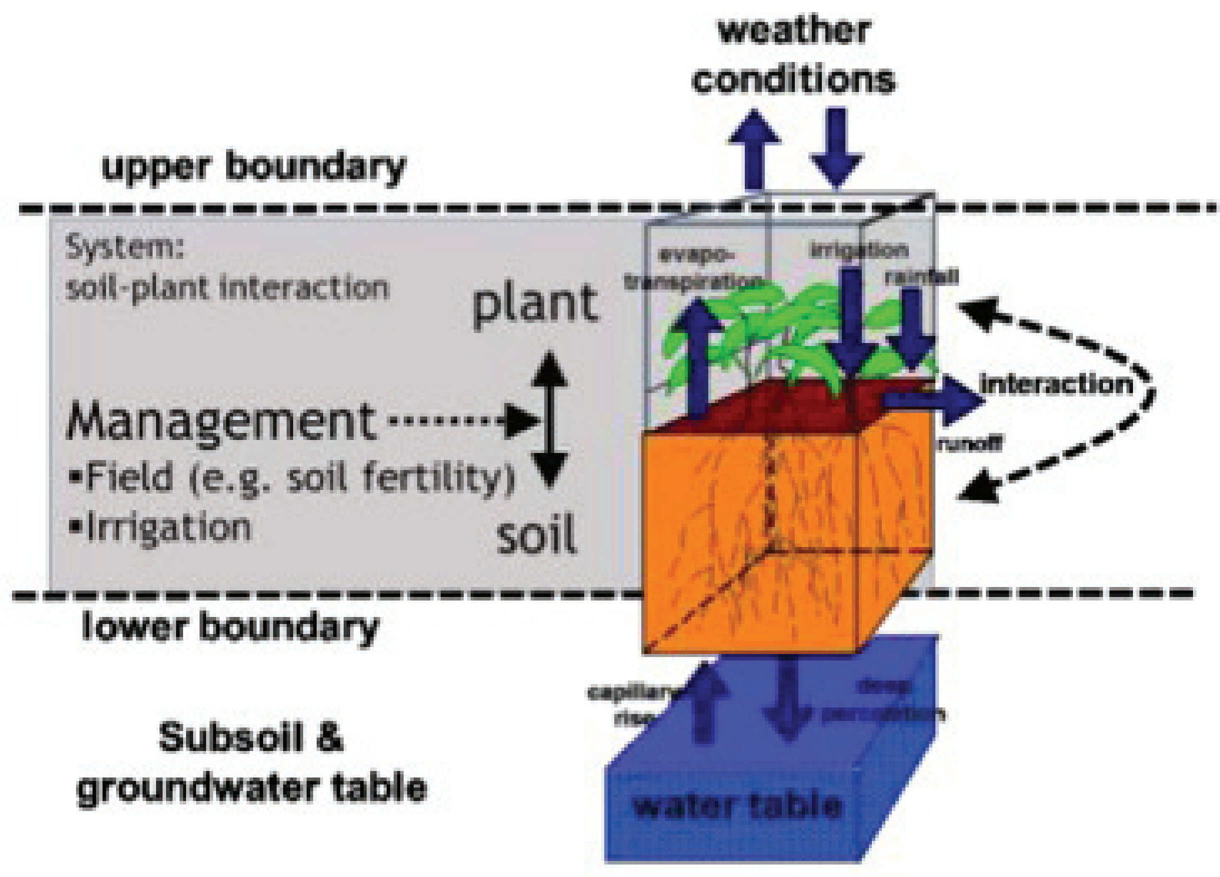
Introduction

Natural risks, especially natural drought and flood occurrences, caused by weather extremes constantly threaten the agriculture economy. Manitoba's rapidly changing climate conditions are characterized by increased frequency and intensity of extreme moisture events. Most recently, in 2020, a series of extreme moisture events took place in the southern Manitoba during the months of June and July with some areas receiving over 200 mm of rain within a three-day period. These extreme moisture events resulted in overland flooding and approximately 20 to 30 % of the land in the regional municipalities of southern Manitoba remained unseeded. Crops already seeded in the worst affected areas were drowned out as significant portions of seeded fields were under water for an extended period. Pastures and hay-land in affected areas were also flooded and forage productivity was severely impacted. Prolonged extreme moisture conditions cause negative effects on agricultural operations that result in loss of crop yield, quality, and farm income. It is becoming increasingly important for Manitoba producers to use yield forecast tools in order to understand the scope of extreme moisture events on crop yield and quality. This information would allow producers to respond appropriately in order to overcome the extreme moisture event. Moreover, crop yield forecasts are important for determining the difference between potential and actual yields which aids government and producer organizations in the development of export-import policies, food security policies, and efficient land management practices. Traditional crop yield estimates, conducted through farm surveys or by experts based on their evaluation of crop conditions, are somewhat subjective, time-consuming and often unrepresentative due to small sample sizes. Farm simulation models use climate state analysis to forecast crop yields and offer several benefits over traditional methods, including higher precision, reduced cost, and the elimination of human-related biases and errors. The state of the climate can be analysed by using various statistical methods such as frequency, magnitude, and trend analysis. These analyses are employed in a simulation model to predict future changes in climatic conditions and its subsequent affect on crop yield and quality.

Several farm models are available to measure the effects of weather extremes on crop yields. However, these models are calibrated in different climatic zones and with different regional crop characteristics. Assessment of impacts and adaptability to climate change at southern Manitoba's local scale necessitate parameterization of models to incorporate Manitoba's local conditions and management practices. To analyze the potential impacts of projected climate scenarios on crop yield variability in the southern Manitoba, the Rural Development Institute (RDI) of Brandon University calibrated the AquaCrop farm model using Manitoba's 30-year historical climatic data (1990 – 2019) and simulated local crop characteristics in the model interface. This farm model has the ability to simulate extreme moisture scenarios and can be of use to many including producers, farm production consultants, planners, and economists to make business-informed decisions in their areas of expertise at the targeted spatial scale.

The AquaCrop model system simulates the interaction between plant and soil, which is affected by management practices, and links it with the climate/weather conditions (i.e., upper boundary), and groundwater (i.e., lower boundary) conditions. A schematic diagrams of AquaCrop working principals and model inputs are shown in Figure 1. The model uses separate input components of climate data, crop parameters, management (irrigation and field management), soil (soil characteristics and groundwater level) and simulation period for simulating crop yield. In order to calibrate the model in Manitoba's local conditions, model input data was collected using data from different local and global sources.

Figure 1: AquaCrop Schematics (Raes, 2017)



In the phase 1 of this project activity, RDI calibrated the farm model AquaCrop using Manitoba's historical climatic data to simulate crop yield under different extreme moisture management scenarios. Phase 2 aims to identify current yield forecasting tools being used by producers, government analysts, and agricultural businesses and enterprises in Manitoba. In order to achieve this objective, RDI organized a series of surveys to receive feedback from targeted stakeholders involved in this study in terms of how yield forecasting models might be useful to their decision making. The main objectives of this research activity are to:

1. Identify current yield forecasting tools available and being used by stakeholders at different scales of operations.
2. Evaluate the willingness of producers and other stakeholders in crop yield forecasting models including AquaCrop model.

Review of Literature

Agroecosystems are complex where crop yield is the dependant on the interactions between plants, soil, atmosphere, water, and socio-economic factors. Agricultural production is significantly affected by environmental factors including extreme moisture events, temperature extremes, and wind velocity. Weather influences crop growth and development, causing large intra-seasonal yield variability. In addition, spatial variability of soil properties and its interaction with the weather can cause spatial yield variability. Crop agronomic management (e.g., planting, fertilizer application, irrigation, tillage etc.), and extreme moisture management strategies (water reservoirs, tile drainage, land grading, cover cropping etc.) can be used to reduce the loss in yield due to effects of weather. As a result, yield forecasting represents an important tool in selecting extreme moisture management strategies, optimizing crop yield, and to evaluate the crop-area insurance contracts. Various methods have been developed for quantifying crop at research plot levels and using simulation models at regional and national levels. The traditional method of yield forecasting is the evaluation of crop status by experts. Other methods used to forecast crop yield are the use of remote sensing and crop simulation models. The objective of the yield forecast is to give a precise, scientifically sound, and unbiased forecasts of crops' yield as early as possible during the crops' growing season by considering the effect of the weather and climate.

Crop yield forecasts are important for determining potential and actual yield losses aiding government and producer organizations in the development of export-import policies, food security policies, and efficient land management practices. Crop yield forecasts provide an understanding of the precise impact of long term metrological variations on crop yield, allow managing risk associated with moisture extremes (excess or deficit), and cause reduction in the risks related with local or national food systems. Risk reduction contributes to improved economic returns, the livelihood of producers, and in the long run, the capacity of producers to invest and innovate. There are several crop yield forecasting methods agricultural stakeholders are currently using at their targeted scale of operation. A brief overview of these methods are provided below.

Historical Methods

Crop yield estimation allows producers to quantify the impact of climate change on future crop yields by menstruating the difference between potential and actual farm yields, and help in appropriate mitigation decision making without compromising smallholder livelihoods and rural development (Rosenstock et al., 2013). Historically, farmers have been always making forecasts in order to plan their agronomic practices. For example, the planting window, the choice of a cultivar, the amount of fertilizer to apply depend on the climate. If farmers know that the subsequent week there is a good chance for rain, then they will rush into the field to seed their crops. In this method, observations and measurements are made throughout the crop growing season, such as tiller number, spikelet number and their fertility percentage, percentage of damage from pests and fungi, percentage of weeds infestation etc. Using this data, yield can be forecasted using regression methods, or by the knowledge from local experts including producers, agronomists, extension workers etc. Forecasting crop yield also allows forecasting other important parameters. For example, quantifying the area planted at the starting of the growing season and quantifying the area harvested.

Remote Sensing

Remote Sensing is the science of acquiring information about an object through the analysis of data obtained by a device that is not in contact with the object (Lillesand and Keifer, 1994). Remotely sensed data be obtained from a variety of platforms such as satellite, airplanes, unmanned vehicles, and handheld radiometers. The data may be gathered by different devices like sensors and digital cameras in the form of images. Multispectral and hyperspectral satellite images are used to determine crop growth conditions at different spatial and temporal scales. These images can describe the crop development, biomass accumulation, leaf area index (LAI), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (ENDVI), Perpendicular Crop Enhancement Index (PCEI), and many other indices (Silva et al., 2018).

Statistical Models

In this method, a simple statistical model is built using a matrix with historic yield and several weather parameters (temperature and rainfall etc.). Using this data, a regression equation is derived between yields as function of one or several weather parameters. The advantages of a statistical model is that the calculation is easy, less time is required to run the model and the data requirements are limited. However, they are limited in the information they can provide outside the range of values for which the model is parameterized. In addition, they do not take into consideration the soil-plant-atmosphere continuum, which is important when dealing with regions having different soil types. For example, the response of a crop to an extreme moisture event on a sandy soil is different than a crop on a clay soil. The timing of the extreme moisture event occurring during the growing season is also important and often ignored in statistical models. For example, an extreme moisture event occurring at flowering will reduce yield more than an event happening during the vegetative phase. This is important for correctly forecasting yield and for giving producers important agronomic advices including the timing of seeding, timing and amount of fertilizer application, amount of irrigation application etc.

Crop Simulation Models

Crop Simulation Models (CSM) are computerized representations of crop growth, development, and yield, simulated through mathematical equations as functions of soil conditions, weather, and management practices (Hoogenboom et al., 2004). These models are designed to inform producers and other stakeholders with real-time information about their crops, giving risk-assessment information and monitoring decision support relevant to farm management. The strength of a CSM is in its ability to extrapolate the temporal patterns of crop growth and yield beyond the experimental sites from which it was developed. These models are built with the aim to consider the soil-plant-atmosphere continuum and its daily changes on the accumulation of biomass and nitrogen. A CSM can capture the effects and timing of wet/dry cycles on crop growth; which can significantly help producers in planning their agronomic management (Shin et al., 2009). Crop simulation models can be used to evaluate the impact of an extreme weather event on crop's physiological processes and forecast the crop yield accordingly.

The difficulties of adopting a CSM has usually been associated with the intensive data for models' parameterization. The need for calibration can be quite data extensive and laborious for producers. Another limitation of the CSM is that they are point-based and inadequate to run at regional or national scales. To address these limitations, Land and Water Division of FAO (Food and Agriculture Organization of the United Nations), developed AquaCrop farm model in 2009 (Steduto et al., 2009; Raes et al., 2009). It requires a relatively small number of explicit and mostly intuitive parameters to be defined as compared to other crop models. AquaCrop has been validated and applied successfully for multiple crop types across a wide range of environmental and agronomic settings (Vanuytrecht et al., 2014). AquaCrop simulates yield response to soil moisture, and is particularly well suited to assess the impact of soil moisture extremes on crop yield. The model was developed for the purpose of using relatively small number of explicit parameters in a balance of simplicity, accuracy, and robustness. The calculation procedure is grounded in biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system.

Calibration of AquaCrop Farm Model

In the phase-1 of this study, RDI calibrated the AquaCrop farm model using Manitoba's historical climatic data to simulate crop yield under different extreme moisture management scenarios. The AquaCrop model was chosen in part due to its relatively easy operation, open access software program availability, and providing user-friendly interfaces which do not require extensive modeling knowledge. The software also provides an interface to communicate visually how the various components of the modeling system are interacting. This offers a better method of communicating the complexity of the modeling system to the end user than conventional code-based models. Version 6.1 of AquaCrop standard windows program was downloaded from the Food and Agriculture Organization (FAO) website to calibrate the model for Manitoba's Metrological conditions.

The AquaCrop model system develops an interaction between plant and soil, which is effected by management, and link it with the outside world i.e. upper boundary (climate/weather conditions), and lower boundary (groundwater). The model uses separate input components of climate data, crop parameters, moisture management (extreme/balanced/deficit moisture levels), soil (soil characteristics and groundwater) and simulation period for simulating crop yield. The AquaCrop farm model was calibrated using Manitoba's 30-year historical climatic data (1990 – 2019) and simulated local crop characteristics in the model interface to analyze the potential impacts of projected climate change scenarios on crop yield variability in the southern Manitoba. Daily mean weather data of southern Manitoba with a focus on Assiniboine River, and Red River basins were used to calibrate the model in Manitoba's climatic conditions. The AquaCrop model includes five module to connect the soil-crop-atmosphere continuum.

1- Climate Module

2- Crop Module

3- Management Module

4- Soil Module

5- Simulation Module

Model input data was collected using different local and global data sources. Data required to calibrate the AquaCrop farm model is summarized in Table 1.

Table 1: Data Required to Calibrate the AquaCrop Farm Model

Input Data	Data Source
Climate Module	
Minimum Temperature	Environment and Climate Change Canada
Maximum Temperature	Environment and Climate Change Canada
Precipitation (Rainfall and Snow)	Environment and Climate Change Canada
Mean of Relative Humidity	POWER – A web based GIS application by NASA
Wind Speed at 10 m above ground	POWER – A web based GIS application by NASA
Solar Radiations	POWER – A web based GIS application by NASA
Reference Evapotranspiration	FAO Penman-Monteith equation
Global Atmospheric CO2 Concentration	Mauna Loa Observatory in Hawaii
Crop Module	
Conservative Crop Parameters	AquaCrop's default file (Standard crop parameters)
Non- conservative Crop Parameters	AquaCrop's default file modified to Manitoba's local conditions based on data collected from various local sources
Management Module	
Soil moisture	Soil moisture data is entered for the field under study
Field management	In-field data for soil fertility levels and weed management
Soil Module	
Soil Properties	Data for water retention in the soil fraction at saturation, field capacity, and permanent wilting point, and the hydraulic conductivity of the soil at saturation (AquaCrop's default file)
Groundwater Parameters	Field data for groundwater depth below the soil surface and groundwater quality (salinity).

A detailed description of AquaCrop model's operation, calculation scheme, and calibration and simulation process is outlined in the phase 1 report of this study.

Research Design

RDI organized a series of surveys to identify current yield forecasting tools available and being used by stakeholders at different scales of operations, and to receive feedback from targeted stakeholders involved in this study in terms of how yield forecasting models might be useful to their decision making.

Criteria for Selecting Survey Participants

All 13 stakeholders were recruited using a snow-ball sampling approach following the selection criteria set by RDI, focusing on the prospective research participants' levels of decision making based on yield forecasting approach, scale of operation, producers' farm possession age and history, their major crop commodities, and their interest to participate in the survey activity.

All 13 survey participants were identified by the RDI research team by reaching out to contacts available in the database of Manitoba Agriculture and Resource Development (MARD), Agriculture and Agri-Food Canada (AAFC), Statistics Canada, University of Manitoba, agricultural/commodity organizations and online searching tools. These organizations were asked to provide names and contact information of stakeholders whom they believe might be interested in the research project. After receiving a formal consent from targeted stakeholders, these organizations provided a list of potential participants to RDI. Agricultural businesses, and government analysists were identified exclusively using online searching tools. All potential participants were contacted by phone and/or email, based on their expressed interest and contact sources available, to send an invitation of participation in the survey along with the Project Overview document. The invitation to participate included an overview of the data collection activities, time commitment, and protocol for giving informed consent and withdrawal of data.

After receiving an expression of interest from a stakeholder to participate in the survey, the RDI research team scheduled a date, time, and venue with the participant to conduct the survey interview. These interviews were conducted during a six months period starting from July 2020; in the middle of a pandemic (COVID-19). In order to follow Brandon University's research travel orders and Provincial State of Emergency & Public Health Orders, the RDI team adopted a hybrid in-person and remote model to collect survey data. With the relaxation in provincial health orders during the months of July, August, and September; a total of 70% surveys were conducted in-person at the personal choice of producers and stakeholders following provincial physical distancing protocols and other fundamentals (e.g. use of face masks/shields, hand sanitizers etc.). However, we used remote communication tools (Zoom, MS Teams, phone, and Email communications) to conduct rest of survey interviews when the province of Manitoba moved to first code orange and then code red on the Provincial Pandemic Response System to halt COVID-19 transmission.

Recruiting Survey Participants

The targeted stakeholders involved in this study include agricultural producers, government analysts, and agricultural businesses and enterprises. A total of sixteen representative producers growing a range of crop commodities were selected from southern Manitoba following the selection criteria set by RDI to send an invitation of participation in the survey. Out of 16 producers, a total of six producers submitted an expression of interest to participate in the survey.

A total of four federal government analysts were contacted following the selection criteria set by RDI to send an invitation of participation in the survey. All four government analysts were available to participate in the survey. At the recommendation of participating government analysts, some information and data under this category were also collected from the Agriculture and Agri-Food Canada, and Statistics Canada websites.

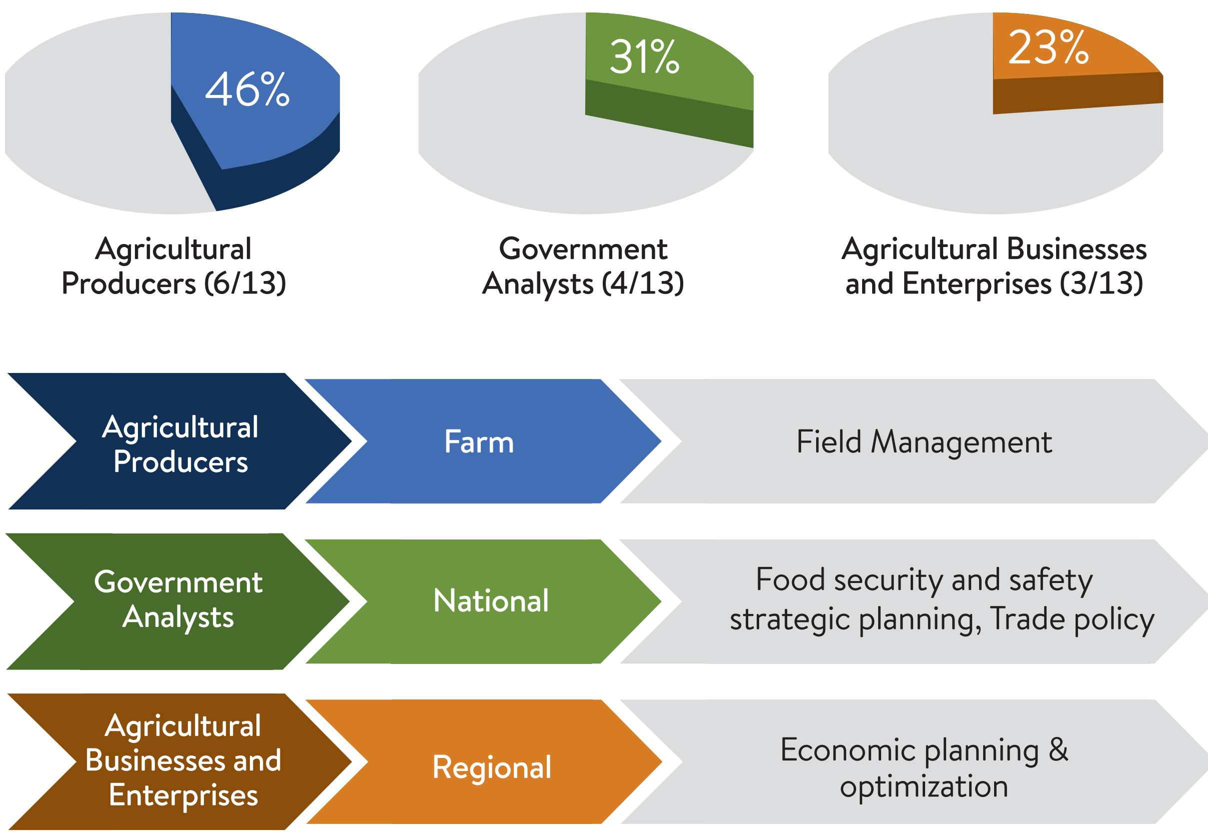
A total of five agricultural businesses and enterprises (including cereals, oilseeds, forages, and horticulture focused groups) were randomly selected from Manitoba following the selection criteria set by RDI to send an invitation of participation in the survey. However, only a total of three members of agricultural businesses and enterprises were available to participate in the survey.

Characteristics of Survey Participants

Following the selection criteria and filters developed by RDI survey team, a number of stakeholders were selected with features listed below:

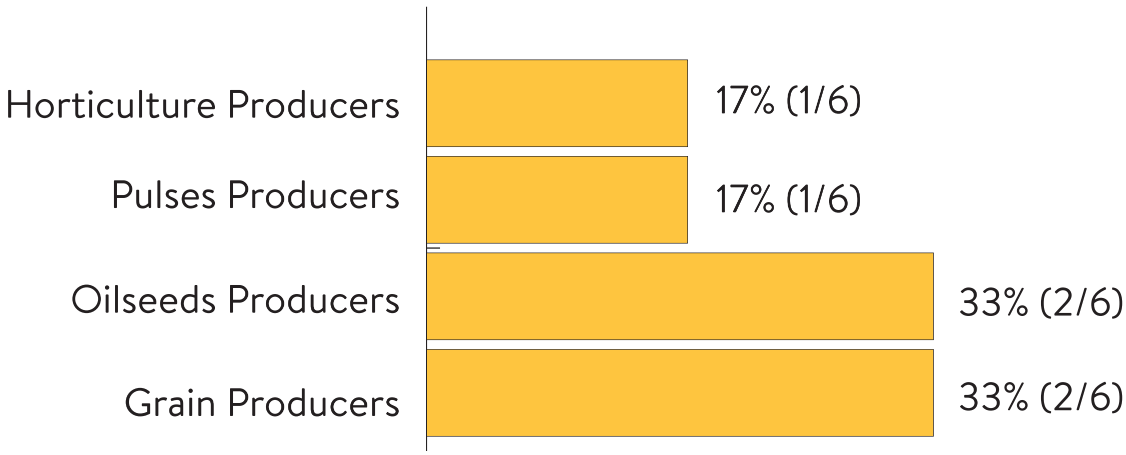
- The participants in this survey included agricultural producers/farmers, government analysts, and agricultural businesses and enterprises delivering services at farm, regional and national level (Figure 2).

Figure 2: Scale of Operation and Decision Level of Survey Participants



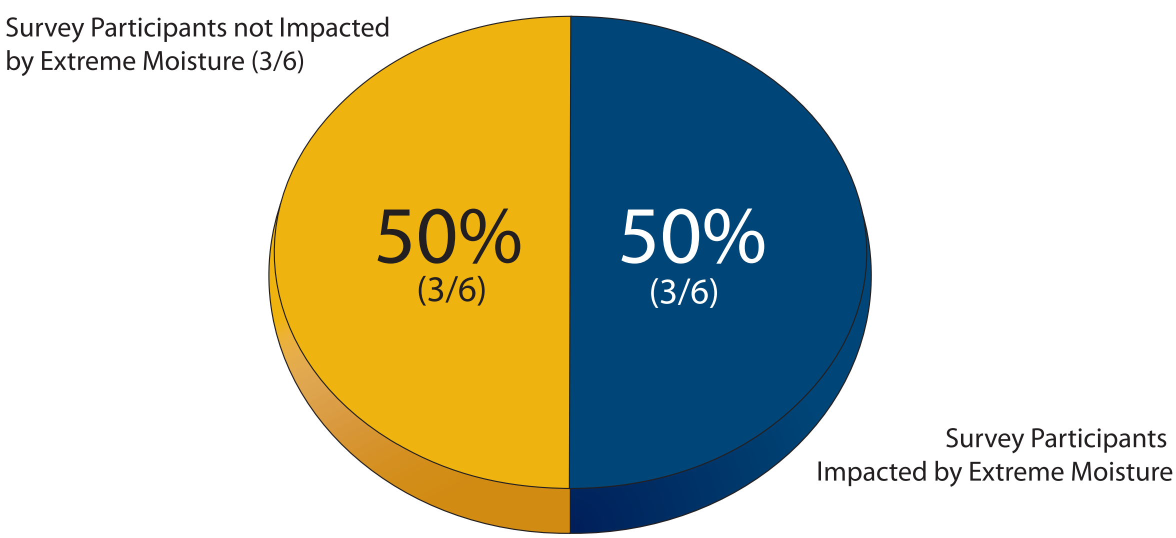
- The agricultural producers/farmers participants in this survey belong to a cross-section of major commodities produced in southern Manitoba such as grain, oilseeds, pulses and vegetable crops (Figure 3).

Figure 3: Major Crop Commodities of Producers' Participants



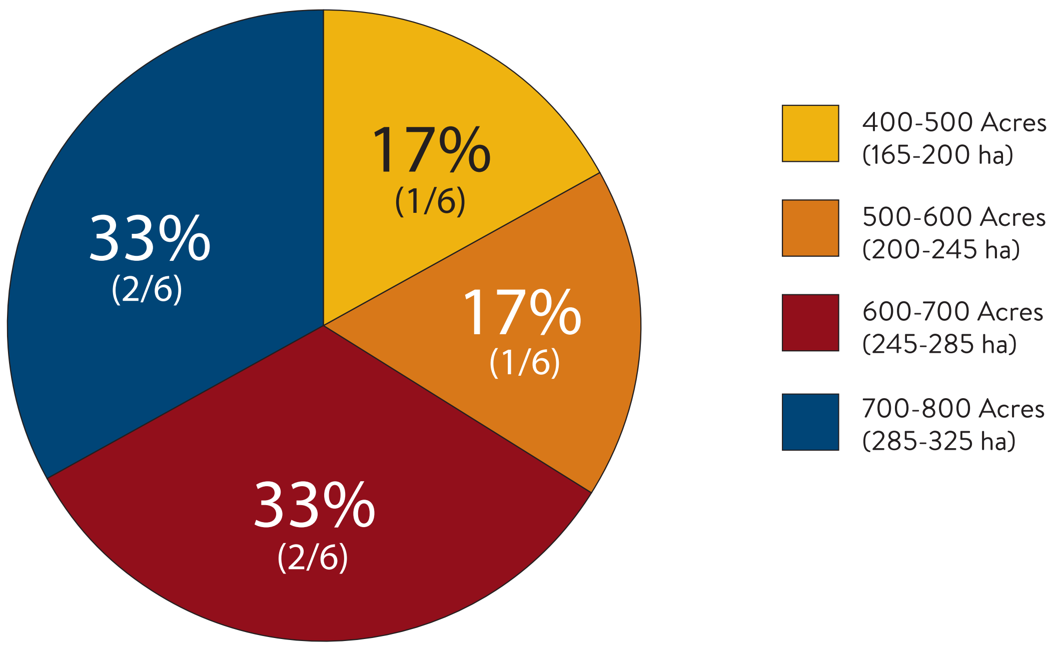
- All producers are performing their field operations either within the Assiniboine River or Red River Basins.
- Out of six participant producers, three producers' farming operations have been impacted by extreme moisture events during the last 25 years. The remaining three participant producers had not been impacted by extreme moisture events during the last 25 years (Figure 4).

Figure 4: Farm Extreme Moisture Events' History of Survey Participants during Last 25 Years



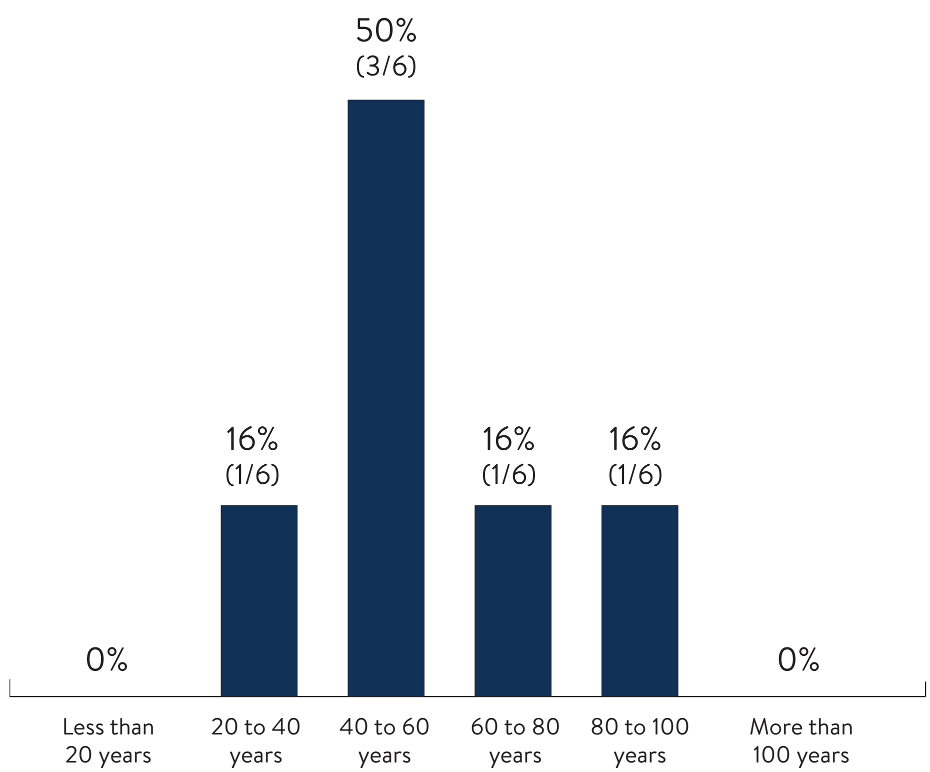
- Participant producers' land holding, and scale of operation were also taken in to account in selecting a representative sample of participants (Figure 5).

Figure 5: Land Holding and Scale of Operations of Producers' Participants



- Figure 6 shows the participation of producers with a diverse range of farm possession age where producers have maintained continuous production on new and family farms.

Figure 6: Farm Possession Age of Producers' Participants



Research Methodology

The RDI survey team developed two research instruments for this survey activity. The first instrument was a discussion guide of AquaCrop farm model calibrated by RDI as a yield forecasting tool to assess the impact of projected extreme moisture events on crop yield; the second instrument was a set of open-ended interview questions and discussion topics to facilitate the identification of decision factors and yield forecasting methods considered by targeted stakeholders participating in this study.

All producer participants were asked to provide feedback on the use of a moisture response model (including AquaCrop) calibrated for local weather conditions to forecast crop yield at farm level and how this information might be useful for producers in the selection of investment options to manage on-farm extreme moisture. The length of the interview process was targeted at 60 minutes. However, the RDI surveyor was available to discuss in detail the methodology and input data required to run AquaCrop model calibrated by RDI after the formal interview process was completed. If the interview was not completed during this time-period, the RDI surveyor asked to schedule another meeting time to complete the data collection at the stakeholder's convenience, providing an estimate of the time required to complete the interview. Within a period of two weeks after the survey interview was completed, the RDI surveyor scheduled a 5-10 minutes follow-up call with the survey participant to clarify the data collected during the interview. According to the terms and conditions of the survey process, all survey participants will remain anonymous through the use of pseudonyms (e.g., a producer, a stakeholder etc.).

Key questions addressed during this survey are:

- What is the importance of yield forecasting at different levels of decision making?
- What current yield forecasting methods are available and how they are related to extreme moisture impacts?
- What factors are involved in precise and accurate yield forecasting?
- Which stakeholders are involved in decision making and what type of decisions are made based on yield forecasting information?
- What yield forecasting models are being used in Manitoba?
- Is there a willingness to use a farm model over traditional yield forecasting tools to predict yield?

In order to seek survey respondents' feedback to find answer for key questions, survey interviews in this study surrounded topics listed in Table 2:

Table 2: Data Collected from Survey Participants during Interviews

Survey Topic	Data Collected
Farm Information	• Farm location • Site characteristics • Major crops • Crop production area • Yield patterns • Irrigation sources
Farm Flooding History	• Flood frequency and pattern • Extreme moisture impacts • Access to flood information
Flood Forecasting Information	• Flood forecasting sources • Information availability • Correlation with the scale of operation • Response to flood forecasting information
Current Yield Forecasting Strategies	• Importance of yield forecasting • Level of decision making • Reason for selecting current yield forecasting methods • Factors considered in yield forecasting • Accuracy analysis of current yield forecasting methods
Future Considerations	• Satisfaction level of current yield forecasting method • Willingness to use farm model in yield forecasting • Climate data consideration in yield forecasting • Sources of climate data acquisition • Interest in the combination of yield forecasting methods
Capacity Analysis	• Skills required to use a farm model • In-put data accessibility for a farm model • Hardware availability • Data interpretation ability

In discussing the importance of crop simulation models, the RDI surveyor established that crop damages caused by extreme moisture events are directly related to yield change, which requires accurate assessment to quantify the damages. Estimating the direct impact/loss as well as understanding the indirect economic impact of extreme moisture events could be important information for decision makers for accurate cost-benefit analysis and appropriate prevention plans. The surveyor identified that the crop simulation models are important for hazard assessment and the selection of an extreme moisture event management strategies (water reservoirs, tile drainage, land grading, cover cropping etc.) suitable to their farms.

Limitation of the Study

With the goal to gauge producers' reactions and gain their insight on the use of the aqua-crop model, this study serves as a preliminary assessment. Given the four limitations listed below, the findings assist in giving an early indication if producers see value in this model. As a result, the findings can not be generalized.

1. The survey data was collected in the southern Manitoba from a limited number of producers soon after an extreme moisture event during the 2020-planting year. It is difficult to measure changes in the population unless two or more surveys are done during different times of the year. Such repetition is often expensive and time-consuming, making frequent periodic surveys impractical.
2. A small sample size was studied to gain preliminary insight from a range of producers. Although, the participants in this survey include agricultural producers from a cross-section of all crop commodities produced in southern Manitoba, the study findings can not be generalized to all producers growing a range of crop commodities in the province. However, it provides sufficient information regarding producers' current yield forecasting methods and their interest level in using crop simulation models as a yield forecasting tool.
3. Since agricultural producers were recruited based on the recommendations of Manitoba Agriculture and Resource Development (MARD), University of Manitoba, agricultural/commodity organizations, and other stakeholders groups, they were not randomly selected participants. They may already be in favour of managing extreme moisture at their farms, which may bias findings and they may not fully represent full range of producers in the southern Manitoba.
4. The researchers aimed to conduct face-to-face surveys during this study as these surveys are clearly structured, flexible and adaptable for producers. However, mandated social distancing and lockdowns made face-to-face surveys a challenge in this study.

Research Findings and Discussion

In order to report survey respondents' feedback to find answers for key questions identified the research findings focusses on the following three themes: 1) current yield forecasting tools available and being used by stakeholders at different scales of operations; 2) the willingness in using crop yield forecasting models; and 3) producers' experience about recent extreme moisture events.

Current Crop Yield Forecasting Methods

Diverse feedback was received from all survey participants about the current crop yield forecasting methods they are using at their targeted scale of operations. The feedback of participating stakeholders on their current crop yield forecasting tools is given below.

Agricultural Producers

Manifesting the importance of yield forecasting in their decision making, all producer participants of the survey recognized, "An estimation of the expected yield from a given field is important for making many crop management decisions at farm level including crop insurance purposes, harvest planning, delivery estimates, planning of storage requirements, and cash flow budgeting."

Participant producers in this study, are using several methods to forecast crops' yield including:

1. Field Sampling Method
2. Unit Area Harvesting Method
3. Producer's Estimate
4. Expert Assessment

A brief overview of these methods are given below.

Field Sampling Method:

Four out of six participating producers are using field sampling method as their primary tool of crop yield forecasting. These producers recognized, "Estimating crop yield by sampling a small crop area within the cultivated field is the standard method of crop yield estimation. We use this method at early stages of crop growth." They further identified, "An extensive personal experience is essential for estimating yield at early stages of crop growth. However, it becomes easier to estimate yield with greater accuracy near crop maturation stage."

In this method, yield in one or more unit areas in the cultivated field is measured and total yield per unit area is calculated as total production divided by total harvested area. Following steps were identified by producers to estimate the yield using field sampling method:

1. Select an area that is representative of the seeded crop field.
2. Measure and flag an area of one square meter and count total number of heads/pods within this flagged area.
3. Repeat this step at least five times to collect five data sets of total number of heads/pods.
4. Take an average of the heads/pods data collected for the crop.
5. Count the number of grains in each heads/pods and average.
6. Determine the standard weight of 100 grains' of the mature crop sample.

Example: Methodology for estimating wheat yield using field sampling method.

Average weight of 100 grains of wheat	=	3.5 g
Number of heads/pods per square meter	=	210
Average number of grains per head/pod	=	26
Number of grains per square metre	=	210 x 26 = 5,460
Yield per square meter	=	5,460 x 3.5/100 = 191.1 g
Yield in t/ha	=	179.52/100 = 1.91 t/ha

The producers using field sampling method as their primary tool of crop yield forecasting acknowledged, *"The accuracy of yield estimates depends upon an adequate number of counts being taken so as to get a representative average of the seeded crop field. In a field with variable crop performance, we either use larger sampling area or we increase number of field samples to be harvested for yield estimation."* These producers' further identified, *"When estimating crop yield by using this method, the size of sampling area should be at least 1 m2."* This method does not account the climate data and harvesting losses which introduce an additional source of error.

Unit Area Harvesting:

Two out of six participating producers are using unit area harvesting method as their primary tool of crop yield forecasting. These producers recognized that they use this method to estimate crop yield at the crop maturation stage. Giving a brief description of this method, a producer said, *"We harvest a small unit area in the field using a combine harvester. Then the harvested crop is weighed, and the crop yield of the entire field is extrapolated from the sample."* One of two producers identified, *"We select multiple unit areas within the selected field and take an average weight of harvested samples to bring field variability and harvesting losses in to account."* However, the other producer recognized, *"A single harvested sample is sufficient to provide an estimated yield of a crop field."* This method does not account the climate data in forecasting the crop yield.

Producer's Estimate:

All survey participants of this category acknowledged that they are using this method alongside either field sampling method, and/or unit area harvesting method as an additional tool of crop yield forecasting at their farms. In this method, producers predict what quantity they expect to harvest by visual observation of the crop. Providing the detail of this method, a producer participant recognized, *"We base our predictions of expected yield on previous experiences, by comparing the current crop performance to previous crop performances. The yield estimation following this method should be made at maximum crop growth stage."* All producers identified, *"We take the yield for up to three-to-six previous seasons in to account for our yield forecast." "The estimate is not always accurate"*, they further acknowledged. This method does not account the climate data, field variability across the field, and harvesting losses which introduce an additional source of error.

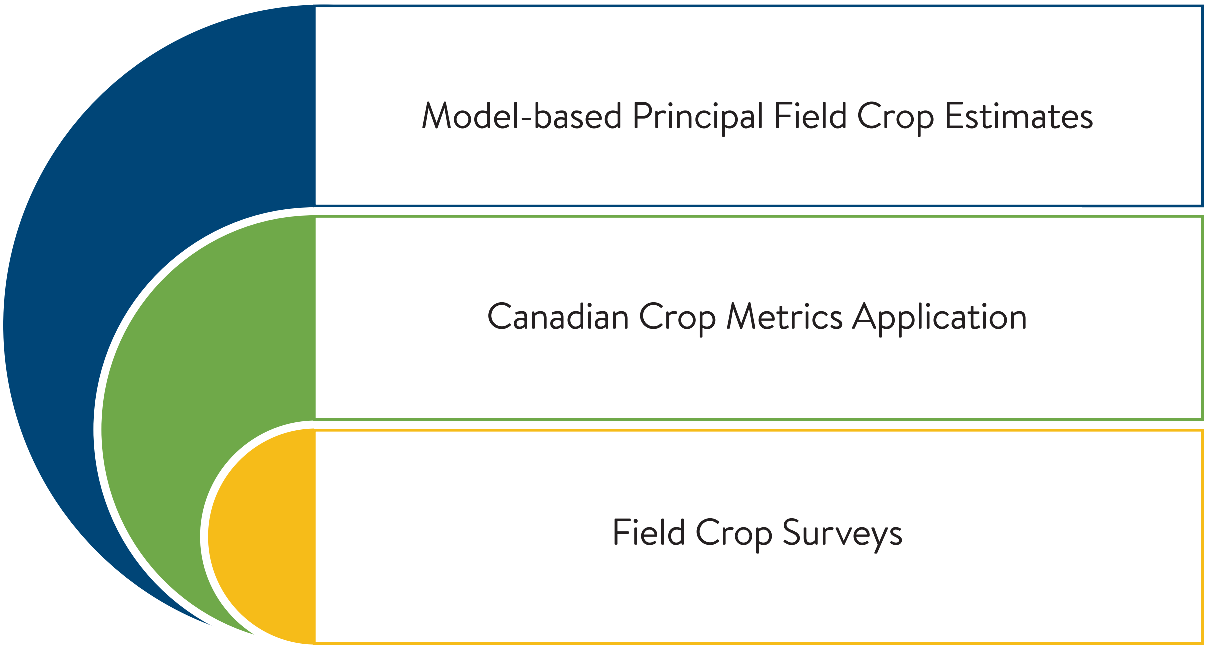
Expert Assessment:

Another tool of crop yield forecasting identified by producers is summarizing the opinions of field agronomists, extension specialists and agricultural researchers in a given year. Providing an overview of this method, participating producers said, *"A number of experts estimate crop yield by visually assessing the crop condition such as color, plant vigour, plant density etc. in the field close to the crop maturation stage."* Three out of six survey participants of this category acknowledged that they are using this method as an additional tool of crop yield forecasting at their farms. They said, *"We combine experts' assessment with other yield forecasting tools to make a field level decision in terms of crop yield"*. However, other three producers identified, *"The estimate made by experts is not always accurate"*. Identifying some drawbacks of this yield forecasting method, these producers further added, *"The expert assessment varies from person to person. The estimation of crop yield by this method requires practical as well as technical familiarity with the yield potential of different varieties of crops in different environments. Therefore, accuracy of the yield assessment, in this method, will strongly depend on the level of expertise of the personnel involved in the assessment."* This method does not account the climate data which introduce an additional source of error.

Government Analysts

The survey data under this category was collected from the four scientists of the Science and Technology Branch of Agriculture and Agri-Food Canada (AAFC), Ottawa, Canada. At the recommendation of participating government analysts, some information and data under this category were also collected from the Agriculture and Agri-Food Canada, and Statistics Canada websites. The survey participants recognized, *"Crop yield forecasts are important for determining potential and actual yield losses for the development of export-import policies, food security policies, and efficient land management practices."* They further identified, *"Crop yield forecasts develop an understanding of precise impact of long term metrological variations on crop yield, allow managing risk associated with moisture extremes and cause reduction in the risks related with local or national food systems. Risk reduction contributes to improved outcomes in terms of the environment i.e. better flows of and access to natural capital, and socioeconomic aspects including increased farm income, employment, and economic growth."* Recognizing the importance of crop simulation models in yield forecasting, the survey respondents in this category were in agreement that the combined use of remote sensing technology, agro-climatic data and field survey data is important to model reliable crop yield forecasting within a region. Government analysts/scientists in this study, are using several methods to forecast yield of various crops (Figure 7).

Figure 7: Yield Forecasting Methods used by Government Analysts



The participating government analysts recognized that all above listed yield forecasting tools are interconnected. In some cases, they are used as an independent yield forecasting tool e.g. field crop surveys. However, Model-based Principal Field Crop Estimates takes field crop surveys, and Canadian Crop Metrics Application in to account for final yield forecasting results.

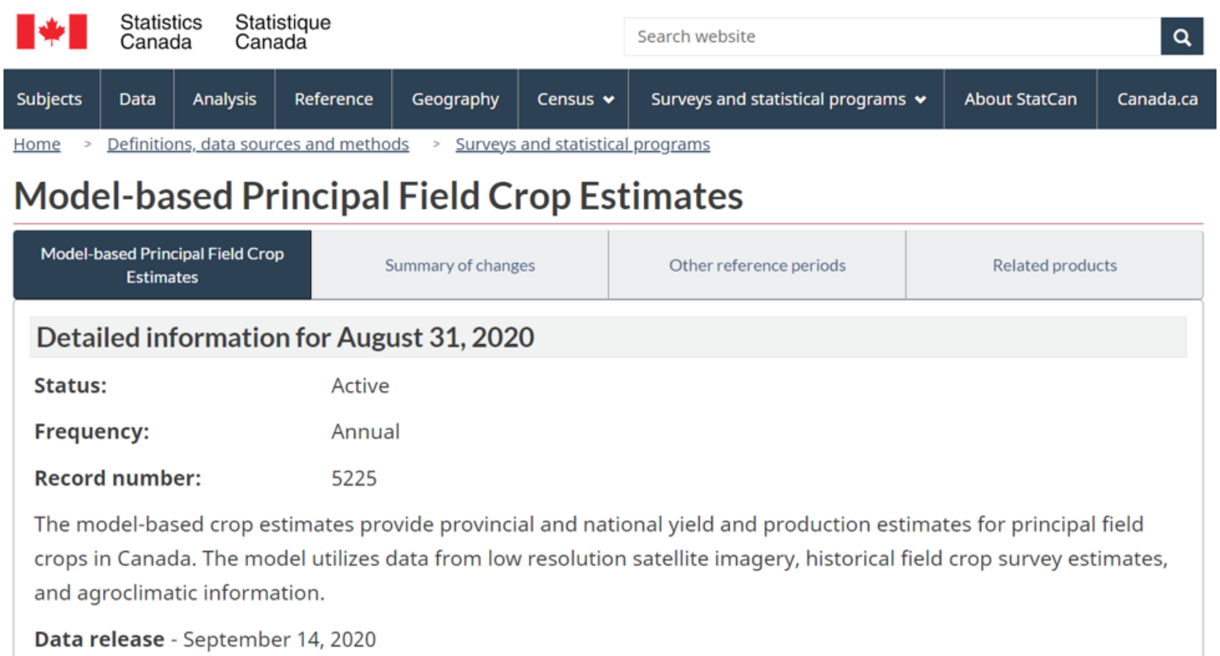
A brief overview of these methods are given below.

Model-based Principal Field Crop Estimates:

The Government Analysts survey participants reported that regional or national crop yield estimates are traditionally made by field surveys and/or producers' interviews conducted during or after the crop growing season. However, the traditional survey-based yield reporting method faces increasing challenges including restrictions in resources, demands to increase the lead time, lower responding rate from producers, and credibility concerns associated with sampling and non-sampling errors. They acknowledged that the Statistics Canada is collaborating with Agriculture and Agri-Food Canada (AAFC) and Environment Canada (EC) on a model called Integrated Canadian Crop Yield Forecaster (ICCYF) to derive crop yield estimates for principal crops grown in Canada (Figure 7). The ICCYF is a modelling tool for crop yield forecasting and risk analysis based on the integration of geospatial Earth observation data using statistics and a Geographic Information System (GIS). By integrating climate, remote sensing and other Earth observation information (e.g., historical yields, soil and cropland maps), it generates crop yield outlooks at various spatial scales during and shortly after the growing season. The model-based crop estimates provide provincial and national yield and production estimates for principal field crops in Canada. The model utilizes data from low resolution satellite imagery, historical field crop survey estimates, and agro-climatic information.

The modelled crop yield estimates are produced at the provincial and national levels for dissemination. These estimates provide important information for global food security, crop products markets, and planning for transporting crops from the farm to market. Federal and provincial government agencies, grain marketing agencies, crop insurance companies, researchers and producers are typical users of the yield and production estimate information. As more and more regional Earth Observation (EO) datasets become available in Near Real Time (NRT), the EO based crop forecasting methods are thus received increasing attention as an alternative to the traditional survey method.

Figure 8: Portal of Model-based Principal Field Crop Estimates at Statistics Canada Website

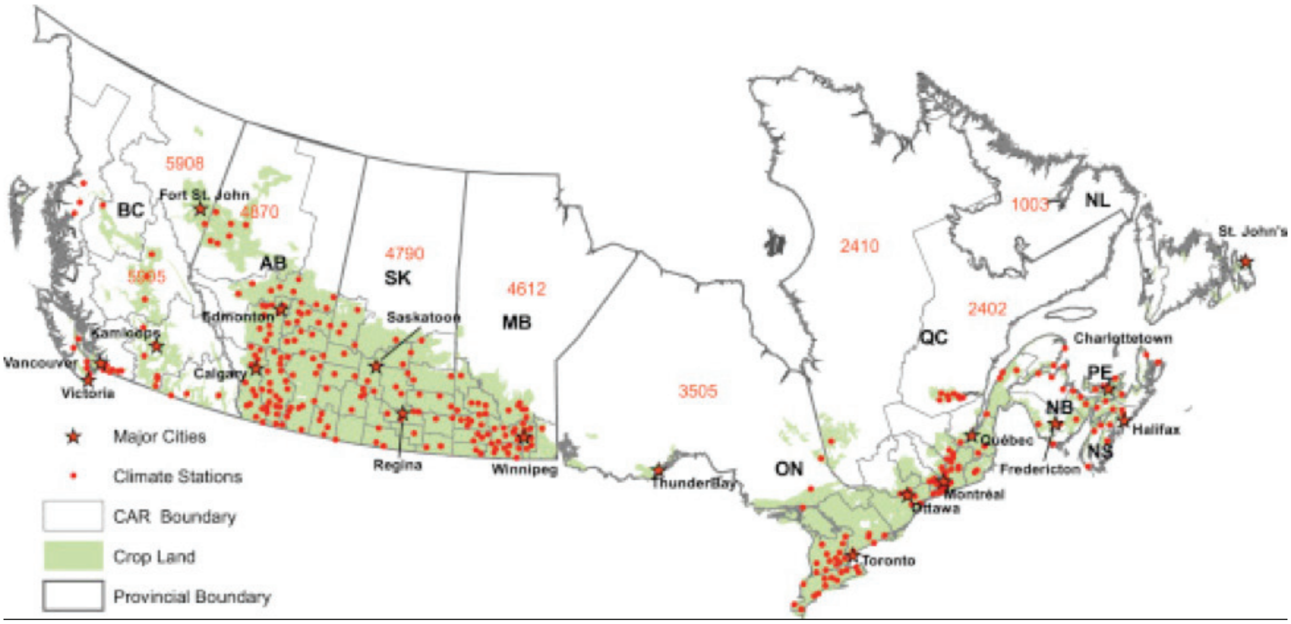


Source: Statistics Canada, 2020

Data sources and methodology

The agricultural land on the Canadian Prairies has been divided into Census Agricultural Regions (CAR) by Statistics Canada (Figure 8). The target population of CAR is the entire agricultural area of Québec, Ontario, Manitoba, Saskatchewan and Alberta.

Figure 9: Census Agricultural Regions (CARs), crop land extent and selected climate stations across Canadian agricultural landscapes



Source: Chipanshi et al., 2015

Following three data sources are used as input variables for the ICCYF crop model:

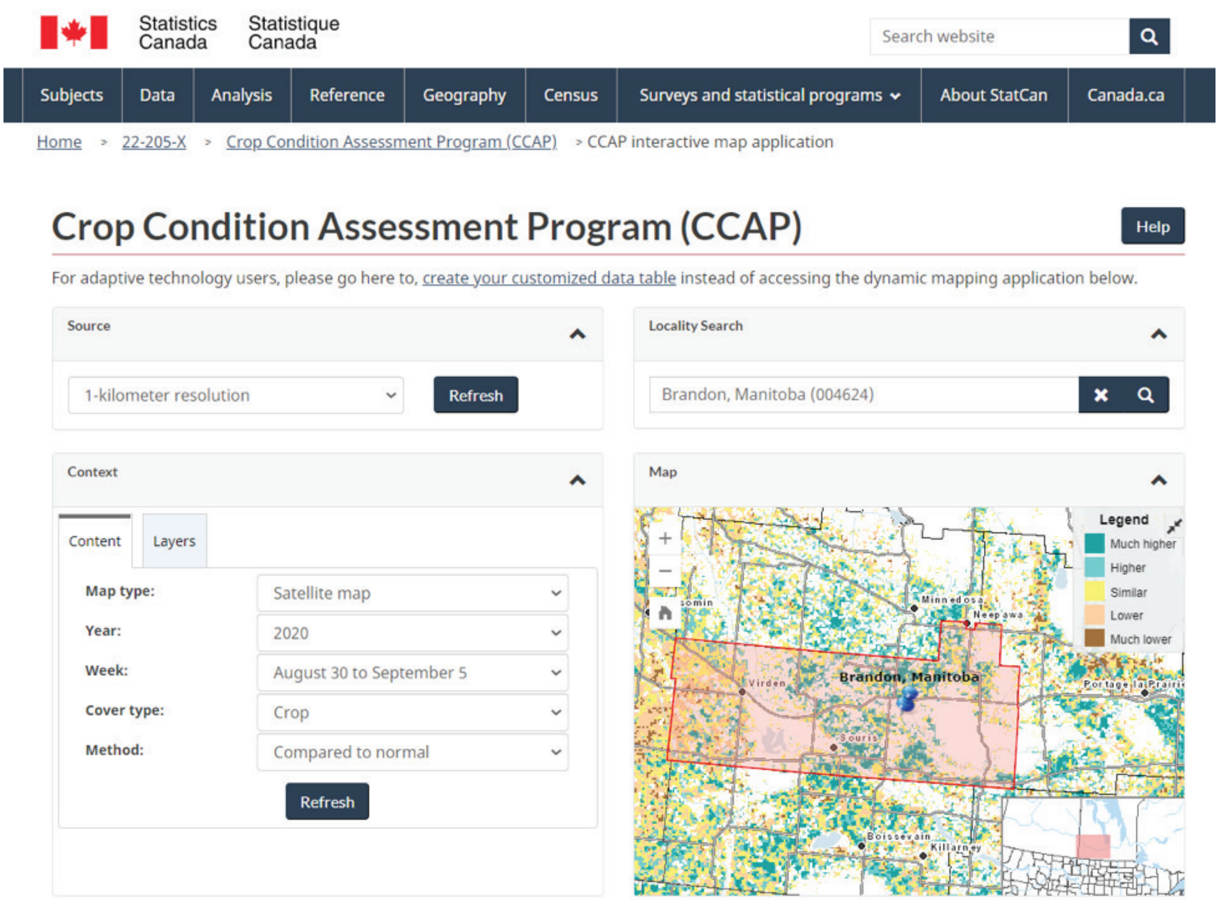
1- Normalized Difference Vegetation Index (NDVI), derived from coarse resolution satellite data

2- Survey yield data

3- Agro-climatic indices

The NDVI is a standardized index of vegetation health and allows the direct comparison of changing vegetation conditions within a time series. The mean NDVI value for an individual CAR is computed by averaging all of the pixels within a CAR. After the mean NDVI values are computed, they are imported as one of the input variable databases to the ICCYF model as three-week moving averages from Julian week 18 to 35 (May to August). The weekly NDVI data is retrieved from Statistics Canada's Crop Condition Assessment Program (CCAP) (Figure 9).

Figure 10: Statistics Canada's Crop Condition Assessment Program (CCAP)



Source: Statistics Canada, 2020

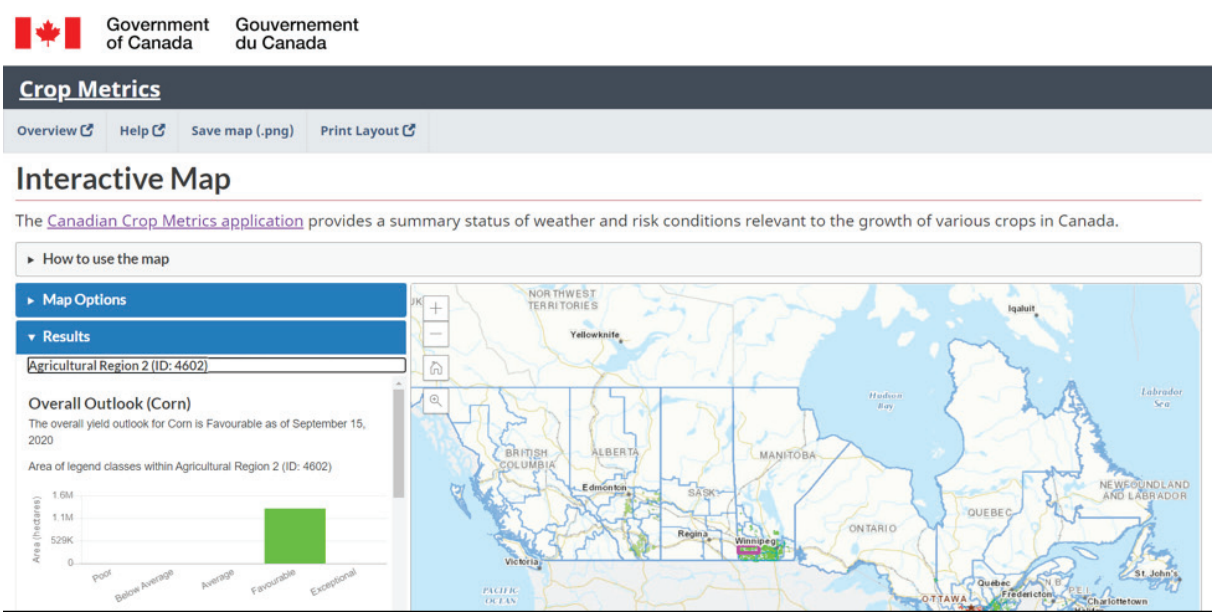
The survey data obtains information on grains and other field crops stored on farms (March, July, and December farm surveys), seeded area (March, June, July, and November farm surveys), harvested area, expected yield and production of field crops (July, and November farm surveys). The resulting estimates are based on sample surveys collected at five points throughout the year, principally via telephone interviews with farm operators. Historical and current year expected crop yield from the July farm survey are used as input variables for the model. The historical November survey crop yield estimates are used as the dependent variable in the model. Modelled production estimates are calculated by multiplying the harvested area from the July farm survey by the modelled crop yield estimate.

As model input, the station based agro-climate information (climate data) measured during the growing season are provided by Environment and Climatic Change Canada. In the ICCYF, daily series of air temperature and precipitation are fed into a simple process-based Versatile Soil Moisture Budget (VSMB) model to generate the agro-climate indices including Growing Degree Days (GDD), precipitation (P), Soil Water Availability (SWA) expressed as the percentage of plant Available Water Holding Capacity (AWHC), Water Deficit Index (WDI) and Crop Seeding Date (CSD). The VSMB model outputs are generated at a daily time step and used as potential yield predictors. The quality control and gap-filling of the missing data is performed by AAFC. The ICCYF use several statistical algorithms to forecast the yield. Average values of the indices at all stations within the cropland extent of a specific CAR are used to represent the mean agro-climate of that CAR. If a CAR lacks input climate data, stations from neighboring CARs are used.

Canadian Crop Metrics Application:

The Canadian Crop Metrics application is a web-based application to link key pieces of information on historical and forecasted yield, weather conditions and risks and make these accessible to the sector in real time over the growing season (Figure 10). Crop metrics are based on) the Integrated Canadian Crop Yield Forecasting System (ICCYF), which predicts crop yields based on weather and satellite information, and is updated four times per year. The Yield forecast is completed at the level of Census of Agriculture Region (CAR). This application provides a summary status of weather and risk conditions relevant to the growth of various crops in Canada. The variables include the accumulated precipitation, crop heat units, vegetation health, soil moisture and any reported diseases and pests and are presented region by region to aid in the interpretation of the crop yield projections presented in the metric tables.

Figure 11: Portal of Canadian Crop Metrics Application at Statistics Canada Website



Source: Statistics Canada, 2020

Field Crop Surveys:

Every year, over the course of a typical crop cycle (from spring to late fall), Statistics Canada provides data on field crops. This information helps to track major grain production nationally and provincially, indicates the availability of crops, provides annual trend information by crop and regions to assist producers in their planning. The field crop surveys track four key variables:

1- Areas seeded and harvested at farm level

2- Yield estimates

3- Production levels attained

4- On-farm stocks levels at precise times during the crop year

Statistics Canada conducts these surveys five times a year, from early spring to the end of harvest season. This allows the agency to provide accurate crop data at key times throughout the year. Each of the five surveys provides insight of the field crop situation at key times. The five surveys in the Field Crop Reporting Series are listed in Table 3.

Table 3: Data Collection in Field Crop Surveys conducted by Statistics Canada

Field Crop Survey Month	Survey Data Collection
March	Producers provide preliminary area estimates of the type of crop and the area that, at the time of the interview (typically end of March), they intend to seed. These intentions are recorded before seeding when there is often still snow on the ground. Agriculture and Agri-Food Canada uses this data to set up their preliminary grain estimates for the summer farm income forecast.
June	Producers provide the final area estimates that, at the time of the interview (mid-May to mid-June), they have actually seeded. If important climatic events occur between the March and June surveys, estimates can differ substantially, as seen during the 2011 spring floods in Manitoba, where the March expected number of unseeded acres had more than tripled at June survey release.

Field Crop Survey Month	Survey Data Collection
July	Producers provide the preliminary yield and production estimates that, at the time of the interview (the last three weeks of July), they expect to obtain. These estimates are based on the Producers' best assessments given the growth stage of the crops they see in their fields. Many factors, including droughts, floods and diseases, can have a large impact on the final estimates, which come in after harvests are completed in the fall.
November	Producers provide the final yield and production estimates that, at the time of the interview (mid-October to mid-November), they actually obtained.
December	Producers provide the first reading of on-farm stock levels after the preceding fall harvests are completed. The second and third readings are obtained from the March and July field crop surveys the following year.
Capacity Analysis	• Skills required to use a farm model • In-put data accessibility for a farm model • Hardware availability • Data interpretation ability

On-farm stock levels

On-farm stock levels, which measure the quantities of grain still in storage, are an important component of the field crop surveys. The on-farm stock levels are estimated three times a year. This information is a key element in the supply and disposition analysis, which ensures that the volume of grain produced or imported in a given crop year is equal to the volume of the same grains that made their way to the grain market. The estimates are referenced at precise dates and occur on:

1- December 31 (December field crop survey)

2- March 31 (March field crop survey)

3- July 31 (July field crop survey)

Agricultural Businesses and Enterprises

There are several agricultural companies and enterprises in Manitoba who provide farm-based services to producers including agronomic recommendations, field scouting, crop inputs (fertilizers, pesticides, and growth regulators), crop selection guidance, yield forecasts, and other precision agriculture services. A total of three farm services providing businesses were contacted during this survey process to investigate their use and experience of yield forecasting tools. The crop yield forecast determined by these stakeholders enable growers to estimate their yields across their farm before harvesting. These agricultural businesses and enterprises have generated their own yield forecasting software to help producers in determining crop yield estimates at their farm holdings.

All survey participants under this category recognized, "The yield is difficult to predict until the harvesting time comes. Many variables can impact yield, both before and during the season that help or hurt the final number that comes up in the cab during harvest." "In order to provide an early warning to producers, we use in-field data, on-fa rm hardware such as weather stations and soil moisture probes, remote sensing data, high-resolution satellite imagery, soil test information, and analytics to provide yield prediction", they further added. These companies use multiple datasets to predict yields in five main crops: canola, corn, lentils, soybeans, and wheat. These datasets involve statistical analyses, agronomic data, crop plans (crop type, seeding date, crop in rotation etc.), and field-centric information (soil nutrients, supplemental irrigation, climatic data from field weather stations, crop damage by wildlife/insects etc.) that impact yield throughout a season.

Data Required for Yield Forecasting

All survey participants reported that the following data sources are used in conjunction with one another, each making up a different weighting on yield prediction numbers based on the current scenario for the cropping season in different regions.

Pre-season Data

All survey participants are in agreement that the accurate pre-season data is critical for yield forecasting process. This data consists of field location, current and past crop, field-centric weather data before planting or seeding, soil test information and data, and regional climate trends for the last decade.

In-season Data

Survey participants acknowledged that in-season data provides insight into conditions that impact yield during the growing season. Field-centric data is collected from on-farm weather stations. Values for forecasted and predicted weather parameters are recorded and reset as data comes in each day, continually updating the models. Other in-season data such as nutrient application is also considered during the season, whether planned or not, to enhance field diagnostics and determine predicted yield values.

Crop Specific Data

In-season data also extends to crop-specific data delivered through the local agronomists. For the five main crops in yield prediction (corn, canola, lentils, soybeans, and wheat), agronomists identify crop-specific data that impacts yield during a growing season such as moisture levels during key growth stages or hours above average temperatures for crops during key yield determining periods.

Crop and Field Imagery

Spatial information is taken from high-resolution satellite imagery to observe issues with crops that may lead to impact the yield. These spatial trends help identify if areas are on track for predicted yields, or if environmental pressures have undermined the predicted yield values.

Producers' Feedback on using Farm Models for Yield Forecasting

Diverse feedback was received from all producer participants about the importance and methodology of yield forecasting at the farm level. All producer participants were recognized the importance of crop simulation models in yield forecasting. Furthermore a profound interest was observed in the yield forecasting model calibrated by RDI for the southern Manitoba conditions to track impact of weather extremes with a focus on extreme moisture events on crop yield.

All producer participants acknowledged, *"The consideration of historical climatic data in the yield forecasting process provides accurate, precise, and reliable yield estimations."*

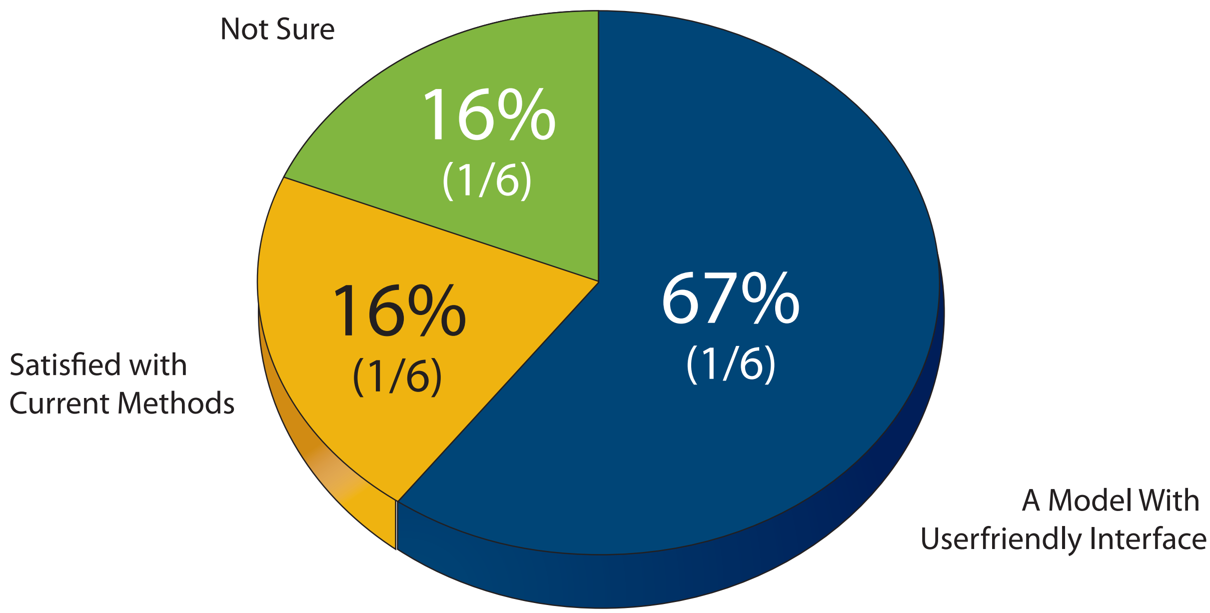
Five out of six producers recognized, "The use of mathematical models in the farm planning system is an important decision support tool and it can make farm operations efficient and effective. However, the major challenge associated with the use of complex crop simulation model is the requirement of an extensive model operating knowledge, expertise in advanced model languages, and highly detailed input data."

They further added, *"A yield forecasting model with the user-friendly interface would allow us to estimate the potential farm land losses (including crop yield and property) under possible occurrence of extreme weather events including floods."* In contrast, one producer submitted, *"It sounds good to use scientific models for yield forecasting and as early warning system but the knowledge and use of this model is beyond the expertise and skills of a producer."*

During the discussion of AquaCrop input requirements, producers suggested, *"It is also essential to calibrate the model for different soil types, groundwater level below the ground surface, and groundwater quality status to forecast the crop yield as soil texture and groundwater characteristics vary from region to region and sometimes field to field in a region."*

At the willingness of a producer, a demonstration of AquaCrop model operation was given to the participant. After the demonstration model run, the producer acknowledged, *"I agree that the model has easy operation, and providing user-friendly interfaces which do not require extensive modeling knowledge. However, it's nice to have a user manual of AquaCrop model with all essential information for the user and step-by-step procedure for the model access and use."* Given the interest of producers, a user-friendly manual of AquaCrop model is developed by RDI researchers. Figure 11 shows the data collected in the survey regarding future considerations of producers to forecast their farm yield using different methods available.

Figure 12: Future Considerations of Participant Producers to forecast their farm yield using different methods available



Discussion

The survey was undertaken to directly ask a diverse range of targeted stakeholders to identify current yield forecasting tools available and being used by these stakeholders at different scales of operations, and to evaluate the willingness of producers and other stakeholders to use user friendly and open access farm models calibrated for Manitoba's local climatic conditions with crop parameters adjusted to Manitoba crop growth periods. It was observed that agricultural producers participating in this study are familiar with the significance of yield forecasting in making several crop management decisions at the farm level including crop insurance appraisals, harvest planning, delivery estimates, planning of storage requirements, and cash flow budgeting. The yield forecasting methodologies being used by these producers are based on their evaluation of crop conditions in the field. These conventional methods are time-consuming and unrepresentative due to small sample sizes. Moreover, these methods do not account for the historical climate data, field variability across the farm, and harvesting losses in yield forecasting which introduce an additional sources of error. The RDI researchers observed that Manitoba's producers understand that the use of mathematical models is an important decision support tool in the farm level planning and it can make farm operations efficient and effective. However, the major challenge associated with the use of crop simulation model is the models' complexity and requirement of an extensive model operating knowledge, expertise in advanced model languages, and highly detailed model input data. A demonstration of the AquaCrop model operation given to a producer participant convinced them that the model has easy operation, and providing user-friendly interfaces which do not require extensive modeling knowledge. A participant producer suggested to develop a user manual of AquaCrop model with input data requirement, data sources, and step-by-step procedure to operate the model.

The government agencies and agricultural enterprises recognized that regional or national crop yield estimates are traditionally made by field surveys and/or producers' interviews conducted during or after the crop growing season. The traditional survey-based yield reporting method faces increasing challenges including restrictions in resources, demands to increase the lead time, lower responding rate from producers, and credibility concerns associated with sampling and non-sampling errors. These stakeholders recognized that the combined use of remote sensing technology, agro-climatic data and field survey data is important to model reliable crop yield forecasting within a region. These stakeholders perceived that crop simulation models with an easy operation and user-friendly interface like AquaCrop model are important early-warning tools for producers. However, these models provide precise yield forecasting only at farm scale or within a small regional area as model is calibrated with local climate and crop parameters.

Soil moisture is not only important for crop production, input decisions and yield outcomes – it is also an important determinant of runoff volume and flood risk assessment. The AquaCrop yield forecasting model make an account of the impact of extreme moisture events e.g., spring snowmelt runoff, intensive rainfalls, and flood occurrences on crop yield. That is why it is an important tool in selecting extreme moisture management strategies (water reservoirs, tile drainage, land grading, cover cropping etc.), optimizing crop yield, and to evaluate the crop-area insurance contracts.

Conclusion

Timely and accurate estimates of crop yield are critical for the economic forecasting and risk assessment of agricultural production. Driven by the effects of increasingly frequent extreme moisture events on crop yields, and the associated increasing demand for information from stakeholders (producers, grain traders, transporters, and government policymakers) for food security planning, the development of crop monitoring and yield forecasting systems to provide regional, national, and global production outlooks for major field crops is indispensable. This information would also allow producers to respond appropriately in order to overcome the extreme moisture event. Traditional crop yield estimates, conducted through farm surveys or by experts based on their evaluation of crop conditions, are somewhat subjective, time-consuming and often unrepresentative due to small sample sizes. Farm simulation models use climate state analysis to forecast crop yields and offer several benefits over traditional methods, including precision, reduced costs and the elimination of human-related biases and errors.

In the phase-1 of this project activity, RDI calibrated the AquaCrop farm model using Manitoba's 30-year historical climatic data (1990 – 2019) and simulated local crop characteristics in the model interface to analyze the potential impacts of projected climate scenarios on crop yield variability in the southern Manitoba[1]. This farm model has the ability to simulate extreme moisture management scenarios and can be of use to many – producers, farm production consultants, planners, and economists to make business informed decisions in their areas of expertise at the targeted scale. Developed by the Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO), it has a user-friendly interface and does not require extensive modeling knowledge. In the phase-2 of this project, RDI organized a series of surveys to receive feedback from targeted stakeholders involved in this study in terms of how yield forecasting models might be useful to their decision making. The goals of this survey was to identify current yield forecasting tools available and being used by targeted stakeholders at different scales of operations, and to evaluate the willingness of producers in using crop-yield models for yield forecasting. All six producer participants were asked to provide feedback on the use of a moisture response model (including AquaCrop) calibrated for local weather conditions to forecast crop yield at farm level and how this information might be useful for producers in the selection of investment options to manage on-farm extreme moisture.

The participants in this survey included agricultural producers/farmers, government analysts, and agricultural businesses and enterprises delivering services at farm, regional and national level. This baseline survey of targeted stakeholders provided a valuable and unique insight into the current yield forecasting tools available and being used by stakeholders at different scales of operations, and willingness of survey participants in using crop yield forecasting models. Diverse feedback was received from all 13 survey participants about current crop yield forecasting methods they are using at their targeted scale of operations. All six producer participants acknowledged the importance of crop simulation models in yield forecasting and a profound interest was observed in the yield forecasting model calibrated by RDI in the southern Manitoba conditions to track impact of weather extremes with a focus on extreme moisture events on crop yield. All six producers were agreed that consideration of historical climatic data in yield forecasting provides accurate, precise, and reliable yield estimations. Five out of six producers recognized that the use of mathematical models in farm planning is a very important decision support tool and it can make farm operations efficient and effective. However, the major challenge associated with the use of complex crop

1 Assess Impact of Excess Moisture on Crop Yield and Farm Income

simulation model is the requirement of an extensive model operating knowledge, expertise in advanced model languages, and highly detailed input data. Participant producers were in agreement that a moisture response yield forecasting model with the user-friendly interface like AquaCrop would allow them to estimate potential farm land losses (including crop yield and property) under possible occurrence of extreme moisture event.

A participant producer proposed the development of a user manual of AquaCrop model with all essential information for the user and step-by-step procedure for the model access and use. It is recommended that a user manual of AquaCrop model be developed with a description of the model functions and capabilities, contingencies and alternate modes of operation. The AquaCrop model calibrated by the RDI researchers is adapted to forecast yield at farm scale using southern Manitoba's local climate and crop parameters. Comparing the yield forecasting output results of AquaCrop model with regional and national level yield forecasting models to evaluate the performance of AquaCrop farm model at the large scale may be another area of future research.

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