

**BUILDING RESILIENCE IN THE AGRICULTURAL SECTOR OF THE OMINECA:
ASSESSING BARLEY (*HORDEUM VULGARE*) CULTIVARS RESPONSE TO
WATER STRESS AND CULTURAL PRACTICES OF NORTHERN PRODUCERS**

by

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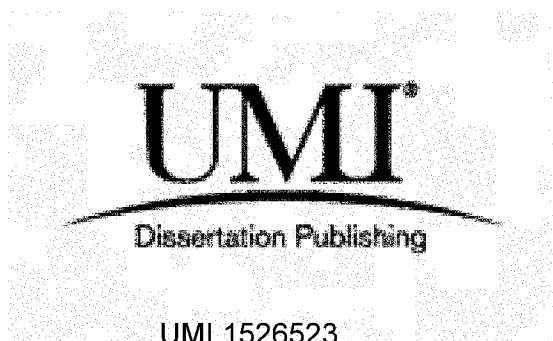
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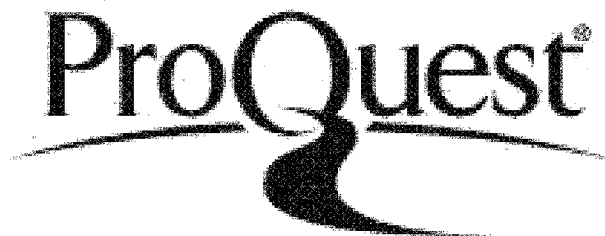


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ABSTRACT

A gap in regional agriculture research and extension has restricted farmers' ability to cultivate long-term sustainable, profitable operations in the Omineca Region, BC. An interdisciplinary project was designed to re-initiate regionally focused research. First, an autoethnography was conducted (2012-2014) to explore cultural practices of northern farmers and to identify needs and opportunities within the region. It was found that diversity of environment, economic and cultural contexts of farmers will impact management decisions, and there is an immediate need for contextual, regional research that addresses the realities of farmers working outside the industrial agriculture system. Second, a greenhouse study was designed to examine the implications of breeding strategies on water stress tolerance of modern and heritage barley (*Hordeum vulgare*) cultivars. Significant differences were found in phenology and resource allocation traits of modern and heritage cultivars, suggesting breeding strategy has impacted adaptive tolerance of modern cultivars and may impact future management practices within the region.

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INTRODUCTION

The agriculture sector of the Omineca Region, British Columbia composes about 13 percent of the province's total farmland (~347,241ha) (Statistics Canada, 2011), but currently lacks the research and resources to support increased production capacity. The region crosses a diverse landscape of northern interior BC, starting on the east side of the Coastal Mountain Range in the Bulkley Valley to the west, and spanning across Highway 16, east through the Nechako Plateau and the McGregor Plateau, and ending in the Robson Valley on the western edge of the northern Rocky Mountain Range (Figure 1.0). The region poses numerous challenges for agriculture: short growing seasons and limited access to water (only 1.2 percent of Omineca farmland is irrigated) (Statistics Canada, 2011); complex topography that favours numerous, smaller fields across a range of elevations; forest-origin soils that dominate the region are often rocky, with low organic matter, and soil varies not only across the region, but also within each field; all of which is compounded by the future implications of climate change and increasing variability in annual weather patterns (Burns, 1952; Farstad and Laird, 1954; Crawford and Bevrige, 2013). As such, it is difficult to manage farms in the Omineca Region in ways, and on a scale, that is competitive with the industrial agriculture system.

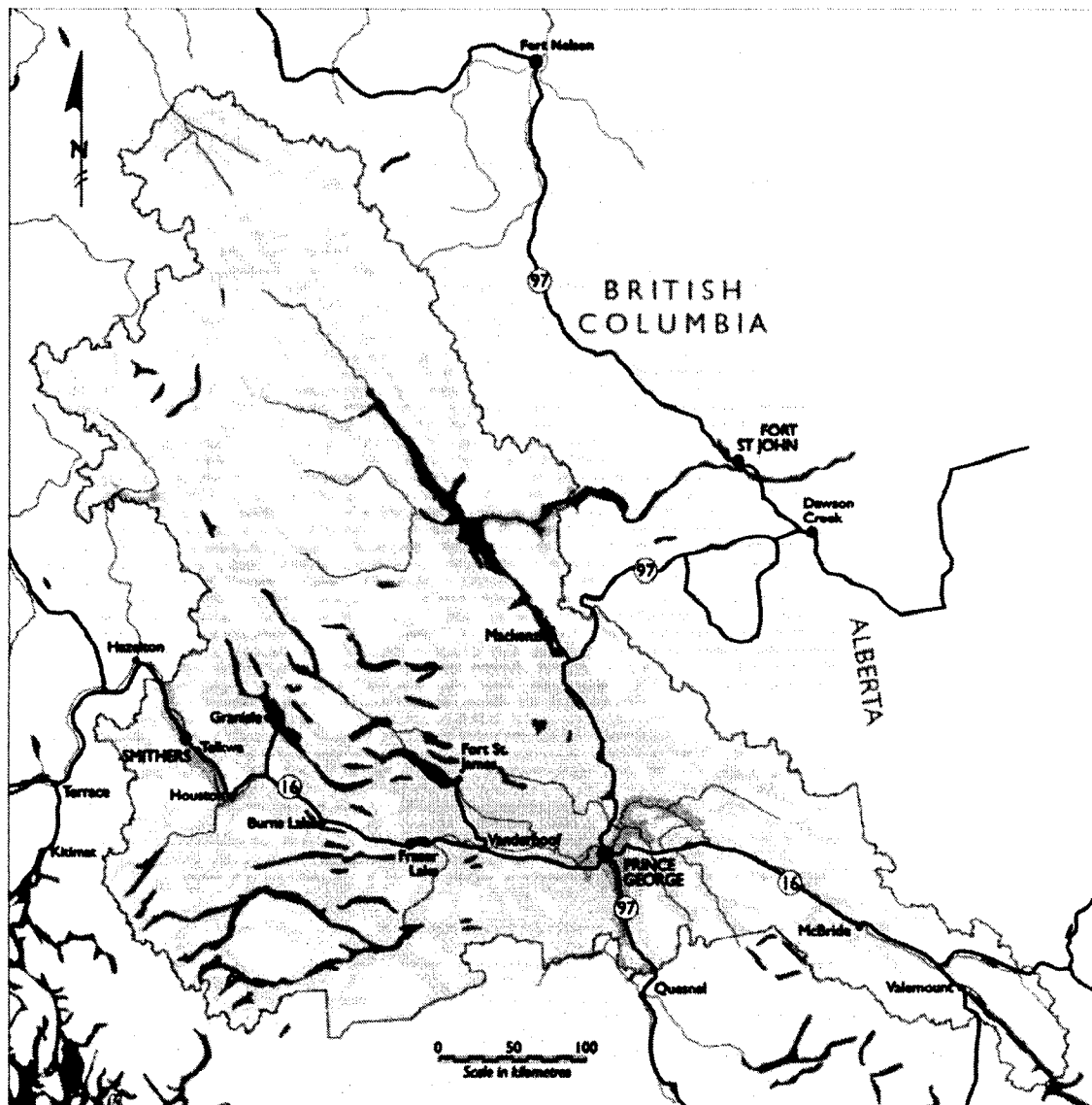


Figure 1.0. Omineca Region, British Columbia, Canada (OBAC, 2015).

Agricultural research in the region was previously conducted through federally-funded Experimental Farms, located in Smithers and in Prince George and Illustration Stations located along Highway 16. The Experimental Farm staff not only conducted various applied research projects that provided producers with localized information (e.g. cultivar trials, soil fertility management, cultural practices, etc.), but the farms were also a place where producers hosted meetings, shared local knowledge and gathered

new information. The closure of the Prince George (1990s) and Smithers (1960s) Experimental Farms left a gap in regional research and extension; therefore, restricting producers' ability to develop long-term sustainable and profitable farming operations. Therefore, the aim of my research was to begin the process of building a relevant, useful research program that would support the range of agricultural operations, to support farmers who must adapt to changing conditions in an increasingly complex and variable environment and economy.

To start, it was recognized that grain and vegetable production in the Omineca Region had decreased in area under cultivation since 2001 (OBAC, 2009). Discussions with local producers and stakeholders helped contextualize the needs of the regional agricultural sector and identify research objectives. With new cultivars coming out each year, and with little information about their regional adaptability and performance potential, there was broad interest in cultivar trials. Additionally, some producers expressed interest in how heritage and modern cultivars compared in regards to yield potential and yield stability. Barley (*Hordeum vulgare*) was identified as the study crop, and water stress (from excess and deficit regimes) tolerance as a primary adaptation characteristic of concern to producers in the region.

Thus, my research objectives were to: 1) to explore the cultural practices of northern producers, as well as identify the needs and opportunities, through autoethnography; and 2) to examine some of the implications of breeding strategies on water-stress tolerance of modern cultivars compared to heritage cultivars. To accomplish these objectives, a multi-method approach was developed to ensure that

each aspect of the research informed and directed the other.

First, the study aimed to achieve a thorough understanding of the “food-scape” of the Omineca Region, and of prioritized research needs. To accomplish this task, ethnography was incorporated not only as a method to explore the different cultural practices in these regions, but as a style of research that aimed to better understand the social meanings and activities of Omineca farmers (Brewer, 2000; Chang, 2008). An autoethnography, the combination of cultural analysis, and the interpretation with narrative details (Chang, 2008), was conducted over two years (2012-2014) with the aim to identify short and long-term challenges for producers, and to explore the diversity of farming cultural practices. This approach ensured that I developed a comprehensive understanding of the context of agriculture in the Omineca and, therefore, that the research objectives were pertinent to northern farmers.

Second, a controlled-environment study was designed to examine how different cultivars of barley responded to varying levels and types of water stress. The study sought to establish a baseline of information on cultivar performance to help inform producer management decisions, and to identify relevant areas for future research. As a pilot project, the greenhouse study was designed to prioritize number of cultivars over the number of replicates so that each cultivar group (modern and heritage) had broader representation in the study; study traits included phenology, resource allocation and yield, and these traits were used to compare adaptive tolerance of heritage and modern cultivars.

LITERATURE REVIEW

Cereal crops and genetic diversity

Cereal crops have dominated agricultural production since humans adopted a lifestyle around cultivation and settlement approximately 10,500 years ago (Serna-Saldivar, 2010). Cereals are annual generalists, and can adapt to a variety of environments and are grown readily around the world. As the world population began to increase rapidly in the middle of the last century, so did the demand for grain production; in just 40 years (1960-2004), both human population and cereal production doubled (Serna-Saldivar, 2010, p.4). Grain yield increases can be attributed to increased: (1) land under cultivation; (2) irrigation; (3) use of nitrogenous fertilizers and pesticides; and (4) genetic improvements (Loomis and Conner, 1992; Serna-Saldivar, 2010). These advancements were associated with the Green Revolution in the 1960s and 70s, which was a manifestation of crop improvement programs, largely through new breeding programs, that gave rise to the cultivars used in contemporary conventional agriculture (Serna-Saldivar, 2010).

The main objective of plant breeding is to create cultivars with superior, uniform and more predictable performance in the field, which subsequently results in the narrowing of genetic structure to ensure that all individuals within a population display desired physiological and phenological traits (e.g. height, yield, heading and maturity date) (Brush, 1992; Loomis and Conner, 1992). Prior to the Green Revolution and modern agronomic science, humans collected seeds and cultivated plants through a

continual selection process, creating distinct populations, or *landraces*. Landrace populations are assumed to be adapted to more local environmental conditions, as they have been selected in a specific environment over many years and are not bred to exhibit a narrow range of specific traits. Therefore, landraces are assumed to be more genetically diverse, and different landraces respond differently to varying environmental conditions (Ceccarelli, 1996; Vandeleur and Gill, 2004).

The heavy adoption of modern cultivars over landraces since the Green Revolution has raised concern among some researchers about the loss of crop cultivars and genetic diversity (genetic erosion hypothesis), and that the widespread adoption of a small number of cultivars will increase the long-term vulnerability of production (National Research Council, 1972; Anderson and Hazell, 1989; Brush, 1992). That is, there is a growing dependence on a decreasing number of cultivars to provide the majority of the food for the world. Due to intensive breeding programs, these crops may not have the genetic diversity to allow adaptation to changing levels of stress caused by climate change or lack of requisite inputs (e.g. water, fertilizers, pesticides). The discussion around the simplification of genetics (e.g. uniformity of modern cultivars) and the demands of high input systems has led some researchers to explore the comparative adaptive capacity and production potential of modern and heritage (or *landrace*) cultivars (Poutala et al., 1993; Entz et al., 2001; Kitchen et al., 2003; Mason and Spaner, 2006).

Furthermore, because modern cultivars are bred for engineered landscapes that are input intensive and highly mechanized to ensure minimal environmental stress on

the crop, the cost of the industrial agriculture system is substantive. In areas with fertile soils and large acreages of land, these practices can be profitable if producers have access to high-yielding cultivars, irrigation systems and fertilizers to achieve the necessary economy of scale associated with industrial commodity farming. In areas that are not economically conducive to these methods, that is areas which do not obtain sufficient yield for cost of production (e.g. the Omineca Region), the high input costs and low profit margin preclude farm profitability. Moreover, with increasing pressures of climate change and increasingly limited resources, yield stability under stressful conditions (one possible measure of adaptive capacity) of a given cultivar may be more important than the potential of high yield potential (Ceccarelli, 1989; Jaradat, 2009).

Breeding strategies for adaptation

Adaptation is a foundational concept in evolution and ecology, and can have different connotations in various fields of research. Adaptation often refers to the concept of fitness, which can be described as both a condition and a process (Cooper and Byth, 1996). The *condition* of adaptation refers to the specific constitution of a genotype and how well it is suited to a specific environment (e.g. how adapted a species is to its environment at a single point in time), while the *process* of adaptation refers to how the genetic constitution of an individual or a population changes to better suit the environment over time (Cooper and Byth, 1996). However, adaptation in an agricultural context refers to “the quantity, quality and reliability of harvestable product and stability of production system” (Cooper and Byth, 1996, p.10).

There are two main philosophies in regards to breeding for adaptation in agriculture: breeding for wide adaptation vs. breeding for specific adaptation. Both concepts relate to how cultivars respond to environmental variation (e.g. Genotype x Environment Interactions (GE)) (Ceccarelli, 1989). Wide adaptation aims to increase cultivar performance *across* mega-environments¹, and cultivars often have a high average yield potential with a low GE (Ceccarelli, 1989; Braun et al., 2010). Most modern cultivars are bred for wide adaptation, and are selected for environments with high yield potential. This strategy reflects the industrial agriculture system that relies on prodigious inputs and highly mechanized practices in order to reduce the impacts of environmental stresses on a crop.

Specific adaptation aims to increase performance and reliability of a cultivar *within* a mega-environment, and is characterized by having a high GE, and either a high or low yield potential (Ceccarelli, 1989). The majority of modern breeding programs do not incorporate specific adaptation because a high GE makes it difficult to select for heritable traits. Still, specific adaptation can span a relatively wide geographical range (e.g. millions of hectares) that exhibits a common stress (e.g. poor soil capacity, temperature extremes, growing season length, or water regimes) (Ceccarelli, 1989).

These two adaptation breeding strategies support different production strategies in regards to stress responses of individuals and populations (Cooper and Byth, 1996). Modern cultivars are bred to produce uniform crops, and a cultivar's adaptive capacity

¹ A *mega-environment* is defined as "a broad, not necessarily contiguous, area occurring in more than one country and frequently transcontinental, defined by similar biotic and abiotic stresses, cropping system requirements, consumer preferences and for convenience, by a volume of production" (Braun et al., 2010, p.118).

relies on the ability of the plant, or specific genotype, to acclimatize to environmental variation (*individual buffering*). In industrial agriculture, the mono-crop system of modern cultivars creates uniform vulnerability to insects, pathogens and other pests (Cooper and Byth, 1996; Jackson and Koch, 1997; Scott, 1998). Landraces, on the other hand, often possess sufficient population-level diversity, to allow for varying performance of individuals to help acclimatize to stress (*population buffering*), in addition to individual buffering capacity, thus reducing vulnerability to disease and pest epidemics (Cooper and Byth, 1996).

While modern, improved cultivars are known to have improved yields under non-stress conditions, landraces are assumed to have higher tolerance to abiotic stress and higher yield stability under low-input cultivation methods (Laing and Fischer, 1977; Ceccarelli, 1989; Poutala et al., 1993; Ceccarelli, 1996; Zeven, 1998; Kitchen et al., 2003). Pswarayi et al. (2008) evaluated 188 barley cultivars, both modern cultivars and landraces, to study adaptation and improvement in various moisture regimes across the Mediterranean basin. Their study suggests that landraces are generally better adapted to high-stress environments and modern cultivars to low-stress environments. Still, landraces are not well adapted to all stress conditions, but to specific stressful environmental conditions characteristic of the regions where they originate (Pswarayi et al., 2008). This finding suggests that breeding for genotypes for large agro-ecological environments (e.g. mega-environments) (Ceccarelli, 1989) may only be suitable for high-production environments, while areas with lower productivity environments would benefit from breeding for specific adaptation.

Studies exploring cultivar responses to low-input and conventional systems (representing stressed and limited-stress environments respectively) have had varying results. However, Kitchen et al. (2003) conducted field trials in several locations in Australia, comparing the differences between old and modern grain cultivars in conventional and organic systems and found that none of the cultivars tested were better adapted to stress. Still, there was greater weed stress (competition) observed in the low-input system, which makes it difficult to distinguish the degree of stress associated with drought level vs. weed competition. A controlled environment study could lead to more specific observations as to cultivar response to specific stresses, without the challenges of working with a production system (low-input vs. conventional) as a whole.

More research is needed on the changes in phenological, physiological and agronomic characteristics of grain in response to various types and levels of stress. Most studies evaluate varietal responses to different conditions using field trials and each study exhibits different environmental conditions, using different cultivars (Kitchen et al., 2003; Jaradat, 2009). As such, controlled experimentation comparing how both modern cultivars and landraces respond to stress is needed, in order to explore the implications of breeding for wide adaptation within the regional context of the Omineca Region of British Columbia, Canada, and could be extended to other regions as well.

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CHAPTER ONE: THE INVISIBLE COMMUNITY: AUTOETHNOGRAPHY OF STRENGTH AND RESILIENCE

“There needs to be a shift in this threatening trend in society. There has to be more respect for the noble profession of growing our nation’s food.” – Omineca Farmer

1.0 Introduction

Food is something that links everyone together, crossing disciplines from crop and production science, to cultural studies, to business and economics. Agricultural practices and management should be contextually driven, specific to the place and to the ethno-culture of the people who reside on that land (Scott, 1998; Ison and Russell, 2000). However, globalization has vastly altered the food system, creating a prevalence of industrial scale agriculture in order to match the increasing demands of large corporations (Ullrich, 2011). The industrial agriculture system demands uniformity and mechanization in its production, processing and distribution, creating challenges to small-scale producers and increasing risk to local food systems (Jackson and Koch, 1997; Ullrich, 2011). Extensive amounts of research have focused on supporting the industrial system and creating more efficiency within this system, and there are fewer resources available that provide contextual, regionally relevant information.

However, the Omineca Region may not be suited to the industrial agriculture model of production for many reasons, including the great diversity of the region’s topography and soils, its short growing season, the increasing variation in weather year-to-year, and the diversity of the producers and operations themselves. Therefore, the current approach to agricultural fails to support these producers; there is no one solution for producers across the Region, and in the end it is the farmers who decide

which practices and technologies will, and will not, be adopted. Therefore, this research started on a participatory, collaborative ground, with farmers and researchers working closely together towards a common goal – to enhance the success of the agricultural industry and provide meaningful, regionally appropriate support to its producers.

There is a strong history of agriculture in the Omineca Region of British Columbia, Canada, though the dominant industry in the region is forestry. Since the mountain pine beetle epidemic has created challenges for the forestry sector, there is interest in developing a more diversified economy, and there is potential to increase the capacity of the agriculture sector (OBAC, 2009). In order for producers to be able to realize more full production potential, access to regionally-contextualized information and resources is required. Research was previously conducted in the region through federally-funded Experimental Farms in Prince George and Smithers (established in 1940 and 1938 respectively), but these were decommissioned in the late 1960s (Smithers) and the 1990s (Prince George), as stations were centralized to increase resource efficiencies, which has left limited capacity to conduct research and generate new knowledge, and no centralized place to store regionally-specific information.

Particular vulnerability was identified in the production of vegetables and grain, which have been decreasing in area under cultivation since 2001 (OBAC, 2009). Grain production served as a starting point for me to engage producers in helping develop relevant research objectives, and begin to connect researchers to the needs of the industry. From the start, this research was conducted in context of the local producers,

meaning it was not possible to disassociate production challenges from the complex social and economic issues (Ison and Russell, 2000).

To accomplish this, an auto-ethnographic approach was used, initiated from a feminist standpoint and incorporated insights of decolonizing methodologies (Chang, 2008; Denzin, 2010; Tuhiurai Smith, 2012) in order to support egalitarian, reflective and change-provoking research. Therefore, it is important to be self-critical and introspective of my own discourse and of that which may have shaped my world-view and thus approach to this research (Ison and Russell, 2000; Saukko, 2003; Chang, 2008; Muncey, 2010)

About the researcher

I am not a farmer, but a greenhorn (inexperienced) in agriculture. While I cannot say there was a definitive moment that lead me to study agriculture and food systems, there were several experiences that brought me further along this path, varying from being in 4H for a couple of years and always having a vegetable garden, to going to my first farmers' market in Thailand, and having my first discussions with new friends about the importance of supporting sustainable agriculture systems. Still, the strongest driver that I have and that keeps me propelled into this work, is hearing the stories of producers in the region; their perseverance and determination simultaneously inspires and humbles me.

I am, on the other hand, a Northerner. The fourth generation born in the Cariboo (central-interior of British Columbia), I consider this region to be my home, my land, and

my inheritance. My family came from various countries and settled in the Cariboo, clearing land and building modest farming operations around the Dragon Lake and Alexandria areas, located near Quesnel, BC. My grandparents were the last to grow up on the farm, though some of the land is still owned by extended family. I have always had a passion for local history and for the land of the region; I feel deeply connected to my agricultural and northern roots.

Growing up in a blue-collar household, I am one of the first generation in the family to continue into post-secondary education. My parents have labored for everything they have, and instilled a value of hard-work and determination into their children. This do-it-yourself persona has shaped who I am, and the kind of researcher I have become. Especially for work reported herein, I feel my background and my history in this region has reduced the language and cultural barriers between the producers and me; barriers that needed to be broken down in order to allow us to accept each other as equal collaborators in the research.

1.1 Literature Review

Creating a strong understanding of the food-scape of the Omineca region was critical to the development of regionally-relevant agricultural research. Recently, there is a trend toward more research on the motivations, behaviours and attitudes of farmers, likely because of increasing concerns around the industrial agricultural system, and the need to support more sustainable agricultural systems (Chouinard et al., 2008; Selfa et al., 2008; Oreszczyn et al., 2010; Baumgart-Getz et al., 2012). Farmers' motivations,

behaviours and attitudes are interconnected to their communities of practice, and are related to how producers share and acquire new knowledge around technology and production practices, all of which is inherently contextual (Scott, 1998; Wenger 1998). With little research being done with farmers in the Omineca, it was important to incorporate a cultural study aspect to my work, so that I could understand farmers' context and realities, as well as to build trust within the community (Ison and Russell, 2000; Shindler et al., 2014).

I also believed that understanding what motivates producers to change or adopt new practices would provide insight into farmers' needs and barriers to future opportunities. Studies suggest that producers do not adopt new technology/sustainable practices either because they lack knowledge (suggesting farmers would change their practices once informed), or will only adopt practices if there is an economic benefit (Chouinard et al., 2008). Chouinard et al. (2008) found that capital was the best financial predictor of adoption, followed by the percentage of income that was coming from the farm. Other studies found that formal education proved insignificant, suggesting that there is a great amount of local knowledge not recognized by Western-approaches to knowledge (Samburg and Okali, 1997; Tuhiurai Smith, 2012). Indeed, research and information on new technologies or practices may not be adopted not because producers "lack knowledge", but rather because these technologies and practices are not appropriate to the producer (e.g. does not address the challenges producers face, is too expensive, etc.), or the information is too generic, and does not reflect the context of the region in which the producer is working (Baumgart-Getz et al.,

2012). It is reasonable to assume that both egoistic-financial and social-moral factors would influence the production decisions on a farm, and it is important to identify and recognize the on-the-ground restraints farmers' face when deciding on best practices for their operations.

Farmers have detailed knowledge of their environment and often conduct deliberate, on-site experiments that can be undermined by traditional, top-down approaches (e.g. centralization of research stations to increase efficiency) (Samburg and Okali, 1997). Baumgart-Getz et al. (2012) found networking as a significant predictor of best management practice (BMP) adoption, with agencies and local networks having the largest impacts. Producers are more influenced and receptive to local knowledge that is directly applicable to their situation, rather than broad concepts and technologies that have been developed without consideration of the producers' realities (Baumgart-Getz et al., 2012). This finding correlates with other studies, which have found that farmers tend to draw upon their own time-dependent, geographically-situated knowledge to help inform production/management decisions (Selfa et al., 2008; Oreszczyn et al., 2010).

Communities of practice and networks of practice have been recognized as being practical concepts to aid in understanding informal knowledge gathering (Oreszczyn et al., 2010). Oreszczyn et al. (2010) found that farming networks of practices have a strong working identity, though are often weak in their organizational framework. Often, farmers found it more useful to work through informal connections they had built than working with professional training, because informal connections

often proved to be more personal and more applicable to their own operations (Oreszczyn et al., 2010). Throughout the study, farmers reiterated a feeling that scientists and policy makers often lack an understanding of farm-level practices and operations (with specific mention of little engagement with farmers around the design and reporting of field trials) and, therefore, lacked trust within these relationships (Oreszczyn et al., 2010).

Farmers in marginalized areas (which could apply to the Omineca Region in the provincial and national context) cannot depend on government extension services to provide contextual information and support, as these services often have too few people, spread across large geographies with small budgets (Samburg and Okali, 1997). Therefore, there is a growing push for researchers to be working in a participatory way (farmer participatory research), to ensure the science is interacting with the end-users (e.g. farmers). There is growing support for the need to ensure that research is deeply connected to the cultural and environmental context of the producers; one way to ensure that this is possible is through engaging producers as co-researchers in order to identify appropriate research needs (Samburg and Okali, 1997; Ison and Russell, 2000; Oreszczyn et al., 2010; Baumgart-Getz et al., 2012). As such, there is recognition that iterative reflection on shared experience is essential to these projects, with the researchers placing themselves as far into the system as possible (van de Fliert and Braun, 2002; Chang, 2008; Oreszczyn et al., 2010).

1.2 Methodologies and methods

Methodologies

This research was conducted from a feminist standpoint, supporting egalitarian, reflective and change-provoking research. That is, I gave equal time and respect to all members of the households and operations who participated, and was committed to returning this knowledge to those who helped create it. Moreover, I strove to equalize the power between researcher and participants by conducting farm stays (participant observation, creating mutual understanding), and ensuring research was flexible and adaptable to reflect the needs and perspectives of participants (e.g. activities encouraging with, rather than on, farmers). The main priority of this project is to produce research that is connected to its participants, to inspire change and to have a lasting, positive impact on the farming communities in the Omineca Region. To accomplish this task, ethnography was incorporated not simply as a method to explore the different cultural practices in these regions, but as much as a style of research that is aimed at better understanding the social meanings and activities of north-central BC farmers (Brewer, 2000; Saukko, 2003).

Western academia is surrounded by a history of power and control on macro- and micro-scales. On a macro level, Western science has negated indigenous populations and traditional knowledge (Tuhiurai Smith, 2012). Researchers must find a way to acknowledge their own worldviews and not impress these views onto the meaning and understanding of others. On a more micro sense, there is a power dynamic between researchers and participants – not only on what topics are

researched, but regarding the questions that are asked, the direction of the questions, and even how the results are disseminated (Tuhiurai Smith, 2012). Therefore, I borrowed insights from decolonizing methodologies in order to bring equality to these relationships on both a macro and micro level; that is, I worked with participants as equal partners from the beginning, and tried to ensure that they had an equal voice throughout the entire research process (Tuhiurai Smith, 2012). Moreover, different ways of knowing and informal knowledge (e.g. traditional knowledge, land-based knowledge, etc.) must be incorporated into research in a meaningful way if researchers intend on building lasting, trusting relationships with participants (Ison and Russell, 2000; Tuhiurai Smith, 2012; Shindler et al., 2014).

Autoethnography was used to begin the process of developing connections and understanding between farmers and researchers. My research follows Chang's (2008) approach to autoethnography, which combines cultural analysis and interpretation, through narration, as a way to understand self (as a researcher) and others, in order to promote cross-cultural collaboration. Researchers who are aware of their traditions of understanding are more open to acknowledging informal knowledge, allowing a mutually beneficial relationship to be established (Ison and Russell, 2000). New ethnography aims to better understand and appreciate the meaning that a person brings to an experience, and accept multiple realities (Ison and Russell, 2000; Saukko, 2003; Denzin, 2010). Self-observation and self-reflection are also put forth in Chang's (2008) proposal for autoethnography, are interwoven with Denzin's (2010) persistence to meld the personal with the political, and considered essential in active systemic

research (Ison and Russell, 2000). Muncey (2010) argues that to truly connect and engage with a culture, the researcher must recognize and address their assumptions, bias and stereotypes. This “ontology of the self” has developed into the self-reflective autoethnography approach to research, allowing the author to investigate the shared experience (their own experience in respect to those of the research participants) and how these experiences impact each other (Saukko, 2003; Chang, 2008).

Chang (2008) relates that culture cannot be considered without reflection on the role of self and others, rather that culture is “a product of interactions between self and others in a community of practice” (Chang, 2008, p.23). Culture is inherently group-oriented, and autoethnography examines the relationship between self and others. In other words, Chang (2008) argues that to truly study culture and its meanings, researchers must place themselves as deep into the culture as possible, which requires self-observation and reflection. Chang’s discussion of self and culture complements the ideas of Krieb (1999), who espouses the notion of researchers as “edgewalkers”, in that they should be able to thoughtfully cross cultures, and successfully integrate into multiple communities through trusting relationships, yet maintain a healthy understanding of self. As such, self-observation and reflection throughout the research process will better enable researchers to build applicable, relevant research.

Therefore, the aim of this aspect of my research was to: 1) build equality and trust between researchers and farmers; and 2) conduct research that engages the community and promotes change, allowing the collective narrative of the farmers of the region to be shared and understood. In this way, this research intends to initiate a

lasting, mutually beneficial relationship in order to build the resources and support required to make the agriculture sector realize its full potential.

Methods

I conducted primary consultations to assess the willingness of the farmers to engage in the project and allow for their input into the format and direction of the research. I recruited participants by word of mouth and via snowball sampling through the use of an advisory circle (including key informants from Omineca Beetle Action Coalition, BC Ministry of Agriculture, and Community Futures Fraser Fort George, Beyond the Market Project). I also invited farmers to share names of others who they thought might be willing to participate in the project.

Data collection methods include semi-structured interviews, document analysis, participant observation and self-reflection/self-observation. All research participants were given a research information sheet, and consent form prior to the start of research (Appendix 1).

Participant observation

To gather data, I stayed on-site at the participants' property for a minimum of four days, with separate living accommodations. I participated in the daily life of the farmers to help build shared experience and understanding. I recorded information throughout the day, which was distinct from the self-observational and self-reflective data (as described below). Participatory observation adds a dimension of personally

experiencing and sharing the same, everyday life of the participants, and builds experience in the field that is a central part of understanding the culture (Brewer, 2000).

Semi-structured interviews

Farmers participated in a semi-structured interview during the main visit, at a time and place of the farmers' convenience, following interview guidelines (Appendix 2). Farmers who did not participate in the farm-stay aspect of the project, but were still interested in the research, were also interviewed. All interviews were recorded by a digital audio recorder, with the permission and knowledge of the participants, along with hand-written notes. I transcribed the recordings to confirm content recorded, and farmers had the option to review the transcripts, with two weeks to make changes and/or deletions before they were coded for analysis.

I kept all recordings and transcripts in my office at UNBC. All identifying features of the research participants were omitted from any records, unless the research participants specifically stated that they wished otherwise, to help confidentiality – a concern for small communities. Only members directly related to the project have access to the raw data, in order to compile reports (e.g. data return to the participants and funder of the project) and for the sake of performing various analyses and written publications.

When used for autoethnography, interviews help provide external perspective and contextual information to confirm, complement, or reject introspectively-generated data (e.g. any of my own preconceived notions of meaning) (Chang, 2008). Interviews

are useful in helping stimulate memories, filling information gaps, gathering new information, validating personal data and gaining other perspectives.

Self-observational and self-reflective data collection

Collecting personal memory data included writing exercises around creating an autobiographical timeline, through inventorying self through five thematic categories (proverbs, virtues and values, rituals and celebrations, mentors, and artifacts), as well as visualizing self through kinship diagrams and free drawing (Chang, 2008).

Systematic self-observational and self-reflective data collection was recorded in a narrative format. These accounts were a mix of immediate and retrospective observations, and were used for further reflection and analysis throughout the study period. A field journal was used for self-reflection data recording, allowing for the analyses of personal values and preferences, and for the identification of different aspects of northern farmers' cultural identity, and identify those who participate within this cultural group.

Photography of the study sites, willing participants and related activities was an integral part of documenting my experiences and the project itself. Participants were asked for permission to be photographed, including during any informal meetings/gatherings. These photographs complemented the narrative format of the data collection, and were incorporated into the final reports.

Document data collection

As previously noted, there have been different agriculture research and initiatives in the Omineca Region. In order to build our capacity to conduct relevant agriculture research, we needed to have a cohesive understanding of the work previously done and the knowledge already acquired. Rather than starting from the beginning, a portion of this research effort was to connect the past research from the Experimental Farms, and future into the present (Denzin, 2010), to ensure the best way to move forward was realized. Researchers simultaneously gathered farmers' assessments of current needs and future opportunities (Ison and Russell, 2000).

Data analysis

Qualitative data generates a large, cumbersome database, which makes analysis particularly difficult. In this study, data was jointly collected, coded and analyzed, therefore directing what data to collect next (a process referred to as theoretical sampling) (Bryman, 2008). Throughout the process of collecting data, I analyzed data, and used open coding to build concepts that were used to distinguish different themes. These were analyzed until the point of theoretical saturation, where there was no new information collected. At this point, relationships between categories were explored, leading to preliminary conclusions.

By using multiple sources of data (participant observation, semi-structured interviews, self-observational/self-reflective data and external documents/artifacts) to generate themes and analysis, I achieved a greater degree of validity and accuracy of

results. This approach allows the findings of the study to be more applicable on a broader scale (e.g. in regions not included in this study).

Data return to the producers

Voluntary, informal gatherings allowed for preliminary results to be discussed with research participants. Participants were asked to whom they thought information should be disseminated to, allowing for more information regarding the network of practice and for reports to reach a broader audience. All participants were provided with the final report of the project, and invited to the thesis defense. In the summer of 2013, I displayed preliminary results at various agricultural fairs throughout the region, including the Northern Exhibition (in Prince George, BC), the Nechako Valley Exhibition (in Vanderhoof, BC), the Lakes District Fall Fair (in Burns Lake, BC) and the Bulkley Valley Exhibition (in Smithers, BC).

1.3 Results and discussion

The objective of autoethnographic study was to increase my understanding of the cultural values and practices of producers in the Omineca Region. To do this, I considered how management practice decisions are made (e.g. factors of adopting new practices), how producers generate and share information, and what producers believe are the largest barriers and/or challenges to their operation (both short- and long-term). Interwoven throughout the discussion of the main themes are stories that highlight the complexity of these challenges, and how the perceptions that producers and

researchers have of each other impact the process. In total, I collected data from 18 producers, through farm stays, semi-structured interviews and/or informal meetings and gatherings (Table 1.1).

Table 1.1. Descriptive characteristics of the Omineca producers who participated in either farm stays, semi-structured interviews and informal meetings.

Gender	Age	Region	Time in Region (Yr)	Farm Size (ac)	Product
Male	50+	Robson	35	> 1,600	Grain; bison
Couple	50+	Robson	--	--	Cattle; chickens; vegetables
Couple	30-50	Robson	< 5	--	Cattle (100); goats
Male	50+	Nechako		> 2,000	Cattle (background/cow-calf); grain; forage; poultry
Male	50+	Nechako			Grass-fed cattle; grains
Couple	50+	Prince George	40+	--	Cattle (cow-calf); grain; forage; vegetables; u-pick
Male	50+	Prince George		> 3,000	Cattle; grain; forage
Male	30+	Nechako	20+	--	Cattle; grain; forage
Female/	30+/ Male	Nechako	30+	> 4,000	Cattle; grain; forage
Couple	80+				
Couple	40+	Quesnel	< 10	> 500	Agro-tourism; poultry; wool; birch syrup
Couple	40+	Quesnel	10	> 500	Agro-tourism; horse boarding/therapy; forage; cattle
Male	40+	Bulkley	30+	> 1,000	Cattle (600, start to finish); forage
Female	50+	Bulkley	--	< 100	Forage; market garden
Male	40+	Bulkley	< 10	< 500	Swine; chickens (laying and meat)
Male	30+	Bulkley	< 5	< 100	Grain; forage
Male	50+	Bulkley	> 20	> 1,000	Cattle; grain; forage
Male	60+	Bulkley	> 60	> 3,000	Cattle; grain; forage
Male	30+	Bulkley	> 30	> 3,000	Cattle; grain; forage

Factors influencing decision-making: moving towards resilience and adaptation

One of the most influential challenges that impact producers is the economic viability of their operations; producers, particularly grain and cattle producers, recognize that they are “price takers”, and they have seen increasing costs of inputs every year, but a decrease in market prices. Producers in the region are not independent of the industrial model of agriculture that dominates in North America, and without the economies of scale, smaller producers (typical of northern BC) are finding it increasingly difficult to compete economically in the system. “The greatest vulnerability as a farmer is being [disenfranchised within] the supply chain; we don’t set the prices or demand, and have no voice in establishing those prices,” said one Nechako producer. As the agricultural sector started to industrialize, more of the economic risk associated with production has been placed onto the producer (Crawford and Bevrige, 2013), which influences how producers make management decisions around adopting new practices.

My study found that the main reasons farmers adopt new practices, cultivars or technologies are: 1) economic; 2) contextual relevance; and 3) experiential knowledge that they have gathered, supporting the results Baumgart-Getz et al. (2012). One producer explained that the initial push to change practices was economic, saying, “last year we spent \$80,000 on fertilizer alone, [...] this year we looked at our economics, and we couldn’t afford it, so had had to think about another way to do it.” As they began to think about other systems in order to address their financial constraints, their focus shifted to considering a more holistic approach to address soil fertility, by considering plants not strictly for their yield characteristics, but also for how the plants could

Box 1.1. A narrative of a Vanderhoof producer explaining the risk of adopting new production practices when there is no regional information to provide context.

“We used to over-winter our cattle in the feedlot, but it gets expensive, and it is time consuming. It takes a lot of machinery and man-hours to harvest and move everything off the field and to the feedlot, then back out in the feedlot every day throughout the winter. Also, all the manure is then concentrated in one place, creating concerns over leaching and water health. It takes more time to then move that manure, and all its nutrients, back to the field.

We have tried alternative strategies, such as swatch grazing, which sounded really promising; you don’t have to harvest and bail the feed, so it’s less machinery and less work. But, if we get too much snow that year, we lose the feed altogether. Then we have to worry about sourcing feed late into the season, when there’s not always enough. To make it work, we have to know which of our fields get more snow, and which don’t. It can be very risky, depending on where you’re located.”

decrease their input costs. Another producer felt economically restrained from running a specialized cattle operation, and has responded by adopting a grazing model that includes chickens, adding diversity to their income. They said, “it created economic diversity for us, but also environmental diversity. We’re trying to build a system that works together, that is complementary.” Still, producers are weary about adopting practices that they have not seen being used in the region, as it increases their risk if it is not successful (Box 1.1).

The trend in developing sustainable agriculture reflects the understanding that some agricultural practices degrade the surrounding environment, and often producers are perceived as being environmentally unconscious. However, throughout this study, all producers who participated discussed long-term environmental considerations in their management decision process, recognizing that their livelihood is based on the environment, including producers who primarily used “conventional” production

practices (e.g. large scale operations, machinery, chemical fertilizers and pesticides, etc.). One conventional operation in Vanderhoof expressed their concerns by saying:

“[With the switch to more industrial style production] the focus was quick production, because if you increased production, you can increase your sales. But what we’re finding is that that’s not economically viable. [...] You have to be building up your soils as you’re harvesting crops, it’s finding that balance and sustainability. When we use chemical fertilizer, yes we get that kick-start we need in the first year, and maybe the second, but then it stops working. Looking at a more holistic and sustainable approach, trying to use both the animals and the plants to correct the balance, rather than chemicals and fuel, *that* is what we’re always aiming to do.”

In addition to their environmental considerations, producers in the region are noticing greater variation of weather from summer to summer, and said it has been a struggle to adapt their production to increasing unpredictability of summer conditions. For example, there was an unusually hot, dry summer in 2014; producers in the region, who were used to cooler, wet summers, were not equipped to manage the change (e.g. no irrigation systems, or systems that were only meant to run a few times in a year), resulting in achieving 40-50% of their average yields (Stevenson, *pers. comm*, 2014). This pattern of unpredictability highlights the need to work with producers to develop resilient production systems that have greater adaptive capacity.

The overarching theme around making best practices decisions and adopting new cultivars, crops, etc., is the dependence on the context in which producers are working. Throughout the farm stays and field days, I began to recognize the amount of diversity that exists between producers, not only in the micro-site conditions in which they are working (e.g. climate, topography and soils types), but also in the socio-economics of the household. Within the first summer of working with producers it

became clear that there is no one culture of northern producers (Anderson, 1991); rather I have come to understand how cultures of northern producers in the Omineca impact how they make short and long-term decisions, based on their connection to land and the structure of their operation. For example, a multi-generational farming operation will have different socio-economic challenges than new operations (Box 1.2).



Figure 1.1. During one farm stay, I participated in the tradition of the entire family bringing dinner out to the field during the first day of haying. It was a great experience, and sparked many stories.

Box 1.2. Exploring the cultures of northern producers living in the Omineca Region, through three farm stays, in order to illustrate how various cultural and socio-economical factors influence the context of an operation and subsequent decision-making.

Farm stay #1:

My first farm stay was at an operation where two families, with several generations within each family, were involved in managing the operation and are living on the property. Having a rich history in the region, they had adopted a mixed-system, they focused on growing different grain and forage crop, and have been involved in different sectors of the cattle industry over the last few decades. The farm began actively experiments with other crops and with other livestock, including chickens, goats and swine. Due to their location, they have access to irrigation, increasing the diversity of crops they could successfully grow. Having an established, multi-stakeholder operation has provided the capital and capacity to be flexible in the crops and livestock management on the farm. With two families heavily invested in the operation, the farm fluctuates as the younger generation moves on and off the farm. While this system provides economic flexibility to respond to the market, having multiple stakeholders creates long-term challenges around successional planning, and division of assets as the older generation retires.

Farm stay #2:

During my second farm stay, I was introduced to an operation that had three generations raised and working on the same operation property. They are focused on backgrounding and finishing cattle (including access to a feedlot), as well as forage and grain crops. However, without access to irrigation, they were limited to which crops and cultivars they could grow successfully, and regional variety trials would be beneficial. While they owned land, they also leased other land for grazing livestock and to grow more forage. The farm was primarily managed by the father who had grown up on the land, with several of his children who were still actively working the farm. While having multiple generations on the farm meant there was generally greater support to manage the farm, some of the children's spouses came from non-farming families. This dynamic created more of a time strain on the family; having off-the-farm jobs and desire for work-life balance often conflicted with the responsibilities of the farm. Still, the family's history on the farm meant I witnessed some valued traditions, including having the entire family bringing a picnic dinner to workers in the field for the first cut of hay (Figure 1.1).

Farm stay #3:

My final farm stay was with new entrants, whose main challenges were financial (e.g. the capital required to start up, off-farm jobs, and loans). Therefore, they use agro-tourism and have actively built relationships with different organizations around town to supplement their farm income (e.g. school camps, horse therapy sessions). Community education and extension has been an integral part of their operation's start up. Just starting on their new property, they have to build up soil health in order to plant desired crops. While facing several immediate challenges, they felt access to regionally relevant information and lack of resources pose the greatest long-term challenge.

Developing context

The farm stays and participant observation experiences were instrumental to building my appreciation for the nuances described above; I believe building a shared experience with the producers was a crucial aspect to the process. By taking part in producers' day-to-day activities, I was able to build insight on the time constraints, and other short-term challenges they faced. By immersing myself in their operation, I was able to build trust, and learned more about the complexities of the issues they face than I could have from being in a classroom. For example, during the farm stays I camped out of the back of my truck, which proved to be a quick way to demonstrate that I was rugged, and well suited to farm work (Figure 1.2). It was also intriguing to see the shift in how they perceived me as a researcher; at first they were hesitant about my enthusiasms and my naivety, and as the stay continued, a mutual sense of trust and understanding was developed. By the end of the visit, producers were more open to discuss the restraints they felt daily, and their hopes for the future. They had very little time to spare, and felt lack of time and resources (regional research and extension) really hindered them from effectively planning for the farm long-term.



Figure 1.2. During my farm stays I kept separate sleeping quarters, which was back of my truck. Most producers found it amusing, and proved that I really was a rugged, northern woman after all.

After numerous conversations with producers, it appeared that part of their hesitation to participate in research was due to the recent gap of applicable research being conducted in the region. Producers' social memory of government and university research was that the process was time consuming and resulted in information that was either out of date or not applicable. As one producer recalled, "The parameters [of the work] were unknown or constantly changing, and the work was developed by people who were off-the-ground and disconnected from producers – especially producers in the north." There are several examples in the literature that suggest that the traditional approach to research and extension does not initiate change on the ground (Ison and Russell, 2000), and producers in the Omineca expressed similar sentiments.

Producers were aware of many new management practices, cultivars, crops and technologies, but the majority of this information was developed outside of the region and without consideration of the producers' realities (e.g. lack of funding for regional research and extension, and the incompatibility of industrial agriculture system in certain regions). For example, while new cultivars of grain are being released annually, they are not often tested in the region and producers have no information on local performance. Moreover, if cultivars are being bred for wide adaptation (see Chapter 2 and 3), then it is probable that few cultivars are suitable to the region – and if they are, they may not be available locally. Ison and Russell (2000) argue that 'first-order tradition' of research and development results in a minority of producers adopting the proposed solutions largely because it is based on the idea of transferring or sharing knowledge, rather than finding a way to create knowledge together through a process of mutual understanding. Furthermore, traditional research is often disciplinary, breaking agriculture systems into various parts rather than addressing the complexities and interconnections of all the various issues (Scott, 1998; Ison and Russell, 2000).

Compounding the lack of applicable research is the general lack of extension and technical support for producers in the region. One government employee often services large areas of the region, and recently there have been large gaps (5+ years) where regions were left without any regional agrologist. A Vanderhoof farmer said, "We used to have a district agrologists in this area, and almost every town had one, but now because all the cut backs [in the Ministry], we don't anymore." Farmers who have been in the region for several decades often told stories of the "high point" of government

extension when the Experimental Farms and Illustration Stations were open, and how these farms provided a space for producers to meet and share information on what worked and what did not, as well as a visual demonstration of the research happening at the stations. Lacking contextually applicable research, and the proper extension and support, producers feel there is greater risk at trying to adopt new practices or cultivars. A producer explained that, “we now rely on generic information, and while the concept is perfect, nobody knows what your conditions are or what your fields are like, so it might not work in your context.” Consequently, producers are not taking advantage of unique opportunities in the region; there is a distinctive need to build the region’s capacity to conduct relevant research, and to consider the framework of *how* research and extension is conducted, in order to ensure its relevance for the greatest number of farmers.

Incorporating multiple ways of knowing

Learning how producers gather, share and generate new knowledge (their *community of practice*) will help inform a new approach (Scott, 1998; Wenger, 1998; Ison and Russell, 2000). Unanimously, producers depend primarily on local, informal knowledge generated within their communities. They said most of their networking happens with local organizations (e.g. Farmers’ Institutes, Cattlemen’s Associations, Dairymen’s Associations, Farmers’ Markets, etc.), or randomly when they run into others in the community from time to time. When considering whether to try a new crop or management practice, most producers said that they first consult with somebody they

know who has tried it before to get their advice, then might go to the local agri-business, or online for more information. However, all producers expressed that time constraints limited the opportunities they had to have these interactions, supporting the conclusion that producers tend to be organizationally weak (Oreszczyn et al., 2010), though this reflects their constraints, rather than their intentions. The majority of producers were eager to find more opportunities to learn and discuss their ideas, and expressed frequently that they have more ideas of what to try than the time to explore them. Most participants said they found field days were the most informative and encouraging experiences. A Bulkley Valley producer recalled a recent field day he had in Vanderhoof, stating, "Visiting the new pellet plant, I learned more in that hour than I did a year in school. When you can go and see the potential, visualize it, it's much easier to get excited about how you could incorporate that into your business."

Throughout my experiences on the farm, it became clear that social memory did not favour most farmers' willingness to participate in formal research. From their perspective, research was a foreign concept that happened in institutions that did not understand their realities – a perspective that exists in some other places as well (Ison and Russell, 2000). Research has not always respected or incorporated informal knowledge acquired by producers, further distancing research from the needs of producers (Brewer, 2000; Denzin, 2010; Tuhiurai Smith, 2012). It became clear from conversations with Omineca farmers that for any future research to be successful, it will be necessary to break down the barriers that farmers believe that they cannot contribute to research, and the perspective that researchers do not value or consider

Box 1.3 Deconstructing research and embracing multiple ways of knowing.

At an informal meeting with 16 producers in the Bulkley Valley, I asked for everyone to introduce themselves and their operations. Throughout this process, almost every producer stated that they felt they “had nothing of value to share”, and were “unsure of why they were invited to participate.” Though I was prepared to take the lead and direct the meeting if needed, I wanted to have the producers direct the process and set the agenda.

As producers began to share their stories and perspectives regarding the main challenges and opportunities for agriculture in the region, they became more comfortable, and showed excitement about the idea of doing research together. By having an opportunity to actively share their stories and experiences, the producers began to feel empowered, and began to share more as the meeting continued. At the end of the meeting, they invited me back to discuss more about how we, collectively, could find a way to move forward on a research project. For my purposes, this was the great success from the project; finding ways to engage producers and identify what they are passionate about, and willing to actively participate in, is an important first step towards generating knowledge together, through mutual understanding.

The sentiment that the producers felt they had little to contribute, which I heard over numerous years working in the community, reflects the disconnection producers feel with research. Due to previous experiences, producers often view research as something that is complicated, that happens in laboratories, and that is not tangible or meaningful to them. I have come to believe that part of my role as researchers is to break down this barrier, and acknowledge the amount of local knowledge and experience producers have to contribute, and that they themselves are researchers.

local knowledge held within each community (Box 1.3). One farmer lamented, “for a long time, farming has not been given the respect it deserves in the community. [...] To be a farmer, you have to stay on it everyday, be curious and inventive and find a way to make it work. We need to be proud of what we do – we are an essential service to society, and we need to be treated as such.” Indeed, producers are inherently innovative, resourceful and creative – it the foundation to their day-to-day activities, and these values of resourcefulness and persistence is largely what has attracted me to the

culture of northern farming. Therefore, finding a way to break down these barriers, and embrace various ways of knowing to build projects that are mutually beneficial will be essential in the success of future research initiatives within the Omineca Region.

3.4 Conclusions

The agricultural industry in the Omineca Region has yet to reach its full potential – though not because producers have lacked the enthusiasm or desire for it to do so. The producers in the region face not only the challenges of growing in a northern, climate with short growing season, but they also must compete with the industrial agriculture system that prevails in North America. Since the closure of the Experimental Farms in the region, producers have also been left with a lack of applicable, regional research that can contextualize information on new practices, crops and cultivars. Even more, there is now a pattern of discontentment and mistrust of government and academic institution.

From my experiences throughout this research, and from the stories I have heard from farmers, I am convinced that in order for the agriculture industry to sustainably grow and reach its potential there needs to be long-term applied research initiatives taking place that are not only connected to the producers, but are conceived and executed in full collaboration with them. Meaningful change and improvement will necessitate collaboration first between researchers and producers, but also eventually will need to work in partnership with all levels of government (municipal, provincial and federal), and other stakeholders within the communities. The diversity of the landscape

and cultures that exist in the Omineca Region must be recognized and incorporated in any future initiative or project. The challenges and issues facing the agriculture industry are complex and inter-related, demanding an inter-disciplinary approach based on the accepting multiple ways of knowing.

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CHAPTER TWO: PLANT DEVELOPMENT

2.1 Introduction

Building agricultural capacity in northern British Columbia will be critical to simultaneously strengthen food security and economic diversity of the region. Agriculture in the Omineca Region, located in north-central BC, is characterized by non-industrial scale livestock, forage and grain production. Following the closures of the Experimental Farms in this region due to centralization of the system, there is now a dearth of regionally-focused research and extension services. One strategy to promote sustainable and reliable forage and grain production on comparatively marginal lands is to identify cultivars that are well adapted to local conditions. Producers and industry stakeholders identified barley (*Hordeum vulgare*) cultivars' response to water stress as a relevant research priority for the region.

The genus *Hordeum* is believed to have originated in Southeast Asia and has been shown to have wide adaptive tolerance, growing in high- and low-fertility soils (von Bothemer et al., 2003; Ullrich, 2011). Among other temperate cereals, barley is able to mature in areas with shorter average growing seasons, and can therefore be cultivated at higher latitudes, higher elevations and more arid areas compared to wheat or maize (Tivy, 1990; von Bothemer et al., 2003). Phasic development (phenology) in barley is influenced primarily by temperature, though secondary influences include water availability, light, salinity, nutrients

and carbon dioxide (McMaster and Wilhelm, 2003; McMaster et al., 2008; Ullrich, 2011). While many physiological studies have focused on measuring plant-water relations in cereal crops, phenological effects are not always included in these studies, or considered in breeding programs (McMaster et al., 2008).

Most breeding programs in North America focus on increasing yield potential, pest resistance and grain quality. Regarding cultivar adaptation, there are two main breeding philosophies: wide adaptation and specific adaptation (Ceccarelli, 1989). Wide adaptation aims to improve crop performance across macro-environments, which includes the majority of modern cultivars. Breeding for wide adaptation translates to selecting for genotypes by measuring a cultivar's performance temporally (e.g. regarding a specific location over many years) and spatially (e.g. regarding several locations with different climates) (Ceccarelli, 1989; Ullrich, 2011). This breeding paradigm requires prescriptive management to ensure conducive conditions and is accomplished through prodigious use of fertilizers, irrigation, and pesticides, which works to rectify the unnatural and ecologically unstable simplicity of the agro-ecosystem in order to create a uniform product that can be mechanically cultivated and harvested quickly and efficiently (Scott, 1998). If the underlying requirements for this production model are violated, due to economics, lack of resources or climate change, a cultivar's plasticity, which is linked to its phenology, will be important to local and global food security. Not all farmers in northern and rural areas such as the Omineca Region can adhere to the requirements of high-yield production, as the

landscape and climate often do not support this agriculture system (e.g. poor soil conditions, short growing season, varied topography, and/or limited water availability/precipitation).

Cultivar breeders that select for specific adaptation, such as response to drought or other environmental stress, must consider every potential environment, and then breed for different traits based on the environment (Ceccarelli, 1989; Ullrich, 2011). Specific adaptation aims to improve crop performance within specific macro-environments, a process that is similar to the development of landraces, which is the result of years of natural selection in a given environment; a primary adaptive trait is their stability of performance under a wide range of stresses in a given environment (Ceccarelli et al., 1992). This breeding strategy may be better suited when breeding cultivars for use in agri-systems with more variable and/or stressful environments, and therefore using these cultivars would require less management relative to a high-input system, because the crop has adapted for the environment, instead of adapting the environment for the crop (Ceccarelli, 1989; Scott, 1998; Pswarayi et al., 2008; Ullrich, 2011; Zhang et al., 2013). Some studies suggest that as inputs such as fertilizers, water, and fossil fuels become more limited, this may be a better long-term strategy (Ceccarelli 1989; Scott 1998; Ullrich 2011). For example, breeding for earlier flowering could lead to higher and more stable crop yields in areas of low and/or variable rainfall (Zhang et al., 2013).

Phenological characteristics can be an important aspect of crop or cultivar management and adaptation to a particular environment, especially in northern climates where the growing season is shorter with less heat accumulation. For instance, in short-season environments, a cultivar that matures in less time (90-130 days) has a better chance of reaching physiological maturity than cultivars taking more time (130+ days) (McMaster et al., 2008; Serna-Saldivar, 2010; Ullrich, 2011). Phenological responses to water stress can differ between crops and between cultivars, and it reflects sensitivity to the timing and intensity of stress (Gimenez et al., 1997; McMaster et al., 2005; Brown, 2007; McMaster et al., 2008; Ullrich, 2011). A cultivar's phenological profile is potentially associated with its adaptive response to varying climatic conditions; Ullrich (2011) suggests that climate change will likely require farmers to alter the sowing date to mitigate change, or select cultivars based on growth habit and/or heading time, as these traits facilitate the synchronization of the plant life cycle to seasonal rhythms.

Phenological traits are also linked to a plant's drought resistance mechanisms (e.g. drought avoidance or drought tolerance). Phenological drought avoidance can be expressed through early growth habits (e.g. early days to heading, or sensitivity to early season water deficit/stress) to facilitate plant physiological maturity prior to extended periods of limited water availability. Drought tolerance refers to a plant's physiological ability to withstand internal deficits. Generally, annual plants tend to have growth habits to avoid water stress, while perennials tend to have adaptations that allow them to tolerate

water deficits (Brown, 2007). Phenology and growth habit are linked to how a plant has adapted to its local site conditions and, therefore, can be used as an indicator of its adaptive tolerance (Brown, 2007; McMaster et al., 2008; Ullrich, 2011).

Barley cultivars that exhibit early heading, early flowering and/or early maturation should promote avoidance of late-season drought, and are thus likely better adapted to rain-fed cultivation regimes (Ullrich, 2011). Furthermore, phenological traits such as days to heading, grain-filling period and days to maturity are correlated to several yield components, including number of kernels per spike and kernel weight, and can therefore impact a cultivar's overall grain yield (Fageria et al., 2006; Ullrich, 2011).

Early developmental stages of barley (e.g. jointing, flag leaf appearance) have shown little response to water stress, while later developmental stages (e.g. anthesis, grain filling and physiological maturity) show greater response to drought (Brown, 2007; McMaster et al., 2008). The timing of anthesis is often related to a cultivar's adaptation to a particular location, and reducing the days to heading in drought-prone areas has permitted comparatively increased yields by lowering the amount of late/terminal stress (Araus et al., 2008; Ullrich 2011). Early planting is one way to encourage early anthesis, though producers in less temperate climates (e.g. Omineca Region) must consider the possibility of late-spring frosts that could damage or destroy the crop.

In this chapter, I analyze key phenological traits of nine barley cultivars (six modern and three heritage) and one wild type (*Hordeum zeocrithon*) under a wide range of water regimes (excess and deficit), as a way to assess the relative adaptive capacity of each cultivar group. Modern cultivars are the result of intensive breeding programs that select for specific traits from parents with known traits (controlled pollination), while heritage cultivars still have a degree of open pollination, increasing genetic diversity within the crop (von Bothmer et al., 2003) (see Appendix 3 for cultivar descriptions). While all cultivars were expected to hasten maturity under adverse water conditions, heritage cultivars were expected to show less treatment responses, reflecting greater stability under varying stress conditions. It was also expected that there would be greater variation between cultivars within the heritage group's phenology compared to modern cultivars, reflecting their specific adaptation traits.

2.2 Methods

Study design

The study was set up in a completely randomized design. The six modern barley cultivars were AC Lacombe, CDC Cowboy, Xena, CDC Bold, CDC Dolly and McBride, and the three heritage cultivars were Black Hulless, Bere and Himalayan, and the one wild-type was *Hordeum zeocrithon*. Single-plant plots (eight replications per cultivar in each water treatment) were grown during the

summer of 2012 in a controlled environment (Enhanced Forestry Lab, University of Northern British Columbia, 53°54'N, 122°49'W) (Montagnon et al., 2001).

Water regimes

Six water regimes were used to mimic a wide range of moisture stress. One regime established a benchmark of non-limiting moisture, and study plants were maintained near field capacity (FC); four regimes were allowed to decrease to different moisture-deficit levels in relation to the FC benchmark based on volumetric weights (i.e., 80%, 60%, 50% and 35% saturated weight) to reflect a range of slight to extreme moisture deficits (see Table 2.0); a final regime maintained continuous saturated soil conditions. All study plants were grown under non-limiting moisture conditions until the fourth leaf stage, at which point moisture-stress regimes were initiated, corresponding to the beginning of tillering (Teulat et al., 1997). Oscillating fans were set up in the greenhouse to emulate wind and to minimize temperature gradients in the greenhouse.

Table 2.0 Quantitative values in regard to Field Capacity of regime as associated to qualitative description.

Quantitative Value (% Field Capacity, FC)	Qualitative Description
n/a	Saturated
100%	Optimal
80%	Slight moisture deficit
60%	Moderate moisture deficit
50%	Severe moisture deficit
35%	Extreme moisture deficit

Study set-up

Study plant pots (1 gallon) were filled and weighed to ensure consistent volume of soil (between 5.5-6 lbs), and filled pots were saturated with water and allowed to drain overnight before seeding (Anyia et al., 2007). The growth medium was a 50% sphagnum peat and 50% pasteurized sand mixture, which provided a relatively neutral substrate for good moisture control and facilitation of easy and consistent root harvesting. Micromax Micronutrients Granular (Fe 17%, S 12%, Ca 6%, Mg 3%, Mn 2.5%, Cu 1%, Zn 1%, B 0.1%, Mo 0.05%) was added to the soil mixture prior to sowing. Each treatment block had a Styrofoam buffer on the outside to reduce heat loading of soil in the outer row of pots.

Seed sowing took place in early June 2012. Each water regime was applied to eight individuals of each of the 10 cultivars (80 plants per regime). Pots were double sowed to ensure successful germination, and thinned to one plant/pot one

week after emergence. Nutrients (NPKS: 80/35/25/10) were applied 2-3 times a week in soluble form after germination was established. Regime cohorts were rotated across along north-south and east-west gradients weekly, to minimize the effect of any light gradients in the greenhouse. Daytime air temperature was maintained at 26 degrees Celsius to promote high photosynthetic rates (Medlyn et al., 2002), and night temperature was maintained at 15 degrees Celsius to minimize growth reductions due to high rates of respiration (Berry and Björkman, 1980); a transitional period of one hour at 21 degrees Celsius between temperature shifts was used to reduce any stress created by rapid temperature change. Plants were grown under ambient light and photoperiod to ensure that phenological responses reflect northern growing conditions.

Three phenological traits were measured during the growing period. Days to heading (DH), the number of days from planting that at least one spike had fully emerged from the boot (Brown, 2007), was determined separately for each individual plant. A plant was determined to have reached physiological maturity once 80% of the spikes on the plant were mature (kernels were firm by touch and complete discoloration of peduncle) (Brown, 2007). The grain filling period was calculated as the days to maturity minus days to heading.

Statistical analysis

All analyses were conducted using SAS® 9.3 (2013). Phenological traits were examined for normal distribution using Shapiro-Wilk statistic. Means for

phenological traits were compared within and between cultivars by one-way analysis of variance. Where significant differences were found within or between cultivars, pairwise comparisons were conducted with Tukey's multiple comparison test to determine specific differences between cultivar means. Results were graphed with Delta Graph® v.6.0.18. The wild-type *Hordeum zeocrithon* had a small sample size due to large mortality rates and was not included in the statistical analysis; however, it has been included in the data for illustrative purposes.

2.3 Results

The modern and heritage barley cultivars displayed unique responses to varying levels of water stress. Generally, modern cultivars had little difference in mean days to heading, and showed uniform responses to stress, generally taking significantly longer to reach heading and maturity under the optimal and saturated regimes. Heritage cultivars tended to show more variation in mean days to heading, with little significant treatment response; though following a similar trend in days to maturity and grain filling as modern cultivars, there was a smaller range in the difference from the optimal and saturated treatments and the slight, moderate, severe and extreme water-deficit treatments. No significant difference was observed between the slight to extreme water deficit treatments for any cultivar for all three traits (some significant differences were observed in

days to maturity for cultivar (cv.) McBride, and in days to heading for cv. CDC Cowboy).

Days to maturity (DM)

Within cultivars, all modern cultivars took significantly longer to reach maturity in the optimal treatment compared to all water-stress treatments ($p < 0.0001$); the saturated treatment took significantly longer than all the water-deficit treatments ($p < 0.0001$) (Figure 2.1a). There were generally no significant differences within modern cultivars across the water-deficit treatments, except for cv. McBride where the extreme moisture-deficit treatment took significantly fewer days to reach maturity than it did in saturated conditions treatment, and in the slight and severe moisture-deficit treatments ($p < 0.0001$). Heritage cultivars, while exhibiting similar response as modern cultivars, generally showed proportionally less response to moisture deficits and excesses than modern cultivars (Figure 2.1a). Modern cultivars had a greater range of days to maturity between optimal and water-deficit treatments relative to heritage cultivars, taking between 26.1 and 30.4 days longer to reach maturity in the optimal treatment versus 10.3 to 15.9 days longer in the heritage group.

Across all cultivars within water-stress regimes, modern cultivars took significantly longer to reach maturity in the optimal and slight moisture-deficit regimes compared to heritage cultivars ($p < 0.0001$ in all cases) (Figure 2.1b). The cultivar Himalayan was the only cultivar with significantly shorter DM in the

saturated treatment, as well as in moderate and severe moisture-deficit treatments ($p < 0.0001$). Comparing within modern cultivars only, there were no significant differences in DM for any of the water-stress regimes, with the exception of cv. CDC Cowboy taking longer than cv. McBride to mature in the extreme water-deficit treatment ($p = 0.047$). Across heritage cultivars, Himalayan had significantly shorter DM relative to cv. Black Hulled in the saturated treatment ($p = 0.061$), as well as in severe ($p = 0.001$) and extreme ($p = 0.106$) water-deficit treatments, and shorter DM than cv. Bere in moderate moisture deficit ($p = 0.005$).

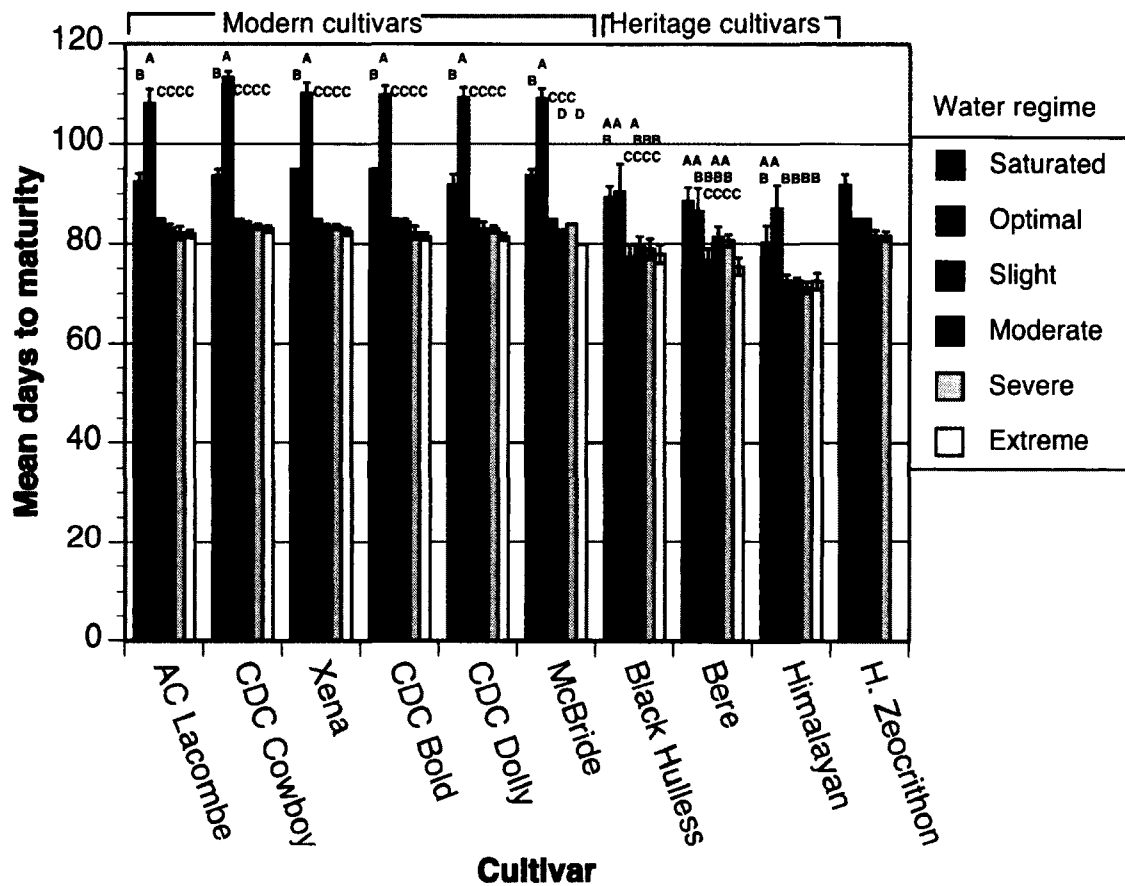


Figure 2.1a. Mean days to maturity (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime. Different letters indicate significantly different means within each cultivar at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

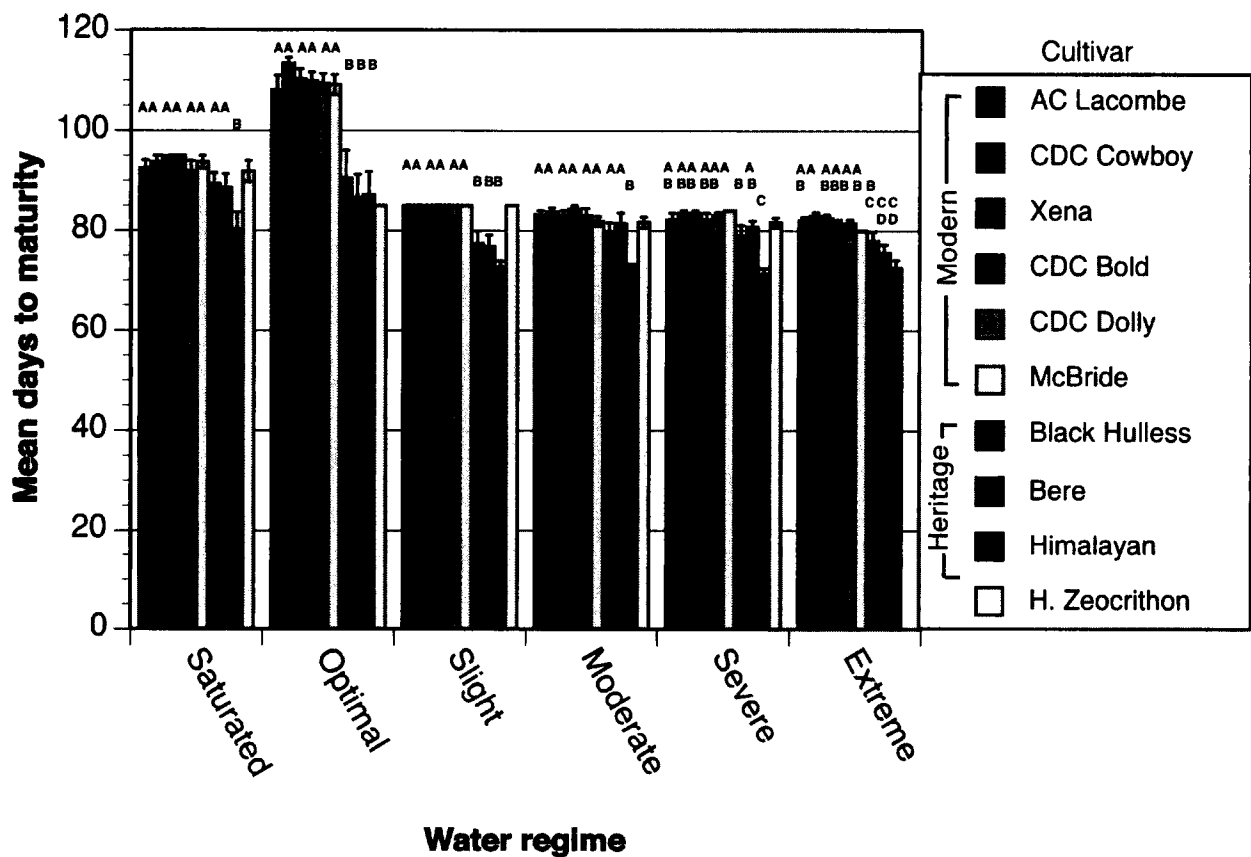


Figure 2.1b. Mean days to maturity (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) compared within water stress regimes, grown under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime. Different letters indicate significantly different means within each water regime at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Days to heading (DH)

Within cultivars there were few significant treatment responses in DH for either group (i.e. modern or heritage), though most cultivars had greater mean DH under the optimal treatment (Figure 2.2a). The cultivars CDC Bold, CDC Dolly, Black Hulless and Himalayan had no significant difference among any water-stress regimes. The optimal treatment had significantly longer DH than the extreme moisture-deficit treatment in cvs. AC Lacombe ($p=0.047$), Xena

($p=0.001$), McBride ($p=0.092$) and Bere ($p=0.072$). Cultivars Xena and Bere had the highest mean DH range of 9.2 days, with cv. CDC Cowboy following with a DH range of 7.9 days. Cultivar Black Hulless had the lowest mean DH range, with 1.75 difference between treatments, while cv. Himalayan had 2.5 difference.

Responses to water-stress regimes for DH were quite distinct between modern and heritage cultivar groups. Across cultivars and treatments the mean DH range was 15.4 days among the modern cultivars, while heritage cultivars had a mean DH range of 32.9 days (Table 2.1a).

Comparing across all cultivars within each water-stress regime, cvs. CDC Cowboy and Xena took the longest to head in every treatment, and significantly longer than most cultivars (Figure 2.2b), while cvs. Black Hulless and Himalayan took significantly fewer days to head in every treatment ($p<0.0001$). Cultivars had the greatest range differences in the saturated treatment (31.7 days difference between cultivars), and lowest range in extreme deficit (20.0 days difference between cultivars) ($p<0.0001$) (Table 2.1b).

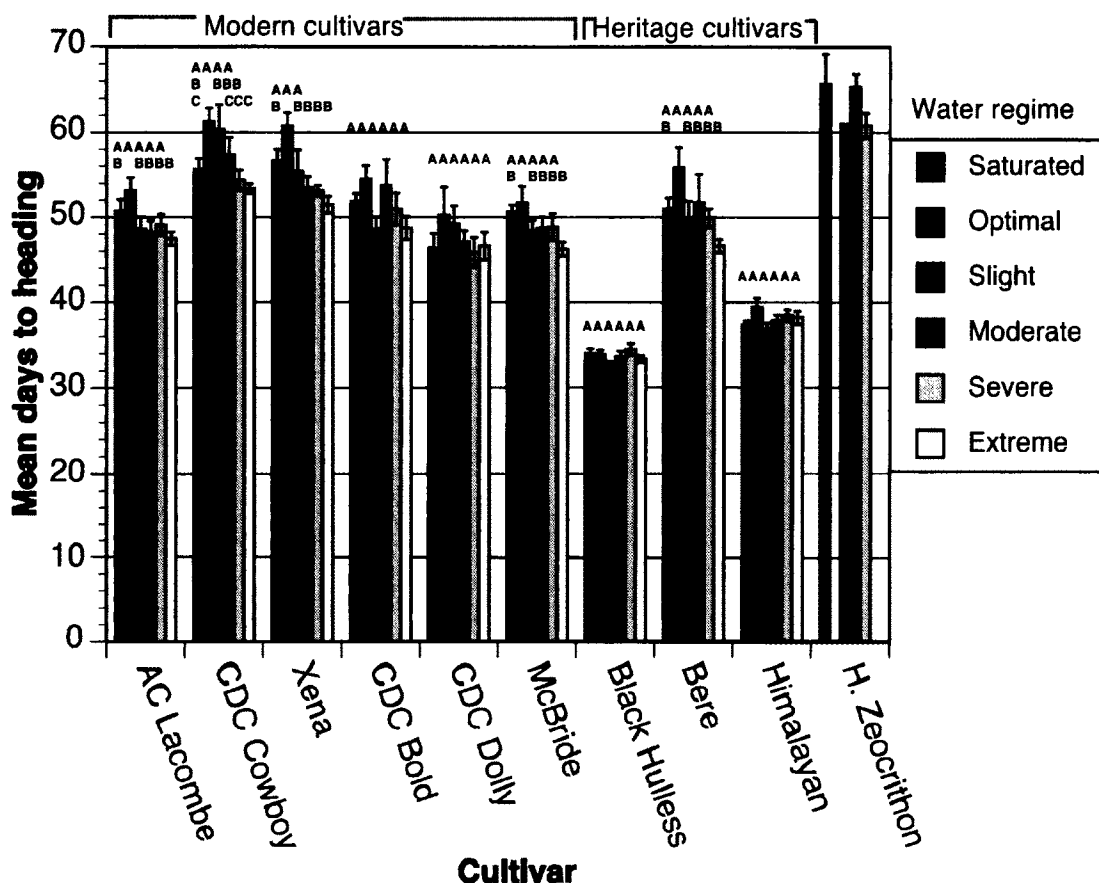


Figure 2.2a. Mean days to heading (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime. Different letters indicate significantly different means within each cultivar at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Table 2.1a. The descriptive statistics of mean days to heading of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) across water excess and deficit regimes under greenhouse conditions.

Modern cultivars				Heritage cultivars			
Cultivar	Minimum days	Maximum days	Range	Cultivar	Minimum days	Maximum days	Range
AC Lacombe	47.5	53.1	5.6	Black Hulless	32.8	34.5	1.8
CDC Cowboy	53.4	61.3	7.9	Bere	46.6	55.8	9.2
Xena	51.5	60.8	9.3	Himalayan	37.0	39.5	2.5
CDC Bold	48.6	54.5	5.9	H. zeocrithon	60.8	65.7	4.9
CDC Dolly	45.9	50.3	4.4				
McBride	46.3	51.8	5.5				
Overall range	45.9	61.3	15.4	Overall range	32.8	65.7	32.9

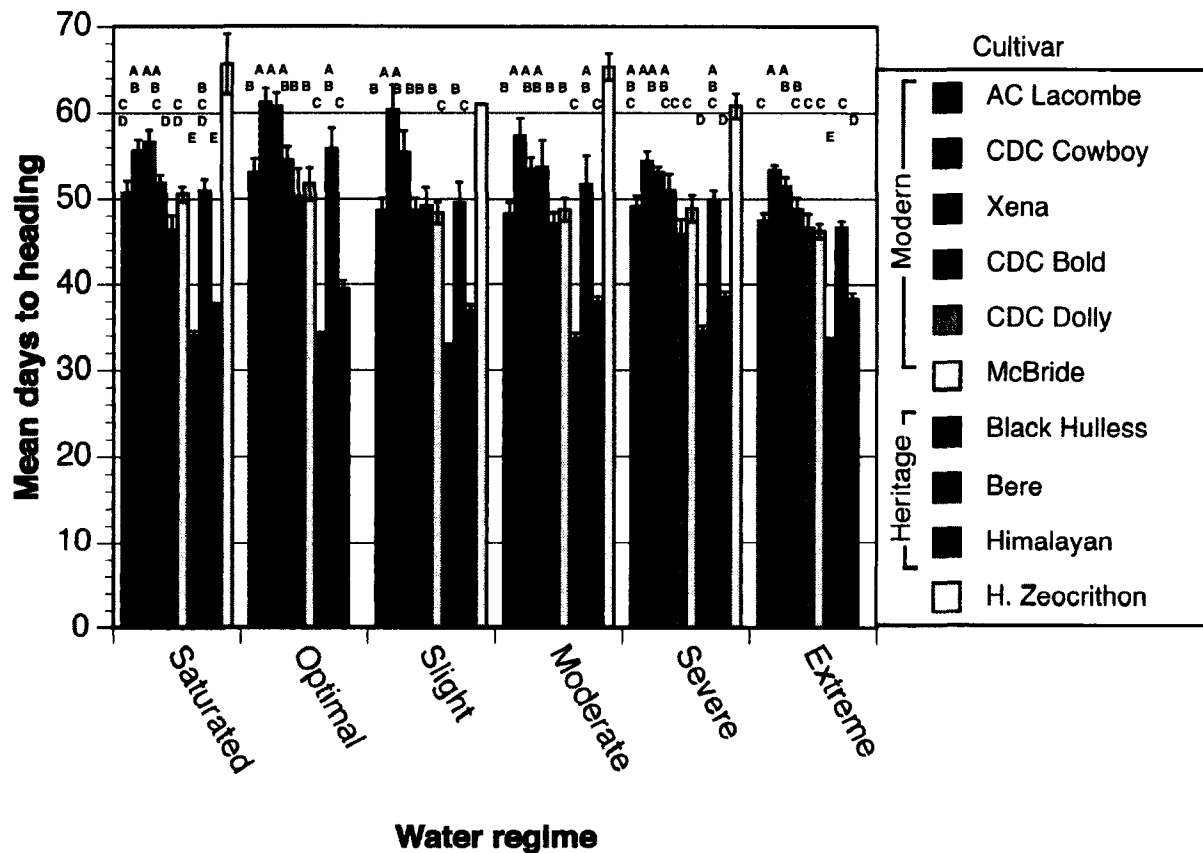


Figure 2.2b. Mean days to heading (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) compared within water stress regimes, grown under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime. Different letters indicate significantly different means within each water regime at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Table 2.1b. The descriptive statistics of mean days to heading of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) within six water excess and deficit regimes under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime.

Regime	Minimum days	Maximum days	Range
Saturated	34.00	65.67	31.67
Optimal	33.88	61.25	27.38
Slight	32.75	61.00	28.25
Moderate	33.63	65.33	31.71
Severe	34.50	60.80	26.30
Extreme	33.38	53.38	20.00

Grain filling period (GF)

For almost all cultivars, any level of water stress shortened the grain filling period, especially for moisture deficit regimes (Figure 2.3a). Within most cultivars, slight moisture deficits resulted in significant decreases in GF, although cultivar groups differed. Modern cultivars had significantly longer GF in the optimal treatment relative to all stress treatments ($p < 0.0001$), and the saturated treatment had the second longest GF, which was significantly longer than the water deficit treatments ($p < 0.0001$). Heritage cultivars showed the same general response as modern cultivars, but with less significant treatment responses and a greater variation among the cultivars in how each responded; the saturated treatment did not have a significantly longer GF compared to water deficit treatments across heritage cultivars. Cultivar Black Hulless had the longest GF for all the water deficit treatments compared to all other modern and heritage cultivars; cultivar Bere had no treatment responses in GF (Figure 2.3a). Further, in both cultivar groups the grain filling period varied little from slight to extreme water deficit.

Across all cultivars within water-stress regimes, cv. Black Hulless had a significantly longer GF compared to all other cultivars under saturated, moderate, severe and extreme moisture deficit treatments ($p < 0.0001$) (Figure 2.3b). Across modern cultivars only, there was no significant differences in the optimal treatment, though cv. CDC Cowboy had a significantly shorter GF than cv. CDC Dolly in saturated ($p = 0.024$), slight ($p = 0.0002$), moderate ($p = 0.022$), severe

($p=0.011$) and extreme ($p=0.009$) moisture deficit treatments, as well as cv. AC Lacombe in slight ($p=0.0002$) and moderate ($p=0.024$) moisture deficit treatments. Across only heritage cultivars, cv. Black Hulless had significantly longer GF than cvs. Bere and Himalayan in the saturated treatment ($p=0.001$), as well as the slight ($p=0.0001$), moderate ($p=0.001$), severe ($p<0.0001$) and extreme ($p<0.0001$) water-deficit treatments; cultivar Bere had a significant shorter GF than cv. Himalayan in slight and extreme moisture-deficit treatments.

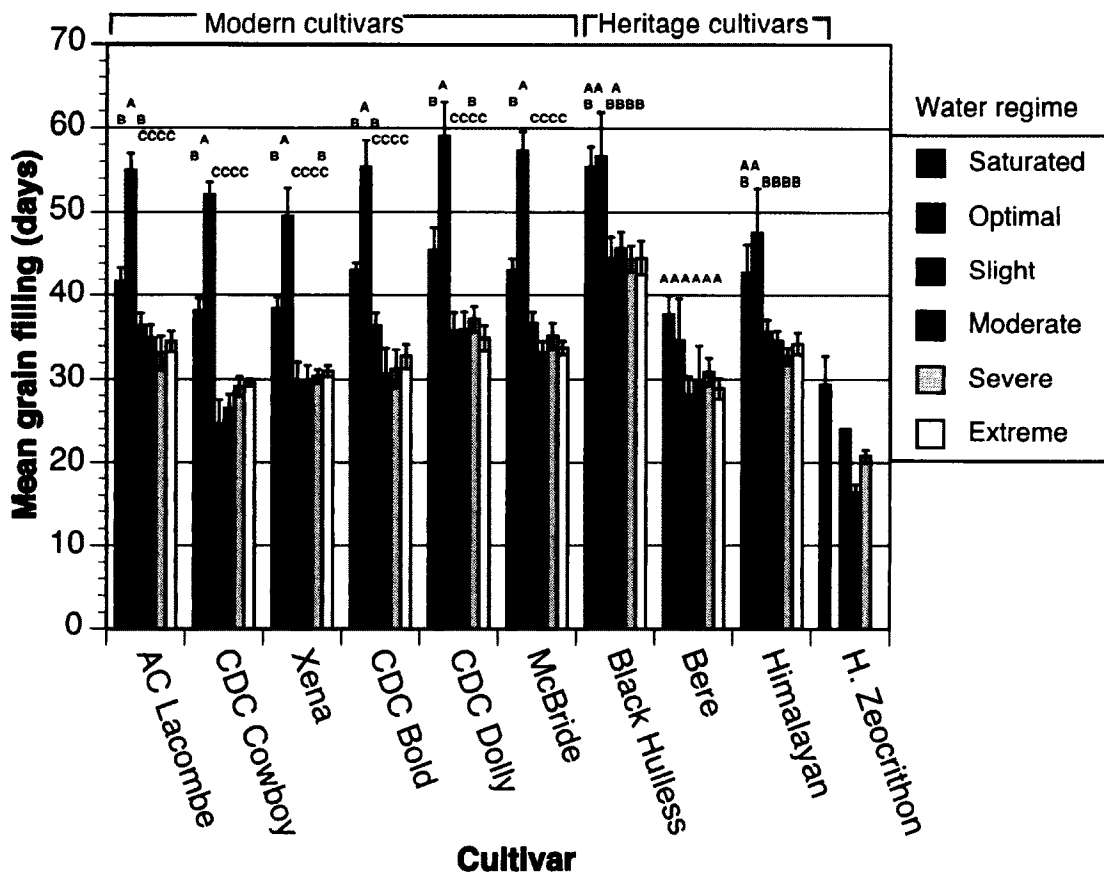


Figure 2.3a. Mean grain filling period (days \pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime. Different letters indicate significantly different means within each cultivar at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

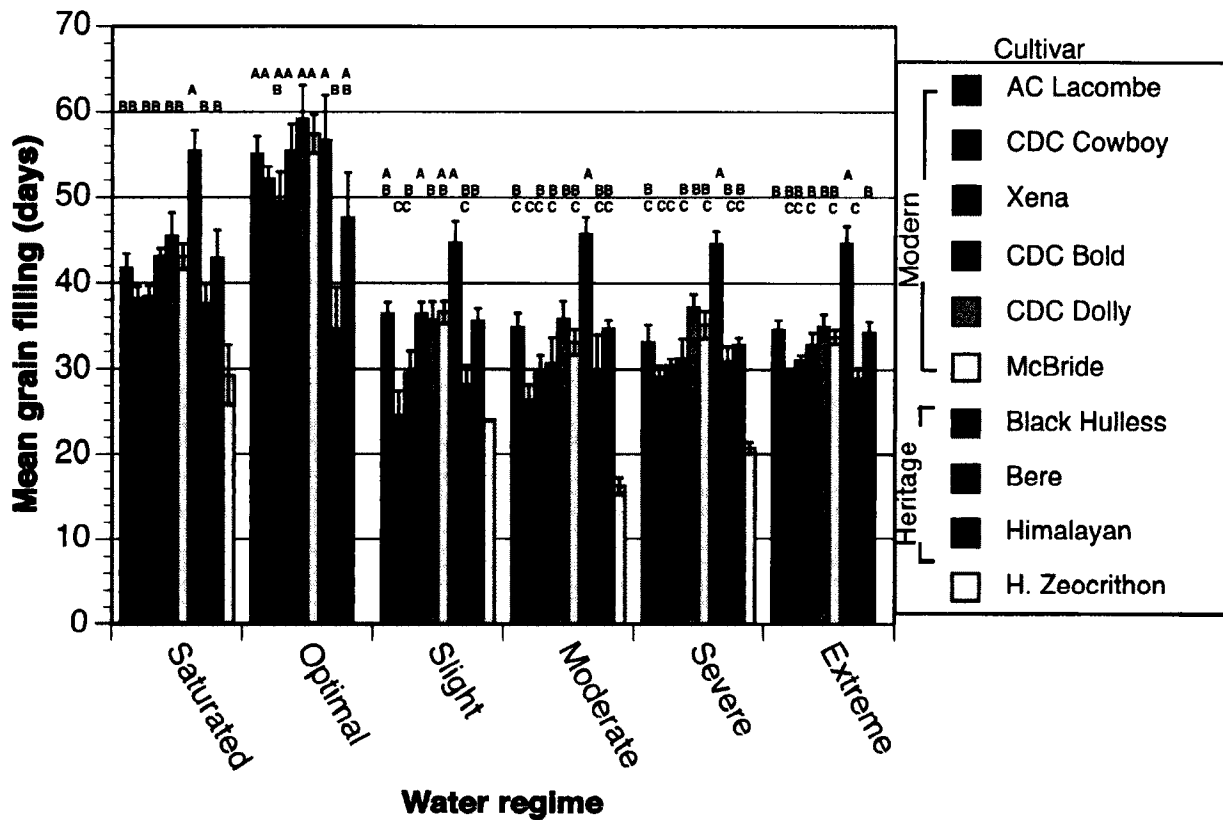


Figure 2.3b. Mean days to heading (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) compared within water stress regimes, grown under greenhouse conditions. See Table 2.0 for quantitative field capacity values for each regime. Different letters indicate significantly different means at within each regime $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

2.4 Discussion

Examining wide and specific adaptive traits in cultivar groups

Most studies examining phenological responses of grain crops to water stress focus primarily on how phenology impacts yield components and overall yields, rather than implications on stress tolerance. Phenology, and particularly days to heading, is related to a cultivar's adaptation to an environment, and helps determine its performance under those conditions by adjusting for stress

tolerance and/or avoidance (Slafer, 2003; Araus et al., 2008). Study results suggest that the modern and heritage cultivar groups generally reflect different adaptive, and likely breeding, strategies. Specifically, heritage cultivars generally showed smaller treatment responses to water stress (Figure 2.1a,b, 2.2a,b, 2.3a,b). This “buffering capacity” in such cultivars promotes tolerance and stability when encountering unpredictable abiotic stresses, which may provide an adaptive advantage under varying climate conditions and/or cultural practices, both short and long term.

While modern cultivars are bred to ensure phenology matches expected environmental stress (e.g. early maturity for terminal water stress), increased management and inputs such as irrigation have made it possible to extend growth stages that increase yield (e.g. days to heading and grain filling period) and reduce late-season stress (Jackson and Koch, 1997; Ceccarelli et al., 2010). This has resulted in phenological uniformity to match uniformity in the production system, which is consistent with these results, and is reflected in the modern cultivars showing a greater range in days to heading and grain filling period to stress treatments compared to heritage cultivars (Figure 2.2a,b, 2.3a,b. Table 2.1a).

Days to maturity

Overall within treatments, modern and heritage cultivars had similar DM (except that for heritage cultivars matured in fewer days in some treatments),

which likely reflects a breeding strategy focused on uniform maturity to facilitate mechanical harvesting and processing (Figure 2.1b). Physiological maturity is a measure representing the combined effect of timing of emergence, days to heading and length of grain filling period; results suggest that generally modern cultivars reach maturity in the same way (e.g. later heading and average grain filling, suggesting phenology does not reflect a stress avoidance or tolerance strategy), while heritage cultivars show different paths from each other, and from the modern group, exhibiting various tradeoffs between days to heading and grain filling period. The difference in cultivar group pathways is likely a reflection of the different breeding strategies or pressures on each group, but also reflects the complexity of adaptive mechanisms. A single trait (e.g. days to maturity) may not be sufficient to assess a cultivar's adaptive tolerance, and therefore, it should be recognized that simple indicators might limit the ability to determine the best suited cultivar, crop or management practice for a given environment.

Physiological maturity is accelerated under high temperatures and low water availability, often due to the shortening of the grain filling period (Gonzalez et al., 2007; McMaster et al., 2008), yet there was no significant difference in the water-deficit treatments for either modern or heritage cultivars in our study (Figure 2.1a); the greatest differences observed was that modern cultivars take longer to mature when water is not limited. This is possible because optimal conditions permit cultivars to more fully exhibit their genetic potential (Fageria et al., 2006) and the delay in maturity is likely due to the longer grain filling period in

these regimes, and the deficit regimes could be representative to field (actual) potential. The heritage cultivars, while exhibiting a similar trend, had a smaller treatment response (Figure 2.1a), suggesting that there is less difference between actual and potential grain sink potential, and greater tolerance to water stress for heritage cultivars.

Days to heading

Most cultivars responded consistently with studies that have shown that mild stress can cause anthesis to occur earlier (Angus and Moncur, 1977; Robertson and Guinta, 1994). Robertson and Guinta (1994) have shown that stress occurring around booting is likely to cause heading to hasten 4-5 days and, therefore, anthesis 2-3 days. Though without significant differences, AC Lacombe, CDC Bold, CDC Dolly, McBride, Xena, and *Hordeum zeocrithon* reached heading 3-5 days earlier than optimal across treatments; CDC Cowboy and Bere hastened 6-9 days; while Himalayan and Black Hulless headed 1-2 days before those in optimal treatment.

Days to heading showed the smallest treatment responses (e.g. little sensitivity to early-season stress) among cultivars, compared to the other phenological traits measured; there was a difference between cultivars, suggesting that it is a trait that can distinguish between cultivars' adaptive strategies (e.g. tradeoff between production and tolerance). Though there were little significant differences between modern cultivars, they generally took more

DH than heritage cultivars. Black Hulless and Himalayan, on the other hand, had no significant variation between treatments, implying strong genetic control for DH, which coupled with early DH compared to all other cultivars suggests a conservative growth habit (Jackson and Koch, 1997).

Grain filling period

Cultivars had the greatest sensitivity to water stress during the grain filling period, which has been shown to have implications on yield (Fageria et al., 2006; Brown, 2007; Ullrich, 2011). Again, heritage cultivars showed a more muted response compared to the modern cultivars, and Bere had no significant treatment responses. While modern cultivars had little significant difference in their GF and DM, heritage cultivars exhibited different growth strategies from each other, as well as modern cultivars. Comparing within regimes, Black Hulless had a significantly longer GF to all cultivars under stressed conditions (Figure 1.3b), and coupled with early heading and a high root:shoot ratio, this suggests that it has a strong specific adaptation to water stress exhibiting both stress avoidance and stress tolerance. Though Brown (2007) suggests most annual plants exhibit growth strategies for stress avoidance rather than stress tolerance, the results with Black Hulless suggests that it is possible that heritage cultivars may exhibit complexities which permit various traits for adaptive tolerance, though a more comprehensive study would be needed to explore this further. Himalayan, in contrast, showed early DH comparative to modern cultivars, but

similar GF lengths resulting in significantly lower DM, and is suggestive of an avoidance adaptive strategy. Moreover, Bere appeared to have no adaptation for terminal stress, exhibiting later heading and a shortened GF period. Some studies characterized older cultivars as having a more conservative strategy, as they had lower leaf conductance even under non-stressed conditions, supporting our results (Jackson and Koch, 1997; Fageria et al., 2006; Ullrich, 2011).

Implications of phenological selection in adaptation and production

In this study, modern cultivars all exhibited uniform responses to stress and had less variation between cultivars than heritage cultivars, which suggests modern cultivars were bred for the same selection objectives (e.g. high yield potential and increased uniformity), that is, bred for wide adaptation (Ceccerelli, 1989; Jackson and Koch, 1997). Heritage cultivars were each bred under different selection pressures, likely reflecting the diversity of environments from which they originated. Pswarayi et al. (2008) evaluated productivity of 188 cultivars (comprising of landraces, old cultivars and modern cultivars) across the Mediterranean basin, and found that landraces outperformed modern cultivars when grown in the region in which they originated, but yielded poorly in areas outside of where they originated. This would suggest that cultivated areas that have more predictable conditions are likely to be able to rely on cultivars developed for wide adaptation to successfully increase yields; for operations interested in adopting cultivars with greater adaptive tolerance (e.g. heritage

cultivars), it will be critical to have contextual information about the cultivar's performance in the specific environment they are working in, as there is a great diversity in heritage cultivars' adaptive tolerance and overall performance.

Phenology is an important component to a cultivars adaptive response (e.g. stress tolerance and/or avoidance), as well as being associated with various yield characteristics. It is clear that tradeoffs are made amongst the phenological traits, as cultivars can arrive at the same date of maturity by following very different patterns – patterns that are indicative of a particular breeding strategy. It is likely that heritage cultivars' muted treatment response compared to modern cultivars is reflective of a conservative growth habit and specific adaptation.

Supporting a complex agricultural strategy

Depending on location and available resources, some producers will have varying goals and challenges; those that cultivate under favourable conditions and follow the industrial agricultural model will likely benefit from cultivars bred for wide [performance] adaptation, while producers that work with less resources or less productive fields, adaptive tolerance may be more beneficial for long-term yield reliability. It is unrealistic to assume that there is a universal solution for producers on a global, national, or regional scale due to diversity of producer needs; therefore, it will be essential to have a diverse set of strategies and approaches to develop a sustainable agricultural system (Ceccerelli, 1989; Jackson and Koch, 1997). The Omineca Region, for example, is geographically,

climatically and topographically diverse, and therefore there is no single crop, cultivar or management system that can be universally adopted successfully. As such, there are fewer management options for northern producers, and it may be more viable to run smaller scale operations, and work multiple, small fields (“patch farming”) and, therefore, a breeding strategy that could consider both adaptation to high and low productivity environments may be more suitable.

There are benefits and limitations to both breeding for wide adaptation and for specific adaptation, and which strategy is more appropriate must be locally determined. Different breeding objectives (e.g. increased yield under favorable growing conditions vs. increased adaptive tolerance to stress variability) will result in a fundamental biological tradeoff, as each will have different implications on growth and resource allocation (Jackson and Koch, 1997). Breeding for traits associated with increased yields (e.g. harvest index, reduced height, increased response to fertilizers) likely results in a diminishing of adaptive traits that would allow cultivars to tolerate stress. Studies suggest that modern cultivars adapted to increased inputs are not well adapted to stress and, therefore, cultivars adapted to stressed environments are best bred under similar conditions (Fisher and Wood, 1979; Ceccarelli, 1996; Able et al., 2006; Ceccarelli et al., 2010).

Limitations of the study

While the benefit of controlled-environment studies is the ability to isolate plant responses to a single variable, there are associated limitations. First, plants

grown in controlled environments and pots often show different morphology and growth than in the field (Gibson et al., 1999) and, therefore, results may not be replicable in field trials. The study looked at response of individual plants, and did not consider the competitive interactions that would be exhibited in field conditions; a more robust experiment would have had more replicates consisting of multiple plants per pot. Also, it is recognized that the study lacked the resources and capacity to explore physiological mechanisms more closely. Further, modern experimental methods tend focus on a single factor at a time, resulting in the inability to assess complex interactions that are occurring; simplifying responses to a single trait does not adequately reflect the complexity of field conditions (Scott, 1998).

Future research needs

Research could extend into multi-year trials at various locations throughout the Omineca Region to determine whether the results of this study translates to field conditions, and to help identify phenological characteristics that are best adapted to environmental conditions of the region. Further work in exploring how to establish a diverse, applicable agricultural research strategy in the region is also required, to provide contextual, relevant information to the producers to enhance local agriculture capacity.

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CHAPTER THREE: PARTITIONING AND YIELD

3.1 Introduction

There is considerable potential to strengthen agricultural production in the Omineca Region, located in north-central British Columbia, Canada, to increase economic diversity and strengthen the region's food security. Small-scale livestock, forage and grain production characterizes the region's agricultural sector. Regional challenges to production agriculture include topography (e.g. highly variable and inferior soil types, smaller field sizes, variable elevations, steep slopes, etc.), northern climate (e.g. short growing season, limited and variable access to water, variable annual weather patterns, etc.) and lack of regionally appropriate and focused research and extension services. Establishing regionally applicable research, including projects exploring cultivar suitability to local growing conditions, will support farmers' need to identify best practices for the region, and promote sustainable and reliable forage and grain production. To begin the process of re-establishing agricultural research in the Omineca (since the closures of the Experimental Farms in Prince George and Smithers), key producers and industry stakeholders were consulted, and they identified barley (*Hordeum vulgare*) cultivar tolerance to water stress as a relevant initial project that would benefit regional farmers.

Modern breeding programs have successfully increased yields of cereal crops around the world, largely by developing cultivars designed specifically for

industrial agriculture methods; that is, cultivars exhibiting uniformity to increase mechanical harvest efficiency, are pest resistant and have increased yield potential (Scott, 1998; Araus et al., 2008; Serna-Saldivar, 2010; Ullrich, 2011). Yield potential has been defined as “the productivity of adapted, high-yielding cultivars achieved in the absence of yield reductions due to either the presence of diseases, weeds, and insects or insufficient availability of water and major nutrients” (Araus et al., 2004, p.2).

Increased yield potential is accomplished partly by breeding for an alteration of the plant’s resource partitioning, such as a semi-dwarf habit to increase total dry matter partition to the head (Harvest Index, HI) (Jackson and Koch, 1997; Araus et al., 2004; Álvaro et al., 2008; Auras et al., 2008). Increased partitioning to reproductive growth automatically decreases allocation to vegetative growth and is believed subsequently to have inadvertently reduced allocation to root systems in modern cultivars. This can be problematic in stressful or variable water regime environments (Jackson and Koch, 1997; Fageria et al., 2006).

Partitioning and adaptation

Environmental stresses have always limited agricultural production capacity. While management practices such as irrigation, altering planting date, crop rotations, and no/minimal tillage systems often help reduce the incidence of stress, stress can also be mitigated by choosing crops and cultivars with greater

tolerance to stress(es) (Fageria et al., 2006). A cultivar's growth, development, biomass accumulation and partitioning traits are associated with how it will withstand, acclimate to and recover from stressful environmental conditions (Fageria et al., 2006; Prasad and Staggenborg, 2008; Ehdaie et al., 2012). Cultivars may exhibit different adaptive mechanisms to deal with stress. Some plant traits enhance tolerance of stress (e.g. permitting a cultivar to survive under extreme stress), while others enhance stress avoidance (e.g. permitting a cultivar to exhibit minimal yield reductions under moderate stress) (Araus et al., 2004; Fageria et al., 2006). A cultivar's *adaptive phenotypic plasticity* refers to its ability to alter physiological and morphological traits (e.g. phenology, total biomass, resource partitioning and root characteristics) under stress, to increase chance of survival and reduce negative impacts (Fageria et al., 2006; Prasad and Staggenborg, 2008; Ehdaie et al., 2012).

One way to compare adaptive tolerance related to water stress in modern cultivars or heritage cultivars is through biomass partitioning analysis, including total aboveground weight, harvest index and root:shoot ratio. Yields are determined by the amount of assimilates a cultivar partitions to grain; leaves are generally the greatest *source* of photo-assimilate production, while grain heads are the primary *sink*. To achieve increased yield potential, breeding programs have worked to increase sink capacity (increased grain weight, number of grains per head, grain/m²), which in turn requires greater source capacity (Fageria et al., 2006). While cereals are bred for increased partitioning to the head, they also

have been improved for greater photosynthetic capacity, largely through modified canopy structure to intercept more insolation (Fageria et al., 2006; Álvaro et al., 2008).

A cultivar's source-sink relationship is connected to its phenology. A cultivar's source capacity is determined largely during the vegetative growth phase (Days to Heading, see Chapter 2). Studies suggest source capacity is a greater limitation than sink capacity, in areas at higher latitudes and with cooler temperatures (Tollenaar and Daynard, 1978; Uhart and Andrade, 1991). Whether a cultivar will realize its sink capacity is associated to the length of the grain-filling period, which is often abbreviated by the short growing season in the Omineca Region (Voltas et al., 1997; Fageria et al., 2006; Álvaro et al., 2008; Dordas, 2012). Sink capacity (yield potential) is genetically determined, while actual grain yield in field conditions is mediated by environmental conditions (Fageria et al., 2006). Modern cultivars generally require more nutrients, water and protection from pests, to achieve as close to their genetic potential as possible, and produce high yields.

Harvest Index (HI), which is the ratio of grain yield to total yield (g), is impacted not only by various yield components (e.g. number of kernels per head and individual kernel weight), but also by number of tillers and number of fertile heads. There are direct connections between a cultivar's phenology and its yield, especially in relation to stress response and resource allocation (Araus et al., 2004; Fageria et al., 2006; Ehdaie et al., 2012). Studies indicate modern cultivars

bred for increased HI will continue to exhibit high HI in both unstressed and stressed conditions, as mobilizing plant reserves to the harvestable organs can minimize yield reduction under stress conditions (Jackson and Koch, 1997; Araus et al., 2004; Álvaro et al., 2008). Still, stress can reduce HI as a result of non-seed-bearing vegetative tiller production, which is expected if there is stress during the grain-filling period (Brown, 2007; Reynolds, 2010).

While breeding programs have altered aboveground biomass partitioning, implications of increased yield potential on a cultivar's belowground attributes are often ignored (Jackson and Koch, 1997; Fageria et al., 2006). Root systems are complex and dynamic, differing between plant species and between cultivars. A grain cultivar's capacity to adjust its root system in response to water stress is a heritable trait, and is related to the timing and severity of stress (Fageria et al., 2006; Prasad and Staggenborg, 2008; Ehdaie et al., 2012;). Root systems in particular can provide insights into a plant's stress-response capacity; deeper, denser root systems provide enhanced soil moisture interception and absorption, but this capacity is influenced by various soil characteristics and is often site-specific (Fageria et al., 2006; Prasad and Staggenborg, 2008; Ehdaie et al., 2012). Under non-stressed conditions, a high root:shoot ratio suggests better adaptation to dry environmental conditions (Fageria et al., 2006).

By assessing biomass partitioning traits (e.g. aboveground weight, harvest index and root:shoot ratios) in different cultivars, we can evaluate their relative adaptive tolerance, which is relevant to developing adaptation strategies to

mitigate negative impacts of climate change. One of the objectives of this study was to determine whether breeding selection has altered the growth and resource partitioning of six modern and three heritage barley (*Hordeum vulgare*) cultivars and a barley wild-type (*Hordeum zeocrithon*) under varying levels of water stress. Modern cultivars are the result of intensive breeding programs that select for specific traits from parents with known traits (controlled pollination), while heritage cultivars still have a degree of open pollination, increasing genetic diversity within the crop (von Bothmer et al., 2003) (see Appendix 3 for cultivar descriptions). The implications of different breeding strategies may provide useful information for assessing cultivar suitability under the variable environmental conditions encountered by Omineca producers. It was expected that modern cultivars would have higher yield potentials and greater aboveground weights compared to heritage cultivars, but that heritage cultivars would have less adverse response to water stress due to their lower resource demands. While it was expected that modern cultivars would have a higher Harvest Index, as suggested by previous studies, heritage cultivars were expected to have a greater root:shoot ratio.

3.2 Methods

Study design

The study was set up as a completely randomized design to examine growth and yield responses of nine barley (*Hordeum vulgare*) cultivars and one

wild type (*Hordeum zeocrithon*) to a single environmental regime variable (six levels of water stress). The *H. vulgare* cultivars included six modern cultivars (AC Lacombe, CDC Cowboy, Xena, CDC Bold, CDC Dolly and McBride) and three heritage cultivars (Black Hulless, Bere, Himalayan). Single-plant pots were grown during the summer of 2012 in a controlled environment (Enhanced Forestry Lab, University of Northern British Columbia, 53°54'N, 122°49'W) (Montagnon et al., 2001).

Water regimes

Six soil water regimes levels were imposed to mimic a wide range of moisture stress. One regime established a benchmark of non-limiting moisture level, and study plants were maintained at or near field capacity (FC); four regimes were allowed to decrease to different moisture-deficit levels in relation to the FC benchmark based on volumetric weights (i.e., 80%, 60%, 50% and 35% saturated weight) to reflect a range of slight to extreme moisture deficits (see Table 3.0); a final treatment maintained continuous saturated soil conditions. All study plants were grown under non-limiting moisture conditions until the fourth leaf stage, at which point moisture-stress treatments were initiated, corresponding to the beginning of tillering (Teulat et al., 1997). Oscillating fans were set up in the greenhouse room to emulate wind and to minimize temperature gradients in the greenhouse; all fans were placed on a randomized timer to mimic natural variability.

Table 3.0 Quantitative values in regard to target Field Capacity of regime as associated to qualitative description.

Quantitative Value (% Field Capacity, FC)	Qualitative Description
n/a	Saturated
100%	Optimal
80%	Slight moisture deficit
60%	Moderate moisture deficit
50%	Severe moisture deficit
35%	Extreme moisture deficit

Study set-up

Study plant pots (1 gallon) were filled and weighed to ensure consistent volume of soil (between 5.5-6 lbs), and filled pots were saturated with water and allowed to drain overnight before seeding (Anyia et al., 2007). The growth medium was a 50% sphagnum peat and 50% pasteurized sand mixture, which provided a relatively neutral substrate for good moisture control and facilitation of easy and consistent root harvesting. Micromax Micronutrients Granular (Fe 17%, S 12%, Ca 6%, Mg 3%, Mn 2.5%, Cu 1%, Zn 1%, B 0.1%, Mo 0.05%) was added to the soil mixture prior to sowing. Each treatment block had a Styrofoam buffer on the outside to reduce heat loading of soil in the outer row of pots.

Seed sowing took place in early June 2012. Each water treatment had eight individuals of each of the 10 cultivars (80 plants per water treatment). Pots were double sowed to ensure successful germination, and thinned to one plant/pot one

week after emergence. Nutrients (NPKS: 80/35/25/10) were supplied 2-3 times a week in soluble form after germination was established. Pots were rotated weekly across north-south and east-west gradients to minimize the effect of any light gradients in the greenhouse. Daytime air temperature was maintained at 26 degrees Celsius to promote high photosynthetic rates (Medlyn et al. 2002), and night temperature was maintained at 15 degrees Celsius to minimize growth reductions due to high tissue respiration (Berry and Björkman, 1980); a transitional period of one hour at 21 degrees Celsius between temperature shifts was used to reduce any stress created by rapid temperature change. Plants were grown under ambient light and photoperiod to ensure that phenological responses reflected northern growing conditions.

Plant partitioning and yield traits were quantified post-harvest. Total aboveground weight composed of total dry shoot weight (g) and total head weight (g). The root:shoot ratio (to assess water supply/demand relations) was calculated using dry root weight (g) and dry shoot weight (g), not including head weight. Harvest index was calculated as the ratio of dry head weight of the total aboveground weight (g).

Statistical analysis

All analyses were conducted using SAS® 9.3 (2013). Partitioning and yield traits were examined for normal distribution using Shapiro-Wilk statistic. Means for partitioning and yield traits were compared within and between cultivars by

one-way analysis of variance. Where significant differences were found within or between cultivars, pairwise comparisons were conducted with Tukey's multiple comparison test to determine specific differences between cultivar means.

Results were graphed with Delta Graph® v.6.0.18. *Hordeum zeocrithon*, due to high mortality rate, was not included in the statistical analysis; however, it has been included in the data for illustrative purposes.

3.3 Results

There were differences in biomass production and resource allocation between modern and heritage cultivars. Generally, modern cultivars had greater total aboveground weight (TAW) and a greater response to water stress compared to heritage cultivars. While modern cultivars had significant reductions in TAW under slight stress relative to non-limiting and saturated conditions, generally heritage cultivars had no significant differences in weight, with the exception of cultivar (cv.) Himalayan under extreme water-deficit. Heritage cultivars generally showed similar HI levels as modern cultivars under the optimal treatment, and cvs. Black Hulless and Himalayan had higher HI under some stress regimes. This correlates with heritage cultivars having greater percentage of number of tillers producing fertile heads. Finally, heritage cultivars had higher or similar root:shoot ratios than modern cultivars; heritage cultivars also showed less treatment response for all traits measured compared to modern cultivars, except under extreme water deficits.

Total aboveground weight (TAW)

When comparing across water regimes within cultivars, there were distinct differences in total aboveground weight (TAW) in regards how modern cultivars and heritage cultivars responded to water stress (Figure 3.1a). Modern cultivars exhibited two distinct thresholds; first, the optimal and saturated treatments showed higher TAW than in the slight, moderate and severe water-deficit; and second, cvs. AC Lacombe, Xena, CDC Bold and McBride had significantly lower TAW in the extreme water-deficit treatment compared to all other treatments ($p < 0.0001$). Heritage cultivars showed more varied responses to water stress, as well as generally less significant regime responses. The cultivar Black Hulless exhibited a response opposite to all other modern and heritage cultivars, with the lowest TAW in the saturated and optimal treatments, and increased TAW with increased water-deficit stress (only extreme water-deficit treatment was significantly different than saturated and optimal treatments). The cultivar Himalayan significantly decreased in TAW with the extreme water-deficit regime compared to all other regimes ($p < 0.0001$), but had no other regime response (Figure 3.1a).

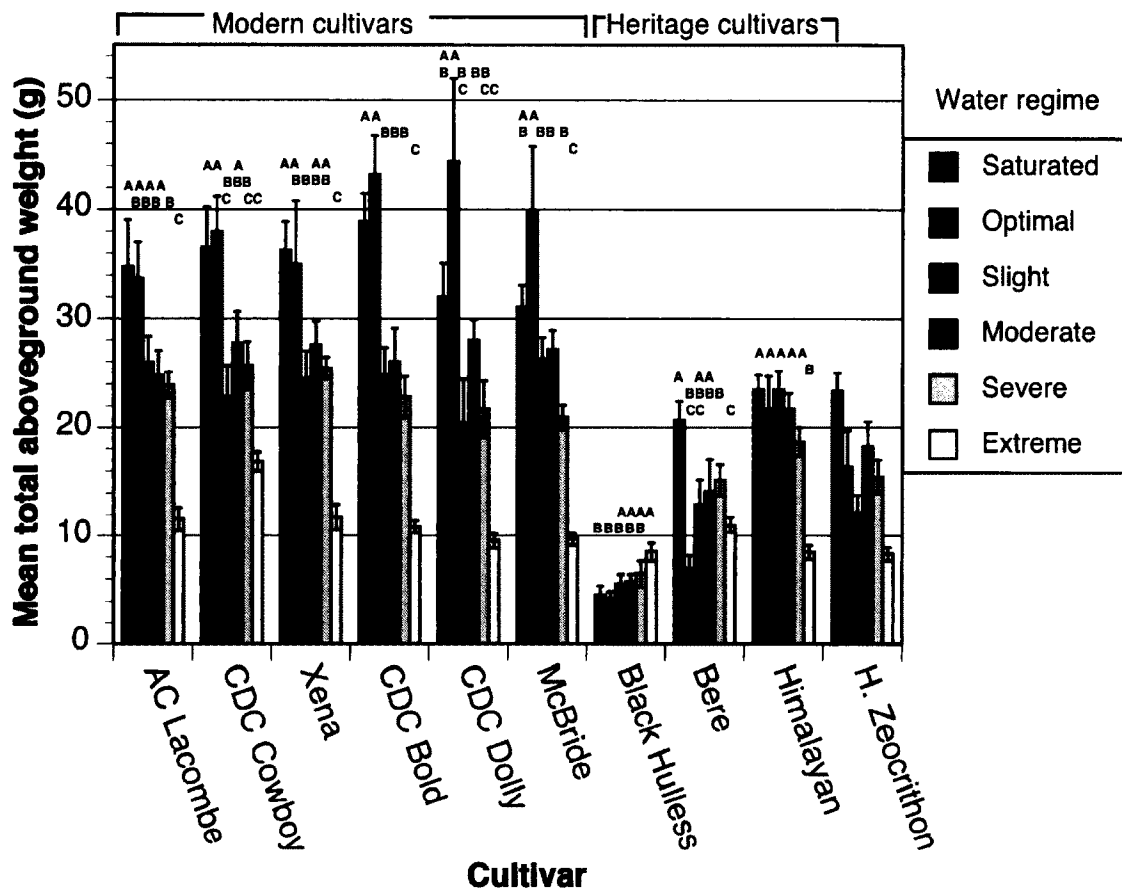


Figure 3.1a. Mean total aboveground weight (g) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. Different letters indicate significant different means within each cultivar at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Across cultivars within water regimes, generally modern cultivars had a significantly higher TAW than the heritage cultivars in the optimal ($p<0.0001$) and saturated ($p<0.0001$) treatments (Figure 3.1b). Cultivar Black Hulless had significantly lower TAW than all cultivars in saturated ($p<0.0001$) and severe deficit regimes ($p<0.0001$), and significantly lower TAW than all cultivars except for cv. Bere in optimal ($p<0.0001$), slight ($p<0.0001$) and moderate deficit treatments ($p<0.0001$). The cultivar Himalayan, however, had similar TAW to

modern cultivars in all water deficit regimes, and cvs. CDC Dolly and CDC Bold were the only modern cultivars that had significantly higher TAW than cv. Himalayan in the optimal treatment ($p < 0.0001$). Cultivar CDC Cowboy, a silage cultivar bred for drought stress, had significantly higher TAW to all other cultivars and heritage cultivars in the extreme water deficit regime ($p < 0.0001$).

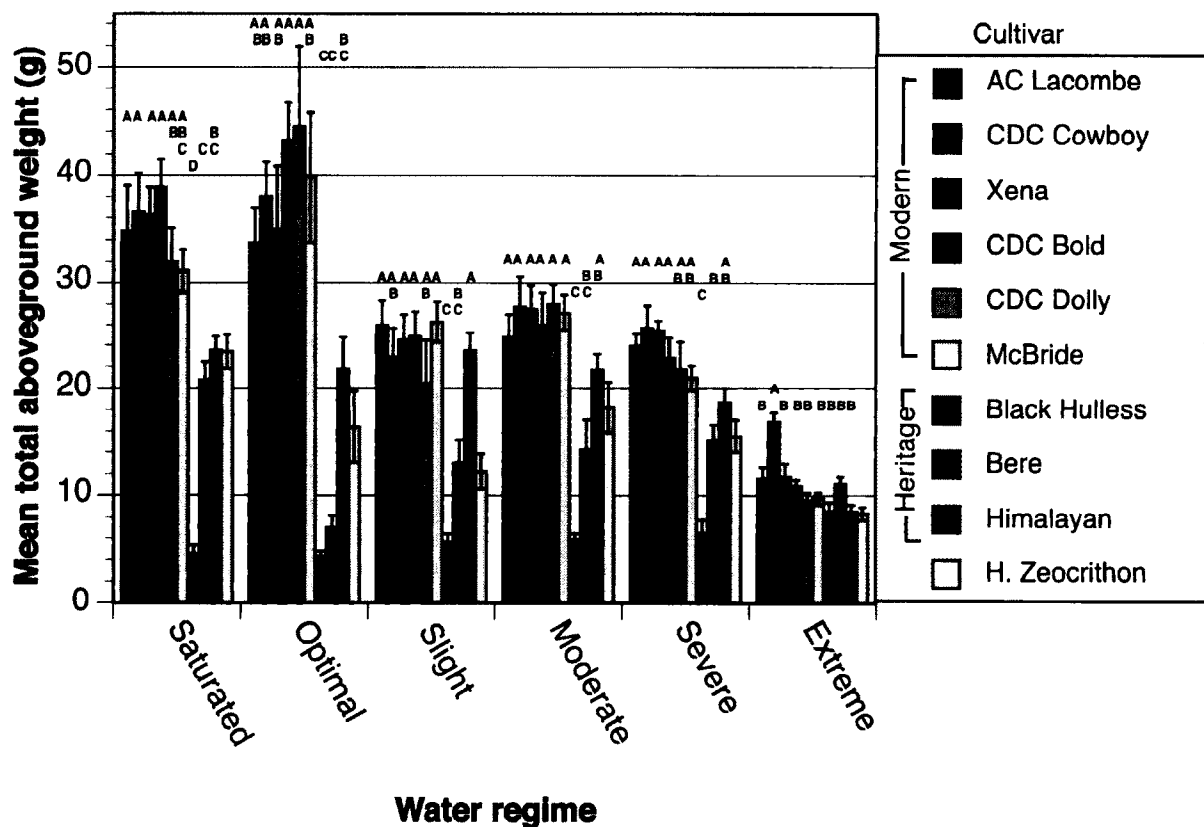


Figure 3.1b. Mean total above ground weight (g) ($\pm se$) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) compared within water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. Different letters indicate significant different means within each regime at $\alpha = 0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Harvest index (HI)

Generally, within all cultivars across water regimes, there was significantly higher HI in the saturated regime (except for cv. Black Hulless) compared to all other regimes (Figure 3.2a). Among modern cultivars, the lowest HI was generally in the slight water-deficit treatment, and it was generally lower than the optimal treatment for all cultivars, and significantly for cvs. CDC Cowboy ($p < 0.0001$), Xena ($p < 0.0001$), CDC Bold ($p < 0.0001$), and McBride ($p < 0.0001$). Heritage cultivars showed various HI responses to water stress. Cultivar Himalayan showed a similar response to modern cultivars ($p < 0.0001$), while cv. Black Hulless had no significant treatment response, and cv. Bere showed a trend to increase HI with increased stress from the optimal treatment through the water-deficit regimes, and significantly higher in the saturated treatment to all other regimes ($p < 0.0001$).

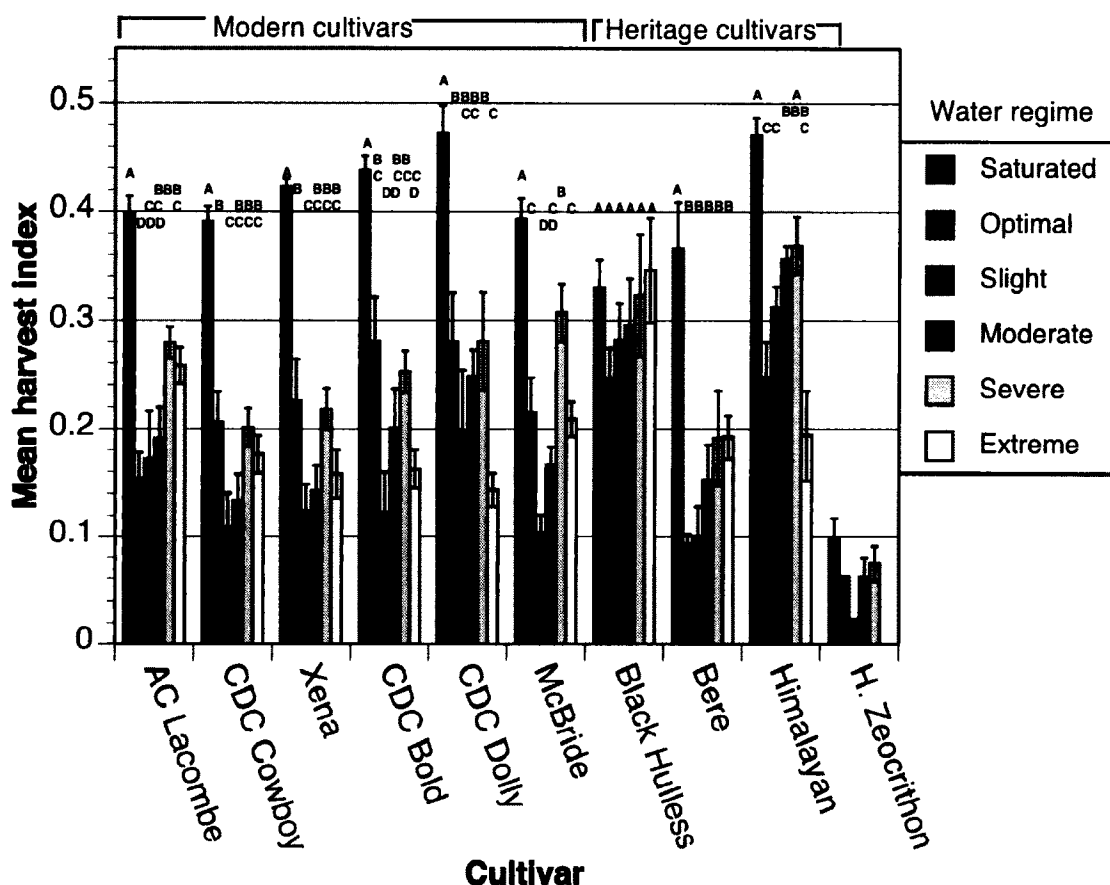


Figure 3.2a. Mean harvest index (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. Different letters indicate significant different means within each cultivar at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Across cultivars within water regimes, there were no significant differences between modern cultivars in optimal and slight water-deficit regimes (Figure 3.2b). Comparing all cultivars, cvs. CDC Bold and CDC Dolly had a significantly higher HI than cv. Bere in the optimal treatment, ($p=0.025$), but there were no other significant differences. Cultivar Himalayan had significantly higher HI than all cultivars except for cvs. Black Hulless and CDC Dolly in slight ($p<0.0001$) and moderate ($p<0.0001$) water-deficit regimes; cultivars Black Hulless and CDC Dolly had significantly higher HI than cvs. CDC Cowboy, Xena, McBride and Bere in slight ($p<0.0001$) and moderate ($p<0.0001$) water-deficit regimes. Cultivar Himalayan had a significantly higher HI than cvs. CDC Cowboy and Xena in severe water-deficit treatment ($p=0.006$), and significantly higher than cvs. Black Hulless and Bere in the saturated treatment ($p=0.0002$), but there were no other significant differences between cultivars in HI for those regimes. In extreme water-deficit stress, cv. Black Hulless had a significantly higher HI to all other cultivars except cv. AC Lacombe ($p<0.0001$).

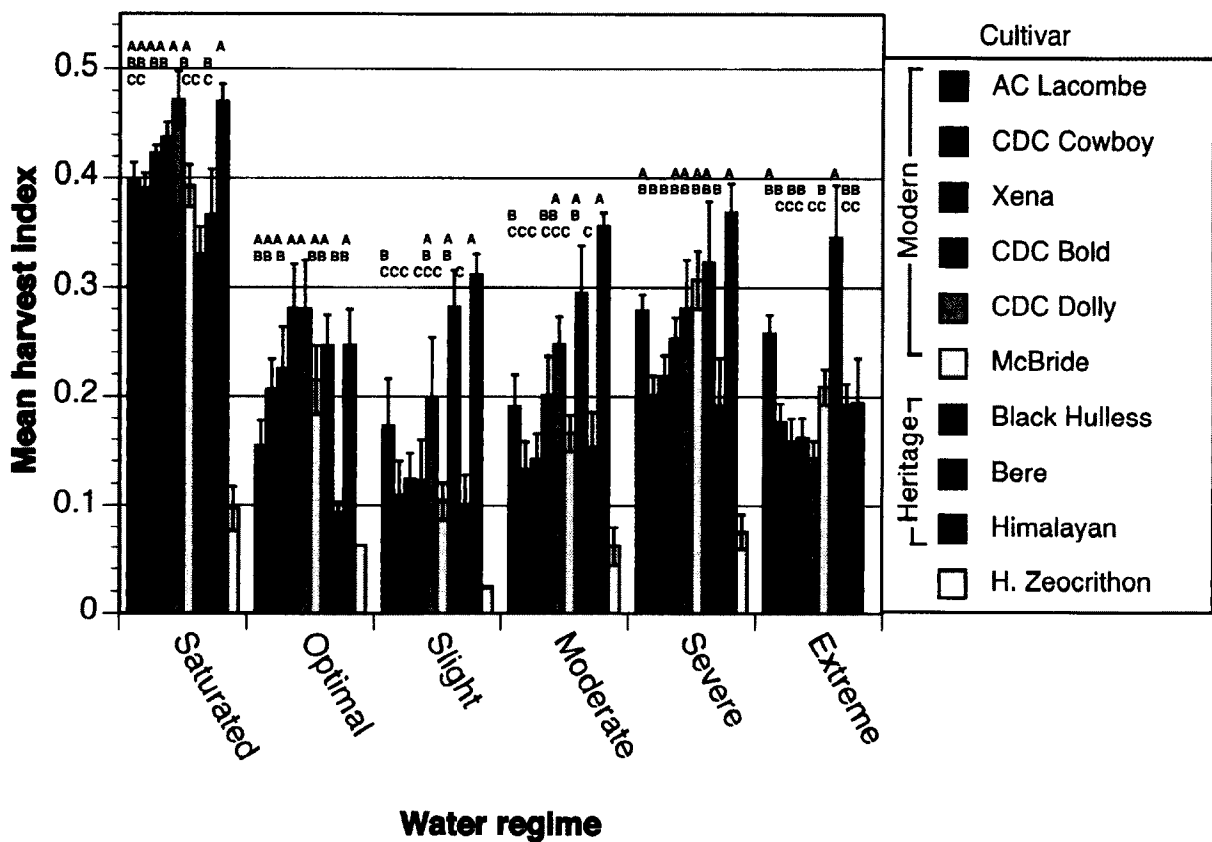


Figure 3.2b. Mean harvest index (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) compared within water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. Different letters indicate significant different means within each regime at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Cultivar Himalayan showed the highest percentage of tillers producing viable heads in optimal, slight and moderate water-deficit treatments, and second highest percentage in severe and extreme water-deficit regimes, following cv. Black Hulless (Table 3.1). The lowest percentage in every regime was *H. zeocrithon*. All cultivars, with the exception of cv. Black Hulless, had their highest percentage of number of tillers producing viable heads in the saturated regime.

Table 3.1. Mean percentage of tillers producing viable heads of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime.

Cultivar	Saturated	Optimal	Slight	Moderate	Severe	Extreme
AC Lacombe	86%	46%	44%	50%	56%	30%
CDC Cowboy	81%	37%	28%	37%	40%	18%
Xena	86%	46%	35%	46%	52%	15%
CDC Bold	81%	48%	28%	50%	34%	16%
CDC Dolly	88%	65%	46%	57%	53%	22%
McBride	77%	54%	35%	66%	67%	27%
Black Hulless	56%	57%	52%	69%	70%	64%
Bere	71%	28%	36%	53%	43%	30%
Himalayan	84%	77%	65%	71%	68%	46%
<i>H. Zeocrithon</i>	26%	23%	9%	23%	26%	--

Root:Shoot ratio (R:S)

Within cultivars across water regimes, modern cultivars show similar treatment responses of increased root:shoot ratio (R:S) with increased water stress. Generally, modern cultivars (except cv. CDC Cowboy) had a significantly higher R:S in the saturated, moderate and severe water-deficit regimes compared to the optimal treatment, and a significantly higher R:S in extreme water-deficit treatment to all other regimes ($p < 0.0001$) (Figure 3.3a). Cultivar CDC Cowboy showed the same response, though no significant difference between treatments (possibly as a result of high standard error in the saturated treatment). Heritage cultivars showed varied treatment responses in R:S. Cultivar Himalayan showed the same response as modern cultivars, but had no significant difference between saturated, optimal and slight, moderate and severe water-deficit regimes. Cultivar Black Hulless had no significant regime response,

though R:S generally decreased with increased water-deficit stress (Figure 3.3a).

Cultivar Bere also showed no significant differences between saturated, optimal and slight, moderate and severe water-deficit regimes, though extreme water-deficit treatment had a significantly higher R:S to all other regimes except for optimal ($p=0.001$).

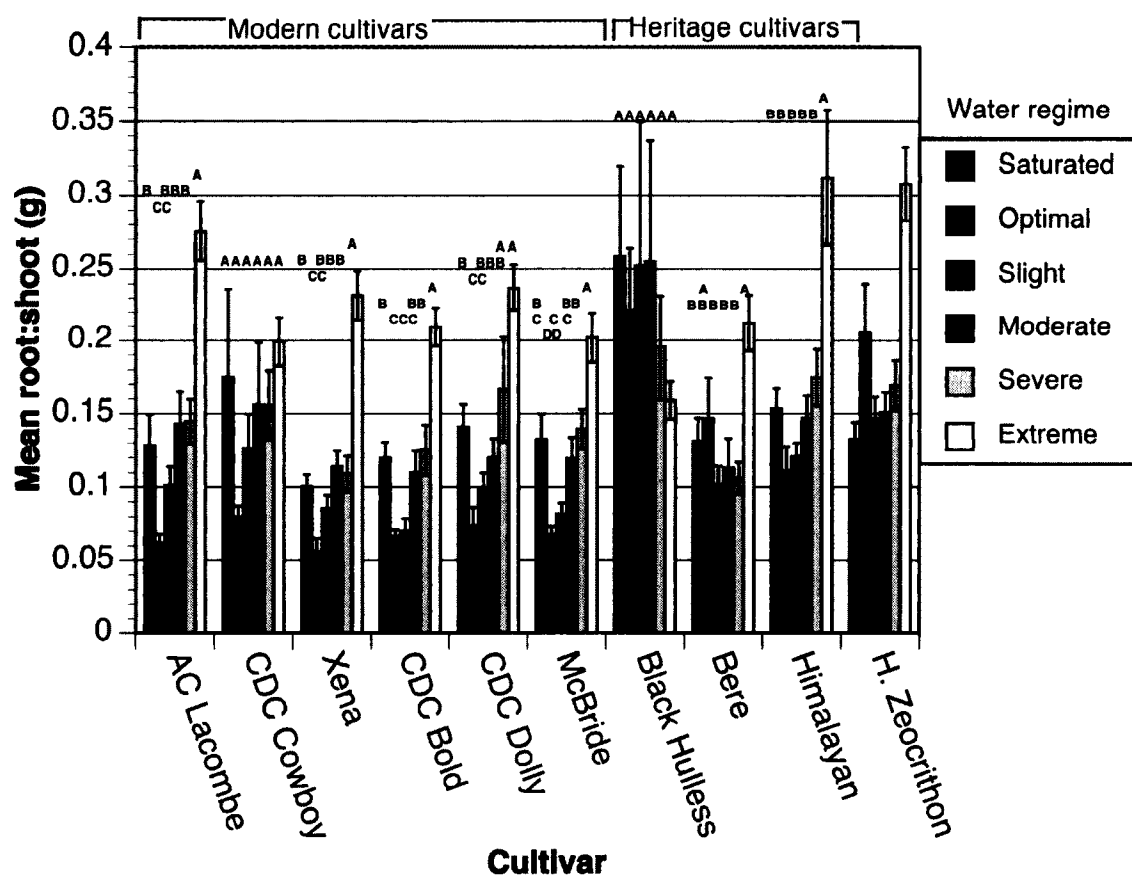


Figure 3.3a. Mean root:shoot ratio (g) (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. Different letters indicate significant different means within each cultivar at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

Generally, across cultivars and within water regimes, there was no significant difference in R:S between modern cultivars in saturated, optimal, slight and severe water-deficit regimes. There were some differences between heritage cultivars, and between heritage cultivars and modern cultivars (Figure 3.2b). In the optimal treatment, cv. Black Hulless had a significantly higher R:S compared to modern cultivars and cvs. Himalayan, and Bere had a significantly higher R:S to cvs. AC Lacombe, Xena and CDC Bold ($p < 0.0001$). Cultivar Black Hulless had a significantly higher R:S than cvs. Xena and CDC Bold in saturated ($p = 0.049$) and moderate ($p = 0.087$) water-deficit regimes, and as well as cv. AC Lacombe in slight water-deficit regime ($p = 0.023$). There were no significant differences between any cultivar in the severe water-deficit regime. In the extreme water-deficit regime, cv. Himalayan had a significantly higher R:S than cvs. CDC Cowboy, CDC Bold, McBride, Black Hulless and Bere ($p = 0.001$), otherwise there was little significant difference between cultivars (Figure 3.3b).

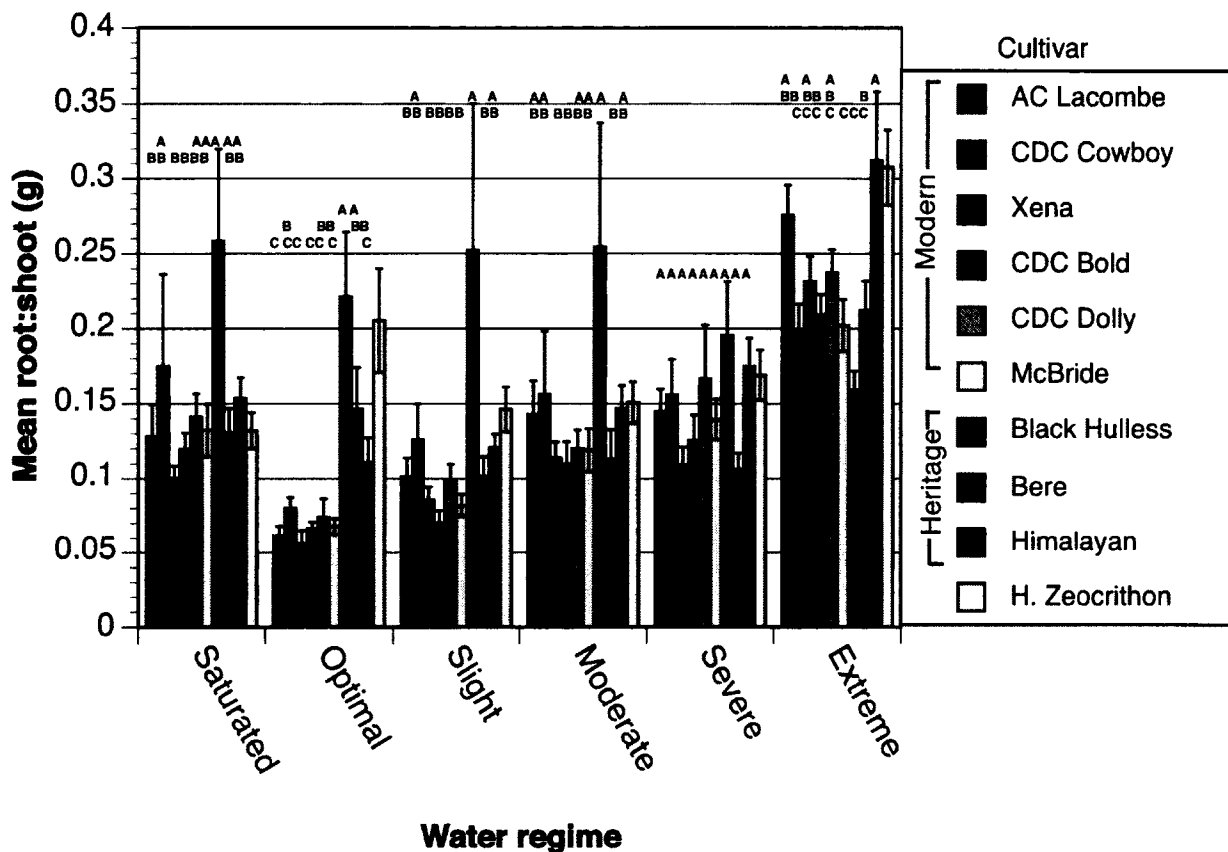


Figure 3.3b Mean root:shoot ratio (g) (\pm se) of nine cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) compared within water stress regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. Different letters indicate significant different means within each regime at $\alpha=0.1$. *Note: Statistics were not applied for *Hordeum zeocrithon* as the sample size was insufficient; it was included in the figure for illustrative purposes only.

3.4 Discussion

Agriculture and agronomic practices are inherently contextually driven, using management practices that are connected to the needs and challenges of the specific sites within a specific environment. In the case of industrial agriculture, the inputs to mitigate limiting environmental factors (e.g. irrigation, fertilizers, pesticides, etc.) are imposed to mitigate that inherent link, but at a

cost, environmentally, economically and socially. For any given crop, cultivars will have different yield potentials that can only be expressed if factors determining growth and development are not limiting (Jackson and Koch, 1997; Fageria et al., 2006; Álvaro et al., 2008). Modern cultivars are bred to be highly responsive to input of nitrogenous fertilizer, water and pesticides, and demand more resources than older cultivars to achieve their high production potentials (Jackson and Koch, 1997; Scott, 1998). As such, heritage cultivars are often chosen for performance in low-input systems and for cultivation in adverse and variable environments (Jackson and Koch, 1997).

The Omineca Region has unique challenges associated with the landscape, and one of the major challenges is soil fertility and structure. The soils have mostly developed under woodland vegetation, and various parent materials, and climate and biological processes have created a diversity of distinct soil types, even within a single field. The soils are characterized with low level of organic matter and nitrogen, and are eroded in much of the region (Farstad and Laird, 1954). For these reasons, combined with constraints associated with the region's remoteness and limited and varying access to water, it is economically challenging to farm using the industrial agricultural method. As such, identifying cultivars with appropriate resource demands to the natural resource supply (e.g. comparing the supply-demand relationship in modern and heritage cultivars) is important for developing adaptive tolerance of a farm (Jackson and Koch, 1997).

Examining resource supply and demand in cultivar groups

Breeding for improved cultivars has effectively changed plant resource allocation on a source-sink level (resource allocation to the leaves vs. to the head), and the supply-demand relationship of a crop at the field scale. In order to increase yield potential, breeding programs have increased sink size (e.g. kernel weight, kernels/head) by selecting for shorter plants that allocate more assimilate into the head (Fageria et al., 2006; Álvaro et al., 2008; Auras et al., 2008). Álvaro et al. (2008) found modern cultivars (released between 1988-2000) were more sensitive to source-limitation (studied through various source-sink modification treatments) than intermediate cultivars (released between 1950-1985), which in turn had greater response than older cultivars (released before 1945), likely due to increased demand from the sink in newer cultivars (supporting these results). Still, whether barley is source- or sink-limited is inconclusive; studies conducted under non-stress environments suggest sink-limitations, while studies under stressful environment suggest source-limitations (Dordas, 2012). The source-sink relationship varies not only between cultivars (and therefore cultivars used in a study becomes a variable), but also depends on the environment the cultivar is grown in (Voltas et al., 1997; Álvaro et al., 2008; Dordas, 2012). Changes in source-sink relationships in response to different stress levels result in variation of yield in these environments, creating greater vulnerability for producers and requiring increased dependence on the use of inputs (Jackson and Koch, 1997; Voltas et al., 1997).

High demanding cultivars with increased sink sizes will require high levels of nutrients and water, and low-production environments may not be able to support the input demands naturally. When breeding for a wide adaptation, cultivars are selected to be highly input-responsive in order to take advantage of all available resources (Braun et al., 2010). However, most environments rarely have the conditions required for widely adapted cultivars to reach their yield potential; therefore, it is worthwhile to consider specifically adapted cultivars that have lower-yield potentials, but can reach potential under various levels of stress. For example, this would require selecting cultivars that are better suited to the environment, rather than altering the environment to suit the cultivars.

Total aboveground weight

My results support the expectation that modern cultivars would exhibit increased TAW; therefore, suggesting greater yield potential under non-stressed environments compared to heritage cultivars (Fageria et al., 2006; Auras et al., 2008); the increased source potential is consistent with modern cultivars' increased length of Days to Heading (extended vegetative growth) under non-stressed conditions compared to heritage cultivars (Chapter 2). The decrease in shoot weight from optimal to slight water-deficit treatment suggests that modern cultivars only realize their increased source capacity under non-stressed conditions. The trend of modern cultivars having greater proportional decrease in head weight (e.g. number of viable heads/tillers, individual kernel weight)

compared to shoot weight between optimal and slight water-deficit stress (Appendix 4) suggests that even slight water-deficit results in a gap between potential and actual yield in modern cultivars, unless non-stressed conditions could be maintained by increased management in order to ensure stable economic yields.

Heritage cultivars showed various source potentials (as measured through TAW under non-stressed conditions) and generally were lower than modern cultivars, suggesting heritage cultivars demand less water resources and could reach yield potential under varying water-deficit conditions (tolerance to water-deficit regimes varied among heritage cultivars). Himalayan generally had lower shoot weight compared to modern cultivars across regimes, but its head weight increased its TAW to match modern cultivars in the water-deficit regimes (Appendix 4). This finding suggests that Himalayan has lower yield potential compared to modern cultivars, but has more consistently yields under water stress. Black Hulless had significantly lower yield potential compared to all modern cultivars studied (except under extreme water-deficit), which could be partly associated to its short length of days to heading and limited source capacity (Fageria et al., 2006). Still, Black Hulless showed high percentage of tillers producing viable heads and had long grain filling period even under stress, showing less yield reduction in response to water stress than other cultivars, suggesting that it is drought-tolerant cultivar that is likely specifically adapted to marginal environments (Fageria et al., 2006).

Harvest index

Much of the yield increases of modern breeding have been attributed to the increase in Harvest Index (Auras et al., 2008), but this study showed few significant differences in HI among modern moderns and two heritage cultivars in the optimal treatment. Under slight water-deficit, Himalayan and Black Hulless have significantly higher HI levels compared to the modern cultivars, likely correlated to higher number of tillers with viable heads; still, this maintenance of high HI supports the conclusion that heritage cultivars have lower resource-demand, and have high phenotypic plasticity to varying levels of water-deficit compared to modern cultivars. The unexpected results in HI could be a result of the growing conditions, as the greenhouse study does not represent field conditions, and increased seeding rates would likely increase competition and not permit plants to reach the tillering capacity exhibited in this study, therefore altering the results.

Most modern cultivars had a yield that was disproportionally low compared to its total biomass, which is referred to as *haying-off* (vanHerwaarden et al., 1998a). Haying-off has been shown to be a result of increased vegetative growth during low-stress conditions, followed by water-deficit conditions that inhibit the crop from reaching yield potential. While this study does not mimic these specific conditions, the decrease in both TAW and HI under slight water-deficit has relevant management implications, as haying-off reflects an environmentally imposed imbalance in the supply-demand relationship, which is dependent on the

availability and interaction of nitrogen and water (vanHerwaarden et al., 1998b). Increased nitrogen at the beginning of the growth phase will result in increased vegetative growth, as well as increased water demand in order to utilize the nutrients; therefore, water-deficit (particularly terminal water-deficit) reduces the cultivars' capacity to produce viable heads or reduces kernel weight, causing a reduction in HI. This hypothesis is also supported by how modern cultivars have fewer tillers producing viable heads compared to heritage cultivars (Table 3.1).

Root:Shoot ratio

A key determinant of adaptive tolerance for plants is resource partitioning under stress, therefore a greater root:shoot ratio (R:S) under non-stress conditions is indicative of greater adaptive tolerance (Fageria et al., 2006; Ehdaie et al., 2012). Studies suggest that while shoot mass typically decrease in response to water deficit, roots may also increase or maintain mass (Fageria et al., 2006; Prasad and Staggenborg., 2008; Ehdaie et al., 2012). In the optimal treatment, heritage cultivars showed greater R:S compared to modern cultivars, often significantly, conferring that heritage cultivars inherently have a greater adaptive tolerance. Black Hulless in particular maintains a high R:S throughout water stress regimes, consistent with a conservative growth strategy. Generally, Black Hulless had large standard errors, likely because Black Hulless has less biomass compared to all other study cultivars and root mass lost during processing would have a greater impact on R:S. Therefore, the R:S is likely

underestimated in study results. Studies suggest that cultivars with greater root phenotypic plasticity often produce more stable yields, which is consistent with these results (Ehdaie et al., 2012). This finding is supported by my data, as Himalayan showed less treatment response comparatively to modern cultivars, and had little negative impacts to actual yield in slight to severe water deficit regimes, as well as the saturated regime.

Modern cultivars increased R:S with increased stress, but reduced overall yield and more variable yield under water stress conditions, supporting previous studies (Prasad and Staggenborg, 2008; vanHerwaarden et al., 1998a). Still, CDC Cowboy, which was bred for drought tolerance, showed no significant difference in R:S across stress treatments, potentially due to a high root weight compared across all cultivars (data not shown). It also had significantly greater TAW in extreme water-deficit stress, as it was bred for, potentially suggesting specific adaptation to drought conditions.

Implications of changing resource allocation on adaptation

Breeding strategies and associated selection pressures have fundamental implications on traits associated with resource acquisition and allocation (Jackson and Koch, 1997). Study results suggest that breeding has impacted resource allocation and adaptation tolerance of modern barley cultivars. Modern cultivars had greater yield potential than heritage cultivars, but only under optimal conditions, suggesting that modern cultivars require more water (and potentially

other resources) to reach their increased yield potential (Jackson and Koch, 1997). Heritage cultivars showed greater adaptive tolerance to water stress, showing more stable yields under slight to moderate water-deficit, higher root:shoot ratio, and greater efficiency in resource allocation (e.g. higher percentage of tillers producing viable heads). Still, heritage cultivars showed a wide range in yield potentials compared to the modern cultivars, suggesting that heritage cultivars are adapted to specific environmental conditions (e.g. faced various selection pressures depending on the local conditions, while modern cultivars generally have uniform selection pressures); consequently, when considering adopting a heritage cultivar for use, there must be a strong understanding of the characteristics of the specific cultivar to ensure that it matches local conditions.

Due to the diversity of landscape throughout the Omineca Region, the agricultural capacity of producers' land varies, depending on location within the region, and the specific field (Burns, 1952; Farstad and Liard, 1954). Therefore, it is important to consider crops and cultivars that have been developed using breeding strategies that match growing conditions (Jackson and Koch, 1997; Scott, 1998). Since the Omineca Region presents a more limiting growing environment, there are significant economic costs to provide the levels of inputs required for modern cultivars to reach full yield potential, and these management practices are likely more demanding of soil nutrients, resulting in long-term soil degradation. Some producers may benefit from adopting cultivars that are better

adapted to variable climates have lower input requirements, produce more reliable yields in stressed or variable environments, and demand less soil resources, thus promoting long-term environmentally and economically sustainable farm operations.

Limitations of the study

The benefit of controlled-environment studies is the ability to isolate plant responses to a single variable, and explore certain plant characteristics, such as root:shoot ratios, that is not possible in field trials. However, plants grown in pots often show different morphology and growth than in the field (Gibson et al., 1999); this is particularly true for measuring resource allocation in this study, as planting density in field conditions would have restricted an individual plants tillering capacity and thus altering the analysis of total aboveground weight and harvest index. The study looked at response of individual plants, and did not consider the competitive interactions that would be exhibited in field conditions; a more robust experiment would have had more replicates consisting of multiple plants per pot. Furthermore, it is difficult to account for the complexities of stress on a crop level in a greenhouse study, compared to an individual plant response, as tolerance mechanisms for different types of stress (e.g. water vs. heat stress) may be different and confounding in field conditions (Prasad and Staggenborg, 2008). Also, the study lacked the capacity to explore nutritional content of the cultivars, which would have significant implications to cultivar selection.

Future research needs

Multi-year trials at various locations throughout the Omineca Region to determine whether the study results translate under field conditions are required. Determining whether there is a significant difference in resource demand between modern and heritage cultivars under varying soil types, climatic conditions and more cultivars will be of importance prior to recommendations. Establishing regional contextual research will be essential in establishing best management practices, and ascertaining which cultivars are best adapted to the region.

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CONCLUSION

Farmers face continuous and increasing challenges associated with unpredictable annual weather patterns and events, soil health, and loss due to pests; while new technology and management innovations have worked to decrease stress and unfavourable growing conditions, these practices are designed for the industrial agriculture system and are often not suitable to small-scale operations or in environmentally limited areas. Finding locally appropriate solutions that will reduce vulnerability and increase resilience in the agriculture sector is critical to supporting food security on a regional scale. However, the closure of the Experimental Farms in the Omineca Region left a gap in contextual, regional research available to producers. As one producer described, “we now rely on generic information, and while the concept is perfect, nobody knows what your conditions are or what your fields are like, so it might not work in your context.” Therefore, there is a great need to increase support and resources for northern agricultural producer, providing the capacity for the region to increase its production potential.

This thesis was an exploration into how to re-initiate research in a way that addresses the complexity of the current and future challenges in the Omineca Region. There is very little history of agricultural research at the University of Northern British Columbia, and no existing relationships between the university and local agriculture producers. Therefore, this research had to establish

connections with local farming associations, and incrementally build trust within these communities. Though challenging and time consuming, these relationships are invaluable for researchers to understand the realities of farming operations in the Omineca Region and develop an appreciation of the complexities of the challenges producers face.

Following a gap of centralized research happening within the Omineca Region, this study focused on establishing connections and partnerships with producers to ensure regional relevance and applicability from the beginning. Initial consultations with key stakeholders identified the need to study the adaptive capacity of barley cultivars under varying levels of moisture stress. Barley is grown throughout the region as cattle feed; moreover, the majority of the farmland in the region depends on a rain-fed system (1.2% of farmland in the Omineca has irrigation, (Statistics Canada, 2011)). In addition to the cultivar study, an autoethnography of northern producers was conducted to gain an appreciation of the local knowledge and context of local farmers. This engagement provided direction on which traits were relevant to local farmers and the growing conditions within the region (e.g. phenology is important in a region with short growing seasons and early frosts, and root morphology is relevant with poor soils and variable access to water).

The controlled-environment study showed that there were measureable differences between modern and heritage cultivars in regards to phenology, resource allocation and adaptive tolerance. Modern cultivars showed more

uniform responses to increased stress, reflecting a wide-adaptation breeding strategy, while heritage cultivars showed various responses from each other and from modern cultivars, suggesting more specific-adaptation as a result of the environments they originated from. Generally, modern cultivars exhibited greater yield potential than heritage cultivars, but these resource-demanding cultivars may not be well suited to resource-limited environments. Modern cultivars are bred for industrial agriculture systems that depend on inputs (e.g. nitrogenous fertilizers, irrigation and pesticides) to mitigate the impacts of stress and the associated economic and environmental costs are often unsustainable in the Omineca Region. Still, the study results need to be verified through field trials across the region, to reflect the variation in growing conditions and micro-climates; moreover, there may be different cultivars available that are better suited to the region, but have yet to be evaluated for regional performance.

Over the three years of the project, it became evident that agricultural challenges vary across the region. Every farming operation has unique challenges and opportunities, and the most influential factor in management decisions was the environmental, social and economic context in which the farmer was working. Therefore, it is incontrovertible that there is an increasing demand for regionally-focused agricultural research that can adequately address the complexities and interconnectedness of the challenges producers have in the Omineca Region.

Study limitations

Controlled environment studies are often used to isolate a single variable, which can facilitate the examination of innate differences between cultivars. Isolating the responses of cultivars to a single stress limits our understanding of more the complex relationships between multiple stresses experienced in the field, and studies have shown that results vary between experiments measuring the same traits under controlled-environment and field studies (Gibson et al., 1999). Therefore, the conclusions of this study are preliminary, and require verification through long-term field trials across the Omineca Region.

A goal of this study was to explore various traits in multiple cultivars to gather baseline data that would inform future studies. The study was not a comprehensive study of all cultivars available (neither modern cultivars nor heritage cultivars). Still, the results provide direction into which cultivars, as well as which agronomic traits may be best suited to the growing conditions across the region, and a future field study could incorporate additional cultivars. That is, a more extensive study of cultivars regional performance could provide a more accurate analysis of the suitability of various cultivars to the region, and inform best management practices.

Recommendations

There are many pressures facing agriculture in British Columbia, from impacts and risks associated to climate change, to an aging farming population and competing with global markets (Crawford and Bevrige, 2013). As demonstrated in this study, there is an urgent need for more collaborative research and extension support that will provide relevant, regional information that enable producers to implement sustainable management practices and help the agriculture industry adapt to climate change and increasing variation and potential risk (Crawford and Bevrige, 2013).

Moreover, research must have an interdisciplinary focus, drawing on an appreciation for the complexity and inter-relatedness of the social, economic and environmental context of a specific place. Researchers must respect and understand producers' realities in order to develop tangible, sustainable on-farm practices; this can be achieved through listening and sharing stories, visiting producers at their properties (e.g. farm stays), and building trust over-time (Ison and Russell, 2000; Shindler et al., 2014). Producers must be involved as equal collaborators from the start, taking ownership over the design, process and outcomes of the project, thus ensuring that the research is grounded contextually, and producers will benefit from the project. Research capacity within a community is built through small, manageable projects that are successful, and incrementally build up into larger, more complex projects, which require continuous, long-term investment.

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Appendix 1. Information and consent form.

Information/Consent Form

Ecosystem Science and Management Program
University of Northern British Columbia
Prince George, B.C.

Enhancing northern grain production through applied
Research and community engagement

Primary Researcher: Serena Black, blacks@unbc.ca
(250)960-7800

Research Assistant: April Haubold, haubold@unbc.ca

Supervisor: Dr. Scott Green, Associate Professor
greens@unbc.ca
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All: UNBC, 3333 University Ave, Prince George, BC. V2N 4Z9

UNBC Research Ethics Board: (250) 960-6735

Introduction: Serena Black is a graduate student at the University of Northern British Columbia, working to complete a thesis that explores grain production in northern BC. The study will include participatory observation (e.g. Black participates in the daily activity of the producer and records observation), a semi-structured interview and personal reflection (Black records her experiences and observations, to be analyzed). Producers are invited to participate in this completely voluntary study, as information gathered could lead to more applicable research, and the development of a stronger community of practice among northern producers.

Procedure: The goal of this project is to explore the cultural practices and local knowledge of different agri-producers in northern British Columbia. This project will include a final report that will be distributed to all participants. The data collected will be used by the project team members to write publications and media pieces as well.

The interviews will be recorded by hand, as well as on a digital audio recorder, with the permission of the participant. The recording will be transcribed by Serena Black or April Haubold (research assistant) and will be used to clarify the accuracy of the hand written interview notes. A time period of two weeks will be given for participants to review the transcript and make requests for information or quotes to be changed and/or omitted from any final results. After the editing process, the transcripts will be coded, analyzed and a final report will be written. If participants have any questions or concerns or would like someone to go over the transcript in person, participants are encouraged to call one of the researchers. Participants will have access to the preliminary and final reports. All recording and transcripts will be kept in a locked filing cabinet in Serena Black's office at UNBC. All data will be stored on UNBC servers and computers; the database with participant names will be kept separately from the rest of the results. Only research team members will have access to these data forms. All digital recordings will be kept for at least one year after the interview, before being destroyed.

Photography: Photographs will be taken by research team members during formal and informal gatherings, upon permission being granted by the research participants. Warnings will be given before any photos are taken. Photographs will be used for presentations, the final report, and other publications (including thesis). Participants will be advised prior to any publication (including social media). Photos will be stored on a memory stick in a locked filing cabinet in Black's office at UNBC.

Risks and benefits: There are no anticipated risks with this research activity. The interviews will be voluntary and do not include sensitive questions. The benefits include that the final report and thesis report, both of which will enable the further development of research initiatives around agriculture in northern BC, and allow participants to help determine the direction of future research.

Confidentiality: The data will be identified using alphanumeric codes, protecting respondent identity; all data will be presented in anonymous and/or aggregated forms, unless participants specifically request that their names be used.

Withdrawal: Participants are able to skip questions and end the interview at their will and any information collected will be destroyed.

Contact information: If participants have any questions subsequent to the interview, they are invited to contact Serena Black by email (blacks@unbc.ca) or phone (250-960-7800), or Scott Green by email (greens@unbc.ca).

Questions/Concerns: If at any time, participants have any additional questions that have not been adequately addressed through contacting the two individuals above, please contact the UNBC Research Ethics Board at reb@unbc.ca or 250-960-6735. Participants will be given a copy of this sheet for their own record.

Name of participant

Date

Signature of participant

Signature of Researcher

Date

Notes re: participant withdrawal from any aspect of the study: (researcher and participant to initial)

Appendix 2. Semi-structured Interview Guides

2012 Semi-structured Interview Guide

The goal of the research is to explore the cultural practices and local knowledge of different agri-producers in northern British Columbia. You can skip any question and are free to end the interview at anytime.

1. What food do you grow/raise?
2. i) How did you begin your life as a producer?
ii) Why did you become a producer?
3. i) How long have you been working in the region?
ii) What is the most common type of farming in the region (crop, size, etc)?
4. i) What is your main market to sell your products?
ii) Does this market seem to be changing? Yes / No (*interviewer to circle response*)
iii) If yes, how so? (e.g. growing or diminishing)
5. What would be the main motivation to change your practices – either what you grow, on adopting new technology, etc.?
6. When choosing grain cultivars, what characteristics are you most interested in? (*interviewer to circle all responses given by participant*).
 - a) overall yield
 - b) disease/lodging-resistance
 - c) plant height
 - d) quality
 - f) other: _____
7. Where do you get information around new cultivars, new technologies and different management practices? (*interviewer to circle all responses given by participant*).
 - a) government sources
 - b) local agri-businesses
 - c) agencies/organizations
 - d) other producers
 - e) universities

f) other: _____

8. i) Do you communicate with other producers? Yes / No (*interviewer to circle response*)
ii) If yes, what are the main avenues, formal and informal, do you use? If no, why not?
9. i) Are there any concerns around the environment? Yes / No (*interviewer to circle response*)
ii) If yes, what are they?
10. How would you define sustainable practices?
11. What practices are working for you right now?
12. i) What are the major challenges you face in the short-term?
ii) What are the major challenges you face in the long-term?

13. Respondent demographics

Gender: male femalegender neutral

Age range: a) 18-30
 b) 31-40
 c) 41-50
 d) 51-60
 e) 61-70
 f) 71+

Region: a) Quesnel
 b) Prince George
 c) Robson Valley
 d) Vanderhoof

The goal of the research is to explore the cultural practices and local knowledge of different agri-producers in northern British Columbia. You can skip any question and are free to end the interview at anytime.

1. Can you describe your operation - what do you grow/raise?
2. i) How long have you been working in the region?

ii) What is the most common type of farming in the region (crop, size, etc)?
3. What would be the main motivation to change your practices – either what you grow, on adopting new technology, etc.?
4. Where do you get information around new cultivars, new technologies and different management practices? (*interviewer to circle all responses given by participant*).

a) government sources
b) local agri-businesses
c) agencies/organizations
d) other producers
e) universities
f) other: _____
5. i) Do you communicate with other producers? Yes / No (*Interviewer to circle response*)

ii) If yes, what are the main avenues, formal and informal, do you use? If no, why not?
6. i) Do you conduct on the farm experiments?

ii) If yes, can you describe them for me?
7. i) What are the opportunities in the region that are currently unexplored?

ii) Do you see a need for new infrastructure in the region (e.g. grain dryer, silos, etc). If so, what type of infrastructure?
8. As a producer, what resources do you feel would be beneficial that currently is not available?

9. What type of future agriculture-related research would you like to see in the region?

10. Respondent demographics

Gender:

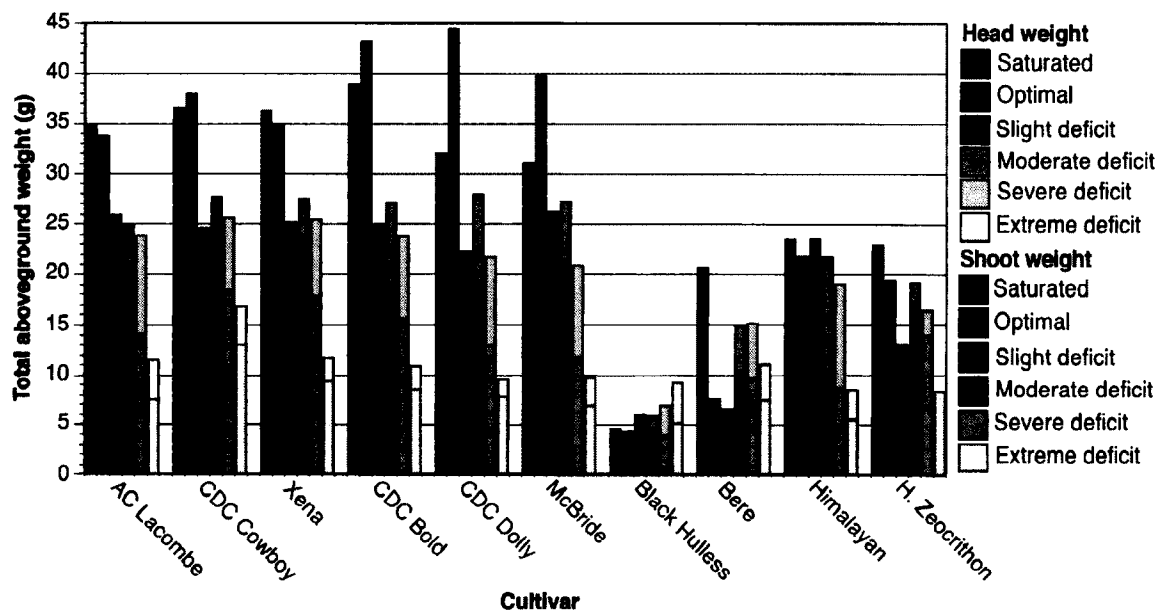
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Appendix 3. Description of the nine cultivars and one barley wild-type used in the controlled environment study comparing phenological and resource allocation responses to water excess and deficit treatments.

Cultivar	Row type	Description	Year
AC Lacombe	6-Row Feed/Silage	Considered the leading silage cultivar, and used for comparison	1991
CDC Cowboy	2-Row Silage	Bred for low input and drought tolerance	2004
Xena	2-Row Feed	One of the leading cultivars in southern Alberta	1999
CDC Bold	2-Row Feed	Semi-dwarf cultivar	1999
CDC Dolly	2-Row Feed	Superior plumpness, often used for comparison	1994
McBride	2-Row Feed	Bred for northern conditions out of McBride, BC (hulless)	Unknown
Black Hulless	2-Row	Very short, possibly a cultivar from Australia (hulless)	~1910
Bere	6-Row Malting	Oldest cultivar available from Europe (Bere Island, north of Britain)	9 th Century
Himalayan	6-Row	A dependable, Asiatic barley with gold brown seed (hulless)	Unknown
<i>H. Zeocrithon</i>	2-Row	Wild-type cultivar	n/a

Appendix 4. Additional figure of mean total aboveground weight (g), separating head and shoot weight.



Mean total aboveground weight (g), separating head and shoot weight, of 9 cultivars of barley (*Hordeum vulgare*) and one barley wild-type (*Hordeum zeocrithon*) in response to water excess and deficit regimes under greenhouse conditions. See Table 3.0 for quantitative field capacity values for each regime. See Figure 3.1a for statistical significance and standard error values.