POTATOES FOR A CHANGING CLIMATE

Report of the Crop-Climate Trials 2014 - 2016

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SUMMARY

Climate change threatens food security globally and in Canada. Communities need to develop sustainable food systems as an adaptation to climate change. Crop biological diversity is a central element of food sustainability. Potatoes are the fourth most important food crop in the world and are widely grown in Canada.

We undertook a three-year field trial of twelve heritage and conventional potato varieties in a wide range of climatic regions across Canada. We used standard planting and observation methods to track potato development and yield while recording in-field weather variables.

Our trial sites experienced a great range of weather conditions including extreme drought, heat and precipitation representative of the variability of climate and weather anticipated with climate change. Potato plant development and yields varied widely across our trial sites and from year to year at each site, presumably in part because of the great weather differences.

Potatoes grew best at mean growing season temperatures between 14 °C and 17 °C, with monthly soil temperatures below 20 °C, and a well-distributed growing season precipitation of 100-150 mm. A minimum of 1000 Growing Degree Days (a measure of heat accumulation and a proxy for growing season length) were required for potato production, but higher yields were not obtained from regions with more accumulated heat. Soil temperatures above 20 °C resulted in poor yields and precipitation below 100 mm as experienced regularly on southern Vancouver Island strongly reduced yields. Even in the short season climate of Mayo, Yukon all varieties including heritage ones produced harvestable yields.

Several heritage varieties grew and yielded as well as some conventional varieties and at least one conventional variety yielded poorly at most sites. Three conventional varieties—Russet Burbank, Kennebec, and Chieftain—generally performed well at all sites but not always. The heritage variety, Ozette-Nootka, originally introduced by Spanish to Vancouver Island more than two hundred years ago. performed as well as conventional varieties in all regions and under the full range of growing season weather. Heritage varieties Sieglinde, Banana, Corne de Mouton, Russian Blue, and Mrs. Moehrle's Yellow Fleshed also grew and yielded well in several trial sites. Yukon Gold, a popular commercial type, yielded poorly at most sites in most years.

We uncovered a uniquely Canadian heritage variety, Likely, and included it in our trails. Although not a strong yielding variety, it apparently has exceptional cold tolerance and performed especially well in the north. Tubers were sent to the Potato Gene Resources Centre in Fredericton where it was clonally propagated, cleaned of viruses and diseases and is now available for research and growing.

In addition to our formal trials, we received informal observations from casual growers that confirmed many of our trial observations. There was great interest from growers and gardeners in our project and our heritage varieties and we distributed thousands of tubers.

Using our results, we developed variety profiles for the twelve types we trialed. These can be used by growers to select potatoes suitable to their region tastes and growing techniques. One of our trial participants established production of several heritage varieties on a commercial scale.

We summarized several practical tips for people interested in growing potatoes as the climate changes. Observing and recording local weather, particularly first and last frost date, as well as extreme heat, humidity, and rainfall, will be increasingly important for ongoing understanding of potato growth and adaptation. Local knowledge of cultural practices, variety selection, soils, and weather are the indispensable foundation for food security - it should be shared widely, but also provides the basis for experimenting with new techniques and crops. Potatoes are highly vulnerable to pathogens that build up in the seed tubers: practice strict rotation, limit the number of years you grow from the same seed source, select only the best potatoes for future seed crops, and renew your personal seed sources regularly by purchasing certified seed.

The three-year field trials form the basis for moving forward. Access to a wider variety of clean seed potatoes can be supported by a network of regional living variety collections and tuber production centres. We recommend strengthening the network of climate stations, particularly in underserved areas in the north where potato production is likely to expand. We also encourage people to make the information available in a practical format that can help guide decision making about key adaptive practices in a rapidly changing foodscape. Continuing to distribute and test more varieties in more areas - and particularly food-insecure northern regions can engage local people, develop knowledge, and set in motion the local selection and adaptation process.

For the next two years we propose selecting 15 potato varieties to distribute three varieties each to 100 growers who are trained in simplified observation techniques. Growers not served by climate stations may also receive a simple weather recording instrument. Weather and variety performance data will be compiled to create new variety profiles.

Our project demonstrates that potatoes can be grown more widely across Canada than is common practice, particularly if heritage varieties are used. By planting several varieties growers and communities can establish reliable yields of a key food crop and develop food self-reliance in the face of changing and highly variable climate. Our Crop-Climate approach and methods may have wide application to other crops and other regions of the world.

ACKNOWLEDGEMENTS

The Crop-Climate project trials were made possible thanks to the generous support of the W. Garfield Weston Foundation, and particularly director and Weston family member Mrs. Gretchen Bauta. Mrs. Bauta has long been a champion of seed security in Canada - and is making a difference through her support of many projects, including ours.

We also acknowledge Sharon Rempel, who initiated the pilot project through the Garden Club of BC with Richard Hebda in 2012. Without her initial vision and guidance, this project would not have happened.

The Pacific Institute for Climate Solutions at the University of Victoria has supported the program from the beginning under then-director Tom Pedersen and continuing with the support of current director Sybil Seitzinger. Megan Jameson and Nancy Chan have provided indispensable logistic support and financial administration.

Canadian Potato Genetic Resources, Agriculture and Agri-food Canada, Fredericton Research and Development Centre has the important mandate to conserve and distribute the genetic biodiversity of Canadian potatoes while breeding new climate-resilient varieties. Benoit Bizimungu and Teresa Molen have provided guidance on developing the potato monitoring protocol, helped with the selection of varieties, provided tubers of many new heritage varieties for future trials. They accepted the Likely potato into their collection and used tissue culture to remove pathogens.

Garrett Pittenger has single-handedly collected and maintained hundreds of heritage varieties of potatoes and shared them generously with the project. He has mentored numerous individuals in the art of saving potatoes, and in collaboration with Bob Wildfong of Seeds of Diversity, works to maintain potato diversity in Canada. Mr. Pittenger has deposited numerous uniquely Canadian potatoes into the Canadian Potato Genetic Resources centre for conservation and cleansing.

We give special thanks to our growers for the field trials: Richard Hebda, Chris Wooding, Catherine Allen, Rob Borsato, Gail Elder, Benoit Bizimungu, Colleen Prentice and Maureen Huggard. Especially thank you to Maureen Huggard of Whitehorse Yukon who brought on the Nacho Nayak Dun First Nations community of Mayo, Yukon. Many hundreds more people have been growing varieties distributed as part of the project and we thank them for their interest and participation.

PHOTOGRAPHY CREDITS

All photos in this report are used with the permission of the photographer, including Chris Wooding, Valerie Huff, Gail Elder, Richard Hebda, Christopher Hebda, Nicholas Hebda and Colleen Prentice.

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BACKGROUND

Climate change and the rising concentrations of CO^2 and other greenhouse gasses show no signs of abating (Hansen et al. 2017). Atmospheric CO^2 concentrations reached over 412 parts per million in May of 2018 at the Mauna Loa, Hawai'i Observatory (https://www.co2.earth/weekly-co2) and global mean temperatures continued well above mean values for 1981-2010, a mean already elevated because of climate change (https://www.ncdc.noaa.gov/sotc/global/201804). The spring months of 2018 again recorded higher than normal and in places record warm temperatures around the world including key agricultural regions such as Australia and Europe (https://www.ncdc.noaa.gov/sotc/global/201804).

According to Hansen et al. (2017) at a minimum, the targets for limiting global warming must aim to avoid global temperatures warmer than those already reached today (about 1 °C warmer than pre-industrial levels). To achieve such a target, we must find ways not only to reduce greenhouse (GHG) emissions but also begin removing CO^2 from the atmosphere. Improved agricultural practices, especially those that foster soil fertility and increase its carbon content are vital tools in removing CO^2 from the atmosphere (Hansen et al. 2017).

At the same time, rapidly changing climate and the increasing occurrence of extreme weather such as floods and droughts stress global agricultural systems and food supply (Porter et al. 2014). Furthermore, agriculture is a major source of GHG emissions and it contributes to other forms of environmental degradation.

Bioversity International (2017) summarizes the issues with global food production and nutrition most of which are directly or indirectly linked to climate change (Table 1).

ISSUE	LINK TO CLIMATE CHANGE
Malnutrition including obesity	Yes; poor yields, starvation
Greenhouse gas emissions	24% of emissions
Dominant fresh water use	Yes, droughts and extreme events
Threatened species affected by agriculture	Indirect, water and land demands impact key habitats such as wetlands
Increasing food demand and decreased production because of climate change	yes
Homogenized global diet; starches and meats and dairy	no
Production of fruit and vegetables, nuts and seeds according to nutrition recommendations	? possibly, if limited by drought
Underuse of the diversity of food species (and varieties) and focus on narrow range: rice, wheat, maize	Not directly, (but potential for more productive climate-adapted crops)

Table 1. Summary of global food issues and their link to climate change.

At the same time crop biodiversity, a central element of sustainable future food systems, is declining as conventional agriculture focuses on fewer foods and fewer cultivars of those foods. "Agrobiodiversity holds the key to future food security," according to A. Tutwiler (Bioversity 2017). Preserving crop biodiversity is a means to improve global nutrition and food security, promote sustainable agro-ecosystems and to help adapt to climate change.

The three-year Crop-Climate project supported by the W. Garfield Weston Foundation was developed to address climate change adaptation while exploring the natural capital of crop biodiversity. Potatoes were chosen as the crop to investigate because they are readily cultivated in most regions of Canada, are a major global food source and are remarkably diverse crop (Hebda and Huff 2013B). Many potato varieties unique to Canada have been developed since the Spanish landed in Nootka Sound and planted the first potatoes there (Brown n.d.). Many of these varieties have been grown locally, exchanged among growers, and selected for local conditions and tastes.

This report summarizes the results of three years of the Crop-Climate project (2013-16 growing seasons). It presents the principles and methods of the project first. Crop-Climate methods are then described, followed by a summary and discussion of results. We then describe and discuss the challenges and benefits of using farmer scientists to observe crops and gather data. The report concludes with recommendations for future projects and initiatives.

CLIMATE SMART AGRICULTURE

This part of the report is summarized or taken directly from previous annual reports and proposals and information on the Crop-Climate website at “www.heritagepotato.ca”

Dispersed Adaptation to Climate Change

As noted earlier, the conventional food supply depends on few varieties, mass-produced on industrial-scale farms in conventional ways. This “few-eggs-in-a-few-baskets” approach provides huge amounts of food, but it puts that food supply at high risk to rising mean temperatures and unpredictable extreme weather events already evident in parts of the world.

Dispersed adaptation takes advantage of the power of the “many-eggs-in-many-baskets” strategy (see http://heritagepotato.ca). The concept is to grow a diversity of crop varieties in many ways and in many places to disperse the risk to climate uncertainty and extremes. Dispersed adaptation builds strategies and resilience to change and lowers the risk of major crop failures. It also fosters forward thinking and innovation by enabling communities to identify and develop varieties best suited to their local climate. Through dispersed adaptation communities develop food self-reliance.

PLANT MANY VARIETIES – “MANY EGGS”

Growers can reduce climate risk by planting a range of varieties and experimenting with different growing techniques. For example, wheat yields diminish when extreme heat occurs during the flowering period (White and Edwards 2008). A farmer can mitigate risk by planting several varieties that flower at different times; a heat wave might only affect one of the varieties. Similarly, different varieties may be resistant to different diseases; an outbreak of a specific disease might only impact part of a diversified crop, while still maintaining food supply from other varieties. Potato growers in Bolivia use the "many eggs" approach as standard practice to counter weather variability (Castelhano 2008).

PLANT IN MANY PLACES – "MANY BASKETS"

Conventional agronomic trials are usually carried out in one or few locations with relatively similar climate and weather patterns. Running the trials for a few years may provide a limited amount of data on variability of the varieties in response to a range of weather. Many staple crops however are grown under an incredibly wide range of climatic conditions. Furthermore, future climates will present weather conditions far outside those experienced in a region today. The Crop-Climate Project engages growers across a range of climates in Canada's regions to grow and observe growth and yield of promising heritage varieties while recording key weather variables. In this many-baskets approach, the project accumulates information about how varieties perform under differing conditions over several years much more rapidly than if the varieties were grown at a single or few locations, especially in the relatively mild climates of middle latitudes.

Using standard methods, the performance of heritage varieties can be compared across a wide range of conditions, generating "performance profiles". Observations are compiled, analyzed and shared through a web site, publications and presentations to foster innovation and expand choices for all growers across Canada. Thousands of tubers of heritage potato varieties are distributed to the public for trial to encourage informal participation in the dispersed adaptation strategy.

Food Sustainability and Crop Biodiversity

Food sustainability challenges the globe because nearly a billion people are chronically under-nourished and our current system of food production has major negative impacts on the environment (Table 1) (Bioversity 2017). Many solutions have been proposed at the global scale such as improving yields, using resources more efficiently, and even changing human diets (Foley et al. 2011). However, the urgency, extent and magnitude of potential effects of changing global climates are not adequately being factored into the development of food sustainability strategies.

Climate-smart agriculture (CSA), proposed by the United Nations Food and Agriculture Organization (FAO) encourages farmers to shift from current food producing strategies to practices that are more climate adaptive and at the same time more sustainable. CSA assists food producers to deal with climate change as it impacts crop yields and human health by fostering practices to reduce greenhouse gas emissions, conserve soil carbon and improve water use. A research collaborative of 15 international agricultural research centres and partners recently announced to commit at least 60% of its budget to climate-smart agriculture (Nosowitz 2014).

HERITAGE VARIETIES

Heritage agricultural varieties are being lost at an alarming rate. Heritage plants may be defined in various ways, though they are generally considered to be older cultivars that have been maintained and passed down by a family or shared within a small community. They are generally raised on a smaller scale than varieties grown in industrial agriculture. The rich genetic diversity of heritage varieties is the result of thousands of years of selection, plant breeding and seed saving by farmers around the world. These locally-adapted crops are an important part of our agriculture; they are also critical to our future food sustainability.

Conserving heritage varieties helps Canadian farmers prepare for climate change in several ways. These varieties contain vital traits needed for adaptation to different climatic characteristics and they have important genetic variation that may protect them against emerging diseases. They have the potential to be used in breeding programs to improve non-heritage varieties and increase crop resilience to a range of stresses.

Good information about heritage varieties is not widely available, and many standard characteristics, such as the number of days to maturity, are unknown. Growers need this basic information to decide which varieties will grow well in their local soils and climate as well as to choose appropriate cultural practices (when to plant, how to amend the soil, how to minimize pest outbreaks) for best yield. Furthermore, little is known about the influence of climatic stressors such as heat, high humidity, drought, heavy rainfalls on heritage varieties.

Knowing key crop traits is especially important in an era of shifting climatic zones and the development of new climatic regimes. Suitable or optimal areas for growing potatoes and wheat will certainly shift northward in general and upward in mountainous regions. Local site conditions, such as the optimal soil characteristics (texture and drainage for example) for a specific variety, may change as new climatic regimes evolve and weather patterns change.

Food Security, Climate Change and the Humble Potato

Potatoes have traveled a long way from the high Andes of Peru and Bolivia where they were first domesticated (Spooner et al. 2005). They are the world's fourth most important food crop, eaten around the world by more than a billion people. Potatoes remain the staple crop in many Andean communities (Castelhano 2008).

Globally, there are more than 4,000 varieties of potatoes, selected and locally adapted by growers to suit local conditions and cultural preferences. Cultivated potatoes come in a range of colours, shapes and sizes. In Canada, early European settlers brought different varieties with them, and over time, they have been selected for local conditions and taste.

The rich genetic diversity held within these heritage varieties is the product of centuries of selection, plant breeding and garden trials by farmers around the world. And this genetic richness is built on thousands of years of experience and the wide natural genetic variation from the Andean homeland. This exceptional diversity offers a broad range of adaptive traits for growers to test and exploit.

Potatoes, in particular, are easy to grow and as such can be part of a strategy for locally grown crops and food security. The plants are relatively easy to observe and their yields easy to measure by simply weighing the tubers. They also have uncomplicated sensitivities to elements of climate such as high and low temperatures, moisture levels and relative humidity (Bodlaender 1963, Levy 1985, Hijmans 2003). These climatic factors can be observed in relatively straightforward manner and are often being "recorded" through oral histories in local communities by gardeners.

Citizen Science

FARMERS AS CITIZEN SCIENTISTS

The need for many observations in many places cannot be met by research and government institutions alone. In Canada there are few agricultural research stations and they are largely focused on conventional crops and main-stream varieties or on the results of specific breeding programs. Furthermore, their interest concerns crops with high potential for significant economic return. The research and trials are usually carried out under a narrow standard range of controlled climatic and field conditions.

There is another approach that, perhaps not as agronomically as strict as research trials, nevertheless yields valuable and diverse data for analysis and consideration especially during a time of rapidly changing climate. This approach draws on the participation of farmer scientists.

For thousands of years farmers have been the scientists**.** They tested and adapted crops and farming methods, remembered successes and failures and passed their experience on to others. They saved productive heritage varieties for future generations. These citizen scientists accumulated and passed on a wide range of knowledge and many continue to do so today. In the context of climate change, there is so much to learn about so many varieties in so many places and so little time to do so. Only by involving many growers can we gain and provide the vital knowledge for food security under shifting climates. This knowledge needs to be collected in a reliable manner and made as widely-available as possible. The Crop-Climate project contributes to this important work.

MONITORING GROWTH STAGES FOR ADAPTATION

Phenology is the study of the timing of seasonal changes in plants and animals and the influence of variation in weather and climate on developmental stages. These key annual stages for plants include germination, flowering and fruit ripening. In the context of climate change, many plant species and varieties now flower several days earlier than they did in the past at the same location. Phenology is an important indicator of the impacts of climate change. It is also a key indicator for the adaptability of heritage varieties to differences in the timing of climatic factors such as temperature and rainfall.

Farmers need to understand plant phenology and local climate to decide when to plant to avoid frosts, when to harvest, as well as how weather affects the development of plant diseases and insects. Understanding the progression of a crop variety through growth stages helps in the choice of planting and harvest dates. Uncertainty in the timing of key climatic event indicators such as the accumulation of Growing Degree Days (GDD) and the occurrence of extreme weather conditions (such as high temperatures) poses challenges to famers and food production systems. The timing of growth stages as indicators in general may also reveal the adaptability of varieties to broad climatic regions. Considering the importance of phenology, we know very little about the climatic profiles and suitability of heritage varieties.

Crop-climate project participants observed the timing of key growth stages in potatoes in different climates across Canada. In this way, they contribute to the development of climatic profiles of heritage varieties and identify their suitability for different conditions. We hope that these observations will help future growers choose the best varieties for their locations and even identify varieties to grow outside traditional geographic areas as climate zones shift. Observations under a range of climates also helps point to potential new agricultural areas, with previously unsuitable climates, to grow food crops.

Collaboration

We emphasize in the background section the need for gathering a lot of information over a short interval of time because of the rapid advance of changing climate. In part this urgency is based on the large number of varieties to be tested, and the great range of conditions and limitations under which they can be grown. A second factor is the time it takes to develop and establish adaptation approaches in local communities and in agriculture in general. Once successful varieties are identified, it takes time to get them accepted broadly by people. It also takes time to communicate and establish in practice the most effective ways to grow them.

The previously mentioned factors require as wide a range of participants and collaborators as possible. The field trials themselves need grower participants. Meeting this requirement, in itself, is a major challenge. There are two kinds of participants in general, formal ones who undertake the proscribed methods in their trials, and the informal ones who may grow one or several varieties and provide feedback of various types. Both types were involved in our project and the formal growers are listed in Table 2. Numerous known and unknown informal collaborators have also been involved. These were largely folks who received seed tubers through various mechanisms, usually at talks or chance encounters. There are likely as many as 1000 of these, some of which have reported their results back to us (Box 1).

FARM	LOCATION	YEAR
Haliburton Farm	Saanich BC	2012
Heritage Organic Farm	Tompkins SK	2012
Garrett Pittenger Farm	Caledon ON	2012
Ironwood Organics	Gananoque ON	2012-2018
First Nation of Nacho Nyak Dun	Yukon	2016
Elder Farm	Winlaw BC	2013, 2015-2016
Mackin Creek Organics	Mackin Creek BC	2014-2018
Three Phantom Arbour Farm	Three Fathom Harbour NS	2015
Potato Research Centre	Fredericton NB	2014
Horticulture Centre of the Pacific	Saanich BC	2014-2015
Camassia Bulb Farm	Saanich BC	2012-2018
Huff Garden	Trail BC + Nelson BC	2012-2018

Table 2. Crop-Climate Project field trial locations and participants.

Trial By Fire – Ozette-Nootka outperforms

We love to receive reports from our far-flung growers.

In 2017, British Columbia experienced one if its worst fire seasons ever. Growers Phil and Carla Burton report on their experience near Smithers, BC. — by Phil Burton

A quick update on the heritage potato plantings up here at Smithers.

We planted them in our cabin garden (borderline in the Sub Boreal Spruce zone, 54.72506 N x 127.17514 W, 680 m elev.) in good (imported) loamy soil on April 29th, 2017 — the earliest I've ever tried planting/sowing anything up here.

Seed potatoes were split to plant 12-14 hills of each variety, always with at least two apparently viable eyes. The varieties included Likely, Ozette-Nootka, Mrs. Moehrle's Yellow, and Irish Cobbler; and I think you included Kennebec and Russet. No other (modern) varieties were planted this year — we have a pretty small garden patch.

It was a cool spring, not much happening until late June, early July, when temperatures started getting hot. We watered the garden intermittently in May and June, a little more regularly in July, but then we were gone all of August and September during the peak of the drought and fire season.

So, between the slow start and the droughty summer, it was pretty much the poorest potato crop I'd ever harvested. By the time we were back home October 9th, it appeared that most plants had withered and died back sometime in the interim. The greatest numbers of survivors (4 or 5 as I recall), largest plants, and greatest yield was shown by the Ozette-Nootka, but even then, with no tubers larger than a tennis ball, and most the size of a ping pong ball.

So Ozette-Nootka wins the trial by fire and neglect, but not in shining colors. We ate the harvest over the next month, so I hope no-one was counting on another set of seed potatoes from us.

Box 1. Testing potatoes under very challenging conditions.

We specifically engaged and continue to engage First Nations communities. particularly because they often live in isolated or difficult to reach settlements where food is often expensive. We partnered with the First Nation of Nacho Nyak Dun in Yukon for one year and out of the collaboration came a unique experiment on taste testing. More First Nations involvement is highly desirable (informally undertaken in 2018 with the Kitasoo / Xai'Xais at Klemtu on the central coast of BC).

Several institutions and agencies played a central role in initiating the project and keeping it going. The W. Garfield Weston Foundation (especially Board Member Mrs. Gretchen Bauta) has played the key role in the project by providing funding for its duration. Even before the formal project began, in a proof-of-concept trial, funding was provided by Mrs. Bauta to the

Garden Institute of BC because of the leadership and effort of Sharon Rempel. Without this initial support there would have been no Crop-Climate project.

We have sourced potatoes from several seed potato growers either through the generosity of their donation or through purchases. Garett Pittenger of Caledon, Ontario provided several varieties in the pre-project trial, several of which were incorporated into the three-year project (Irish Cobbler and Mrs. Moehrle's Yellow being examples). Garrett has also been the source of additional varieties that are still being trialed by several growers. Ozette-Nootka has been grown by Hebda for several years as a result of a donation by ethnobotanist Nancy Turner of University of Victoria. The Likely potato came to us via Jim Gibson of Likely BC (Hebda and Huff 2014). The Fredericton Research and Development Centre of Agriculture and Agri-Food Canada (FRDC), Fredericton, NB participated for one year and has been the source recently of cleaned clones of several varieties. The Centre also cleaned up the Likely potato provided to them by this project.

Several community groups have provided support either logistically or through travel assistance for the presentation of talks. Support from the Canadian Climate Forum made it possible for Richard Hebda to present the Crop-Climate concept and some project results, as well as introduce the Honest Food Principles in Ottawa in the fall of 2015.

The potato monitoring protocol was developed in collaboration with Benoit Bizimungu and Teresa Molen (Fredericton Research and Development Centre), Martin Entz (University of Manitoba), Bob Wildfong (Seeds of Diversity Canada), as well as our farmers. Connection to potential growers was provided by these individuals and by the Bauta Family Initiative on Canadian Seed Security, USC Canada, and organic growers organizations across Canada.

The Pacific Institute for Climate Solutions at the University of Victoria, and particularly Dr. Thomas Pedersen (former director) and administrative staff Megan Jameson and Nancy Chan have been strong supporters of the project and managed the project's financial mechanisms.

From the preceding account it is evident that the project has involved collaboration with many participants without whom the work would not have been possible.

Climate Change and Potato Agronomy

As noted earlier potatoes are the world's fourth most important food crop (after rice, wheat and corn), eaten by more than a billion people and an essential part of the livelihoods of millions of people. There are more than 2500 varieties of potato grown in Peru, in a rainbow of colours, shapes and sizes. Worldwide, there are at least 4000 varieties grown in a wide variety of climates. Canada is part of this global potato diversity. From the introduction of the Ozette-Nootka potato by the Spanish into Nootka Sound as early as 1791, European settlers have been bringing their preferred varieties, and selected and adapted them to local climate conditions and tastes. Potato breeding continues to this day, with public research programs, private breeders, and small farmers actively developing new varieties. Keeping our genetic heritage in cultivation is one way to prepare for, adapt to, and buffer our food system as the climate changes.

Climate change presents many challenges, and some opportunities, for food production. Climate models predict not just a gradual warming of the climate, but also more volatile weather with more frequent and severe extreme heat, drought and heavy rain events. Growers will need strategies to adapt to both warmer conditions and a less predictable climate. There will also be opportunities to expand potato production northward, particularly with short-season potatoes. Growers can also consider planting varieties adapted to longer-day conditions and a longer season than those currently experienced.

Growers are most concerned with crop yield both quantity and quality. These are strongly influenced by numerous interacting factors, including climate factors such as temperature, relative humidity and precipitation as well as management practices. Soil characteristics especially soil nutrients and texture are important elements too. Varying soil conditions under the same climatic regime and experiencing the same weather can strongly influence yield. Climate models simply do not resolve the local and field-scale differences that growers are no doubt familiar with. The models also only provide general projections for future conditions in areas where people have little or no experience with growing potatoes. Furthermore, climate and changing climate trajectories will mediate pest and disease occurrence and cultural practices.

For these reasons, people need to experiment with varieties in different communities on different sites until they find those that are most suited to their circumstances. Particularly for small scale growers and new growers knowing the general features of potato agronomy is helpful, however local knowledge and site variation are much more important. There is a lot of widely-available information on how to grow potatoes but little on how to choose cultivars and how to adapt to climate change.

As far as potatoes go, there are many climate/weather related factors that influence yield and quality. These will undoubtedly be affected as climate changes. Temperature-related factors are the easiest to project into the future. For this reason, we are certain that people will be able to grow potatoes well beyond traditional locations. Precipitation is much less easy to project especially because its seasonal distribution will most likely change whether or not there is much of an increase. In the next section we describe they key weather-related factors that influence potato growth, yield and quality as background for the interpretation and application of the results of our trials.

STRESS EVENTS AND POTATO GROWTH AND DEVELOPMENT

Extreme weather due to climate change will stress food crops and increasingly put our food supply at risk (Porter et al. 2014). Volatile weather will bring more frequent and severe extreme heat, drought and heavy rain events. Understanding how crops respond to different stresses can help adaptation and build resilience into the agricultural ecosystem. Growers will need strategies to adapt to a less predictable climate.

Potato quality and yield are affected by various stress events during critical growth periods. Excess heat, frost, high or low humidity, drought, extreme precipitation, and physical damage can all reduce tuber quality and number if these stressors occur during critical growth stages (Table 3). For an extensive discussion on potential effects on potatoes, see Hebda and Huff (2013B).

STRESSOR		POSSIBLE IMPACTS
Temperature	Daytime Air Temperature > 30 ˚C	Over 30 ˚C stresses potato plants, reducing yield and causing tuber defects (Rykaczewska 2015)
	Daytime Air Temperature < 7 ˚C	Temperatures below 7 ˚C slow growth and development
	Nighttime Air Temperature > 18 ˚C	High night temperatures can delay tuber formation (Slater 1968) and cause misshapen tubers.
	Frost	Early frosts may kill or set back emerging plants.
		Late frosts may prevent full maturity of later varieties
	Soil Temperature < 8 ˚C	Slow emergence reduced root penetration, rot of seed tubers. (Epstein 1965)
	Soil Temperature > 22 ˚C	Increased tuber deformities, lower dry matter, decreased yields (Epstein 1965).
Precipitation	Heavy Rain Event	Flooding reduces growth, tubers may be more susceptible to blight
	Hail	Physical damage to leaves can harm developing tubers
	Seasonality	Seasonal distribution of precipitation obviously affects yield and quality. Lack of spring moisture inhibits sprouting and tuber development and growth. Heavy late season moisture affects quality of tubers: lenticel growth,, renewed growth and misshapen form.
Drought	Soil Moisture Deficit	Slow growth, early death, delayed tuber set, poor tuber development,

Table 3. Climatic stresses on potatoes and their potential effects on growth and development.

PESTS AND DISEASES

A changing climate will also affect the distribution and abundance of many potato pests and diseases, with existing pathogens spreading northward and new threats emerging. Insect and disease resistance and/ or susceptibility has not previously been documented for many of our heritage varieties. Participants in the trials have been noting the appearance and timing of various pests and diseases on individual varieties, contributing to a broader understanding of both varietal susceptibility and geographic distribution. Ongoing observations also can form part of an early alert system for climate change adaptation.

FIELD TRIAL METHOD SUMMARY

The original "big picture" objectives of the project were simple: to get numerous people trying various potato varieties in different places under differing growing conditions. The hope was that participants would share their experiences and through growing various potatoes find a variety that suited their location, climate and way of gardening (Hebda 2012).

The project began with a standard weather observation and growing and recording protocol for all participants (Huff and Hebda 2013A). In-field weather monitoring devices recorded local conditions (Box 2) while participants monitored the above-ground growth of potatoes (Box 2). For potatoes, above-ground phenology indicates below-ground development of tubers, and depending on the growth stage, potatoes are sensitive to various weather stresses (Box 3). Full protocol descriptions are available electronically by making a request through the project website.

Weather Data Collection Methods

A 2012 pilot study compared different equipment types for acquiring reliable climate data directly within the field where the crops were grown, using equipment that we felt was easy to use by growers. We also aimed to demonstrate that gardeners and farmers can collect climate change research data (Huff and Hebda 2013A).

Readings were made at fixed intervals (every 30 minutes) using two types of automatic weather recording equipment. A Davis Vantage Pro2™ weather station with solar radiation and UV sensors recorded data in the crop field at about 1.5 m above ground every 30 minutes. Davis weather stations collected a range of weather parameters, including rainfall, wind speed, and solar radiation. This information is necessary to calculate evapotranspiration and moisture deficit. Less costly Onset Corporation HOBO sensors recorded temperature and relative humidity at ground level, 75 cm above ground, and at the elevation of the Davis weather station. A HOBO sensor also measured soil temperature 15 cm below the surface and air temperature at ground level. The weather data were compiled on a regular basis in order to ensure that the sensors were working properly and continuously. Our analysis of the comparative study revealed that a combination of a Davis weather station, two HOBO temperature and RH loggers at one at 75 cm and one at 5cm above ground and a HOBO soil temperature logger provided adequate data for the study.

Box 2. In-field weather data collection for monitoring parameters related to potato growth.

Potato monitoring protocol

Participants were asked to plant tubers 15 cm deep spaced according to their normal practice with a suggestion for 30-50cm separation. Beyond this, growers could manage the crop as they preferred, such as using mulches. Organic methods of cultivation were required.

A series of standard developmental stages was chosen for potato observations including emergence from soil, two-leaves horizontal, appearance of flower buds (some varieties do not flower), leaf yellowing and the drying out of plants. Most of these stages are relatively easy to recognize, whereas others, as we found out, were somewhat ambiguous to observe (Hebda 2012). We also provided general guidelines for the interval of observation (every few days, weekly) however participants were at liberty to make the observations in accordance with the demands of their schedules. Data were collected using standard forms and a technical bulletin was provided for planting and observations (with e-mail up-dates as required) (see project website). Suggested observation time was based on anticipated rate of change of growth. Participants were encouraged to make additional observations about vigour, diseases and pests and other unusual phenomena. Observation forms were revised according to the feedback received from project participants and to improve the efficiency of data compilation.


Figure 1. Gail Elder planting Ozette-Nootka spacing trial.

As time progressed, the project encountered various methodological challenges including changes in participants, misunderstanding of protocol, equipment failures and general non–compliance with the protocol. In consideration of these issues, the results we present here are limited to areas where there were fewer inconsistencies in data, and some sites are excluded from some numerical analyses. Observations by growers are interpreted in the context of the diversity of growing systems rather than as a strict agronomic trial. These varied methods still served the project's main aim of learning from the growers, evaluating heritage potatoes under different climatic and management regimes and sharing this information widely. A simplified, adapted method will be necessary, going forward, to continue collaboration and to spread the growing of heritage potatoes in different regions of Canada.

Potato Growth and Development

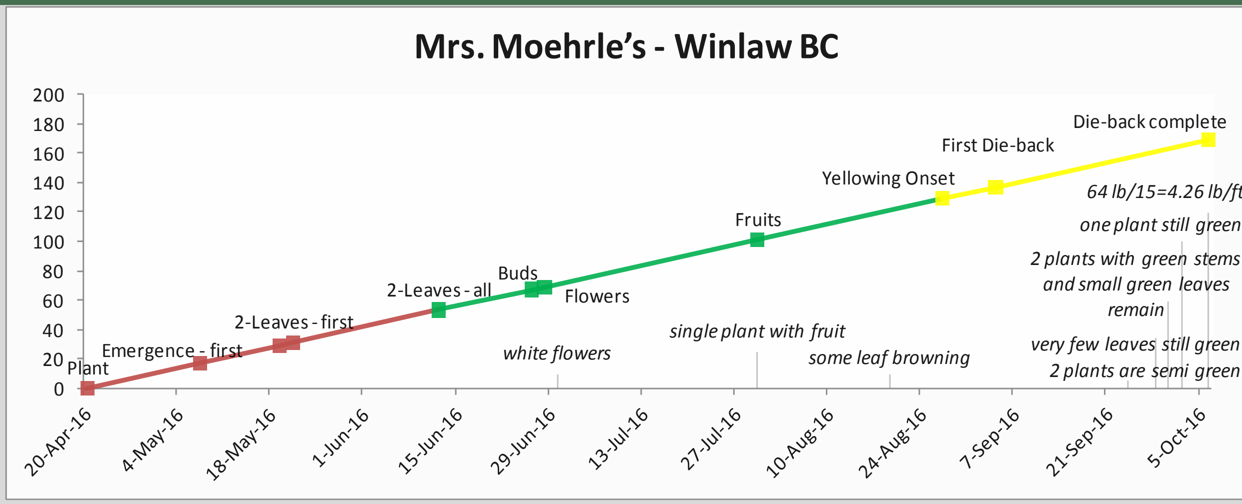


Figure 2. Growth and development monitoring of Mrs. Moehrle's Yellow at Winlaw BC in 2016. Boxes mark a phenological phase as monitored by the grower. The emergence phase (from planting to the 2-leaf stage) is in red, active growth and development in green, and senescence in yellow.

Planting

- sprouts emerge from soil, roots develop at base of emerging sprouts
- soil temperature and moisture most important at this stage

Emergence

- root and stolons are developing below ground as vines grow rapidly above ground
- emerging plants are most vulnerable to frost at this stage

First buds

- tubers form at stolon tips, tuber initiation (most cultivars) usually ends at first flowers
- even moisture and ideal air temperatures important during this phase

Flowering

- tubers bulk up and accumulate water, nutrients carbohydrates
- high heat, humidity and drought stresses in this period can harm tuber development, increase in tuber malformation, and disease susceptibility

Maturation

- tuber dry matter maximized, tuber skins set as above ground leaves yellow and die back
- excess moisture may decrease tuber quality, drought may lead to poor skin set

Box 3. Potato phenology monitoring, below-ground development and weather effects at each stage.

RESULTS

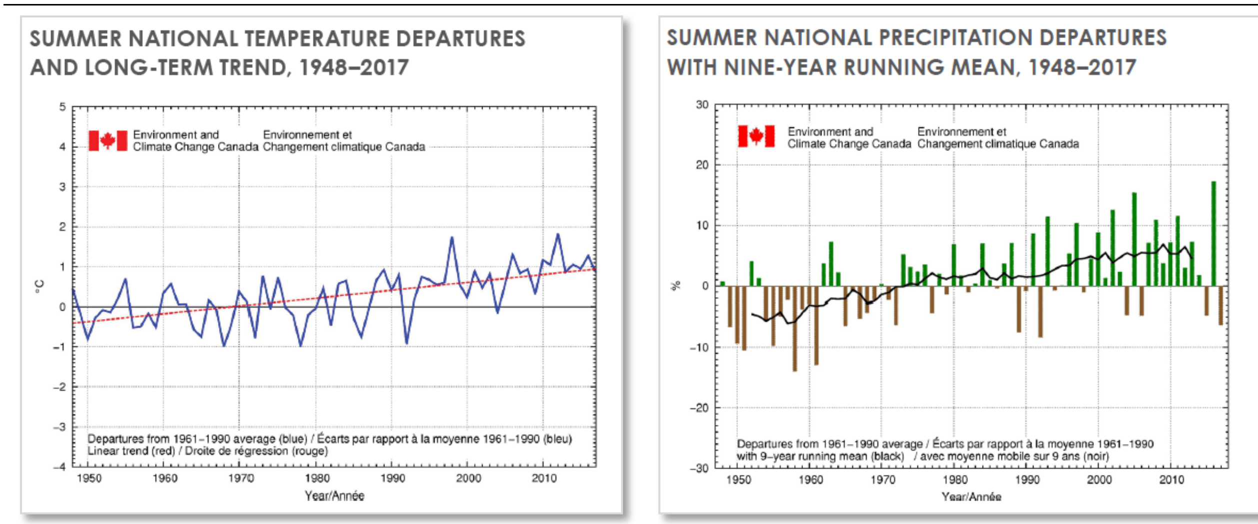
Field trials were conducted over three years at several sites across Canada under a wide range of weather conditions in different climates. Four growers were involved for the full three years in the standard trial and two growers for a single year. During the trial the growing conditions varied greatly representing cold to hot temperatures and moist to very dry seasons. We present the analyses in a summary form to identify responses of potatoes in general. We also look at individual variety responses and compare them to each other. We summarize our experiences with growing each variety to provide guidance to those who may be interested in growing our selected heritage varieties. In so doing we draw in the experiences of other growers who were not part of the standard field protocol.

Our analysis is not comprehensive considering the large amount of climatic data that we collected. We explore high-level relationships to temperature and precipitation (and watering). We then focus our analyses on conditions known to stress potatoes and presumably affect development and yield in the hope that by doing so we can identify places in Canada and elsewhere that people can successfully grow potatoes as a staple food as part of their climate change adaptation strategy.

Climate and Weather Summaries

NATIONAL AVERAGES

Across Canada, national average temperatures for much of the growing interval (June-August) have warmed by 1.5 °C over the past 70 years (Environment and Climate Change Canada 2017), with the years 2014-2016 being well above the baseline average (Figure 3a), consistent with the trend in global combined land and sea surface temperatures. As might be expected growing season precipitation varied widely from one year to the next, with 2014 and 2016 being wetter than average, and 2015 and 2017 being drier than average Figure 3b).



A B

Figure 3. Summer national temperature departure and long-term trend, 1948-2017. (b) Summer national precipitation departures with nine-year running mean, 1948-2017. (Source: Environment and Climate Change Canada 2017)

TRIAL LOCATION SUMMARIES

The national trends were reflected generally in the weather recorded in the trial fields and exhibiting local and regional differences as expected. For convenience we summarize the site conditions in Table 4, noting that the summary brings together hundreds of thousands of instrumental readings.

The growing season is defined as the period from first planting to final harvest during which participants observed potato growth stages. Participants were not always able to plant all varieties on the same day, and harvest happened sequentially as potatoes matured, so the numbers here represent the total potential growing days and heat accumulation for the entire growing period. See Box 4 for an explanation of heat accumulation and the calculation of Growing Degree Days). Growing degree days were calculated for the season by Hoboware ® software, using a base of 8℃. Temperatures and Relative Humidity (RH) were averaged over the growing season, along with reported highs and lows. Visible frost events and irrigation amounts were reported by growers.

Table 4 provides a sense of the differences among the trial sites during the growing season but does not show the variation over the season; that variation (summarized in Tables 5-9) has a key role in the progression of the varieties through their growth stages and the eventual yield. For example, it is obvious that the Saanich Peninsula on Vancouver Island has the driest growing season with precipitation often well below 100 mm. Generally summer temperature maxima reach into the mid 30's (Celsius). Other obvious features include an incredibly wet summer in 2014 at Gananoque. Tables 5-9 refine the general data by showing whether or not stress events occurred during key growth stages. For example, May and June of 2015 in Saanich experienced extreme drought. During this time tubers would have been expected to sprout, and the plants emerge and set new tubers. From such refined observations we can get a sense of the effects of projected future climatic extremes.

Stress events, reported in Table 4, are based on factors that can directly affect the development and growth of potatoes. The impact of the stress on the potato depends on the intensity, frequency and time of occurrence relative to the growth stage of the potato. For temperature, a stress day is defined as a day when the temperature recorded by the HOBO at 75 cm exceeded 30°C or fell below 7°C. For humidity, a stress day is defined to occur when the average daily RH exceeded 80% or fell below 40%.

	G-2014	G-2015	G-2016	W-2013	W-2015	W-2016	M-2014	M-2015	M-2016	S-2014	S-2015	S-2016	F-2014	T-2015
Growing Season														
Planting Date	7-May	16-May	4-May	7-May	16-May	5-May	23-May	10-May	28-Apr	12-May	1-May	24-Apr	23-May	12-Jun
Harvest Date	28-Aug	20-Sep	20-Oct	11-Oct	9-Sep	8-Oct	21-Sep	30-Sep	27-Sep	4-Oct	15-Oct	20-Aug	1-Oct	24-Oct
Growing days	113	127	169	157	116	156	121	116	152	157	167	118	131	134
GDD (base 8)	1450	1935	2510	2090	2058	1960	1040	1170	971	1580	1746	1260	1750	1050
Temperature														
Average (°C)	15	19	19	15	20	16	17	14	13	17	16	16	17	16
Max (°C)	28	32	36	35	38	36	37	33	29	35	35	35	33	27
Min (°C)	2	-4	0	-1	6	-1	-3	-2	-2	3	2	0	1	-2
Frost							Sept.							
RH (%)														
Average (%)	72	83	75	81	57	65	64	58	63	75	78	73	76	90
Max (%)	100	100	100	100	100	100	100	100	100	99	100	99	99	100
Min (%)	24	4	22	18	83	8	13	87	76	24	21	18	21	35
Precipitation														
Season total	451	134	214	243	102	214	225	97	174	114	27	38	337	292
Irrigation est.	-	-	-	-	150	150	-	100	75	-	-	-	-	-
Stress Days														
Temp > 30°C	0	1	9	66	43	27	5	4	0	2	2	8	14	0
Temp < 7°C	0	5	18	21	1	11	42	43	47	2	17	19	23	5
RH > 80 %	37	59	33	37	9	10	15	8	18	27	43	14	62	45
RH < 40 %	0	0	0	4	8	3	9	21	6	1	0	17	0	0
Rain > 40 mm	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table 4. Summary of climate conditions during the growing season at each site during all trial years.

GROWING DEGREE DAYS

Growing degree day (GDD) calculations are commonly used in agriculture to show the amount of heat available for the growth and maturation of crops, weeds, and insect pests. Different species and varieties of organisms have individual requirements and thresholds for development.

This diversity of heat need is reflected in the many ways that the calculations are made. There are advantages and disadvantages to the different methods. Two ways of calculating GDD useful for climate change adaptation and planning are compared in the following table.

Simple Method	Electronic Data Collection
GDDs are calculated with a simple formula using daily minimum and maximum temperatures.	GDDs accumulated based on temperatures recorded by field HOBOs at half hour intervals.
Minimum temperature base (such as 5°C, 10°C) at which degree days accumulate is set.	Minimum *and* maximum temperatures can be tailored to the physiology of the crop.
Assumes linear plant growth above minimum temperature.	Flexible calculation can more closely mirror non-linear plant growth between the minimum and maximum temperature.
Useful for generalizing over large areas for many crops	Useful for directing management for a particular crop (and crop pests) in the location where the weather equipment is located.

The Climate Atlas of Canada (https://climateatlas.ca/map/canada/dd5_2060_85#) projects Growing Degree Days at different base temperatures at a large scale into the future. This tool can be used to anticipate where there will be appropriate growing conditions for potatoes under different climate change scenarios.

Electronic Data Collection, such as we collected with in-field HOBO instruments, are a tool that can be tailored to specific crops in different locations to help with crop management such as choosing planting date and managing pests.

Box 4. Growing Degree Days - a primer.

Seasonal distribution of weather variables at growing sites

	G-2014	G-2015	G-2016
TEMPERATURE			
Highs	Temperatures were in the optimal range for most of growing season, rarely above 30 °C	Temperatures were in the optimal range for most of growing season, rarely above 30 °C	High temperatures throughout July and August
Lows	Low temperatures in May occurred prior to planting and likely had no impact	Low temperatures in May just after planting.	Cool start to the growing season.
Frost	No	Temperature fell below zero on May 23, but there were no reports of frost damage.	No
RAINFALL			
Seasonal distribution	Lots of rain throughout growing season.	Rain in early May, then dry until late July, after most potatoes had grown.	Very dry in May and mid-July, some rain in June, early July and August.
RELATIVE HUMIDITY			
Seasonal distribution	High RH in July and August	High RH in June, July and August.	High RH in July and August

Table 5. Seasonal distribution of weather variables at Gananoque, ON, 2014-2016.

	M-2014	M-2015	M-2016
TEMPERATURE			
Highs	Regularly above 30 °C in July and August.	Hot weather in late June and early July.	Temperatures never reached above 30 °C.
Lows	Some early lows just after planting.	Some early lows just after planting.	Cool start to the season, may have slowed or delayed emergence.
Frost	Two consecutive hard frosts in Sept. killed all plants.	No frost reported.	None reported.
RAINFALL			
Seasonal distribution	Rainfall relatively well distributed.	Dry early in season, light rains in late June and July.	
RELATIVE HUMIDITY			
Seasonal distribution	Both high and low RH, but generally within ideal range.	Regular high humidity; low RH also common. Most days were within ideal range.	Low RH at beginning of season, humidity high during regular rain events.

Table 6. Seasonal distribution of weather variables at Mackin Creek, BC, 2014-2016.

	S-2014	S-2015	S-2016
TEMPERATURE			
Highs	Occasionally above 30 °C.	Higher than average temperatures, often over 30 °C, throughout the growing season.	Optimal range for most of growing season, occasionally above 30 °C late in the season.
Lows	Occasional low temperatures occurred through the growing season.	Air temperature rarely fell below 7 °C, except at night in the beginning of the growing season.	Cool temperatures frequent during emergence phase.
Frost	No.	No.	No.
RAINFALL			
Seasonal distribution	Spring precipitation, followed by very dry in June, July and first part of August.	Little rain in May and June. Extreme drought.	Well distributed early in growing season.
RELATIVE HUMIDITY			
Seasonal distribution	RH high throughout the growing season.	RH high throughout the growing season.	High RH throughout the growing season.

Table 7. Seasonal distribution of weather variables at Saanich, BC 2014-2016.

	W-2013	W-2015	W-2016
TEMPERATURE			
Highs	Sustained high temperatures (regularly above 30 °C) through July and August.	Well above average through May- July, with temperatures frequently reaching 30 °C.	Regularly above 30 °C in July, August and early September.
Lows	Cool temperatures in mid-late May.	Daytime temperatures rarely below 7 °C.	Regularly below 7 °C at the beginning of season.
Frost	Killing frost on Oct. 11.	None.	No.
RAINFALL			
Seasonal distribution	Dry in May and early June, showers through late June, early July.	Dry in early part of season, heavy rain in early June, then dry until mid-July.	Regular small amounts of rain in early part of planting season.
RELATIVE HUMIDITY			
Seasonal distribution	Low humidity in May and June, occasional high values late June.	Mostly within ideal range, occasional high values recorded in June.	High values early in season, and again in July.

Table 8. Seasonal distribution of weather variables at Winlaw BC 2013, 2015 and 2016.

	F-2014	T-2015
TEMPERATURE		
Highs	Temperatures were in the optimal range for most of growing season, rarely above 30 °C.	At no point did the temperature reach above 30 °C.
Lows	Early cool temperatures just after planting but before emergence.	Early cool temperatures just after planting but before emergence.
Frost	Not recorded.	None during growing season.
RAINFALL		
Seasonal distribution	n/a	June was the rainiest month, but there was regular rain through September.
RELATIVE HUMIDITY (RH)		
Seasonal distribution	Low RH early in season, high RH common July – Sept.	RH frequently above 80%, a challenge for growing potatoes in this location.

Table 9. Seasonal distribution of weather variables at Fredericton, NB (2014) and Three Fathom Harbour, NS (2015).

Soil Temperatures

In the trials, soil temperature was measured at 15 cm below the surface in the potato row. Mean daily May soil temperatures ranged from 11 °C to almost 19 °C at our trial sites. July mean daily soil temperatures ranged from 18 °C to more than 24 °C (Table 10). The coolest early season mean soil temperatures were recorded in the Maritimes at Fredericton, New Brunswick and Three Fathom Harbour in coastal Nova Scotia.

	F-2014	T-2015	G-2014	G-2015	G-2016	W-2013	W-2016	M-2014	S-2014	S-2015	S-2016
May	11.2		15.4	18.7	17.3	14.4	15.3	13.7	16.8	16.3	16.8
June	17.0	16.8	21.1	19.4	24.1	16.9	18.6	16.6	20.9	21.2	17.3
July	20.6	18.4	21.6	21.2	23.1	19.6	21.6	19.7	24.3	23.1	18.7
Aug	20.4	19.6	20.6	20.0	22.7	18.9	20.1	18.5	24.2	21.8	20.9
Sept	16.0	19.2	20.5	18.4	18.4	14.8	16.2	13.0	19.7	16.8	17.2

Table 10. Soil temperature monthly averages during the growing season for 11 trials.

The warmest values occurred in Gananoque and Saanich. Saanich had very warm July soil temperatures in two of the three years in the 23-24 °C range, and these high soil temperatures were sustained from mid-July to mid-August (Figure 4). Only Gananoque soils approached these high values. Mackin Creek farm and Winlaw had the lowest average soil temperatures, below 20 °C throughout the season. Unfortunately, we have only one year of soil temperature data from Mackin Creek and two from Winlaw because of equipment failure.

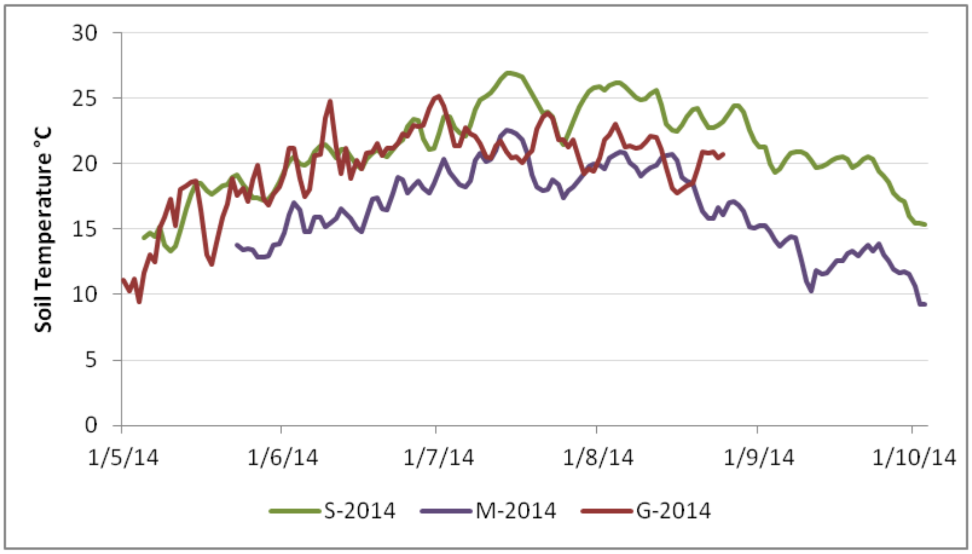


Figure 4. Daily average soil temperature during the 2014 growing season at Saanich, Mackin Creek, and Gananoque.

Potato Growth, Development and Yield

With weather data in hand we can look at general responses of the potatoes and compare them on a variety by variety basis. These responses can be also considered in the context of the notes provided by the growers with respect to diseases and cultural practices.

TEMPERATURE AND HEAT ACCUMULATION

Air Temperature and Growing Degree Days

Our results show that a daily mean growing season temperature of about 12 °C and accumulation of 1000 GDD (base 8) are enough to grow potatoes with abundant yields as demonstrated by results from Mackin Creek Farm in central BC (Figure 5). Potatoes grew best at mean growing season temperatures between 14 °C and 17 °C, with monthly soil temperatures below 20 °C. Figure 5 also demonstrates that long growing seasons do not improve yields as evident in the data from Gananoque (G sites) and Saanich (S sites) with more than 2000 GDD. Except for stress temperatures (see following), there may be little relationship of yield to mean growing season temperatures, with pattern/value of temperature at key parts of the season being more important. However, some varieties such as Likely, Ozette-Nootka and Kennebec seem to be more sensitive to high temperatures with lower yields at higher values (Figure 6). Others such as Irish Cobbler appear less sensitive showing no trend with increasing average temperature.

All varieties except Likely seem to yield similar amounts regardless of GDD (base 8) suggesting that the growing season heat is adequate for most varieties and types of potatoes regardless of the location of the trial or year (Figure 7). Only Likely appears to be more productive in a short growing season rather than a long one.

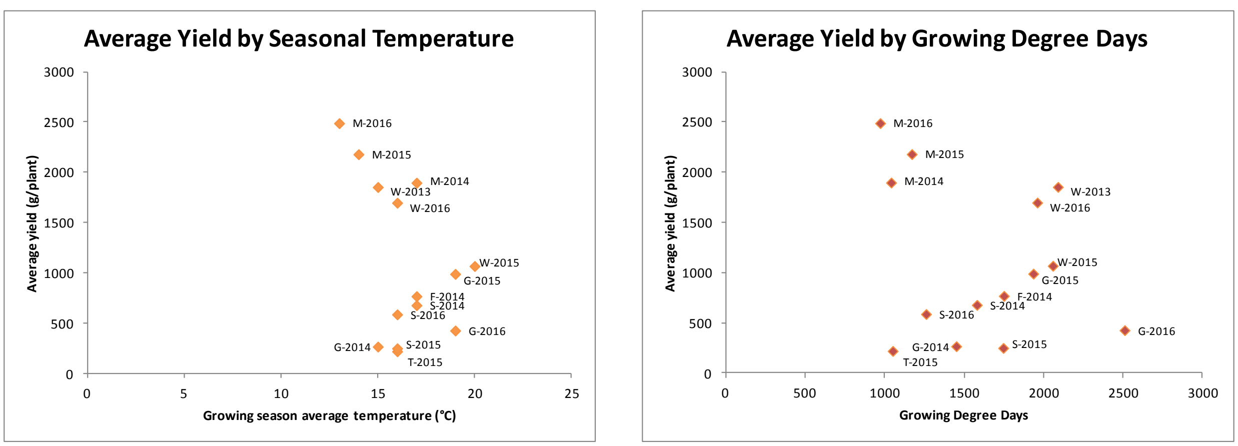


Figure 5. Average yields for all trials by average seasonal temperature (left) and Growing Degree Days (right).

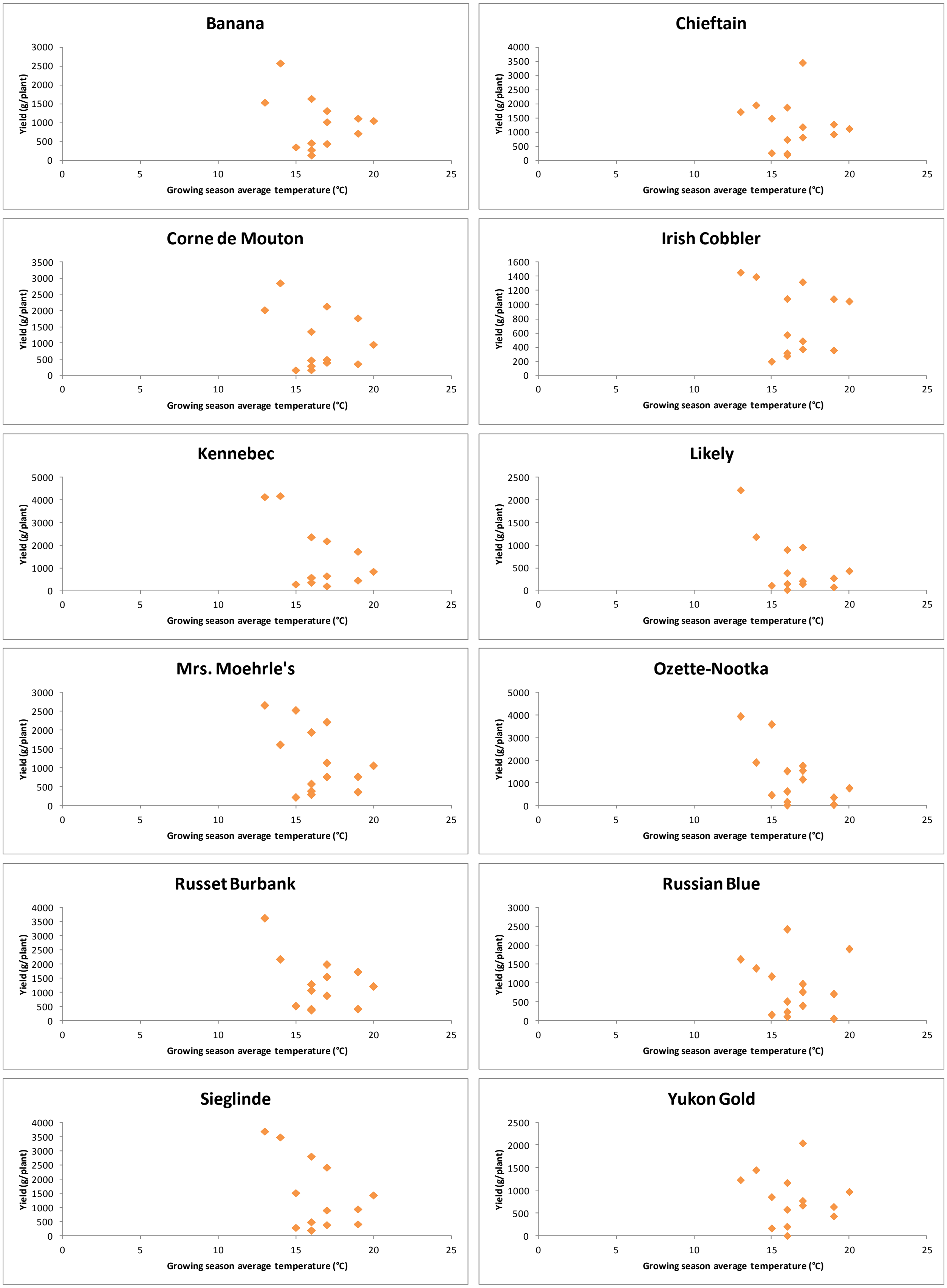


Figure 6. Varietal yields by average temperature.

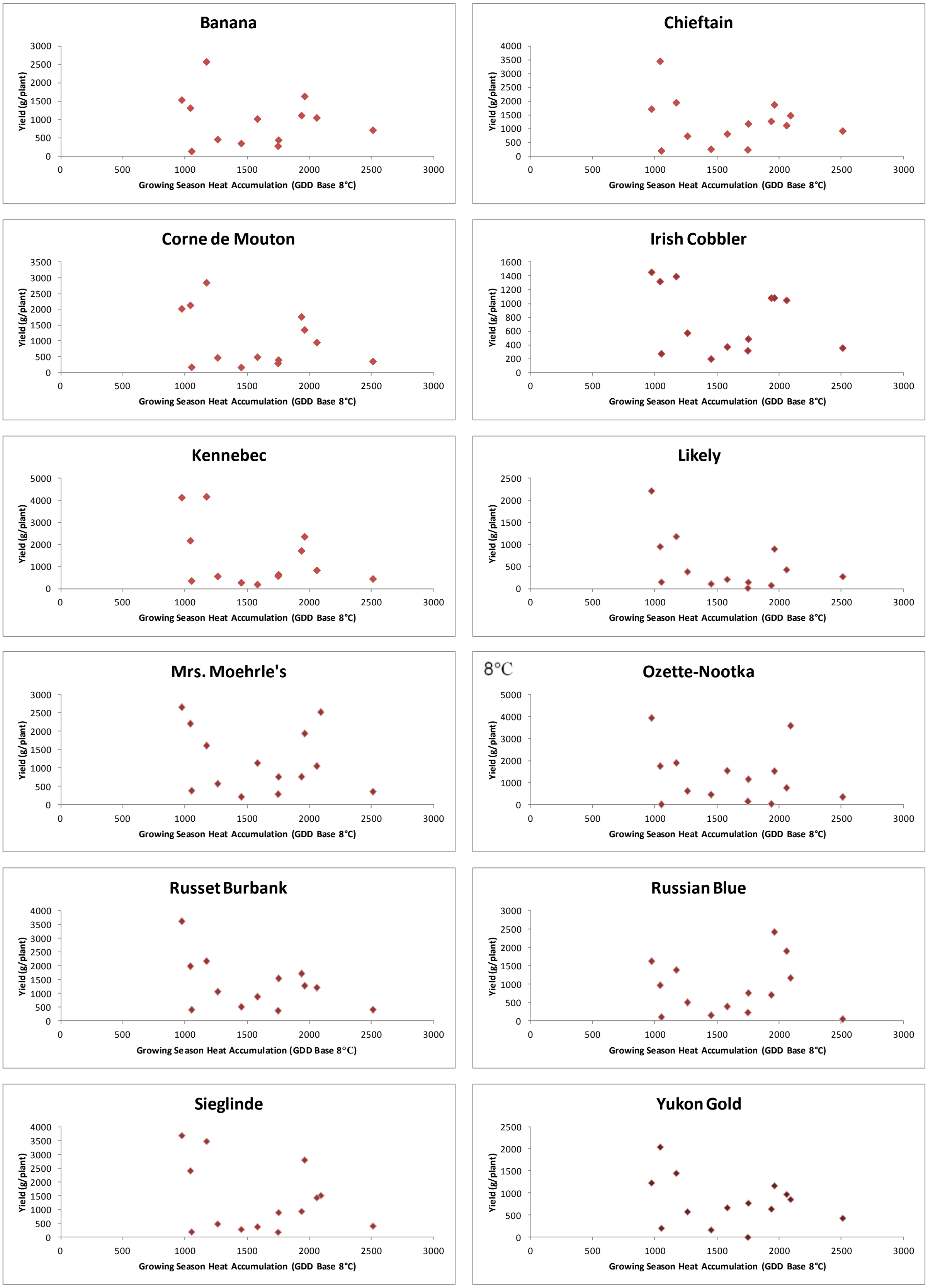


Figure 7. Varietal yields by season total growing degree days.

Soil Temperature

The highest yields consistently came from Mackin Creek and Winlaw, where the mean soil temperature rarely exceeded 20 °C (2014 an unirrigated year). Lower overall yields in Saanich and Gananoque were obtained in soils that were consistently above 20 °C. The lowest overall yield was obtained in Three Fathom Harbour, which also had cool soil and air temperatures as well as high humidity.

The complex interplay of factors (air and soil temperature, soil moisture, soil texture, precipitation, cultural practices) that influence potato quality and yield make it challenging to determine causative effects of any particular factor. There are, however, general guidelines that can be taken from our results. For example, a practical application of data on soil temperatures is to take advantage of the part of the growing season where soil temperatures are optimal. Early planting is possible when soil temperatures reach about 8 °C. This could be advanced even further by pre-sprouting the tubers. Early planting may also allow the potatoes to mature before the soil temperatures become too warm for optimal growth (above 20 °C see Table 3). Cultural practices such as mulching and hilling may also reduce soil temperatures in the growing zone and could be used during times of extreme heat.

PRECIPITATION

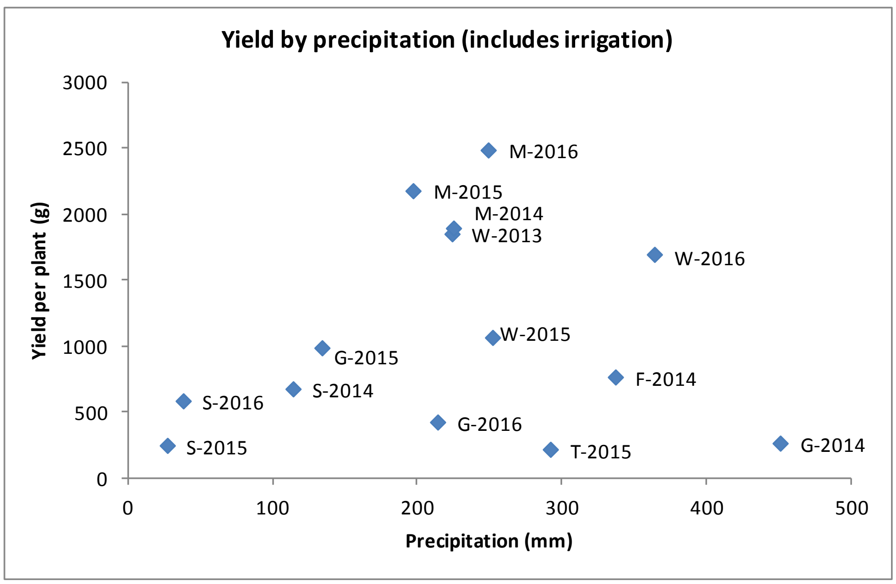
Precipitation over the growing season was measured in-field or determined from nearby climate stations. Where used, an estimated amount of irrigation was added to the total growing season precipitation. Our analysis focuses on precipitation during the main part of the growing season, with the assumption that once the plants have begun to yellow increased moisture had little effect on yield because the plants have senesced and are unable to take up much moisture.

Total growing-season precipitation ranged widely from a low of 27 mm in Saanich BC in 2015 to a high of 451 mm in Gananoque in 2014 (Table 4), demonstrating great differences in moisture availability from site to site and year to year. This range may represent the kinds of extremes to be expected with climate change. Climate change models are not yet very effective in projecting precipitation, though they may indicate changes in seasonal distribution. Models cannot project individual events and especially extreme events, whether droughts or downpours, though it is likely that these will occur more frequently and be more intense,

The roles of precipitation in yields include total amount of precipitation, as well as its distribution through the growing season and particularly during tuber initiation and bulking up. Table 5 provides a short description of the growing season precipitation during our trials. The intensity of rainfall can also influence development and yields especially if fields flood during a key development stage of the plants.

Average yields were highest in the precipitation range between 100 and 250 mm (Figure 8). Looking at each variety individually, a similar pattern emerges (Figure 9). Highest yields for most varieties were achieved between 100-250 mm growing season moisture. On this basis, it seems that a growing season precipitation or precipitation plus irrigation of 100 mm is adequate to obtain reasonable yields for most varieties whether heritage or conventional. Saanich had the lowest of all seasonal precipitation except for one year where it had the second to least moisture availability. In all three years the yields were very low compared to most other sites.

The seasonal distribution of precipitation at each site (Table 5) presumably also influenced yields. A comprehensive analysis of timing and yield needs to be carried out to look at this relationship and is beyond the scope of this summary report. However, the results from Saanich may point to the importance of early to mid-season rainfall in a situation where there was no irrigation (Figure 8 , Table 5). 2015 was a very dry year and the spring months of May and June were extremely dry. The yield was the poorest for all stations and years. In 2014 there was significantly more spring (May) rain, though later in the season it was dry. Nevertheless, the yields were 2-3 times greater. At Gananoque strong precipitation in the spring was associated with strong yields whereas in 2016 even though precipitation was 80 mm greater, the key late spring early summer growing months were dry and the yield was much less.



S Saanich
W Winlaw
M Mackin Creek
Y Yukon
T Three Fathom Harbour
F Fredericton
G Gananoque

Figure 8. Average yield per plant compared to growing season precipitation for each site-year.

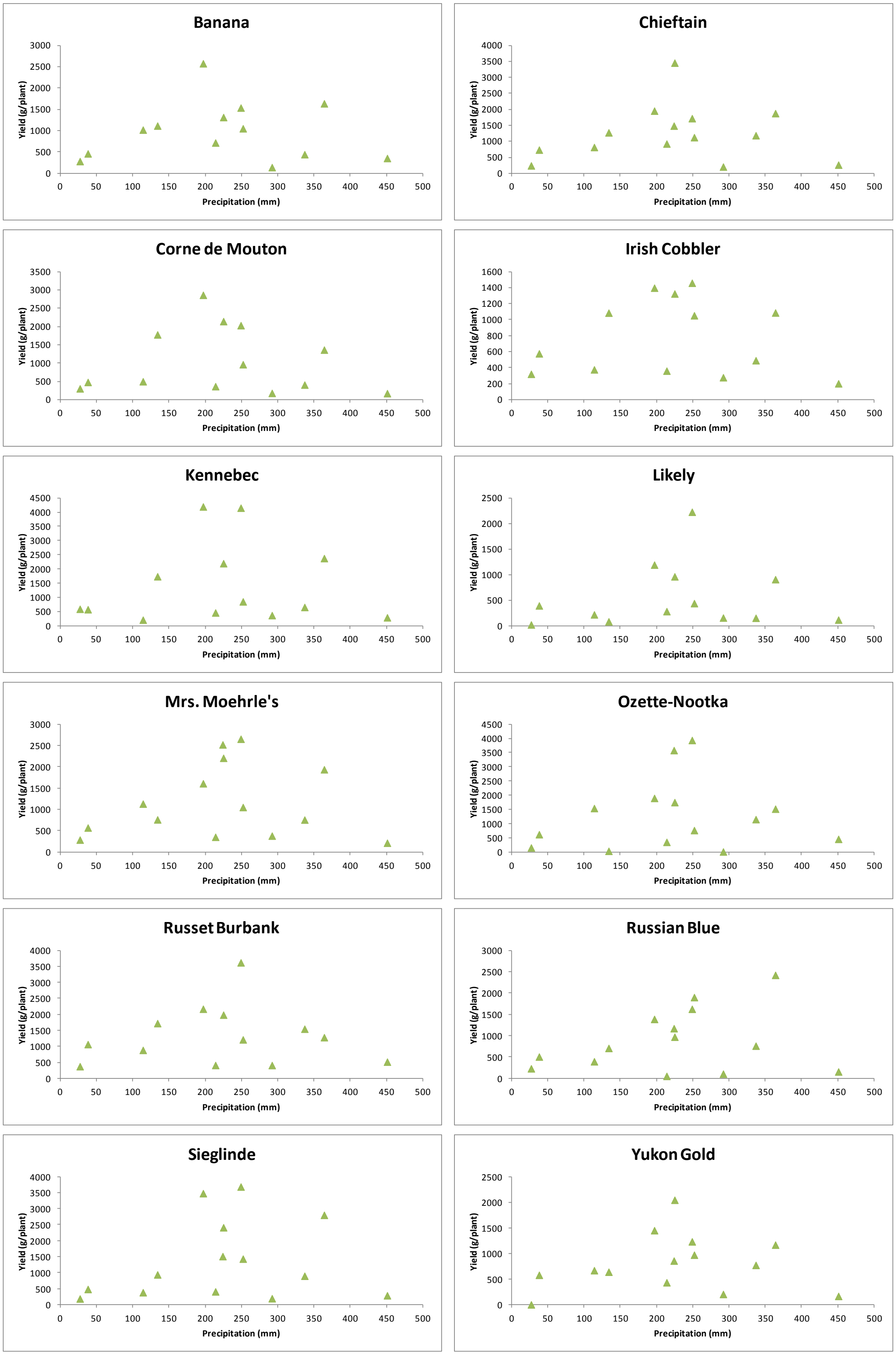


Figure 9. Potato variety yields compared to precipitation (all sites 2014-2016).

RELATIVE HUMIDITY

Relative Humidity during the growing season was measured in-field at 75 cm above the ground. Most sites and years had average RH of 60-80 %. Mackin Creek and Winlaw in the dry interior of British Columbia were the least humid sites (Figure 10). The most humid site was Three Fathom Harbour on the cool Atlantic coast of Nova Scotia.

Notably the irrigated Mackin Creek location had the highest yields, suggesting that as long as water is supplied, low relative RH has no negative consequences. However, the very humid and low-GDD Three Fathom Harbour site had the lowest yields. None of our sites exhibited daily average low stress values for RH.

Many varieties exhibited low yields at high relative humidity values (Figure 11). These included conventional and well-known standards such as Yukon Gold and Kennebec and heritage varieties Russian Blue and especially Likely. Mrs. Moehrle's Yellow and Irish Cobbler exhibited at least one example each of high yields at relatively high RH.

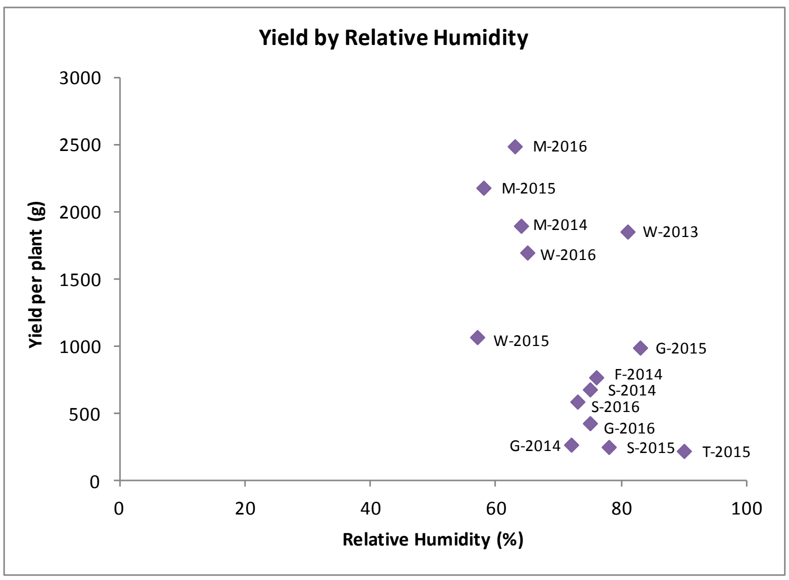


Figure 10. Site yields compared to seasonal average Relative Humidity.

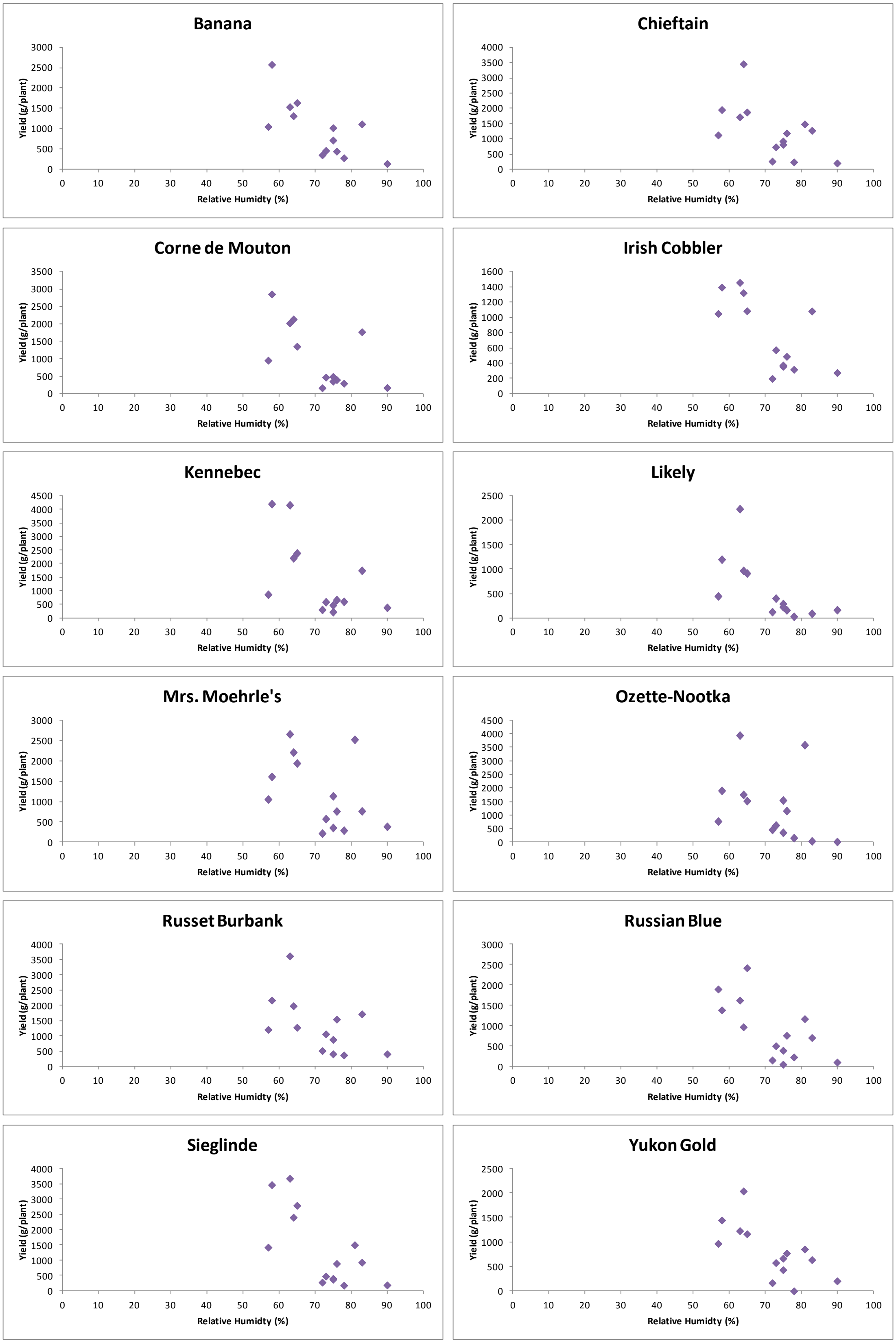


Figure 11. Varietal yields compared to seasonal average Relative Humidity.

STRESS EVENTS

The timing of stress events relative to the growth stage of the potato (as indicated by above ground phenology) is important for an understanding of the potential impact of stress on potato growth and development. Stresses, such as excess heat and high humidity, have direct effects on potato quality, yield and storability. Stresses also affect the development and spread of insects and diseases, and ultimately the yield.

Different climatic regions experience different stresses. Winlaw experienced many days of high temperature stress. Mackin Creek saw the most low-temperature stress yet achieved high yields. The Nova Scotia coastal site had the highest high relative humidity, though Gananoque came close second. Generally, the number of stress-factor days seems not be related to yield (Table 11, Figure 12). Nor was the total number of stress days related to yield. With the exception of moisture availability, perhaps more intense and longer duration stress events are required to impact yields. Observations of Russian Blue point to some of the effects of stress on potato quality and yield in Gananoque (Box 5).

Stress Days	G-14	G-15	G-16	W-13	W-15	W-16	M-14	M-15	M-16	S-14	S-15	S-16	F-14	T-15
Temp > 30 °C	0	1	9	66	43	27	5	4	0	2	2	8	14	0
Temp < 7 °C	0	5	18	21	1	11	42	43	47	2	17	19	23	5
RH > 80%	37	59	33	37	9	10	15	8	18	27	43	14	62	45
RH < 40%	0	0	0	4	8	3	9	21	6	1	0	17	0	0

Table 11. Summary of temperature and humidity stress days for each trial.

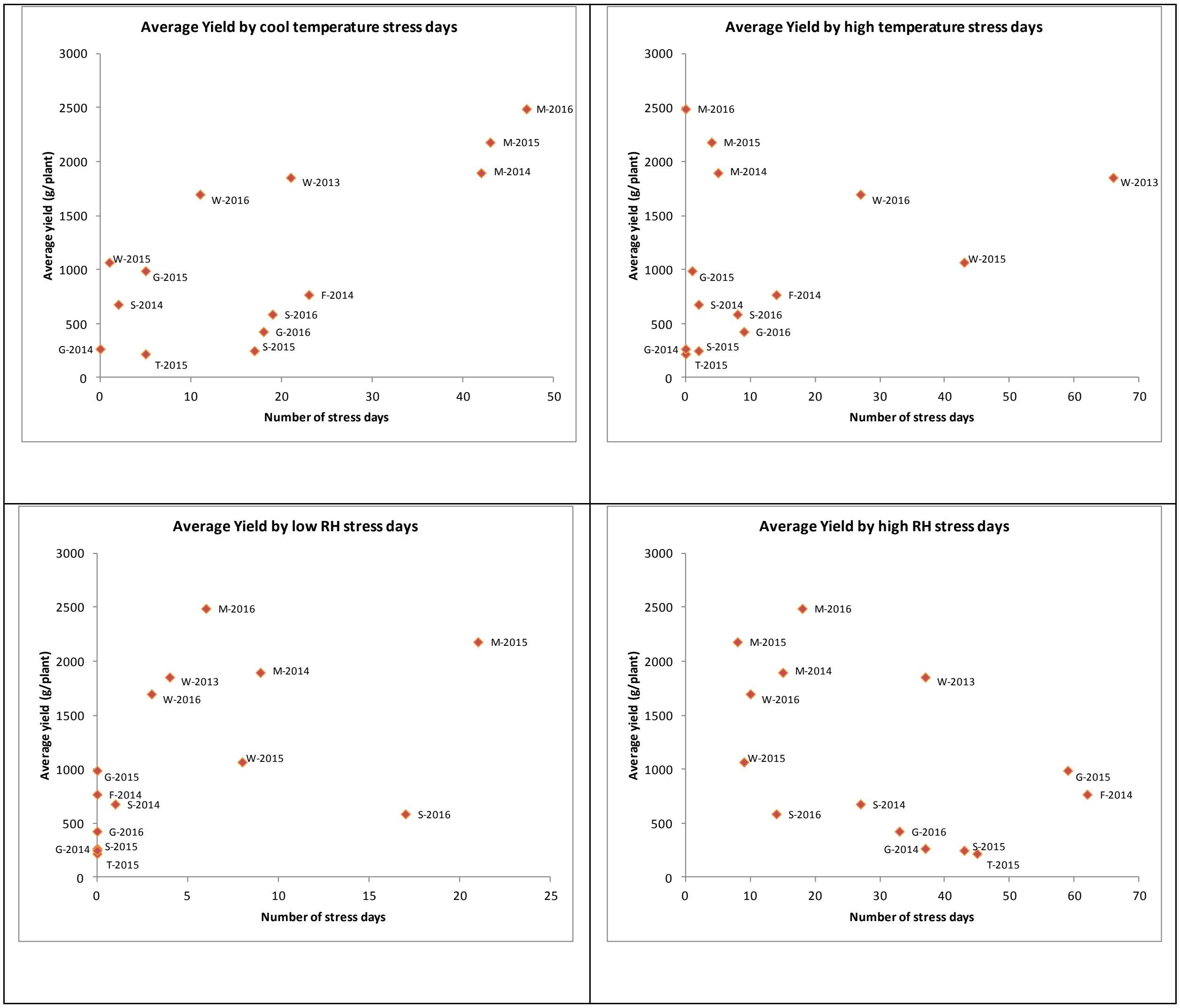
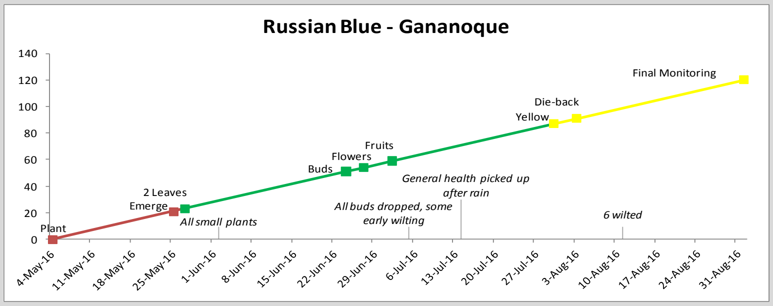
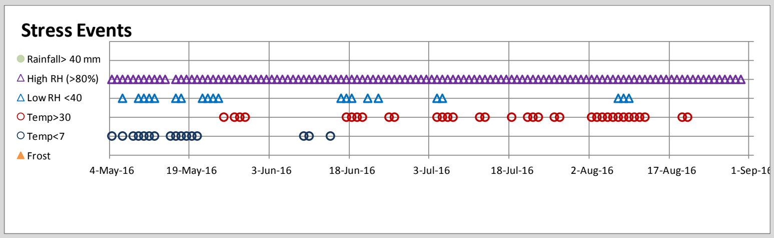


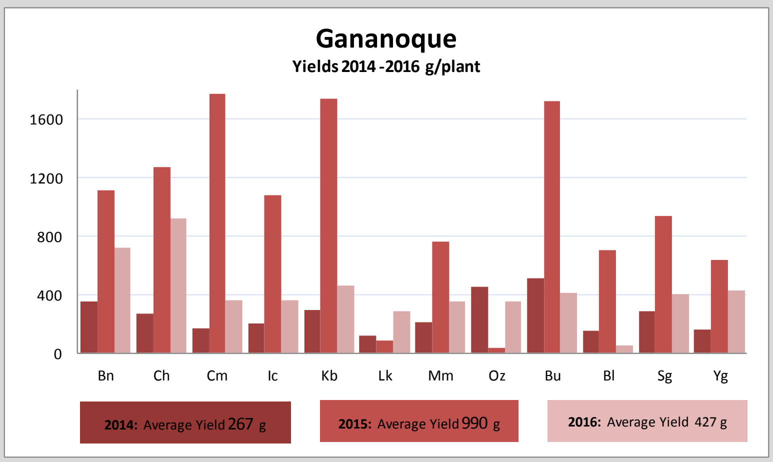
Figure 12. Average yield for each trial relative to cool temperature stress days, high temperature, low relative humidity and high relative humidity stress days.

An understanding of the types and timing of stresses typical at a site relative to the phenology of varieties, and the stress tolerance of each variety gives the grower options for choosing potatoes best suited to typical conditions. Such observations also point to management strategies for stress events as they begin to emerge in the year. For example, a grower may observe the plants coming into flower, indicating a transition to the bulking up phase of tuber growth. During this phase, high heat and low moisture availability can halt tuber growth. With the addition of water (rain or irrigation), the potatoes will start growing again, often producing knobby growth. If a grower can avoid having their field dry out during this critical phase, they can maintain even growth and raise quality tubers.

Climate stressors and Russian Blue growth and development in Gananoque, ON







In 2016, early-season temperatures were cool in Gananoque, which may have contributed to slower than average emergence and development.

Drought conditions developed early with extended periods of high heat. Soil moisture stress combined with high humidity led to wilting and early die-back.

Tubers were few and very small with low yields (53 g/plant) - much lower than 2015 (708 g/plant) and 2014 (156 g/plant).

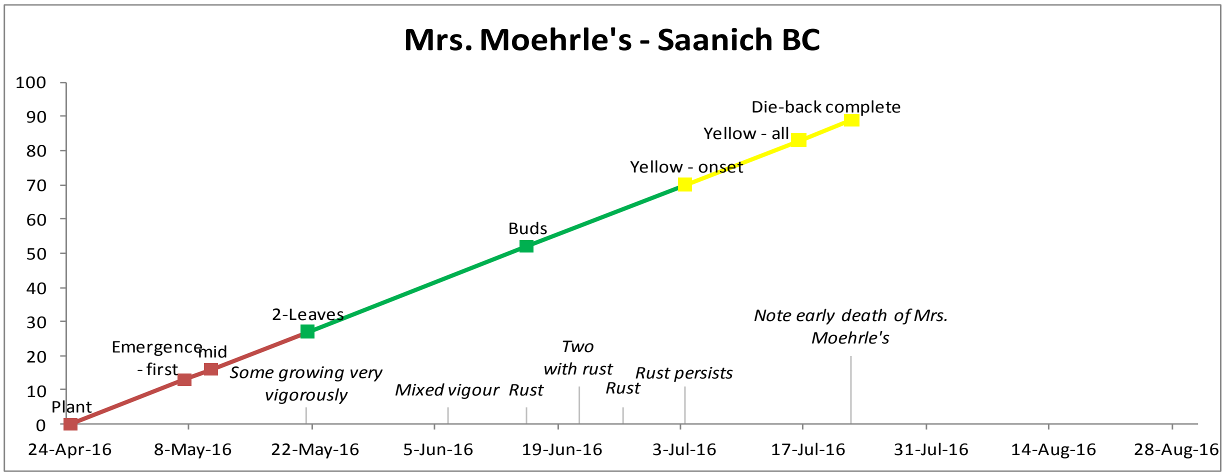
Other varieties withstood the conditions better. Banana and Chieftain both produced more than in 2014, though less than 2015, while Likely produced higher than in both years.

Box 5. The effect of weather stresses on the growth and development of Russian Blue in Gananoque, 2016.

GROWTH AND DEVELOPMENT MONITORING

Crop-climate project growers monitored the growth and development of different varieties in the same location, adding their observations of pest appearance, vigour, and unusual growth. This information allows comparisons among the varieties at a site and for a single variety among sites. For the poorly known heritage varieties we can see which mature early, and those that are late. Site-to-site comparison may reveal whether different climates influence the rate of development and even change the relative order or development. As noted earlier, above-ground progression through growth stages is key to estimating tuber maturity and harvesting dates.

Figure 13 compares the growth and development of Mrs. Moehrle's Yellow in Saanich and in Winlaw. Mrs. Moehrle's Yellow is a long-season potato, often not dying back before frost hits. In Winlaw, BC, this variety took 120 days to mature, and developed fruits during this period. In Saanich, BC, it started growing vigorously, but then developed rust, never flowered and quickly dried 89 days after planting.



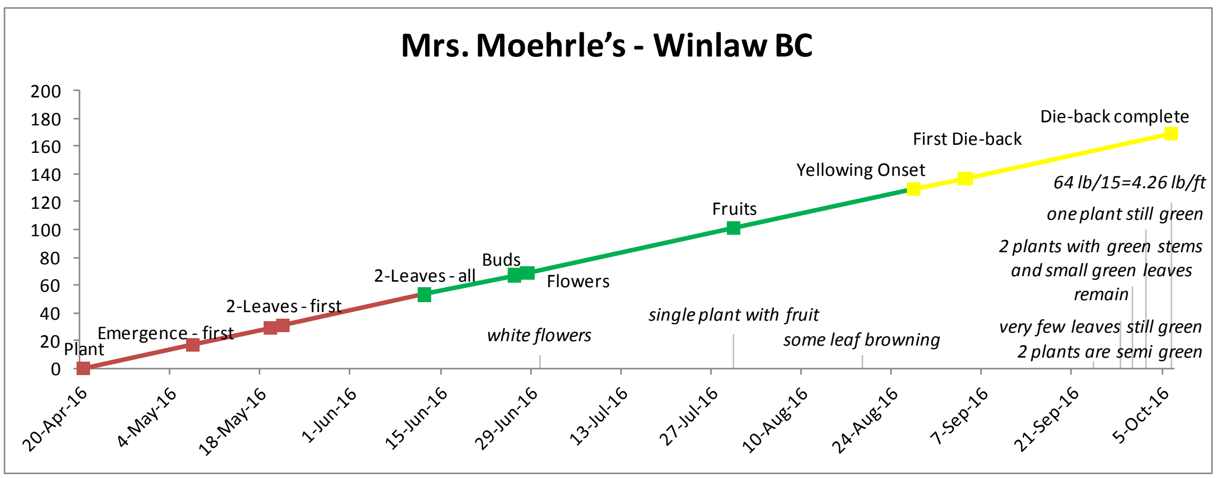


Figure 13. Growth and development of Mrs. Moehrle's Yellow at two British Columbia sites, with observer comments below the line. Brown line represents the emergence phase, the green line is the active growth phase and the yellow line is the maturity phase.

Figure 14 shows growth curves for three potatoes: Banana, Calico and Ozette-Nootka monitored in Saanich BC. The emergence phase (represented by the brown line) was fastest in Calico, and slowest in Ozette-Nootka. Once the plants have reached the '2-leaf' phase, it began the active growth phase (represented by the green line). During this phase plants produce new leaves, initiate and bulk up tubers, and flower. Calico had the shortest active growing period, whereas Banana had the longest. The notes accompanying the growth stage monitoring showed Calico dropping its buds and beginning to wilt, possibly due to adverse weather conditions or stress due to pests or disease. During the die-back phase (yellow in the graphs), tubers continue to bulk up as long as there continue to be green leaves. Ozette-Nootka began yellowing unusually early in Saanich in 2016, where in other years it remained green until harvest.

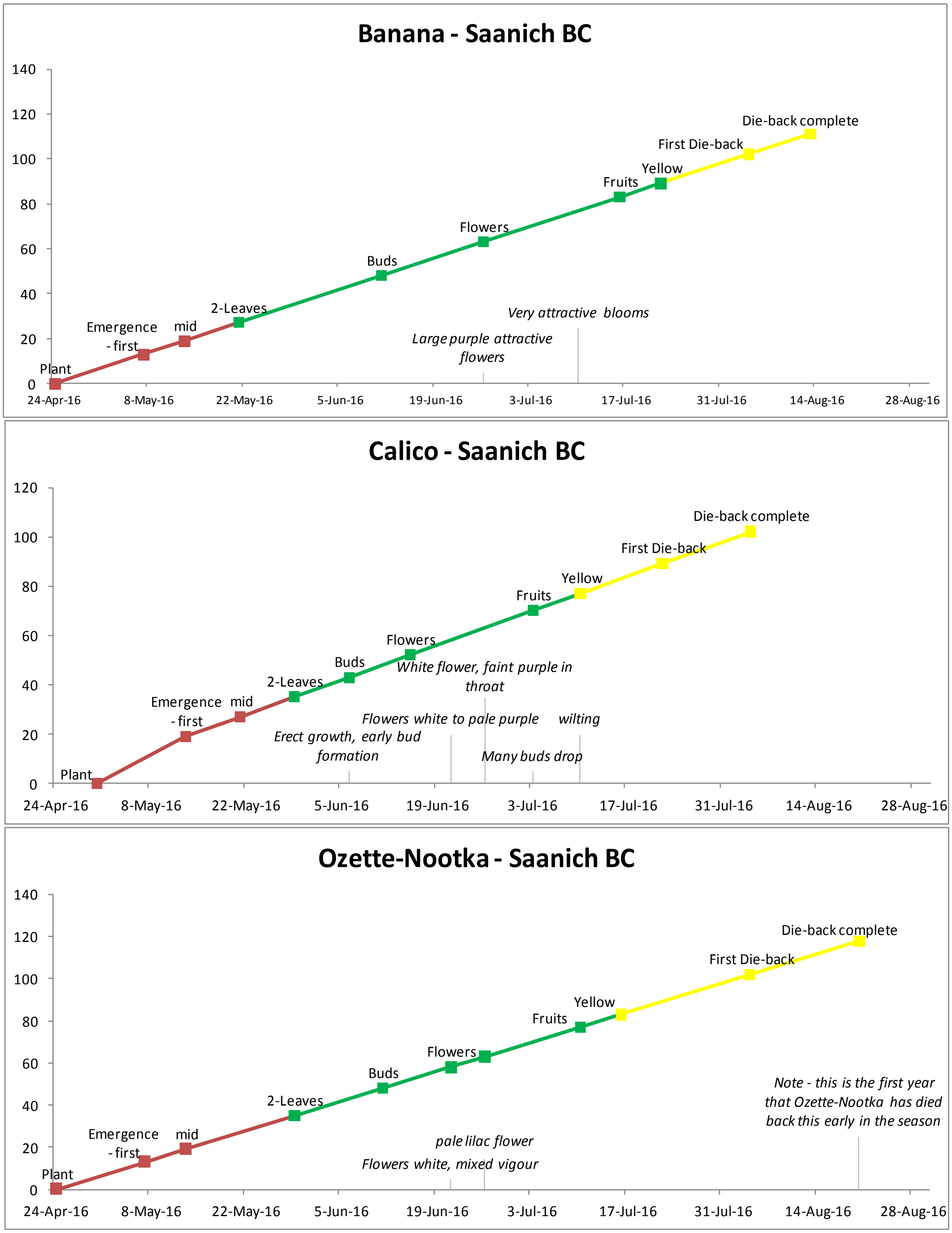


Figure 14. Growth and development of Banana, Calico and Ozette-Nootka heritage varieties in Saanich BC in 2016. Brown line represents the emergence phase, the green line is the active growth phase and the yellow line is the maturity phase. Y-axis is number of day

Comparing the growth and development of Mrs. Moehrle's Yellow and Ozette-Nootka against GDD accumulation and stress events, it is possible to speculate which stressors were affecting the plants at a particular growth phase as well as how much heat accumulation was required for each stage (Figure 15). Mrs. Moehrle's reached the two leaf stage at just over 200 GDD. Ozette-Nootka required close to 400. Early in the active growth phase, Mrs. Moehrle's Yellow experienced two days of very high humidity which could have triggered development of rust which ultimately killed the plants. Ozette-Nootka was slower to develop and slower to die back. During the die-back phase, potatoes are bulking up - heat stress at this stage (indicated by red dots) can cause quality problems for the tubers.

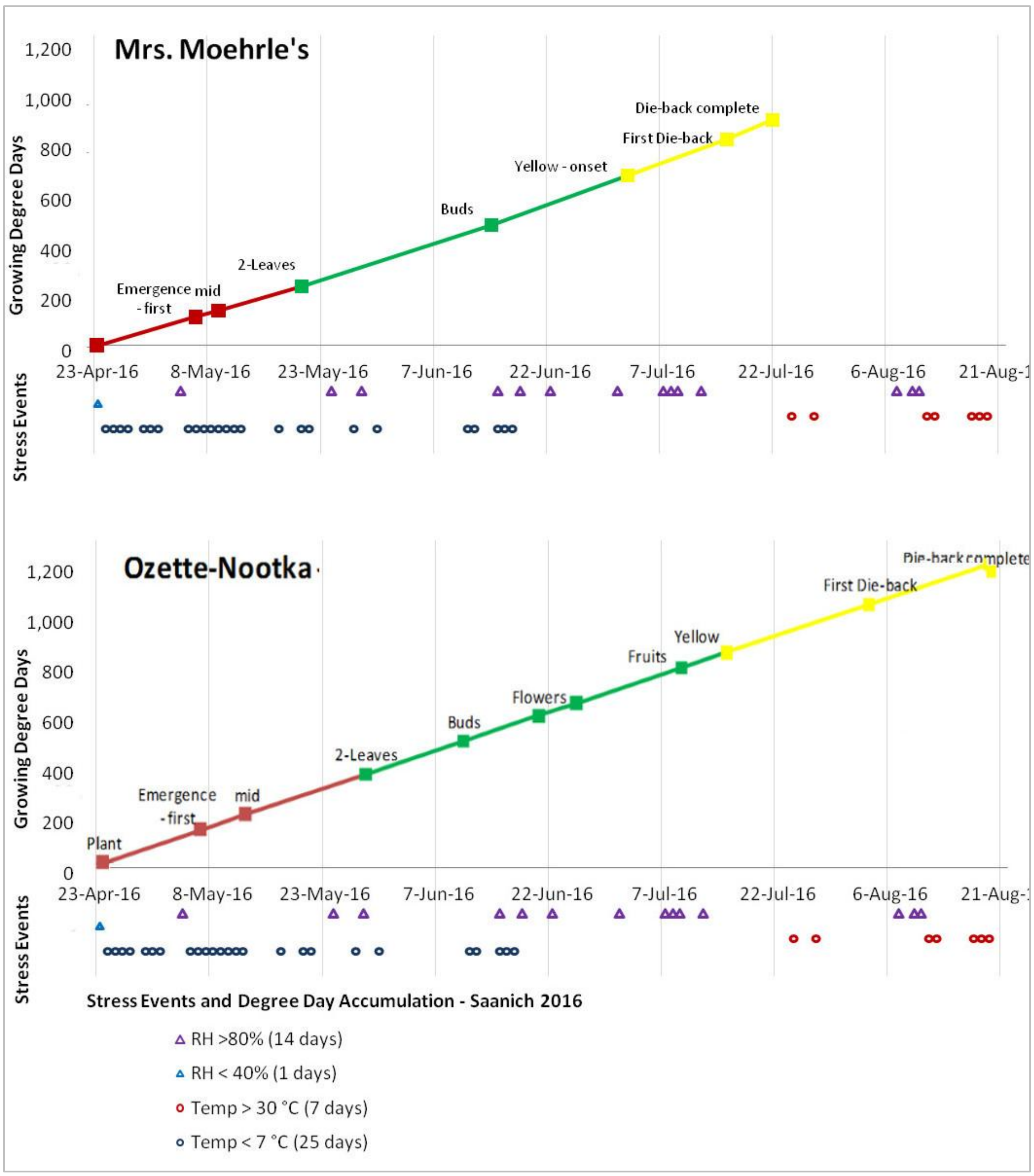


Figure 15. Stress events and degree day accumulation during growth and development of Mrs. Moehrle's Yellow and Ozette-Nootka in Saanich 2016.

PESTS AND DISEASES

As always, observers recorded a variety of pests in their potatoes, many of which affect yield or quality (Box 6). The detailed notes show the timing of emergences of pests (which may be related to heat or rain) as well as the susceptibility or resistance of each variety to each pest. Insect and disease resistance or tolerance have not previously been documented for many of our heritage varieties. Detailed observations are available in the individual reports (Huff and Hebda 2015, 2016, 2017). Overall, several main pests and diseases were reported in different years and different locations.

Colorado Potato Beetle

One of the most problematic pests of potatoes, the Colorado Potato Beetle (CPB) was noted in Fredericton, Three Fathom Harbour, Gananoque, and Trail. The most heavily infested varieties were Banana, Irish Cobbler, Likely, Chieftain, and Bauer Grün Rote Auge. CPB was never reported for Saanich, Williams Lake, Winlaw, or Mayo. CPB outbreaks predicted to expand to areas that have never had them before and will likely move further north with climate warming. To help control CPB, eliminate volunteer potato plants where larvae overwinter, and practice good crop rotation.

Wireworms

Saanich has reported wireworms in several different years, with Mrs. Moehrle's Yellow, Sieglinde, Chieftain and Kennebec most affected. No other location reported wireworm damage. Wireworms are frequently found where a garden is established in newly overturned sod. They can also migrate into a garden patch from an adjacent lawn. Wireworms chew holes into plant roots, causing damage to root crops as well as reducing growth of other plants.

Aphids

Aphids were noted only by our grower in Mackin Creek in 2016. Banana suffered from prolonged infestations, Corne de Mouton, Likely, Yukon Gold, Chieftain were the next most vulnerable. Calico, Kennebec, Mrs. Moehrle's Yellow and Siberian Fiery Eye had no aphids. Aphids harm the plant by sucking juices from the stems and leaves of plants and can transmit virus diseases in the process.

Flea Beetles

Growers frequently noted the presence of small holes in the leaves of young plants, particularly Banana. The plants usually recovered with minimum apparent damage. The holes were likely flea beetles - a common garden pest.

White Grubs

Grub damage to potatoes was reported in both Gananoque and Three Fathom Harbour, where they caused damage to the surface of the tubers. As with wireworms, grubs are most problematic in a garden established from sod.

Early Blight

Early blight, a fungal disease of potatoes and tomatoes, was reported in various years, by several growers, including in Saanich, Trail, Gananoque and Fredericton. It can cause defoliation and a loss of yield. It overwinters in or on the soil surface in infected plant debris as well as in compost. Crop rotation and removal of infected plants are recommended for prevention of reoccurrence.

Figure 16. Early blight on leaves of Bauer Grün Rote Auge in Saanich, 2018.

Common Scab

Common scab has been reported on some varieties in all locations. Varieties that are reportedly susceptible to scab include Banana, Likely, Corne de Mouton, Yukon Gold, Irish Cobbler, Kennebec, Mrs. Moehrle's Yellow, Chieftain and Sieglinde. Scab is caused by a bacteria and is most prevalent in soils with a pH above 5.4. Liming and adding wood ashes to potato soil is not recommended where scab is prevalent.

Rhizoctonia

This common fungal infection was reported in Fredericton on Banana, Corne de Mouton, and Sieglinde in 2014, and again on Corne de Mouton in Mackin Creek in 2016, It is likely more common and widespread than reported in our trials, as it is often mistaken for scab. Also known as black scurf, the *Rhizoctonia* fungus typically causes small black specks on the tuber that are readily removed by scrubbing. It is primarily a cosmetic problem, reducing marketability of infected tubers.

Silver Scurf

Silver scurf is another fungal disease which often builds up in storage of seed tubers. In 2015, Gail Elder discovered it on Ozette-Nootka potatoes stored over winter. Potatoes infected with silver scurf are perfectly edible, but they should not be used as seed potato as the fungus can inoculate other varieties. When found in stored potatoes, it is important to disinfect the storage space and carefully inspect any other nearby seed potatoes.

What makes a good potato?

Potato quality depends on the context and personal preferences of the grower and the consumer. Growers for the commercial market require potatoes of consistent size (not too small, not too large), free from knobbiness, scab, bruising and other defects. Many people have not been exposed to the diversity of shapes, colours, flavours, and textures that are available and our expectations about what a potato 'should' be is therefore limited. Varieties with deep eyes, for example, are largely out of favour and people see this as a defect, requiring extra work to clean and peel.

Home growers have the opportunity to try different varieties and can also tolerate minor defects and inconsistent sizing more easily. For example, the oversized Chieftain potato (right) would be culled by a market gardener. A home gardener could make it in to several meals!

Inconsistent sizing was common for Banana, Kennebec, Irish Cobbler, Yukon Gold and Ozette-Nootka. Different sizes (right), knobby, and scabby potatoes are rejected by most consumers, but can be dealt with easily by home growers.

Gananoque oddball potatoes – 2015 (photos C. Wooding)

Giant (oversized) Chieftain potato

Grub and disease damage on Irish Cobbler

Knobby Russet Burbank

Mixed sizes of Yukon Gold

Small to large Corne de Mouton potatoes with some greening

Box 6. Potato tuber quality observations at Gananoque. Ontario 2015.

TUBER QUALITY

Growers in the Crop-Climate Project reported on tuber size, shape, health, appearance, and marketability of potatoes at harvest. At Saanich the distribution of tuber size was recorded also for each plant. These reports supplement the climate monitoring data and provide a better understanding of the individual varieties and grower's experience with these varieties. Detailed summaries are available on our website, in the various annual reports, and in the varietal descriptions.

COMPARATIVE YIELDS

There are many ways of looking at yield when comparing varieties. In this section we examine overall varietal performance integrated under all conditions experienced by the trial sites. In other words, what are the best potato varieties over all, rather than what variety fits what conditions best. We also gain insight into the best potato growing conditions overall.

Yield data are presented in several ways: actual yield per year per site (Table 12), range of yields by variety (Figure 17), various ranked yields by variety and by site by year (Tables 12-14).

Table 12 shows how widely yields can vary: from 0 to 4.2 kilograms per plant. The table also shows that the highest yields by far were obtained at Mackin Creek farm, near Williams Lake BC. Clearly the cultural practices and presumably to some extent climatic conditions are superior for potato production at this location. Yields also varied hugely at a single site from year to year as demonstrated by Corne de Mouton at Gananoque between 2104 and 2015: 171 grams per plant in 2014 compared to 1777 in 2015. Seed tuber quality aside, climatic factors can be strongly suspected in this case (see Table 4, heavy rain).

	F-2014	T-2015	G-2014	G-2015	G-2016	W-2013	W-2015	W-2016	M-2014	M-2015	M-2016	S-2014	S-2015	S-2016	Y-2016
Banana	444	141	355	1115	718		1052	1637	1315	2576	1538	1021	283	463	353
Chieftain	1186	207	267	1275	926	1486	1125	1877	3455	1955	1719	817	243	736	473
Corne de Mouton	405	178	171	1777	362		962	1362	2141	2861	2030	496	302	477	393
Irish Cobbler	490	277	201	1085	360		1052	1087	1324	1397	1459	376	320	576	440
Kennebec	656	370	293	1736	463		853	2376	2196	4192	4149	210	593	577	327
Likely	154	158	118	84	283		440	908	963	1192	2225	220	23	395	507
Mrs. Moehrle's	758	382	215	762	354	2520	1052	1937	2206	1609	2653	1132	288	571	293
Ozette-Nootka	1152	14	458	38	352	3580	767	1519	1750	1898	3935	1542	156	622	687
Russet Burbank	1545	409	516	1720	410		1211	1280	1985	2169	3619	883	373	1064	560
Russian Blue	761	105	156	708	53	1171	1900	2421	971	1388	1626	395	230	506	327
Sieglinde	896	192	284	936	406	1509	1430	2800	2411	3477	3684	380	184	481	240
Yukon Gold	771	203	165	638	432	856	971	1167	2044	1450	1231	668		578	267
Site Avg	768	220	267	990	427	1854	1068	1698	1897	2180	2489	587	678	272	406
Site Rank	8	15	14	7	11	4	6	5	3	2	1	10	9	13	12

Table 12. Varietal yields (g/plant) from all locations and trial years. (Orange bars are a visual comparison of yields across all varieties and sites.)

Figure 17 demonstrates that some varieties are much more sensitive to variation in growing conditions, weather and climate presumably being important factors. Looking at the boxes representing the main portion of the yield values, Yukon Gold, Likely and Irish Cobbler vary much less than Sieglinde and Kennebec. The lesson here may be that sites and regions with highly varying climate are better suited to growing the first group. Kennebec and Corne de Mouton in particular seem to have low mean yields but respond positively when conditions are to their liking.

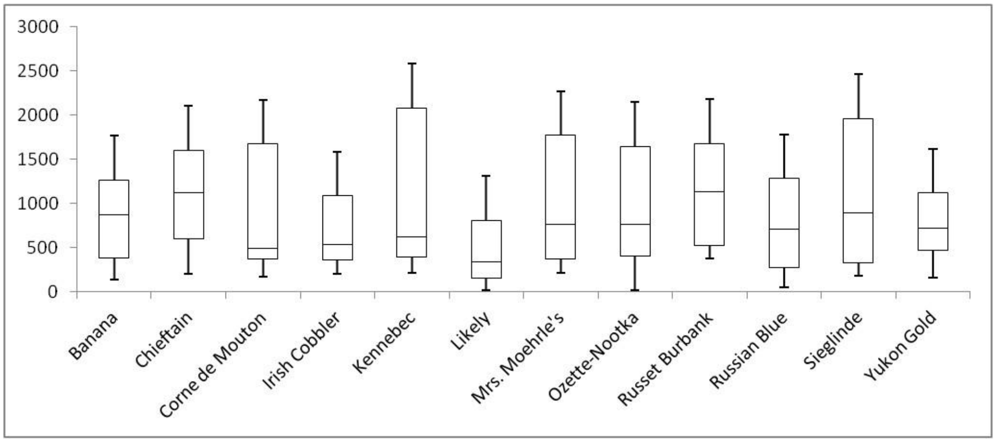


Figure 17. Box-and-whisker plot of varietal yields. The 'box' represents the middle range of yields, the line in the 'box' shows the average yield per plant. The lines extending from the boxes (the 'whiskers') show the maximum and minimum yield values.

Table 13 demonstrates yield and the relative rank of each variety on an average per-plant-yield basis for all years. The final column shows the ranking of the varieties with the 2015 year excluded. We had various seed tuber concerns that year: at Saanich only 3 of 10 Ozette-Nootka tubers emerged at all and only after extra watering, and the quality of Yukon Gold tubers seemed to vary; in Winlaw and Nova Scotia, Chieftain tubers appeared compromised, and in Nova Scotia and Gananoque, Likely tubers were in very poor shape and only 3 emerged. A second seed source of Ozette-Nootka tubers were used that year for spacing and planting date experiments, with much higher yields than the seed tubers for the field trials.

Considering all years, Kennebec, Sieglinde and Russet Burbank rank the highest and Likely and Irish Cobbler the lowest with respect to yield. Removing the problematic 2015 year, Ozette-Nootka a heritage variety rises to first rank with Russet Burbank and Sieglinde remaining in the group. Kennebec falls well back into 6th place. The poorest yielders remain the same. The top ranking of Ozette-Nootka is consistent with many informal reports we have received from growers such as that described by Phil and Carla Burton in Box 1.

	YIELD	RANK	RANK (x 2015)
Kennebec	1357	1	6
Sieglinde	1287	2	3
Russet Burbank	1268	3	2
Ozette-Nootka	1231	4	1
Chieftain	1183	5	4
Mrs. Moehrle's Yellow	1115	6	5
Corne de Mouton	994	7	8
Banana	930	8	7
Russian Blue	848	9	9
Yukon Gold	763	10	10
Irish Cobbler	746	11	11
Likely	548	12	12

Table 13. Varietal average yield (g/plant) and overall rank - all years and without 2015 data.

Average yield values can be affected by heavy yields of particular plant in specific years at any site, or mistakenly combining the yield of two plants together. A more realistic way is to compare the relative performance of the varieties at each site in each year (Tables 14,15). In this case the cultural conditions and weather presumably were the same for all the varieties. Considering the top three ranks, Russet Burbank, Kennebec, and Ozette-Nootka rank the highest (Table 14). Mrs. Moehrle's Yellow, Sieglinde and Chieftain rank relatively well also. Yukon Gold, a popular conventional variety, never ranks in the top three, and places last 3 times. The average lowest yielding variety overall - Likely - actually ranked third highest in Yukon in 2016. Similar rankings occur when weighting the top three yielders at each site for each year (Table 15).

	HIGHEST	2ND HIGHEST	3RD HIGHEST	LOWEST
F-2014	Russet Burbank	Chieftain	Ozette-Nootka	Likely
T-2015	Russet Burbank	Mrs. Moehrle's	Kennebec	Ozette-Nootka
G-2014	Russet Burbank	Ozette-Nootka	Banana	Likely
G-2015	Corne de Mouton	Kennebec	Russet Burbank	Ozette-Nootka
G-2016	Chieftain	Banana	Kennebec	Russian Blue
W-2013	Ozette-Nootka	Mrs. Moehrle's	Sieglinde	Yukon Gold
W-2015	Russian Blue	Sieglinde	Russet Burbank	Likely
W-2016	Sieglinde	Russian Blue	Kennebec	Likely
M-2014	Chieftain	Sieglinde	Mrs. Moehrle's	Likely
M-2015	Kennebec	Sieglinde	Corne de Mouton	Likely
M-2016	Kennebec	Ozette-Nootka	Sieglinde	Yukon Gold
S-2014	Ozette-Nootka	Mrs. Moehrle's	Banana	Kennebec
S-2015	Kennebec	Russet Burbank	Irish Cobbler	Yukon Gold
S-2016	Russet Burbank	Chieftain	Ozette-Nootka	Likely
Y-2016	Ozette-Nootka	Russet Burbank	Likely	Sieglinde

Table 14. Highest (Columns 1-3) and lowest (column heading 12) yielding varieties by location and trial year.

VARIETY	WEIGHTED HIGH YIELD SCORE
Russet Burbank	18
Ozette-Nootka	15
Kennebec	14
Sieglinde	11
Chieftain	10
Mrs. Moehrle's	7
Russian Blue	5
Banana	4
Corne de Mouton	4
Irish Cobbler	1
Likely	1

Table 15. High yielding varieties ranked by weighted frequency of top 3 performance (1st place rank - 3 points, 2nd place - 2 points, 3rd place - 1 point).

Growers can inspect our data to get some guidance as to what varieties to try in their region's climate with respect to yields. Notably, as far yield goes, one little-known variety Ozette-Nootka, produces as much or more in most regions than all the conventional varieties. Several heritage varieties such as Sieglinde and Mrs. Moehrle's Yellow often yielded as well as conventional types. One popular type Yukon Gold yielded very poorly under almost all climatic conditions. And one very poor yielding variety, Likely, can produce good yields under a marginal climate (Mayo, Yukon).

The other feature evident in the yields is that differences in weather from one year compared to another at the same site resulted in huge differences in yield (see Kennebec at Saanich and Corne de Mouton at Gananoque). For those relying on regular and dependable yields from year to year this observation demonstrates the value of the many-eggs approach to growing potatoes. When one variety fails others may well shine. Unambiguously for potatoes, growing several varieties from year to year supports adaptive sustainable food production in Canada.

Other Observations

Participants have made other observations that have contributed to our understanding of potato growing in a changing climate. We have summarized some of these results in earlier reports, on our website, and in the varietal summaries. In this section, we focus on some of the interesting mini-experiments that people have carried out.

TASTE IS IMPORTANT – NACHO NYAK DUN TASTE TEST

In a preceding section we concentrated on yields, but this is only one aspect of the desirability of a potato variety. A critical feature of any new crop or variety is its acceptability to the grower and consumer.

The Nacho Nyak Dun undertook an informal taste test; none of the high-yielding varieties got a high ranking (Figure 18). Sieglinde and Kennebec only got negative reviews. Presumably the results would differ in other communities. Nevertheless, this innovative taste test reveals that poor yielding varieties such as Banana and Likely can be the tastiest. In the case of Likely it is notable to point out that at Mayo in central Yukon where the test was carried out Likely had relatively high yields compared to conventional varieties.

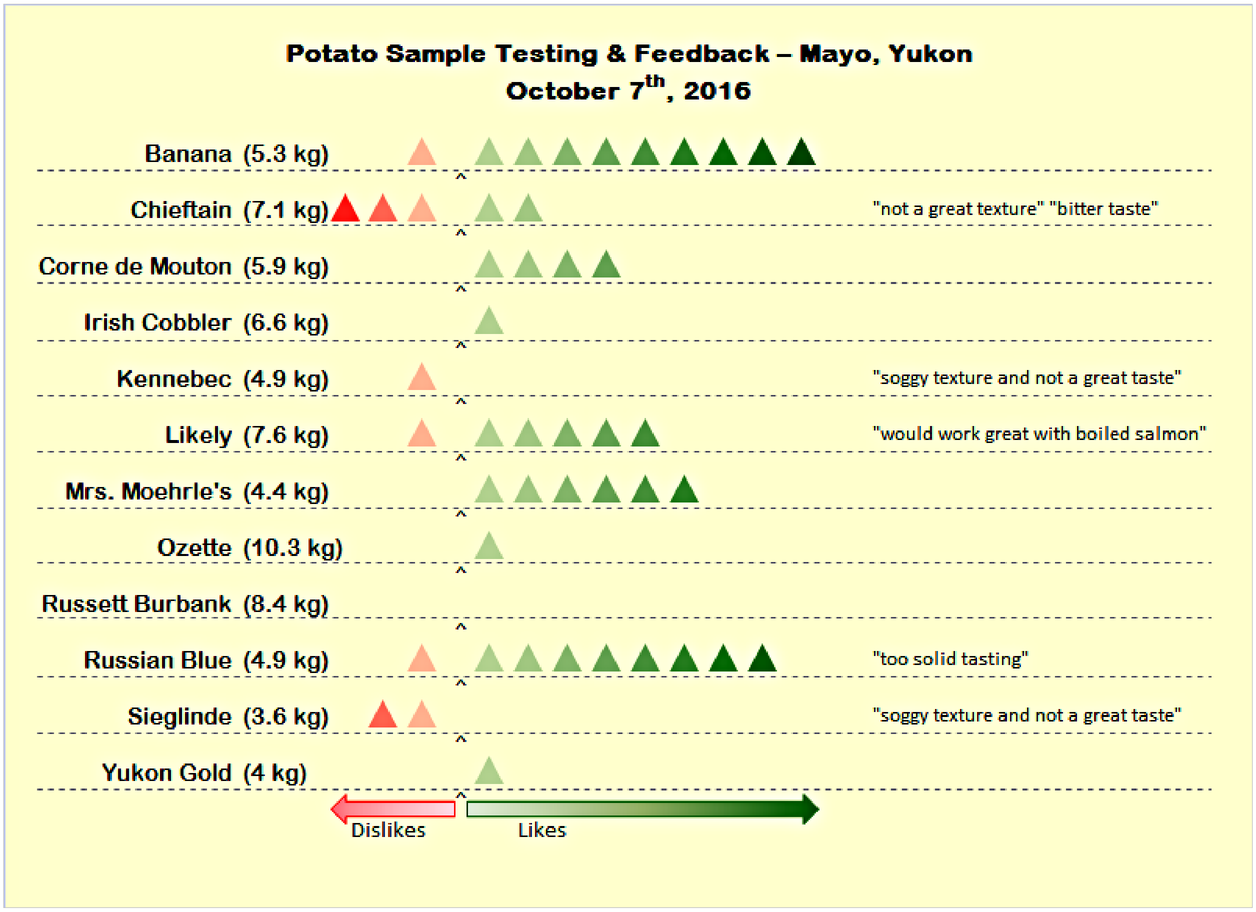


Figure 18. Potato variety taste test with varietal yields and sampling of comments in Nacho Nyak Dun First Nation in Mayo, Yukon, 2016.

Many potatoes in our trials are grown, primarily for their flavour. Yukon Gold has been a very poor performer overall (see previous section), but it remains one of the most widely accepted potatoes for its flavour. It was the standard against which all other potatoes were compared in the Nacho Nyak Dun taste test.

Other participants have adopted different potatoes as their favourites. Tom Pederson savours the flavour of Corne de Mouton, Dianne Luchtan likes Ozette-Nootka for its lower glycemic index and heritage connection, Valerie Huff loves the buttery flavour of Mrs. Moehrle's Yellow. The taste and texture of Irish Cobbler keep people growing this potato in spite of its propensity for scab and rhizoctonia. High yields are desirable, but there are always other considerations for keeping different varieties in the mix.

TRANSPLANTING VOLUNTEER POTATOES

When harvesting potatoes, particularly indeterminate varieties such as Siberian Fiery Eye (see Huff and Hebda 2017), Banana and Ozette-Nootka, tiny tubers are frequently missed and left in the ground. The following spring, volunteer sprouts frequently emerge. A number of our participants who are careful with crop rotation, dig up the volunteers and transplant them into a new area of the garden, with good success. While this is not a typically recommended practice, due to the possibilities of disease build-up and transfer to new areas of the field, we have received reports of excellent results from Richard Hebda and Dianne Luchtan.

IRRIGATION EXPERIMENT

A constant supply of moisture results in high quality potatoes. Irrigation makes up for rain in dry areas and years. In 2013 and 2016, Richard Hebda compared irrigated and non-irrigated potato plots for selected varieties (Figure 19).

Some varieties responded to added moisture whereas others did not. Ozette-Nootka and Siberian are two potatoes that have indeterminate growth in common; they keep growing and are green until frost kills them. They grow like vines and a Victoria gardener reported an Ozette-Nootka grown in shade that reached 3 metres in length. These varieties just keep making more potatoes as long as they can grow. Mrs. Moehrle's Yellow is reported to be late season potato and may have some tendency to continue forming new tubers. In the case of Likely regular watering increased the yield of medium to large tubers compared to the typical numerous small ones. For the other varieties regular heavy watering did not improve yields and the tubers developed white lenticels (white growths) on the tubers perhaps to "breathe".

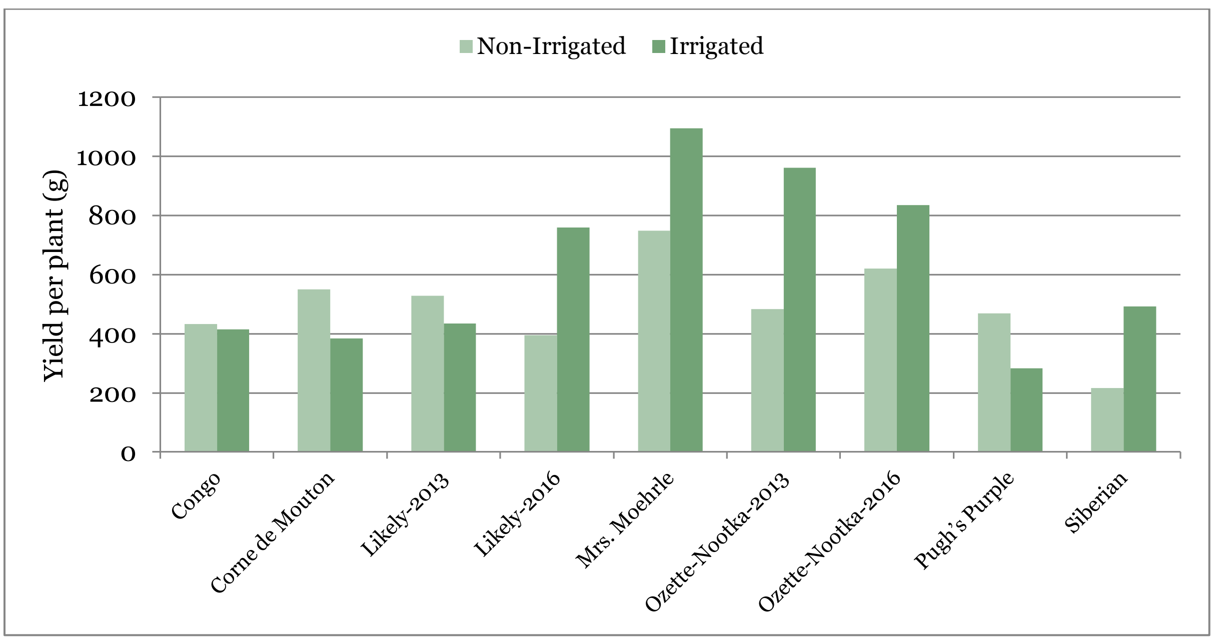


Figure 19. Comparison of irrigated and non-irrigated yields for selected heritage varieties grown on southern Vancouver Island. Likely and Ozette-Nootka were tested in two different years, as indicated by year in parentheses.

We noted earlier that optimal growing season moisture seems to be 100-250 mm per season. Watering later in the season may not be particularly useful to varieties that have formed and sized their tubers early. But for those that continue to grow (indeterminate sorts) late season watering increases yields. Too much watering however may lead to a decrease in tuber quality.

POTATO VARIETY PERFORMANCE

In this section, we summarize the results of the field trials by variety to provide information that can be used to help growers select varieties for the diverse regions in Canada. The section includes those varieties that were part of our formal trials as well as many other others that growers tried. For those the information is not as comprehensive but useful observations were made.

Commercial Varieties

We included three commercial/conventional potato varieties - Chieftain, Kennebec, and Russet Burbank in our field trials for comparison with the less commonly grown sorts (Figure 20). These potatoes are readily available to growers, have high yield potential, and are widely used for conventional purposes such as fries and bakers. They have a familiar flavour profile. Conventional types, including these three will remain part of the suite of potatoes grown across Canada. In our field trials, they were consistently among the highest yielding varieties. Their yields vary widely and there were years and places when and where these varieties yielded poorly (Figure 21).

Figure 20. Chieftain (left), Kennebec (centre) and Russet Burbank (right) single plant yields, Gananoque 2015.

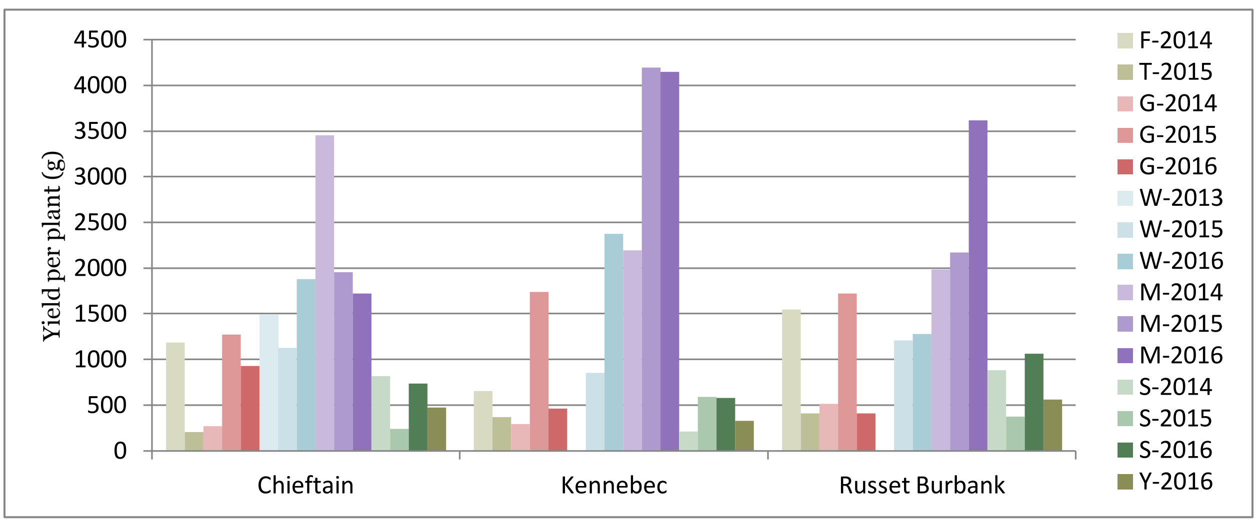


Figure 21. Yields of Chieftain, Kennebec and Russet Burbank from all trials across Canada. See Figure 8 for abbreviations of site location names.

CHIEFTAIN

Chieftain is a red-skinned, white-fleshed mid season potato bred in Iowa in 1957. The variety appears to be widely adapted to a wide range of climates today. It performed well in most years in most locations, though seemed to suffer during particularly hot years such as 2015 in Gananoque. It was susceptible to potato beetle infestations, flea beetle leaf damage and aphids. On harvest, in most years the tubers were reported to be clean and free from scab. Quality was often rated as good, though some trials recorded different problems such as under-sizing, over-sizing, and growth cracks. In the Mayo taste test in 2016, Chieftain had the most dislikes, citing its 'bitter flavour' and poor texture.

Chieftain may be well adapted for cooler growing locations with few days of heat stress. As the climate warms, it may become easier to grow it in more northerly regions and harder to protect from heat stress in hot and dry locations and years.

KENNEBEC

Kennebec, a mid to late season white potato, has long been a staple for Canadian growers and consumers. It performed well in field trials in terms of yield, though it was the lowest producer in at least one trial (Saanich 2014) and was reported to be susceptible to oversizing and cracking at other locations in other years. Kennebec's yield varies widely and perhaps it should be planted along with other varieties. It may rank poorly under stress conditions.

RUSSET BURBANK

Russet Burbank is the most widely grown potato in North America and is the standard french fry and baking potato. In our field trials, it was ranked highest for yield overall, with lower yields in droughty locations and years without irrigation. Quality was generally good, though there were problems with scab, knobbiness, oversizing and leaf curl.

According to Benoit Bizimungu, at the Fredericton Research and Development Centre and Agriculture Canada's lead potato breeder, Russet Burbank's high requirements for a uniform moisture supply and nitrogen management, make it a less than ideal candidate for sustainable production systems (Glen 2018). It is not drought tolerant, but with a long growing season and good moisture, this potato has high yields and stores very well without losing quality. It is likely to remain a favourite variety of growers where conditions can be managed.

Most Promising Heritage Varieties

Included here are the heritage varieties that performed well - with good yields and few problems. The star performer among the heritage varieties is Ozette-Nootka, the first potato as far as we are aware to be grown in what is now Canadian territory. Sieglinde, Banana, Corne de Mouton, Russian Blue, and Mrs. Moehrle's Yellow, performed well in some years too, especially so Sieglinde which ranked second or third overall compared to others in the trails.

These varieties provide a wide range of choices from fingerings to purple to conventional rounded yellow types. They could well be part of a Many-eggs strategy for sustainable potato production especially in regions with varying weather and marginal agricultural climate.

OZETTE-NOOTKA

The Ozette-Nootka (also known as "Makah") potato is likely the descendent of a potato planted in Nootka Sound on Vancouver Island as early as 1791. Unlike most other potatoes grown in North America today, which are derived from potatoes grown in Europe, the Ozette-Nootka was brought directly from South America by Spanish explorers. It was apparently cultivated by the Makah in Neah Bay, Washington State for more than 200 years, and was likely spread along the West Coast by European settlers. The Haida potato is a descendent of the Ozette-Nootka. The tubers used in the crop-climate project originate from material brought to Victoria from the Makah Reservation in the late 1980's and grown and shared locally by Richard Hebda.

Figure 22. Ozette-Nootka potatoes, showing yield from a single plant Saanich, 2012 (left), and the flower buds which frequently drop off before opening.

Ozette-Nootka is a very promising potato for all regions of Canada with a long enough growing season. It has been among the top three yielders in many of our trial years at locations across the country, including in Mayo, Yukon. It has been enthusiastically adopted by gardeners across the country, and we have received dozens of reports of success under challenging conditions (drought, excess heat) and interesting cultural practices. D. Luchtan reports some success in her attempts to 'rewild' or naturalize it on her farm near Nelson, BC. It was even featured in the documentary film 1491: The Untold Story of the Americas Before Columbus.

Ozette-Nootka has grown largely free of pests during our trials, although we did detect silver scurf on potatoes stored over winter, and there was an issue with the seed used for the 2015 trials when no location reported high yields, and it ranked lowest in two locations (Huff and Hebda 2016). If we exclude the 2015-year results due to seed potato quality concerns (see above under comparative yields), Ozette-Nootka was the highest yielding potato in all our trials.

In addition to the standard field evaluation, we conducted several small-scale tests on Ozette-Nootka to best understand its agronomy and management. These results are summarized here, full details can be found in Huff and Hebda (2016, 2017). On south Vancouver Island in 2012, Ozette-Nootka responded to irrigation by producing large heavy tubers with few knobs and other deformities. In Winlaw in 2016, a spacing of 30 cm produced a slightly lower yield than at 20 cm, but resulted in consistent tuber size, with very few culls for small size, and fewer deformities than at the wider 40 cm spacing. Sequential planting dates in Gananoque in 2015 (Figure 23) showed highest yield and best quality on the second earliest planting date. Early plants likely suffered from cooler soil temperatures, while later plantings may not have had enough cumulative heat to fully develop and set tubers.

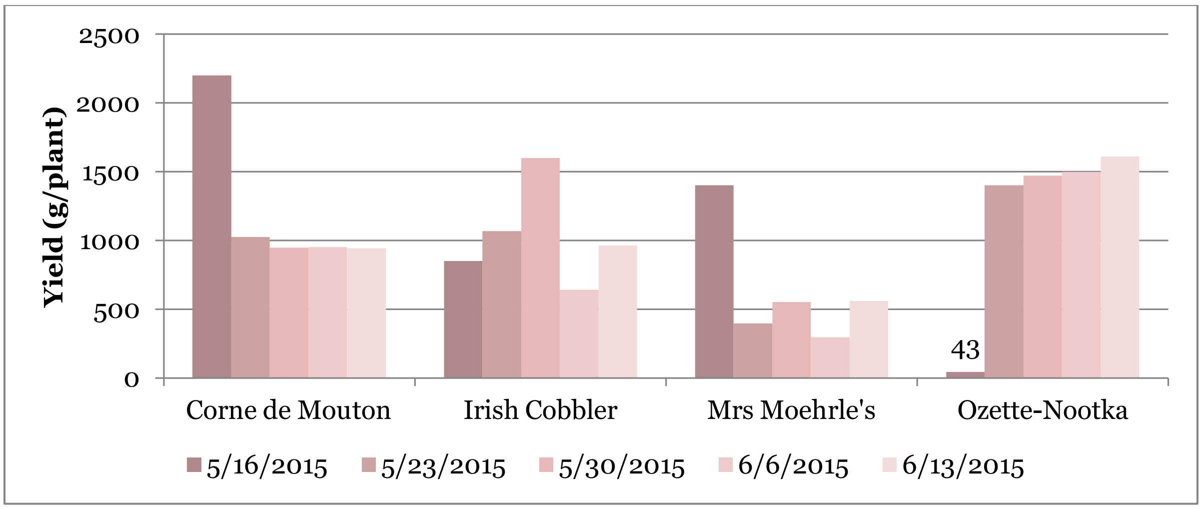


Figure 23. Effect of planting day on potato yield for Corne de Mouton, Irish Cobbler, Mrs. Moehrle's Yellow, and Ozette-Nootka, in Gananoque, 2015. Note Ozette-Nootka's poor performance on first planting, which came from that year's problematic seed source. Remaining plantings were from different source material.

Despite its unconventional shape and deep eyes, it is easy to bake in pieces or slices with skin on. Many people have informally reported that they like its taste and that it is their favourite potato. We have distributed thousands of tubers. Ozette-Nootka is highly recommended as a heritage variety for a wide range of climates.

BANANA

Banana potatoes are a late maturing yellow-fleshed fingerling, with many small banana-shaped tubers (Figure 24). They have been grown in British Columbia for at least 90 years and are widely available as seed potatoes. Banana has been a consistent performer in field trials across Canada and under varying climatic stresses. It appears to be adapted to a variety of growing conditions and performs well under moisture stress. It produces tubers early and continues to grow and produce until late in the fall.

Figure 24. Banana fingerling flowers (left) and single plant yield from Saanich British Columbia, 2012 (right). The range of sizes is typical for this variety.

In 2013, Banana was the highest yielding of four fingerling potatoes grown in Gananoque, Ontario; it was the second lowest yielding in Saanich, BC (Figure 25). When looking at multiple years among sites and at the same site over three years, a similar pattern of highly varying yields emerges. These diverse results suggest that Banana yields (as well as yields of other varieties) are highly sensitive to local conditions throughout the growing season.

Tubers tend to be very numerous and small, often too small to be marketable, challenging for cleaning, and hard to store. Quality problems include greening, susceptibility to scab, damage by flea beetles, wireworms, aphids and Colorado Potato Beetle.

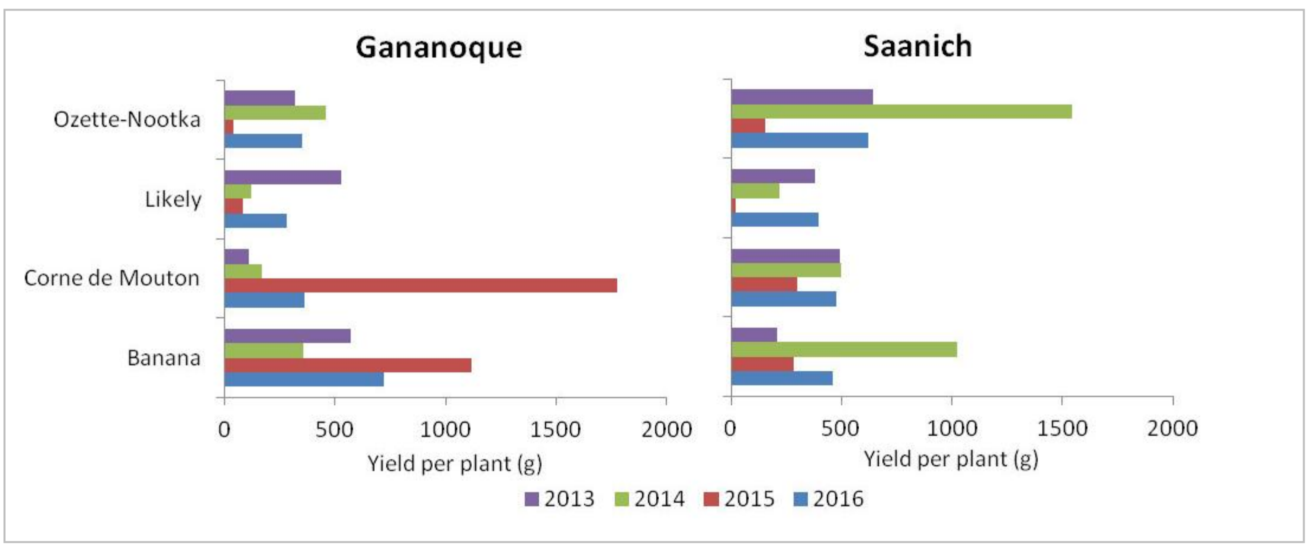


Figure 25. Yields of four fingerling potatoes: Banana, Likely, Corne de Mouton, and Ozette-Nootka in Saanich and Gananoque 2013-2016.

For home growers, they can be a reliable source of small fingerlings - they produce continuously through the season. They are a good option to supplement a main crop potato. In some years, they can outperform other varieties, reinforcing the need to plant more than one variety to cope with a changing climate.

CORNE DE MOUTON

This fingerling potato of French origin, also called La Ratte and Ram's Horn is valued for its nutty rich flavour (Figure 26). It is available from several seed potato growers in Canada. In our trials it was a solid performer, a mid-season potato, with good yields and relatively few problems such as minor amounts of rhizoctonia, leaf rust and some greening of tubers. Yields may vary widely as demonstrated in Figure 25 and it may benefit from early planting for maximum production, as seen in Figure 23.

Figure 26. Corne de Mouton potatoes grown in 2012 for the Crop-Climate Project in Victoria, British Columbia (left). The flowers of this variety are a lovely pale pink (right)..

Overall, this is a promising potato with some tolerance to heat and drought. Several of our informal participants have continued to grow this variety for its ease of care and its delicious taste.

MRS. MOEHRLE'S YELLOW-FLESHED

Mrs. Moehrle's Yellow came to us from Garrett Pittenger, a heritage potato collector from Caledon, Ontario. In 2012, Mrs. Moehrle's Yellow was highly productive in all test locations, producing large clean round tubers (Figure 27A), and we identified it as having excellent potential in areas with a long growing season. It typically grows until it is either harvested or killed by frost (Figure 27C). In the trial years, it continued to produce good yields most years, but suffered from a variety of problems, including early blight, low set, inconsistent sizing, and scaly and warty flesh (Figure 27B). In the Gananoque planting date trial, it benefited from early planting (Figure 23).

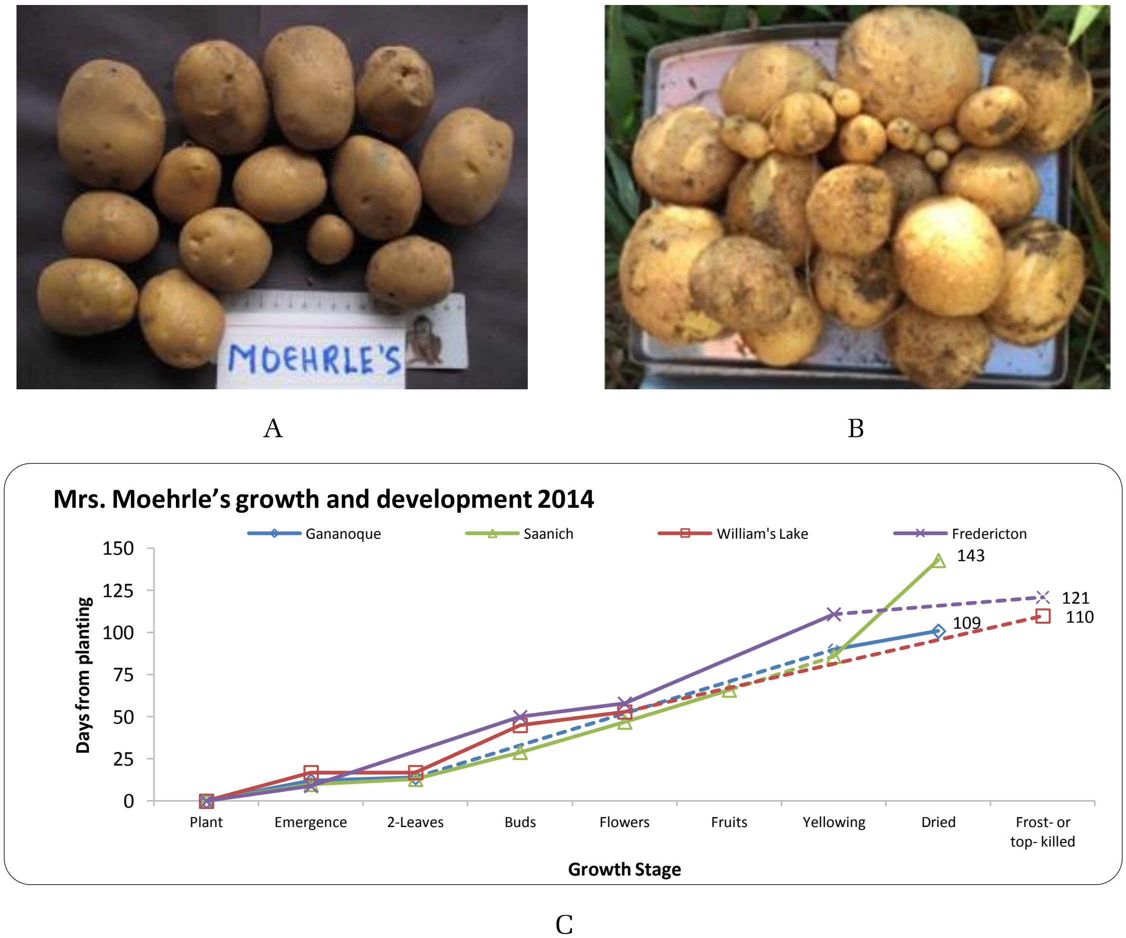


Figure 27. Mrs. Moehrle's Yellow from a single plant in Saanich, 2012 (A) and Gananoque, 2016 (B), showing inconsistent tuber sizes. Growth and development through 2014 at four sites are shown in the lower part of the figure (C) with the numbers illustrating the number of growing days until the plant dried or was harvested green.

We suspect that the increasing skin quality problems arise from declining seed tuber quality as virus and disease accumulate in the tuber. Other possible explanations for skin deformities include waterlogged soils (whether from too much irrigation or from high rainfall) or over-fertilizing with manure or very rich compost.

Seed tuber quality will always be a challenge for home and market growers of heritage potatoes which are not (yet) part of the commercial seed potato market. A small number of virus-free mini-tubers can be obtained from the Fredericton Research and Development Centre (Agriculture and Agri-Food Canada), and we highly recommend renewing the seed stock for future years.

RUSSIAN BLUE

A blue fleshed potato with dark purple skin which is reported to be a heritage variety from Russia (Figure 28). These are commercially available through various sources. Russian Blue performed erratically in the field trials from year to year and site to site. In Winlaw in 2015 and 2016, it was the highest yielding (Figure 28B) and second highest yielding variety; in 2016 in Gananoque, it was the lowest yielding variety, producing only a few small tubers per plant (Figure 28C). It was also highly favoured in the Mayo Taste Test (Huff and Hebda 2017).

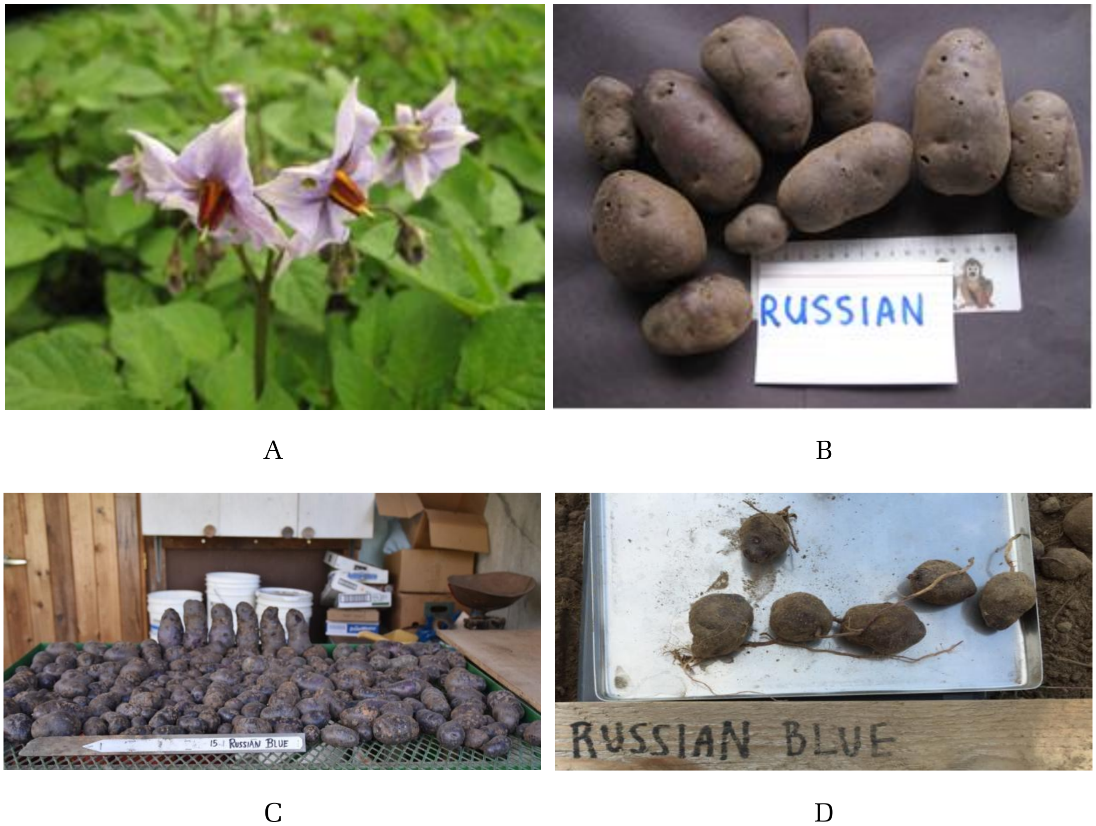


Figure 28. Russian Blue flowers are pale purple with orange stamens (A), Yields are variable: High tuber yield from single plant average yield, Saanich 2012, 10 plants very high yield in Winlaw 2016 (C), and low yield from single plant in Gananoque, 2016 (D).

SIEGLINDE

This is an early season potato variety with vigorous growth. It produces large oblong, slightly-flattened, smooth tubers covered with clear yellow skin. The skin is very thin, making it a preferred variety in European cuisine. The eyes are shallow and the flesh is yellow and firm. The tubers store well. This potato has good resistance to scab, mosaic virus and warts - and tastes great as well.

Growers reported excellent results with Sieglinde, with very few problems. Richard Hebda has had great success transplanting sprouting tubers from the previous year. Seed potatoes are readily available from many growers, so access to clean seed should be quite straightforward. Many growers to whom we have distributed seed report that it is their favourite potato, although testers in Mayo reported that it 'tasted soggy'. Sieglinde is widely grown as a crop on southern Vancouver Island, particularly by organic growers.

Remaining Trial Varieties

The remaining varieties performed poorly in our trials but may find a place in the garden in some areas and or may be an important source for breeding material for future adaptations. For example, “Likely” a British Columbia origin potato performed better than others in the Yukon. Despite its poor yields Yukon Gold is widely grown for its cooking qualities and is commercial variety. Irish Cobbler is Garrett Pittenger’s (Caledon, Ontario) favourite potato. These three varieties demonstrate that despite poor yields heritage and commercial varieties have other qualities that make them worth growing.

IRISH COBBLER

This very early heritage potato was problematic in our trials, with low yields and numerous disease reports (Figure 29). It appears to be neither heat nor drought tolerant, and unlikely to be adapted to anticipated fluctuations in climate.

Despite this, it remains a popular potato, due to its exceptional earliness and great flavour. It may produce well in cooler, more northerly regions as the climate warms.

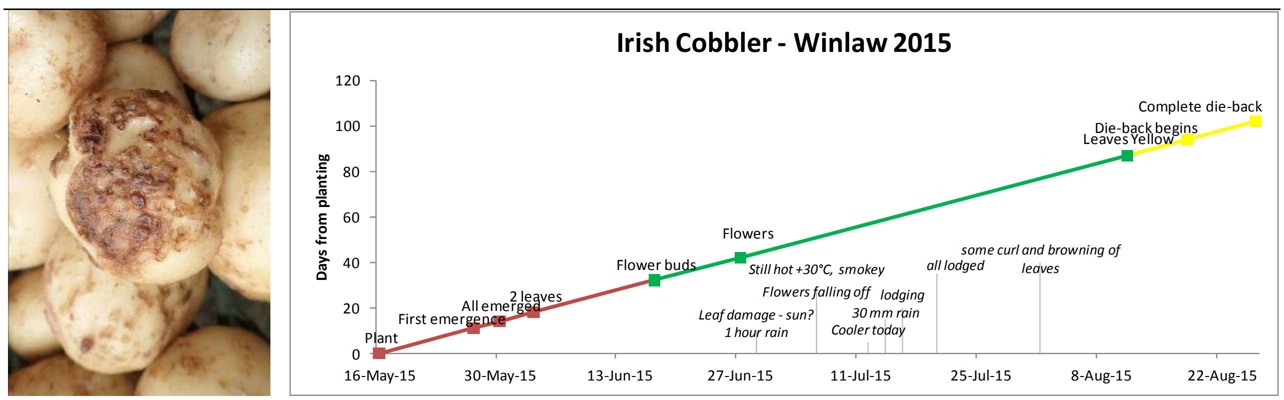


Figure 29. Diseased Irish Cobbler tuber (left). Growth and development Irish Cobbler, Winlaw 2015 (left),

LIKELY

Likely, British Columbia lends its name to this fingerling potato. This potato survived many years outside of cultivation on the shores of Quesnel Lake, originally thought to have been brought to the west coast by Russian fur traders. They were passed on to First Nations people who eventually passed them on to placer gold miners in the Cariboo region of BC (Hebda and Huff 2014).

Figure 30. The white flowers of the Likely potato plant (left) and the tuber yield from a single plant grown with irrigation in Metchosin, BC in 2013.

We included Likely in our trials as we thought it may have disease and/or frost tolerance which allowed it to survive outside of cultivation for so long.

In our field trials, it has typically been the lowest producer, with small, below market-size tubers (Figure 29). The exception is in Mayo, YK, where it was out-produced only by Ozette-Nootka. In dry 2016, in Gananoque, ON, while still one of the lowest yielding varieties, it out-yielded all other years, hinting that there may also be desirable drought tolerance. In Mackin Creek in 2016, it outperformed many other varieties.

The yield potential of this historical tuber may not have been realized yet, and its frost and disease tolerance were not tested by weather conditions in any of our growing years. Our 2016 seed was produced by Chris Wooding in Gananoque from healthy sized tubers; yield from these seed tubers was higher than any other year. This observation suggests it may be responsive to further selection by local growers. It is also now possible to obtain virally-cleansed Likely clones from the Fredericton Research and Development Centre. In 2018, we are growing these out as a seed source for future comparisons.

Likely may yet prove to be a very useful early potato, particularly in the north and where growers wish to naturalize a potentially frost-hardy variety. It may also provide important genetic material for future breeding efforts by individual growers and the potato industry, if its frost or drought tolerance and disease resistance are realized in future testing.

YUKON GOLD

Yukon Gold is a very popular potato that is well known and readily available to gardeners. Its performance varied notably in our trials. It ranked 10th overall for yield (all sites, all years) and in some trials it ranked dead last (W-2013, M-2016, S-2015). There were health and quality issues as well: scab, low set, and odd tuber sizes. Yukon Gold may be a tasty, desirable potato but it appears not to be a reliable producer.

Hebda has noticed, and others have also reported, that Yukon Gold is a short season potato drying up earlier than most other varieties. It may be that early season weather conditions, especially moisture, play a critical role in getting a good crop. Good yields are not achieved until a growing season moisture of 200 mm (Figure 9). And although Yukon Gold does not require many GDD for good yields (1000), it does not exhibit the high yields of most of the other types at lower growing season temperatures (12 °C) and needs warmer temperatures for (15 °C) for good yields (Figure 6).

For growers looking for a good yellow potato, we suggest including Sieglinde and Mrs. Moehrle's Yellow in their mix of varieties. There are also many better yellow potato varieties available for growers that would provide better yields than Yukon Gold. Since yellow fleshed “buttery” potatoes are popular and sell for premium prices, a comprehensive comparative trial of similar varieties in several climatic regions is highly desirable.

Other Varieties Grown in Trials

Once engaged in the project, participants threw into their trials many other varieties just to see how these would do. Some of them were perhaps familiar to the growers, others were planted just to see what happens. Several varieties were part of our preliminary trials (Hebda 2013). This type of ad hoc experimentation is precisely what we were hoping for, and it adds a wide range of preliminary observations to share with other growers and the public.

Twenty-seven additional types were tried, some only at one site others at several sites. We thank Garrett Pittenger for supplying many of these varieties from his collection (Table 16). Several varieties show good promise across a range of conditions. Top among these are Bauer Grün Rote Auge, Siberian Fiery Eye, and Matsuyama with yields above 1000 gm per plant and even above that of our better trial varieties. We include the information here to provide a wider choice for potential growers.

The wide range of productive types, from yellow fleshed to fingerlings demonstrates the huge range of choices and adaptability. Much wider trials, even if only informal ones, are highly desirable to create performance profiles and options for the future. Siberian Fiery Eye is an example. Yielding as well as our best formal trial performer Russet Burbank, it has the continuous growth characteristics of Ozette-Nootka, persisting until frost. It seems to keep setting tubers all growing season long unlike many of the conventional types.

For information on a wider range of varieties the Kenosha Potato Project also contains entries in their catalogue http://www.curzio.com/N/PotatoCatalog.htm).

Variety	Yield (g/Plant)	# Trials
Agria	**1577**	1
Banana	725	24
Bauer Grün Rote Auge	**1096**	3
Buckskin	397	1
Calico	407	4
Cecile	224	1
Chieftain	**1118**	20
Congo	784	6
Corne de Mouton	**979**	21
Dakota Pearl	568	1
Desiree	**1162**	1
Digby	348	3
German Butterball	**1005**	1
Gold Rush	190	1
Hunza	672	2
Irish Cobbler	698	19
Kennebec	**1357**	15
Kifli	180	3
La Viene Rose	130	1
Likely	501	20
Linzer Deladatess	518	1
Matsuyama	**2100**	2
Mozart	**1269**	2
Mrs. Moehrle's Yellow	**1103**	22
Nicola	792	2
Norland	297	1
Ozette-Nootka	**1178**	22
Pacific Russet	**1329**	1
Prince of Orange	572	1
Pugh's Purple	345	5
Purple Viking	284	1
Red la Soda	689	1
Rose Fingerling	207	1
Russet Burbank	**1268**	15
Russian Blue	762	21
Siberian Fiery Eye	**1347**	9
Sieglinde	**1064**	21
Slovenian Crescent	642	5
Yukon Gold	810	16

Table 16. Yields of potato varieties grown in extended trials. High yielding varieties are highlighted in green.

LESSONS LEARNED: ADAPTATIONS FOR A CHANGING CLIMATE

Our report includes many ideas and a great deal of information. In this section we summarize key findings and suggestions for growers, whether backyard gardener or farmer. We also provide recommendations for those interested in undertaking projects similar to ours.

Practical advice to growers

PREPARE FOR CHANGES IN GROWING CONDITIONS

Growing conditions in parts of Canada where potatoes are currently grown will also be changing. In some areas, an increasing growing season means that longer season potatoes can be grown and that they can be planted earlier. Some areas currently well-suited to this cool season crop may be less suitable in the future. Almost all regions will need to prepare for increasing frequency and intensity of stressful weather events (drought, high heat, heavy rain events, etc.). Sharing experience and knowledge of adaptive practices is increasingly important.

Northern Canada has the potential to greatly expand potato production as the climate warms. With the warming already apparent, it is likely that large regions of Canada are now suitable for potato production where it was previously limited by frost and a short growing season. For those interested in experimenting in the north we note that potatoes are regularly grown in coastal Greenland. Cool northern soils may even harbour organisms that fight potato pathogens (http://www.nunalerineq.gl/english/fakt/potatoes.pdf). The discovery of the Likely potato, with its seeming strong cold tolerance, affords the opportunity for the breeding of a truly northern Canadian potato.

The increasing growing season length and the possibility of planting tubers much earlier than traditional practice will allow for the production of long-season potatoes. Some of these such as Ozette-Nootka yield as much or more than conventional types. Combined with frost management such as using row cover, most northern communities can grow their own potatoes and not have to depend on bringing heavy and expensive foods from the south. In so doing they can improve their nutrition and strengthen their own food security.

OBSERVE AND RECORD WEATHER

Our trials demonstrate widely varying yields and performance of all the varieties we grew. We linked some of this variation to differences in year-to-year weather at a single site and among sites. We also noted that there are optimal ranges of temperature and precipitation for good yields and that certain climatic measures such as growing degree days and soil temperature are valuable for establishing and managing the crop.

Although it may not be a regular practice, having at hand weather and climatic data is especially valuable in understanding why varieties succeed or fail. Information from the nearest Environment Canada climate station is a helpful way to gain insight. However, these data may not be and often are not representative of garden or field conditions. Many regions simply have too few climatic stations in any case. For these reasons, the gardener or small grower needs to observe their specific conditions such as the last date of a killing frost in the spring and in the fall.

Simple maximum-minimum thermometers placed in the field can provide valuable information if checked every couple of days. Inexpensive garden soil thermometers can reveal when soils are warm enough to plant tubers. For those interested in more comprehensive information and with large fields dataloggers such as the HOBOs in our project are especially valuable. A community or garden club can purchase a few HOBOS and a single data shuttle and software package to keep the cost low.

Growers who collect these kinds of data are encouraged to provide them along with their reports on variety performance to on-line sites such as ours. In this way more varieties get profiled across a wider range of conditions. The information can also be shared locally. In the past there was a general understanding of the typical seasonal weather in an area. However, with rapidly changing climates and especially increasing variation, the old local knowledge may not be appropriate and may actually limit the crop possibilities and the opportunity for local food sustainability.

DEVELOP AND SHARE LOCAL KNOWLEDGE

Many people have their own ideas about how to grow potatoes especially developed for local conditions. Surprisingly however some people have no idea how to grow them, for example we are often asked how deep to plant the tubers. An important lesson is to share your knowledge and find those in your community who have experience in producing potatoes. Even those who raise their own potatoes may discover that others in the community have developed clever and effective ways of growing their crop, ways that improve yields and reduce effort. Local residents often know when the earliest time to plant potatoes occurs; that time may be very different than the generally recommended dates.

Search your community for locally preferred or adapted heritage or other varieties. Do not be constrained by what is available in the local garden centre. Local residents may be willing to share their favoured varieties with you. Join Seeds of Diversity, a Canadian organization leading the seed sharing movement for decades (see Box 7), to contribute to and receive their annual seed catalogue. They also have sources for some Canadian potato varieties on their website.

Preserving and perpetuating Canadian agrobiodiversity

Seeds of Diversity has been working to "search out, preserve, perpetuate, study, and encourage the cultivation of heirloom and endangered varieties of food crops" since 1984. This pioneering Canadian non-profit helps coordinate seed sharing events across Canada, releases an annual seed directory, and provides links to Canadian seed growers - including potato growers - where Canada's seed diversity is cherished and maintained.

Links: https://seeds.ca/

Potato Seed Availability: https://seeds.ca/diversity/seed-catalogue-index?psp=245

Box 7. Connect with Seeds of Diversity for seed potatoes and other heritage seeds.

Experiment with different varieties in different fields or spots in your garden. Especially if you are growing for yourself, choose types with flavor or texture that appeal to you rather than those varieties that are grown for standard boilers, bakers and mashers. We have received many reports of people's favourites for taste such as Corne de Mouton (a.k.a. La Ratte) and Ozette-Nootka.

Try potatoes in the north of Canada even if no one has ever grown them in your community. People at Mayo in the Yukon were able to get good crops of many different varieties. Certainly, with the amount of warming Canada has already experienced large areas are now suitable for raising potatoes when previously they were not able to grow.

Planting date

Potatoes are a cool season crop, and growers need to plan to optimize their planting date to take advantage of the best possible growing conditions for their location. In our trials, planting date was coordinated as much as possible to minimize differences in seed age and sprouting among the trials with individual growers using their preferred planting date based on knowledge of local conditions. The earliest planting date was April 22 on the mild BC coast; the latest was June 8 in foggy Nova Scotia, where our grower had to wait for cold waterlogged soils to warm and dry. The ideal planting date (or dates) in any year and location can only be determined by local site conditions, within the range of optimum growing conditions for individual varieties. The 'Goldilocks zone' is one where temperatures are not too hot, not too cold, not too wet, and not too dry both at the time of planting and throughout the growing season.

Early planting, as soon as soils are warm enough and the risk of frost after emergence is low, can extend the growing season. In areas with hot summers, this also allows plants to avoid growing during high stress days (see Table 3) and to take advantage of optimum temperatures. Early planting can also provide good first-of-season crops. From our observations and from knowledge in other potato growing areas such as central Europe, the potato planting date can be moved forward by days and maybe even weeks. In Saanich for instance, good late May yields have recently been obtained from late February and early March plantings of early season varieties. Late season varieties, such as Ozette-Nootka, continued to grow through the longer growing season and had excellent late yields. In more northerly regions, where potatoes are being grown for the first time, selection of short season varieties helps get a successful crop. The season can be extended by sprouting the seed tubers in a well-lit location prior to planting.

Later plantings can be recommended for varieties for overwintering, as a later maturity favours long-term storage. Late plantings are also recommended for varieties being stored for seed. As soon as the potatoes come out of the ground, even with optimal cool storage conditions, they begin to age physiologically. Minimizing the time from harvest to replanting improves seed tuber quality and late season plantings produce more vigorous tubers for the following year.

We also recommend staggering planting dates to reduce the potential of crop loss from a single stress event (such as a late frost, or spring flooding) at a particularly vulnerable growth stage. Space your planting dates every two weeks or so. As Chris Wooding's experiments at Gananoque, Ontario showed there are no major differences in yield unless you plant very late.

Generally, though potatoes like cool growing conditions during which the plants can take advantage of natural spring soil moisture to bulk up tubers.

Spacing

Potatoes are typically planted in rows about a metre apart. From Garrett Pittenger we learned that with this spacing the potato plants will form a solid row canopy and shade out weeds. It also allows for hilling of potatoes without damaging the developing tubers. Some varieties may need wider rows, as Gail Elder reported. Ozette-Nootka, Mrs. Moehrle's Yellow and Siberian Fiery Eye had large lush top-growth that sprawled and fell over, making it hard to walk between the rows. Other varieties produce smaller plants that could be grown in closer rows.

Tubers spacing within rows is a matter of varietal needs and personal preference. We have seen them spaced from just 20 cm to more than half a metre apart. Individual varieties respond to spacing in different ways and it is important to pay attention to varietal recommendations, where they exist. Kennebec, a large, high-yielding potato is prone to hollow core and cracking if planted at the standard 30 cm spacing, so growers are encouraged to plant it closer, at 20-25 cm. Smaller potatoes, such as Irish Cobbler and many fingerlings, can be spaced more closely for abundant yield of high quality potatoes. For heritage varieties, little is known about the best spacing, and some experimentation will be necessary. In the Winlaw spacing trial with Ozette-Nootka, yield per area was highest at 20 cm spacing and yield per plant was highest at 40 cm. Close spacing resulted in numerous small potatoes, wider spacing had larger potatoes with more knobby tubers. For Ozette-Nootka, we recommend larger spacing (30-40 cm) to optimize yield, size and quality trade-offs.

Growers might consider their own spacing experiments and may be surprised how many potatoes can grow in a small area with appropriate spacing and cultural practices.

Water Use and Irrigation

Our trails concerned potato growth under natural field conditions. At first we asked that participants not irrigate or water because we were interested in growth and development under natural conditions, rather than optimizing yield for farmers, market gardeners or home growers. Our growers made it clear to us that they would not normally raise a crop without irrigation; it made no sense to them. From our results at Mackin Creek farm and at Saanich, it is clear that potatoes need watering to maintain soil moisture to produce worthwhile yields. On the other hand, over-irrigation (and excess soil moisture generally) can cause swollen lenticels (white growth at the eyes), as observed in 2012 in Metchosin trials, as well as increased top-growth at the expense of tuber initiation. Mid to late season irrigation seemed to have little benefit to yield with the exception of varieties that grow indeterminately until they are killed by frost or harvested (Ozette-Nootka, Siberian Fiery Eye).

Under a changing climate, even in regions not prone to drought, well-timed irrigation is required to obtain worthwhile yields of good quality tubers. For smaller growers, watering can be combined with moisture management strategies such as mulching. Soil moisture monitoring is especially useful to make sure potatoes grow evenly.

Fertility management

Our trials did not address the issue of fertilizer and soil management, leaving those choices to the growers. Potatoes generally are not heavy feeders and will yield well in soils of average fertility. Too much organic fertilizer and lime in the soil especially if in direct contact with the developing tubers causes scab formation. Slovenian Crescent planted into beds where "sea soil" (mixture of fish remains and wood waste) had been worked only two months before showed lots of scab (Saanich, BC).

RENEW YOUR SEED REGULARLY

Since the time of the Irish Potato Famine, potato growers have been aware of the threat from potato viruses and diseases to wipe out entire crops and the need to be vigilant about seed quality. With seed potatoes being a clone of the parent, pathogens build up year to year, and yield decreases. Commercial seed potato production deals with these issues with a highly regulated production environment.

The Canadian Seed Potato Certification Program oversees production of seed potatoes. All seed originates from disease-free tissue culture, grown in approved labs. Seed potato growers follow strict guidelines and a farm inspection system, growing the seed potatoes out for a maximum of seven generations from their tissue cultured origins (potatoescanada.com/seed-potatoes.aspx). Clean, certified seed is highly recommended where the supply is available. As we experienced in our trials, even certified seed can have quality problems, as we saw with Yukon Gold in 2015, which had an extremely low yield year.

Most heritage varieties are not available through the certification program, and growers can learn to safely grow, store and exchange interesting varieties. Home storage can be challenging, with quality being affected by numerous factors (time of harvest, health of the plant at harvest, curing process, and the innate storability of the variety). We experienced problems in Saanich when storage conditions weakened the tubers, which then sprouted early and had poor emergence. This was particularly a problem for the seed potatoes shipped to growers with a later planting dates in colder regions of Canada.

One possibility for people wanting to expand and/or continue their seed potato production is to order small tubers from Potato Gene Resource Centre, in Fredericton NB (see list in Figure 31) every few years. These are potatoes that are in the public domain and can be grown out to keep clean heritage varieties in circulation. Starting with small number of tubers in the first year, large numbers of seedling tubers can be available in two years for wide dispersal. We are growing such cleaned tubers for the first time in 2018 for comparison to grower-raised tubers.

For those who have varieties that are not on the Potato Gene Resources list, they might consider having a few sent to Fredericton and having them cleaned. Cleaning up the variety is expensive, so one needs to make a strong case for the variety, usually best if it is part of some research or other initiative. We provided the unique Likely seed tubers to Fredericton and are now carrying out trials to see how the cleaned material performs compared to the tubers received from growers.

CANADIAN POTATO GENETIC RESOURCES 2017-2018

Two test tubes or two tubers (as available) of each clone are provided

Please send request and completed Standard Material Transfer Agreement to:
Canadian Potato Genetic Resources
Attention: Sylvia Soucy
Agriculture and Agri-Food Canada
Fredericton Research and Development Centre, P.O. Box 20280
Fredericton, New Brunswick Canada E3B 4Z7
E-Mail: Sylvia.Soucy@agr.gc.ca Telephone: 506-460-4399 Facsimile: 506-460-4377

ABNAKI	EARLY OHIO	NIPIGON
AC BELMONT	EARLY ROSE	NISKA
AC BLUE PRIDE	ELMER'S BLUE	NORGOLD RUSSET
AC BRADOR	EPICURE	NORTHERN WHITE
AC CHALEUR	ERAMOSA	NOVA SCOTIA BLUE
AC DOMINO	EXPLOITS	NRBK 01 to NRBK11
AC NOVACHIP	F 58050	OAC ROYAL GOLD
AC OUELLE	F 66041	OAC RUBY GOLD
AC POCAT	F 79055	OAC TEMAGAMI
AC RED ISLAND	F 79070	O'HIGGINS BLUE
AC SUNBURY	F 87084	O'HIGGINS CALICO
ACADIA RUSSET	F61101	PEANUT
ALL RED***	FINGERLING	PINK FIR APPLE
ANGELINA MAHONEY'S BLUE	FORTYFOLD	PINK PEARL
ANSON	FUNDY	POORLANDER
ARRAN VICTORY	GARNET CHILI	PRINCE ALBERT
AUSTRIAN CRESCENT	GERMAN BUTTERBALL	PURPLE CHIEF
AVON	GLENWOOD RED	PURPLE PERUVIAN
BANANA	GOLD COIN	PURPLE VIKING
BATOCHE	GRAND FALLS	RAMBLING ROSE
BAUER GRÜN ROTE AUGE	GREEN MOUNTAIN**	RARITAN
BEAUTY OF HEBRON	HAIDA***	RATTE
BELLE-DE-FONTENAY	HEIDZEL BLUE	RED ACADIAN
BELLEISLE	HINDENBURG	RED DUTCH
BINTJE	HOUMA	RED GOLD
BLACK MIGNION/THE CUP	HUNTER	RED WARBA
BLISS TRIUMPH	HURON	RICHTER'S JUBEL
BLUE MAC	IRISH COBBLER	RIDEAU
BLUE SHETLAND	JEMSEG	RIVER JOHN BLUE
BLUE VICTOR***	JOGEVA YELLOW ESTONIAN	ROSE FINN APPLE

Figure 31. Some of the varieties available from Canadian Potato Gene Resources centre in Fredericton, NB. Along the top are clean tubers for seed increase of Cariboo, Marc Warshaw's Quebec, and Red Acadian.

We can learn from experienced heritage seed potato growers such as Garrett Pittenger, Gail Elder and Chris Wooding, and take care to minimize pathogen load by following strict rotation, careful curing and selection of only the best potatoes, and careful preparation and observation during storage. Vigilance will always be required for seed potatoes, and regularly renewing seed tubers is highly recommended.

CONTRIBUTE OBSERVATIONS AND BE A LOCAL TUBER SEED SAVER

Contribute to your own community gardening circles and to organizations such as Seeds of Diversity and ours at www.heritagepotato.ca. We obtained much useful information from amateur growers, even though it was not gathered through standard experiments. This information and way of getting it confirms our approach of the many eggs in many baskets. By accumulating and summarizing these collective experiences, the regional suitability of a potato variety is quickly discovered. Our results from Ozette-Nootka were verified by numerous informal growers.

PARTICIPATE IN SELECTION AND BREEDING OF NEW CLIMATE-RESILIENT VARIETIES

Conservation of heritage varieties is critically important; equally important is developing new varieties that are adapted to our newly emerging conditions. Although this has not been a focus of our project, breeding has always been and will continue to be critical to our food security.

Historically, plant breeding and selection have been done by farmers as they adapt to local conditions. As our food system has become more centralized and industrialized, breeding is more typically done by large agribusiness, and selection has been geared toward a small number of varieties that are broadly adapted to an industrial farming system. Individual growers do, however, continue to grow and select varieties most suited to their needs, conditions and tastes.

Potatoes are a challenge for home breeders, as they are typically grown from clones rather than from seeds. Selecting the most promising tubers one year is certainly possible, but the potential to build up viruses as the clone is replanted may result in reduced yields, even of the best potatoes. Crossing potato varieties is even more challenging. Varieties selected for crossing may flower at different times. Many varieties rarely or never flower, and among those that do, many do not produce viable pollen. Those that successfully cross may or may not produce fruits that ripen within the season.

Participatory Plant Breeding

Participatory Plant Breeding is an approach being undertaken in collaboration with the Bauta Family Initiative on Canadian Seed Security (Box 8), the University of Manitoba and Agriculture and Agri-food Canada. Information about the potato breeding program can be found here: https://umanitoba.ca/outreach/naturalagriculture/articles/ppb_potato.html. We hope these, and other initiatives will make interesting new varieties available in the future.

THE BAUTA FAMILY INITIATIVE ON CANADIAN SEED SECURITY

From http://seedsecurity.ca/en/about:

"The Bauta Family Initiative on Canadian Seed Security is building a movement for resilient seed systems across Canada. Working with farmers, seed producers, researchers, and partners from civil society, government and business, we are taking action to conserve and advance biodiversity, maintain public access to seed, deliver research and training programs on ecological seed production, and promote the wisdom and knowledge of farmers."

Box 8. The Bauta Family Initiative on Canadian Seed Security

New Varieties from Seed

Another simple way to produce and test new varieties is through planting potato seed from natural crosses and trial them in the garden. As a serendipitous outgrowth of this project Hebda is participating in a trial of potato seedlings provided through Metchosin Farm (Box 9). Potato seeds are readily extracted from the green tomato-like fruit of potatoes. The dried seed is sown and grown into plants and then the tubers dug up and replanted. Those that do well are kept whereas those that fare poorly are rejected. The first-year tubers may be small, but in the case of vigorous and potentialyl good selections those tubers will produce many offspring for the following year. In such experiments and trials the crosses may not be selective but the variety of progeny is large and there are many types to choose from.

Richard Hebda planted 35 new varieties from plants raised from seed last year. The diversity of shapes and sizes is huge from red fingerlings to conventional brown rounds. The flowers of some plants are stunning and very ornamental.

These plants are being raised and observed in the standard manner of our trials. Many plants are especially vigorous.

Growers can raise their own diverse seedlings from the tomato-like fruits. It's a bit tricky to get them to grow into full-sized plants but then you have the tubers as seed for the next year. Growers may be able to raise and select potato especially suited for their own climate and taste.

Outstanding ornamental flowers of a new seedling potato variety grown at Camassia Bulb Farm in Saanich BC. The tubers are red fingerlings.

Box 9. Growing potatoes from true seed.

Many potato varieties may not produce fruits and seed, but some such as Russian Blue do. Repeated harvesting and growing of the seed and selection in a region leads to varieties adapted to local growing conditions. Growing original varieties in this way is also lots of fun. The best tubers from such a random cross selection process can be distributed throughout a community. From informal observation, it seems that many of the results of such crosses are very vigorous and productive growing taller and bushier that several of the heritage and conventional varieties.

RECOMMENDED VARIETIES

As climate warms and growing degree days increase, the choice of varieties suitable to each growing area will change. In general, long season varieties may be able to produce well in areas where the growing season currently is not long enough for them; short season varieties may no longer be productive in areas with rapid warming in the spring season and high summer soil temperatures. Increasing drought and heat, combined with increasing variability and unpredictability of stress events such as heat waves and high precipitation add to the challenge of growing potatoes. Varieties that show more heat and drought tolerance could be part of a suite of types that balance yield, quality and reliability. More experiments in each climatic region are highly desirable. We only investigated a small group of heritage types yet there are so many more. One strategy might be to find the general category of best-adapted potato for a region such as fingerling, purple, red, conventional and explore the range of available cultivars in a trial.

In our study, we identified several heritage varieties that perform as well as the standard sorts in challenging conditions even in areas where they have never been grown, including Ozette-Nootka, Mrs. Moehrle's Yellow, Sieglinde, Banana, Siberian Fiery Eye and Bauer Grün Rote Auge. In cooler, more northerly and/or higher elevation regions, we recommend for initial testing short season varieties with possible frost tolerance. These include Likely, Slovenian Crescent, Russian Blue, and Irish Cobbler.

HONEST FOOD: THE BIG PICTURE

Figure 32. The Honest Food circle.

Our study has focused on a particular strategy of adaptation to climate change by linking local weather and climatic conditions, cultural practices and heritage varieties. Successful and appropriate food production at all spatial and cultural scales operates in a much broader context (Figure 32) which we call Honest Food. This broad context links crop biodiversity and climate change to ecological sustainability, nutrition, economic well-being and fairness and the sustaining of cultures and communities.

The idea of Honest Food and its elements derived directly from the Crop-Climate project and has been presented along with the description of the project and its results. Consequently, the idea and principles of Honest Food are a result of the project just as much as the actual field trial results.

We include a summary of the principles as posted on our website as well as that of the Canadian Climate Forum (Figure 33). The principles were also published in the Royal BC Museum magazine What's In-Sight (Hebda 2016).

There is much concern about food these days. Droughts and starvation in Asia and Africa threaten lives and force migrations. Food prices in general and those for specific crops keep rising or fluctuate widely. People worry about the ecological impact of conventional food production and discuss food diversity and human health and fair compensation to food growers. These challenges are becoming more acute as global climates change and stress food production systems.

To meet these challenges, we propose a set of basic principles that acknowledge the need to undertake sustainability initiatives broadly rather than in isolation. The principles extend beyond the laudable objectives of organic food and recognizing the role of food systems in supporting biological diversity. They also identify the need to reduce greenhouse gases in the atmosphere. The context of our incredibly complex food system makes it is all the more critical that we make food decisions guided by a set of principles that are universal in their moral and ecological goals. Honest Food aims to contribute to the improvement of the condition of human society and of the global ecosystem, while mitigating and adapting to stresses such as climate change.

We urge those using our data or adopting our approach to consider these principles as they strive to adapt to climate change and to produce food in a sustainable manner.

Honest Food

10 Principles for People and Planet

Food production faces increasing challenges as our climate changes. Agriculture produces greenhouse gases, yet it provides opportunities to reduce climate change. I offer the following guiding principles for evaluating our food systems from ecological, economic and social perspectives.

Richard J. Hebda

1 ENSURES RELIABLE AND AFFORDABLE FOOD FOR ALL

Provides food security: "all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life." (World Food Summit 1996)

2 MITIGATES AND ADAPTS TO CLIMATE CHANGE

Reduces greenhouse gas emissions from agricultural production, puts carbon back into the soil. Develops climate-resilient food systems.

3 SUSTAINS ECOLOGICAL INTEGRITY

Avoids harm to ecosystems.
Contributes to water quality, soil formation and ecological processes.

4 SUSTAINS THE DIVERSITY OF LIFE

Supports biological diversity of crop varieties.
Practices food production in biodiverse landscapes.

5 CONTRIBUTES TO HUMAN COMMUNITIES

Conserves and shares traditional and local agro-ecological practices.
Fosters local adaptation and resilience.

6 RESPECTS AND REWARDS GROWERS

Recognizes key role of the food producer through fair economic and social returns and sustainable livelihoods.

7 IMPROVES PEOPLE'S HEALTH

Produces healthy, nutritious food and fosters healthy diets.
Reduces exposure to toxins through organic agriculture.

8 BUILDS STABLE ECONOMIES

Creates sustainable economic structures that include principles of fair trade throughout the production and distribution system.

9 MEETS MEASURABLE AND OBJECTIVE STANDARDS

Tracks and reports on progress toward practical outcomes using rigorous protocols.

10 INCORPORATES PUBLIC EDUCATION AND AWARENESS

Encourages the sharing of practical knowledge across all regions and cultures.

 honestfood@climateforum.ca http://heritagepotato.ca

Figure 33. Principles of honest food

NEXT STEPS

The need to adapt to a changing climate, to conserve our potato and other food crop heritage and to support honest food systems has never been more acute. Our three-year project demonstrated that lots of practical information can be generated over a relatively short interval of time. We identified superior heritage varieties and less-than-productive conventional types too. We demonstrated that potato production and self-reliance is possible across a wide range of climates. We distributed productive heritage varieties widely. Yet we have only scratched the surface as far as the thousands of potato varieties available and the many ways and places in which they can be grown. We also uncovered some of the challenges in involving growers in the collection of useful information. We think our approach can be adapted widely to gather the information needed for the future and make it widely available.

We propose three areas for future work: regional potato collections, strengthened collection of climate and weather data, expanded testing of varieties and techniques.

1. Support the development of regional seed tuber collections and production for heritage and promising new varieties

Potatoes are uniquely challenging from a seed security perspective even though they are easy to grow. Unlike most annual crop plants, they are not grown from true seed but from a 'seed potato' - a tuber from the previous year's plant. Storage of these tubers for the following year's planting requires special facilities and careful preparation for planting. The tubers are identical clones of the parent plant, and each year they are grown, they can accumulate pathogens which are then carried into the following year's crop. In each subsequent year, they may lose vigor and yield.

Commercial producers of seed tubers are limited in the number of years they can grow seed potatoes before they are required to renew the stock from virally-cleansed tubers. Regular cleaning is carried out only for potatoes that have a large commercial market. Heritage varieties are rarely a part of this system, and the only source of virally cleansed seed is Canadian Potato Genetic Resources at the Fredericton Research and Development Centre. Individuals may order a small number of mini-tubers of many of the varieties Fredericton maintains. These clean tubers can be grown out to produce more seed tubers. However, there is limited interest in increasing the stock of such varieties and they are rarely bulked up for wider distribution.

Maintaining healthy viable seed from one year to the next and distributing that seed in a timely manner for a region is also a challenge. It requires specialized storage conditions and expertise. As we discovered, even commercially available seed it is not always in the best condition.

Considering these issues, we suggest that regional tuber collections be established to include the most suitable varieties. In this way the collections can supply seed tubers at the right time for planting in each area. In the process of establishing and maintaining the collection, experience would develop for the region and its climate. The Seeds of Diversity program mentioned earlier is an excellent source of a limited number of non-commercial varieties, but it is limited in scope and not region-based. British Columbia, for example, has a dedicated certified zone in the Pemberton Valley for tuber production (https://bcseedpotatoes.com/wp-content/uploads/2017/05/Pemberton_Brochure_final.pdf). Several heritage varieties are grown there. Perhaps, in this case, selected cleaned tubers of little-known varieties could be provided to some of the growers to establish and maintain a collection. A similar model might be introduced elsewhere with equivalent standards. In this way, we could improve access and conservation of promising climate-resilient potatoes, build local capacity to support regional food supply, and secure a supply of clean potato seed for future generations.

The establishment of regional collections would require the collaboration of key agencies such as Agriculture and Agri-Food Canada, provincial agencies, educational institutions and established producer and community groups.

2. Strengthen the climate station network

Adaptation to climate change is a key reason for this project. We noted in several previous sections the value of having specific weather and climate data in making decisions about what varieties to grow and when to plant them and how to manage them. We made the point that potatoes can likely be grown in many locations where they are not grown today. We also noted how variable year-to-year weather can be.

The best choices for growing crops are made with the most reliable, location-specific climate and weather data. Our trials used readily available instruments to record data and supplemented these observations with information from nearby climatic stations where available. Purchasing, deploying and monitoring the instruments requires money, expertise and time. Observing the potato crop is generally a much simpler and less expensive undertaking. For those wishing to grow crops on a commercial scale the purchase and installation of in-field instruments is likely a good idea.

However, a lot of useful information could be obtained, quickly, by using climate station data. In general, if the source station of the data is near a garden or farm field, then valuable insight may be gained into the suitability and performance of potato varieties. Similar temperatures, for instance, occur over relatively wide areas. Precipitation during the growing season may be more site-specific, nevertheless, rainy conditions generally occur over relatively wide areas too.

The data can also be compiled for developing weather/climate profiles for varieties over a wide range of southern climates. Vancouver Island has an outstanding regional school weather station network at http://www.islandweather.ca/. It provides real-time weather conditions and archives the data. On a much larger scale, there are global-scale weather models which include daily and hourly information.

Southern and populated parts of Canada are well served so that growers can access useful information from regional climatic stations. Many communities in Canada especially in the north and away from centres of population do not have climate stations. The absence of such stations is particularly a problem where the landscape has complex topography such as the western Canadian provinces or near the ocean shoreline. In such regions, the only regional climate station is often located at the airport which may not represent growing conditions in peoples' fields. Williams Lake station is on an upland plateau for example whereas most people (such as Mackin Creek Farm) live at lower elevations.

We strongly suggest the expansion of the Canadian and provincial and territorial climate station networks, especially outside urban and suburban areas. Observational data from many more informal and formal variety testers could be then compiled into a national database. The provincial and federal stations could be supplemented by regional school models such as that installed on Vancouver Island. Full weather stations should certainly be established at the sites of regional variety collections, an initiative that might involve a partnership of Environment Canada and Agriculture and Agri-Food Canada.

An enhanced climate station network would be especially valuable to document the increasing natural variation in weather as climate change advances. Such a network would provide live-time detection of changing climates too and identify sites where new crops and new varieties could be grown.

3. Test more varieties and climate-adaptive growing techniques

Developing and sharing knowledge on climate-smart growing techniques and locally adapted varieties is critically important. The previous two suggestions require broad initiatives involving several agencies. We will be making the case for these strategies whenever we can. With respect to our project, we will focus on gathering more information on heritage varieties in more regions.

Since 2015, we have been using a simplified form for reporting, collecting anecdotal observations and distributing our favourite seed tubers locally. We have also been testing more heritage and uncommon varieties. We have distributed many tubers into the hands of interested people to test for their local growing conditions and have discovered that many people want to carry out informal varietal trials on a small scale. Practically, using such community observer-growers is the only way in which to assess a large number of varieties and techniques in a short time. The community testing approach also engages other local people and sets in motion the local selection and adaptation process.

For 2019, we will test and implement a community-observer approach by using the crowdsourcing software 'ClimMob' developed by Bioversity International to implement the "Tricot Method" (Box 10). Using this method, each grower receives a simplified observation protocol with reporting on straightforward checkbox cards (or on a mobile app), three varieties to observe, and a final report, which is generated by the software comparing their preferred varieties as well as the preferred varieties of growers in similar locations. Robust statistical analysis is possible through the online program and minimizes manual data entry. We have chosen this program because it is designed to facilitate participation in climate-smart agriculture adaptation.

Crowdsourcing with ClimMob – How it works

Statistical approaches:

Each farmer receives a package of **three different varieties**. The farmer has to note **which of the three is best and which worst on a list of characteristics that they develop together with the researchers.** The varieties are drawn from a pool of several varieties, so while one farmer receives A, B and C, another receives A, B and D and so on.

Even though no farmer compared A and D directly, statistical methods can reveal whether A or D is better. Additional variables, such as whether a farmer has access to irrigation, or the altitude of the plot, can also be examined to see whether they affect the performance of the varieties.

An additional benefit is that the varieties are grown **in the farmers' fields** rather than a **trial plot**, allowing a greater number of farmers to take part, and to capture other data such as performance at different altitudes or in varying climatic conditions.

"We adapt our statistics to work with what the farmers are able to observe, rather than the other way round," Jacob van Etten, Bioversity International scientist who developed ClimMob with colleagues.

The online platform and mobile app are up and running for anyone to use, with a full set of explanatory videos (in English and Spanish) showing how to use it.

Looking ahead, ClimMob can be used to gather big data on farmers' varietal preferences, and to share that information with relevant actors to create a **2-sided business platform** allowing for small quantities of a diverse selection of planting materials to be marketed to targeted consumers.

Find out more:
ClimMob – a software for crowdsourcing climate-smart agriculture

Box 10. Proposed crowdsourcing software developed by Bioversity International for climate-smart agriculture.

Initially, we propose selecting 15 potato varieties to distribute to 100 growers who are trained in the simplified observation technique. We will request supplemental information on growing techniques (irrigation, mulch, etc.). Growers not served by climate stations may also receive a simple weather recording instrument, such as a HOBO or an iButton, to be returned with their data at the end of the project.

If the method is successful, we believe this approach could be applied more widely to evaluate other crops such as beans and to check different techniques. When coupled with the deployment of weather recording devices, it can help guide further development of climate-appropriate methods and varieties.

The data collected in this manner will be made available on the project website. In this way, we hope to develop additional heritage variety profiles so that growers may have a wider choice of potato types suitable to their regional conditions.

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