FARM-LEVEL ADAPTATION TO CLIMATIC VARIABILITY AND CHANGE: CROP DIVERSIFICATION IN THE CANADIAN PRAIRIES

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Abstract. Among other foci, recent research on adaptation to climatic variability and change has sought to evaluate the merit of adaptation generally, as well as the suitability of particular adaptations. Additionally, there is a need to better understand the likely uptake of adaptations. For example, diversification is one adaptation that has been identified as a potential farm-level response to climatic variability and change, but its adoption by farmers for this reason is not well understood. This paper serves two purposes. The first is to document the adoption of crop diversification in Canadian prairie agriculture for the period 1994–2002, reflect upon its strengths and limitations for managing a variety of risks, including climatic ones, and gauge its likely adoption by producers in response to anticipated climate change. The second purpose is to draw on this case to refine our current understanding of climate change adaptation more generally. Based upon data from over 15 000 operations, it was determined that individual farms have become more specialized in their cropping patterns since 1994, and this trend is unlikely to change in the immediate future, notwithstanding anticipated climate change and the known risk-reducing benefits of crop diversification. More broadly, the analysis suggests that 'suitable' and even 'possible' climate change adaptations need to be more rigorously assessed in order to understand their wider strengths and limitations.

1. Introduction

Agriculture is inherently sensitive to climatic conditions, and hence is frequently cited as a sector vulnerable to anticipated global climate change (Parry and Carter, 1985; Rosenzweig and Parry, 1994). Of course, the vulnerability of an agricultural system to long-term changes in temperature or precipitation, or the frequency and magnitude of extreme weather events, is greatly influenced by its adaptive capacity, and it is for this reason that the literature on climate change and agriculture has increasingly directed attention to the issue of adaptation (for reviews see Tol et al., 1998; Smit and Pilifosova, 2001). Adaptation is generally described as those responses by individuals, groups and governments to climatic change or other stimuli that are used to reduce their vulnerability or susceptibility to adverse impacts or damage potential. Recent research on adaptation has followed a variety of paths, one of which has been to evaluate the merit of adaptation generally, as well as the suitability of particular adaptative strategies. While a desire to ensure efficiency has driven much of this research, given the potentially onerous costs of pro-active adaptation (see Mendelsohn, 2000), adaptions have also been evaluated according

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to broader criteria such as effectiveness, institutional compatibility and flexibility (e.g. Carter et al., 1994; Smith and Lenhart, 1996; Mizina et al., 1999; de Loë and Kreutzwiser, 2000; Dolan et al., 2001). Whether intended or not, these evaluations contribute to the efforts of national governments, as required by Articles 4.1 and 10, respectively, of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, to formulate and promote adequate adaptation to climate change.

In addition to identifying suitable adaptations that ought to be adopted, there is clearly a need to better understand the likely uptake of adaptations to climatic variability and change by agents (Smit et al., 1996; Smithers and Smit, 1997; Tol et al., 1998; Wheaton and McIver, 1999; Bryant et al., 2000; Hanemann, 2000; Kandlikar and Risbey, 2000; Kelly and Adger, 2000; Pittock and Jones, 2000; Polsky and Easterling, 2001). In the case of agriculture, for example, diversification, be it increasing the variety of production locations, crops, enterprises, or income sources, is one adaptation that has been commonly identified as a potential response to climatic variability and change (e.g. Smit, 1993; Kelly and Adger, 2000; Mendelsohn, 2000; Wandel and Smit, 2000); however, its adoption by farmers for this purpose is not well understood. In theory, diversification can serve to buffer farm business risks, be it yield risk associated with variable climatic conditions or price risk associated with variable commodity markets (Fleisher, 1990; Hardaker et al., 1997), and this benefit would appear to be especially vital in an era marked by less dependable government support (see Bradshaw and Smit, 1997). Further, farmers themselves commonly identify diversification as an effective strategy for managing business risks (e.g. Knutson et al., 1998) and climatic risks in particular (Sonka and Patrick, 1984; Boggess et al., 1985). Notwithstanding this, our current knowledge provides limited grounds for estimating its likely adoption by farmers in response to current or anticipated climatic conditions.

Given the need to better understand the likely uptake of farm-level adaptations to climatic variability and change generally, and the converging interest in diversification as a tool for managing a variety of risks in contemporary agriculture specifically, it seems appropriate to assess more rigorously this potential farm-level adaptation. This paper, then, serves two main purposes. The first and more narrow one is to empirically assess the farm-level adoption of one common form of diversification, crop diversification, in Canadian prairie agriculture for the period 1994–2002, and reflect upon its strengths and limitations for managing a variety of risks, including climatic ones, in contemporary agriculture. While its relatively narrow temporal scope and largely descriptive nature[1] compel us to designate this an exploratory assessment, significant trends are discernable in the data, and these are drawn upon, in tandem with broader arguments, to gauge (conservatively) the likelihood of farmers adopting crop diversification as a response to anticipated climate change. In addition, this case offers insights for refining our current understanding of the process and likelihood of farm-level adaptation to climatic variability and change more generally, which is the paper's second and broader purpose.

Canadian prairie agriculture, which has long been recognized as a significant contributor to world cereal production based on highly specialized production systems, [2] offers a particularly useful case for consideration of this issue. Since initial settlement, agricultural production in Canada's semi-arid prairies has been greatly influenced, and indeed constrained, by climatic conditions such as inconsistent moisture availability. Under projected climate change this influence is expected to intensify given anticipated warmer temperatures, higher overall precipitation yet reduced soil moisture owing to increased evapotranspiration, and more frequent extreme events, including heat waves and associated drought conditions (Herrington et al., 1997; Luciuk and O'Brien, 1999; Cohen and Miller, 2001). Governments and producers themselves are therefore looking for ways for prairie agriculture to adapt to anticipated climatic conditions. Among other strategies (e.g. improved irrigation, reduced tillage, etc.), crop diversification has been a focus of government attention and promotion,[3] not only in light of anticipated climate change but also recent agricultural policy reforms that have significantly altered the production and risk environments of prairie producers (Agriculture and Agri-Food Canada, 1998; Luciuk and O'Brien, 1999). While shifts towards more diverse cropping patterns for the Canadian prairies as a whole have recently been identified (Agriculture and Agri-Food Canada, 1998; Campbell et al., 2002; Zentenr et al., 2002), and this has led to inferences of increased crop diversity at the individual farm scale, this has not been empirically verified.

The paper follows in five further parts. Section 2 provides a more detailed review of agricultural adaptations as characterized in the climate change literature, and draws attention to three key barriers to improving our understanding of farmer adaptation to climatic variability and change. Following this, one specific adaptation strategy, diversification, is examined in order to identify its various meanings and possible forms. In Section 4, relevant policy, economic, climatic and technological conditions for the Canadian prairies are documented for the decade to 2002 in order to provide a context for an analysis of crop data from a sample of over 15 000 Canadian prairie farms that identifies change in far-level crop diversity between 1994 and 2002. Given this evidence, a discussion follows on the strengths and limitations of crop diversification as a tool for managing a variety of risks, including climatic ones, in contemporary agriculture, and the likelihood of its adoption by Canadian prairie farmers in response to anticipated climate change. Additionally, wider lessons from this particular case are identified in order to improve our understanding of farm-level adaptation to climatic variability and change more generally. Finally, conclusions are drawn in Section 6.

2. Adaptations in Agriculture to Climatic Variability and Change

A wide variety of agricultural adaptations to climatic variability and change are available and reported in the literature (for a recent review, see Smit and Skinner, 2002). Adaptations come in many forms and can be characterized according to a suite of attributes such as intent (spontaneous versus planned), timing (reactive, concurrent or anticipatory), duration (short- versus long-term), spatial extent (localized or widespread) or responsibility (e.g. government, producers, etc.) (Carter et al., 1994; Smit et al., 2000; Smit and Skinner, 2002). Expanding on this last attribute, adaptations undertaken by governments typically refer to conscious policy measures that aim to enhance the adaptive capacity of agricultural systems (Bryant et al., 2000). These measures might include funding technological adaptations such as crop development (Smithers and Blay-Palmer, 2001), improving the state of weather forecasting (Murphy, 1994), or promoting and even subsidizing certain farm-level adaptations (Brklacich et al., 2000). Possible farm-level adaptations to climatic variability and change are many. For example, farmers can adapt tactically to climate change conditions by changing the timing of planting, input use and harvesting (Smit, 1993; de Loë et al., 2001). They can also adapt strategically by altering soil management practices such as tillage (Dumanski et al., 1986) or their selection of crop types/varieties (Smit, 1993; Mendelsohn, 2000; Wandel and Smit, 2000), by diversifying their farm enterprise (Smit, 1993; Kelly and Adger, 2000), or purchasing crop insurance (Smit, 1994).

Rather than simply identifying all possible adaptations for managing climate-related risks, recent research in the field has sought to evaluate the suitability of adaptions according to criteria such as economic efficiency, effectiveness, flexibility or institutional compatibility (e.g. Carter et al., 1994; Fankhauser, 1996; Smith and Lenhart, 1996; Mizina et al., 1999; de Loë and Kreutzwiser, 2000). Implicit to all such evaluations is an assumption that suitable adaptative strategies *can* be recognized that make sense to agents in the actual context in which adaptations are adopted. This assumption may be reasonable; indeed, it mirrors a widely expressed belief in the climate change impacts and adaptation literature. For example, when Mendelsohn (2000, p. 590–591) calls on governments to offer suggestions to private individuals regarding 'what they could do to adjust' where private adaptation is hindered by onerous information needs, and 'subsidize desirable changes' where private adaptation is constrained by externality costs, the author assumes that suitable adaptations can be identified. Similarly, when Schneider et al. (2000, p. 206) describe a spectrum of farm-level adaptation to climatic variability and change, the positive end of which is marked by the developed world's 'land grant universities with their research and extension centers continually monitor[ing] environmental trends and develop[ing] adaptive strategies for farmers', they imply that suitable adaptative strategies are discernable.

Based on their multi-criteria suitability assessment of agricultural adaptation options in the Canadian context, Dolan et al. (2001) argue that, in fact, this assumption may be problematic. Selected potential adaptations were evaluated from the perspective of producers and governments relative to criteria drawn from the literature. The exercise suggests that, while multi-criteria evaluative frameworks can serve to identify adaptations that are generally suitable for managing climate-related risks, they are less effective at identifying adaptations that are suitable for managing multiple risks be they downturns in commodity markets, changes to government support programs, fluctuations in currencies and interest rates, or the loss of export markets due to livestock diseases or consumer health concerns; even more problematic is their limited capacity to identify adaptations that are suitable for responding to multiple opportunities. While Dolan et al. (2001) acknowledge that actual farm-level decisions are seldom made with respect to just one stimuli, a fact that has long been acknowledged in the climate change impacts and adaptation literature (e.g., Timmerman, 1989; Chiotti and Johnston, 1995; Easterling, 1996; Smit et al., 1996; Smithers and Smit, 1997; Brklacich et al., 2000; Bryant et al., 2000; Eakin, 2000; Kandlikar and Risbey, 2000; O'Brien and Leichenko, 2000; Schneider et al., 2000), their evaluative framework and others like it are not structured to capture this complexity. Hence, what ought to happen at the farm level given the risks associated with climatic variability and change may not match what actually happens.

The difficulty of accounting for the inevitable compounding effect of non-climatic risks and opportunities represents just one of many barriers to improving our understanding of the likely adaptive response of farmers to anticipated climate change. A second complication, and one that has attracted considerable attention in the literature (e.g. Robock et al., 1993; Smit, 1993; Downing et al., 1997; Mearns et al., 1997; Kandlikar and Risbey, 2000; Schneider et al., 2000; Yohe, 2000; Smit and Pilifosova, 2001; Pielke and Sarewitz, 2002/3), derives from the fact that long-term climate change will be experienced by farmers, and indeed by all agents, through year-to-year variable conditions and especially extreme events, what Yohe (2000) labels 'inter-periodic variability'. Will farmers differentiate between the so-called 'signal' and 'noise'? For some (e.g. Smit, 1993; Downing et al., 1997; Yohe, 2000), this distinction is unimportant; where farmers improve their capacity to manage climatic variability and especially extreme events, they should generally be better prepared for longer term climatic change. However, for others (e.g. Schneider et al., 2000; Mendelsohn, 2000), farmers' and other agents' observance of natural climatic variability, especially where that variability masks slower underlying trends, may prompt complacency, inefficient adaptation or, worse, maladaptation. Either way, this distinction adds further complexity to the question 'to what, exactly, are farmers adapting?'.

A third key barrier to improving our understanding of the likely adaptive response of farmers to anticipated climate change derives from the heterogeneity of human decision-making and behavior (Kandlikar and Risbey, 2000). Clearly, the behavior of individuals cannot be solely attributed to factors external to those individuals. As conceptualized by Smit et al. (1996) in the case of agriculture, internal attributes of individual farms, farm operators and farm families will affect an individual's perception of, and sensitivity and response to, exogenous stimuli such as climatic conditions. In other words, highly variable and often very personal circumstances such as debt, family breakdown or the availability of off-farm income, may account for a significant portion of observed behavior. This inherent variability in individual behavior appears to underlie the debate surrounding assumptions of non-adapting ('dumb') farmers versus perfectly adapting ('smart' or 'clairvoyant') farmers in integrated climate change impact models (see Smit, 1991; Rosenberg, 1992; Yohe, 1992; Schneider et al., 2000), and arguably diminishes the accuracy and ultimate utility of these models' results. Indeed, as argued by Rothman and Robinson (1997), these models should assume a 'realistic farmer'; however, the exact character of this individual remains unknown. Instead, Schneider et al. (2000) suggest that future impact assessments simply identify the sensitivity of their results to a range of assumptions regarding human adaptive behavior and ensure that these assumptions are made explicit to users of the results.

In light of these and other barriers to improving our understanding of the likely adaptive response of farmers to anticipated climate change, many in the field have called for empirical assessments of actual adaptative behavior in particular places over particular periods of time (e.g. Smit et al., 1996; Smithers and Smit, 1997; Kandlikar and Risbey, 2000; Polsky and Easterling, 2001), even though such behavior is place- and time-specific, and likely represents a response to inter-periodic climatic variability, as well as to multiple non-climatic risks and opportunities. In an agricultural context, such case studies, or what Tol et al. (1998) label 'temporal analogues', are relatively few. For example, Smithers and Smit (1997) drew on aggregate data representing thousands of producers to look for covariations in climate stimuli, cropping areas, crop yields, crop insurance and technology over three decades in southern Ontario, and determined that climate stimuli accounted for limited change in cropping areas, due in large part to the presence of crop insurance. In the cases of Smit et al. (1996, 1997) and Brklacich et al. (2000), a limited number of farmers in different regions in Ontario were surveyed to document specific changes in farm practice over a prior period and the reasons offered for such changes. In all cases, surveying revealed that some farmers had undertaken tactical and strategic changes in light of climatic stimuli, especially annual conditions, but these changes also reflected the risks and opportunities presented by economic, technological, social and political factors.

The empirical assessment undertaken herein follows the more extensive approach of Smithers and Smit (1997), focusing on one commonly identified farm-level adaptation to climatic variability and change, crop diversification, in order to assess its adoption among 15 000+ farmers within a relatively large region over the period 1994–2002. Before this is done, the next section reviews the various meanings and forms of diversification as used in a variety of related literatures and within policy circles.

3. Meanings and Forms of Diversification

While diversification is commonly advocated as an effective tool for managing a variety of farm business risks, the precise form of diversification that is advocated is often unclear. This is especially so with respect to the scale at which diversification is undertaken, and the degree to which acts of diversification add to, or simply replace, existing activities. Agricultural diversification at national or regional scales generally implies a broadening of the aggregate mix of farm enterprises, activities, and outputs within that defined area. These scales of analysis tend to be of particular interest to economic modelers projecting the likely implications of trade liberalization for agricultural production patterns (e.g., Anderson, 1992) and governments promoting economic diversification in depressed agricultural regions (e.g., Agriculture and Agri-Food Canada, 1998). Of course, a change in regional or national levels of diversity does not necessarily imply a similar change in the degree of diversity at the individual farm scale. For example, the introduction of novel crops or livestock, such as triticale or emus, may augment the overall number of outputs in a region; however, this increase in regional diversity may derive from the replacement of traditional outputs such as wheat and cattle on numerous individual farms, thereby resulting in no change in farm-level diversity. In fact, it could be argued that regional scale diversification reduces the degree of output overlap among farms and thereby enables further farm-level specialisation. While, in exact terms, the substitution of one output or activity for another within a single operation does not constitute an act of farm diversification, some analysts have employed the term diversification to reflect such circumstances (e.g. Ilbery, 1991). Farm-level (re)specialization in unconventional outputs may be welcomed by governments promoting regional economic diversification and may serve to improve short-term farm profitability, but such an approach, at least according to agricultural risk management theory, is unlikely to improve the capacity of individual producers to manage a variety of farm business risks.

Focusing on the individual farm scale, Wandel and Smit (2000) identify and categorize a variety of forms of agricultural diversification available to producers for managing climatic and non-climatic risks. Geographic diversification (i.e., increasing the number of locations of production) and crop diversification (i.e., increasing the number of crops or varieties/hybrids of a particular crop) both act to reduce the susceptibility of an operation to micro-climatic events such as hail and other bio-physical events such as a pest outbreak that might result in crop failure. Crop diversification, as with enterprise diversification (i.e., increasing the number of marketable activities such as adding livestock to a cash crop operation or undertaking value-added processing), also serves to reduce business risks resulting from price downturns.[4] Lastly, income diversification (i.e., increasing the number of income sources through off-farm work or investments) reduces business risks that might result from climatic, production, or market events.

Of these many forms of farm-level agricultural diversification, crop diversification has attracted considerable interest in Canadian prairie agriculture over the past decade as a suitable tool for managing a variety of risks in contemporary agriculture. These many risks and the degree to which individual producers in the Canadian prairies have sought to manage them via a strategy of crop diversification over the 1994–2002 period are documented in the next section.

4. Change in Farm-Level Crop Diversity in Canadian Prairie Agriculture (1994–2002)

Agricultural production in the Canadian prairies has historically centered on highly specialized, indeed often monoculture, cereal cropping, and especially hard red spring wheat, enabled via frequent summer-fallowing for moisture retention and extensive use of conventional tillage for weed control and bed preparation (Zentenr et al., 2002).[5] More recently, however, producers have increasingly replaced summer fallow and conventional tillage with extended crop rotations and conservation tillage, and expanded the production of oilseeds such as canola and flax, and pulses such as field peas and lentils. Given a parallel decline in seeding of traditional spring wheat through much of the 1990s, the overall acreage of principal crops in the region has become more balanced, leading some to identify crop diversification as a new trend in the region (e.g. Campbell et al., 2002; Zentenr et al., 2002).

In striving to explain these evolutionary, if not revolutionary, shifts in Canadian prairie agriculture, analysts have pointed to a number of political, economic, climatic and technological factors. In 1995, a year marked by relatively buoyant prices for most grains and especially wheat (see Figure 1), a century-old government program that aggressively subsidized the cost of transporting export grains and oilseeds to ports in Vancouver, Thunder Bay, and Churchill was discontinued.[6] While in existence, the Western Grain Transportation Act (WGTA) was criticized for its perceived effects on land use, and, in particular, its favoring of (a narrow range of) cereal grains and oilseeds over perennial forage crops (Pierce, 1993). Hence, with its demise, it was widely anticipated that prairie producers would not only reverse this imbalance, but also seek to diversify into non-traditional crops (Kerr et al., 1991; TAEM, 1992). Of equal significance, in the years following the termination of the WGTA, a commodity-based revenue protection program, the Gross Revenue Insurance Plan, was phased out thereby increasing prairie farmers' exposure to both price and yield risks.

With respect to economic conditions, prices for traditional cereal crops, and especially spring wheat, declined significantly after the 1995 peak year to levels comparable to the early 1990s but well below those of the prior decade in real dollar terms (see Figure 1). In the prairie region in particular, this downturn, coupled with steadily increasing input costs, put a significant strain on farm profitability through the latter years of the 1990s; in Saskatchewan, for example, 1999 realized net incomes were down by 87% relative to a 1994–1998 average baseline (Agriculture and Agri-Food Canada, 2000). Wheat prices rebounded in 2002, but many farmers were unable to capitalize on them owing to drought-induced production declines.

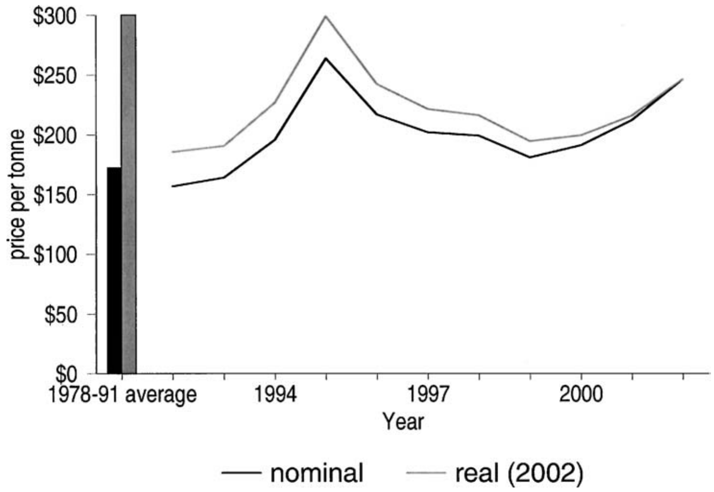

Figure 1. End of season price per tonne (Can$) for #1 western red spring wheat (12.5%), 1992–2002 relative to the 1978–1991 average (source: Canadian Wheat Board, 2003).

Record dry conditions were experienced in many parts of the prairies in both 2001 and 2002 following two decades of generally warmer and drier conditions. Indeed, for the period 1948–2003, 9 of the 10 warmest springs and 5 of the 10 driest springs in the prairies have occurred since 1980 (Environment Canada, 2003). While events such as the 2001 and 2002 droughts were within climatic norms, they and the general conditions of the past two decades have increasingly been viewed in the context of anticipated climate change (Agriculture and Agri-Food Canada, 2003).

Lastly, on the technology front, increased use of irrigation has enabled the production of novel crops (e.g. potatoes) in traditionally semi-arid zones, while effective and relatively inexpensive herbicides have facilitated a shift towards conservation tillage. Zero- and minimum-tillage systems not only save time for producers and contribute to long-term soil quality, but also serve to limit greenhouse gas emissions and soil erosion, two environmental issues of particular concern to the region. Indeed, conservation tillage, as with irrigation, crop diversification and other favored innovations, has been actively promoted, of late, through a well-funded extension effort to promote adaptation of Canadian prairie agriculture to a less subsidized and more risky production environment. While the termination of the WGTA provided the specific justification and impetus for the provision of over Can$ 2 billion to prairie farmers and regional 'adaptation councils' in the 4-year period following 1995, its broader aim was to foster greater self-sufficiency among producers in anticipation of future climatic and market threats. Given this concerted effort, recent evidence of crop diversification and other shifts in practice has been well received by federal and provincial officials; however, it is not clear that crop diversification has occurred at the individual farm scale.

Table I
Crops (and ground covers) included in the annual seeding survey as of June, 2002

Durum wheat	Lentils – eston	Triticale
Hard red spring wheat	Lentils – others/unknown	Fababeans
Red prairie spring wheat	Dry peas – yellow	Safflower
White prairie spring wheat	Dry peas – green	Sugar beets
Soft white spring wheat	Dry peas – other/unknown	Potatoes
Extra strong spring wheat	Mustard seed – yellow	Borage seed
Other spring wheat	Mustard seed – oriental	Chick peas
Winter wheat	Mustard seed – brown	Coriander
Oats	Mustard seed – other/unknown	Soybeans
Barley	Sunflower seeds	Other crops
Mixed grains	Canary seed	Alfalfa and alfalfa mixtures
Flaxseed	Caraway seeds	All other tame hay
Linola	Buckwheat	Forage seed
Canola	Corn for grain	Summer fallow
Spring rye	Fodder grain	Pasture
Winter rye	Dry white beans	
Lentils – laird	Dry coloured beans	

Each spring, Statistics Canada surveys a random sample of producers in order to develop seeded area estimates for Canada's principal crops. Farm operators are asked to identify their total seeding areas for that year, whether undertaken or intended, for a wide range of crops and ground covers (see Table I). For the period 1994 to 2002, the number of farmers included in the survey from the Canadian prairie region ranged from 21 723 (in 1998) to 24 205 (in 1997). While other recent assessments of crop diversity (see above) have drawn on this same survey, all have done so based on summarized results (i.e. aggregated data) that preclude analysis below the regional scale. For this analysis, the farm-level (i.e. disaggregated) data were assessed to generate a number of descriptive statistics. In order to exclude those farm operations deemed inactive or insignificant in a prairie cash crop context, the dataset was reduced to include only those farms with at least 40.5 ha (100 acres) in production and at least one reported crop. Using 1996 as an example, Table II identifies the resulting sample sizes relative to the total population of Canadian prairie farms as per the 1996 census. Additionally, in order to investigate whether crop diversity varied by farm size, the sample was split into four equally represented groups (i.e., quartiles) for each year. Table III provides the ranges for these four groups for the years 1994, 1998 and 2002, and thereby also reveals the pattern of farm enlargement over the study period.

At the individual farm scale, the simplest measure of crop diversity is the total number of (different) crops per farm. Figure 2 identifies the average number of crops per farm for the period 1994–2002, for all prairie farms (regardless

Table II
1996 sample sizes relative to the total population of farms as per the 1996 Canadian census

	Total population of farms as per the1996 census	Sample size	Sample to population (%)
Manitoba	24385	3567	14.6
Saskatchewan	56995	7313	12.8
Alberta	59005	5318	9.0
All (including British Columbia)[a]	162220	16429	10.1

[a]The western Canada dataset includes a small sample (882 in 1996) of British Columbian farmers from mainly the Peace district.

Table III
Farm size ranges (1994, 1998, and 2002) based upon quartiles (ha)

	1994	1998	2002
Small	40–182	40–194	100–190
Medium	183–372	194–419	190–425
Large	373–671	419–778	425–842
Extra large	672+	778+	842+

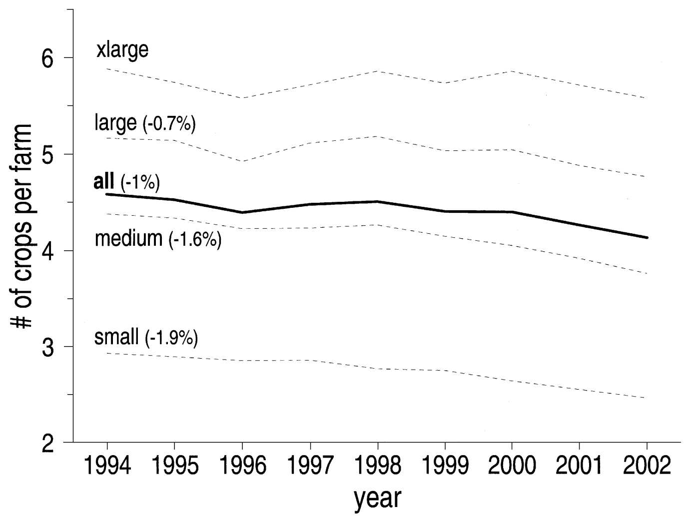

Figure 2. Average number of crops per farm (for all farms and by size) for the Canadian prairies, 1994–2002. The annual percent change is noted for significant trends. (Note: see Table III for farm size ranges.)

of size) and by four farm size classes. By this measure, the level of crop diversity declined from 4.58 crops per farm in 1994 to 4.12 by 2002, which, based on a statistically significant (at 95%) least squares line, equates to an annual decline of 1.0%. This decline was especially pronounced on small and medium sized farms, which were less diverse than larger farms as of 1994 and became even less so over the remainder of the decade. No discernable trend was identified for the very large farms over the study period.

In order to provide a more precise measure of crop diversity based on proportions rather than absolute counts, the Herfindhal Index was calculated for each individual farm in the dataset based on the relative composition of crops within the area of active farmland. The index, which ranges from zero, reflecting complete diversification (i.e., an infinite number of crops in equal proportions), to one, reflecting complete specialization (i.e., just one crop), is calculated as:

$$H = \sum_{n=1}^{i} P_i^2$$

where P_i is the proportion of the *i*th crop relative to the overall area of active farmland.

Figure 3 identifies the average score for the Herfindhal Index for the period 1994–2002, for all prairie farms (regardless of size) and by four farm size classes. This proportional measure of crop diversity similarly reveals a shift towards more specialized cropping patterns among prairie farms, and once again, this appears most pronounced on small and medium sized farms. Also once again, no discernable

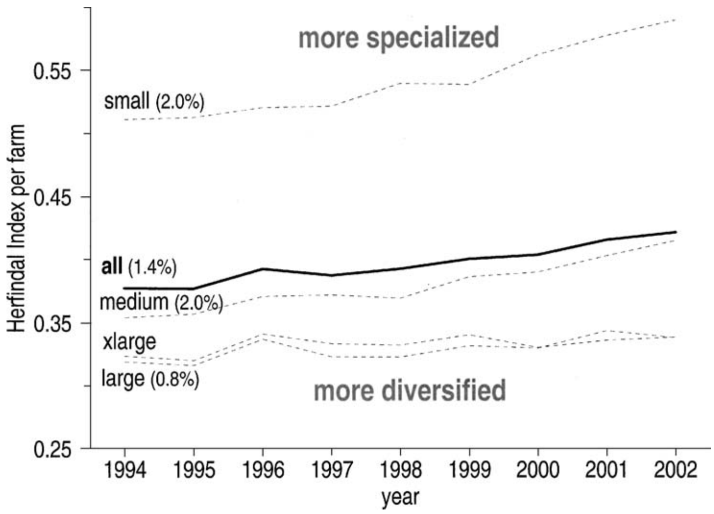

Figure 3. Average Herfindhal Index per farm (0, fully diversified; 1, fully specialized) (for all farms and by size) for the prairies, 1994–2002. The annual percent change is noted for significant trends. (Note: see Table III for farm size ranges.)

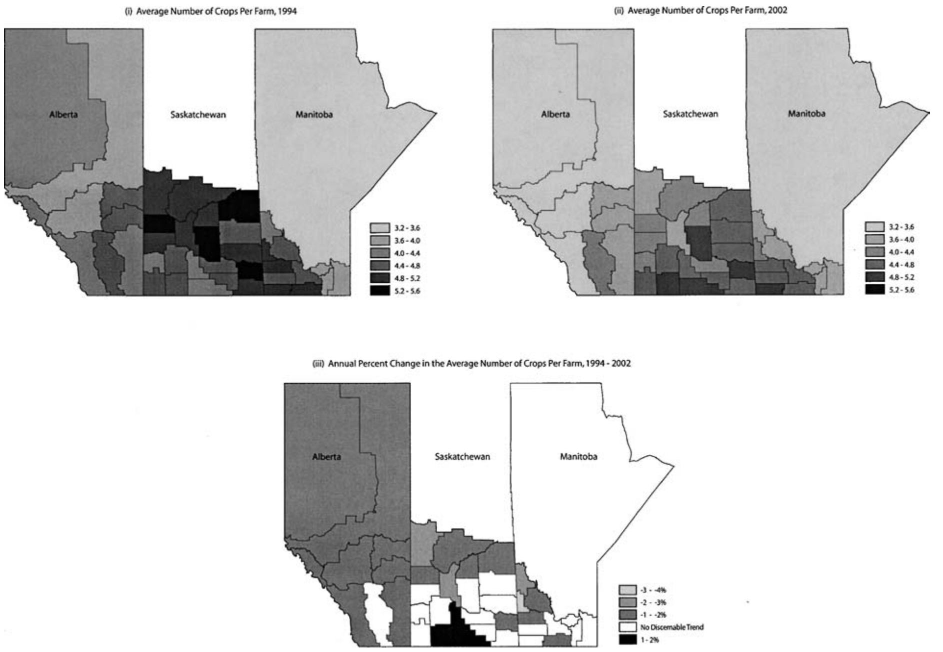

Figure 4. Average number of crops per farm within each agricultural census region for the years 1994 (i) and 2002 (ii) and annual percent change in the number of crops per farm within each agricultural census region between 1994 and 2002 where a significant trend exists (iii).

trend was identified for the very large farms. Interestingly, both the absolute and proportional measures of crop diversity (Figures 2 and 3) indicate a notable shift towards specialization in 1996, followed by a momentary return to more diverse cropping patterns.

In order to observe if individual farm crop diversity, and changes in this diversity, varied regionally within the Canadian prairies, the average number of crops per farm was identified within each of the census (agricultural) regions across Manitoba, Saskatchewan and Alberta. Figure 4 identifies the regional variation in farm-level crop diversity for the years 1994 and 2002, as well as the change in farm-level crop diversity over the study period for those regions displaying a discernable trend based on a statistically significant (at 95%) least squares line. As of 1994, Saskatchewan farms, at least those outside the arid brown soil zone in the southeast corner of the province, generally displayed greater crop diversity than farms in Alberta and Manitoba. Over the period 1994–2002, the crop mix on individual farms within 19 of 40 prairie regions became more specialized, with one region in western Manitoba displaying a greater than 3% annual change. A discernable trend towards crop diversification among individual farms was displayed in just three prairie regions, all of which are located in south-central Saskatchewan within the arid, brown soil zone. Eighteen of the 40 regions displayed no notable change in farm-level crop diversity over the study period.

In sum, while farm-level crop diversity has increased in a few census regions of the prairies, or more precisely three adjacent regions in south-central Saskatchewan, the overall trend for the Canadian prairies over the past decade has been one of specialization, which contrasts with prior expectations and recent inferences.[7] Of particular interest is the notable shift towards more specialized cropping patterns among individual operations in 1996. Notwithstanding the 1995 termination of the WGTA freight subsidy for grains and oilseeds, not to mention the significant extension efforts that aimed to promote adaptation to a new, more risky, production environment via, among other things, crop diversification, Canadian prairie producers greatly expanded their acreage of the region's traditional crop – wheat. In the 1996 production year, the average area in wheat (all varieties) among prairie farms increased to 162.7 ha from 139.5 ha in the prior year; in proportional terms, this represented an increase from an average 25.6% of active farmland area to 29.3%. Perhaps not surprisingly, the 1996 peak year for wheat acreage followed a peak year in the price of wheat (see Figure 1).

What does this evidence suggest about the perceived utility of crop diversification for managing farm business risks generally, and responding to climate change specifically. What are its strengths and weaknesses? Additionally, what does this case tell us about the process and likelihood of farm-level adaptation to climatic variability and change?

5. Discussion

While crop diversification provides a means of buffering farm business risks, be it yield risk associated with variable climatic conditions or price risk associated with variable commodity markets, the strategy's strengths may, in some circumstances, be overwhelmed by its perceived limitations. The evidence presented above suggests that for a majority of Canadian prairie producers, this has been the case for the period 1994–2002, and likely much longer. Indeed, given the historical (at least post-1973 and arguably post-1945) record of crop specialization in the Canadian prairies and North American agriculture more generally, it would have been most remarkable for Canadian prairie farmers to have expanded the range of crops produced on their farms over the 1994 to 2002 period.

Decisions to markedly alter cropping patterns, especially established crop rotations, are usually undertaken with caution by producers. Generally, changes are only initiated if a producer perceives benefits in terms of lower production costs, higher net returns, lower business risk (market and/or yield risk), or some combination of these (Zentenr et al., 2002). In many circumstances, this decision involves a tradeoff between increasing the potential for higher net returns and increasing business risk (Zentenr et al., 2002). This is particularly so in the case of crop diversification given that: (1) a diversified operation will generate lower revenues in a given year than an operation producing just a couple of (clairvoyantly selected) high priced crops, which may explain the observed increase in wheat production among prairie producers in 1996; and (2) crop diversification can reduce the benefits associated with economies of scale,[8] which may explain why small farms were less diversified than large ones throughout the study period, and why a discernable trend of crop specialization was observed for all farms except the very large. In addition, crop diversification may be limited by onerous start-up costs and the added burden of learning to produce a new crop (especially with respect to its impacts on soil fertility and moisture, input use, and weed control), and market it. Lastly, in the specific context of Canadian prairie agriculture, the potential range of crops available to many producers tends to be limited by agroclimatic conditions, soil types, and other farm resource endowments (Bollman and Tomiak, 1988; Kulshreshtha and Klein, 1999).

In terms of the price- and yield-risk benefits of crop diversification, these, of course, depend on the extent to which the prices of crops (in a selected mix) covary and the yields of crops (in a selected mix) covary. In the case of Canadian prairie agriculture for the period 1985–1998, Zentenr et al. (2002) identified high correlations between the prices of spring wheat, the dominant crop of the region, and alternative crops such as durum wheat, canola, barley and field peas, thereby suggesting that diversification based on these crops offers limited to no risk protection from price downturns. Of greatest benefit for reducing price risk was a mix of spring wheat with lentils. The authors also assessed correlations between yields for the same period and found that yield risk was not greatly reduced through a mix of spring wheat with durum wheat, barley, flax or lentils, but could be reduced somewhat through the addition of canola or mustard. In other words, crop diversification in itself does not necessarily ensure reduced price and yield risks.

While the farm-level survey drawn upon in this paper did not assess producer's adoption of other risk-reducing strategies, which would enable the identification of preferred strategies, it is worth identifying others' findings in this regard. In general, recent investigations suggest that farmers perceive greater utility in diversifying income sources, especially through undertaking activities or work off the farm, as compared with geographic, crop, or enterprise diversification on the farm. For example, research conducted in rural Wales by Bateman and Ray (1994) found off-farm work contributing more to family incomes than acts of on-farm diversification. Similarly, Martin and McLeay (1998) in a study of the risk-management practices of New Zealand sheep and beef farmers in the absence of government support found only 19% of their sample adopting an income spreading strategy, one example of which was on-farm agricultural diversification. Additionally, it is widely recognized that publicly funded crop insurance can provide a cost-effective means of reducing yield risk,[9] which most likely limits a farmer's desire to undertake other adaptations (Smit, 1994; Smithers and Smit, 1997).

Given the many limitations of crop diversification and the potential strengths of other risk-reducing strategies, it perhaps is not surprising that Canadian prairie crop producers generally chose to (further) specialize over the 1994–2002 period.

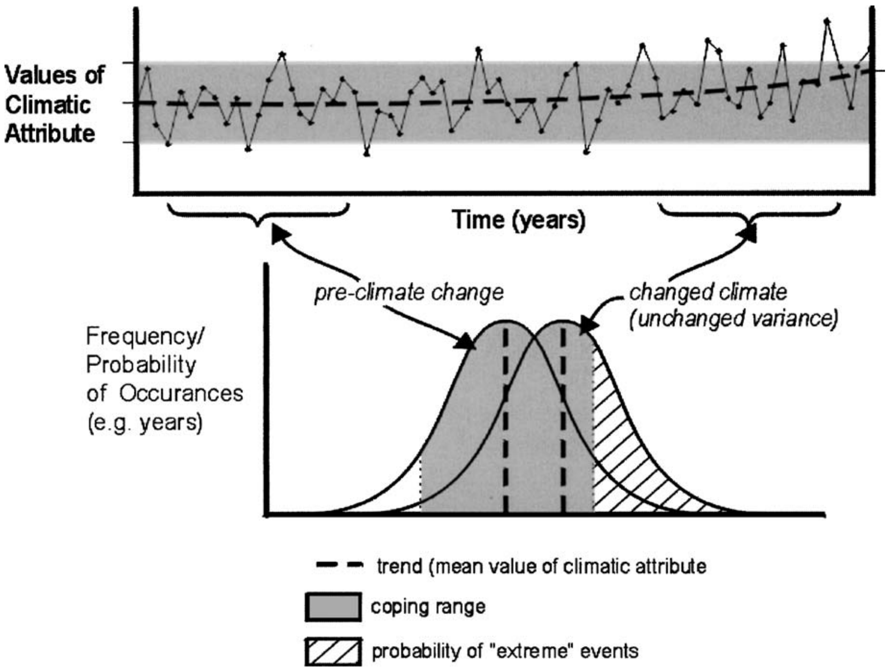

Figure 5. A conceptualization of climate change, variability and the generation of 'extreme' events given an unchanged coping range (source: Smit and Pilifosva, 2001).

The 1996 crop year is particularly telling. In an apparent attempt to maximize returns, farmers greatly expanded the area seeded in wheat at the expense of other land uses, thereby reducing crop diversity at the individual farm scale. Maximizing returns is an obvious aim for most farmers, and it is not clear that crop diversification compliments such an aim. A key question for this paper, then, is whether this evidence suggests that crop diversification represents an unlikely farm-level response to anticipated climate change. Or, to take the perspective of those seeking to identify suitable adaptations, does this evidence suggest that crop diversification is an inappropriate adaptation to climatic variability and change?

A simplified form of a conceptualization presented in Smit and Pilifosva (2001) provides a useful basis for addressing these key questions (Figure 5). In short, the conceptualization suggests that: (1) climatic conditions (or any exogenous condition for that matter) will most likely garner the attention of agents, and perhaps initiate an adaptive response, when these conditions exceed an agent's coping range, thereby producing an 'extreme' event; and (2) under anticipated climate change, these 'extreme' events are likely to increase in frequency and magnitude in the absence of a corresponding shift in an agent's coping range. For the purposes of this discussion, it can be suggested that, all other things being equal, increased crop diversity, especially given a mix of crops with minimal yield and price covariations, serves to expand a farmers' coping range, while crop specialization serves to narrow it.

Drawing on this conceptualization, a number of explanations for the observed behavior of Canadian prairie crop producers is possible. For example, over the 1994–2002 period, crop specialization may simply have been a feasible strategy for producers because relevant climatic conditions failed to exceed producers' narrowing coping range. Alternatively, these producers may have maintained or even expanded their coping range via other risk-reducing strategies such that no 'extreme' events were experienced. These two possibilities suggest that, in the future, if a producer's narrowed, maintained or even expanded coping range is exceeded by relevant climatic conditions, the increased risk associated with crop specialization may become more apparent, the practice of producing a narrow range of crops may be revisited, and a strategy of crop diversification may be adopted. That is, given changes in future climatic conditions, and especially an increase in crop-damaging extreme events, producers might halt and even reverse the long time trend of crop specialization. Of course, such a decision would be made based on a thoughtful comparison of the relative costs and benefits of such a shift in practice relative to other risk reducing strategies, and in this the numerous limitations of crop diversification identified above would be significant. In short, given its potential for reducing yield and price risks, crop diversification can, in narrow terms, be identified as a suitable adaptation to climatic variability and change; however, it is probably an unlikely one in the case of Canadian prairie agriculture and this tells us something about its broader suitability. Or put another way, crop diversification may offer benefits for farmers adapting to climatic variability and change, but farmers do not, and cannot, make decisions based on climatic stimuli alone.

Lastly, what can we draw from this example to refine our understanding of climate change adaptation more generally? Most significantly, this paper's case analysis highlights the difficulty of identifying suitable adaptations for responding to climatic variability and change, which can be expected to work, and hence be adopted, in the multi-risk/opportunity environment in which agents exist. It may even suggest that we revisit the widespread belief that adaptative strategies *can* generally be recognized by analysts and/or extension officers that make sense to agents. Viewed in a more positive frame and given the requirement of national governments to formulate and promote adequate adaptation to climate change, our analysis suggests that adaptations that have been identified as suitable for responding to anticipated climate change based on multi-criteria assessments, and perhaps even those identified as simply possible, need to be more rigorously assessed in order to better understand their wider strengths and limitations. To this end, further case studies of observed adaptive behavior may prove useful.

This case also re-enforces the view that would-be climate change adaptations that constitute a significant (i.e. strategic) shift in behavior will most likely be slow to occur, or may not occur if the costs of non-adoption are deemed insignificant or other less disruptive adaptations are available. In the case of agriculture in particular, decisions to alter behavior in order to respond to the risks and opportunities associated with climate change will be made with caution, especially where such shifts represent a significant break from historical norms. Additionally, given the significant short-term costs associated with some strategic adaptations (e.g. initial capital investment, personal time, learning, and perhaps even lost revenue), the longer term benefits of these adaptations may remain hidden to producers or simply deemed trivial, especially during periods of financial crisis.

6. Conclusions

As called for by others in the growing literature on climate change adaptation, in addition to evaluating the merit of adaptation generally and the suitability of particular adaptative strategies, there is clearly a need to better understand the likely uptake of adaptations by agents. This task is made difficult by a number of complications, such as agents' exposure to non-climatic stimuli, as well as natural climatic variability imbedded within longer term climate change, and the inherent variability of human behavior in general; however, it is essential for estimating the true costs or risks of climate change. This paper has sought to contribute to this research need by: assessing the adoption of one widely identified agricultural adaptation to climatic variability and change, crop diversification, in the case of Canadian prairie agriculture for the period 1994 to 2002; reflecting on its strengths and limitations for managing farm business risks including climatic ones; gauging its likely adoption by Canadian prairie farmers as a response to anticipated climate change; and offering insights from this case that can serve to refine our current understanding of farm-level adaptation to climatic variability and change more generally.

Based upon annual crop seeding data from over 15 000 Canadian prairie farms, it was determined that, in contrast to prior expectations and recent inferences, individual farms have generally become more specialized in their cropping patterns since 1994. Specifically, for the whole of the prairies, a discernable trend of crop specialization was identified via two measures for the 1994 to 2002 period for all farms regardless of size, as well as for small, medium and large farms; the very large prairie operations, those over 842 ha as of 2002, showed no significant change in crop diversity. With respect to regional variation, individual farm crop diversity significantly increased within just 3 of the 40 census regions and significantly decreased within another 19, in one case at a greater than 3% annual rate; the remaining 18 census regions showed no significant change over the study period.

While crop diversification can act to reduce farm business risks, especially given a mix of crops with minimal yield and price covariations, this strength may be outweighed by the strategy's many perceived limitations, such as its start-up costs and its implications for achieving economies of scale. Additionally, other risk-reducing strategies, such as crop insurance or the securing of off-farm income, may be readily available and preferred by producers. Hence, crop diversification can certainly be thought of as a possible adaptation to climatic variability and change, and in narrow climatic terms may even be deemed suitable, but its adoption by producers for this purpose cannot be assumed. Indeed, in the case of Canadian prairie agriculture, widespread adoption of a crop diversification strategy appears most unlikely, at least in the immediate term. Given particular climatic conditions in the future, and especially an increase in extreme events, producers may come to revisit the practice of crop specialization; however, such contemplation would be mindful of many factors of production and marketing beyond climatic ones alone. More generally, this case suggests that the task of identifying adaptations to climatic variability and change that make sense to would-be adopters is a difficult one, and may even be futile. If useful prescription remains a desired goal, research must serve to better identify the wider strengths and limitations of a potential adaptation, and, in this, observations of the actual behavior of agents in light of multiple risks and opportunities can be insightful.

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Notes

[1] A test of temporal association between changes in weather conditions (e.g. increased intra-annual variability) and changes in crop diversification is not undertaken, nor was it contemplated, due to data limitations and the inability to control for the effect of non-climatic stimuli.

[2] For example, for the period 1991–2000 wheat production in the Canadian prairies accounted for approximately 4.5% of world wheat production (Canadian Wheat Board, 2003).

[3] The clearest expressions of this promotion are the Crop Diversification Centres of the provinces of Manitoba, Saskatchewan and Alberta.

[4] In addition, Paoletti et al. (1992) and Zentenr et al. (2002) note that crop diversification can serve to improve soil quality and weed control, and decrease diseases and pest outbreaks, although these benefits are contingent upon the type and scale of production, the use/misuse of crop rotations, and other specific factors of time and place.

[5] In its degree of output specialization, the Canadian prairies are not unique. Indeed, specialization has long been a characteristic trend of western agriculture, at least since the early 1970s (see U.S. National Research Council, 1989; Ilbery and Bowler, 1998). In the grain producing regions of North America in particular, farmers have increasingly specialized into fewer crops owing to a variety of powerful influences, such as high grain prices after 1973, the marginal cost advantage of increasing scales of production, the relative affordability and effectiveness of agrochemicals and single-function machinery, increased demand for standardized output, advice/pressure from agribusiness, creditors and government extension officers, commodity-specific subsidies, and the provision of below market-cost crop insurance (Bollman et al., 1995; Gregson, 1996; Gertler, 1998). While this trend is widely acknowledged, farm-level evidence is difficult to access find (see Gregson, 1996). For the Canadian

prairies, this trend can be crudely verified based on Canadian agricultural census data. By summing the number of farms reported to be growing each of the principle crop types and dividing by the total number of crop farms, a rough approximation of individual farm crop diversity can be established for each of the census years. By this measure, the number of crop types grown per prairie farm declined from 3.84 in 1971 to 3.00 in 1976 and 2.91 in 1981.

[6] This subsidy came to significantly reduce producers' marketing costs. For example, by 1989, the cost of hauling export crops from Moose Jaw, Saskatchewan to the port of Thunder Bay under the WGTA was just Can$ 8.41/tonne compared to a full compensatory rate of Can$ 28.31/tonne (Kulshreshtha and Klein, 1999).

[7] These results do not discredit the claim of Zentenr et al. (2002) regarding the increased use of crop rotations on prairie farms; however, they do suggest that, if prairie farmers have indeed increased the number of crops grown in rotation, this shift has not produced an increase in the number of crop types present within an operation in any one season.

[8] One key variable in this is the cost of farm equipment, which requires considerable acreages to make cost effective.

[9] To provide a regional example, in Saskatchewan about 8.6 million ha of seeded cropland were insured in 1998 out of about 12.4 million possible.

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